TABLE 1
Preregulatory risk levels for chemical carcinogen exposures

Chemical decision	Agency	Individual lifetime risk (per 10^6)	Exposed population size (millions)	Annual cancer cases	Reference
Public					
Acrylonitrile					
1. Food	F	0.01	220	0.01	49-FR-36635
2. Air	E1	380	220	0.5	50-FR-24312
Aflatoxins					
3. Corn	F	70	34	90	FDA Docket No. 78N-0048
4. Peanuts	F	3	220	35	
5. *Aluminum tris*	E2	0.003	—	—	48-FR-50532
6. *Ambien*	E2	0.001	—	—	46-FR-17229
Amitraz					
7. Apples[a]	E2	0.2	220	8	44-FR-2678
8. Pears	E2	0.2	220	8	44-FR-2678
Arsenic					
9. Primary lead smelters	E1	0.7–10	—	0.006–0.1	48-FR-33112
10. Primary zinc smelters	E1	0.1–2	—	0.005–0.008	48-FR-33112
11. Zinc oxide plants	E1	20–300	—	0.002–0.02	48-FR-33112
12. Chemical manufacturers	E1	4–60	—	0.0008–0.1	48-FR-33112
13. Secondary lead smelters[a]	E1	21–340	—	0.04–6	48-FR-33112
14. High copper smelters[a]	E1	2300–36,000	0.37	1–18	48-FR-33112
15. Low copper smelters[a]	E1	430–6900	0.65	2	48-FR-33112
16. Glass manufacturers[a]	E1	64–1000	4.2	0.07–1	48-FR-33112
17. *Asbestos*[a]	E4	1–7	—	—	51-FR-3738
18. *Benomyl*	E2	0.7	—	—	47-FR-46747
Benzene					
19. Maleic anhydride plants	E1	8	10	0.03	49-FR-8386
20. Ethylbenzene styrene plants	E1	14	2.5	0.06	49-FR-8386
21. Storage vessels	E1	4	85	0.04	49-FR-8386
22. Coke byproduct[a]	E1	640	20	2	49-FR-23522
23. Fugitive emissions[a]	E1	20	30	0.5	49-FR-23498
24. Equipment leaks[a]	E1	50	—	0.1	49-FR-23498
25. Paint strippers[a]	C	40	—	—	43-FR-21838
26. *Butadiene*[b]	E1	7600–30,000	52	18.5	50-FR-41466
27. *C.I. Vat Orange #1*	F	0.000003	—	—	50-FR-20405
28. *Carbon tetrachloride*[b]	E1	700	230	70	50-FR-32621
29. *Chloroallyldiethlocarbamate*	E2	0.2	—	—	46-FR-27973
Chlorobenzilate					
30. U.S. population[a]	E2	0.3	210	8	44-FR-9548
31. Florida population[a]	E2	0.7	8	0.8	44-FR-9548
Chloroform[b]					
32. Water	E1	9	—	2	50-FR-39626
33. Waste	E1	2	—	0.5	50-FR-39626
34. *Chlorinated benzenes*	E1	0.2–1	6.5	0.0005–0.007	50-FR-32626
35. *Chlorothalonil*	E2	2	—	—	49-FR-45853
36. *Chromium*[b]	E1	1200–16,000	220	290	50-FR-24317
37. *Cinnamyl anthranilate*[a]	F	0.1	—	—	47-FR-22545
38. *Coke oven emissions*[a]	E1	350–3600	0.12	2–6	41-FR-46742
39. *Cypermethrin*	E2	0.1	—	—	50-FR-1112
40. *Cyromazine*	E2	0.1	—	—	49-FR-18120
41. *Diallate*[a]	E2	10	—	—	PD #4, 1982
1,2-Dibromo-3-chloropropane					
42. Peanuts[a]	E2	60	220	1900	44-FR-65151
43. Vegetable[a]	E2	60	220	1900	44-FR-65151
Dimethylnitrosamine					
44. Baby bottles[a]	F	0.004	—	—	FDA Docket No. 83D-0414
45. Paper, paperboard	F	0.0005	—	—	50-FR-4643
46. *1,4-Dioxane*	F	0.0000004	—	—	50-FR-36872
Epichlorohydrin					
47. Air	E1	1	220	0.001	50-FR-24575
48. Dimethylamine	F	0.0000002	—	—	49-FR-13016
49. Polyamide	F	0.001	—	—	49-FR-13021
50. *Ethalfluralin*	E2	0.4	—	—	49-FR-511
51. *Ethylene bisdithiocarbamates*	E2	50	220	—	47-FR-47669
Ethylene dibromide					
Soil fumigant					
52a. Food[a]	E2	1	230	36	48-FR-46228
52b. Water[a]	E2	8	230	25	PD #4, 1983
53. Stored grain fumigant	E2	100	—	—	PD #4, 1983
54. Spot grain fumigant[a]	E2	24	230	790	49-FR-4452
55. Quarantine fumigant[a]	E2	30	230	330	48-FR-46228
56. *Ethylene oxide*[b]	E1	200	—	60	50-FR-40286
Formaldehyde					
57. High school teachers	E4	3	0.038	0.02	49-FR-21870
58. High school students	E4	0.03	3.8	0.01	49-FR-21870
59. College teachers	E4	7	0.1	0.1	49-FR-21870
60. College students	E4	0.3	2.9	0.1	49-FR-21870
61. Medical students	E4	40.3	40.075	40.005	449-FR-21870
62. Dental students	E4	40.3	40.0215	40.001	449-FR-21870
63. Nursing students	E4	0.3	0.245	0.01	49-FR-21870
64. Mobile homes[b]	E4	13	4.2	8	49-FR-21870
65. Homes (non-urea-formaldehyde foam insulation)	E4	10	100	160	49-FR-21870
66. Rural air	E4	0.3	58	2	49-FR-21870
67. Urban air	E4	3	160	80	49-FR-21870
68. Particle board	E4	20	—	0.01	49-FR-21870
69. Homes (urea-formaldehyde foam insulation)	E4	5	1.8	1.3	49-FR-21870
70. Urea-formaldehyde insulation[a]	C	9–30	1.8	23	46-FR-11188

Chemical decision	Agency	Individual lifetime risk (per 10^6)	Exposed population size (millions)	Annual cancer cases	Reference
FD&C Yellow #5 (total)	—	0.04	—	—	50-FR-35774
71. 4-Aminoazobenzene	F	0.00005–0.001	—	—	50-FR-35774
72. 4-Aminobiphenyl	F	0.01	—	—	50-FR-35774
73. Aniline	F	0.000004	—	—	50-FR-35774
74. Azobenzene	F	0.00002	—	—	50-FR-35774
75. Benzidine	F	0.03	—	—	50-FR-35774
76. 1,3-Diphenyltriazene	F	0.0004	—	—	50-FR-35774
Gasoline products					
77. Bulk terminals[a]	E2	200–400	—	1–2	49-FR-31706
78. Service stations[a]	E2	4.4–7.2	—	3–6	49-FR-31706
79. Self-serve[a]	E2	6–9	—	20–30	49-FR-31706
80. *Lead acetate*	F	0.02	—	—	45-FR-72112
Lindane					
81. Ornamental uses	E2	0.8	0.08	—	45-FR-45362
82. Dog dips[a]	E2	0.4	15	—	PD #4, 1980
83. Shelf paper	E2	2	11	—	PD #4, 1980
84. *Methoxychlor*	E2	0.005	—	—	45-FR-49117
Methylene chloride					
85. Decaffeinated coffee	F	0.1	3.7	0.05	50-FR-51651
86. Aerosol cosmetics[a]	F	10	—	—	50-FR-51551
87. Air[c]	E1	10	—	—	50-FR-42037
88. *4,4'-Methylenedianiline*	E4	0.1–2	0.03	—	48-FR-42898
89. *Methylenebis (o-chloroaniline)*	E4	0.3	0.03	—	48-FR-22954
90. *Metolachlor*	E2	0.1	—	—	47-FR-23932
91. *Oryzalin*	E2	0.06–0.5	—	—	49-FR-45854
92. *2,2'-Oxammidobis*	F	0.007	—	—	48-FR-37616
93. *Oxyfluorfen*					
(perchloroethylene) diet	E2	0.1	—	—	47-FR-27118
94. *Pentachlorophenol*[a]	E2	100	0.02	—	49-FR-28866
95. *Polycyclic organic matter*	E1	7–20	220	200	49-FR-31680
Radionuclides					
96. Department of Energy facilities	E5	70	64	0.07	50-FR-5190
97. Nuclear Regulatory Commission, non-DOE facilities	E5	2	—	0.001	50-FR-5190
98. Elemental phosphorus	E5	100	3	0.06	50-FR-5190
99. Radon-222 uranium mill tailings[a]	E5	1000	—	3–6	51-FR-6382
100. *Saccharin*	F	40	220	600–1200	42-FR-19996
Tetrachlorodibenzo-p-dioxin					
101. Local[a]	E2	20	0.0009	0.02	48-FR-48434
102. General[a]	E2	0.2	220	7.5	48-FR-48434
p-Toluidine					
103. D&C Green #5, #6	F	0.003	—	—	47-FR-24278
104. Diet	F	0.007	—	—	47-FR-14138
105. Contact lenses	F	0.00001	—	—	48-FR-13020
106. D&C Red #6, #7	F	0.002	—	—	47-FR-57681
107. *Trichloroethylene*[b]	E1	9	—	4	50-FR-52442
108. *Trifluralin*	E2	0.05	—	—	PD #4, 1985 (OTS, 1982)[a]
109. *Trihalomethanes*[a]	E3	40	230	340	47-FR-9796
Vinyl chloride					
110. Ethylene dichloride–vinyl chloride monomer plants[a]	E1	260	5	0.6	50-FR-1182
111. Polyvinyl chloride plants[a]	E1	900	5	18	50-FR-1182
112. Food (polymers)	F	0.01	—	—	51-FR-4173
113. *Vinylidene chloride*	E1	80	—	0.07	50-FR-32632
Occupational					
Amitraz					
114. Pears	E2	10	0.005	0.004	44-FR-2678
115. Apples[a]	E2	10	0.005	0.002	44-FR-2678
116. *Arsenic*[a]	O	200–300	—	380	48-FR-1864
Asbestos					
117. 20 Fibers/cm^3[a]	O	17,000	0.4	180	49-FR-14120
118. 2 Fibers/cm^3[a]	O	6400	0.4	90	49-FR-14120
119. *Benzene*[a]	O	4400-15,200	0.05	44–150	50-FR-50512
120. *Chlorobenzilate*	E2	140	0.07	0.01	44-FR-9548
1,2-Dibromo-3-chloropropane					
121. Citrus[a]	E2	9300	—	0.05	Final PD, 1979
122. Cotton[a]	E2	10	—	0.001	44-FR-65151
123. Peaches[a]	E2	360	—	0.6	44-FR-65151
124. Pineapple	E2	9	—	0.001	49-FR-1558
125. Soybeans[a]	E2	9	—	0.01	44-FR-65151
Ethylene dibromide					
126. OSHA[a]	O	7000–11,000	0.0006	1.5	48-FR-45958
127. Soil fumigant[a]	E2	3500	0.014	0.7	48-FR-48228
Spot grain fumigant					
128. Millworkers[a]	E2	2000	0.016	5	49-FR-4452
129. Applicators[a]	E2	10,000	0.006	9	PD #4, 1984
130. Quarantine fumigant[a]	E2	30,000	—	0.5	PD #4, 1984
131. *Ethylene oxide*[a]	O	6300–11,000	0.07	70	49-FR-25734
Tetrachlorodibenzo-p-dioxin					
132. Rights-of-way brush[a]	E2	350	0.086	0.1	48-FR-48434

[a]Agency acted to reduce risk.
[b]No regulatory decision has been made.
[c]Office of Toxic Substances, EPA.

Agency key
C = Consumer Product Safety Commission
E = Environmental Protection Agency
E1 = Office of Air Quality Planning and Standards
E2 = Office of Pesticide Programs
E3 = Office of Drinking Water
E4 = Office of Toxic Substances
E5 = Office of Radiation Programs
F = Food and Drug Administration
O = Occupational Safety and Health Administration

Source key
FR = Federal Register
PD = Position Document

tant for our analysis. All that matters is that when the regulatory decision was made, risk managers were presented with these estimates as the best available upper-bound estimates.

Categories of risk

Figure 1 presents preregulatory levels of maximum individual risk for regulatory decisions involving public exposure to chemical carcinogens. Two patterns are apparent. First, every chemical with an individual risk above 4×10^{-3} (four chances in 1000 that a chronically exposed individual will develop cancer) was regulated. Second, except for one FDA decision (Number 44 in Table 1), no action was taken to reduce individual lifetime risk levels that were below 1×10^{-6}.

The Delaney Clause of the Federal Food, Drug and Cosmetic Act Food Additives Amendment of 1958 states: "No additive shall be deemed safe if it is found to induce cancer when ingested by man or animal." Despite this, in all 11 decisions made between 1980 and 1985 involving indirect carcinogenic food additives, FDA set standards but did not require existing risk levels to be reduced. FDA has recently argued that the Delaney Clause permits use of carcinogenic food additives with cancer risks below 1×10^{-6}; a decision that is being challenged in court. Our analysis shows that FDA's reasoning is consistent with historical practice.

Figure 2 presents 58 cases in which estimates of both individual risk and population size were available at the time a regulatory decision was made. Estimated exposed populations ranged from 9700 to 230 million, the latter for the total U.S. population. There does not appear to be a strong correlation between the size of the population exposed and the likelihood of regulation. This conclusion is contrary to that reached by Milvey, who stated that the de minimis risk level is a function of the size of the population at risk (*1*). To further investigate this question, we review estimates of individual and population risk.

Figure 3 presents decisions for which individual and population risk estimates were available at the time of regulation. Three categories of risk can be identified. De manifestis risks are those that are so high that agencies almost always acted to reduce them, and de minimis risks are so low that agencies almost never acted to reduce them (*2*). The risks falling into the area between these extremes were regulated in some cases but not in others.

Figure 4 shows 19 occupational decisions that have been added to Figure 3 to provide data on small populations at high individual risk; no other data exist for these cases. It is assumed that decisions to regulate occupational exposures can be used to aid in defining de manifestis and de minimis risk levels because public exposures to carcinogenic substances should be regulated at least as stringently as occupational exposures are.

Line A of Figure 4 defines the de manifestis level; above this line, federal agencies always acted to reduce risk. For exposures resulting in a small-population risk, the de manifestis level is approximately 4×10^{-3}. As population risk approaches 250 cancer deaths (which could only occur in a population the size of the entire United States) the de manifestis level drops to about 3×10^{-4}. Line B shows the de minimis level. Below this line, no action has ever been taken to reduce risk. Line B indicates that for small-population effects, regulatory action was never taken for individual risk levels below 10^{-4}. For effects resulting from exposures to the entire U.S. population, the level of acceptable risk drops to 10^{-6}. Line C is the area beyond which no data can fall. Figure 4 is essentially an analysis of the Reagan administration's regulatory decisions; only six decisions in Figure 4 occurred before 1980.

Figure 4 raises two questions. First, what justification is given by regulatory

FIGURE 1
Preregulatory levels of maximum individual lifetime risk reviewed by federal agencies

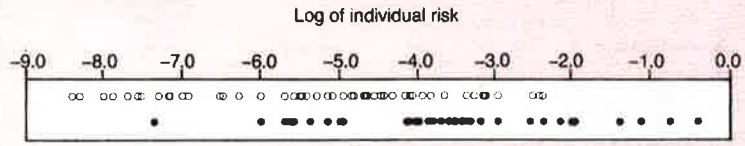


Figure Key: ○ = Agencies did not act to reduce public risk; • = agencies acted to reduce public risk; □ and ■ = action taken or not taken, respectively, for occupational risk; + = no regulatory decision has been made.

FIGURE 2
Effect of individual risk vs. population size on chemical carcinogen regulations

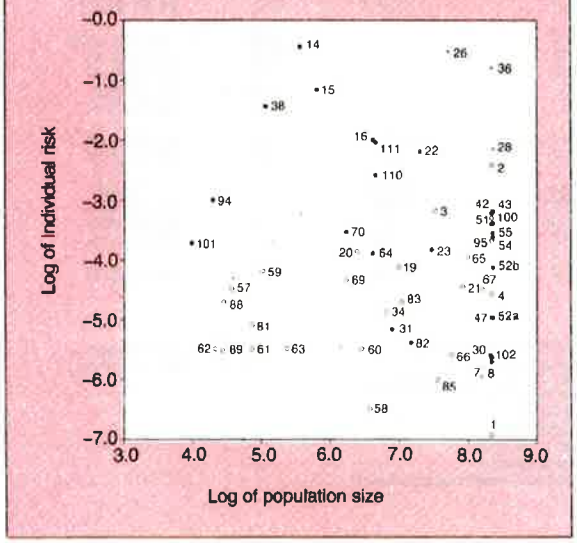
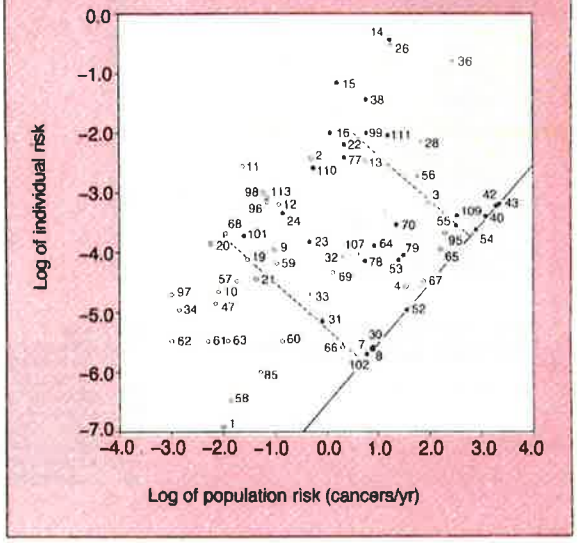
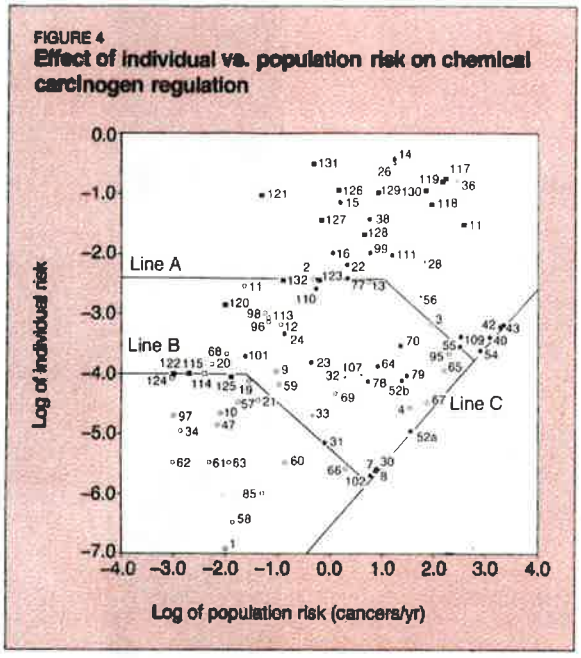
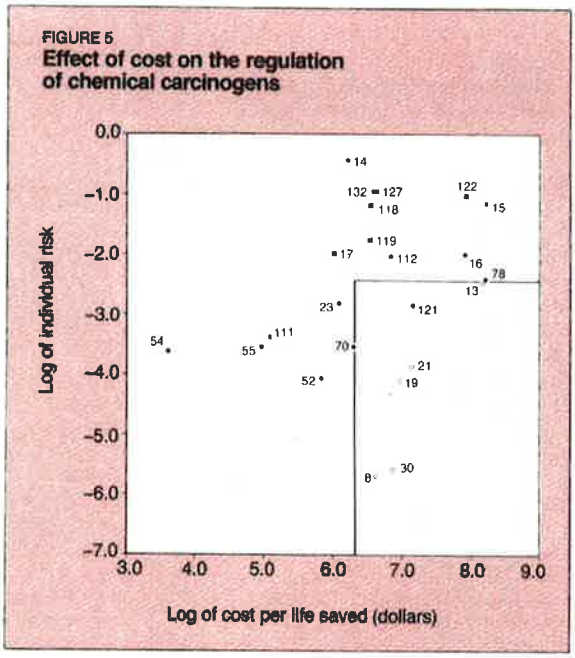


FIGURE 3
Effect of individual vs. population risk on chemical carcinogen regulation







agencies for not regulating chemicals in the de minimis category of risk? Second, what justification is given for regulatory decisions involving chemicals in the region between the de manifestis and de minimis levels? The primary answer given by federal agencies to the first question, as defined in Figure 4, is insignificant population risk. Table 2 shows those regulatory decisions that cited insufficient risk as the reason not to regulate. EPA's most explicit statement on the use of population effects in setting acceptable levels of risk is found in its decision on radionuclide standards (Table 1, Numbers 96–99).

In declining to regulate natural radionuclide emissions from elemental phosphorus plants (with an individual risk of 1×10^{-3}), the EPA decision states, "If risk to the most exposed individuals were the only criterion for judgment, this relatively high risk might well have led to a decision to regulate. However, this risk must be weighted against both the low aggregate risk [0.06 cancer deaths per year] and against other factors," such as cost (*3*).

Only two decisions in the de minimis region of Figure 4 consider factors other than small-population risk. Arsenic emissions from zinc smelters and benzene emissions from storage vessels are regulated by Section 112 of the Clean Air Act, the enforcement of which is heavily influenced by available technology. At the time of regulation, these two sources were already controlled with the best available technology (BAT), and further regulation could have resulted in shutdown of the industry (*4, 5*).

Analysis of regulatory decisions involving chemicals in the region between the de manifestis and de minimis levels indicates that cost effectiveness is the primary determinant of regulation. Figure 5 shows the cost effectiveness (cost per life saved) of regulating exposures to 23 chemicals vs. their preregulatory individual lifetime risk. Substances with individual risks above the de manifestis level were regulated regardless of cost.

In the region between the de manifestis and de minimis levels, substances with risk reduction costs of less than $2 million per life saved were regulated; substances that cost more were not regulated. This conclusion is based on limited data, but it is consistent with EPA guidance suggesting that regulation is warranted if the cost per life saved does not exceed $1.5 million (*6*).

The two major factors that influence the magnitude of cost, and by extension the decision to regulate, are the availability of substitutes (for example, decisions 8 and 30) and whether emissions currently are controlled by BAT (for example, decisions 9–13 and 19–21).

In reviewing the regulatory decisions of the past decade, two trends are apparent. First, there is an increased use of quantitative risk analysis, which extrapolates animal data to humans. Between 1976 and 1980, quantitative risk analysis was used in regulatory decisions involving only eight chemicals; from 1981 to 1985 the number of decisions increased to 53. Second, there are indications that the definition of de minimis is changing.

Prior to 1980, it was generally agreed that the de minimis risk was 10^{-6} per lifetime risk, regardless of population. Figure 4 indicates that for small-population risks, the de minimis risk is now considered to be a 10^{-4} lifetime risk. However, every decision in the de minimis region of Figure 4 was made after 1983.

Regulatory guidelines

The Environmental Protection Agency has specifically requested assistance in developing a quantitative rule for incorporating population risk into the decision-making process (*7*). EPA has suggested a de minimis individual lifetime risk level of 10^{-5} to 10^{-4} for small populations and 10^{-7} to 10^{-6} for large populations. Although no such explicit standard has been developed, we can see that there are simple rules that can be used to guide regulatory decisions. These guidelines incorporate individual risk, population risk, and cost effectiveness into a single framework, even though it is recognized that no absolute rules are possible.

Guideline 1. There is a de manifestis individual lifetime risk level that is a function of population risk, as shown in Line A of Figure 4. Above this level, regulatory action should be taken to reduce risk.

Guideline 2. There is a de minimis individual lifetime risk level that is a function of population risk, as shown in Line B of Figure 4. Below this line, regulatory action generally need not be taken.

Guideline 3. In the region between the de manifestis and de minimis levels, regulatory action should be taken if the

TABLE 2
Decisions citing insignificant population risk as the reason not to regulate

Chemical	Individual risk	Population risk (cancer/yr)	Agency comments
Arsenic			
Zinc oxide	3×10^{-3}	0.02	*Total cancer incidence, even on a national basis, is likely to be small compared to the incidence associated with smoking and diet.*
Secondary lead smelters	3×10^{-3}	6	
Primary lead smelters	1×10^{-4}	0.1	
Chemical manufacturing	6×10^{-4}	0.1	
Zinc smelters	2×10^{-5}	0.008	
Radionuclides			
Elemental phosphorus	1×10^{-3}	0.06	*This risk [10^{-3} individual risk] must be weighed against both the low aggregate risk and against other factors.*
Vinylidene chloride	8×10^{-4}	0.07	*Magnitude of the public health risk is small.*
Radionuclides			
Department of Energy facilities	7×10^{-4}	0.07	*[Population impact] insufficient to warrant regulation.*
Nuclear Regulatory Commission, non-DOE	2×10^{-5}	0.001	
Formaldehyde			
Teachers	7×10^{-5}	0.1	*[Population risk below one cancer risk per year, which is] insignificant risk of widespread harm.*
Students	3×10^{-6}	0.001–0.1	
Chlorinated benzenes	1×10^{-5}	0.007	*Health risk is not sufficient to warrant regulation.*
Epichlorohydrin	1×10^{-5}	0.001	*Relatively low aggregate risk.*

cost is below $2 million per life saved.

These guidelines have significant implications, for example, concerning remedial action at hazardous-waste sites. Most such sites pose risk to only a limited geographic area, where population risks presumably are small. Past regulatory actions by EPA indicate that 10^{-4} would be the de minimis risk level for these areas.

Perhaps the most surprising aspect of our study is the consistency found among federal agencies' methods in the use of cancer risk estimates for regulatory decisions. With the possible exception of FDA decisions concerning de minimis risks, the history of federal decision making indicates that all agencies are fairly consistent in their implicit definitions of de manifestis and de minimis levels of risk. If the above three guidelines were adopted explicitly, consistency with past decisions would be maintained and the process of regulatory decision making would be simplified considerably.

Acknowledgment

Oak Ridge National Laboratory is operated by Martin Marietta Energy Systems, Inc., under contract De-AC05-84OR21400 for the U.S. Department of Energy.

This article was reviewed for suitability as an *ES&T* feature by Daniel Byrd, EPA, Washington, D.C. 20460; Lester Lave, Carnegie-Mellon University, Pittsburgh, Pa. 15213; and David Salsburg, Pfizer Central Research, Groton, Conn. 06340.

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Regulatory Impact Analysis: A Primer

With this document, the Office of Information and Regulatory Affairs is providing a primer to assist agencies in developing regulatory impact analyses (RIAs), as required for economically significant rules by Executive Order 13563, Executive Order 12866, and OMB Circular A-4.[1]

In accordance with those requirements, agencies should include the information described below in their RIAs. This primer is limited to the requirements of Executive Order 13563,[2] Executive Order 12866,[3] and Circular A-4[4]; it does not address requirements imposed by other authorities, such as the National Environmental Policy Act, the Regulatory Flexibility Act, the Unfunded Mandates Reform Act, the Paperwork Reduction Act, and various Executive Orders that require analysis. Executive Order 13563, Executive Order 12866, and Circular A-4, as well as those other authorities, should be consulted for further information.

The purpose of this primer is to offer a summary of the requirements of OMB Circular A-4. The primer is not meant to be a substitute for the more detailed description in that Circular. Nothing in this primer is intended to alter existing requirements or policy.

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[1] Agencies may also find "Regulatory Impact Analysis: Frequently Asked Questions" (http://www.whitehouse.gov/sites/default/files/omb/circulars/a004/a-4_FAQ.pdf) and "Agency Checklist: Regulatory Impact Analysis" (http://www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/RIA_Checklist.pdf), helpful as well.
[2] Available at: http://www.reginfo.gov/public/jsp/Utilities/EO_13563.pdf
[3] Available at: http://www.reginfo.gov/public/jsp/Utilities/EO_12866.pdf
[4] Available at: http://www.whitehouse.gov/sites/default/files/omb/assets/omb/circulars/a004/a-4.pdf

A. Introduction

Executive Orders 13563 and 12866 require agencies to provide to the public and to OMB a careful and transparent analysis of the anticipated consequences of economically significant regulatory actions. This analysis includes an assessment and (to the extent feasible) a quantification and monetization of benefits and costs anticipated to result from the proposed action and from alternative regulatory actions. Executive Order 13563 specifically requires agencies "to use the best available techniques to quantify anticipated present and future benefits and costs as accurately as possible."

The purpose of the RIA is to inform agency decisions in advance of regulatory actions and to ensure that regulatory choices are made after appropriate consideration of the likely consequences. To the extent permitted by law, agencies should proceed only on the basis of a reasoned determination that the benefits justify the costs (recognizing that some benefits and costs are difficult to quantify). Regulatory analysis also has an important democratic function; it promotes accountability and transparency and is a central part of open government.

Important goals of regulatory analysis are (1) to establish whether federal regulation is necessary and justified to achieve a social goal and (2) to clarify how to design regulations in the most efficient, least burdensome, and most cost-effective manner. To that end, Executive Orders 13563 and 12866 require agencies to consider a range of regulatory alternatives, including the option of not regulating, and to design their regulations in the most cost-effective manner to achieve the regulatory objective. Agencies should select the alternative that maximizes net benefits, while also taking into consideration distributive impacts and qualitative benefits and costs, unless a statute requires another approach.

B. Key Elements of a Regulatory Impact Analysis

An RIA should include the following three basic elements:

A statement of the need for the regulatory action: An analysis should begin with a clear explanation of the need for the regulatory action, including a description of the problem that the agency seeks to address. Agencies should explain whether the action is intended to address a market failure or to promote some other goal, such as improving governmental processes, protecting privacy, or combating discrimination. If the action is compelled by statute or judicial directive, agencies should describe the specific authority and the extent of discretion permitted.

A clear identification of a range of regulatory approaches: If an agency has decided that Federal regulation is appropriate, it should identify and include in its RIA a range of alternative regulatory approaches, including the option of not regulating. Alternatives to Federal regulation include State or local regulation, voluntary action on the part of the private sector, antitrust enforcement, consumer-initiated litigation in the product liability system, and administrative compensation systems. Where relevant, agencies should consider flexible approaches that reduce burdens and maintain freedom of choice, such as warnings, appropriate default rules, and

disclosure requirements. To the extent feasible, agencies should specify performance objectives, rather than specifying the behavior or manner of compliance that regulated entities must adopt.

An estimate of the benefits and costs—both quantitative and qualitative—of the proposed regulatory action and its alternatives: After identifying a set of potential regulatory approaches, the agency should conduct a benefit-cost analysis that estimates the benefits and costs associated with each alternative approach. The benefits and costs should be quantified and monetized to the extent possible, and presented in both physical units (e.g., number of illnesses avoided) and monetary terms. When quantification of a particular benefit or cost is not possible, it should be described qualitatively. The analysis of these alternatives may also consider, where relevant and appropriate, values such as equity, human dignity, fairness, potential distributive impacts, privacy, and personal freedom.

The agency's analysis should be based on the best available scientific, technical, and economic information. To achieve this goal, the agency should generally rely on peer-reviewed literature, where available, and provide the source for all original information. In cases of particular complexity or novelty, the agency should consider subjecting its analytic models to peer review.[5] In cases in which there is no reliable data or research on relevant issues, the agency should consider developing the necessary data and research. In addition, the agency should comply with the Information Quality Guidelines for the agency and with OMB's "Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies."[6] Executive Order 13563 also provides that "[c]onsistent with the President's Memorandum for the Heads of Executive Departments and Agencies, 'Scientific Integrity' (March 9, 2009), and its implementing guidance, each agency shall ensure the objectivity of any scientific and technological information and processes used to support the agency's regulatory actions."

The agency should clearly document all of the assumptions and methods used in the analysis, discuss the uncertainties associates with estimates, and publicly provide the supporting data and underlying analysis (if possible on the Internet; see Executive Order 13563, section 2 (b)), so that a qualified third party reading the analysis could understand and reproduce the analysis. Regulatory analysis should also include a clear, plain language executive summary, including a table, that summarizes the benefit and cost estimates for each regulatory action and alternative under consideration, including the qualitative and non-monetized benefits and costs.[7]

C. Preparing a Regulatory Impact Analysis

This section provides a step-by-step guide to preparing an RIA. The three key elements discussed in the previous section are important; this section focuses primarily on the benefit and

[5] For additional discussion, see OMB's "Final Information Quality Bulletin for Peer Review", available at: http://www.whitehouse.gov/sites/default/files/omb/assets/omb/fedreg/2005/011405_peer.pdf

[6] Available at http://www.whitehouse.gov/omb/fedreg_reproducible/

[7] For additional discussion, see 2010 Report to Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities, page 51. Available at: http://www.whitehouse.gov/sites/default/files/omb/legislative/reports/2010_Benefit_Cost_Report.pdf

cost assessment of regulatory alternatives required by Executive Order 13563, Executive Order 12866, and Circular A-4.

Benefit -cost analysis (BCA) provides a systematic framework for evaluating the likely outcomes of alternative regulatory choices. It allows agencies to evaluate different regulatory options with a variety of attributes using a common measure – a monetary unit. When important benefits and costs cannot be expressed in monetary units or quantified in any manner, the BCA can provide useful information about the relative merits of regulatory alternatives, but the "net benefits" estimate, viewed in isolation, may be incomplete and misleading.

To provide a complete RIA, agencies should follow these steps:

- Describe the need for the regulatory action
- Define the baseline
- Set the timeframe of analysis
- Identify a range of regulatory alternatives
- Identify the consequences of regulatory alternatives
- Quantify and monetize the benefits and costs
- Discount future benefits and costs
- Evaluate non-quantified and non-monetized benefits and costs
- Characterize uncertainty in benefits, costs, and net benefits

Below we provide additional information for each of these steps.

Step 1: Describe the need for the regulatory action

As discussed in the previous section, an analysis should begin with a reasonably detailed description of the need for the regulatory action and should include an explanation of how the regulatory action will meet that need. The RIA should explain whether the action is intended to address a significant market failure (e.g., externality, market power, and inadequate or asymmetric information) or to meet some other compelling public need such as improving governmental processes or promoting values such as privacy or human dignity. If the regulation is designed to correct a significant market failure, the RIA should describe the failure both qualitatively and (where feasible) quantitatively. If a regulation is required by statute or judicial directive, the RIA should clearly explain the specific authority, extent of agency discretion, and permissible regulatory instruments.

Step 2: Define the Baseline

The baseline represents the agency's best assessment of what the world would be like absent the action. To specify the baseline, the agency may need to consider a wide range of factors and should incorporate the agency's best forecast of how the world will change in the future, with particular attention to factors that affect the expected benefits and costs of the rule. For example, population growth, economic growth, and the evolution of the relevant markets should all be taken into account. For regulations that largely restate statutory requirements, the analysis

should use a pre-statutory baseline. For analyses supporting modifications to an existing regulation, a baseline assuming no change in the regulatory program generally provides an appropriate basis for evaluating regulatory alternatives.

The analysis should focus on benefits and costs that accrue to citizens and residents of the United States. Where the agency chooses to evaluate a regulation that is likely to have effects beyond the borders of the United States, these effects should be reported separately.

Step 3: Set the Time Horizon of Analysis

When choosing the appropriate time horizon for estimating benefits and costs, agencies should consider how long the regulation being analyzed is likely to have economic effects. The time frame for the analysis should cover a period long enough to encompass all the important benefits and costs likely to result from the rule. However, the agency should also consider for how long it can reasonably predict the future and should limit its analysis to that time period. Thus, if a regulation has no predetermined sunset provision, the agency will need to choose the endpoint of its analysis based on the foreseeable future or the agency's ability to forecast reliably. For rules that require large up-front capital investments, the life of the capital is also an option.

Step 4: Identify a Range of Regulatory Alternatives

The agency should consider a range of potentially effective and reasonably feasible regulatory alternatives. The relevant alternatives might involve different approaches, with distinct advantages and disadvantages. In considering which alternatives to discuss, an agency should reasonably explore which approaches are feasible and plausible ways of meeting the regulatory objective. An agency should give particular attention to identifying and assessing flexible regulatory approaches, including providing economic incentives to encourage the desired behavior, such as user fees or marketable permits, or providing information upon which choices can be made by the public.

Consistent with Executive Order 13563, section 4, an agency might consider flexible approaches that maintain freedom of choice. If, for example, an agency is considering banning the sale of a potentially unsafe product, it might consider instead requiring disclosure of health risks to the public. Once an agency identifies the least burdensome tool for achieving its regulatory objective, measuring the incremental benefits and costs of successively more stringent regulatory alternatives will allow an agency to identify the alternative that maximizes net benefits.

Agencies should consider any of the following, alone or in combination, to develop regulatory alternatives:

- *Deferral to state or local regulation.* Agencies should consider the option of deferring to regulation at the State or local level. To be sure, problems that affect interstate commerce or spill across State lines may best be addressed by Federal regulation. But more localized problems may be more efficiently addressed locally. In such situations,

deferring to state and local regulation can encourage regulatory experimentation and innovation while also fostering learning and competition to establish the best regulatory policies.

- *Market-oriented approaches rather than direct controls.* Agencies should consider market-oriented regulatory approaches that use economic incentives to achieve regulatory goals and that afford entities greater flexibility in compliance. Such approaches include fees, penalties, subsidies, marketable permits or offsets, changes in liability rules or property rights, and required bonds, insurance, or warranties. In the domain of environmental protection, for example, emissions trading may deserve careful consideration as an approach that might achieve the same gain at a significantly lower cost.
- *Performance standards rather than design standards.* Performance standards express requirements in terms of outcomes, for example requiring achievement of a particular emissions level. By contrast, design standards specify the means to achieve those outcomes, for example requiring installation of a particular emissions control technology. Because they allow firms to have the flexibility to choose the most cost-effective methods for achieving the regulatory goal, and create an incentive for innovative solutions, performance standards are generally preferred to design standards.
- *Informational Measures.* If intervention is contemplated to address a market failure that arises from inadequate or asymmetric information or poor information processing, informational remedies will often be preferred. To the extent feasible, specific informational measures should be evaluated with reference to their benefits and costs.
- *Default rules rather than mandates.* Agencies should consider whether default rules are a better instrument than mandates for achieving regulatory objectives. If, for example, there is significant heterogeneity in the relevant population, a default rule may be preferable to a mandate because it allows people to act in ways that are suited to their own situations.
- *Enforcement Methods.* Alternative monitoring (e.g., Federal, State, or local authorities) and reporting methods (e.g., on-site inspections, periodic reporting, and noncompliance penalties) may vary in their benefits and costs.
- *Stringency.* Typically both the benefits and costs associated with a regulation will increase with the level of stringency. Agencies should study alternative levels of stringency to determine the level that maximizes net benefits.
- *Compliance dates.* The timing of a regulation can have an important effect on its net benefits. Agencies should consider various possible compliance dates, because (for example) a later date might, in some circumstances, promote predictability and significantly reduce compliance costs without greatly reducing benefits.
- *Requirements based on firm size.* If the expected costs or the expected benefits of compliance vary based on firm size, different requirements for large and small firms, based on these estimated differences, may be appropriate. Greater flexibility for small business, in the form of delayed compliance dates or partial or total exemptions, is worth careful consideration. At the same time, agencies should consider whether such differences in regulatory treatment provide one group of firms with a competitive advantage over others, create artificial incentives to keep firm sizes small (and thus deter hiring), or lead to foregone benefits that exceed the cost savings to exempted firms.

- *Requirements based on geographic regions.* Where there are significant regional variations in benefits and/or costs, agencies should consider setting different requirements for different regions to maximize net benefits.

At a minimum, agencies should compare, with their preferred option, a more stringent and less stringent alternative, and assess the benefits and costs of the three possibilities, with careful consideration of which achieves the greatest net benefits. And when the preferred option includes a number of distinct provisions, the benefits and costs of different regulatory provisions should be analyzed separately in order to facilitate consideration of the full range of potential alternatives.

Step 5: Identify the Consequences of Regulatory Alternatives

Benefits and costs. Agencies should identify the potential benefits and costs for each alternative and its timing. It may be useful to identify the benefits and costs in the following manner:

- Benefits and costs that can be monetized, and their timing;
- Benefits and costs that can be quantified, but not monetized, and their timing;
- Benefits and costs that cannot be quantified.

In addition to the direct benefits and costs of each alternative, the list should include any important ancillary benefits and countervailing risks. An ancillary benefit is a favorable impact of the alternative under consideration that is typically unrelated or secondary to the purpose of the action (e.g., reduced refinery emissions due to more stringent fuel economy standards for light trucks). A countervailing risk is an adverse economic, health, safety, or environmental consequence that results from a regulatory action and is not already accounted for in the direct cost of the action (e.g., adverse safety impacts from more stringent fuel-economy standards for light trucks). As with other benefits and costs, an effort should be made to quantify and monetize both ancillary benefits and countervailing risks.

Distributional effects. Those who bear the costs of a regulation and those who enjoy its benefits often are not the same people. The term "distributional effect" refers to the impact of a regulatory action across the population and economy, divided up in various ways (e.g., income groups, race, sex, industrial sector, geography).

The regulatory analysis should provide a separate description of distributional effects (i.e., how both benefits and costs are distributed among sub-populations of particular concern) so that decision makers can properly consider them along with the effects on economic efficiency (i.e., net benefits). Executive Order 13563 and Executive 12866 authorize this approach. Where distributive effects are thought to be important, the effects of various regulatory alternatives should be described quantitatively to the extent possible, including the magnitude, likelihood, and severity of impacts on particular groups.

Examples of distributional effects that could potentially be quantified include:

- Health benefits that accrue principally to low-income groups
- Regulatory costs that are imposed principally on low-income groups
- Reductions in sales by one business that are matched by increases in sales by another (transfer in economic activity from one business to another)
- Reductions in well-being for some consumers that are matched by increases for others (transfer of well-being among consumers)

Transfer payments. Distributional effects may arise through "transfer payments" that stem from a regulatory action as well. Transfer payments are monetary payments from one group to another that do not affect total resources available to society. For example, transfers payments include revenue collected through a fee, a surcharge in excess of the cost of services provided, and a tax.

Distinguishing between real costs and transfer payments is an important, but sometimes difficult, problem in cost estimation. A stylized example may help to clarify. Consider a regulation that taxes an air pollutant that is harmful to human health and is a by-product of some manufacturing process. In response to the tax, firms modify their manufacturing process to reduce (but not eliminate) the pollutant. The benefits of the regulation are reductions in premature death, illness, and disability resulting from the decreased emission of the regulated pollutant, as well as benefits to ecosystems, improvements in visibility, and so on. The cost of the regulation is equal to the cost to firms of modifying their production process (e.g., purchasing abatement technology). The taxes paid on the pollutant by the firm to the government are a transfer and have no effect on the net benefits of the regulation.

Examples of costs include:

- Goods and services required to comply with the regulation
- Reductions in consumer and producer well-being due to regulation-induced price or quantity changes
- Increases in premature death, illness, or disability (e.g., in the case where a regulatory proposal that would reduce certain safety and/or health risks would also have the consequence of increasing other safety and/or health risks).

Examples of transfer payments include:

- Changes in sales tax revenue due to changes in sales (monetary transfers from consumers to government)
- Payment by the Federal government for goods or services provided by the private sector (monetary transfers to the government to service providers, such as reimbursements by the Medicare program)
- Fees to government agencies for goods or services provided by the agency (monetary transfers from fee payers to the government—the goods and services are already counted as government costs and including them as private costs would entail double counting)

Step 6: Quantify and Monetize the Benefits and Costs

The agency should use the best reasonably obtainable scientific, technical, economic, and other information to quantify the likely benefits and costs of each regulatory alternative. Presenting benefits and costs in physical units in addition to monetary units will improve the transparency of the analysis. For example, the benefits of a regulation that reduces emissions of air pollution might be quantified in terms of the number of premature deaths avoided each year; the number of prevented nonfatal illnesses and hospitalizations; the number of prevented lost work or school days; improvements in visibility in specific regions; and improvements in ecosystem health as measured by specific indicators (e.g. lake acidification). Some costs – such as countervailing risks – may also be quantified in similar terms before they are turned into monetary equivalents.

As discussed in greater detail below, the agency should, to the extent feasible, estimate the monetary value of the benefits and costs of each regulatory alternative considered. Both benefits and costs are measured by the value that individuals place on the change resulting from a particular regulatory alternative. This value is typically and most easily measured in terms of the amount of money the individual would pay ("willingness to pay" (WTP)) or require as compensation ("willingness to accept" (WTA)), so that the individual is indifferent between the current state of the world (baseline), on the one hand, and the consequences of the regulatory alternative along with the monetary payment, on the other hand.

To the extent possible, agencies should estimate people's valuations of benefits and costs using revealed preference studies based on actual behavior. Revealed preference methods develop estimates of the value of goods and services — or attributes of those goods and services — based on actual market decisions by consumers, workers, and other market participants. If the market participant is well-informed and confronted with a real choice, and properly processes information, it may be feasible to determine accurately and precisely the monetary value of the changes associated with an alternative.

If the goods or attributes of goods that are affected by regulation — such as preserving environmental or cultural amenities — are not traded in markets, it may be difficult to use revealed preference methods. In such cases, the value of the goods or attributes may arise both from use and non-use. "Use values" arise where an individual derives satisfaction from using the resource, either now or in the future, for example by living in or moving to a neighborhood with clean air or water. "Non-use values" arise where an individual places value on a resource, good, or service even though the individual will not use the resource, now or in the future, for example by valuing wildlife in remote areas.

In the absence of an organized market, it is difficult to estimate use and non-use values. When studies are designed to elicit such values either though indirect market studies or stated preference methods, agencies should pay careful attention to characterization of the uncertainties. However, overlooking or ignoring these values may significantly understate the benefits and/or costs of regulatory action.

Agencies should include the following effects, where relevant, in their analysis and provide estimates of their monetary values:

- Private-sector compliance costs and savings;
- Government administrative costs and savings;
- Gains or losses in consumers' or producers' surpluses;
- Discomfort or inconvenience benefits and costs; and
- Gains or losses of time in work, leisure, and/or commuting/travel settings.

To improve the transparency of the analysis, monetary values of distinct benefits and costs should be presented separately, in addition to being summed and presented as total benefits and total costs.

Considerations in monetizing health and safety effects

In monetizing health and safety benefits, the agency should use the WTP measure (or, if appropriate, the WTA measure), rather than other alternatives (e.g., avoided cost of illness or avoided lost earnings). This is because WTP/WTA attempts to capture pain and suffering and other quality-of-life effects.

When monetizing nonfatal health effects, the agency should consider two factors: (1) the private demand for prevention of the nonfatal health effect, to be represented by the preferences of the target population at risk and (2) the net financial externalities associated with poor health, such as net changes in public medical costs and any net changes in economic production that are not experienced by the target population. Revealed-preference or stated-preference studies are necessary to estimate the private demand; health economics data from published sources can typically be used to estimate the financial externalities caused by changes in health status. If an agency uses literature values to monetize nonfatal health and safety risks, it is important to make sure that the values selected are appropriate for the severity and duration of health effects to be addressed by the alternative under consideration.

Since agencies often design health and safety regulation to reduce risks to life, evaluation of the benefits of reducing fatality risks can be the key part of the analysis. The goal of this analysis is to monetize the value of small changes in fatality risk – a measurement of WTP for reductions in only small risks of premature death. This concept is commonly referred to as the "value of statistical life" (VSL).[8] A considerable body of academic literature is available on this subject. Current agency practice provides a VSL ranging from roughly $5 million to $9 million per statistical life.

Another approach to express reductions in fatality risks is to use the life expectancy method, the "value of statistical life-years (VSLY) extended." If a regulation protects individuals whose average remaining life expectancy is 40 years, a risk reduction of one fatality is expressed as "40

[8] The term “value of life” is sometimes used to describe this concept. However, this term can be misleading because it suggests, erroneously, that the monetization exercise tries to place a "value" on individual lives. Use of VSL should not suggest that the value of any individual's life can be expressed in monetary terms. The sole purpose is to help estimate the likely benefits of a regulatory action that reduces the risks that people face.

life-years extended." Those who favor this alternative approach emphasize that the value of a statistical life is not a single number relevant for all situations. In particular, when there are significant differences between the effect on life expectancy for the population affected by a particular health risk and the populations studied in the labor market studies, they prefer to adopt a VSLY approach to reflect those differences. It is appropriate to consider providing estimates of both VSL and VSLY, while recognizing the developing state of knowledge in this area.

Step 7: Discount Future Benefits and Costs

The benefits and costs of a regulatory action typically take place in the future. Moreover, benefits and costs may not be distributed across time in the same manner. For example, a common challenge in evaluating alternatives that have health-related consequences is to quantify the time lag between when an action would take effect and when the resulting change in health status will be observed.

To provide an accurate assessment of benefits and costs that occur at different points in time or over different time horizons, an agency should use discounting. Agencies should provide benefit and cost estimates using both 3 percent and 7 percent annual discount rates expressed as a present value as well as annualized. These are "real" interest rates that should be used to discount benefits and costs measured in constant dollars. Unlike typical market interest rates, real rates exclude the expected rate of future price inflation.

The 7 percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy, based on historical data. It is a broad measure that reflects the returns to real estate and small business capital as well as corporate capital. It approximates the opportunity cost of capital, and it is the appropriate discount rate whenever the main effect of a regulation is to displace or alter the use of capital in the private sector.

The 3 percent discount rate is based on a recognition that the effects of regulation do not always fall exclusively or primarily on the allocation of capital. When regulation primarily and directly affects private consumption, a lower discount rate is appropriate. The alternative most often used is sometimes called the "social rate of time preference." This term simply means the rate at which "society" discounts future consumption flows to their present value. If one assumes the rate that the average saver uses to discount future consumption is a measure of the social rate of time preference, the real rate of return on long-term government debt may provide a fair approximation. Over the last thirty years, this rate has averaged around 3 percent in real annual terms on a pre-tax basis.

Special considerations arise when comparing benefits and costs across generations. Although most people demonstrate time preference in their own consumption behavior, it may not be appropriate for society to demonstrate a similar preference when deciding between the well-being of current and future generations. Future citizens who are affected by such choices cannot take part in making them, and today's society must act with due consideration of their interests. Many people have argued for a principle of intergenerational neutrality, which would mean that those in the present generation would not treat those in later generations as worthy of less

concern. Discounting the welfare of future generations at 7 percent or even 3 percent could create serious ethical problems.

An additional reason for discounting the benefits and costs accruing to future generations at a lower rate is the longer the horizon for the analysis, the greater the uncertainty about the appropriate value of the discount rate. Private market rates provide a reliable reference for determining how society values time within a generation, but for extremely long time periods no comparable private rates exist. As several economists (including Martin Weitzman[9]) have explained, for the very distant future, the properly averaged discount factor corresponds to the minimum discount rate having any substantial positive probability.

At the same time, some economists have cautioned that using a zero discount rate could raise intractable analytical problems. They have argued that with zero discounting, even a small improvement in welfare, if permanent, would justify imposing any cost on current generations since the benefits would be infinite.

If the regulatory action will have important intergenerational benefits or costs, the agency might consider a sensitivity analysis using a lower but positive discount rate, ranging from 1 to 3 percent, in addition to calculating net benefits using discount rates of 3 percent and 7 percent.

Step 8: Evaluate Non-quantified and Non-monetized Benefits and Costs

Sound quantitative estimates of benefits and costs, where feasible, are preferable to qualitative descriptions of benefits and costs because they help decision-makers to understand the magnitudes of the effects of alternative actions and compare across different types of consequences. However, some important benefits and costs (e.g., protection of human dignity, equity, or privacy, see Executive Order 13563, section 1(c)) may be difficult or impossible to quantify or monetize given current data and methods. Agencies should carry out a careful evaluation of non-quantifiable and non-monetized benefits and costs.

Benefits and costs that are difficult to monetize. If monetization is not possible, the agency should explain why and present all available quantitative information. For example, an agency may not be able to monetize a benefit in terms of privacy or dignity, but it may be able to quantify the number of beneficiaries. Alternatively, an agency may be able to quantify, but not to monetize, increases in water quality and fish populations resulting from water quality regulation. If so, the agency should attempt to describe benefits in terms of (for example) stream miles of improved water quality for boaters and increases in game fish populations for anglers. When estimates of monetized effects and quantified physical effects are mixed in the same analysis, the agency should describe the timing and likelihood of such effects, and should avoid double-counting of effects.

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[9] Weitzman ML In Portney PR and Weyant JP, eds. (1999), *Discounting and Intergenerational Equity*, Resources for the Future, Washington, DC.

Benefits and costs that are difficult to quantify. If the agency cannot quantify a benefit or cost, the agency should explain why and present any available quantitative information. For example, the agency may not be able to quantify the number of individuals exposed to a risk but may be able to quantify the magnitude of the risk to those who are exposed. The agency should also provide a detailed qualitative description of any unquantified effects, such as ecological gains, improvements in quality of life, and aesthetic beauty. The agency should provide a discussion of the strengths and limitations of the qualitative information.

When the unquantified benefits or costs affect a policy choice, the agency should provide a clear explanation of the rationale behind the choice. Such an explanation could include detailed information on the nature, timing, likelihood, location, and distribution of the unquantified benefits and costs. The agency should include a summary table that lists all significant unquantified benefits and costs, highlighting (e.g., with categories or rank ordering) those that the agency believes are most important (e.g., by considering factors such as the degree of certainty, expected magnitude, and reversibility of effects).

Breakeven analysis. When quantification and monetization are not possible, many agencies have found it both useful and informative to engage in threshold or "breakeven" analysis. This approach answers the question, "How large would the value of the non-quantified benefits have to be for the rule to yield positive net benefits?" Suppose, for example, that a regulation that protects water quality costs $105 million annually, and that it also has significant effects in reducing pollution in rivers and streams. It is clear that the benefits of the regulation would exceed its costs if and only if those effects could reasonably be valued at $105 million or more. Once the nature and extent of the water quality benefits are understood, it might well be easy to see whether or not the benefits plausibly exceed the costs – and if the question is difficult, at least it would be clear why it is difficult. Breakeven analysis is an important tool, and it can provide insights when quantification is speculative or impossible.[10]

Cost-effectiveness analysis. Cost-effectiveness analysis (CEA) can provide a helpful way to identify options that achieve the most effective use of the available resources (without requiring monetization of all of the relevant benefits and costs). Generally, cost-effectiveness analysis is designed to compare a set of regulatory actions with the same primary outcome (e.g., an increase in the acres of wetlands protected) or multiple outcomes that can be integrated into a single numerical index (e.g., units of health improvement). This approach provides useful information about relative performance of regulatory alternatives (i.e., best 'bang for the buck'). At the same time, a comparison of monetized benefits and costs is necessary to determine which alternative maximizes net benefits.

When CEA is applied to public health and safety rulemakings, a measure of effectiveness must be selected that permits comparison of regulatory alternatives. Agencies currently use a variety of effectiveness measures. There are relatively simple measures such as the number of lives saved, cases of cancer reduced, or cases of paraplegia prevented. Sometimes these measures

[10] For additional discussion, see *2011 Report to Congress on the Benefits and Costs of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*, page 66-67. Available at: http://www.whitehouse.gov/sites/default/files/omb/inforeg/2011_cb/2011_cba_report.pdf

account only for mortality information, such as the number of lives saved and the number of years of life saved. There are also more comprehensive, integrated measures of effectiveness such as the number of "equivalent lives" (ELs) saved and the number of "quality-adjusted life years" (QALYs) saved. While OMB does not require agencies to use any specific measure of effectiveness, an Institute of Medicine report recommends that agencies use QALYs for all health and safety issues.[11] In any event, the regulatory analysis should explain why a measure was selected and how it was implemented.

Step 9: Characterize uncertainty in benefits, costs, and net benefits

Regulatory analysis requires forecasts about the future. What the future holds, both in the baseline and under the regulatory alternative under consideration, is typically not known for certain. The important uncertainties connected with the regulatory decision should be analyzed and presented as part of the overall regulatory analysis. The goal of the agency's uncertainty analysis is to present both a central "best estimate," which reflects the expected value of the benefits and costs of the rule, as well as a description of the ranges of plausible values for benefits, costs, and net benefits, which informs decision-makers and the public of the degree of uncertainty associated with the regulatory decision.

In developing an uncertainty analysis, agencies should follow these steps:

> *Specify potential scenarios*. As a first step, the agency should specify a set of plausible, mutually exclusive *scenarios* for both the baseline and for each regulatory alternative. Each scenario represents a complete description of a state of the world, including its evolution through time, that could arise. The goal is to specify scenarios that cover the full range of how the benefits and costs of the rule might vary. Typically this is done by specifying the set of factors that affect the benefits and costs of the regulatory alternatives.
>
> *Calculate the benefits and costs associated with each scenario.* Once the set of plausible scenarios has been specified, the agency can calculate the benefits and costs associated with each scenario. At this stage, the agency has all of the information it needs to conduct a *sensitivity analysis*. A sensitivity analysis examines how the benefits and costs of the rule change with key uncertain variables.
>
> *Construct a range of values.* When the agency cannot specify probabilities for the relevant scenarios, the agency should develop a central scenario for the baseline and for each regulatory alternative that reflects the agency's *best estimate* of the likely consequences of each regulatory alternative. The agency should use the benefits and costs of these best estimates to approximate the expected value of the benefits and costs of each regulatory alternative to use in its regulatory decision-making. The agency should also characterize ranges of *plausible* benefits, costs, and net benefits of each regulatory alternative. The goal is not to characterize the full range of *possible* outcomes, which

[11] IOM (2006). Valuing Health for Regulatory Cost-Effectiveness Analysis. The National Academies Press, Washington, DC.

may turn out to be extremely large, but rather the range of *plausible* outcomes as in a confidence interval. The agency must use its judgment on the range of scenarios that such ranges should reflect. At a minimum, the range should include a "high" and a "low" scenario that provide plausible upper and lower bounds.

The approach to constructing a range outlined above should be thought of as the minimal analysis that agencies should conduct. When feasible, agencies should also:

> *Assign probabilities and calculate expected values*. Having specified the set of plausible scenarios, the benefits and costs associated with each scenario, and the probabilities of each scenario, the agency should calculate expected values of the benefits and costs for each regulatory alternative. In these cases, where probability distributions can be assigned to each scenario, the agency should conduct a formal uncertainty analysis in which it characterizes the distributions of benefits, costs, and net benefits.

Circular A-4 requires formal quantitative analysis of uncertainty for rules that exceed the $1 billion annual threshold in benefits or costs.

D. Summarizing the Regulatory Analysis

Regulatory analysis should include a clear, plain language executive summary. The summary should include one or more tables that summarize the benefit and cost estimates for each regulatory action and alternative under consideration as well as the qualitative and non-monetized benefits and costs.[12] The summary should include:

- *Alternative regulatory approaches.* At a minimum, one or more tables should generally be used to report the benefits and costs of both the agency's preferred option and at least one alternative that is less stringent (i.e., lower cost) and one alternative that is more stringent (i.e., higher cost). For each of the regulatory alternatives, the agency should calculate benefits and costs relative to a common baseline.

- *Categories of benefits and costs.* The agency should categorize the benefits and costs into three mutually exclusive and exhaustive categories: (1) quantified and monetized; (2) quantified but not monetized; and (3) neither quantified nor monetized. The agency should not include any benefit or cost in more than one of these categories. For example, if the agency has monetized fatalities averted by an alternative, it should report the dollar value as part of the quantified and monetized benefits, and should avoid double-counting the number of "lives saved" in the quantified but not monetized benefits category. (Of

[12] Circular A-4 states: "…you should present a summary of the benefit and cost estimates for each alternative, including the qualitative and non-monetized factors affected by the rule, so that readers can evaluate them." (P.3) In addition, it states: "Your analysis should also have an executive summary, including a standardized accounting statement." (P. 3). It further states, "You need to provide an accounting statement with tables reporting benefit and cost estimates for each major final rule for your agency." (P. 44). Circular A-4 includes an example of a format for agency consideration.

course, the agency may also choose to report the monetized benefits in physical units, but should do so in a way that clearly avoids double-counting).

- *Separate reporting of distributional effects, including transfers.* The agency should report distributional effects, including transfers, separately and avoid the misclassification of transfer payments as benefits or costs.

- *Rank qualitative impacts.* The agency should categorize or rank the qualitative effects in terms of their importance (e.g., certainty, likely magnitude, and reversibility). The agency should distinguish the effects that are likely to be significant enough to warrant serious consideration by decision-makers from those that are likely to be minor.

- *Transparency.* The agency should add notes to the bottom of the tables that enable readers to interpret the information in the tables correctly. For example, when there is significant uncertainty to estimates, a caveat describing the nature of the uncertainty should be provided in the notes.

Control of Toxic Chemicals in Puget Sound

Characterization of Toxic Chemicals in Puget Sound and Major Tributaries, 2009-10

Publication No. 11-03-008

DEPARTMENT OF ECOLOGY
State of Washington

05155

Publication and Contact Information

This report is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/1103008.html.

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search User Study ID, RCOO0010.

Ecology's Activity Tracker Code for this study is 09-538.

For more information contact:

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Control of Toxic Chemicals in Puget Sound

Characterization of Toxic Chemicals in Puget Sound and Major Tributaries, 2009-10

by

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Olympia, Washington 98504-7710

January 2011

Waterbody Numbers

WA-01-1010
WA-02-0020
WA-03-1010
WA-05-1010
WA-06-0010
WA-07-1020
WA-10-1020
WA-18-0010
WA-PS-0240
WA-PS-0250
WA-PS-0290

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Abstract

The Washington State Department of Ecology (Ecology) is conducting a series of technical studies that will inform strategies to control sources of toxic chemicals to Puget Sound. The studies come under the umbrella of the Puget Sound Toxics Loading Analysis (PSTLA). Phases 1 and 2 of the PSTLA developed loading estimates for toxic chemicals and used computer model simulations to predict outcomes of control actions. Ongoing Phase 3 studies are intended to reduce uncertainties associated with chemical loadings and model predictions.

For the present study, Ecology collected seasonal water samples at seven ambient marine sites throughout Puget Sound and its ocean boundary waters, and from the mouths of the five largest rivers flowing into Puget Sound. Samples were analyzed for a wide range of inorganic and organic chemicals of concern.

Many chemicals were seldom or never detected in marine water samples, but concentrations of metals and polychlorinated biphenyls (PCBs) were similar to previously reported values. Concentrations of organic carbon, copper, and PCBs were higher in outgoing Puget Sound waters than in incoming ocean waters. The opposite was true for cadmium. Ocean exchange estimates indicated that most target chemicals of concern appear to be exported from Puget Sound to the ocean.

River water samples contained measurable concentrations of conventional parameters, nutrients, metals, and some organic compounds. Concentrations were generally within ranges previously reported. Petroleum-related compounds, semivolatile organic compounds (BNAs), polycyclic aromatic hydrocarbons (PAHs), and chlorinated pesticides were seldom detected. Daily loads calculated for many chemicals can be compared to estimated loads from other studies and model simulations.

Suspended particulate matter (SPM) was also collected from deep marine waters and river waters, and samples were analyzed for a suite of chemicals similar to those analyzed for water samples. Results from the Hood Canal and South Puget Sound basins were used to estimate loss rates of toxic chemicals from the water column via sedimentation. Toxic chemicals such as PAHs were more often detected in river SPM than in river water.

Acknowledgements

The authors of this report thank the following people for contributions to this study:

- Members of the Puget Sound Toxics Loading Analysis Steering Committee
- Washington State Department of Ecology staff:
  - Bruce Barbour
  - Julia Bos
  - Randy Coots
  - Holly Davies
  - Karin Feddersen
  - Mya Keyzers
  - Stuart Magoon
  - Jim Maroncelli
  - Dean Momohara
  - Dale Norton
  - Greg Pelletier
  - Brian Pickering
  - Mindy Roberts
  - Nancy Rosenbower
  - Dave Serdar
  - Janice Sloan
  - John Weakland
  - Leon Weiks
  - Jeff Westerlund

Executive Summary

Introduction

The Washington State Department of Ecology (Ecology) is working in collaboration with the Puget Sound Partnership and other state and federal agencies on a multi-phase Puget Sound Toxics Loading Analysis (PSTLA). The purpose of the PSTLA is to quantify various sources of toxic contaminants entering Puget Sound and to better understand the behavior and fate of the contaminants within the ecosystem. Results of the PSTLA will form part of the technical basis for a comprehensive strategy to reduce and control toxic chemical releases to Puget Sound.

In Phase 1 of the PSTLA, existing data were used to estimate loadings of toxic chemicals released to Puget Sound via surface runoff, atmospheric deposition, permitted wastewater discharges, combined sewer overflows, and direct spills (Hart Crowser et al., 2007). Phase 2 of the analysis refined land-use classifications and roadway loadings to improve toxic chemical loading estimates for the entire Puget Sound basin (EnviroVision et al., 2008). Overall estimates of surface runoff loading were later recalculated (Herrera, 2010a).

Ecology expanded numerical modeling begun in Phase 2 to provide insights into the relative importance of various loading pathways. The resulting Puget Sound Toxics Box Model (Pelletier and Mohamedali, 2009) allowed managers to investigate the response of contaminant concentrations in the water, sediment, and biota of Puget Sound to various source-control strategies. Initial modeling exercises were performed for polychlorinated biphenyls (PCBs) due to the relative abundance of existing PCB data. Future modeling efforts will examine fate and transport of other toxic contaminants, including polybrominated diphenyl ethers (PBDEs).

Data Gaps

A review of readily available data collected since 1995 on selected toxic chemicals in Puget Sound and the Straits of Juan de Fuca and Georgia (Serdar, 2008) identified significant gaps and limitations in the existing data. With few exceptions, the available data were deemed inadequate for providing representative concentrations for Box Model input and analyses. Phase 2 simulations using the Box Model also indicated more data would improve the accuracy of predictions. The greatest sources of uncertainty for Box Model predictions were:

- Limited data from which to choose input values representing toxic chemical loading from surface runoff.
- Limited data on concentrations of toxic chemicals likely to be exchanged between Puget Sound and ocean boundary waters [1] (*ocean exchange*).

The authors of the modeling study recommended that Phase 3 studies should fill these data gaps and thereby address uncertainties.

[1] For purposes of this study, ocean boundary waters are defined as the sampling locations in the Straits of Juan de Fuca and Georgia that, although they do not reflect true oceanic waters, represent conditions at the ocean boundary used in the Box Model (external to Puget Sound proper).

Study Purpose

The present 2009-10 study was designed to collect data that would improve input values to the Puget Sound Toxics Box Model, thereby reducing uncertainty in model predictions. These data could also be used to calibrate the model. Specific objectives of the study were:

- Measure concentrations of target toxic chemicals and other water quality parameters in samples representing ocean boundary waters likely to enter and marine waters likely to exit the modeled portion of Puget Sound.
  - Whole water samples collected from the deep layer near the main ocean boundary (Strait of Juan de Fuca and Haro Strait).
  - Whole water samples collected from the surface layer of the four primary Puget Sound basins (Whidbey, Main, Hood Canal, and South Sound).
- Measure concentrations of target toxic chemicals and other water quality parameters in the five rivers having the greatest annual discharges to Puget Sound (Skagit, Snohomish, Nooksack, Stillaguamish, and Puyallup).
- Identify sources of variability in concentrations of target toxic chemicals and other water quality parameters.
- Determine concentrations of toxic chemicals associated with suspended particulate matter (SPM) in marine and river waters.

Study Findings

Marine Water and SPM

Major findings from the marine sampling portion of the 2009-10 study include:

- Suspended solids, organic carbon, metals, PCBs, and PBDEs in samples collected from the surface and deep layers of the marine water column were routinely detected but consistently low. Semivolatile organic compounds (BNAs) and chlorinated pesticides were rarely detected and polycyclic aromatic hydrocarbons (PAHs) were never detected in marine water samples.
- The range of total PCB concentrations measured for ambient marine waters was 6.1-75 pg/L (mean = 26.3 pg/L). The mean concentration in ocean boundary waters (20.4 pg/L) was significantly less than the mean for Puget Sound marine waters (30.7 pg/L). Both values were lower than the mean concentration previously reported for the Strait of Georgia (42 pg/l; Dangerfield et al., 2007).
- Total PCB concentrations in the deep marine waters were significantly higher than those in the surface waters. This was true for the ocean boundary waters and Puget Sound (Figure ES-1). A significant positive relationship between total PCBs and total suspended solids (TSS) suggested that sedimentation plays a key role in the fate of PCBs in the Sound.

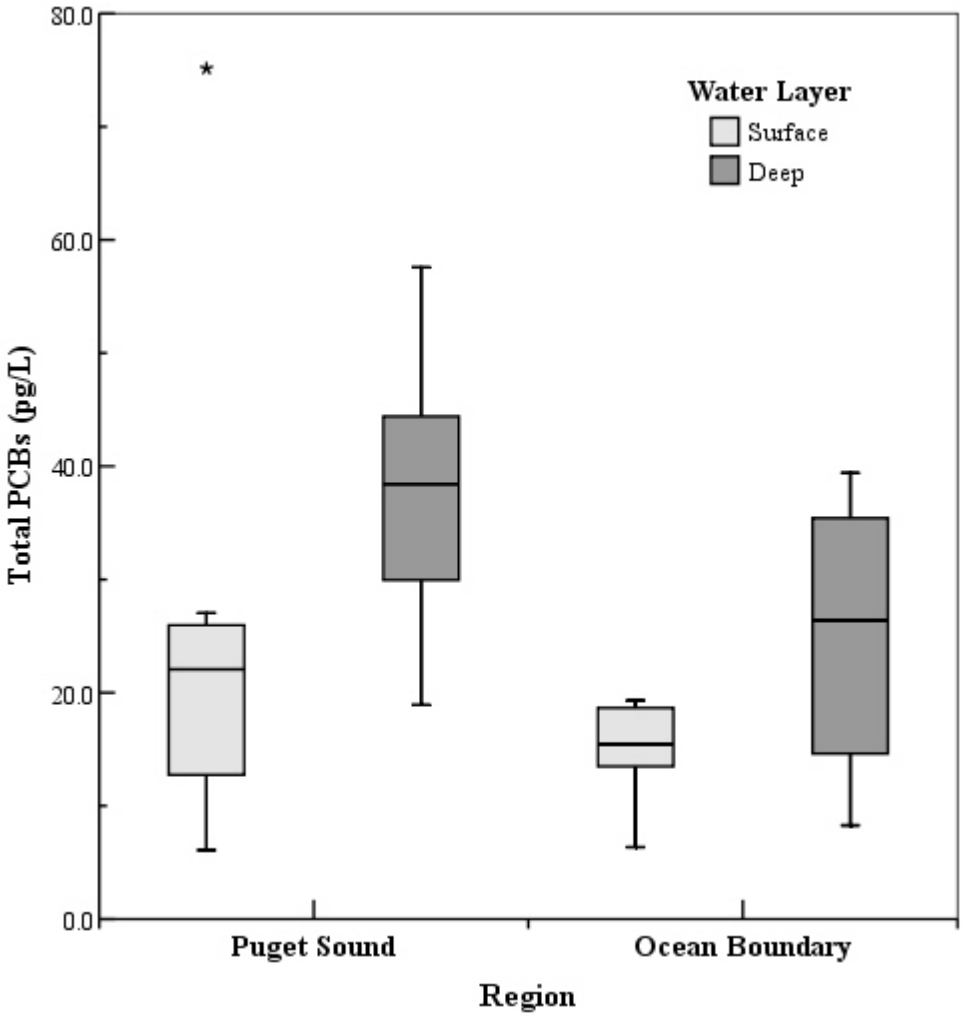

Figure ES-1. Total PCB concentrations in surface and deep marine waters.

- The range of detected total PBDE concentrations in marine waters (51 - 18,700 pg/L) was much wider than the range of total PCB concentrations. Total PBDEs concentrations were often 10 times higher in the present study than concentrations reported by Canadian researchers (Dangerfield et al., 2007). No evidence suggested the higher concentrations were due to sample contamination. Sources of high PBDE concentrations were not identified.
- Organic carbon concentrations in marine water samples resembled concentrations previously reported for the Strait of Georgia (Johannessen et al., 2008), but were substantially lower than marine water concentration records in Ecology's EIM database.
- Calculations of chemical exchange between Puget Sound and ocean waters, based on present study results, indicated most toxic chemicals are probably being exported out of Puget Sound. A notable exception was cadmium, which appeared to be imported into Puget Sound. This was due to incoming ocean waters having significantly higher concentrations than surface waters flowing out of the Sound to the ocean. The direction of net exchange for total PCBs and total PBDEs between the ocean and Puget Sound could not be estimated from the data collected.

- Samples of SPM collected from sediment traps deployed in Hood Canal and South Puget Sound (Case+Carr Inlets) contained similar concentrations of organic carbon, metals, and PBDEs. PCB concentrations in Case+Carr Inlet SPM were more than three times greater than those in Hood Canal.

River Water and SPM

Major findings from the river sampling portion of the study include:

- Concentrations of total suspended solids (TSS), organic carbon, nutrients, hardness, and metals were within the ranges reported from previous studies by Ecology and other monitoring programs (Inkpen and Embry, 1998; Wise et al., 2007).
- River water samples seldom contained detectable concentrations of petroleum-related compounds (oil and grease, TPH-D, and TPH-G), BNAs, PAHs, or chlorinated pesticides. River SPM collected by centrifugation in December 2009 and January 2010 contained detectable concentrations of many individual PAH compounds.
- The average concentration of total PCBs measured in surface water from the five rivers was 16.3 pg/L. The range of concentrations measured was 2.6 - 59 pg/L. This range is somewhat lower than the range reported by King County for the Green/Duwamish Rivers (83 - 814 pg/L; Willston, 2009) that flow through a more urban and industrial watershed.
- PBDEs were detected in less than half of the river water samples. Total PBDE concentrations were highly variable ranging from 10.9 - 265 pg/L, with an average of 55.6 pg/L.
- Total PAH concentrations in SPM (excluding retene) ranged from 32 - 210 µg/Kg, with an average of 120 µg/Kg. Concentrations of individual PAHs were <20 µg/Kg, except for retene which averaged 230 µg/Kg.
- Few other organic compounds (BNAs, TPH-D, chlorinated pesticides) were detected in SPM.
- Estimated daily loading of total PCBs from all five rivers ranged from 0.015 - 0.57 g/day.
- Estimated daily loading of total PBDEs from all five rivers ranged from 0.017 - 4.22 g/day.

Notable relationships between parameters include the following:

- TSS concentrations were significantly correlated with, and explained between 63% and 86% of the variability in, concentrations of total phosphorus and total metals.
- Organic carbon, total nitrogen, and nitrate+nitrite concentrations were significantly lower during July than during the other two sampling periods.
- Congeners belonging to the more polar PCB homolog groups (those with fewer chlorine atoms) were significantly correlated with many parameters in the dissolved phase (ortho-phosphate and dissolved metals). Congeners in the more hydrophobic PCB homologs (those with more chlorine atoms) were significantly correlated with TSS, total organic carbon (TOC), and parameters often found in particulate form (total nitrogen and total phosphorus).

Recommendations

Based on the findings of the present study, the following recommendations are made:

- Future sampling should focus on the collection and analysis of particulate samples to improve the detection frequency of hydrophobic compounds.
- More intensive water column sampling should be conducted near the ocean boundaries to Puget Sound proper (Admiralty Inlet sill and Deception Pass). Samples should be analyzed for a reduced suite of chemicals, with priority given to chemicals exhibiting high variability in the present study (e.g., PBDEs). This would improve current estimates of ocean exchange.
- Depth-integrated water sampling of large rivers should be conducted with focus on increased sampling frequency, a reduced suite of chemicals, and improved detection limits for organic contaminants. More frequent sampling during all phases of runoff-related events is needed to understand seasonal and other temporal patterns. This would facilitate a better characterization of loading during baseflow conditions and runoff-related events.
- Standard operating procedures (SOPs) for the collection and analysis of seawater samples for dissolved (DOC) and particulate organic carbon (POC) should be revised. For example, all equipment used for sample collection and processing should be made exclusively of glass or lined with Teflon.

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Introduction

Puget Sound Toxics Loading Analysis

The State of Washington enacted legislation in 2007 to protect and restore the Puget Sound ecosystem by 2020. The Puget Sound Partnership, while developing the Puget Sound Action Agenda, identified the control of toxic chemical releases as a high priority.

To inform a comprehensive strategy to reduce and control toxic releases, the Washington State Department of Ecology (Ecology) and others [2] undertook a multi-year Puget Sound Toxics Loading Analysis (PSTLA). The PSTLA was intended to quantify various sources of toxic contaminants entering Puget Sound and to better understand the behavior and fate of the contaminants within the ecosystem. Results of the PSTLA will form the technical basis for a toxics control strategy.

Phase 1 of the PSTLA used existing data to estimate loadings of toxic chemicals to Puget Sound via surface runoff, atmospheric deposition, permitted wastewater discharges, combined sewer overflows, and direct spills (Hart Crowser et al., 2007). Phase 2 improved watershed loading estimates for the entire Puget Sound basin by using revised land-use classifications and incorporating roadway loadings (EnviroVision et al., 2008; Herrera, 2010a). Modeling efforts were also expanded to provide insights about the relative importance of various loading pathways. The resulting Puget Sound Toxics Box Model [3] (Pelletier and Mohamedali, 2009) was composed of three parts:

1. Water circulation and transport box model (Appendix B, Figure B-1).
2. Contaminant fate and transport mass balance model.
3. Food web transfer bioaccumulation model.

The Box Model was initially used to predict how concentrations of polychlorinated biphenyls (PCBs) in the water, sediment, and biota of Puget Sound might respond to various source-control strategies. In doing so, the model identified substantial uncertainties and data gaps.

Data Gaps and Recommended Actions

The greatest source of uncertainty about Box Model predictions was the input values used to represent toxic chemical loading to Puget Sound from surface runoff (river loading). Another major source of uncertainty was the limited information available on concentrations and loads of toxic chemicals exchanged between the ocean and Puget Sound (Serdar, 2008). The authors of the modeling study recommended Phase 3 investigations to address these uncertainties. These included the following targeted efforts:

[2] The Puget Sound Partnership, U.S. Environmental Protection Agency (EPA), and other federal, state, and local agencies.
[3] Hereafter, this report often refers to the Puget Sound Toxics Box Model simply as the Box Model.

- **Major tributaries.** Estimates of toxic chemical loadings from surface runoff should be improved by monitoring concentrations of toxic chemicals in rivers, streams, and discharges from publically-owned water treatment facilities (POTWs), especially in relation to land uses and flow regimes (baseflow or storm runoff).
- **Ocean boundary waters.** Estimates of toxic chemicals transported from ocean boundary waters into Puget Sound should be improved because they may:
  - Be similar in magnitude to toxics loadings from major land uses in Puget Sound watersheds.
  - Influence concentrations of toxics observed in Puget Sound and its biota.
- **Puget Sound water column.** Toxic chemical concentrations in major Puget Sound basins, and how they partition between suspended particulate matter (SPM) and water (dissolved), should be measured because they are important determinants of biological uptake.

Goals and Objectives

The principal goal of the present 2009-10 study was to provide concentration data for various toxic chemicals that could be used to address these data gaps. Specific objectives listed in the Quality Assurance (QA) Project Plan (Coots and Osterberg, 2009) included:

- Collect samples representing seawater entering and leaving the modeled portion of Puget Sound, especially:
  - Samples collected from the deep layer of ocean boundary waters (Strait of Juan de Fuca and Haro Strait) [4].
  - Samples collected from the surface layer of four Puget Sound basins (Main, Whidbey, South Sound, and Hood Canal) [5].
- Measure concentrations of the following parameters in seawater samples collected from above *and* below any density gradient (pycnocline) in ocean boundary waters and the four major Puget Sound basins:
  - Total suspended solids (TSS).
  - Total and dissolved organic carbon (TOC and DOC).
  - Total and dissolved fractions of five metals (arsenic, cadmium, copper, lead, and zinc).
  - Semivolatile organic compounds (BNAs).
  - Polycyclic aromatic hydrocarbons (PAHs).
  - Chlorinated pesticides.
  - Polychlorinated biphenyl (PCB) and polybrominated diphenyl ether (PBDE) congeners.

[4] Samples collected from the western end of the Strait of Juan de Fuca would be less representative of seawater entering Puget Sound.

[5] Samples collected from surface layer waters of the Straits of Juan de Fuca and Georgia could include toxic chemicals originating outside of Puget Sound and therefore be less representative of leaving Puget Sound.

- Measure concentrations of the same chemicals of concern *plus* the following parameters in the five rivers with the greatest annual discharges to Puget Sound (Skagit, Snohomish, Nooksack, Stillaguamish, and Puyallup):
  - Hardness.
  - Nutrients (total nitrogen [TN], nitrate+nitrite nitrogen, ammonia nitrogen, total phosphorus [TP], and ortho-phosphate).
  - Petroleum-related compounds.
    - Oil and grease.
    - Diesel and gasoline fractions of petroleum hydrocarbons (TPH-D and TPH-G).
- Identify variability in concentrations of target toxic chemicals and other water quality parameters.
- Determine concentrations of toxic chemicals associated with SPM in marine and river waters.

Outcomes

Results of the present study include the following:

- Concentration ranges for target chemicals in ocean boundary waters and the major Puget Sound basins.
- Estimates of chemical exchange between ocean boundary waters and Puget Sound.
- Concentration ranges for target chemicals near the mouths of five major rivers discharging to Puget Sound.
- Estimates of daily chemical loads from the same rivers to Puget Sound.
- Some indications of spatial and temporal variability in chemical concentrations in the marine water column and near the river mouths.

Study results also provide data for calibrating the existing Puget Sound Toxics Box Model and using it to predict the transport and fate of other toxic chemicals. Consequently, the study contributes to developing a control strategy for toxic chemicals entering Puget Sound.

Study Design

The QA Project Plan (Coots and Osterberg, 2009) described the study design in detail. The following section summarizes the major project elements:

Ocean Exchange of Toxic Chemicals

Ecology collected samples from ocean boundary waters (Strait of Juan de Fuca and Haro Strait) and major Puget Sound basins (Whidbey, Main, South Sound, and Hood Canal) to determine water column concentrations of a suite of chemicals of concern (Figure 1). At each location, samples were collected from two depths representing the surface and deep layers simulated by the Box Model (Table 1). Temporal variability was addressed by sampling the water layers over three seasons. Ecology used the results to estimate the annual mass transport of target chemicals into and out of Puget Sound at the main ocean boundaries (Admiralty Inlet and Deception Pass).

River Loading of Toxic Chemicals

Ecology sampled the five rivers with the greatest mean annual flow near their mouths but upstream of any likely intrusion of marine (salt) water (Figure 1). Each river was sampled on three occasions intended to represent:

- Summer baseflows.
- Fall runoff or storm-related flows.
- Winter baseflows.

Water samples collected using depth-integrated methods were analyzed for the same toxic chemicals as marine waters, plus nutrients and hardness. Surface grab samples were also collected and analyzed for petroleum-related compounds. Instantaneous loads were calculated using measured concentrations of the various parameters and the mean daily flows.

Toxic Chemicals Associated with Particulates

Ecology measured concentrations of toxic chemicals associated with SPM in samples collected during the winter season from the marine water column and from near the five river mouths. Sediment traps were deployed at five locations to collect SPM from the marine water column (Figure 1). Centrifuges were used to concentrate SPM pumped from each river at nearly the same time that whole water samples were collected.

Sampling Methods

Marine Water Column

Ecology chose the marine water column sampling sites shown in Figure 1 to represent ambient conditions in the four major Puget Sound basins and near the main ocean boundaries (Admiralty Inlet and Deception Pass). Sites were established at the deepest location near the centroid of each basin. Two sites in the Strait of Juan de Fuca and one in Haro Strait were chosen to represent boundary waters. All sampling sites were located away from river mouths and nearshore influences. The geographic coordinates for each sampling site are listed in Table 1.

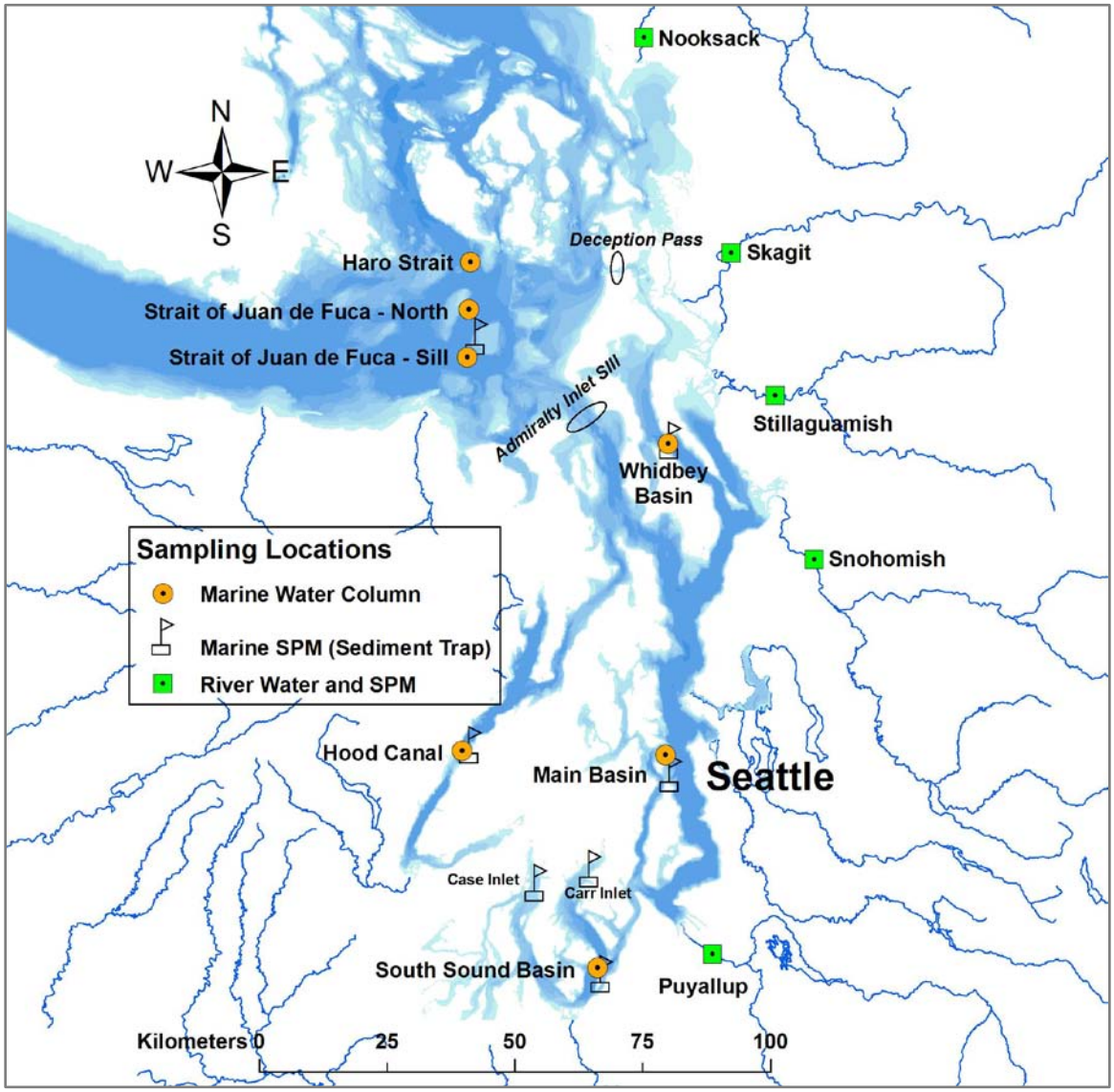

Figure 1. Marine water column and river sampling locations.

Puget Sound Toxics Box Model marine boundaries are shown in italics. Also shown are locations where sediment traps were deployed in Carr and Case Inlets during 2008 (see Results).

Table 1. Marine water column sampling site information.

Coordinates are listed for each sampling site chosen to represent Puget Sound Toxics Box Model regions. Also listed are depths used by the Box Model to divide surface from deep water layers.

Sampling Site ID	Latitude	Longitude	Box Model Region	Depth (meters) Dividing Water Layers
	(Decimal degrees; NAD83)			
Hood	47.5589	-123.0048	Hood Canal South	13
South Sound	47.1847	-122.6378	Puget Sound South	30
Main	47.5616	-122.4759	Puget Sound Main	50
Whidbey	48.1083	-122.4900	Whidbey Basin	9
SJdF at Sill	48.2500	-123.0250	Boundary Conditions	50
SJdF North	48.3333			
Haro Strait	48.4167			

SJdF = Strait of Juan de Fuca.

The circulation and transport component of the Puget Sound Toxics Box Model (Pelletier and Mohamedali, 2009; Babson et al., 2006) divided each basin vertically into surface and deep water column layers, as shown in Table 1. To provide chemical concentration data for model input and calibration, water samples were collected from within the surface and deep layers at the seven sampling locations. To assess the seasonal variability of water column concentrations, each site was sampled on three occasions (July 2009, October 2009, and January 2010).

The platform for marine sampling activities was the research vessel (R.V.) *Skookum*, an aluminum hull vessel with no antifouling coat. The *Skookum* was positioned by GPS within 100 feet of target coordinates, and the engine was off for at least five minutes prior to sampling. All sampling activities were conducted on the windward side to minimize contamination from shipboard sources.

Prior to sampling the water column at each site, a Conductivity/Temperature/Depth profiler (CTD; Model SBE25, Sea-Bird Electronics, Inc.) was deployed to measure temperature, salinity, and density throughout the water column. CTD deployments were conducted according to manufacturer protocols (Sea-Bird, 2009a and 2009b). Density profiles were assessed in the field to evaluate whether the water column was stratified (i.e., a less dense surface layer overlying a more dense deep water layer) and to accordingly select water sampling depths as follows:

- If density stratification was present, sampling depths targeted the approximate middle of the observed surface and deep layers.
- Absent stratification, sample collection targeted depths at the approximate middle of Box Model-defined surface and deep layers (Table 1).

Actual sampling depths are documented in Appendix B (Tables B-1 and B2; Figures B-2 through B-8). CTD data were later post-processed using recommended protocols, standard oceanographic equations, and manufacturer software (Sea-Bird, 2009c and 2010).

Water column samples were collected using a pair of 10-liter, Teflon-coated GO-FLO discrete samplers (General Oceanics, Inc.; Figure 2). Mounted on a non-metallic Vectran rope, the two samplers were deployed simultaneously to collect 20 liters from a targeted depth. Collection of samples from the deep layer preceded surface layer sampling at all locations. To prevent contamination of water samples expected to contain very low concentrations of target chemicals, strict protocols were employed for GO-FLO deployment and sample decanting. These protocols were based on EPA *clean hands / dirty hands* techniques (EPA, 1996), and are documented in Appendix C.

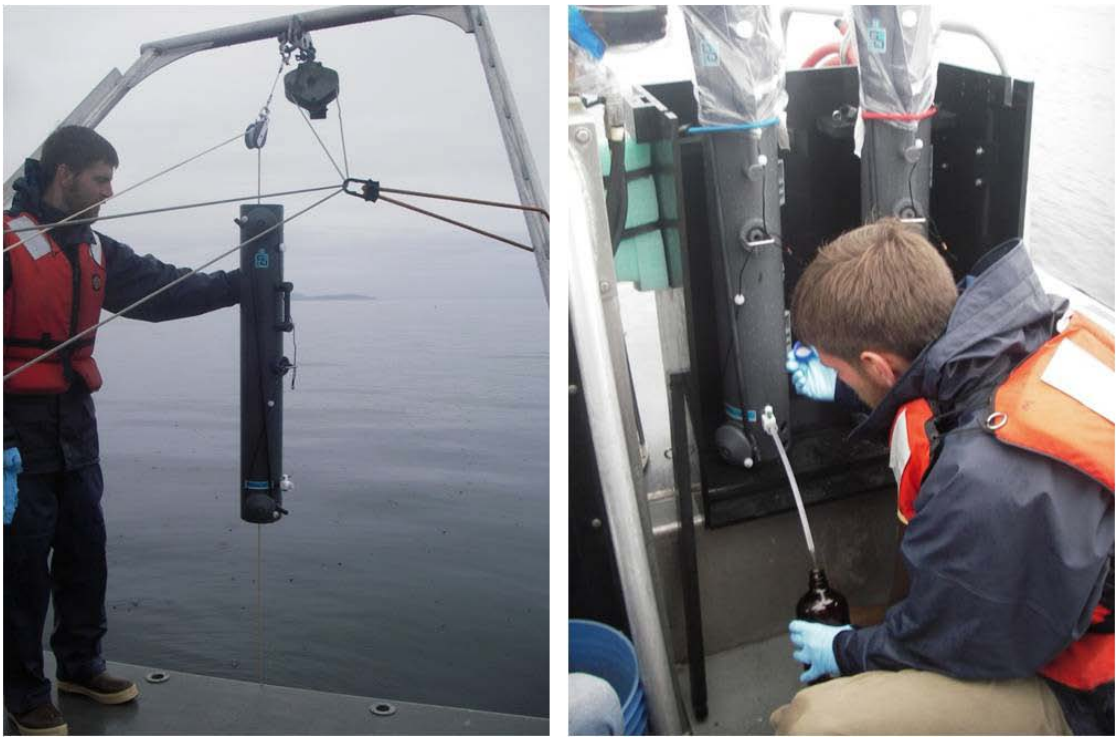

Figure 2. Collecting samples from the marine water column using GO-FLO samplers.

After retrieval, sample water was drained from the GO-FLO samplers through clean Teflon tubing to pre-rinse and then fill certified, pre-cleaned containers. Subsamples were filled in the following order: TSS, particulate organic carbon (POC) and DOC, PCB congeners, PBDE congeners, chlorinated pesticides, PAHs, BNAs, and total and dissolved metals. The volume, container, preservation, and holding times for each of these analytes are listed in Appendix C (Table C-1). Atmospheric exposure of the sample water during a typical bottle fill was minimal, occurring over a distance of approximately one inch (between the end of the Teflon tubing and the receiving bottle) for only 5 to 30 seconds.

Notable modifications to subsampling protocols from those presented in the QA Project Plan included:

- Salinity was not measured to confirm sample collection depth.
- A portable glove box was not used for transferring water to sample bottles (to eliminate exposure of samples to ambient air) because deck space was limited.

No seawater samples were collected for analysis of organic carbon during the first sampling event (July 2009) because previously available methods (Stutes and Bos, 2007) were inadequate for the purposes of this study. New field protocols were developed based on SOPs used by the University of Maryland's Horn Point Environmental laboratory (Lane et al., 2000) and others (Johannessen et al., 2008). The new procedures used an all-glass filtration apparatus and 0.7-µm pore-size glass fiber filters, with the filters and filtrate analyzed for POC and DOC, respectively (see Appendix C for details). Sampling for organic carbon resumed in October 2009 and was conducted at all locations and depths during the final two sampling events.

Various field quality control (QC) samples were also collected during each seasonal sampling. Results were used to assess environmental variability, replicability of sampling and analytical methods, and the potential for sample contamination by sampling equipment and procedures. Appendix D describes the purpose of each type of field QA sample and a description of how it was created in the field. Appendix D also presents field QA data and discusses how these data influenced interpretation of water column sample results.

Marine SPM

Ecology collected samples of SPM settling through the marine water column using moored sediment traps. A total of five moorings were deployed, each equipped with multiple traps. Sampling targeted the four Puget Sound basins where water column sampling was conducted, as well as a single location in the Strait of Juan de Fuca to collect SPM from the ocean boundary waters. All moorings were anchored in water no deeper than 50 meters and located as near as possible to water sampling stations (Figure 1).

Sediment trap moorings were deployed during October 2009. At sites where water column stratification was observed, traps were positioned to collect SPM from both the surface and deep water layers (two traps within each layer). At sites where the water column was completely mixed at the time of deployment, multiple traps were mounted within a single mid-depth zone. The configuration of each site's mooring is presented in Appendix B (Figure B-9).

Individual sediment traps consisted of paired straight-sided glass collection cylinders, each 50 cm tall by 10 cm diameter (5H:1W; 78.5 cm^2 opening area). A schematic of the construction details of the traps and their moorings is presented in the QA Project Plan (Coots and Osterberg, 2009), and further discussion can be found in Norton (2001 and 1996). At deployment, collection cylinders were filled with two liters of high salinity water (4% NaCl) and sodium azide (2% NaN_3) as a preservative to reduce microbial degradation of the samples.

Traps were intended to be deployed for a period of two to three months, collecting SPM between the fall and winter water column samplings. However, efforts to recover the traps during January and February 2010 were mostly unsuccessful, with moorings having either failed or drifted down slope too far to locate. Only the mooring in the Hood Canal was located; unfortunately, it had been disturbed and most of the collection cylinders were damaged. The SPM collected by the deepest (40 meters) sediment trap from the Hood Canal was intact and visibly undisturbed, and was deemed usable.

Upon retrieval, overlying water was removed from the two Hood Canal cylinders using a peristaltic pump. The salinity of the water immediately above the SPM in each cylinder was measured with a refractometer to verify that preservative remained. The SPM from the two cylinders was slurried, combined in a glass sample jar, and allowed to settle overnight. It was then concentrated by laboratory centrifugation (2000 rpm for at least 10 minutes), homogenized, and weighed. Total dry mass was estimated from the measured wet mass and approximate percent solids. Based on the estimated dry mass, chemical analyses were prioritized and subsamples were apportioned into certified, pre-cleaned glass sample containers for each analysis.

The Hood Canal trap yielded enough SPM to analyze a subset of the planned suite of parameters, including percent solids, TOC, five metals, PCB congeners, and PBDE congeners. To supplement these analytical results, archived sediment trap material from a recent Ecology study was also analyzed. The archived SPM had been collected by mid-water column sediment traps (identical to those employed in the present 2009-10 study) moored at sites in the Case and Carr Inlets (Figure 1) between March and June 2008 (Norton, 2009). Archived SPM from the Case and Carr traps was thawed [6], combined, and homogenized. Subsamples were distributed into sample jars for analysis of percent solids, metals, and PCB and PBDE congeners.

River Water

Ecology sampled five rivers contributing the greatest annual discharge to Puget Sound from bridges located beyond the normal upper extent of saline water intrusion. All bridges were near U.S. Geological Survey (USGS) or Ecology gaging stations (Figure 1 and Table 2). Additional details about sampling sites and sampling activities are presented in Appendix B (Table B-3 and Figures B-11 to B-15).

Sampling occurred at times intended to capture three river conditions:

- Baseflows during the dry season (July).
- Flows related to "first fall flush" or storm-related runoff (October).
- Baseflows during the wet season (December/January).

Depth-integrated samples were collected using Teflon one-liter sample bottles fit with Teflon nozzles sized for expected current velocities. Bottles and nozzles were pre-cleaned to priority pollutant standards using laboratory soap, tap water, 10% nitric acid, de-ionized water, acetone, and hexane. Similar cleaning procedures are described elsewhere (PSEP, 1997; Ecology, 2006 and 2008).

[6] Particulate material from Case and Carr Inlet traps had been frozen and stored in glass jars for approximately 18 months.

Table 2. Sampling locations near mouths of the five largest rivers discharging to Puget Sound.

River Name	Watershed Area [1] (km^2)	Annual Flow (Period of Record)		Sampling Location (Decimal degrees, NAD 1983)		Location Description	River Mile (RM)	Nearest Gaging Station
		cfs	cms	Latitude	Longitude			
Skagit	8,010	16,530 (69 yrs)	468	48.4450	-122.3354	Old Hwy 99 Mt. Vernon	15.7	USGS 12200500
Snohomish	4,440	9,810 (38 yrs)	278	47.9107	-122.0987	Avenue D Snohomish	12.7	Ecology 07A090 [2]
Nooksack	2,050	3,925 (38 yrs)	111	48.8189	-122.5801	Slater Road So. of Ferndale	3.4	Ecology 01A050 [3]
Stillaguamish	1,440	3,860 (38 yrs)	109	48.1969	-122.2104	I-5, west of Arlington	11.1	Ecology 05A070
Puyallup	2,460	3,310 (92 yrs)	94	47.2140	-122.3415	66th Avenue Puyallup	5.8	USGS 12101500 [4]

[1] Area of watershed upstream of gaging station where samples were collected.
[2] Mean annual flow based on two USGS gaging stations (12150800 - Snohomish R.; 12155300 Pilchuck River) is 9,993 cfs.
[3] Mean annual flow based on USGS gaging station 12213100 at RM 5.8 is 3,825 cfs.
[4] USGS gaging station is located at RM 6.6, approximately 0.8 miles upstream.

The sampling bottle with nozzle was attached to a US DH-95 sampler (FISP, 2000) that was suspended by steel cable from each bridge deck (Figure 3a). Sampling followed USGS protocols (USGS, 2005) except that water was collected and composited from only three quarter points in the channel. Near-surface grab samples were collected for analysis of petroleum products (oil and grease, TPH-D, and TPH-G), as shown in Figure 3b.

Ecology conducted sample collection and processing activities according to EPA *clean hands / dirty hands* methods (EPA, 1996) to the extent possible to minimize the risk of contamination. However, a portable glove box was not used while compositing and filtering samples because it proved to be cumbersome.

Field QA samples collected during river water sampling are described in Appendix D, which also includes QC sample results and discussion of how these QC samples affected data quality.

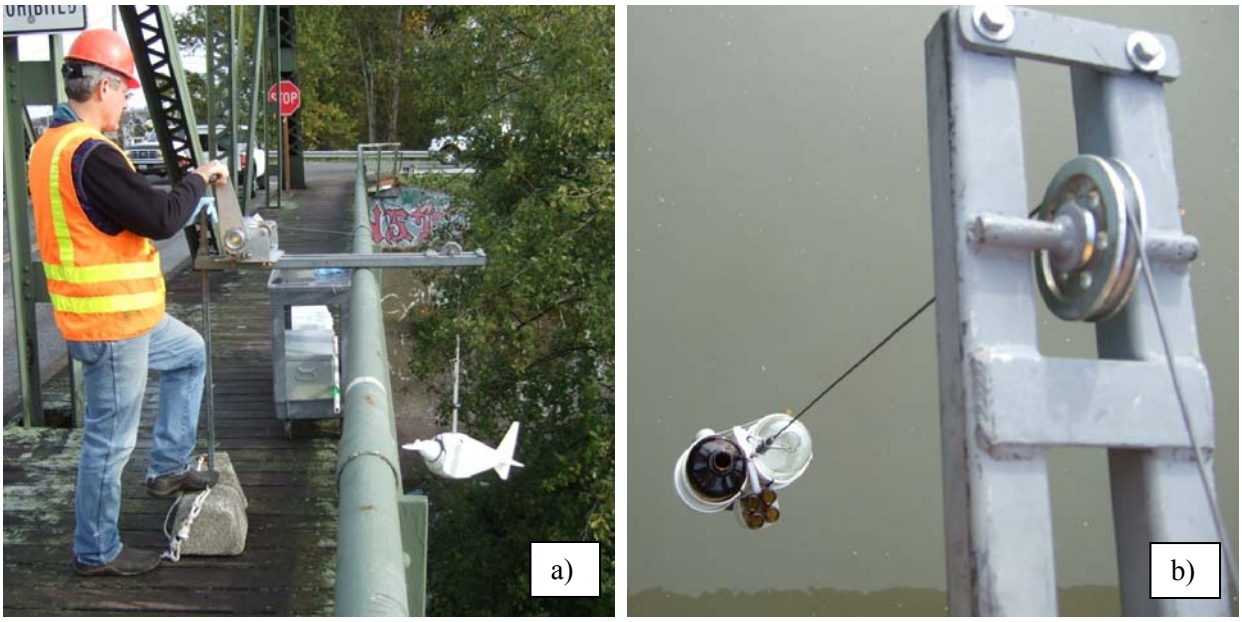

Figure 3. Collecting depth-integrated water samples and surface grabs.

River SPM

Ecology collected SPM from the five rivers only during the winter, as specified in the QA Project Plan. This was done by pumping mid-channel water through continuous-flow centrifuges in which solid material was retained. Sampling occurred within 24 hours of collecting discrete river water samples. A brief description of pump-and-centrifuge field methods follows (also see Coots and Osterberg, 2009; Gries and Sloan, 2009).

A Grundfos groundwater/well pump (Model SP4) was deployed and maintained at about 6/10 maximum mid-channel depth in each river. Water was pumped at about 2.8 gpm through Teflon-lined tubing to two Alpha Laval centrifuges (Sedisamp II, Model 101L). During this process, three discrete samples were collected from both inflow and outflow waters. The samples were composited and analyzed for TSS to assess the efficiency of centrifuges at retaining SPM [7].

After 16 - 22 hours, pumping ceased and centrifuges were shut off. The centrifuged SPM was collected while still at the sampling site. Residual water in the centrifuge bowls was removed using pre-cleaned glass syringes. Solids were collected using stainless steel spoons and Teflon-coated spatulas. Water and solids were placed in separate certified, pre-cleaned glass sample containers. Solids in the bowl water were later concentrated by laboratory centrifugation (approximately 2,000 rpm for at least 20 minutes) and added to the main mass of field-centrifuged solids. The total wet weight of solids collected was recorded. Subsamples were weighed and placed into separate jars for different analyses.

[7] % Efficiency = $[(TSS_{inflow}-TSS_{outflow})/TSS_{inflow}]*100$

Prior to the first river sampling:

- The stainless steel pump was soaked for 48 hours in de-ionized water.
- All tubing and centrifuge parts were cleaned using a 10% solution of nitric acid, de-ionized water, acetone, and hexane.

Between river sampling events, centrifuge parts were cleaned similarly. However, tubing was cleaned using only laboratory detergent, 10% nitric acid, and copious de-ionized water. Water from each river was also pumped through the tubing for at least 15 minutes (>150 liters or >40 gallons) before collecting SPM.

Analytical Methods

This section provides a summary of the analytical methods used for the present study. Additional details can be found in Appendix C, the QA Project Plan (Coots and Osterberg, 2009), and Ecology's Manchester Environmental Laboratory (MEL) *Lab Users Manual* (MEL, 2008).

Marine and River Water

Standard preparation, cleanup, and analytical methods were used to measure the parameters listed in the *Goals and Objectives* section. Table 3 describes the methods used by laboratories to analyze the parameters in the different samples that were collected. The following should be noted:

- The fractions of organic carbon that the Horn Point Lab measured in marine water (DOC and POC) differed from those MEL measured in river water (DOC and TOC).
- MEL measured phosphorus in strong acid extracts of river water samples using a colorimetric method comparable to most nutrient monitoring studies.
- Frontier Geosciences measured concentrations of five metals in marine water samples using methods similar those MEL used to measure the same metals in river water samples.
- The detection limits and reporting limits for oil and grease in river water were based on a grab sample size of one liter.
- MEL's organic chemical analyses provided results for as many as 32 chlorinated pesticides, 55 semivolatile organic compounds (BNAs), and 22 individual PAHs.
- Analytical Perspectives reported concentrations for 209 PCB congeners, and Pacific Rim Labs reported concentrations for 36 PBDE congeners.

SPM from the Marine Water Column and Rivers

Material from the Hood Canal sediment traps was analyzed for percent solids, TOC, five metals, PCBs, and PBDEs. Sediment that was combined from traps previously recovered from Carr and Case Inlets was analyzed for the same metals, PCBs, and PBDEs. Samples of SPM collected from each of the rivers were analyzed for percent solids, TOC, the same five metals, PCBs, and PBDEs. Enough suspended sediment was centrifuged from four of the rivers to also be analyzed for TPH-D, BNAs, PAHs, and chlorinated pesticides. Laboratory methods used for the various analyses are included in Table 3.

Table 3. Analyses of marine water column, river water, and SPM samples.

Parameters	Samples	Method	Method Description	Laboratory
Conventional Parameters, Nutrients, and Hardness (mg/L)				
% Solids	SPM	EPA 160.3		
TSS	S, F	SM 2540 D	Gravimetric	MEL
DOC	S	SM 5310	Combustion; IR detection	Horn Pt
POC			Combustion/oxidation; Thermal conductivity detection	
DOC and TOC	F		Combustion; IR detection	MEL
TOC	SPM	PSEP EPA 415.1	Combustion; IR detection	MEL
Nutrients [1]	F	SM 4500	Colorimetry	MEL
Hardness	F	EPA 200.7	ICP; Calculation	MEL
Total metals [2] (µg/L)	S, F SPM	FGS 054 EPA 200.8	ICP-MS	FGS MEL
Dissolved metals [2] (µg/L)	S, F			
Petroleum-Related Products (mg/L)				
Oil and Grease (HEM)	F	EPA 1664A	Gravimetric	MEL
TPH-D	F, SPM	ECY 97-602	GC/FID	MEL
TPH-G	F		Purge and trap; GC/FID	MEL
Organic Compounds				
Chlorinated Pesticides (ng/L) [3]	S, F	EPA 8081	GC/ECD	MEL
PAHs (µg/L) [4]	S, F SPM	EPA 8270 SIM	GC/MS	MEL
Semivolatile Organic Compounds BNAs (µg/L) [5]	S, F	EPA 8270	Capillary GC/MS	MEL
209 PCB Congeners (pg/L)	S, F SPM	EPA 1668A	GC/HRMS	AP, PRL
36 PBDE Congeners (pg/L)	S, F SPM	EPA 1614		PRL

[1] Includes total nitrogen (TN), nitrate+nitrite-N, ammonia-N, total phosphorus (TP), and ortho-phosphate (ortho-P)
[2] Includes arsenic, cadmium, copper, lead, and zinc.
[3] See Appendix E, Table E-2, for list of 32 chlorinated pesticides measured.
[4] See Appendix E, Table E-8, for list of 22 PAH compounds measured.
[5] See Appendix E, Table E-14, for list of 55 semivolatile organic compounds measured.

See LEGEND on following page.

LEGEND:

Analytes or Parameters

BNAs = base/neutral/acid extractable, semivolatile organic compounds
DOC = dissolved organic carbon
PAHs = polycyclic aromatic hydrocarbon compounds
PCBs = polychlorinated biphenyls
PBDEs = polybrominated diphenyl ethers
TOC = total organic carbon
TPH-D = total petroleum hydrocarbons - diesel fraction
TPH-G = total petroleum hydrocarbons - gasoline fraction
TOC = total organic carbon
TSS = total suspended solids

Sample Type

F = freshwater (river samples)
S = seawater (ocean boundary and Puget Sound water samples)
SPM = suspended particulate matter (trap and centrifuge samples)

Method

ECD = electron capture detection
ECY = Washington State Department of Ecology (method number)
EPA = U.S. Environmental Protection Agency (method number)
FID = flame ionization detection
GC = gas chromatography
HR = high resolution
ICP = inductively-coupled plasma detection
MS = mass spectrometric confirmation
PSEP = Puget Sound Estuary Program Protocols and Guidelines (PSEP, 1986; PSEP, 1997)
SIM = selective ion monitoring
SM = Standard Methods (APHA, 2005)

Laboratories

AP = Analytical Perspectives, Inc.
FGS = Frontier GeoSciences, Inc.
Horn = University of Maryland Environmental Laboratory, Horn Point, Maryland
MEL = Manchester Environmental Laboratory
PRL = Pacific Rim Laboratories, Inc.

Data Quality

Data Verification

Laboratory chemists, MEL's QA Officer, and project staff conducted data quality reviews. The reviews evaluated the acceptability of sampling and analytical results based on the measurement quality objectives (MQOs) outlined in the QA Project Plan. This section describes the data quality review process and summarizes the findings. Additional details can be found in Appendix D.

Field Data Quality Review and Findings

Project staff reviewed field notes and found that measurements were made consistent with methods described in the QA Project Plan, except as noted in the *Sampling Methods* section. Three minor data quality concerns were identified:

- Some salinity results from marine water column CTD profiles were flagged as suspect.
- Water depths recorded for river samplings (quarter points and pump intake depths) were only accurate to ± 1 foot due to water levels that changed with tides or flows.
- Flow rates and the water volume pumped to collect SPM from the Puyallup River (December 2009) were uncertain because debris sometimes accumulated in the tubing and impeded flow.

Analytical Data Quality Review and Findings

MEL and contract laboratory chemists conducted initial QA reviews to verify that samples were handled and analyzed according to QA Project Plan requirements. The reviews focused on:

- Sample storage conditions and holding times.
- Sample preparation, extraction, and analytical methods.
- Instrument calibrations.
- Method detection limits (MDLs) and reporting limits (RLs).
- Lab QC sample results.

MEL staff found that the results, with few exceptions, reflected the storage conditions, holding times, and analytical methods listed in the QA Project Plan. Results that met all MQOs were accepted without qualification.

Results were assigned a "J" qualifier code (indicating an estimated value) if the detected concentrations were less than the RL, or if one or more lab QC samples failed to meet MQOs. For example, chemical concentrations were qualified with a "J" if spiked QC samples showed consistently low recovery. However, the number of "J" qualifier codes assigned for different reasons was not easily quantified. Ecology's QA Officer assigned an "N" qualifier code for PCB and PBDE congeners that could only be tentatively identified (or "NJ" if also below reporting limits). A "UJ" qualifier code was assigned to sample results for various reasons but usually

because concentrations were less than ten times (<10 X) those measured in batch-specific method blanks. This indicated potential contamination from sample handling and analysis in the laboratory. Analytes for which this occurred were lead, zinc, Lindane, di-N-butyl phthalate, PCB-011, PBDE-047, PBDE-099, and PBDE-100. Consistent with laboratory best practices (EPA and MEL), results assigned "N", "NJ", "U" and "UJ" qualifiers were not used in analyses unless stated otherwise.

Analytical results were rarely rejected (0.5% of all individual chemical concentrations reported). The chemicals for which concentrations were sometimes assigned a "REJ" qualifier code were 2-chloronaphthalene, 3-nitroaniline, 4-chloroaniline, acenaphthylene, benzoic acid, n-nitroso-diphenylamine, PBDE-007, PBDE- 010, and PBDE-015.

In terms of traditional measures of data quality:

- *Accuracy* of results was ensured by verifying calculations of final concentrations. Only a few corrections were required. The accuracy of metals results for marine water samples was also assessed by analyzing certified reference materials (CRM) [8]. CRM results were generally within the range of acceptable values, with exceptions often close to the limits of the acceptable range. Sample results were not qualified based on CRM analyses.
- *Bias* was evaluated by examining the recoveries of parameters spiked into de-ionized water or samples. Concentrations in laboratory control samples, matrix spikes, surrogate spikes, and internal standards were generally recovered within MQOs for the different parameters. Sample results were assigned a "J" when results for more than one QC sample were outside the MQOs. The nature of any potential analytical bias (high or low) was not preserved in this report or in Ecology's EIM database.
- *Precision* was assessed by analyzing laboratory and matrix spike duplicates. A relative percent difference (RPD) between concentrations in duplicates and their associated field samples that did not meet the relevant MQO was cause to assign a "J" qualifier [9].

MEL summarized data quality review findings in laboratory narratives and compiled final analytical results in printed-copy format and electronic data deliverables (EDDs) [10]. Project staff used these to conduct a similar data quality review and to apply study-specific data quality rules, as documented in Appendix D. This review resulted in some changes to laboratory-assigned qualifier codes and to reported concentrations. Important modifications included:

- Results for TSS, organic carbon, nutrients (nitrogen and phosphorus compounds), hardness, metals, and oil and grease were reported down to the MDL.
- Sample results were assigned a "UJ" only if they were less than or equal to three times (≤ 3X) the batch-specific method blank concentration.
- Concentrations of DOC and POC in marine water samples were adjusted to account for concentrations detected in method and field blanks.

[8] National Research Council Canada CASS-4 and NASS-5 CRMs were the only reference materials analyzed during this study.
[9] Relative standard deviation (RSD) control limits applied to results for more than two lab replicates.
[10] Copies of laboratory narratives may be requested from the authors.

- Concentrations of metals in marine water samples were recalculated (the contract laboratory had subtracted the mean method blank concentration).

Rules pertaining to each of the modifications listed above are described in Appendix D. The number of each type of revision made by project staff to laboratory qualifier codes is shown in Tables D-1 to D-4. Reporting down to the MDL (instead of the RL) did not affect any marine water column data, but 62 river water sample results (1.2% of freshwater samples) were changed from nondetects ("U") to "J"-qualified or unqualified results. Of more than 19,000 individual chemical analyses of marine and river water samples, project staff assigned "UJ" or "J" qualifiers codes to 432 results received from MEL (2.3%) due to parameter concentrations in the lab method blanks.

Field Quality Assurance Sample Review and Findings

The various field QA samples from marine and river water sampling are described and discussed in Appendix D. Field QA sample results are presented in Tables D-5 through D-14.

Results for the field replicates and duplicates usually indicated a homogeneous environment and repeatable analytical results (Tables D-5 to D-8, D-11, D-13, and D-14). No chemical qualifier code was assigned to field replicate results that were substantially different because there were no pre-defined MQOs for such samples and the results may reflect spatial or temporal variability.

Bottle, filter, transfer, and equipment blanks sometimes contained measurable concentrations of copper, dissolved lead, zinc, PCB congeners, and PBDE congeners (Tables D-9, D-10, D- 12, and D-14). This indicated potential for marine and river water samples to become contaminated with low concentrations of these parameters during routine sampling, handling, and analysis. Field blank concentrations exceeding those in method blanks appeared to implicate sampling equipment and the sampling process as sources of contamination. Similar concentrations in field and method blanks indicated contamination likely occurred in laboratory settings.

Chemical concentrations in field blanks were not subtracted from sample results. Despite attempts to mimic marine water column and river water sampling procedures described in *Sampling Methods*, field blanks could not be created in exactly the same manner. Field blanks were exposed to sources of contamination longer than were marine and river water samples. For example, marine water was only exposed to ambient air while clean sample containers were being filled, whereas the associated field blanks were also exposed to air while being created. There was also evidence that rinsing sampling devices with ambient marine or river water eliminated or at least reduced contamination from the cleaning, storage, and handling processes. Therefore, subtracting field blank concentrations would inappropriately underestimate sample concentrations. Further discussion can be found in Appendix D.

Data Usability

Field measurements were nearly all usable. CTD results flagged as "suspect" did not affect interpretation of water column profiles because the suspect results always represented a single depth or limited depth range. Uncertain pumping rates and volumes pumped did not prevent calculation of centrifuge efficiency or alter chemistry results for samples of SPM.

In terms of traditional descriptions of data usability:

- *Representativeness*. Marine water column samples were collected from locations representing ocean boundary and main basin waters and from depths representing layers defined by the Box Model. River water samples were depth-integrated and SPM samples were time-integrated. Whether the results for marine and river water samples collected during three seasons represented average seasonal or annual conditions could not be determined.
- *Completeness*. The total number of water samples collected, the number of SPM samples collected from rivers, and the total number of QC samples created were similar to what was planned. The total number of analyses conducted using these samples also reflected plans. Only the deepest sediment traps deployed in Hood Canal were recovered, so the number of marine SPM samples and analyses failed to meet targets.
- *Comparability*. Sampling and analytical methods were chosen based on their history of previous use within and outside of the region. With the exception of oil and grease, analytical detection and reporting limits were similar to ones achieved for other studies. Limits for oil and grease were elevated relative to a related study (Herrera, 2010b) because these limits were based on a one-liter sample size instead of four liters.

Based on all data quality reviews, this study collected samples that were reasonably representative of environmental conditions, stored and handled appropriately, and analyzed for parameters of interest using methods comparable to other regional studies. Most laboratory results met study MQOs. Those that did not were appropriately qualified. All analytical results were deemed usable for the purposes of the present study except for:

- A few results for individual BNA and PAH compounds that were rejected.
- Some results for several PCB and PBDE congeners qualified with "N" and "NJ".
- Results for dissolved lead and zinc concentrations in marine water column samples (discussed below).

Marine water column samples sometimes contained dissolved metal concentrations greater than the associated total metal results. In most cases, the dissolved form was within 100% - 120% of the total concentration. This indicated a high fraction of the total metal concentration was in dissolved form and that the analysis could not distinguish between two low concentrations. However, some dissolved metal results were as much as 250% of the total. These samples appeared to reflect contamination of the dissolved sample at some stage of collection and handling. The marine water column data for metals were handled as follows:

- Arsenic and cadmium concentrations in marine water column samples were low, and it was often difficult to distinguish between them [11]. There was no evidence of sample contamination from filter blank results (Table D-9, Appendix D). Dissolved concentrations were included in summary statistics and data analyses.
- The dissolved copper concentration exceeded the corresponding total concentration in only two marine water column samples. The ratios of dissolved to total copper were 109% and 123%. All dissolved copper data were considered usable.
- Dissolved lead and zinc concentrations were more variable than those of the other metals and sometimes were more than two times the corresponding total concentration. For these reasons it was difficult to determine which dissolved results were analytically indistinguishable from total results and which reflected field or lab contamination. Therefore, descriptive statistics for dissolved lead and dissolved zinc are not presented in this report, and dissolved concentrations of these chemicals were not used in analyses.

Overall, perhaps the three greatest limitations on data usability are:

- Concentrations of organic chemicals detected in less than 50% of all samples (e.g., oil and grease in river water) or that were highly variable when detected (e.g., PBDEs in marine water samples) may not represent the normal range and variability. Uncertainty associated with estimates of loading or ocean exchange for these chemicals is relatively high.
- Concentrations of some organic chemicals (TPH, BNAs, chlorinated pesticides) were seldom detected in marine water column or river water samples. Consequently, transport estimates for these chemicals based on one-half the RL or MDL are likely biased high and also uncertain.
- Data for toxic chemicals associated with marine SPM collected during this study were limited because of the failure to recover most sediment traps. Estimates of the downward flux of toxic chemicals due to sedimentation will be limited and difficult to apply to other areas of Puget Sound and the ocean boundary.

[11] For 21 arsenic results where the dissolved concentration exceeded the total, the average ratio was 1.05 (max=1.13). For 16 cadmium results, the average exceedance ratio was 1.08 (max=1.25).

Results

Marine Water Column

Ecology collected marine water column samples at seven sites during three seasonal sampling events (July 2009, October 2009, and January 2010). Sampling depths targeted surface and bottom waters, the division between layers being determined by CTD profiles and Box Model-defined boundaries. Details of sampling activities and water column conditions are provided in Appendix B, Tables B-1 and B-2. Collection depths from each location and sampling event are shown with vertical water density profiles and Box Model layers in Figures B-1 through B-7 of Appendix B.

Density profiles revealed that water column stratification at the three ocean boundary water sites varied seasonally. Stratification at these sites was strongest during July, became slightly degraded in October, and was absent in January apart from a near-surface freshwater lens. The stratification depths observed at the four Puget Sound basin sites did not differ markedly between the sampling events and were consistent with divisions defined by the Box Model. Stratification in the South Sound basin was always weak-to-absent, except for a shallow lens of freshwater from recent heavy rains was present at the surface in January 2010.

For each sampling location, the total number of samples collected and analyzed is summarized in Table 4. Nearly 500 analyses were conducted by a total of five laboratories. This section summarizes the marine water column results, with complete results tabulated in Appendix E and available from Ecology's EIM database.

Conventional Parameters

The TSS results from marine water column sampling are summarized in Table 5. With the exception of several elevated TSS concentrations in the Whidbey basin and at the San Juan de Fuca (SJdF) North station, values at all sites were between 0.8 and 2.3 mg/L over the course of the three sampling events. The average concentration of TSS was significantly lower in samples collected during October than in samples collected at other times. Results of various statistical analyses are presented in the *Discussion* section.

Organic carbon concentration results for samples collected during October 2009 and January 2010 are also summarized in Table 5. Measured DOC and POC concentrations were summed to represent TOC concentrations.

The concentration of DOC averaged 0.76 mg/L (63.1 µM) across all samples and showed little variability (CV = 0.12). Concentrations differed little between the seven sampling sites and between the surface and deep water layers. The average DOC concentration was greater at Puget Sound basins sites than at ocean boundary water sites. Concentrations were also greater in October than in January, but the apparent temporal difference was small (< 0.20 mg/L).

Table 4. Inventory of marine water column samples collected and analyzed.

Parameter → / Marine Site ↓	TSS	POC	DOC	Metals – Total [1]	Metals – Dissolved [1]	BNAs [2]	PAHs [3]	Chlor. Pesticides [4]	PCBs [5]	PBDEs [6]	Total
Hood Canal	6	4	4	6	6	6	6	6	6	6	56
South Sd Basin	6	4	4	6	6	6	6	6	6	6	56
Main Basin	6	4	4	6	6	6	6	6	6	6	56
Whidbey Basin	6	4	4	6	6	6	6	6	6	6	56
SJdF at Sill	6	4	4	6	6	6	6	6	6	6	56
SJdF North	6	4	4	6	6	6	6	6	6	6	56
Haro Str	6	4	4	6	6	6	6	6	6	6	56
Field QA samples	6	21	14	6	5	6	5	4	11	5	83
Total =	48	49	42	48	47	48	47	46	53	47	475

[1] Metals included arsenic, cadmium, copper, lead, zinc analyses.
[2] BNAs included 55 individual compounds.
[3] PAHs included 22 individual compounds.
[4] Chlorinated Pesticides included 33 individual compounds.
[5] PCBs included 209 individual congeners.
[6] PBDEs included 36 individual congeners.

Table 5. Summary statistics for TSS, DOC, POC, and TOC in the marine water column.

Parameter (mg/L)	Times Detected	Percent Detected	Min.	25th %ile	Median	Mean	CV	75th %ile	Max.
All 7 Stations									
TSS	42	100	0.80	1.2	1.6	1.8	0.60	1.9	6.0
DOC	28	100	0.61	0.70	0.75	0.76	0.12	0.81	0.97
POC	28	100	0.03	0.05	0.06	0.13	2.44	0.09	1.78
TOC *	28	100	0.66	0.75	0.81	0.89	0.43	0.87	2.75
Ocean Boundary Stations (3)									
TSS	18	100	1.0	1.2	1.6	1.9	0.59	2.2	6.0
DOC	12	100	0.61	0.66	0.70	0.70	0.09	0.71	0.81
POC	12	100	0.04	0.04	0.05	0.06	0.35	0.07	0.11
TOC *	12	100	0.66	0.73	0.75	0.76	0.08	0.77	0.89
Puget Sound Stations (4)									
TSS	24	100	0.8	1.2	1.4	1.7	0.61	1.7	5.5
DOC	16	100	0.71	0.75	0.78	0.80	0.10	0.84	0.97
POC	16	100	0.03	0.05	0.07	0.19	2.25	0.12	1.78
TOC *	16	100	0.74	0.81	0.85	0.99	0.48	0.99	2.75

CV = Coefficient of variation.
* Values for TOC are calculated as the sum of DOC and POC concentrations.

The average POC concentration was 0.13 mg/L (11 µM). Concentrations in surface waters of Puget Sound basin sites during October were the most variable (Figure 4) and exceeded concentrations measured in ocean boundary waters. The average POC concentration was greater in October samples than in January samples.

The pool of organic carbon was dominated by the dissolved fraction, with DOC averaging more than 90% of TOC. The October Whidbey Basin surface water sample was an exception. It contained an unusually high POC concentration (Figure 4) that was 65% of TOC.

As was true for DOC, average TOC concentrations were greater in Puget Sound basins than in boundary waters, and greater during the fall than in the winter. TOC concentrations in surface water samples collected in October exceeded those in the deep waters by an average of nearly 0.6 mg/L. However, by January, TOC concentrations at the two depths differed little.

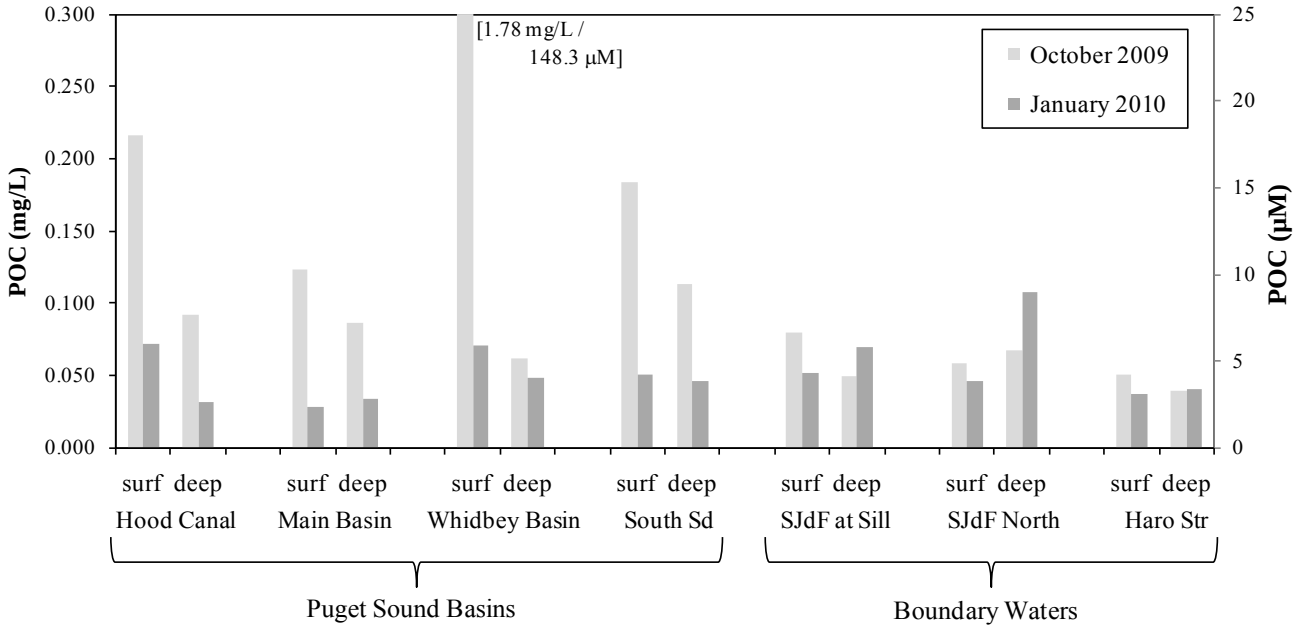

Figure 4. Summary of marine water column POC results.

Metals

Marine water column samples were analyzed for total and dissolved forms of arsenic, cadmium, copper, lead, and zinc. Summary statistics for marine metals are presented in Table 6, and complete results can be found in Table E-1 of Appendix E.

Dissolved metal results sometimes exceeded their corresponding total concentration. For the purposes of this project, all dissolved results for arsenic, cadmium, and copper were deemed usable. However, uncertainties associated with the results for dissolved lead and dissolved zinc caused these data to be excluded from analyses. See *Data Usability* section.

Table 6. Summary statistics for total and dissolved metals in the marine water column.

Parameter (µg/L)	Times Detected	Percent Detected	Min.	25th %ile	Median	Mean	CV	75th %ile	Max.
All 7 Stations									
Arsenic, Total	42	100	1.16	1.36	1.41	1.42	0.06	1.49	1.56
Arsenic, Dissolved	42	100	1.26	1.35	1.42	1.42	0.06	1.46	1.70
Cadmium, Total	42	100	0.059	0.079	0.084	0.085	0.12	0.091	0.112
Cadmium, Dissolved	42	100	0.067	0.074	0.081	0.083	0.13	0.089	0.111
Copper, Total	42	100	0.19	0.29	0.38	0.41	0.52	0.44	1.37
Copper, Dissolved	42	100	0.16	0.24	0.30	0.30	0.26	0.37	0.51
Lead, Total *	37	88	0.015	0.043	0.070	0.085	0.64	0.110	0.230
Zinc, Total *	42	100	0.41	0.55	0.69	0.86	1.23	0.84	7.44
Ocean Boundary Stations (3)									
Arsenic, Total	18	100	1.31	1.36	1.45	1.43	0.06	1.52	1.56
Cadmium, Total	18	100	0.080	0.087	0.089	0.090	0.07	0.092	0.105
Copper, Total	18	100	0.19	0.24	0.29	0.34	0.43	0.38	0.72
Lead, Total	15	83	0.025	0.050	0.070	0.086	0.62	0.109	0.230
Zinc, Total	18	100	0.41	0.52	0.58	0.69	0.39	0.79	1.44
Puget Sound Stations (4)									
Arsenic Total	24	100	1.16	1.35	1.41	1.40	0.07	1.47	1.54
Cadmium, Total	24	100	0.059	0.076	0.081	0.081	0.13	0.086	0.112
Copper, Total	24	100	0.26	0.36	0.40	0.47	0.51	0.46	1.37
Lead, Total	22	92	0.015	0.039	0.074	0.085	0.66	0.114	0.206
Zinc, Total	24	100	0.48	0.60	0.70	1.00	1.38	0.85	7.44

***** Summary statistics for concentrations of dissolved lead and zinc are not presented here. Dissolved concentrations often exceeded total concentrations to a degree that complicated distinguishing valid results from ones that reflected field or laboratory contamination.

Arsenic

The range of total arsenic concentrations measured in regional marine waters was 1.16 - 1.56 μg/L (Figure 5). The overall average concentration was 1.42 μg/L. Total arsenic concentrations were greater in January than in October and also greater in deep waters than in surface waters.

Results for dissolved arsenic are shown in Figure 6. Dissolved arsenic averaged 96% of the total concentration in one-half of all samples (21/42). However, the dissolved fraction marginally exceeded the total concentration in the remaining 21 samples. Filter blanks showed no evidence of contamination. Therefore, these apparently anomalous results were attributed to the analytical difficulty of differentiating between dissolved and total forms at such low concentrations.

Cadmium

Total cadmium concentrations, shown in Figure 7, ranged from 0.059 - 0.112 μg/L. The average concentration at all locations and depths was 0.085 μg/L. Ocean boundary water concentrations were greater than those in Puget Sound. In addition, the average deep water concentration exceeded that for surface waters.

Like arsenic, dissolved cadmium was the predominant form. In 23 samples, dissolved cadmium averaged 91% of the total concentration. The dissolved form exceeded the total concentration in the remaining 19 samples. Filter blanks again showed no evidence of contamination (similar to the arsenic results) so these exceedances were also attributed to difficulties distinguishing between the dissolved fraction and the total at low concentrations.

As with total concentrations, dissolved cadmium was greater in ocean boundary waters than in Puget Sound. Surface water dissolved concentrations at all sites except SJdF Sill increased from July to October and again from October to January (Figure 8). Dissolved cadmium was greater in deep waters than in surface waters during July and October. This was especially true for ocean boundary sites, where concentrations exceeded those in surface waters by as much as 0.028 μg/L. However, by January the ocean boundary sites had higher dissolved cadmium concentrations in the surface waters than in deep waters.

Copper

Total copper concentrations in the marine water column ranged from 0.19 - 1.37 μg/L (Figure 9) and were more variable than dissolved concentrations (Figure 10). Elevated total copper concentrations occurred on one occasion at the Hood Canal, Main Basin, SJdF North, and Haro Strait sites. The elevated results did not appear to be associated with any spatial or temporal pattern. Dissolved copper concentrations ranged from 0.16 - 0.51 μg/L, representing 30% to 100% of the total (average of 80%). Dissolved copper was greater than the total in only two samples.

The waters of Puget Sound contained greater concentrations of total and dissolved copper than did ocean boundary waters. For example, dissolved copper in Puget Sound ranged from 0.28 - 0.51 μg/L while boundary waters contained 0.16 - 0.28 μg/L. Total and dissolved copper

concentrations were lowest in October in all but one location. The maximum observed total and dissolved copper concentrations were in the deep water sample collected from Hood Canal in July.

Lead

Total lead in the marine water column, shown in Figure 11, ranged from 0.015 - 0.230 µg/L. Total lead concentrations in the deep waters usually exceeded those in surface waters. October concentrations of total lead in five samples (SJdF North, surface; SJdF Sill, surface and deep; South Sound, surface and deep) were within three times the concentration in the associated laboratory method blank. These results were qualified as "UJ" (as described in Appendix D). Dissolved lead results were not usable for the purposes of this project (see *Data Usability*).

Zinc

The range of total zinc concentrations in the marine water column was 0.41 - 7.44 µg/L (Figure 12). The average for all locations, seasons, and depths was 0.86 µg/L. Total zinc concentrations in deep waters were often greater than in surface waters, especially during October and January. Dissolved zinc results were not usable for the purposes of this project (see *Data Usability*).

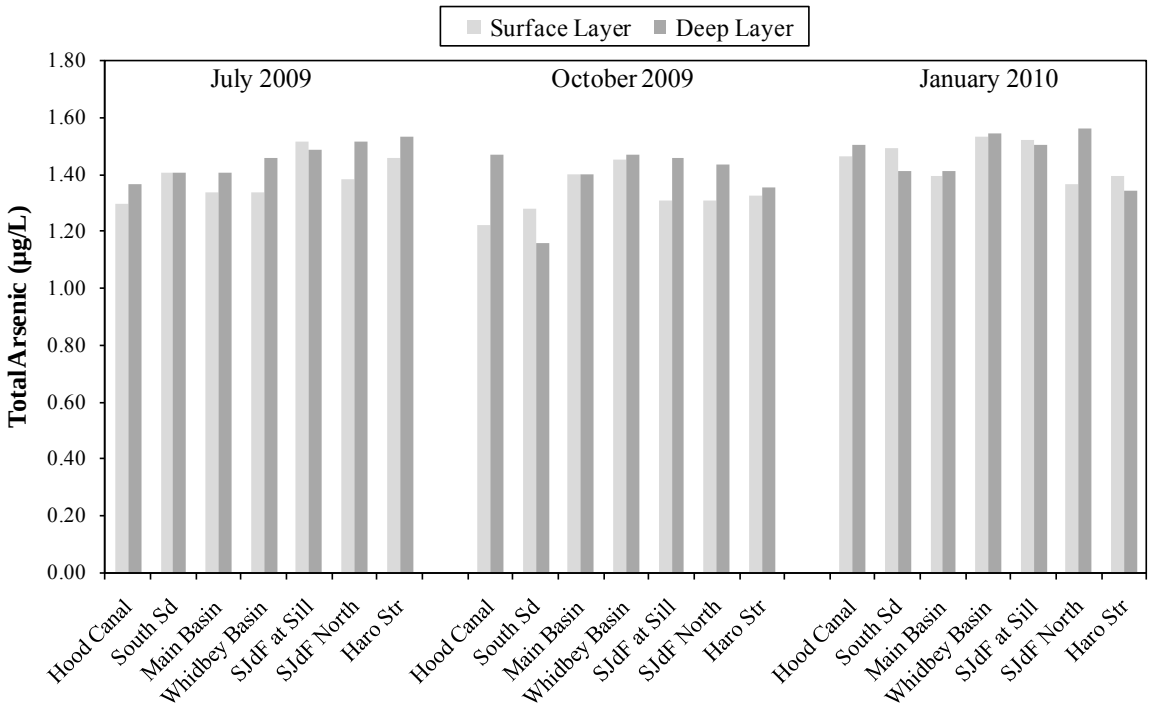

Figure 5. Concentrations of total arsenic in the marine water column.

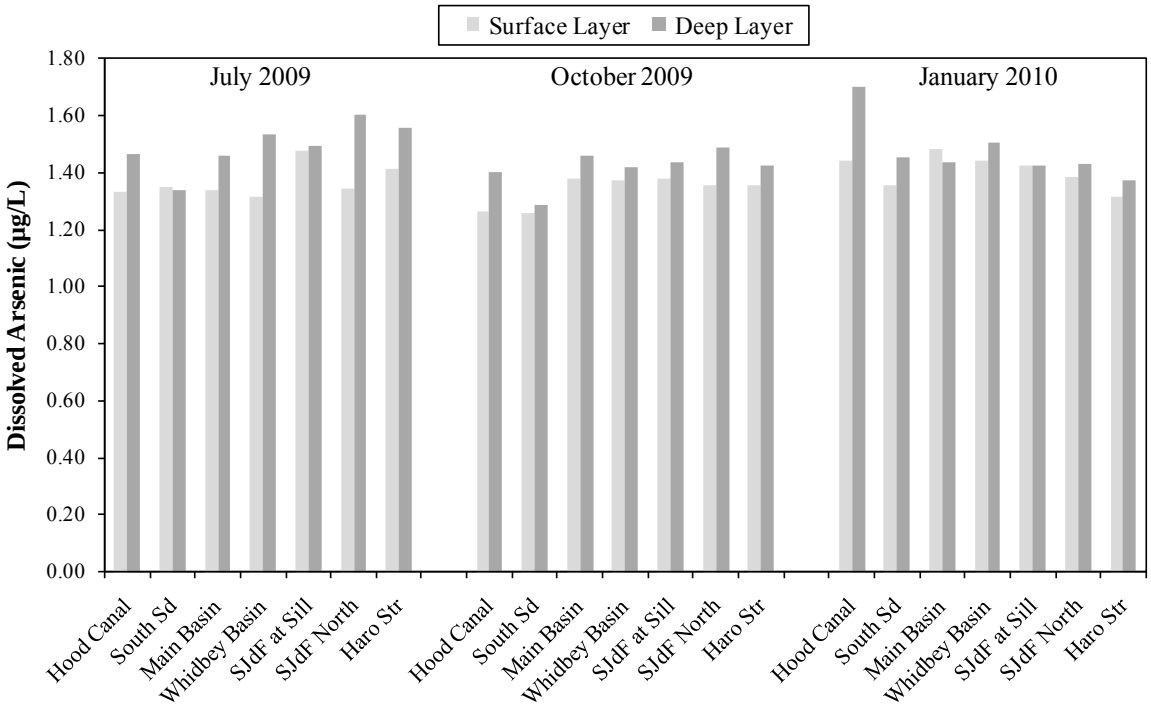

Figure 6. Concentrations of dissolved arsenic in the marine water column.

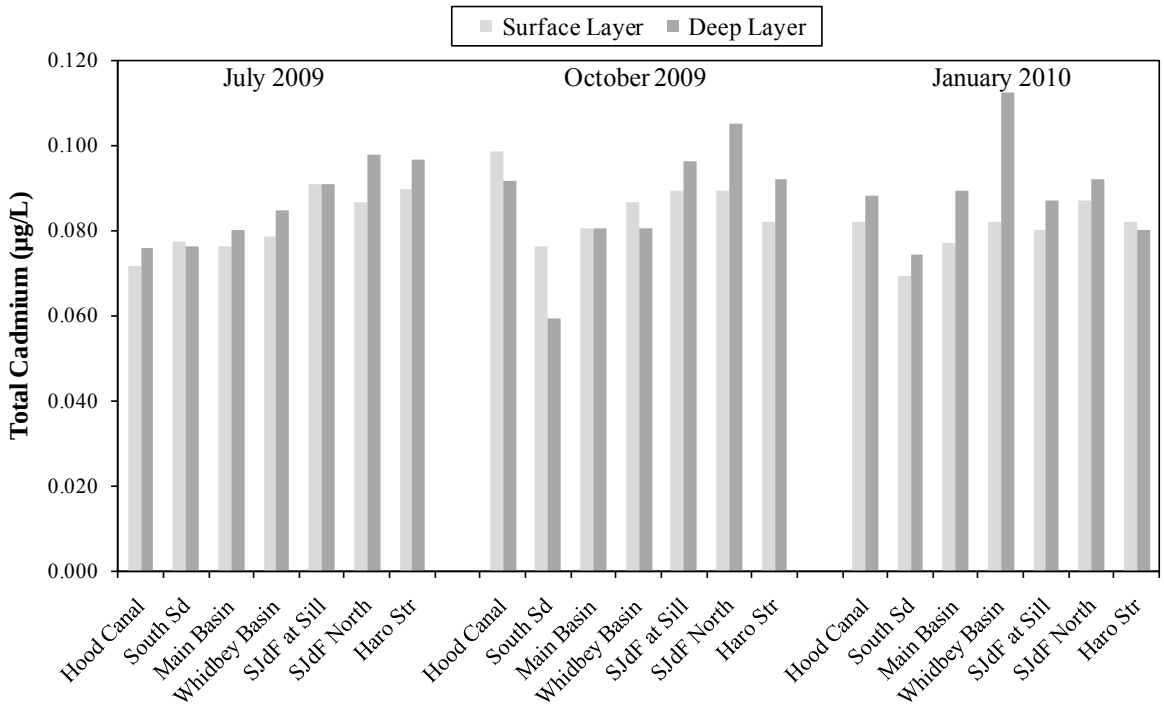

Figure 7. Concentrations of total cadmium in the marine water column.

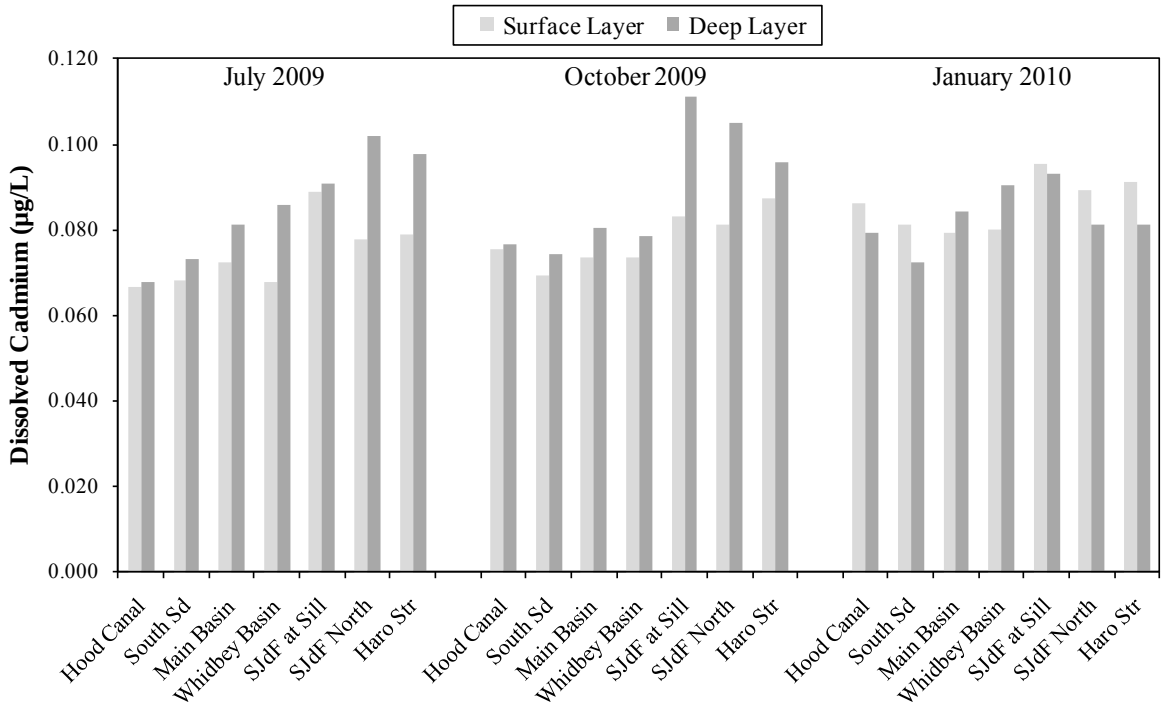

Figure 8. Concentrations of dissolved cadmium in the marine water column.

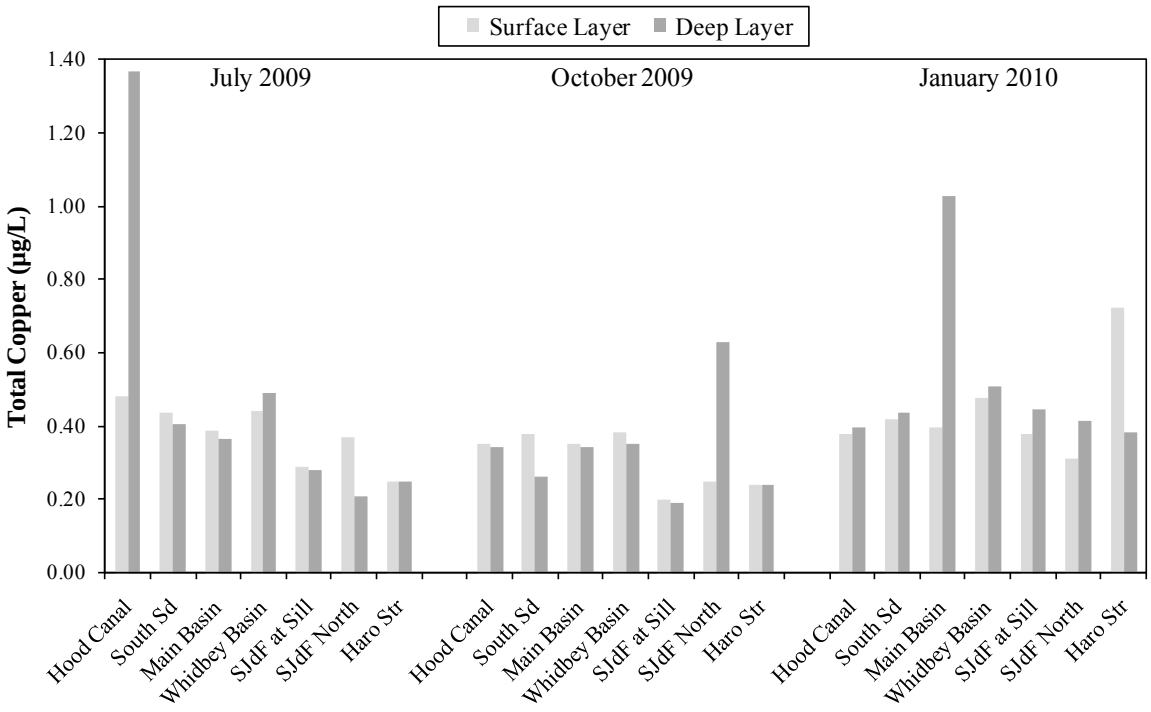

Figure 9. Concentrations of total copper in the marine water column.

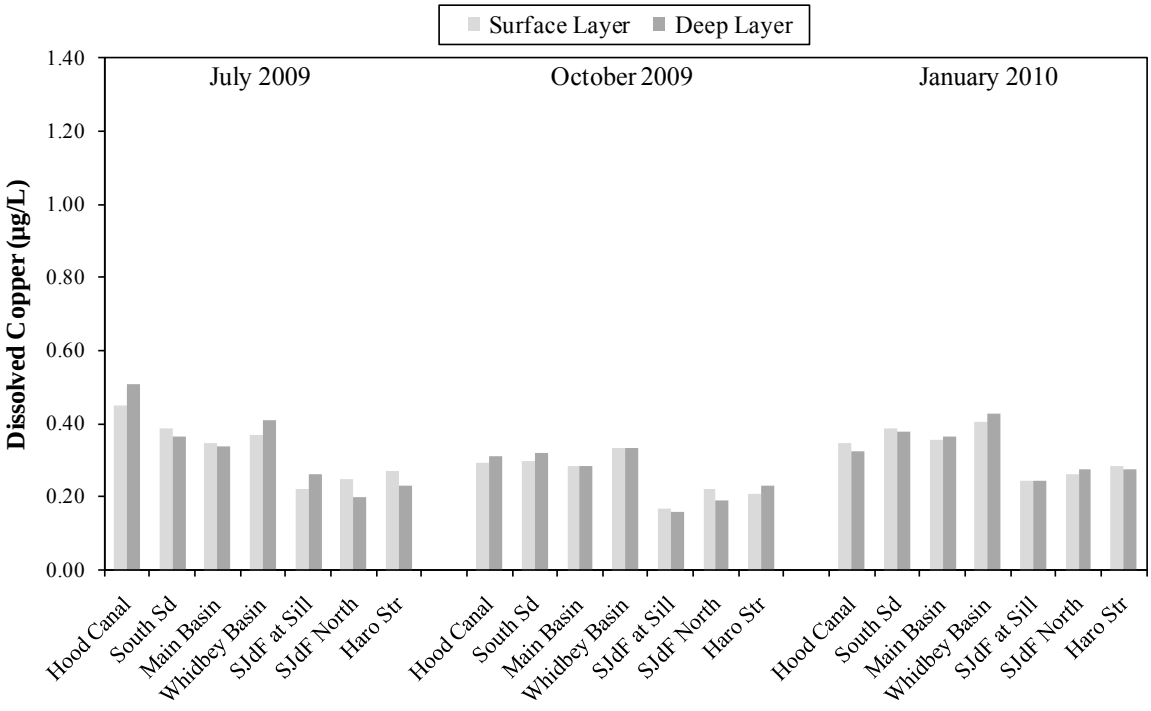

Figure 10. Concentrations of dissolved copper in the marine water column.

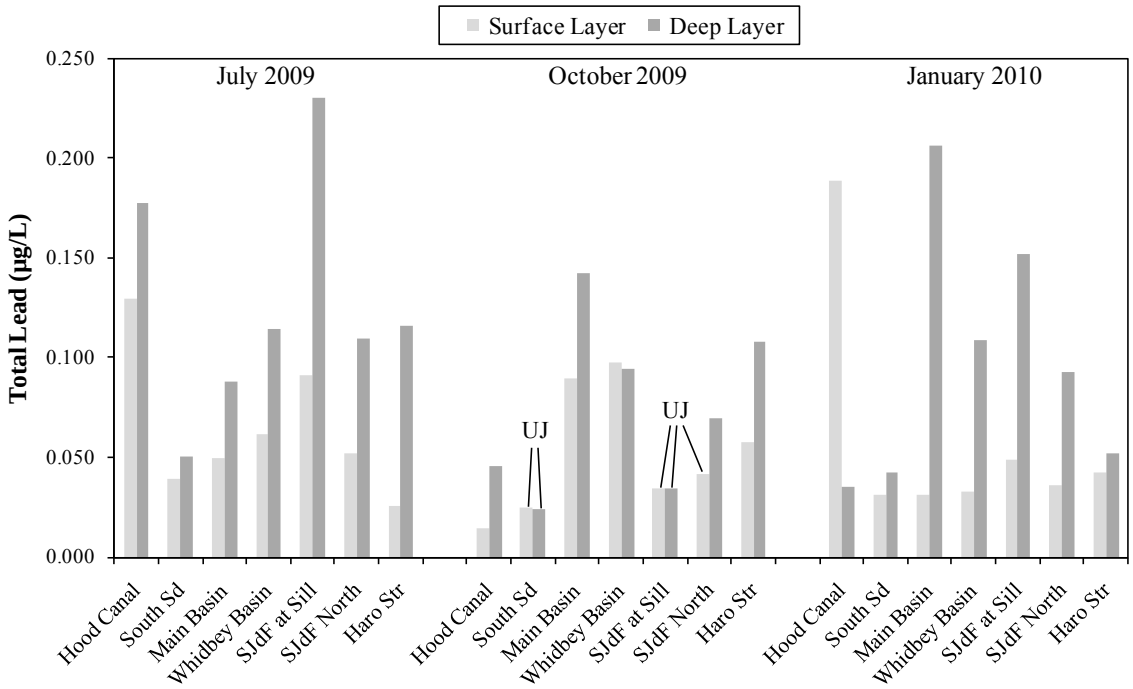

Figure 11. Concentrations of total lead in the marine water column.

Samples collected during October qualified as "UJ" were within three times the laboratory method blank concentration. Dissolved lead results not shown (see Data Usability).

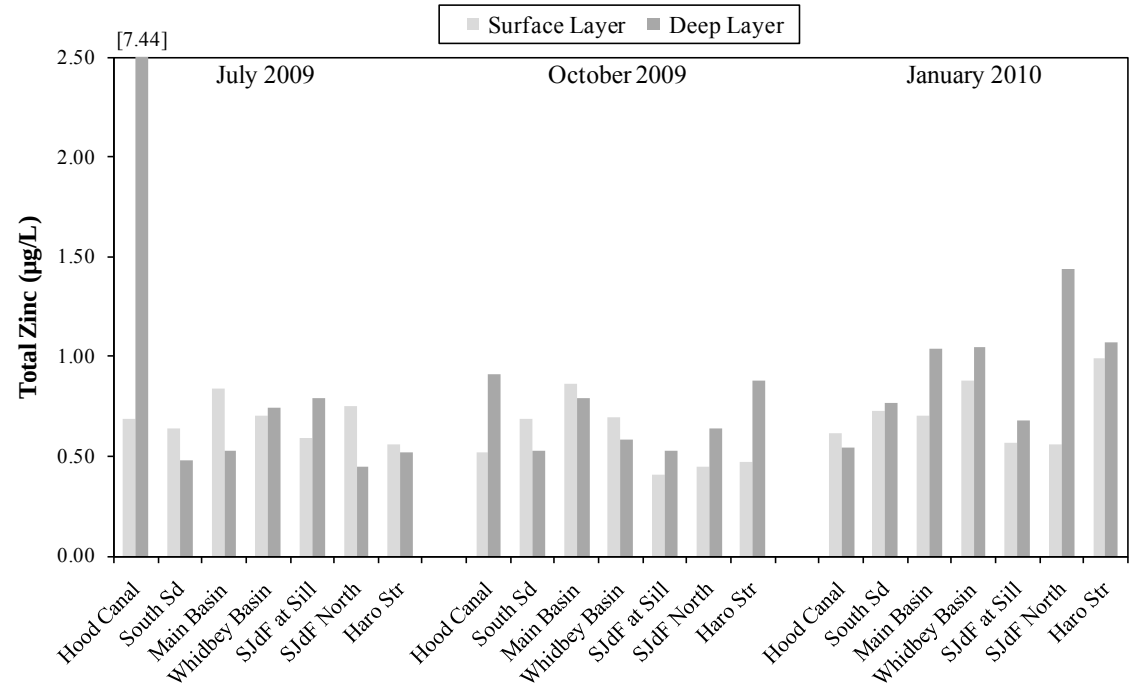

Figure 12. Concentrations of total zinc in the marine water column.

Dissolved zinc results not shown (see Data Usability).

Organics

Marine water column samples were analyzed for 33 chlorinated pesticide compounds, but only five were detected (Table 7). These compounds were found in samples collected during July and October, while no measurable concentrations were detected in January samples. Chlorinated pesticides were detected infrequently and only in the northern boundary waters.

Table 7. Summary of measurable chlorinated pesticides in the marine water column.

Date	Sampling Location	Water Column Layer	4,4'-DDE (ng/L)	Alpha-BHC (ng/L)	Beta-BHC	Delta-BHC (ng/L)	Hexachloro-benzene (ng/L)
7/8/09	SJdF North	surface	0.21 J				
		deep	0.39				
7/8/09	Haro Str	deep	0.21				
9/28/09	Whidbey	deep		0.21	0.32	0.25 J	
10/7/09	SJdF North	surface					0.21

Of the 55 BNA compounds targeted by the analyses, 11 were detected at least once (Table 8). All of these except Triclosan were detected in samples collected during July. A narrow range of cholesterol concentrations was detected in October and January samples. Triclosan was only detected in the samples collected during October. No measureable concentrations of any compounds were found in January.

PAH analyses targeted 22 compounds. PAHs were not detected in any marine water column sample at the detection limits (from 0.0005 to 0.033 μg/L).

PCBs and PBDEs

Results for marine water column PCBs and PBDEs are summarized in Table 9. All results were method blank-qualified at the congener level before calculating homolog totals.

PCBs were detected in all marine water column samples (Figure 13). Total PCBs ranged from 6.09 to 75.1 pg/L, averaging 26.3 pg/L. The sum of the congeners in the tetra- and penta-chlorinated homolog groups comprised an average of 80% of the total PCBs.

Table 8. Summary of measurable BNA compounds in the marine water column.

Date	Sampling Location	Water Column Layer	2,4-Dichlorophenol (µg/L)	2-Methylphenol (µg/L)	3B-Coprostanol (µg/L)	4-Chloro-3-Methylphenol (µg/L)	Bis(2-Ethylhexyl) Phthalate (µg/L)	Bisphenol A (µg/L)	Caffeine (µg/L)	Cholesterol (µg/L)	Ethanol, 2-Chloro-, Phosphate (3:1) (µg/L)	Phenol (µg/L)	Triclosan (µg/L)
7/7/09	Hood Canal	surface	0.06 J	0.01 J	1.2 J	0.06 J	0.05 J			0.62 J			
		deep	0.16 J	0.04 J		0.33 J	0.01 J	0.19 J				0.02 J	
7/7/09	SJdF at Sill	deep				0.03 J							
7/8/09	SJdF North	deep				0.02 J							
7/8/09	Haro Str	deep	0.06 J	0.01 J		0.09 J	0.06 J						
7/9/09	South Sd	surface							0.03 J	0.76 J	0.1		
		deep				0.03 J				0.64 J			
7/10/09	Whidbey	surface	0.04 J	0.01 J		0.02 J				0.75 J			
9/28/09	Whidbey	surface								1.1			
		deep								0.73 J			
9/29/09	Main Basin	surface								0.73 J			
		deep								0.71 J			
9/30/09	Hood Canal	surface								0.77 J			
		deep								0.7 J			
10/1/09	South Sd	surface								0.73 J			
		deep								0.73 J			
10/7/09	SJdF at Sill	surface								0.73 J			0.048 J
		deep								0.71 J			0.048 J
10/7/09	SJdF North	surface								0.73 J			0.051 J
		deep								0.72 J			0.05 J
10/7/09	Haro Str	surface											0.047 J
		deep								0.74 J			0.051 J

Table 9. Summary statistics for PCB and PBDE homologs in the marine water column.

Congener summation rules are described in Appendix D. Congeners in each homolog group are listed in Appendix E (Tables E-20 to E-22, and E-24). Concentrations of tentatively-identified congeners (results qualified as N or NJ) were not included in homolog or overall totals. Note: Homolog concentrations in a single sample can be summed to equal the total concentration in that sample, but summing the homolog statistics below will not result in the total concentration statistics.

Parameter (pg/L)	Times Detected	Percent Detected	Min.	25th %ile	Median	Mean	CV	75th %ile	Max.
PCB homologs and totals (pg/L)									
Mono-chlorinated	11	26	0.40	0.96	1.73	4.28	1.45	2.84	18.7
Di-chlorinated	22	52	1.03	2.58	3.58	3.65	0.47	4.09	7.31
Tri-chlorinated	27	64	0.67	1.61	2.41	3.21	0.63	4.74	8.79
Tetra-chlorinated	42	100	2.84	11.9	14.0	16.5	0.47	21.4	37.1
Penta-chlorinated	31	74	0.98	2.45	3.50	4.08	0.55	5.38	8.92
Hexa-chlorinated	22	52	0.87	1.26	2.25	2.85	0.70	3.38	7.39
Hepta-chlorinated	3	7	1.63	1.74	2.06	2.24	0.32	2.80	3.04
Octa-chlorinated	2	5	0.29	0.29	0.78	0.78	0.89	1.27	1.27
Nona-chlorinated	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PCB-209	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total PCBs	42	100	6.09	14.6	24.0	26.3	0.57	36.8	75.1
PBDE homologs and totals (pg/L)									
Mono-brominated	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Di-brominated	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Tri-brominated	1	2	10.7	n/a	10.7	10.7	1.00	n/a	10.7
Tetra-brominated	3	7	87.5	106	163	279	0.96	480	586
Penta-brominated	6	14	51.0	91.5	194	404	1.25	521	1,380
Hexa-brominated	3	7	61.1	69.4	94.2	126	0.68	192	224
Hepta-brominated	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Octa-brominated	2	5	43	43.0	121	121	0.91	199	199
Nona-brominated	2	5	399	399	1,870	1,870	1.11	3,330	3,330
PBDE-209	5	12	904	945	1,300	4,200	1.47	5,820	15,200
Total PBDEs	10	24	51.0	266	749	2,860	1.98	3,100	18,700

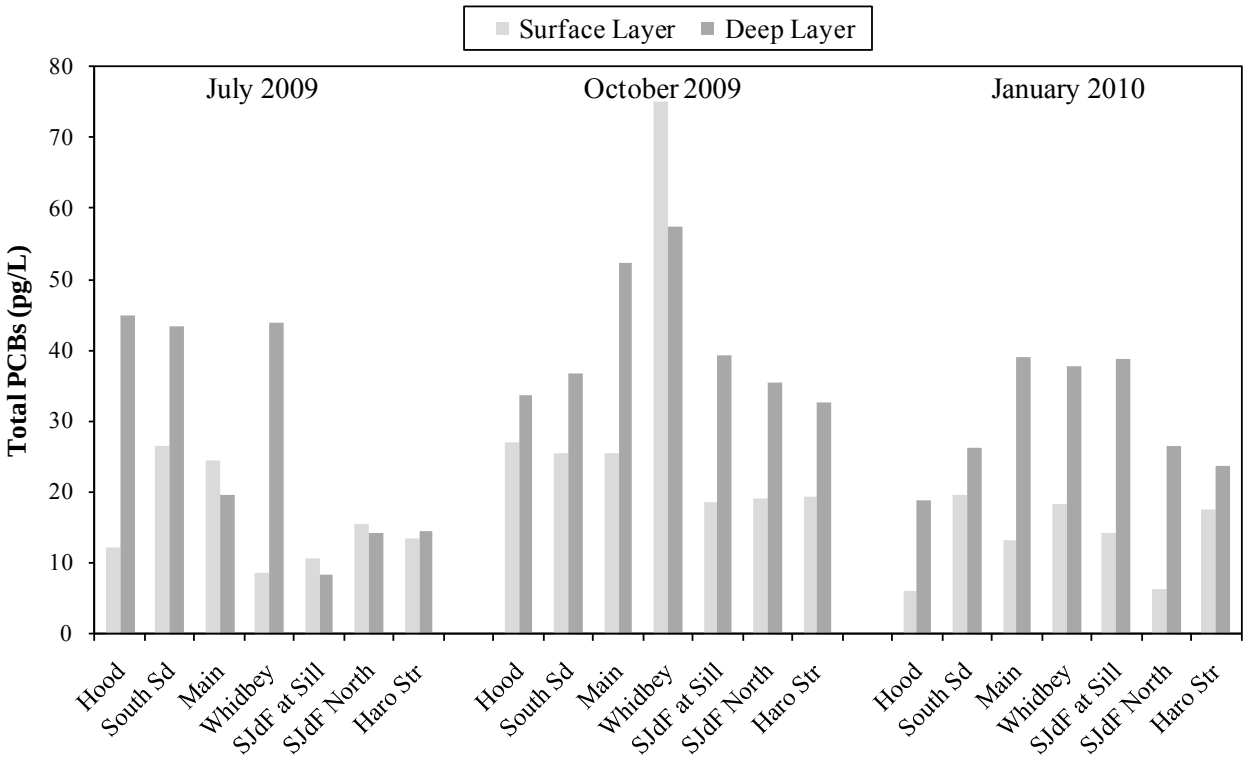

Figure 13. Summary of results for total PCBs in marine water column samples.

Tentatively-identified congeners (qualified as N or NJ) were not included in total PCB sums.

The average concentration of total PCBs in Puget Sound was greater than the average in ocean boundary water samples. October samples usually contained greater concentrations than those in samples collected at other times. Deep layer total PCB concentrations generally exceeded surface water concentrations (Figure 13). One notable exception was that July samples from all three boundary water sites had nearly identical surface and deep layer concentrations. Another exception was the October surface sample from Whidbey Basin, where the highest total PCB concentration of the study was observed (75.1 pg/L). This latter sample also had extremely elevated results for TSS, POC, dissolved lead, and dissolved zinc.

Measureable concentrations of PBDEs were detected in 10 of the 42 samples. Detected total PBDEs ranged from 51 to 18,700 pg/L and were highly variable (CV=1.98). The average total PBDE concentration was 2,860 pg/L, while the median value was much lower at 749 pg/L. Penta-brominated congeners and PBDE-209 were detected most frequently.

The maximum detected total PBDE concentration of 18,700 pg/L was measured in the January sample from the deep water layer at the Haro Strait site. The only other chemical concentration elevated in this sample was total zinc. The next highest concentration of total PBDEs was 3,190 pg/L, also from the Haro Strait site but in the October surface water sample. These and other PBDE concentrations were identified as statistical outliers (Appendix J, Table J-1), but were included in analyses because there was no evidence that the samples had been contaminated.

Marine SPM

As previously mentioned, after a deployment period of three months only one of the five sediment trap moorings was successfully recovered. The particulate sample collected from this mooring represented the deep layer of Hood Canal. Analyses included % solids, TOC, five metals, PCB congeners, and PBDE congeners. To partially compensate for the paucity of marine SPM samples, archived particulates collected from traps deployed in Case and Carr Inlets during the spring of 2008 were submitted for the same analyses of metals, PCBs, and PBDEs. Marine SPM results are presented in Table 10. The Case+Carr results were qualified as estimated values ("J") because the samples were analyzed beyond recommended holding times.

Table 10. Results for sediment trap collections of marine suspended particulates.

Parameter	Hood Canal	Case+Carr Inlets
Conventionals (%)		
TOC	2.75	n/a
Total Recoverable Metals (mg/Kg dry)		
Arsenic	7.53	5.72 J
Cadmium	0.87	1.04 J
Copper	82.0	18.5 J
Lead	9.13	8.78 J
Zinc	90.0	72.0 J
PCB Homologs (ng/Kg dry) *		
Mono-chlorinated	ND	35.3 J
Di-chlorinated	429	840 J
Tri-chlorinated	280	1,290 J
Tetra-chlorinated	343 J	1,230 J
Penta-chlorinated	948	2,290 J
Hexa-chlorinated	642	2,920 J
Hepta-chlorinated	284	909 J
Octa-chlorinated	11.6 J	249 J
Nona-chlorinated	ND	53.4 J
PCB-209	27.8	32.3 J
Total PCBs	2,970	9,850 J
PBDE Homologs (ng/Kg dry) *		
Mono-brominated	n/a	n/a
Di-brominated	14 UJ	17.4 UJ
Tri-brominated	10.2 J	68.7 J
Tetra-brominated	138 J	498 J
Penta-brominated	131 J	269 J
Hexa-brominated	43.6 J	58.4 J
Hepta-brominated	54.1 J	41.2 J
Octa-brominated	57.3 J	28.4 J
Nona-brominated	270 J	92.1 J
PBDE-209	879	174 UJ
Total PBDEs	1,580 J	1,060 J

* Homolog and total concentrations do not include tentatively-identified results (those qualified with "N" or "NJ").

Of the five metals analyzed, Hood Canal particulate concentrations exceeded those found in Case+Carr particulates for four of these metals. Differences in particulate copper concentrations between the two sites were especially large, with Hood Canal concentrations more than four times higher than those measured in Case+Carr solids. Cadmium was the only metal for which Case+Carr particulate concentrations were greater than Hood Canal values, although the difference was small (0.17 mg/Kg dry).

Sediment trap collections revealed marked differences in particulate PCB concentrations between the two sites. Solids from the Case+Carr sample had a total PCB concentration over three times that found in the Hood Canal particulates, and all 10 PCB homolog concentrations were higher in the Case+Carr sample.

In contrast, PBDE homolog concentrations varied between the two locations. Congeners with lower levels of bromination (tri-, tetra-, and penta-BDEs) were found in higher concentrations in Case+Carr SPM. Hexa- and hepta-brominated congeners had similar concentrations at the two sites. Octa-, nona-, and deca-BDEs had higher concentrations in Hood Canal SPM. Overall, the concentration of total PBDEs in Hood Canal particulates was 50% higher than that measured in Case+Carr SPM.

River Water

Ecology sampled the five largest rivers flowing into Puget Sound three times between late July 2009 and early January 2010. Sampling conditions in each river spanned a range of discharges and conditions. The upper panels of Figures 14-18 highlight the mean daily flow in each river on each sampling date atop hydrographs of mean daily flow for the calendar year. For context, hydrographs of long-term median daily flow are also shown for each river. Periods of relatively high flow appear as the darkest areas, while periods of relatively low flow appear under the white areas. In general, the rivers had lower-than-normal flows in 2009, but periods of higher flows did occur in late spring and late fall.

Daily flows encountered while sampling were usually below the long-term median flow for the same dates. Exceptions (higher-than-normal flows) were encountered in the Stillaguamish (October 2009), the Snohomish (December 2009), and the Nooksack (January 2010). Overall, mean daily flows ranged from 13.3 cms (470 cfs) in the Stillaguamish in July to 521 cms (18,500 cfs) in the Skagit in December (Table 11). These flows represented baseflows and runoff-related flows, with the flow regime determined after examining:

- Seasonal hydrographs.
- Mean daily flows preceding and following each sampling (lower panels of Figures 14-18).
- Recent climate records (especially for precipitation).
- Other evidence (long-term flow records, turbidity).

In July, dry-season baseflows were evident in all rivers except the Puyallup (Figure 18). The Puyallup was highly turbid, carrying a high concentration of suspended solids (233 mg/L). However, the relatively high TSS was consistent with long-term ambient monitoring data for late-summer and was probably due to silts in glacier meltwaters enhanced by recent high air temperatures.

In October, baseflows were encountered while sampling the Skagit and Nooksack (Figures 14 and 16). The Snohomish and Stillaguamish were sampled during late stages of obvious runoff events (Figures 15 and 17). It was less obvious in Figure 18 that Puyallup River flow was related to runoff. However, elevated flow and concentrations of suspended solids reflected an early stage of runoff from 1.33 inches of rain that fell upstream the day before.

Sampling during December 2009 and January 2010 found wet-season baseflows in the Stillaguamish and Puyallup. The other three rivers had flows in the rising or falling stage of runoff-related events. River water in the Skagit was running clear when sampling began but became visibly turbid soon afterward.

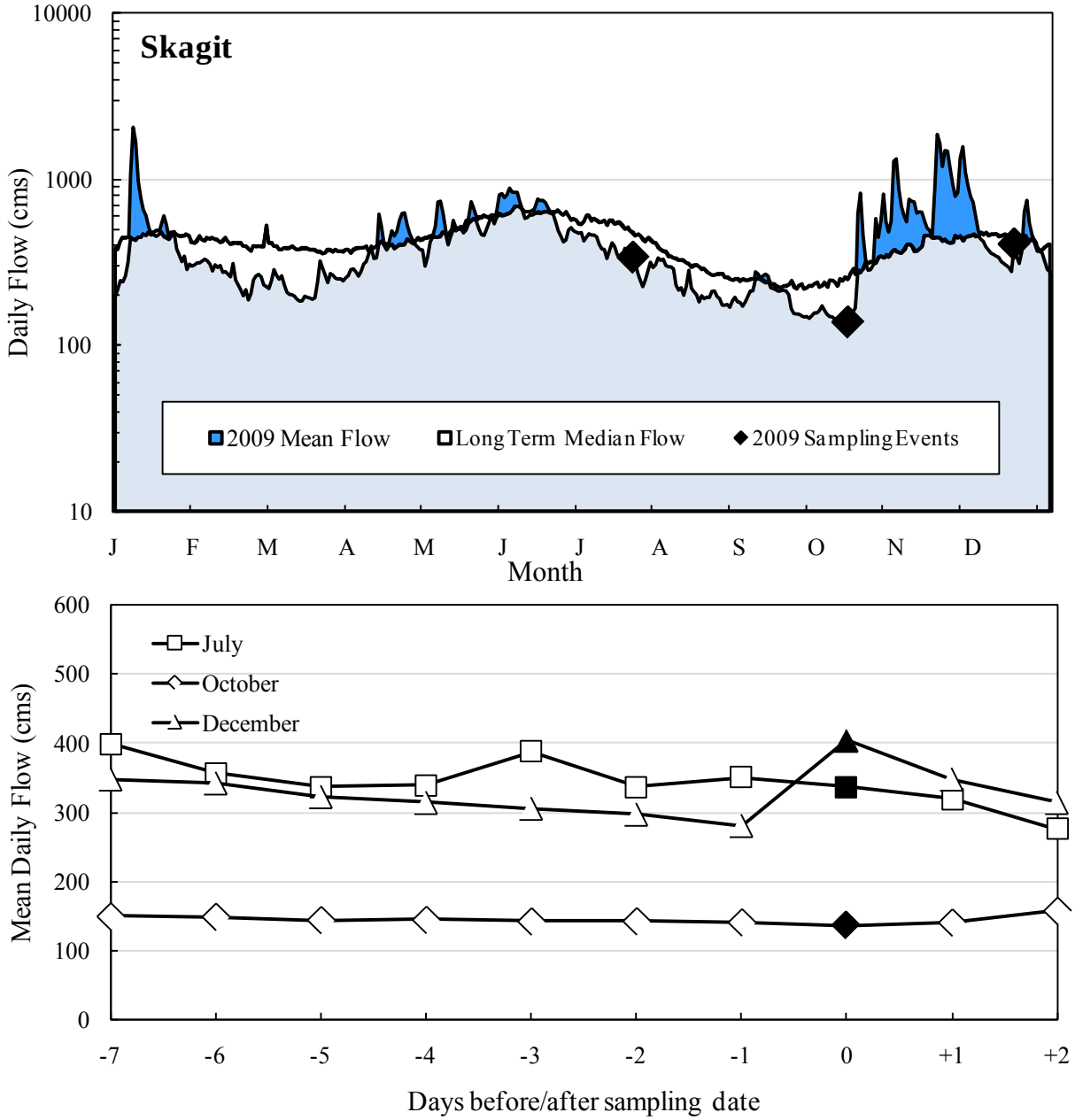

Figure 14. Skagit River daily flows.

- Upper: Sampling events are shown as black diamonds on the hydrograph for mean daily flows during 2009 (shaded beneath). Relative to long-term median flows, periods of high flow appear as the darkest areas and periods of low flow appear under the white areas.
- Lower: Mean daily flows prior to, during, and immediately after each sampling event (solid black symbols).

  July and October sampling occurred during baseflows, while sampling in December was during the late stages of a runoff event.

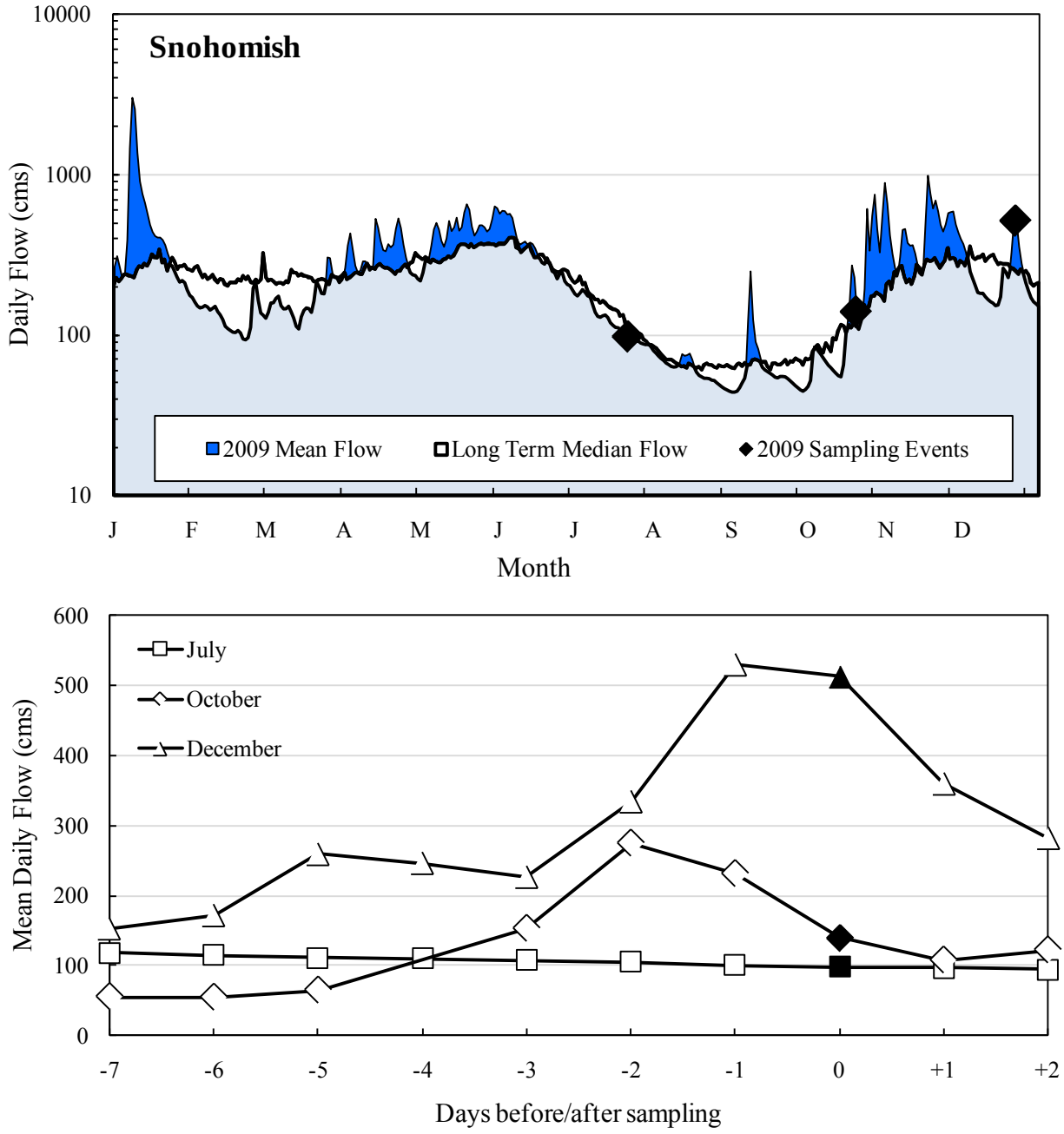

Figure 15. Snohomish River daily flows.

- Upper: Sampling events are shown as black diamonds on the hydrograph for mean daily flows during 2009 (shaded beneath). Relative to long-term median flows, periods of high flow appear as the darkest areas and periods of low flow appear under the white areas.
- Lower: Mean daily flows prior to, during, and immediately after each sampling event (shown as solid black symbols).

Sampling in July was during baseflows. October and December sampling events occurred near the end and peak of runoff events, respectively.

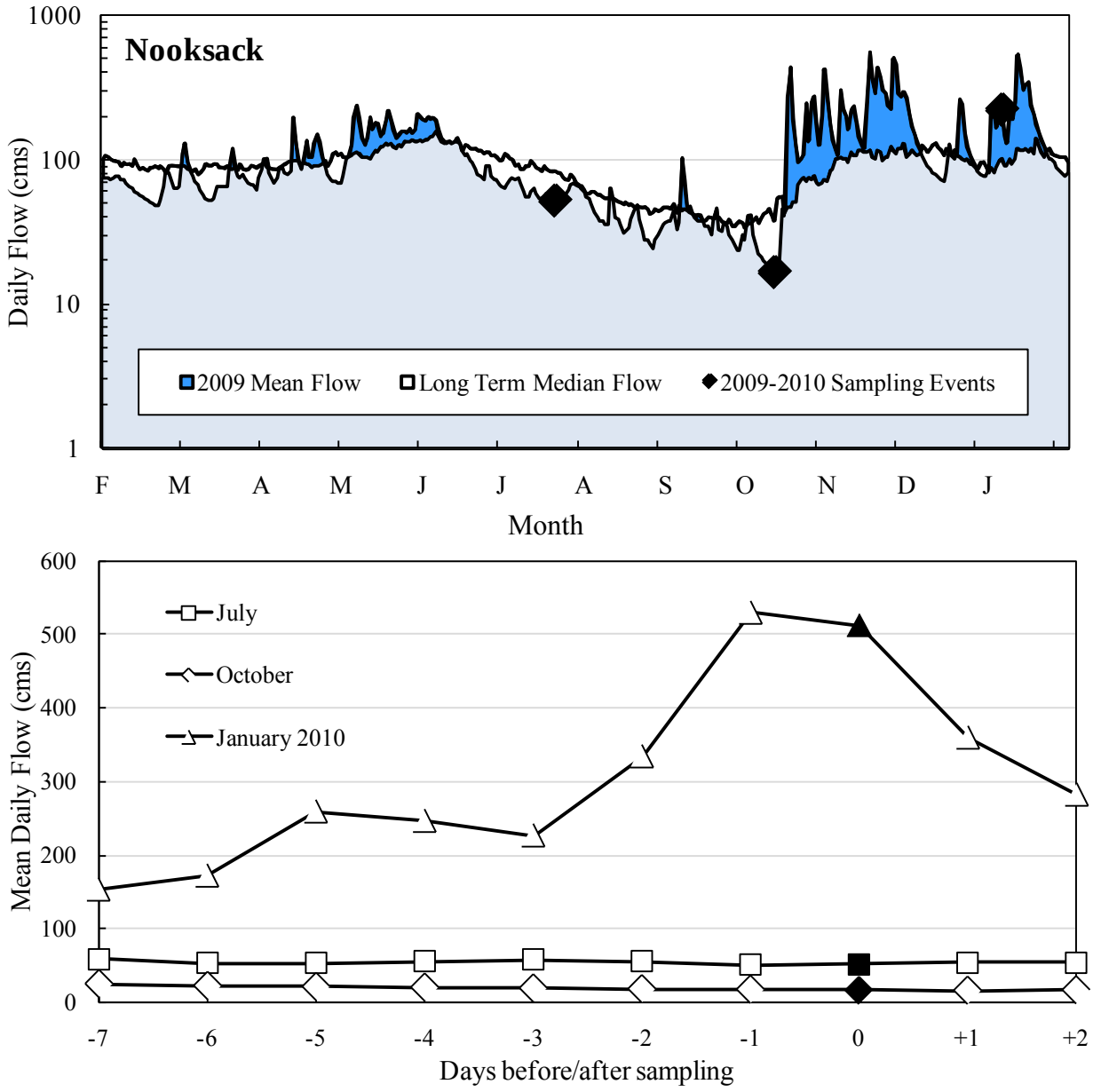

Figure 16. Nooksack River daily flows.

- Upper: Sampling events are shown as black diamonds on the hydrograph for mean daily flows during 2009 (shaded beneath). Relative to long-term median flows, periods of high flow appear as the darkest areas and periods of low flow appear under the white areas.
- Lower: Mean daily flows prior to, during, and immediately after each sampling event (solid black symbols).

July and October sampling occurred during baseflows, while sampling in January 2010 was near the peak of a runoff event.

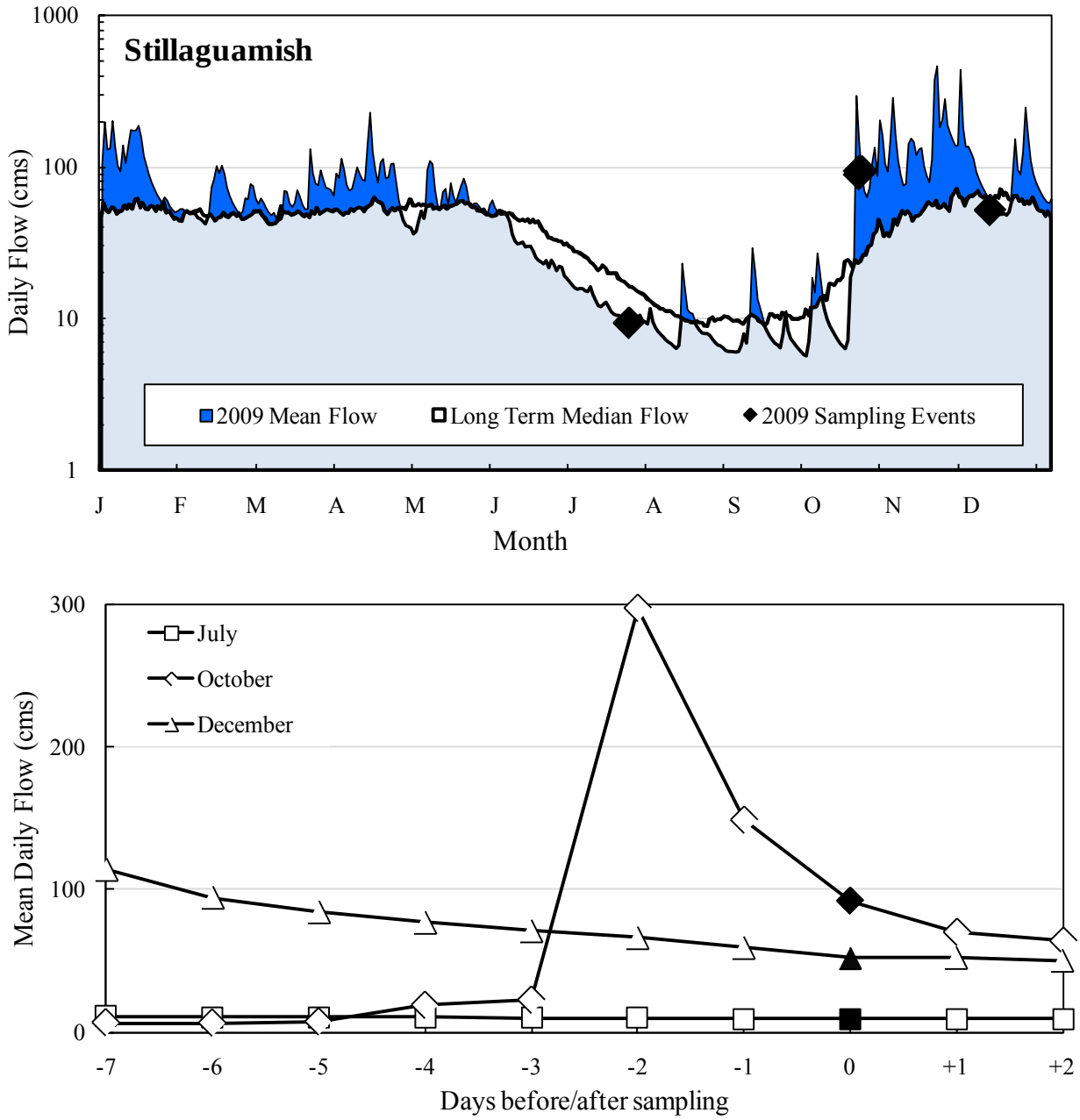

Figure 17. Stillaguamish River daily flows.

- Upper: Sampling events are shown as black diamonds on the hydrograph for mean daily flows during 2009 (shaded beneath). Relative to long-term median flows, periods of high flow appear as the darkest areas and periods of low flow appear under the white areas.
- Lower: Mean daily flows prior to, during, and immediately after each sampling event (solid black symbols).

  July and December sampling occurred during baseflows, while sampling in October was during the falling stage of a runoff event.

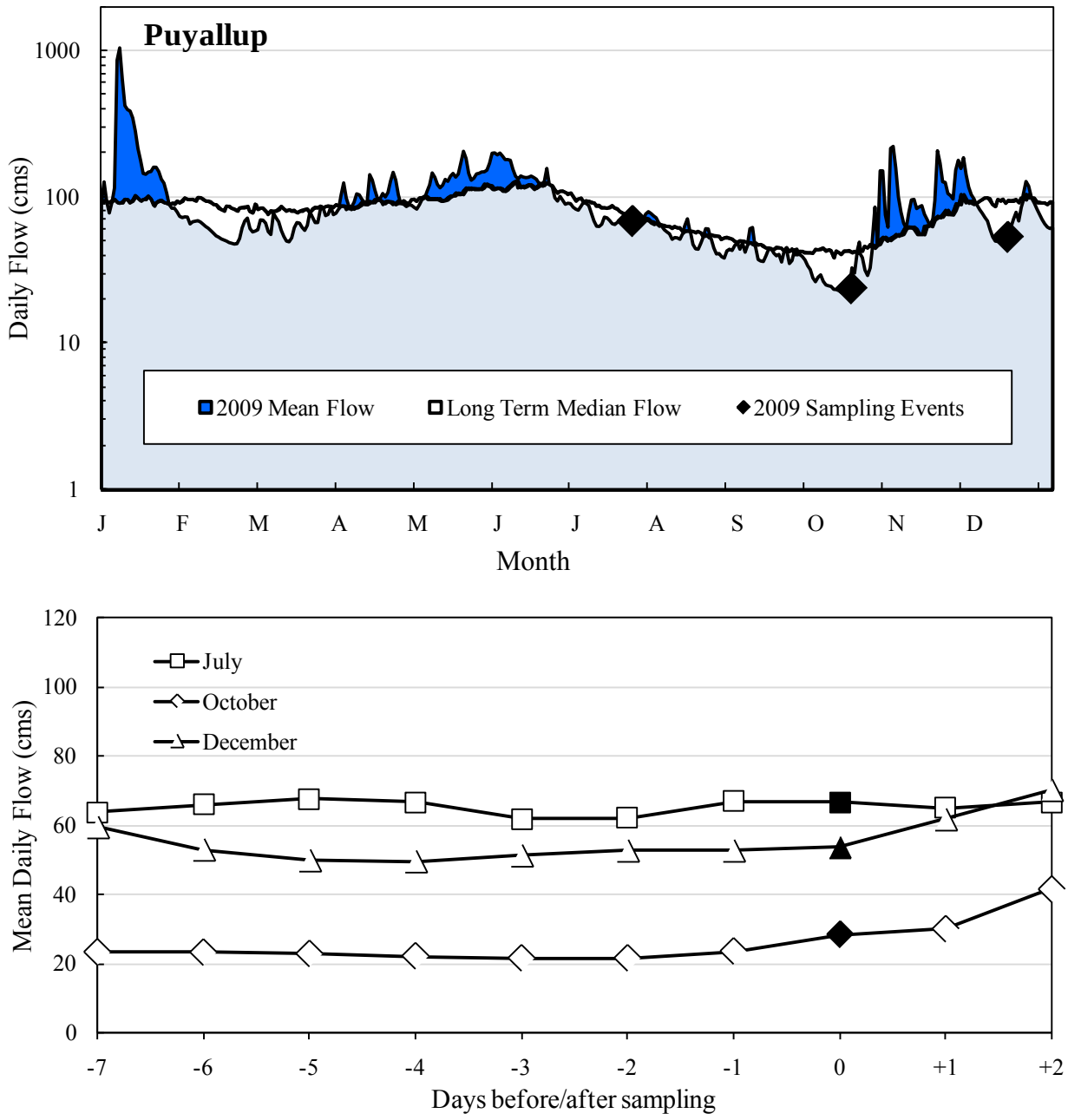

Figure 18. Puyallup River daily flows.

- Upper: Sampling events are shown as black diamonds on the hydrograph for mean daily flows during 2009 (shaded beneath). Relative to long-term median flows, periods of high flow appear as the darkest areas and periods of low flow appear under the white areas.
- Lower: Mean daily flows prior to, during, and after each sampling event (solid black symbols).

Sampling in July was during late seasonal runoff from melting Mt. Rainier glaciers. October sampling was during runoff from 1.33" of rainfall that fell upstream the previous day. The December sampling occurred under winter baseflow conditions, just prior to a runoff event.

Table 11 summarizes the mean daily flows for each river and sampling date, either measured or predicted from gaging station records. Base or runoff-related flow designations are also shown.

Flow conditions did not hinder sampling efforts except as follows. Swift currents made collecting water samples and pumping SPM from the desired depth (0.6 times the maximum mid-channel depth) more difficult. Sampling the Stillaguamish River in December was also complicated by the constant presence of disintegrating ice floes.

Table 11. Summary of field sampling activities for five major rivers discharging to Puget Sound.

River	Date	Mean Daily Flow [1]		Flow Type
		cfs	cms	
Summer – Sampling Event 1				
Skagit	7/21/09	10,500	297	Base
Snohomish	7/22/09	3,470	98.3	Base
Nooksack	7/21/09	1,840 [2]	52.1	Base
Stillaguamish	7/22/09	470 [2]	13.3	Base
Puyallup	7/23/09	2,380	67.4	-- [3]
QA replicate				
Fall – Sampling Event 2				
Skagit	10/13/09	5,400	153	Base
Snohomish	10/20/09	4,940	140	Runoff
Nooksack	10/12/09	590	16.7	Base
Stillaguamish	10/19/09	3,240	91.8	Runoff
Puyallup	10/15/09	1,000	28.3	Runoff
QA replicate				
Winter – Sampling Event 3				
Skagit	12/17/09	13,850	392	Runoff
Snohomish	12/22/09	18,400	521	Runoff
Nooksack	01/06/10	7,880	223	Runoff
Stillaguamish	12/08/09	~1,900	53.8	Base
Puyallup	12/14/09	1,860	52.7	Base
QA replicate				

[1] Flow predicted from stage height recorded at nearby USGS gaging station.
[2] Flow measured by Ecology stream monitoring staff on day of sampling.
[3] Neither baseflow nor related to recent precipitation. Suspended solids were related to seasonal runoff from glaciers, not from recent precipitation events.

The final number of samples collected (328) and analyses conducted (534) was similar to what was planned (Coots and Osterberg, 2009). Table 12 summarizes the analyses conducted on whole or filtered water samples.

Table 12. Inventory of analyses conducted on river water samples.

Parameter → / River ↓	TSS	TOC	DOC	Nutrients *	Hardness	Total Metals **	Dissolved Metals **	Oil & Grease	TPH-D	TPH-G	BNAs	PAHs	Chlorinated Pesticides	PCBs	PBDEs	Total
Skagit	3	3	3	15	3	15	15	3	3	5	3	3	3	3	3	83
Snohomish	3	3	3	15	3	15	15	3	3	5	3	3	3	3	3	83
Nooksack	3	3	3	15	3	15	15	3	3	5	3	3	3	3	3	83
Stillaguamish	3	3	3	15	3	15	15	3	3	5	3	3	3	3	3	83
Puyallup	3	3	3	15	3	15	15	3	3	5	3	3	3	3	3	83
QC samples	3	3	3	10	3	30	30	3	3	5	5	5	5	6	5	119
Total	18	18	18	85	18	105	105	18	18	30	20	20	20	21	20	534

* *Nutrients* include total nitrogen (TN), nitrate+nitrite, ammonia, total phosphorus, and ortho-phosphate (5 analyses per sample).
** 5 analyses (arsenic, cadmium, copper, lead, and zinc) per sample.

Conventional Parameters and Nutrients

Table 13 summarizes results for conventional parameters and nutrients. TSS ranged from a minimum 2.6 mg/L to a maximum 233 mg/L, and averaged 38 mg/L. The greatest concentrations of TSS in four rivers were associated with fall or winter runoff events (Figure 19). The maximum TSS in the Puyallup River (233 mg/L), measured in July, was from seasonal melting of glaciers. The overall mean TSS decreased to 24 mg/L when this value was excluded.

TOC and DOC averaged 1.3 mg/L and 1.5 mg/L, respectively. DOC exceeded TOC in 10 of 15 samples, averaging 115% of TOC. Organic carbon was consistently lowest in the summer. Concentrations were greatest in fall or winter and were usually associated with runoff events or increased TSS (Figure 20).

The mean concentration of total nitrogen (TN), 0.285 mg/L, was 85% dissolved inorganic forms. Concentrations of nitrate+nitrite nitrogen averaged about five times those of ammonia nitrogen. TN in all of the rivers was lower in the summer than in fall and winter (Figure 21), with the Skagit River containing the lowest concentrations. Concentrations of total phosphorus (TP) were associated with TSS, indicating that elevated TP concentrations would be expected in rivers carrying a high load of solids. Ortho-phosphate averaged 41% of TP. Ortho-P concentrations were greatest in the Puyallup River and least in the Skagit River (Figure 22).

Table 13. Summary statistics for conventional parameters and nutrients in river water.

Parameter	Times Detected	Percent Detected	Min.	25th %ile	Median	Mean	CV	75th %ile	Max.
Conventional Parameters (mg/L)									
TSS	15	100	2.6	5.1	11.9	38.0*	1.56	51.2	233
TOC	15	100	0.5	0.6	1.1	1.33	0.66	2.0	3.3
DOC	15	100	0.6	0.8	1.0	1.47	0.65	2.0	4.0
Nutrients (mg/L)									
Total Nitrogen (TN)	15	100	0.057	0.140	0.321	0.285	0.62	0.386	0.656
Nitrite (NO_2^-) + Nitrate (NO_3^-) Nitrogen	15	100	0.045	0.087	0.276	0.221	0.65	0.307	0.544
Ammonia Nitrogen	10	67	0.007	0.010	0.025	0.041	1.17	0.046	0.162
Total Phosphorus	15	100	0.006	0.016	0.032	0.054	1.15	0.078	0.250
Ortho-phosphate	15	100	0.003	0.005	0.010	0.014	0.89	0.019	0.048

* The mean concentration of TSS was 24 mg/L when the maximum (Puyallup River) value was excluded.

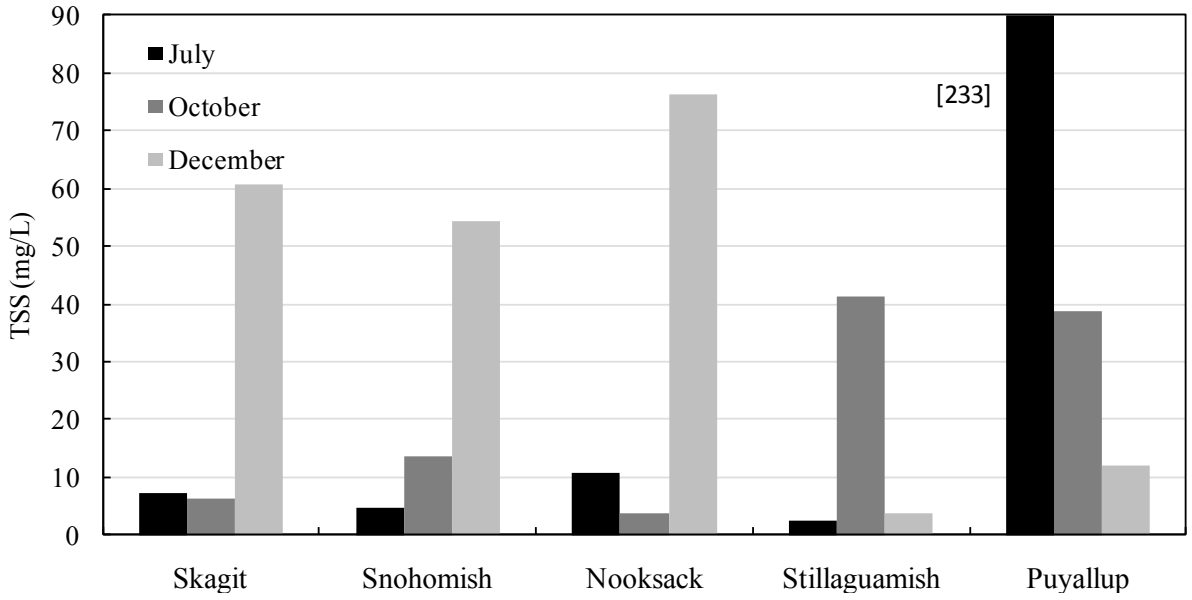

Figure 19. TSS near the mouths of major rivers discharging to Puget Sound in 2009.

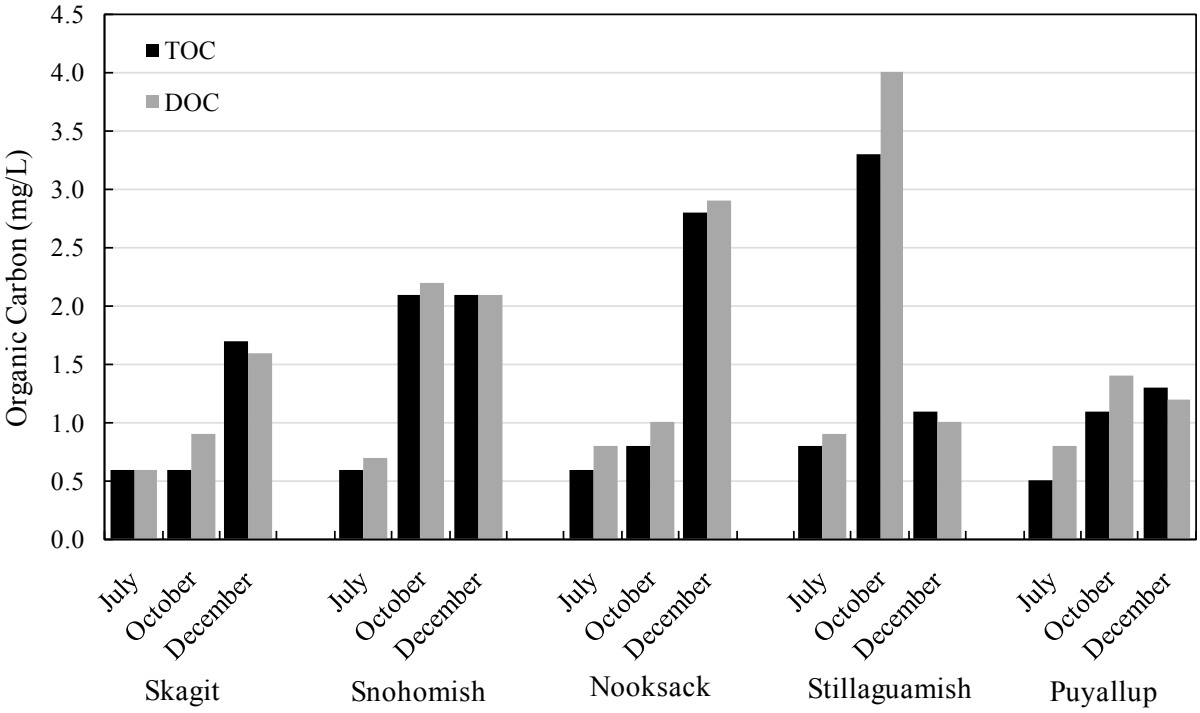

Figure 20. Organic carbon near the mouths of major rivers discharging to Puget Sound in 2009.

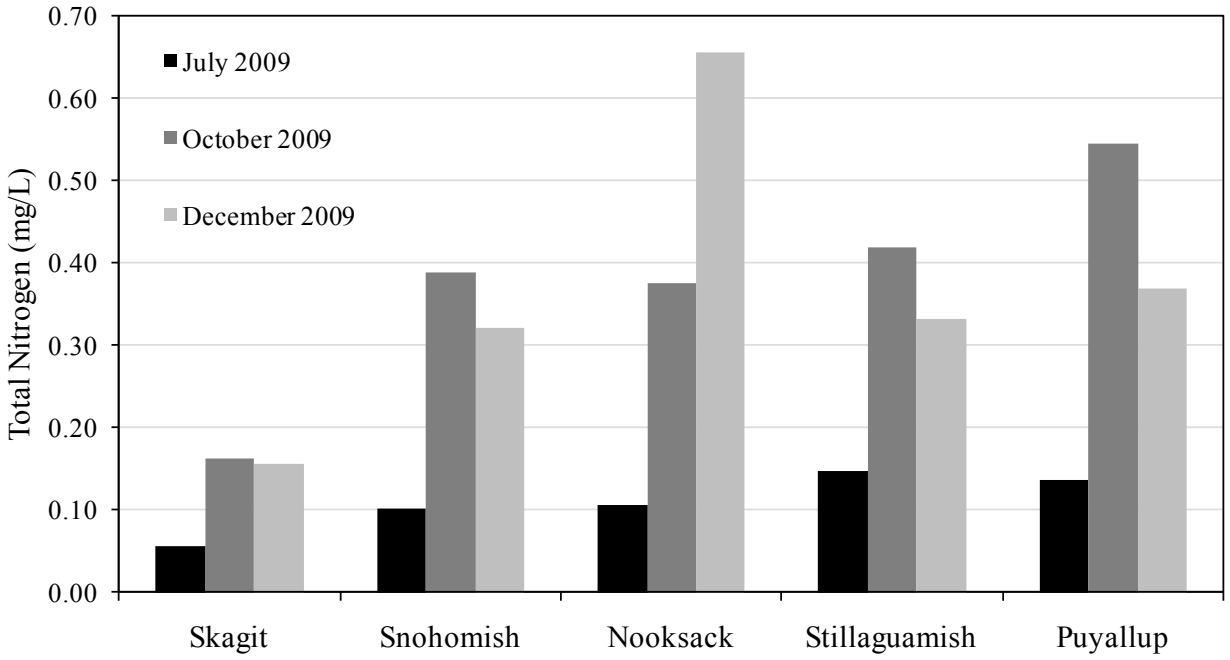

Figure 21. Total nitrogen near the mouths of major rivers discharging to Puget Sound in 2009.

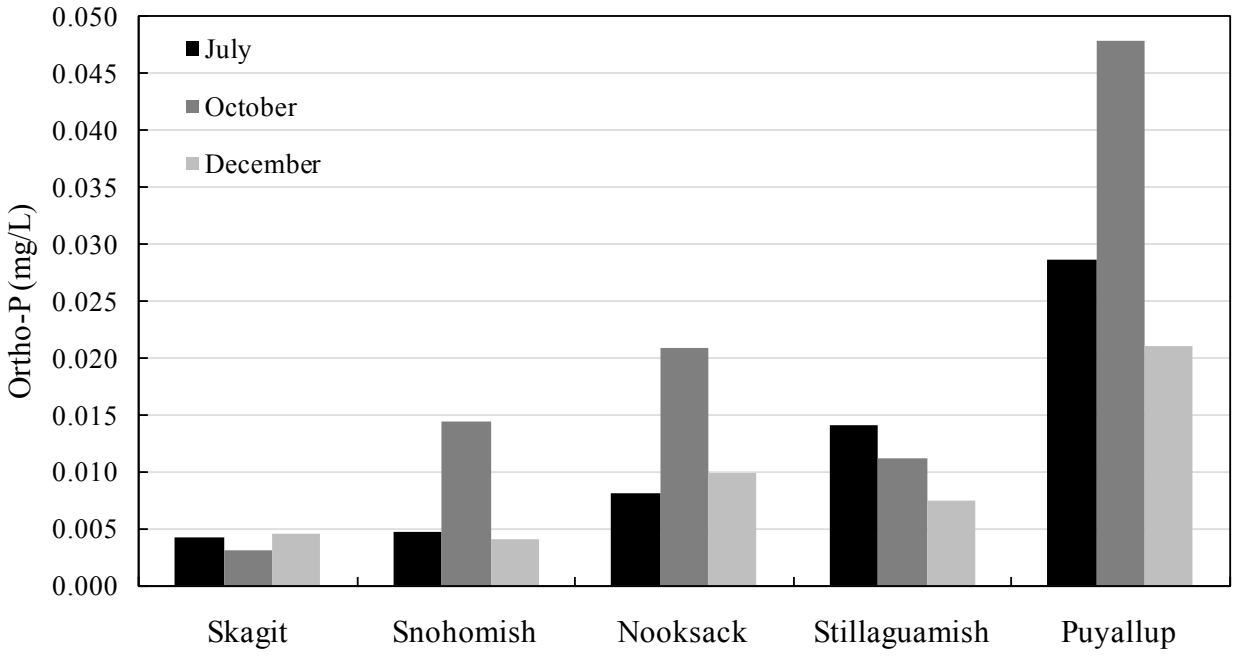

Figure 22. Ortho-phosphate near the mouths of major rivers discharging to Puget Sound in 2009.

Metals

Table 14 summarizes results for hardness, as well as for total recoverable and dissolved fractions of the five metals. The mean hardness for all water samples was 27.3 mg/L (as $CaCO_3$), and the low coefficient of variation (0.41) indicated relatively little variability between rivers. Mean values for total metal concentrations, ranked from high to low, were 6.41 µg/L zinc, 2.99 µg/L copper, 0.75 µg/L arsenic, 0.44 µg/L lead, and 0.012 µg/L cadmium. High total metal concentrations were associated with high TSS that usually accompanied runoff-related flows. This is shown for total copper and total zinc in Figures 23-24. Seasonal variability in concentrations of total arsenic, cadmium, and lead was similar.

The dissolved fraction generally made up the majority of total arsenic and cadmium concentrations. But the majority of copper, lead, and zinc was in particulate form. The relative contribution of particulate metals (total concentration minus dissolved concentration) tended to increase with TSS.

Table 14. Summary statistics for hardness and five metals measured in river water samples.

Parameter	Times Detected	Percent Detected	Min.	25th %ile	Median	Mean	CV	75th %ile	Max.
Hardness (mg/L)	15	100	13.2	20.5	29.9	29.8	0.41	35.6	62
Metals (µg/L)									
Arsenic, Total	15	100	0.26	0.52	0.73	0.75	0.41	0.99	1.24
Arsenic, Dissolved	15	100	0.300	0.463	0.500	0.524	0.30	0.595	0.860
Cadmium, Total	15	100	0.005	0.005	0.007	0.012	0.88	0.018	0.040
Cadmium, Dissolved	9	60	0.003	0.003	0.005	0.008	1.23	0.008	0.035
Copper, Total	15	100	0.75	1.13	1.81	2.99	0.99	4.33	11.6
Copper, Dissolved	15	100	0.35	0.547	1.00	1.20	0.82	1.57	4.19
Lead, Total	13	87	0.05	0.10	0.30	0.44	0.96	0.78	1.42
Lead, Dissolved	11	73	0.014	0.027	0.040	0.059	1.27	0.051	0.28
Zinc, Total	14	93	2.4	3.2	4.55	6.41	0.71	9.7	17.7
Zinc, Dissolved	15	100	0.70	0.92	1.40	1.88	0.65	2.95	4.40

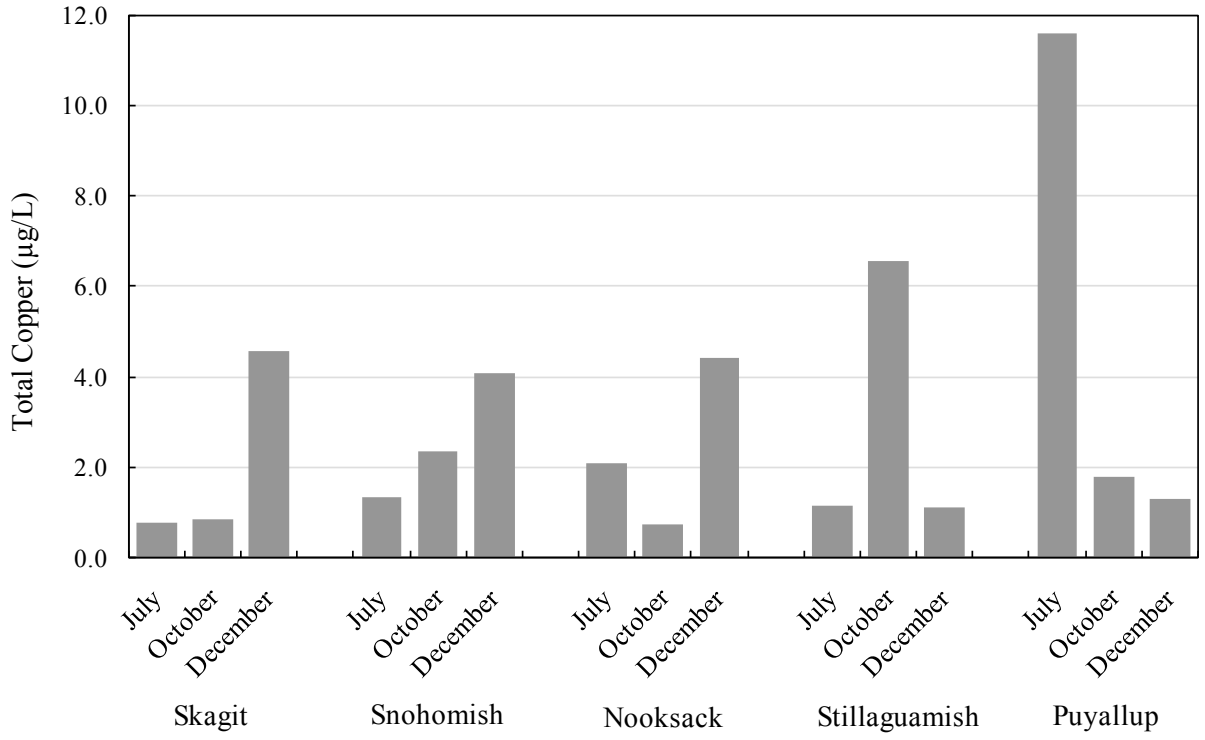

Figure 23. Total copper near the mouths of major rivers discharging to Puget Sound in 2009.

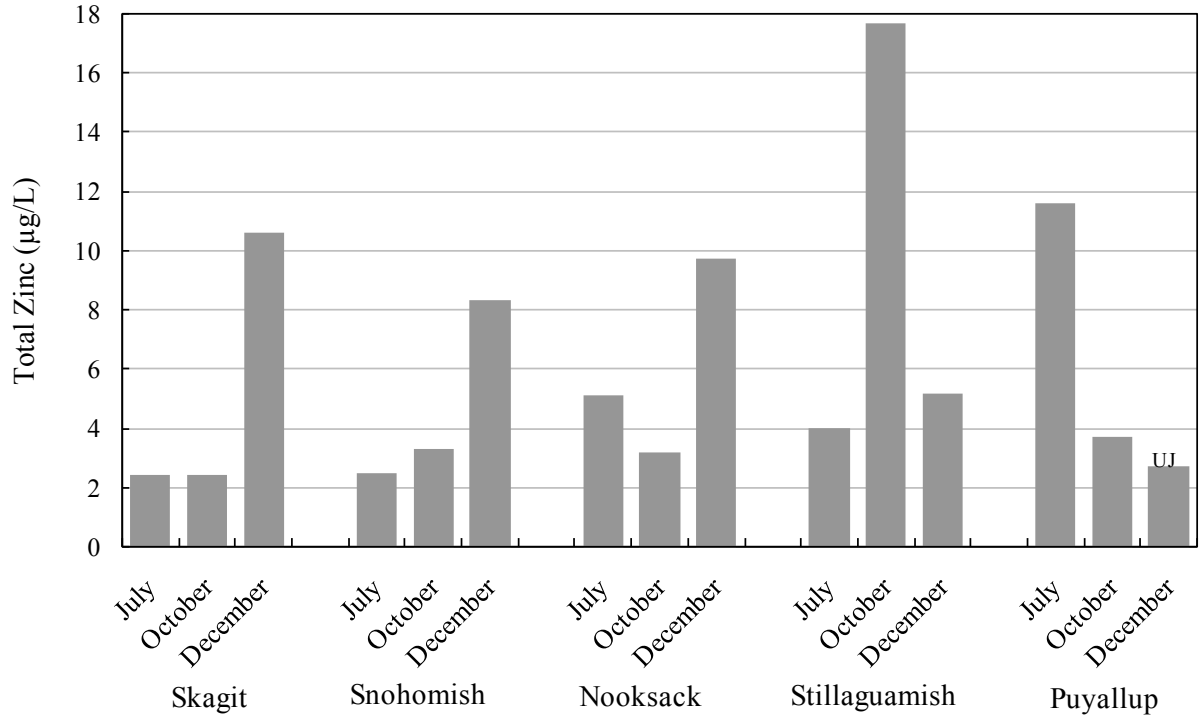

Figure 24. Total zinc near the mouths of major rivers discharging to Puget Sound in 2009.

Organics

Concentrations of 55 BNA, 22 PAH, and 32 chlorinated pesticide compounds were seldom detected. When detected, the compounds were often present in the corresponding method blank at a similar concentration. Table 15 summarizes results for these groups of organics. It shows that only five of the more than 100 compounds in these classes were detected in two or more samples:

- 4-methylphenol (various origins).
- Cholesterol (a biogenic steroid sometimes used as a marker for fecal material).
- Triethyl citrate (food additive, ingredient in cosmetics and pharmaceuticals, plasticizer).
- 1-methyl naphthalene (an occasional pesticide).
- Retene (a biomarker for higher order plants).

Measured concentrations were in the 0.0009 - 0.110 µg/L range. If one-half the RL was used to represent concentrations in nondetect samples, total PAH concentrations were in the range of 0.076 - 0.106 µg/L, and averaged 0.084 µg/L. The subset of seven carcinogenic PAH (cPAH) compounds [12] had toxic equivalent (TEQ) concentrations in the range of 0.009 - 0.014 µg/L, and a mean TEQ of 0.011 µg/L.

Table 16 summarizes results for petroleum-related compounds, total PCBs, and total PBDEs. Petroleum-related compounds were seldom detected. Oil and grease was detected in 40% of the samples (6 of 15), with MDLs ranging from 0.5 to 1.5 mg/L. Measured concentrations ranged from 0.9 - 2.8 mg/L, and averaged 1.6 mg/L. TPH-D or TPH-G were never detected despite MDLs of approximately 0.006 mg/L and 0.014 mg/L, respectively.

PCBs were present in all five rivers and 15 river water samples, with maximum concentrations recorded in three rivers during the fall (Figure 25). Total concentrations were always low: 2.6 - 59 pg/L. After assigning a "UJ" to congener concentrations less than three times (< 3X) those in corresponding method blanks, the average concentration of total PCBs was 16.3 pg/L [13]. The congeners detected most frequently were in the tri-chlorinated, tetra-chlorinated, and penta-chlorinated homolog groups. Congeners in the tri-chlorinated through hexa-chlorinated homolog groups made up an average 84% of total PCBs.

In contrast, PBDEs were detected in less than half of the river water samples. Total concentrations averaged 55.6 pg/L, but results were highly variable (CV = 1.67) within a range of 10.9 - 265 pg/L. PBDEs were detected in all five rivers during the summer, only in the Nooksack and Puyallup Rivers during the fall, and in no river during the winter. Congeners belonging to the tri-brominated and penta-brominated homolog groups were detected most frequently.

[12] Carcinogenic PAH compounds (cPAH) include benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene

[13] If tentatively identified congeners were included, the mean concentration increased 55% to 25.3 pg/L.

Table 15. Summary of measurable BNAs, chlorinated pesticides, and PAHs in river waters.

		BNAs (µg/L)									PAHs (µg/L)					Chlorinated Pesticides (ng/L)	
Tributary	Date (2009)	2-methyl phenol	4-methyl phenol	4-nonyl phenol	BEHP	Bisphenol-A	Cholesterol	DINOP	Triclosan	Triethyl citrate	1-methyl naphthalene	2-methyl naphthalene	Benzo(a) anthracene	Naphthalene	Retene	Endosulfan sulfate	Hexachloro benzene
Skagit	10/13	--	--	--	--	--	0.63 J	--	--	0.058 J	0.0049 J	0.0089 J	--	--	--	--	--
	12/17	--	--	0.052 J	--	--	0.56 J	--	--	--	--	--	--	--	0.11	--	--
Snohomish	07/21	--	--	--	--	--	--	--	--	--	--	--	--	0.01	--	--	--
	10/20	--	0.093 J	--	--	--	0.73 J	--	--	--	--	--	--	--	--	--	--
	12/22	--	--	--	--	--	--	--	--	--	--	--	0.0009 J	--	0.003 J	--	--
Nooksack	10/12	--	--	--	--	--	--	--	--	0.06 J	0.0039 J	--	--	--	--	--	--
	01/06/10	--	--	--	--	--	--	--	--	--	--	--	--	--	0.0097 J	0.42	
Stillaguamish	10/19	--	0.05 J	--	--	0.072 J	0.49 J	--	--	--	--	--	--	--	--	--	1.6
	12/08	--	0.13 J	--	--	--	0.51 J	--	--	--	--	--	--	--	--	--	--
Puyallup	07/23	0.0058 J	--	--	--	--		--	--	--	--	--	--	--	--	--	--
	10/15	--	--	--	--	--	1.4	--	--	--	--	--	--	--	--	--	--
	12/14	--	--	--	0.074 J	--	0.57 J	--	--	--	--	--	--	0.024	0.0015 J	--	--
QA REP [1] (Puyallup)	10/15	--	--	--	--	--	1.4	0.16 J	0.081	0.31 J	0.0034 J	--	--	--	--	--	--

BEHP = Bis(2-Ethylhexyl) Phthalate; DINOP = Di-N-Octyl Phthalate

[1] QA replicate included only because some analytes were uniquely detected in this field replicate.

Table 16. Summary statistics for petroleum-related compounds, PCBs, and PBDEs in river waters.

Congener summation rules are described in Appendix D. Congeners in each homolog group are listed in Appendix E (Tables E-20 to E-22, and E-24). Concentrations of tentatively-identified congeners (results qualified as N or NJ) were not included in homolog or overall totals. Note: Homolog concentrations in a single sample can be summed to equal the total concentration in that sample, but summing the homolog statistics will not result in the total concentration statistics.

Parameter	Times Detected	Percent Detected	Min.	25th %ile	Median	Mean	CV	75th %ile	Max.
Petroleum-related compounds (mg/L)									
TPH-D and TPH-G	0	0	-	-	-	-	-	-	-
Oil and Grease	6	40	0.9	1.4	1.4	1.6	0.40	1.6	2.8
PCB homologs and totals (pg/L)									
Mono-chlorinated	5	33	1.71	1.75	1.80	2.03	0.21	2.14	2.73
Di-chlorinated	9	60	0.71	1.78	2.04	2.52	0.62	2.98	6.14
Tri-chlorinated	13	87	0.80	2.11	3.37	3.73	0.68	3.91	9.68
Tetra-chlorinated	12	80	0.54	1.40	2.10	3.85	1.16	4.51	16.5
Penta-chlorinated	13	87	0.81	1.16	2.74	5.76	1.38	6.49	28.7
Hexa-chlorinated	12	80	0.60	1.12	2.66	3.00	0.77	3.86	8.63
Hepta-chlorinated	2	13	0.72	--	1.11	1.11	--	--	1.51
Octa-chlorinated	2	13	1.14	--	1.21	1.21	--	--	1.28
Nona-chlorinated	0	0	--	--	--	--	--	--	--
PCB-209	1	7	1.09	--	1.09	1.09	--	--	1.09
Total PCBs	15	100	2.61	5.95	9.96	16.27 *****	0.95	19.2	59.0
PBDE homologs and totals (pg/L)									
Mono-brominated	0	0	--	--	--	--	--	--	--
Di-brominated	0	0	--	--	--	--	--	--	--
Tri-brominated	4	27	5.18	7.94	11.6	10.4	0.35	12.9	13.3
Tetra-brominated	1	7	17.0	--	17.0	17.0	--	--	17.0
Penta-brominated	4	27	10.8	11.2	12.6	17.6	0.64	24.0	34.2
Hexa-brominated	0	0	--	--	--	--	--	--	--
Hepta-brominated	0	0	--	--	--	--	--	--	--
Octa-brominated	0	0	--	--	--	--	--	--	--
Nona-brominated	0	0	--	--	--	--	--	--	--
PBDE-209	1	7	260	--	260	260	--	--	260
Total PBDEs	7	47	10.9	13.4	22.3	55.6	1.67	33.0	265

***** The mean concentration of total PCBs in river water would be approximately 60% higher if concentrations of tentatively-identified congeners ("N" and "NJ") were also included.

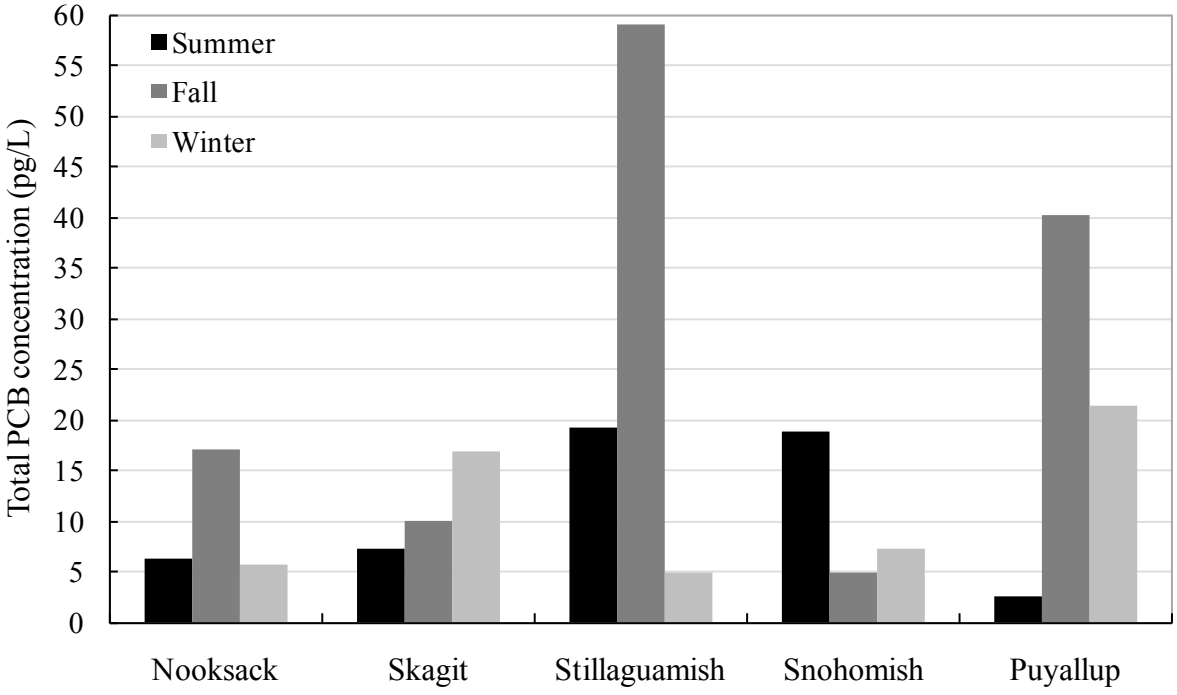

Figure 25. Total PCBs near the mouths of major rivers discharging to Puget Sound in 2009.

River SPM

Collecting suspended solids from river water using pump-and-centrifuge methods required an average of 18 hours per site (Table 17), not including setup and demobilization time. River water was usually pumped at rates of 10 - 13 liters (2.6 - 3.4 gallons) per minute. At these pump rates, SPM retention efficiencies were highly correlated with inflowing TSS concentrations ($r^2 = 0.95$), and the mean efficiency was 72%. Five samples of suspended solids were collected by the centrifuges, one from each river. Sample mass ranged from 153 to 960 wet grams, which was equivalent to approximately 67 to 660 dry grams.

Table 17. Collection of suspended solids from five rivers by continuous-flow centrifuges.

River	Start Date	End Date	Average Pump Rate		Pump Time (hrs)	Volume Pumped (liters)	Inflow TSS (mg/L)	Outflow TSS (mg/L)	Estimated Efficiency (%)
			gpm	L/hr					
Skagit	12/16/09	12/17/09	2.31	524	17.13	8,970	65.8	22.1	66
Snohomish	12/22/09	12/23/09	2.37	539	16.00	8,620	42.6	8.8	79
Nooksack	01/05/10	01/06/10	2.34	531	14.67	7,790	168	97.8	42
Stillaguamish	12/08/09	12/09/09	2.64	599	22.00	13,180	6.4	0.3	95
Puyallup	12/13/09	12/14/09	2.59	588	20.08	11,800	72.2	17.7	75

Conventional Parameters

Table 18 summarizes results for the five samples of suspended river solids. Suspended particulate matter contained 0.36 - 1.88% TOC (mean = 1.2 %).

Metals

Mean concentrations of total metals were rank ordered as were whole water samples: 68.7 mg/kg zinc, 36.5 mg/Kg copper, 7.79 mg/Kg arsenic, 5.86 mg/Kg lead, and 0.16 mg/Kg cadmium.

Organics

BNAs were rarely detected. Only cholesterol, its degradate (3-beta coprostanol), and BEHP were found in all samples. TPH-D, analyzed in BNA extracts, was not detected. Unlike whole water, 16 of 22 PAH compounds were detected in more than one-half the SPM samples. Individual PAHs averaged less than 20 µg/Kg, except for retene (mean = 230 µg/Kg). Mean concentrations of high and low molecular weight PAHs were similar. Total PAHs, excluding retene, ranged from 32 - 210 µg/Kg and averaged 119 µg/Kg. Pesticides were virtually absent from particulates collected this time of year (winter). PCBs were measured in all samples, as were PBDEs. The average concentrations of total PCBs and total PBDEs were 408 ng/Kg and 1680 ng/Kg, respectively.

Table 18. Summary statistics for parameters measured in SPM collected from five rivers.

Parameter (dry weight basis units)	Times Detected	Percent Detected	Min.	25th Percentile	Median	Arithmetic Mean	CV	75th Percentile	Max.
Conventional Parameters (%)									
TOC	5	100	0.36	0.81	1.46	1.23	0.48	1.59	1.88
Metals (mg/Kg)									
Arsenic	5	100	1.45	5.21	6.62	7.79	0.59	11.65	13.3
Cadmium	5	100	0.04	0.11	0.17	0.16	0.49	0.21	0.24
Copper	5	100	17.2	24.6	33.0	36.5	0.43	52.1	53.5
Lead	5	100	1.57	3.74	5.35	5.86	0.54	8.66	9.55
Zinc	5	100	20.3	45.4	77.4	68.7	0.48	91	106
BNAs (µg/Kg)									
3-Beta Coprostanol	5	100	220	235	260	340	0.55	400	670
4-Methylphenol	3	60	43	45	52	58	0.32	72	78
4-Nonylphenol	1	20	15	-	15	15	1.0	-	15
Benzoic acid	1	20	310	-	310	310	1.0	-	310
BEHP	5	100	170	215	510	490	0.67	655	1,000
Bisphenol A	1	20	20	-	20	20	1.0	-	20
Cholesterol	5	100	410	928	1,300	2,560	1.33	3,200	8,600
Phenol	1	20	26	-	26	26	1.0	-	26
TPH-D	0	0	-	-	-	-	-	-	-
PAHs (µg/Kg)									
1-Methylnaphthalene	5	100	3.6	4.9	6.4	9.3	0.65	14.3	18
2-Chloronaphthalene	0	0	-	-	-	-	-	-	-
2-Methylnaphthalene	5	100	6.1	7.4	11	15.2	0.67	23.3	30
Acenaphthene	0	0	-	-	-	-	-	-	-
Acenaphthylene	0	0	-	-	-	-	-	-	-
Anthracene	4	80	1.5	1.5	2.1	3.1	0.79	4.6	6.6
Benzo(a)anthracene	4	80	1.6	2.6	4.1	4.2	0.53	5.8	6.9
Benzo(a)pyrene	3	60	2.8	3.0	3.7	4.5	0.48	6.1	6.9
Benzo(b)fluoranthene	4	80	2.0	5.0	9.5	8.8	0.59	12.5	14

Table 18 (continued). Summary statistics for parameters measured in SPM collected from five rivers.

Parameter (dry weight basis units)	Times Detected	Percent Detected	Min.	25th Percentile	Median	Arithmetic Mean	CV	75th Percentile	Max.
PAHs (µg/Kg)									
Benzo(g,h,i)perylene	5	100	1.8	2.0	5.2	5.7	0.74	8.8	12
Benzo(k)fluoranthene	2	40	1.7	1.7	1.9	1.9	0.15	2.1	2.1
Total Benzofluoranthenes	4	80	2.0	6.1	11.4	9.7	0.56	13.4	14
Carbazole	0	0	--	--	--	--	--	--	--
Chrysene	5	100	2.3	2.7	9.6	8.3	0.67	13	15
Dibenzo(a,h)anthracene	2	40	0.9	0.9	1.0	1.0	0.14	1.1	1.1
Dibenzofuran	5	100	1.4	1.6	3.2	3.9	0.78	5.4	8.8
Fluoranthene	5	100	2.1	2.9	8.9	9.0	0.74	14	18
Fluorene	4	80	1.1	2.5	4.1	4.2	0.63	6.0	7.6
Indeno(1,2,3-c,d)pyrene	5	100	0.9	1.2	3.1	3.6	0.77	5.6	7.5
Naphthalene	5	100	2.7	3.2	8.8	9.0	0.74	13	19
Phenanthrene	5	100	6.7	6.7	22	20	0.66	30	36
Pyrene	5	100	3.5	4.2	11	11	0.64	18	18
Retene	5	100	60	90	280	230	0.63	333	400
Individual PAHs *	82	71	--	--	--	--	--	--	--
Low molecular weight PAHs	5	100	20.9	23.2	55.1	59.1	0.68	88.1	117
High molecular weight	5	100	10.6	15.6	64.3	51.8	0.70	78.6	93.3
Total PAHs	5	100	31.5	38.9	119	111	0.68	167	211
Chlorinated Pesticides (µg/Kg)									
DDE, DDT, hexachlorobenzene, pentachloroanisole	1 each	<1	--	--	--	--	--	--	--
Other pesticides	0	0	--	--	--	--	--	--	--
PCBs and PBDEs (ng/Kg)									
Total PCBs	5	100	150	202	366	408	0.67	557	845
Total PBDEs	5	100	522	671	1,033	1,676	1.03	2,230	4,696

* 82 detected concentrations out of 105 possible results (23 individual PAH compounds measured per sample x 5 samples).

Discussion

Marine Water Column

Comparison with Historical Data

Serdar (2008) conducted a review of readily available data collected since 1995 on selected toxic chemicals in Puget Sound and the boundary waters of the Straits of Juan de Fuca and Georgia. Little existing data were found, especially for organic compounds. Despite the paucity of existing data for the region, the information compiled provides an indication of the range of concentrations that might be expected for each target chemical. Table 19 presents a comparison of results from the present 2009-10 study to existing data.

While data collected for the present study were in good agreement with concentration ranges from historical data (with few exceptions), the 2009-10 results yielded new insights into the variability and range of ambient concentrations:

- Total and dissolved measurements of arsenic, cadmium, and copper agreed well with previously reported values, but also revealed slightly broader ranges of ambient concentrations. Arsenic and cadmium results tended to be somewhat higher than comparable data, while copper concentrations were generally lower than historical values.
- Previously reported total lead concentrations for the region were at the low end of the range of 2009-10 project results, which tended to be markedly higher and more variable. Nearly half of the project measurements were above the highest historical concentration.
- Total zinc concentrations were in good agreement with previous measurements. The exception was the maximum concentration of 7.44 mg/L measured in the deep water sample collected from Hood Canal in July 2009. This was five times greater than the concentration measured in any other sample and may represent the high end of the concentration range for total zinc in marine ambient waters [14].
- The mean concentration of total PCBs in regional marine waters (26.3 pg/L) and for boundary waters (20.4 pg/L) were lower than the mean concentrations reported by Dangerfield et al. (2007) for surface and deep Canadian waters. The diversity of sites and multiple depths sampled for the present study may provide a better indication of the variability in total PCBs concentrations that can be expected in regional waters.
- Total PBDE concentrations spanned a wide range throughout the region. Previously available data were limited and provided a low estimate of typical ambient concentrations. Current project data, however, exposed marked variability in total PBDEs. Concentrations were below detection limits in more than 75% of project samples, but detected total PBDE concentrations were often at least 10 times greater than those reported by Dangerfield et al. (2007). There was no evidence from QC data that the samples had been contaminated. One explanation for the dissimilar results may be that the discrete samples from the present study

[14] It was noted that concentrations of most metals in Hood Canal SPM were also greater than those measured in SPM collected from traps deployed in the more developed South Sound region.

captured heterogeneous concentrations of PBDEs that could be diluted when collecting time-integrated pump samples as was done by Dangerfield et al.

- Organic carbon concentrations throughout Puget Sound and the oceanic boundary waters were very similar to those reported by Johannessen et al. (2008).
  - Results of the present study indicate that the organic carbon concentration records taken from Ecology's EIM database and used by Pelletier and Mohamedali (2009) were above typical ambient concentrations. Past methods used to collect and handle seawater samples for analysis of organic carbon were likely susceptible to contamination. The rigorous sampling procedures used throughout the present study (see Appendix C) appeared to be more successful at preventing contamination.
  - A single high POC result (1.78 mg/L) fell outside the range of concentrations observed by Johannessen et al. (2008; maximum observed POC of 0.36 mg/L). However this result is not unrealistic and may be representative of POC concentrations associated with elevated productivity, as there was high TSS and a strong phytoplankton bloom (revealed by CTD fluorescence profile) at the time of sample collection.
  - The median concentration of TOC in deep waters entering Puget Sound (0.73 mg//L) was greater than the mean of 0.53 mg/L TOC reported for deep waters further west in the Strait of Juan de Fuca (Johannessen et al., 2008) and for typical mid-ocean concentrations (0.5 mg/L; J. Sharp, pers. comm.).

Table 19. Marine water column results compared to previously reported concentration ranges.

Parameter	Present Study Results					Historical Data		
	N	Median	Mean	Low	High	Reported Values		Data Sources*
						Low	High	
Conventional Parameters (mg/L)								
TSS	42	1.6	1.75	0.8	6.0	0.0	64.1	4, 7
DOC	28	0.754	0.757	0.611	0.969	< 0.44	2.16	3, 7
POC	28	0.059	0.133	0.028	1.780	< 0.01	> 5.0	3, 7
TOC	28	0.807	0.891	0.660	2.749	< 0.48	79	3, 7
Metals (µg/L)								
Arsenic, Total	42	1.41	1.42	1.16	1.56	0.41	2.0	1, 8, 9
Arsenic, Dissolved	42	1.42	1.42	1.26	1.70	0.42	2.0	1, 8, 9
Cadmium, Total	42	0.084	0.085	0.059	0.112	0.040	0.075	1, 8, 9
Cadmium, Dissolved	42	0.081	0.083	0.067	0.111	0.031	0.076	1, 8, 9
Copper, Total	42	0.38	0.41	0.19	1.37	0.19	1.3	1, 4, 5, 8, 9
Copper, Dissolved	42	0.30	0.31	0.16	0.51	0.31	1.0	1, 4, 5, 6, 8
Pb Total	37	0.070	0.085	0.015	0.230	< 0.006	0.069	1, 4, 5, 8, 9
Zn Total	42	0.69	0.87	0.41	7.44	0.20	1.3	1, 4, 5, 8
Organics (pg/L)								
Total PCBs	42	24.0	26.3	6.09	75.1	40.3	43.5	2
Total PBDEs	10	749	2,860	51	18,700	14.8	23.4	2

* Data sources:

1. Crecelius (1998) data from the Straits of Georgia and Juan de Fuca, 1997.
2. Dangerfield et al. (2007) data from Boundary Pass and Rosario Strait, Strait of Georgia.
3. Johannessen et al. (2008) data from the Straits of Juan de Fuca and Georgia, 2003.
4. Johnson (2009) data from the Strait of Juan de Fuca, Guemes Channel, and Commencement Bay, 2008-2009.
5. Johnson (2009) summary of King County Department of Natural Resources and Parks data from the Strait of Juan de Fuca for the period 1997-2000.
6. Johnson (2009) summary of Johnson and Summers (1999) data from Commencement Bay, 1997-1998.
7. Pelletier and Mohamedali (2009) summary of EIM data for various Box Model regions; POC calculated as the difference of TOC and DOC.
8. Serdar (2008) summary of KCDNR data for Puget Sound, 1996-2002.
9. Serdar (2008) summary of EIM data for Puget Sound, 1995-2007.

Patterns and Relationships

The nonparametric Kruskal Wallis Test and Test of Medians were used to determine the significance of differences in parameter concentrations. These tests were used because chemical concentrations seldom reflected a normal distribution and only some log-normal distributions became normal when transformed (Appendix J, Table J-1). Test results provided in Table J-2 showed that concentrations of some chemicals were statistically different between regions, seasons, and depth layers.

- **Regional differences**. Comparing all sample results from the three ocean boundary sites (from both depths and all seasons) to those from the four Puget Sound basin sites revealed:
  - Mean concentrations of DOC, TOC, total and dissolved copper, and total PCBs were significantly greater in Puget Sound samples than in ocean boundary waters.
  - Mean concentrations of total and dissolved cadmium in ocean boundary waters were significantly greater than in the basins of Puget Sound.

- **Seasonal differences**. Comparisons of the seasonal mean chemical concentrations (measured at all stations and depths) yielded the following:
  - TSS, total arsenic, and total and dissolved copper concentrations were significantly lower in October than in July or January.
  - Concentrations of all forms of organic carbon were significantly higher in October 2009 than in January 2010.
  - Total PCB concentrations were greatest in the fall.

- **Water column depth layer differences.** Results from all stations and seasons were pooled by collection depth for comparison of surface and deep layer concentrations. Samples were additionally separated by region to test for layer differences within the boundary waters or the Puget Sound basin waters.
  - For the entire sampling area, mean concentrations of total and dissolved arsenic and total lead were significantly lower in the surface layer than in the deep layer.
  - In the Puget Sound basins, dissolved arsenic had significantly greater mean concentrations in the deep layer compared to the surface layer.
  - In ocean boundary waters, mean concentrations of dissolved arsenic, total and dissolved cadmium, and total lead in the deep layer were significantly greater than those in the surface layer.
  - For ocean boundary waters, the mean DOC concentration in the surface layer was significantly greater than the mean DOC in the deep layer.
  - Mean concentrations of total PCBs were significantly lower in the surface layer of ocean boundary waters, Puget Sound basins, and all locations combined than in the deep layer (Figure 26).

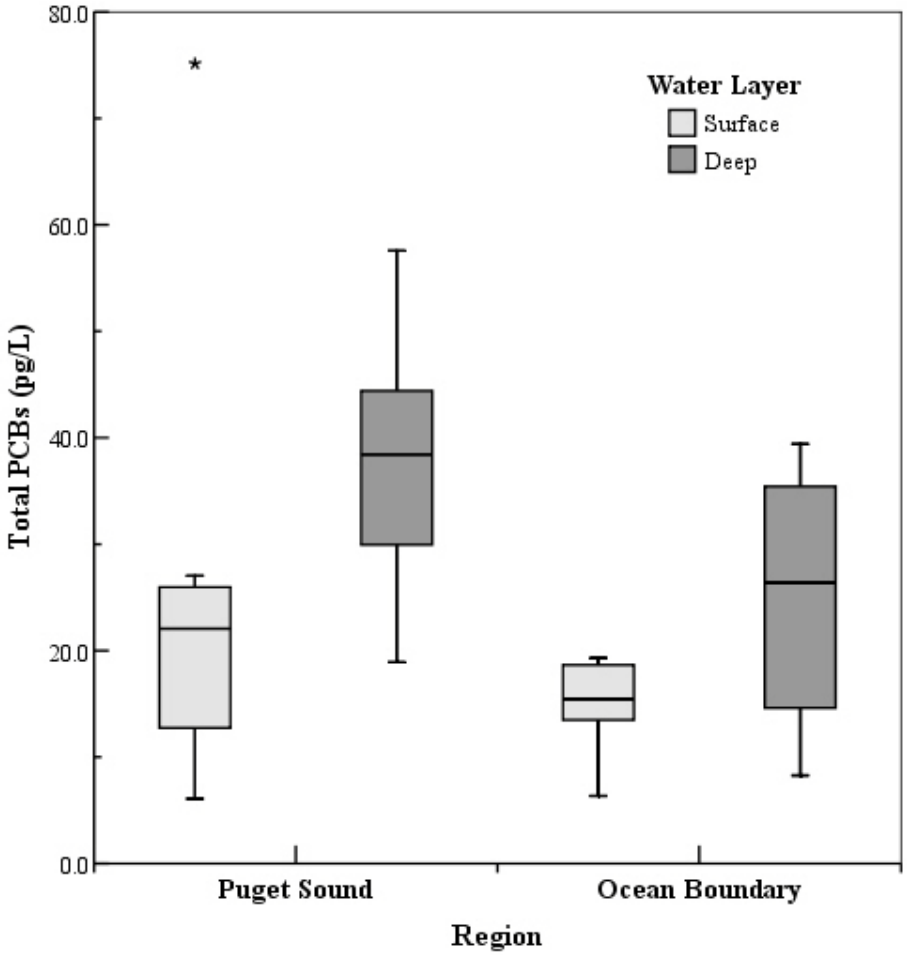

Figure 26. Total PCB concentrations in surface and deep marine water column samples.

Spearman rank correlation analysis was conducted to identify relationships between different chemicals. Results are presented in Appendix J, Table J-3. Significant relationships included:

- Suspended solids were negatively correlated with organic carbon. Both dissolved and particulate forms of organic carbon tended to decrease with increasing TSS.
- Organic carbon was negatively correlated with total and dissolved forms of arsenic and cadmium. When DOC (the main fraction of TOC) was relatively high, concentrations of these metals were low.
- Concentrations of most metals species were positively correlated.
- Total PCBs appeared linked to the presence of particles, as indicated by positive correlations with TSS.
- Total PCB concentrations were negatively correlated with TOC, and its main constituent DOC, in water column samples. (There was no correlation between PCBs and POC.)
- There was no apparent relationship between concentrations of PBDEs and other parameters.

Of the spatial patterns, temporal trends, and parameter relationships identified through statistical analyses, an interesting discovery was that total PCB concentrations in the deep waters were significantly higher than in the surface waters. This was true for all samples but also for the four Puget Sound basin sites and the three ocean boundary water sites separately (Figure 26). This finding was somewhat counterintuitive, as major sources of PCBs were expected to be surface inputs from urban-industrial centers (e.g., stormwater, surface runoff, atmospheric deposition). PCBs from land-based sources may have diminished by the time they reached the mid-basin and ocean boundary sampling sites because:

- Total PCB concentrations derived from land-based sources are diluted by Puget Sound surface waters containing lower PCB concentrations.
- Suspended, particle-bound PCBs settle through the water column into deeper waters.
- Total PCBs are transported downslope from the nearshore environment because of bathymetry- or density-driven focusing processes.

The significant positive correlation between total PCBs and TSS (Table J-3) suggests that sedimentation and sediment focusing contribute to total PCB concentrations in deep waters greater than those in surface waters.

Ocean Exchange

One objective of the present 2009-10 study was to measure concentrations of toxic chemicals in ocean boundary waters. These are generally considered to be near the west entrance to the Strait of Juan de Fuca. However, models of Puget Sound circulation and transport consider the north end of Admiralty Inlet to be the main seaward boundary (Pelletier and Mohamedali, 2009; Babson et al., 2006). This is where higher salinity and density deep waters flow *into* Puget Sound, and lower salinity and density surface waters flow *out of* the Sound. Accordingly, water column samples were collected from sites in the Strait of Juan de Fuca and Haro Strait (Figure 1) where deep water chemistry better represents that of water entering Puget Sound.

Samples were collected from central locations in four Puget Sound basins (Figure 1), but only results from the Main, Whidbey, and Hood Canal basin sites were used to represent water flowing out of Puget Sound for ocean exchange calculations [15]. Chemical concentrations measured in these samples were weighted in proportion to predicted flows from each basin into Admiralty Inlet and used to represent concentrations that exit Puget Sound [16]. To represent chemical concentrations in water leaving Puget Sound through Deception Pass (near Anacortes, Washington), Whidbey Basin surface water sample results were used.

The direction of net exchange with the ocean (ocean exchange) for different chemicals was evaluated using estimates of annual mass transport into and out of Puget Sound. A range of annual mass transport was calculated using 25th and 75th percentile chemical concentrations.

[15] Results for Strait of Juan de Fuca and Haro Strait surface samples were not used to represent water flowing out of Puget Sound because they may have been influenced by sources outside of Puget Sound (Fraser River water).

[16] The Box Model predicted that Main, Whidbey, and Hood Canal basins contribute 56.4%, 27.4%, and 16.2% of the flow into Admiralty Inlet, respectively.

These were multiplied by Box Model-predicted flows into and out of Puget Sound across the two seaward boundaries:

- The long-term median flow of deep water *into* Puget Sound through Admiralty Inlet was -18,555 cms (-5.85 x 10^{11} m^3/year).
- The long-term median flow of surface water *out of* Puget Sound was 20,300 cms (6.40 x 10^{11} m^3/year), with 18,771 cms flowing out through Admiralty Inlet and 1,529 cms flowing out through Deception Pass.

Results of ocean exchange calculations are presented in Tables 20-22. Concentration ranges for TSS, TOC, metals, and organic compounds measured in deep ocean boundary waters are shown in Table 20. The table also presents probable ranges for annual chemical mass transport into Puget Sound. Table 21 shows concentrations of the same chemicals in Puget Sound surface waters, along with ranges for chemical mass transport out of Puget Sound. Table 22 combines results from the previous tables to yield estimates of net chemical exchange between Puget Sound and the ocean boundary waters. Example calculations follow.

The procedure for calculating net exchange of total arsenic, based on median concentrations, is described here. First, the mass of arsenic imported into Puget Sound was calculated by multiplying the median deep boundary water concentration (1.49 µg/L = 1.49 mg/m^3) by the annual incoming volume of water (-5.85 x 10^{11} m^3/year). This resulted in an estimate of -8.72 x 10^{11} mg/year, equivalent to -872 mT/year (see Table 20). Second, the mass of total arsenic exported from Puget Sound through Admiralty Inlet was calculated as the flow-weighted median surface water concentration of the three most northern Puget Sound stations times the outflow volume. The mass exported through Deception Pass was calculated as the median surface water concentration measured at the Whidbey Basin site times the Deception Pass outflow volume. The total exported mass was estimated to be 895 mT/year (Table 21). Finally, the net exchange based on median concentrations, 23 mT/year, was the sum of the exported and imported masses (see Table 22).

The net ocean exchange is positive - out of Puget Sound - for most chemicals. This assumes that the chemical concentrations measured in marine water column samples for the present study adequately represent those transported into and out of the Sound.

Estimates of net exchange predicted that copper and organic carbon were exported from Puget Sound. The export resulted from concentration differentials combined with the net flow of water out of the Sound. For copper, mean and median concentrations in deep boundary waters were not significantly different from those in surface waters leaving the Sound [17]. Nevertheless, the flow-weighted median total copper concentration exiting Puget Sound (0.40 µg/L) was 43% greater than the median value for incoming boundary deep waters (0.28 µg/L). Factors contributing to the concentration differential included:

- Relatively high copper concentrations in surface runoff (the median concentration of total copper in 15 river water samples was 1.81 µg/L).
- Formation of copper complexes that remain dissolved in surface waters.

[17] Kruskal Wallis (means), p = 0.18; Test of Medians, p = 0.64.

TOC concentrations in surface waters of Puget Sound were significantly greater than concentrations in deep waters near the ocean boundary [18]. The flow-weighted median TOC concentration in surface waters leaving Puget Sound (1.17 mg/L) was 60% greater than the median deep water concentration near the ocean boundary (0.73 mg/L). The difference was likely due to:

- Organic carbon loading from surface runoff (rivers).
- Primary productivity in the euphotic zone (especially when the water column was stratified).
- Decomposition of organic carbon in deep waters.

Table 22 shows that TSS, arsenic, zinc, and PAHs were probably exported from Puget Sound. For these parameters, there was no more than a 13% difference between concentrations in surface waters leaving and concentrations in deep boundary waters entering Puget Sound [19]. Therefore, the net flow of water out of Puget Sound played more of a role in the export of these chemicals than did concentration differences. These chemicals could have been imported into Puget Sound if 75th percentile concentrations were used to represent inflows and 25th percentile concentrations represented outflows.

The negative net exchange values in Table 22 indicated that cadmium and lead were imported into Puget Sound. For cadmium, the median concentration in deep boundary waters (0.92 µg/L) was significantly greater than the median for surface waters leaving Puget Sound (0.80 µg/L) [20]. As in the case of copper, concentrations of lead were not significantly different for inflow and outflow waters. However, the median concentration in deep boundary waters (0.109 µg/L total lead) was sufficiently higher than and the flow-weighted median concentration in surface waters leaving Puget Sound (0.065 µg/L) to cause a net import. Only if the 75th percentile concentration of total lead was used to represent outflows and the 25th percentile concentration represented inflows was export indicated.

The direction of net exchange for total PCBs and total PBDEs between ocean boundary waters and Puget Sound was unclear based on results of the present study. Combinations of annual mass transport into or out of Puget Sound indicated these chemicals could be imported or exported (Table 22). Net ocean exchange for total PCBs could range from an export of approximately 2-12 kg/yr to an import of approximately 1-11 kg/yr. Total PBDE concentrations were detected in four deep boundary water samples and two surface water samples. Variable concentrations (CV = 2) led to a large interquartile range for PBDE concentrations and net annual ocean exchange estimates that indicated total PBDEs might be exported or imported. Total PCBs and total PBDEs were likely exported because concentrations in deep boundary waters entering and surface waters leaving Puget Sound were not significantly different [21] and net flow of water is out of Puget Sound. Any net import of total PCBs or total PBDEs into Puget Sound would need to be confirmed by means of future sampling and analysis. If

[18] Kruskal Wallis and Test of Medians, $p<0.01$.
[19] Test of Medians showed no significant difference between inflow and outflow concentrations for these chemicals.
[20] Test of Medians, $p<0.02$. The mean concentration of total cadmium in deep boundary waters was also significantly greater than the mean concentration in Puget Sound surface layer waters (Kruskal Wallis, $p<0.02$).
[21] Kruskal Wallis test results for chemistry of deep boundary water vs. surface Puget Sound waters: $p<0.27$ for total PCBs and $p<0.64$ for total PBDEs.

confirmed, and caused by a substantial concentration differential, then the explanation might involve:

- Adsorption of total PCBs and PBDEs to suspended particles in surface runoff (rivers) entering the Sound.
- Dilution and settling of such suspended particles into the deep waters of major basins before being transported beyond ocean boundaries.
- Ongoing sources of PCBs and PBDEs contributing to the deep boundary waters entering Admiralty Inlet.

To summarize, ranges of values for net ocean exchange of various chemicals were presented in this section (Table 22). The ranges were derived from different estimates of annual chemical mass transport into and out of Puget Sound. Each mass transport estimate was based on two variables – annual flow and chemical concentration. Annual flows across the two boundaries between the Sound and the ocean (Admiralty Inlet and Deception Pass) were long-term median values predicted by the Puget Sound Toxics Box Model [22]. Concentration ranges were calculated from the limited chemical results of the present study.

As such, this evaluation of net ocean exchange was exploratory in nature. Furthermore, this evaluation did not attempt to address transport and fate processes within Puget Sound (e.g., chemical partitioning, horizontal transport, sedimentation and resuspension, burial, volatilization, and biological degradation) that are better examined by modeling.

[22] Calculations did not incorporate interannual variability in flows.

Table 20. Chemical concentrations in deep ocean boundary waters and estimates of annual mass transport *into* Puget Sound.

Percentile concentrations were derived from results for Haro Strait, SJdF North, and SJdF Sill stations.
Annual mass transport estimates were based on the concentrations shown and the predicted median annual flow of deep water into Admiralty Inlet for 2000-2050 (see text). Flows and transports into the Sound are shown as negative values.

			Percentile Concentrations			Range of Mass Transport *into* Puget Sound (mT/year)		
Parameter	UOM	N	25%	Median	75%	25%	Median	75%
Conventional Parameters and Metals								
TSS	mg/L	9	1.2	1.6	2.0	-700,000	-940,000	-1,200,000
DOC	mg/L	6	0.63	0.66	0.69	-370,000	-380,000	-410,000
POC	mg/L	6	0.04	0.06	0.07	-25,000	-34,000	-41,000
TOC	mg/L	6	0.70	0.73	0.75	-410,000	-430,000	-440,000
Arsenic, Total	µg/L	9	1.44	1.49	1.52	-842	-872	-889
Arsenic, Dissolved	µg/L	9	1.43	1.44	1.50	-835	-841	-875
Cadmium, Total	µg/L	9	0.091	0.092	0.097	-53	-54	-57
Cadmium, Dissolved	µg/L	9	0.091	0.096	0.102	-53	-56	-60
Copper, Total	µg/L	9	0.24	0.28	0.41	-140	-160	-240
Copper, Dissolved	µg/L	9	0.20	0.23	0.26	-120	-140	-150
Lead, Total [1]	µg/L	8	0.087	0.11	0.12	-51	-63	-73
Zinc, Total [1]	µg/L	9	0.53	0.68	0.88	-310	-400	-520
Total PAHs								
∑ Nondetects (ND = ½ RL)	µg/L	0	0.080	0.080	0.084	-47	-47	-49
∑ Nondetects (ND = MDL)	µg/L	0	0.024	0.050	0.081	-14	-29	-48
Total PCBs								
∑ Congeners or Homologs	pg/L	9	14.6	26.4	35.4	-0.0086	-0.0155	-0.0207
Total PBDEs								
∑ Detected values only	pg/L	4	290	1,740	7,000	-0.17	-1.0	-4.1
∑ All values (ND = ½ EQL)	pg/L	9	760	830	1,600	-0.44	-0.49	-0.94
∑ All values (ND = EQL_{max})	pg/L	9	130	135	370	-0.076	-0.079	-0.22
∑ All values (ND = 0)	pg/L	9	0.0	0.0	370	0.000	0.000	-0.22

[1] Summary statistics for concentrations of dissolved lead and zinc are not presented because dissolved concentrations sometimes exceeded total concentrations such that distinguishing valid results from ones that reflected field or laboratory contamination was difficult.

UOM = units of measure
N = number of detected values upon which estimates were based
ND = nondetect
½ RL = one-half reporting limit; MDL = method detection limit; EQL_{max} = maximum estimated quantitation limit (similar to RL) for individual PBDE congeners

Table 21. Concentrations of chemicals in surface Puget Sound waters and estimates of annual mass transport *out of* Puget Sound.

Percentile concentrations were derived from results for Main, Whidbey, and Hood Canal stations. Annual mass transport estimates were based on concentrations shown and the predicted median annual flows of surface water out through Admiralty Inlet and Deception Pass for 2000-2050.

			Flow-weighted (see text) Percentile Concentrations			Range of Annual Mass Transport *out of* Puget Sound through Admiralty Inlet (mT/yr)				Percentile Concentrations			Range of Mass Transport *out of* Puget Sound through Deception Pass (mT/yr)		
Parameter	UOM	N	25%	Median	75%	25%	Median	75%	N	25%	Median	75%	25%	Median	75%
Conventional Parameters and Metals															
TSS	mg/L	9	1.3	1.7	2.2	780,000	1,000,000	1,300,000	3	1.7	2.6	4.05	82,000	125,000	195,000
DOC	mg/L	6	0.77	0.80	0.82	460,000	470,000	490,000	2	0.87	0.87	0.87	42,000	42,000	42,000
POC	mg/L	6	0.18	0.32	0.46	110,000	190,000	270,000	2	0.93	0.93	0.93	45,000	45,000	45,000
TOC	mg/L	6	0.96	1.12	1.28	570,000	661,000	755,000	2	1.80	1.80	1.80	87,000	87,000	87,000
As Total	µg/L	9	1.36	1.39	1.42	803	825	841	3	1.39	1.45	1.49	67.2	70.0	72.0
As Dissolved	µg/L	9	1.35	1.37	1.42	797	812	840	3	1.34	1.37	1.41	64.8	66.2	67.9
Cd Total	µg/L	9	0.078	0.079	0.082	46	47	49	3	0.081	0.082	0.084	3.9	4.0	4.1
Cd Dissolved	µg/L	9	0.072	0.074	0.077	43	44	46	3	0.071	0.074	0.077	3.4	3.5	3.7
Cu Total	µg/L	9	0.38	0.40	0.42	230	240	250	3	0.41	0.44	0.46	20	21	22
Cu Dissolved	µg/L	9	0.33	0.35	0.37	190	210	220	3	0.35	0.37	0.39	17	18	19
Pb Total [1]	µg/L	9	0.047	0.066	0.087	28	39	51	3	0.047	0.061	0.080	2.3	3.0	3.8
Zn Total [1]	µg/L	9	0.72	0.77	0.80	430	450	480	3	0.70	0.70	0.79	34	34	38
Total PAHs															
∑ Nondetects (ND = ½ RL)	µg/L	0	0.079	0.080	0.081	47	47	48	0	0.078	0.078	0.080	3.8	3.8	3.9
∑ Nondetects (ND = MDL)	µg/L	0	0.036	0.049	0.065	21	29	39	0	0.036	0.049	0.064	1.7	2.4	3.1
Total PCBs															
∑ Congeners or Homologs	pg/L	9	15.8	20.8	30.1	0.0094	0.0138	0.0178	3	13.6	18.4	46.8	6.5E-4	8.9E-4	2.2E-3
Total PBDEs															
∑ Detects only	pg/L	2	460	460	460	0.27	0.27	0.27	1	1,300	1,300	1,300	0.063	0.063	0.063
∑ All values (ND = ½ EQL)	pg/L	9	600	770	1,100	0.36	0.46	0.65	3	800	840	1,100	0.039	0.041	0.053
∑ All values (ND = EQL_{max})	pg/L	9	140	160	350	0.083	0.095	0.21	3	130	140	720	6.3E-3	6.8E-3	0.035
∑ All values (ND = 0)	pg/L	9	0.0	0.0	230	0.000	0.000	0.14	3	0.0	0.0	650	0.000	0.000	0.031

[1] Summary statistics for concentrations of dissolved lead and zinc are not presented here. Dissolved concentrations sometimes exceeded total concentrations such that distinguishing valid results from ones that reflected field or laboratory contamination was difficult.

Abbreviations as in Table 20.

Table 22. Range of net ocean exchange of various chemicals based on estimated annual mass transport *into* and *out of* Puget Sound.
Positive net exchange transport values indicate export from Puget Sound.

		Range of Annual Mass Transport *into* Puget Sound (Table 20)			Range of Annual Mass Transport *out of* Puget Sound (Table 21)			Range of Estimated Net Annual Ocean Exchange (*Sum of values in appropriate columns to the left*)				
Parameter	UOM	25%	Median	75%	25%	Median	75%	25% *in*/ 25% *out*	Median *in*/ Median *out*	75% *in*/ 75% *out*	Low 75% *in*/25% *out*	High 25% *in*/75% *out*
Conventional Parameters and Metals												
TSS	mT/yr	-700,000	-940,000	-1,200,000	860,000	1,100,000	1,500,000	160,000	160,000	300,000	-340,000	800,000
DOC	mT/yr	-370,000	-380,000	-410,000	500,000	510,000	530,000	130,000	130,000	120,000	90,000	160,000
POC	mT/yr	-25,000	-34,000	-41,000	150,000	230,000	320,000	125,000	200,000	280,000	110,000	300,000
TOC	mT/yr	-410,000	-430,000	-440,000	650,000	750,000	840,000	240,000	320,000	400,000	210,000	430,000
As Total	mT/yr	-842	-872	-889	870	895	913	28	23	24	-19	71
As Dissolved	mT/yr	-835	-841	-875	861	878	908	26	37	33	-14	73
Cd Total	mT/yr	-53	-54	-57	50	51	53	-3.2	-2.9	-3.9	-7	-0.4
Cd Dissolved	mT/yr	-53	-56	-60	46	47	50	-7.1	-8.8	-10	-14	-3.7
Cu Total	mT/yr	-140	-160	-240	250	260	270	110	100	30	10	130
Cu Dissolved	mT/yr	-120	-140	-150	210	230	240	90	90	90	60	120
Pb Total [1]	mT/yr	-51	-63	-73	30	42	55	-21	-21	-18	-43	4.3
Zn Total [1]	mT/yr	-310	-400	-520	460	480	510	150	80	-10	-60	200
Total PAHs												
∑ Nondetects (ND = ½ RL)	mT/yr	-47	-47	-49	51	51	52	3.9	4.1	3.0	1.9	5.1
∑ Nondetects (ND = MDL)	mT/yr	-14	-29	-48	23	32	42	8.8	2.6	-5.8	-25	28
Total PCBs												
∑ Congeners or Homologs	mT/yr	-0.0086	-0.0155	-0.0207	0.0100	0.0147	0.0201	0.0014	-0.0008	-0.0006	-0.0107	0.0115
Total PBDEs												
∑ Detected values only	mT/yr	-0.17	-1.0	-4.1	0.33	0.33	0.33	0.16	-0.67	-3.77	-3.8	0.16
∑ All values with ND = ½ EQL	mT/yr	-0.44	-0.49	-0.94	0.40	0.50	0.70	-0.041	0.011	-0.24	-0.54	0.26
∑ All values with ND = EQL_{max}	mT/yr	-0.076	-0.079	-0.22	0.089	0.10	0.24	0.013	0.021	0.025	-0.13	0.16
∑ All values with ND = 0	mT/yr	-0.00	-0.00	-0.22	0.000	0.000	0.17	0.000	0.000	-0.049	-0.22	0.17

[1] Summary statistics for concentrations of dissolved lead and zinc are not presented here. Dissolved concentrations often exceeded total concentrations such that distinguishing valid results from ones that reflected field or laboratory contamination was difficult.
Abbreviations as in Table 20.

Sedimentation Rates for Toxics

Sediment traps deployed in Hood Canal from October 2009 through January 2010 collected marine particulates from that basin's deep layer. Archived mid-water solids from the Case and Carr Inlets, composited from material collected from March to June 2008 (Norton, 2009), were resurrected for comparison.

Sedimentation rates ($g/cm^2/yr$) were calculated for both locations by dividing the total dry mass of solids collected by the surface area of the traps, and by the duration of deployment. Since resuspended particulates could potentially be included in the trap material, these values should be considered estimates of *gross* sedimentation. Mass accumulation rates ($mass/cm^2/yr$; also called "downward flux") for each parameter were determined by multiplying the measured concentration by the sedimentation rate.

Sedimentation rates from the present study are summarized in relation to historical rates for other areas of Puget Sound in Table 23. The sedimentation rate in the deep waters of Hood Canal was comparable to rates measured by Norton (2009) in the Case+Carr Inlets. Both rates were markedly lower than rates typical of more urban embayments.

Table 23. Gross sedimentation rates for various areas of Puget Sound.

Source	Location	Mean Sedimentation Rate (dry $g/cm^2/yr$)
Present Study (2009-10)	Hood Canal	0.2
Present Study; Norton, 2009	Carr+Case Inlets	0.3
Norton, 2009	Eld Inlet	1.6
Norton, 2009	Budd Inlet	1.0
Norton and Boatman, 1998	Inner Budd Inlet	1.4
Norton, 1996	Inner Commencement Bay	1.5
Norton and Michelson, 1995	Elliott Bay Waterfront	0.7

Analyses conducted on the Hood Canal solids and on the archived Case+Carr Inlet material from Norton (2009) allowed estimation of the downward flux for various parameters. The measured concentrations and calculated mass accumulation rates are presented in Table 24.

Downward flux of organic carbon was low at both sites relative to rates found in more urban embayments. Norton (2009) measured average TOC accumulation rates of 0.048 and 0.033 $g/cm^2/yr$ in the Eld and Budd Inlets, while the Case+Carr Inlet solids averaged 0.011 $g/cm^2/yr$. The Hood Canal TOC accumulation rate from the present study was even lower at 0.007 $g/cm^2/yr$. Likely contributing factors included distance from anthropogenic inputs, lower biological productivity during the late fall and early winter period of deployment, and depth of collection (below the surface mixed layer).

Table 24. Summary of mass accumulation rates for solids, TOC, metals, PCBs, and PBDEs.

All concentrations reported on a dry weight basis.

Parameter	Hood Canal		Case+Carr Inlets	
	Concentration	Mass Accumulation Rate ($g/m^2/yr$)	Concentration	Mass Accumulation Rate ($g/m^2/yr$)
Solids (g)	7.9	2,400	20.7*	3,440
TOC (%)	2.75	66	4.47*	154
As (mg/Kg)	7.53	0.018	5.72	0.020
Cd (mg/Kg)	0.87	0.002	1.04	0.004
Cu (mg/Kg)	82.0	0.197	18.5	0.064
Pb (mg/Kg)	9.13	0.022	8.78	0.030
Zn (mg/Kg)	90.0	0.217	72.0	0.248
PCBs (ng/Kg)	2,970	7.1E-6	9,850	33.9E-6
PBDEs (ng/Kg)	1,580	3.8E-6	1,060	3.6E-6

* Values from Norton (2009)

Metals concentrations in Hood Canal particulates were slightly higher than those from the Case+Carr Inlets for four of the five metals analyzed. With the exception of copper, however, mass accumulation rates of all metals were similar at these sites. Hood Canal copper concentrations were more than four times higher than those measured in Case+Carr Inlet SPM, and the resulting mass accumulation rate in Hood Canal was estimated to be three times greater than that of the Case+Carr Inlets.

Total PCB concentrations were markedly higher in SPM from the Case+Carr Inlets than in SPM collected from Hood Canal. This was consistent with expectations, as South Puget Sound is more highly developed and has more potential sources of PCBs than Hood Canal. Mass accumulation rates in the Case+Carr Inlets and Hood Canal were estimated to be 0.0339 and 0.0071 $mg/m^2/yr$, respectively.

Differences in total PBDE concentrations and mass accumulation rates between the two sites were minor. Rates of total PBDE accumulation were estimated to be 0.0038 and 0.0036 $Kg/m^2/yr$ in Hood Canal and Case+Carr Inlets, respectively.

Rivers

Comparison with Historical Data

Average concentrations of TSS, TOC, and nutrients in the five rivers, based on three seasonal samples, were within ranges obtained from EIM data and other studies (Table 25). The mean values were also remarkably similar to historical median or mean values (Appendix I, Table I-4). In general, the same was true for river water hardness and total metal concentrations (Table 26; Appendix I, Table I-5).

Table 27 compares the concentrations of organic compounds that were measured or estimated for the present 2009-10 study with concentrations reported by other studies. TPH concentrations were never detected. The detection frequency for oil and grease was 40% (6/15), and the measured concentrations ranged from 0.9 - 2.8 mg/L in the five rivers. The mean concentration of 1.6 mg/L changed little when nondetect values were included (1.7 mg/L when ND = ½ RL; 1.2 mg/L when ND = MDL). According to Herrera (2010a), this mean concentration would be observed with reasonable frequency in all land use categories except commercial/industrial.

Possible reasons for the low detection frequency and low mean concentrations included:

- The compounds were not present at the time of sampling (e.g., lost due to volatilization).
- Standard sampling methods failed to collect the surface-most layers most likely to contain compounds less dense than water.
- Current analytical methods could not detect the compounds after the dilution that occurred between points of discharge and sampling locations.

MEL seldom detected PAHs in whole river water samples even with low detection limits. Six of the 15 samples contained concentrations of individual PAHs in the 0.0009 - 0.11 µg/L range. Assuming nondetect concentrations are one-half the RL, total PAH concentrations ranged from 0.076 - 0.11 µg/L. Assuming nondetect concentrations are one-half the MDL, the range was 0.012 - 0.055 µg/L. Using the latter assumption, the range of cPAH concentrations was 0.009 - 0.014 µg/L. This was within the range of cPAH concentrations measured in Lower Green River near Tukwila (<0.001 - 0.040 µg/L; Willston, 2008).

The range of total PCB concentrations measured in the five rivers (2.6 - 59 pg/L) was lower than the range reported for the Green/Duwamish River system (83 - 814 pg/L). It was also lower than most probability-of-exceedance concentrations listed for different land uses in Herrera (2010a). Lower concentrations of toxic organic compounds would generally be expected in the five rivers sampled for the present study than in the Green/Duwamish River system, other areas of commercial/industrial land use, or highway runoff.

Table 25. Concentrations of conventional parameters and nutrients (mg/L) measured in major rivers discharging to Puget Sound.

River	Study/ Data Source	TSS	TOC	DOC	Total Nitrogen	Nitrite/Nitrate Nitrogen	Ammonia - Nitrogen	Total Phosphorous	Ortho-Phosphorous
Skagit	Present Study Mean (n=3 or as noted) Range	24.8 6.4-60.8	1.0 0.6-1.7	1.0 0.6-1.6	0.13 0.057-0.163	0.08 0.045-0.126	0.046 (1) --	0.033 0.006-0.086	0.004 0.003-0.005
	EIM Range [1]	1.0-1,230	0.5-7.0	--	0.033-0.48	0.020-0.200	0.010-2.65	0.003-0.737	0.001-0.030
	Wise et al., 2007 Range [2]	13.6-78.5	--	--	0.13-0.17	--	--	0.02-0.05	--
Snohomish	Present Study Mean and Range	24.3 4.7-54.5	1.6 0.6-2.1	1.7 0.7-2.2	0.271 0.102-0.389	0.211 0.077-0.281	0.044 0.008-0.079	0.032 0.009-0.053	0.008 0.004-0.014
	EIM Range	1.0-260	0.8-6.1	--	0.030-0.840	0.073-0.368	0.010-0.780	0.005-0.160	0.002-0.100
	Wise et al., 2007 Range	9.7-42.4	--	--	0.32-0.34	--	--	0.02-0.03	--
Nooksack	Present Study Mean and Range	30.3 3.7-76.3	1.4 0.6-2.8	1.6 0.8-2.9	0.379 0.106-0.656	0.325 0.087-0.544	0.022 (1) --	0.046 0.021-0.090	0.013 0.009-0.021
	EIM Range	1.0-2,600	--	--	0.097-1.22	0.076-0.684	0.010-0.510	0.009-0.132	0.004-0.121
	Embrey & Frans, 2003 [3] Range	8-2,890	0.7-6.8	--	--	0.13-0.94	<0.015-0.08	<0.01-.30	<0.01-0.02
	Wise et al., 2007 Range	48-301	--	--	0.49-0.55	--	--	0.05-0.20	--
Stillaguamish	Present Study Mean and Range	15.9 2.6-41.3	1.7 0.8-3.3	2.0 0.9-4.0	0.299 0.147-0.418	0.243 0.088-0.341	0.019 0.007-0.039	0.035 0.016-0.072	0.011 0.008-0.014
	EIM Range	0.1-2,700	1.4-2.0	--	0.054-0.767	0.010-0.728	0.010-0.760	0.008-0.698	0.002-0.110
Puyallup	Present Study Mean and Range	94.5 11.9-233	1.0 0.5-1.3	1.1 0.8-1.4	0.351 0.137-0.545	0.240 0.110-0.309	0.066 0.010-0.162	0.124 0.044-0.250	0.033 0.021-0.048
	EIM Range	1.0-2,890	0.9-9.1	1.1-3.2	0.074-0.826	0.056-0.399	0.004-0.580	0.010-1.66	0.007-0.120
	Wise et al., 2007 Range	77.1-407	--	--	0.27-0.41	--	--	0.09-0.15	--

[1] Derived from EIM data representing similar locations in each river and equivalent analytical methods.
[2] Flow-weighted annual mean concentrations for 1997, 2000, and 2001 based on LOADEST model annual loads and annual flows.
[3] Based on approximately 40 samples collected near Brennan, Washington, in 1996-1998.

Table 26. Hardness and concentrations of metals in major rivers discharging to Puget Sound.

River	Study/ Data Source	Hardness	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Zinc
		mg/L	μg/L				
Skagit	Present Study Mean (n=3 or as noted) and Range	26.4 21.8-29.9	0.75 0.43 - 1.24	0.012 0.006-0.020	2.06 0.77-4.56	0.31 0.05-0.78	5.1 2.4-10.6
	EIM Range [1]	13-48	0.45-1.09	--	0.280-12.0	0.023-0.47	0.55-9.34
Snohomish	Present Study Mean and Range	15.4 13.2-17.4	1.00 0.92-1.14	0.015 0.005-0.030	2.60 1.35-4.08	0.34 0.09-0.63	4.7 2.5-8.3
	EIM Range	3.0-52.0	0.48-1.9	--	0.39-5.9	0.020-1.50	0.61-33.9
Nooksack	Present Study Mean and Range	46.2 38.1-62.0	0.55 0.26-1.01	0.017 0.005-0.040	2.41 0.75-4.41	0.32 0.05-0.82	6.0 3.2-9.7
	EIM Range	10.0-71.0	0.23-5.22	--	0.27-21	0.020-3.86	0.34-35.3
Stillaguamish	Present Study Mean and Range	27.0 19.2-31.9	0.79 0.52-1.12	0.011 0.005-0.020	2.95 1.16-6.58	0.58 (2) 0.37-0.79	9.0 4.0-17.7
	EIM Range	11.0-43.0	0.37-2.65	--	0.50-18.0	0.020-0.450	0.45-20
Puyallup	Present Study Mean and Range	33.9 27.7-40.8	0.68 0.52-0.92	0.007 0.005-0.010	4.91 1.32-11.6	0.81 (2) 0.20-1.42	7.7 (2) 3.7-11.6
	EIM Range	14.0-60.4	0.33-1.16	0.003-0.200	0.45-41.4	0.022-6.30	0.21-43.5
Green/Duwamish	Williston (2009) King County (2007) [1,2]	--	0.34-2.4	--	13.1	--	21.3
Surface Runoff	PSTLA (Herrera, 2010a) [3] Concentration Range	--	0.2 -14.9	0.0002 - 9.2	0.1 - 110	0.02 - 309	0.28 - 527

[1] Range of total arsenic concentrations measured during 2006-2008.
[2] Mean copper and zinc concentrations derived from 2003-2005 total annual loads and discharges listed in Table 5-9.
[3] Range of values from Herrera (2010a), Table 2: Probability of exceedance concentrations used to represent major land use types and highways.

Table 27. Concentration of organic compounds in river discharges and surface runoff to Puget Sound.

River	Study/ Data Source	Oil and Grease		Total PAH	cPAH *	Total PCBs	Total PBDEs
		Including ND=MDL/2	Detects only	Including ND=MDL/2			
		µg/L				pg/L	
Skagit, Snohomish, Nooksack, Stillaguamish, and Puyallup	Present Study Mean (n) Range	920 (15) 250 – 2,800	1,600 (6) 900 – 2,800	0.032 (15) 0.012 - 0.055	0.011 (15) 0.009 - 0.014	16.1 (15) 2.6 - 59.0	55.6 (7) 10.9 - 265
Green/Duwamish	Williston (2009) [1] Range	--		0.015 - 0.05	<0.001 - 0.040	38 - 2,360	--
	Gries and Sloan (2009) [2]	--		--	1.2 - 14.3	140 - 1,600	--
Total Surface Runoff	Phase II probability of exceedance concentrations (Herrera, 2010a) [3]	3.7 - 26,400		0.001 - 56.6	0.0002 - 11.8	16 - 810,000	0.30 - 810

* Carcinogenic PAH compounds (cPAH) include benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene.

[1] Based on PAH data collected in 2008.

[2] Estimated range for annual flow-weighted mean concentrations.

[3] Range of values from Herrera et al. (2010a), Table 2: Probability of exceedance concentrations used to represent major land use types and highways.

Patterns and Relationships

The same graphic and statistical methods used to explore marine water column results were used to examine the river water data obtained from this study. Few differences in mean or median concentrations of the various chemicals could be attributed to different seasons, rivers, or flow regimes. This was expected from such a limited data set. However, some statistically significant relationships were identified. As with the marine water column results, most chemicals measured in river waters were not normally distributed (Appendix J, Table J-4) and the nonparametric Kruskal Wallis Test and Test of Medians were conducted. Results are shown in Appendix J, Tables J-5 and J-6. They show the following significant differences between seasons:

- TSS was lowest during the summer (excluding Puyallup River result).
- TOC and DOC were lowest in the summer (Figure 27a).
- Total nitrogen (TN) and nitrate+nitrite N were lowest during the summer (Figure 27b).
- Ammonia nitrogen concentrations were highest during the fall (not shown).
- Concentrations of total lead and zinc were highest in winter (not shown).

The only chemicals for which the mean concentrations (across all seasons) differed between the five rivers were:

- Ortho-phosphate concentrations were highest in the Puyallup River (Figure 28a).
- Hardness was lowest in the Snohomish River and highest in the Nooksack and Puyallup Rivers (not shown).
- Dissolved arsenic concentrations were lowest in the Nooksack River (Figure 28b).

The flow regimes assigned to each seasonal sampling in each river (base or runoff-related in Table 11) were not significant determinants of mean chemical concentrations. This was no doubt due to the limited number of samplings conducted in different systems with high natural variability. Total PCB concentrations were greater during runoff-related events, but the significance level was only $p<0.16$.

Spearman rank-correlations showed significant relationships between many chemical pairings. These are summarized in Appendix J, Table J-6. Total phosphorus (TP) and total metal concentrations were correlated with TSS. The total fractions of the five metals covaried. PCB homologs that were more polar (fewer chlorine atoms) correlated with chemicals such as ortho-phosphate and dissolved metals, while non-polar homologs (more chlorines) sometimes correlated with parameters common in particulate form (TSS, TOC, TN, TP, and total metals).

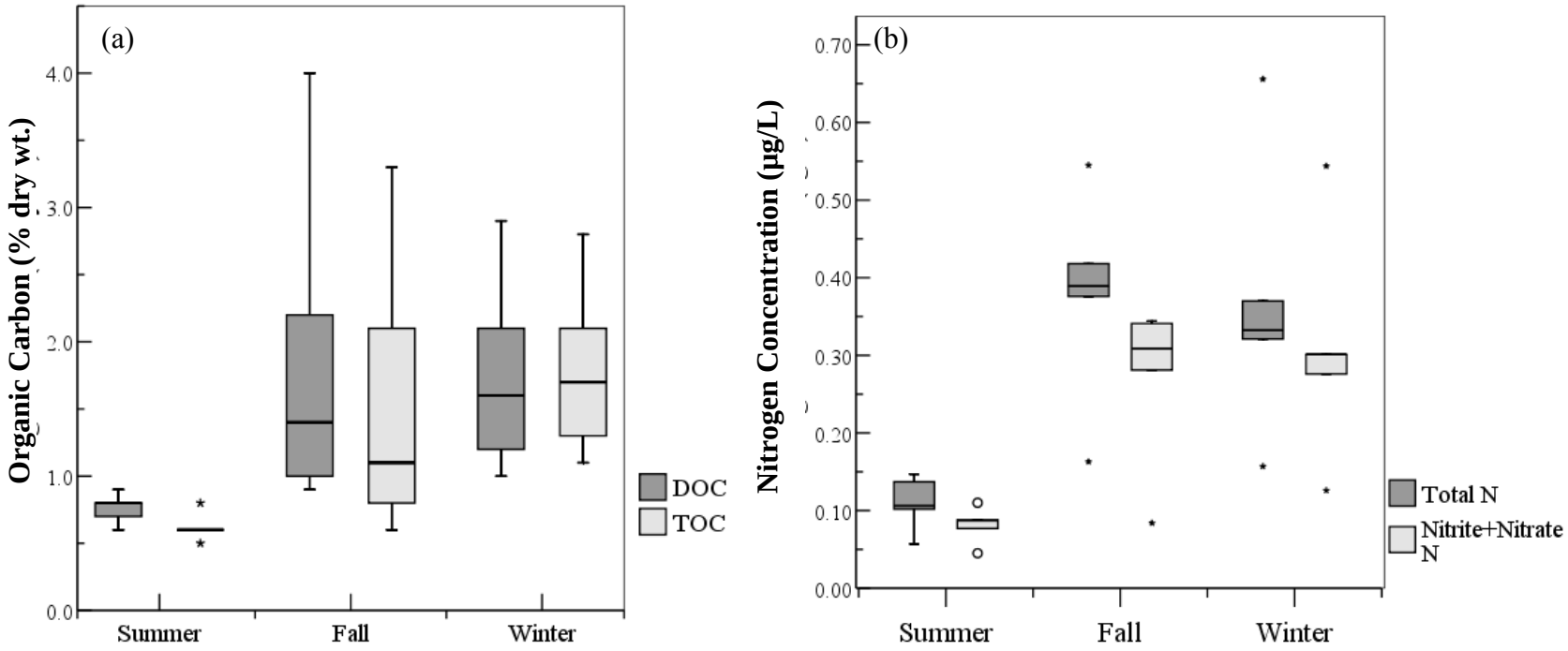

Figure 27. Box plots showing seasonal concentrations of organic carbon and nitrogen species.

*The heavy bars are median concentrations, with the boxes representing the interquartile range. Possible outliers appear as *.*

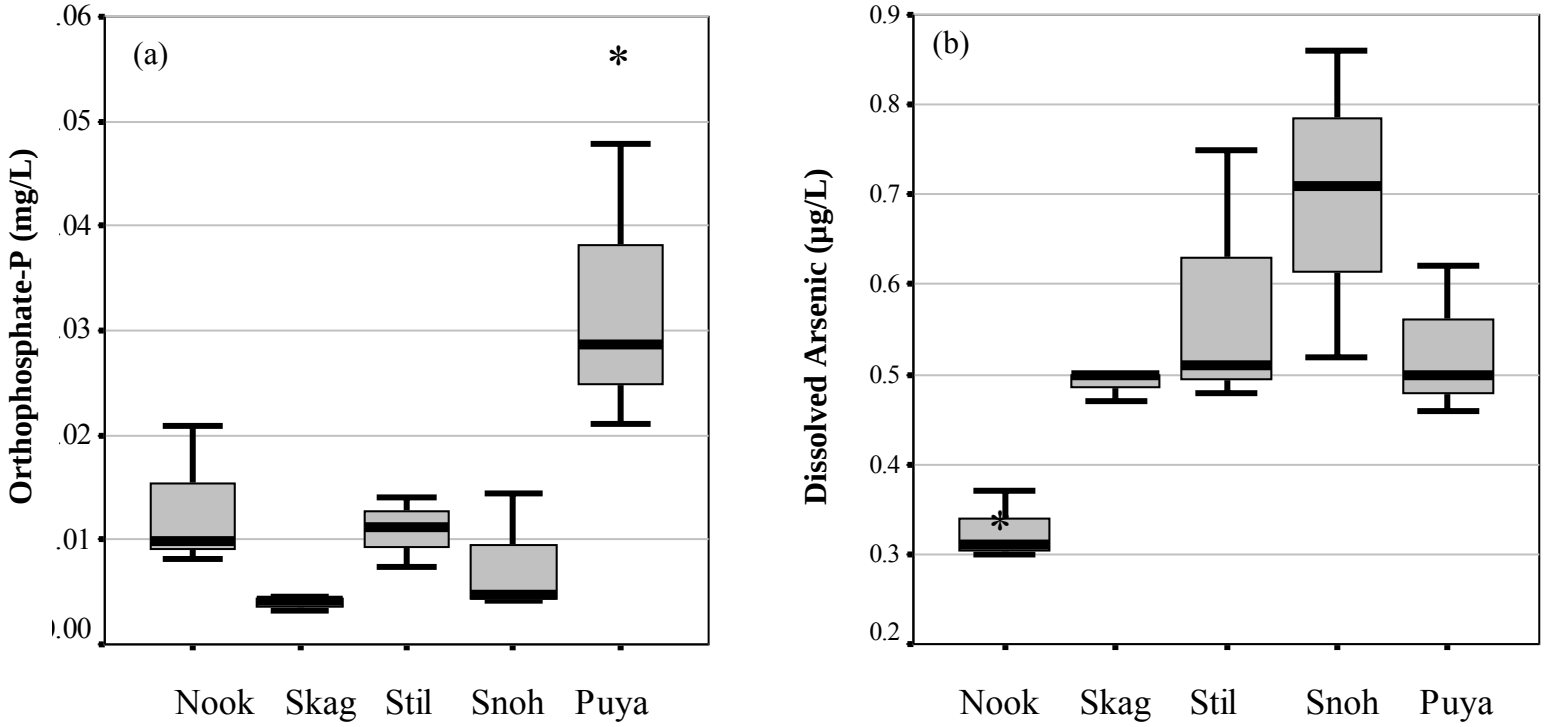

Figure 28. Box plots showing river water concentrations of ortho-phosphate and dissolved arsenic.

The heavy bars show median concentrations, with the boxes representing the interquartile range.

***** *Concentration significantly different from the mean concentration.*

Abbreviations: Nook = Nooksack, Skag = Skagit, Stil = Stillaguamish, Snoh = Snohomish, Puya = Puyallup.

Loading

Instantaneous mass loading rates for TSS, TOC, total nitrogen, total phosphorus, and total metals for the five rivers were calculated by multiplying the mean daily flows (Table 11) by the chemical concentrations measured on the same date (Appendix G, Table G-1). The results are shown as daily loads in Table 28. Total arsenic daily loads for the three smaller rivers studied here ranged from 0.96 - 19 kg/day. This was similar to the 0.13 - 7.28 kg/day arsenic load associated with SPM from the Green/Duwamish River system (Gries and Sloan, 2009) despite different mean annual flows.

Daily loading rates for petroleum-related compounds, total PCBs, and total PBDEs are presented in Table 29. Rates for oil and grease, TPH-D, and TPH-G were based on nondetect concentrations set at one-half the RL and at the MDL. The range of estimated daily loads for the sum of all petroleum-related compounds was 445 - 94,500 kg. The daily loading of total PCBs from the five rivers ranged from 0.015 - 0.57 g. This was lower than but comparable to the 0.06 - 1.2 g PCBs/ day load associated with SPM measured in the Green/Duwamish River system (Gries and Sloan, 2009). Daily loading of total PBDEs was between 0.11 - 5.6 g (using one-half the single highest RL when no PBDEs were detected). Daily loading was not calculated for BNAs, PAHs, or chlorinated pesticides because of their low frequency of detection.

Much of the variability in the daily loads was due to the wide range in mean daily flows. To reduce the influence of flows, instantaneous loads were also normalized to the area of each watershed above the gaging station where sampling occurred (see Table 2). Summary statistics for daily loading across all rivers and sampling events are presented in Table 30 (not normalized) and Table 31 (area-normalized). These rates of daily loading can be compared to results from ongoing and future studies.

Table 28. Instantaneous loads of conventional parameters, nutrients, and total metals from major rivers discharging to Puget Sound.

Instantaneous loads (kg/day) were calculated using measured concentrations and mean daily flow.

		Skagit			Snohomish			Nooksack			Stillaguamish			Puyallup		
		Jan 2010	Jul 2009	Oct 2009	Jul 2009	Oct 2009	Dec 2009	Jul 2009	Oct 2009	Dec 2009	Jul 2009	Oct 2009	Dec 2009	Jul 2009	Oct 2009	Dec 2009
Daily Flow	cfs	7,880	10,500	5,400	3,470	4,940	18,400	1,760	587	13,800	320	350	1,900	2,380	1,000	1,860
	cms	223	297	153	98.3	140	521	49.8	16.6	391	9.1	9.9	53.8	67.4	28.3	52.7
Parameter - Loading (kg/day)																
TSS		1.85E5	8.46E4	2.05E6	3.99E4	1.64E5	2.45E6	4.694	5.3E3	1.47E6	3.0E3	3.54E4	1.72E4	1.36E6	9.47E4	5.42E4
TOC		15,400	7,930	57,400	5,090	25,400	94,500	2,580	1,150	54,000	924	2,830	5,110	2,910	2,690	5,920
Total Nitrogen		1,460	2,150	5,300	866	4,700	14,500	456	540	12,600	170	358	1,540	798	1,330	1,680
Total Phosphorus		188	77.9	2,890	78.1	392	2,400	91.3	36.9	1,740	19.9	61.5	72.1	1,460	195	199
Arsenic, Total		14.6	56.8	41.9	7.81	11.4	51.3	1.59	3.73	19.5	0.84	0.96	2.42	5.36	1.47	2.37
Cadmium, Total		0.23	0.79	0.68	0.042	0.12	1.4	0.022	0.072	0.77	5.8E-3	0.017	0.033	0.058	0.015	0.023
Copper, Total		20	110	150	11	29	180	9.0	11	85	1.30	5.6	5.2	68	4.4	6.0
Lead, Total		2.8	6.6	26	0.76	3.6	28	0.43	0.72	16	0.017	0.68	1.7	8.3	0.49	0.27
Zinc, Total		62	320	360	21	40	370	22	46	190	4.6	15	39	68	9.1	6.4

E = exponent.

Table 29. Instantaneous daily loads for petroleum-related compounds, total PCBs, and total PBDEs from major rivers discharging to Puget Sound.

Instantaneous loads (kg/day) were calculated using measured concentrations and mean daily flow.

		Skagit			Snohomish			Nooksack			Stillaguamish			Puyallup		
		Jul 2009	Oct 2009	Dec 2009	Jul 2009	Oct 2009	Dec 2009	Jul 2009	Oct 2009	Jan 2010	Jul 2009	Oct 2009	Dec 2009	Jul 2009	Oct 2009	Dec 2009
Daily Flow	cfs	10500	5400	13800	3470	4940	18400	1760	587	7880	320	350	1900	2380	1000	1860
	cms	297	153	391	98.3	140	521	49.8	16.6	223	9.1	9.9	53.8	67.4	28.3	52.7
Parameter - Loading (kg/day)																
Oil and Grease (ND=½RL)		36,000	*13,000*	*91,000*	24,000	*11,000*	72,000	6,000	*1,300*	*53,000*	1,600	*770*	*13,000*	5,200	*2,200*	*12,500*
Oil and Grease (ND=MDL)		36,000	*6,600*	*51,000*	24,000	*6,000*	72,000	6,000	*720*	*29,000*	1,600	*430*	*7,000*	5,200	*1,200*	*6,800*
TPH-D (ND=½RL)		*2,300*	*1,100*	*1,000*	*760*	*1,030*	*1,350*	*370*	*120*	*580*	*100*	*77*	*400*	*520*	*210*	*140*
TPH-D (ND=MDL)		*150*	*79*	*54*	*51*	*73*	*72*	*26*	*8.6*	*29*	*6.9*	*5.1*	*28*	*35*	*15*	*7.3*
TPH-G (ND=½RL)		*1,800*	*920*	*2,400*	*590*	*850*	*3,150*	*300*	*100*	*1,400*	*81*	*60*	*320*	*410*	*170*	*320*
TPH-G (ND=MDL)		*360*	*180*	*470*	*120*	*170*	*630*	*60*	*20*	*270*	*16*	*12*	*65*	*82*	*34*	*64*
PCBs (g)		1.9E-4	1.3E-4	5.7E-4	1.6E-4	6.0E-5	3.3E-4	2.8E-5	7.4E-5	2.5E-5	2.2E-5	5.1E-5	2.3E-5	1.5E-5	9.8E-5	1.1E-4
PBDEs (g)		3.4E-4	*1.6E-3*	*4.2E-3*	1.2E-4	1.5E-3	5.6E-3	1.5E-4	1.3E-4	*5.4E-4*	2.6E-5	*1.1E-4*	*5.8E-4*	6.3E-5	6.5E-4	5.7E-4

Daily load in *italics* if >10% was based on nondetect values.

E = exponent.

Table 30. Summary statistics for instantaneous daily loads from five major rivers discharging to Puget Sound.

Instantaneous Loading (kg/day)								
Parameter	Detection Frequency	Calculation Basis (N)	Minimum	25%	Median	Mean	75%	Maximum
TSS	15/15	15	3.0	38	85	540	770	2,450
TOC	15/15	15	920	2,800	5,100	19,000	20,000	94,000
Total Nitrogen	15/15	15	170	670	1,500	3,200	3,400	14,000
Total Phosphorus	15/15	15	20	75	190	660	920	2,900
Arsenic, Total	15/15	15	0.843	1.98	5.36	14.8	17.1	56.8
Cadmium, Total	15/15	15	0.0058	0.022	0.058	0.28	0.45	1.4
Copper, Total	15/15	15	1.3	5.8	11	47	76	180
Lead, Total (Detects only)	13/15	13	0.017	0.58	1.7	6.5	7.4	28
Zinc, Total (Detects only)	14/15	14	4.6	18	40	100	130	370
Oil and Grease (Detects only)	6/15	6	1,600	5,400	15,000	24,000	33,000	72,000
Oil and Grease (ND=½RL)	6/15	15	*770*	*3,700*	*12,500*	*23,000*	*30,000*	*91,000*
Oil and Grease (ND=MDL)	6/15	15	*430*	*3,400*	*6,600*	*17,000*	*26,000*	*72,000*
TPH-D (ND=½RL)	0/15	15	*77*	*170*	*520*	*670*	*1,000*	*2,300*
TPH-D (ND=MDL)	0/15	15	*5*	*12*	*29*	*43*	*63*	*150*
TPH-G (ND=½ RL)	0/15	15	*60*	*240*	*410*	*850*	*1,100*	*3,200*
TPH-G (ND=MDL)	0/15	15	*12*	*47*	*82*	*170*	*230*	*630*
Total PCBs (Detects only)	15/15	15	0.015	0.026	0.074	0.126	0.146	0.573
Total PBDEs ((Detects only)	7/15	7	0.026	0.090	0.13	0.21	0.24	0.65
Total PBDEs (ND=max RL)	7/15	15	*0.026*	*0.12*	*0.54*	*1.1*	*1.1*	*5.6*

Daily load in *italics* if >10% was based on nondetect values.

Table 31. Summary statistics for area-normalized instantaneous daily loads from five major rivers discharging to Puget Sound.

Watershed areas (km^2) above gaging stations: Skagit = 8,010, Snohomish = 4,440, Nooksack = 2,045, Stillaguamish = 1,445, Puyallup = 2,455.

Area-normalized loading (kg/km^2-day)								
Parameter	Detection Frequency	Calculation Basis (N)	Minimum	25%	Median	Mean	75%	Maximum
TSS	15/15	15	2.1	11	23	150	150	720
TOC	15/15	15	0.56	1.1	1.9	5.2	4.6	26
Total Nitrogen	15/15	15	0.12	0.24	0.32	1.0	0.90	6.2
Total Phosphorus	15/15	15	0.010	0.021	0.050	0.19	0.22	0.85
Arsenic, Total	15/15	15	5.84E-04	8.71E-04	1.82E-03	3.25E-03	3.89E-03	1.16E-02
Cadmium, Total	15/15	15	4.0E-06	1.0E-05	2.4E-05	7.0E-05	6.0E-05	3.8E-04
Copper, Total	15/15	15	9.3E-04	2.5E-03	4.4E-03	1.2E-02	1.7E-02	4.2E-02
Lead, Total (Detects only)	13/15	13	1.2E-05	2.0E-04	4.7E-04	1.7E-03	2.2E-03	7.7E-03
Zinc, Total (Detects only)	14/15	14	2.6E-03	6.2E-03	1.1E-02	2.6E-02	3.4E-02	9.1E-02
Oil and Grease (Detects only)	6/15	6	1.1	2.3	3.7	5.4	5.1	16.2
Oil and Grease (ND=½RL)	6/15	15	*0.53*	*1.3*	*3.0*	*6.0*	*7.0*	*26*
Oil and Grease (ND=MDL)	6/15	15	*0.30*	*0.97*	*2.8*	*4.2*	*5.19*	*16*
TPH-D (ND=½RL)	0/15	15	*0.053*	*0.078*	*0.17*	*0.17*	*0.25*	*0.30*
TPH-D (ND=MDL)	0/15	15	*0.003*	*0.005*	*0.011*	*0.011*	*0.015*	*0.019*
TPH-G (ND=½ RL)	0/15	15	*0.04*	*0.09*	*0.15*	*0.21*	*0.23*	*0.71*
TPH-G (ND=MDL)	0/15	15	*0.01*	*0.02*	*0.03*	*0.04*	*0.05*	*0.14*
Total PCBs (Detects only)	15/15	15	6.19E-09	1.45E-08	2.35E-08	3.02E-08	3.81E-08	7.39E-08
Total PBDEs ((Detects only)	7/15	7	1.8E-08	2.6E-08	4.3E-08	7.3E-08	6.7E-08	2.6E-07
Total PBDEs (ND=max RL)	7/15	15	*1.8E-08*	*5.2E-08*	*2.1E-07*	*2.5E-07*	*3.0E-07*	*1.3E-06*

Daily load in *italics* if >10% was based on nondetect values.

Conclusions

The primary purpose of the present 2009-10 study was to measure toxic chemical concentrations in Puget Sound marine waters, ocean boundary waters (Strait of Juan de Fuca and Haro Strait), and freshwater near the mouths of the five largest rivers discharging to Puget Sound. The concentration data obtained will help identify the largest remaining sources of uncertainty in the Puget Sound Toxics Box Model and the data gaps that still require field studies or analysis.

Marine Water and SPM

Major findings from the marine water column sampling portion of this study include:

- Low concentrations of suspended solids, organic carbon, metals, PCBs, and PBDEs were routinely detected in marine water samples. Chlorinated pesticides, BNAs, and PAHs were rarely or never detected in the same samples. Analytical detection limits were not adequate to detect these organic compounds at sampling sites far removed from sources.
- The range of total PCB concentrations measured for ambient marine waters was 6.1 - 75 pg/L. Average concentrations in the ocean boundary waters (20.4 pg/L) and Puget Sound (30.7 pg/L) were significantly different and both were lower than those previously reported for the Strait of Georgia (42 pg/l) by Canadian researchers (Dangerfield et al., 2007).
- Total PCB concentrations in the deep waters were significantly greater than those in the surface waters. This was true for the ocean boundary waters and Puget Sound. A significant positive relationship between total PCBs and TSS suggested that sedimentation may play a key role in the fate of PCBs in Puget Sound.
- The range of detected total PBDE concentrations in marine waters (51 - 18,700 pg/L) was much wider than the range of total PCB concentrations. Total PBDEs concentrations were often 10 times higher in the present study than concentrations reported by Canadian researchers (Dangerfield et al., 2007) and apparently not related to TSS. No evidence suggested the higher concentrations were due to sample contamination. Potential sources of high PBDE concentrations were not identified.
- Organic carbon concentrations in marine water samples resembled concentrations previously reported for the Strait of Georgia (Johannessen et al., 2008) but were substantially lower than marine water concentration records in Ecology's EIM database.
- Estimates of two-directional transport across Box Model boundaries (Admiralty Inlet and Deception Pass) were calculated from concentrations of toxic chemicals in Puget Sound surface waters and deep ocean boundary waters. Estimates showed that most chemicals were probably exported from Puget Sound. Notable exceptions were cadmium and possibly lead, which appeared to be imported into Puget Sound. This was due to significantly higher concentrations in incoming ocean boundary waters than in the surface waters flowing out of the Sound. The direction of net exchange for total PCBs and total PBDEs at the ocean boundaries could not be determined from data collected.

- Samples of SPM collected by sediment traps moored in Hood Canal and the Case+Carr Inlets contained similar concentrations of organic carbon, metals, and PBDEs. PCB concentrations in Case+Carr SPM were more than three times greater than those in Hood Canal SPM.

River Water and SPM

Major findings from the river water sampling portion of this study include:

- Concentrations of TSS, organic carbon, nutrients, hardness, and metals were within the concentration ranges reported from previous studies by Ecology and other monitoring programs (Inkpen and Embry, 1998; Wise et al., 2007).
- River water samples seldom contained detectable concentrations of petroleum-related compounds, BNAs, PAHs, or chlorinated pesticides. SPM centrifuged from December 2009 and January 2010 contained detectable concentrations of a number of PAHs.
- The mean concentration of total PCBs measured in surface water from the five rivers was 16.3 pg/L. The range of concentrations measured was 2.6 - 59 pg/L. This range is somewhat lower than that measured by King County in the Green/Duwamish Rivers (83 - 814 pg/L). This is likely because land use in the lower watershed of the Green/Duwamish Rivers is more urban and industrial in character than the rivers sampled for this 2009-10 study.
- PBDEs were detected in 7 of the 15 river water samples. Total PBDE concentrations were highly variable ranging from 10.9 - 265 pg/L, with an average of 55.6 pg/L.
- Total PAH concentrations in SPM (excluding retene) ranged from 32 - 210 µg/Kg, with an average of 120 µg/Kg. Concentrations of individual PAHs were <20 µg/Kg, except for retene which averaged 230 µg/Kg.
- Few other organic compounds (BNAs, TPH-D, chlorinated pesticides) were detected in SPM.
- Estimated daily loading of total PCBs for the five rivers ranged from 0.015 - 0.57 g/day.
- Estimated daily loading of total PBDEs for the five rivers ranged from 0.017 - 5.63 g/day.

Notable relationships between parameters include:

- TSS concentrations were significantly correlated with, and explained between 63% and 86% of the variability in, concentrations of total phosphorus and total metals.
- TOC, DOC, total nitrogen, and nitrate+nitrite concentrations were significantly lower during July than during the other two sampling periods.
- Congeners belonging to the more polar PCB homolog groups (those with fewer chlorine atoms) were significantly correlated with many parameters in the dissolved phase (ortho-phosphate and dissolved metals). Congeners in the more highly-chlorinated PCB homologs were significantly correlated with TSS, TOC, and parameters often found in particulate form (total nitrogen and total phosphorus).

Recommendations

The following recommendations pertain to the use of present 2009-10 study results for modeling purposes and for future monitoring programs. In particular, more monitoring is needed to better define the normal range of concentrations for various toxic chemicals in marine and river waters.

- Selected study results should be used to revise input values to the Box Model and to calibrate the model.
- Future sampling should place more emphasis on collection and analysis of suspended particulate matter (SPM) in order to improve frequency of detection for hydrophobic compounds such as PAHs.
- More intensive water column sampling should be conducted near the ocean boundaries (Admiralty Inlet sill and Deception Pass). Samples should be analyzed for a reduced suite of chemicals, with priority given to chemicals exhibiting high variability (PBDEs) in the present study. This would improve the assessment of chemical exchange between ocean boundary waters and Puget Sound.
- Depth-integrated water sampling of large rivers should be conducted with focus on increased sampling frequency, a reduced suite of chemicals, and improved detection limits for organic contaminants. More frequent sampling during all phases of runoff-related events is needed to understand seasonal and other temporal patterns. This would facilitate a better characterization of loading during baseflow conditions and runoff-related events.
- Estimates of petroleum-related compound loadings to Puget Sound should be improved by:
  - Refining sampling methods or developing new methods better suited to capturing such compounds.
  - Refining analytical methods for measuring different petroleum fractions in whole water or other collection media (adsorbent material).
- Standard operating procedures (SOPs) for the collection and analysis of seawater samples for DOC and POC should be revised. For example, all equipment used for sample collection and processing should be made exclusively of glass or lined with Teflon.

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Appendix A. Glossary, Acronyms, Abbreviations, and Units of Measurement

Glossary

Ambient: Something commonly found in one's immediate surroundings. In this case, ambient concentrations of toxic chemicals are those within the normal range found in a box within the Puget Sound Toxics Box Model and not influenced by point sources of pollution.

Analyte: Water quality constituent being measured (parameter).

Baseflow: Groundwater discharge. The component of total streamflow that originates from direct groundwater discharges to a stream.

Basin: A drainage area or watershed in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Biota: Flora (plants) and fauna (animals).

Box Model: The simplest type of model. A box model assumes the object being modeled has the shape of a box and substances inside the box are distributed uniformly. In this case, the Puget Sound Toxics Box Model assumes different basins and water layers have the shape of a box and that chemical concentrations in each box are all the same.

Congener: In chemistry, congeners are related chemicals. For example, polychlorinated biphenyls (PCBs) are a group of 209 related chemicals that are called congeners.

Conventional pollutants: Non-toxic pollutants.

Euphotic zone: The uppermost part of a waterbody that receives enough light to allow photosynthesis to occur.

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values. The calculation is performed by: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the values.

Harmonic Mean: A second expression of central tendency (average) among multiple values. The calculation takes the reciprocal of the arithmetic mean of the reciprocals. The harmonic mean is commonly used when average rates are calculated. It tends to mitigate the impact of large outlier values but aggravate the impact of small ones.

Homolog: One of several groups of similar organic chemical compounds whose successive members have a regular difference in composition. For example, mono-chlorinated biphenyls compounds contain one chlorine atom and belong to the homolog group, and bi-phenyl compounds containing 2-9 chlorine atoms belong to the other nine homolog groups.

Load(ing): The mass substance (suspended sediment or contaminant) passing by a horizontal or vertical plane per unit time. For example, the metric tons of sediment calculated to be transported downstream of a particular location.

Marine: Of or having to do with an ocean or sea (salt water).

Marine water column: The vertical column of water representing the entire depth of a marine waterbody. For the present 2009-2010 study, water samples were collected from various subsurface depths in the marine water column, not just dipped from the surface.

Nonpoint source: Pollution entering waters of the state from dispersed land-based or water-based activities, including atmospheric deposition, surface water runoff, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

Ocean boundary waters: Strait of Juan de Fuca and Haro Strait

Ortho-phosphate: The soluble inorganic phosphate ion (PO_4^{3-}) reported as the mass of phosphorus per unit volume (µg P/liter).

Outlier: A number (or observation) that deviates markedly from other numbers in a sample population (group of observations).

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Particulate: Solid matter, such as a grain of fine sand, small enough to be suspended in a gas or liquid.

Pesticide: Any substance or mixture of substance intended for preventing, destroying, repelling or mitigating any pest. Pests include nuisance microbes, plants, fungus, and animals.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Contamination, or alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Pycnocline: Depth at which water density increases most rapidly with depth.

Runoff: The variety of ways by which water moves across the land, including surface (diffuse) runoff and channelized runoff.

Seawater: Water from a sea or ocean, averaging 35 grams of dissolved salts per liter (parts per thousand).

Sediment: Solid fragmented material (soil and organic matter) that is transported and deposited by water and covered with water (example, river or lake bottom).

Spatial: How concentrations differ among various parts of the river.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and watercourses within the jurisdiction of Washington State.

Suspended sediment: Solid fragmented material (soil and organic matter) in the water column.

Temporal trends: Characterize trends over time.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation

X th percentile: A statistical number obtained from a distribution of a data set, above which 100-X % of the data exists and below which X % of the data exists.

Acronyms and Abbreviations

AP	Analytical Perspectives
BEHP	Bis 2-ethylhexyl phthalate
BMP	Best management practices
BNA	(Base/neutral/acid extractable) semivolatile organic compound
cPAH	Carcinogenic PAH compounds [benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene)]
CRM	Certified reference material
CTD	Conductivity, temperature, depth measurement devices
CV	Coefficient of variation (standard deviation divided by the mean)
Ecology	Washington State Department of Ecology
DDD	Dichloro-diphenyl-dichloroethane
DDE	Dichloro-diphenyl-trichloroethylene
DDT	Dichloro-diphenyl-trichloroethane
DOC	Dissolved organic carbon
DUP	Duplicate

EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
EDL	Estimated detection limit
EQL	Estimated quantitation limit
Frontier	Frontier Global (formerly Frontier Geosciences)
GFF	Glass fiber filter
GIS	Geographic Information System software
GPS	Global Positioning System
HDPE	High-density polyethylene
HEM	Hexane-extractable material (synonymous with oil and grease)
HPAH	High molecular weight PAHs [benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-c,d)pyrene, and pyrene]
KCDNR	King County Department of Natural Resources
LPAH	High molecular weight PAHs [acenaphthylene, acenaphthene, anthracene, fluorene, naphthalene, and phenanthrene]
MDL	Method detection limit
MEL	Manchester Environmental Laboratory
MQO	Method quality objective
MS/MSD	Matrix spike/matrix spike duplicate
N	Number
n/a	Not applicable
NAD	North American Datum
ND	Not detected, nondetect
NPDES	National Pollutant Discharge Elimination System
NTR	National Toxics Rule
Ortho-P	Ortho-phosphate
P	Phosphorus
p	Probability of a result as extreme as the one observed assuming the null hypothesis is true
PAH	Polycyclic aromatic hydrocarbon compounds
PBDE	Polybrominated diphenyl ethers
PBT	Persistent, bioaccumulative, and toxic substance
PCB	Polychlorinated biphenyls
POC	Particulate organic carbon
POTW	Publically-owned treatment works
PRL	Pacific Rim Laboratories
PSTLA	Puget Sound Toxics Loading Analysis
QA	Quality assurance
QC	Quality control
REP	Replicate
RL	Reporting Limit
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
Sd	Sound
SJdF	Strait of Juan de Fuca

SOP	Standard operating procedure
SPM	Suspended particulate matter
SRM	Standard reference materials
Stdev	Standard deviation
Str	Strait
TEQ	Toxic Equivalents (for carcinogenic PAHs, relative to toxicity of benzo(a)pyrene)
TOC	Total organic carbon
TPAH	Total PAHs (sum of HPAH and LPAH concentrations)
TPH	Total petroleum hydrocarbons
TPH-D	Total petroleum hydrocarbons - diesel fraction
TPH-G	Total petroleum hydrocarbons - gasoline fraction
TSS	(See Glossary above)
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area

Metals

As	Arsenic
Cd	Cadmium
Cu	Copper
Pb	Lead
Zn	Zinc

Units of Measurement

cfs	cubic feet per second
cm	centimeters
cms	cubic meters per second, a unit of flow.
dw	dry weight
ft	feet
g	gram, a unit of mass
gpm	gallons per minute
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters.
L	liters
m	meter
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mL	milliliters
ng/Kg	nanograms per kilogram (parts per trillion)
pg/L	picograms per liter (parts per quadrillion)
psu	practical salinity units
rpm	revolutions per second
µg/Kg	micrograms per kilogram (parts per billion)
µg/L	micrograms per liter (parts per billion)
µM	micromolar (a chemistry unit)

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Appendix B. Sampling Sites and Field Records

Puget Sound Toxics Box Model

Marine Water Column Sampling

Marine SPM Sampling

River Water Sampling

Puget Sound Toxics Box Model

The Puget Sound Toxics Box Model depicted below, taken from Pelletier and Mohamedali (2009), provides context for the sampling conducted for the present 2009-2010 study. It shows the relative volume of surface and deep water layers in Puget Sound basins, the relative volume of surface runoff to each surface layer, and the relative volume exchanged between each basin and layer. To address data gaps identified by the Box Model, the present study analyzed toxic chemicals in samples collected from surface and deep layers of the four main basins and from the five rivers representing the largest sources of surface runoff. Samples were also collected from surface and deep layers in ocean boundary waters outside Admiralty Inlet.

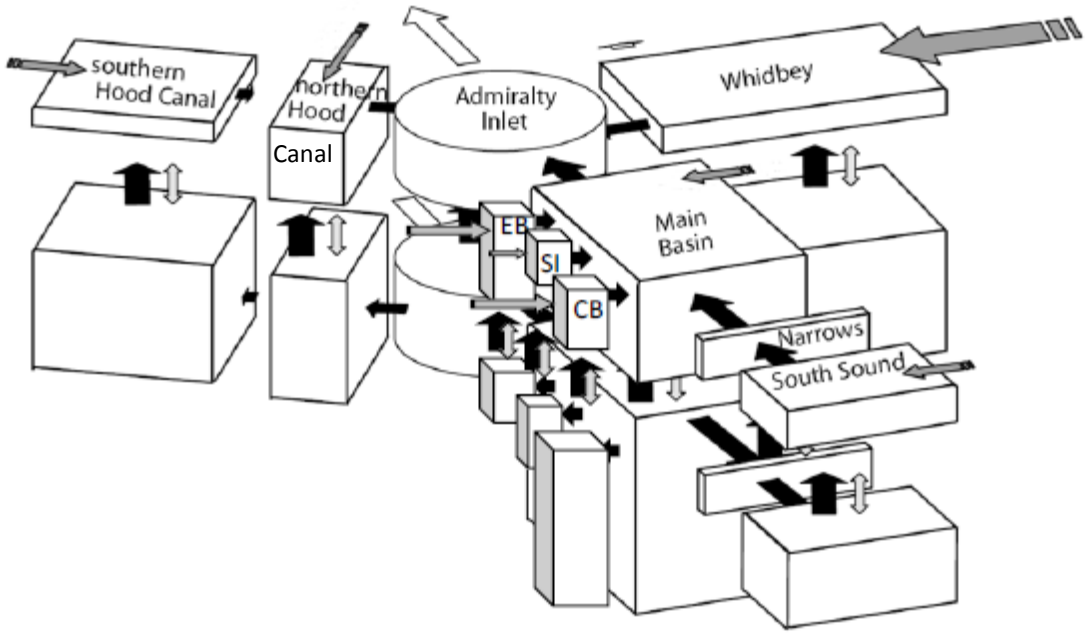

Figure B-1. Diagram of the Box Model of water circulation and transport in Puget Sound.

Grey arrows with dashed ends represent river inputs.
White arrows show exchange with the Strait of Juan de Fuca (ocean boundary waters).
Black arrows show advective transport.
Two-way grey arrows represent mixing between compartments.

Boxes are scaled to show relative volumes of water.
Arrows for rivers are log-scaled.

EB = Elliott Bay; SI = Sinclair Inlet; CB = Commencement Bay.

Marine Water Column Sampling

Table B-1. Sampling depths at Puget Sound basin sites relative to Box Model features and stratification. Two GO-FLO samplers were deployed simultaneously, collecting water at depths A and B.

Station	Seasonal Sampling Event	Date	Station Depth (m)	Box Model Surface/Deep Division (m)	Approx. Pycnocline Depth (m)	Sample Depth A (m)	Sample Depth B (m)	Water Column Layer
Hood Canal	1	7/7/09	152	13	10-15	5	7	surface
						40	35	deep
	2	9/30/09	150		5	2	5	surface
						80	85	deep
	3	1/13/10	n/a		10	25	30	surface
						100	105	deep
South Sound	1	7/9/09	165	30	<10	10	15	surface
						85	90	deep
	2	10/1/09	180		none	10	15	surface
						80	85	deep
	3	1/11/10	170		5	10	10	surface
						90	90	deep
Main	1	7/9/09	160	50	62	15	20	surface
						95	100	deep
	2	9/29/09	230		57	20	25	surface
						80	85	deep
	3	1/12/10	n/a		<5	20	20	surface
						80	80	deep
Whidbey	1	7/10/09	149	9	10	5	10	surface
						75	80	deep
	2	9/28/09	148		8	5	10	surface
						45	40	deep
	3	1/26/10	152		17	15	20	surface
						95	100	deep

Table B-2. Sampling depths at ocean boundary water sites relative to Box Model features and stratification. Two GO-FLO samplers were deployed simultaneously, collecting water at depths A and B.

Station	Seasonal Sampling Event	Date	Station Depth (m)	Box Model Surface/Deep Layer Division (m)	Approx. Pycnocline Depth (m)	Sample Depth A (m)	Sample Depth B (m)	Water Column Layer
SJdF at Sill	1	7/7/09	156	50	30	10	15	surface
						45	50	deep
	2	10/7/09	154		none	15	20	surface
						95	100	deep
	3	2/2/10	156		none	15	20	surface
						120	125	deep
SJdF North	1	7/8/09	136	50	85	15	20	surface
						110	115	deep
	2	10/7/09	134		55	15	20	surface
						95	100	deep
	3	2/2/10	140		<5	15	20	surface
						120	125	deep
Haro Strait	1	7/8/09	183	50	<90	15	20	surface
						115	120	deep
	2	10/7/09	185		50, 115	15	20	surface
						95	100	deep
	3	2/1/10	184		<5	15	20	surface
						95	100	deep

SJdF = Strait of Juan de Fuca.

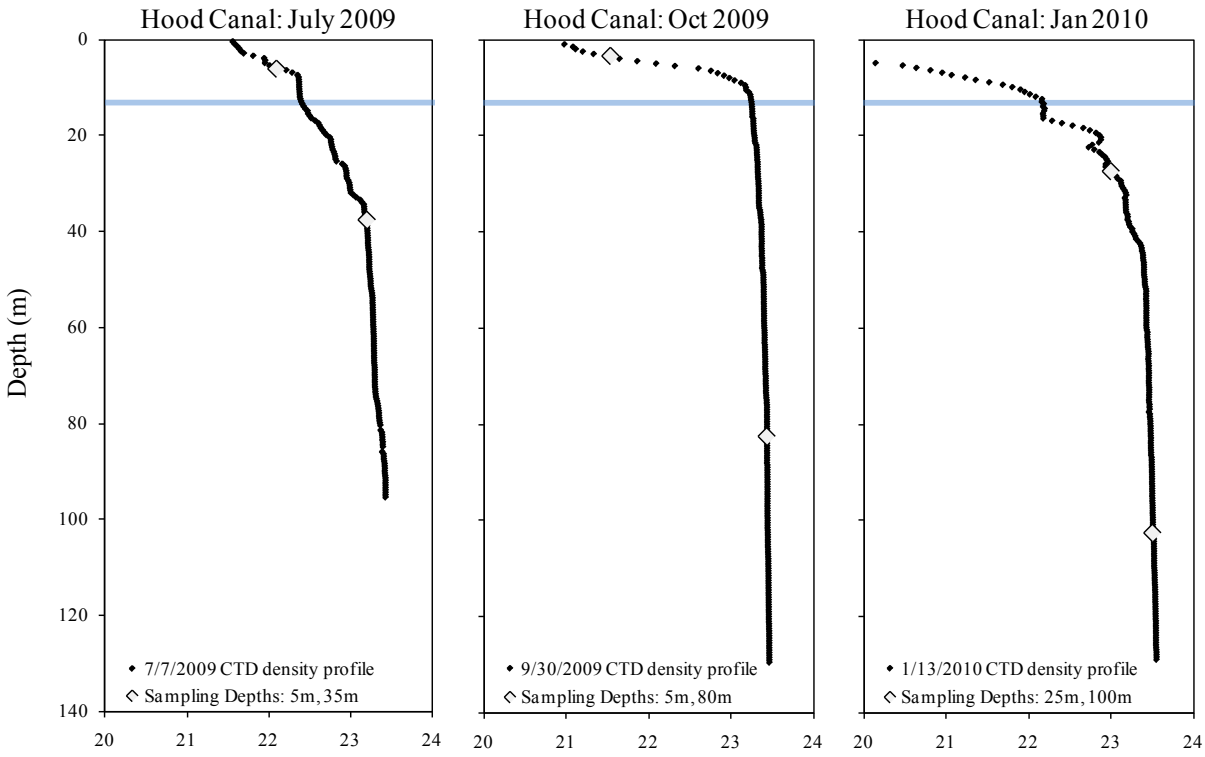

Figure B-2. Hood Canal water column sampling depths in relation to density profiles.
Density (x-axis) given in kg/m^3. Depth of the division between Box Model layers is shown at 13m.

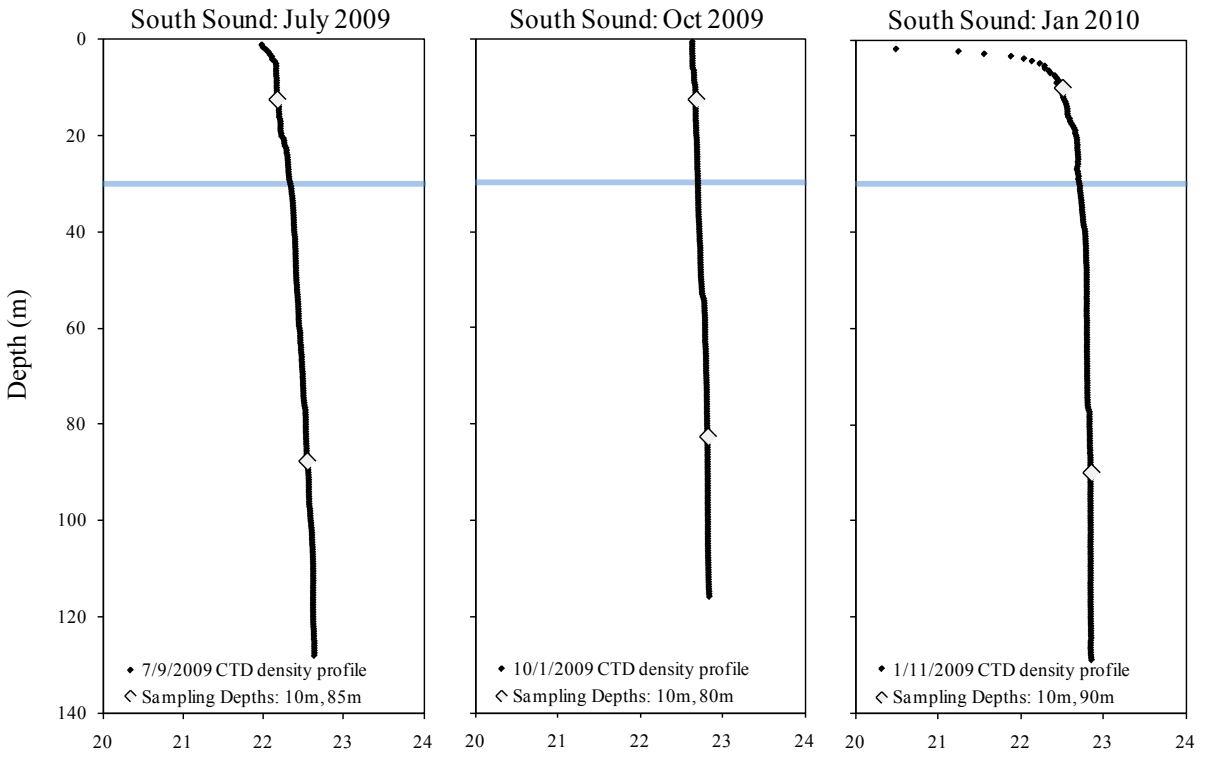

Figure B-3. South Sound water column sampling depths in relation to density profiles.
Density (x-axis) given in kg/m^3. Depth of the division between Box Model layers is shown at 30m.

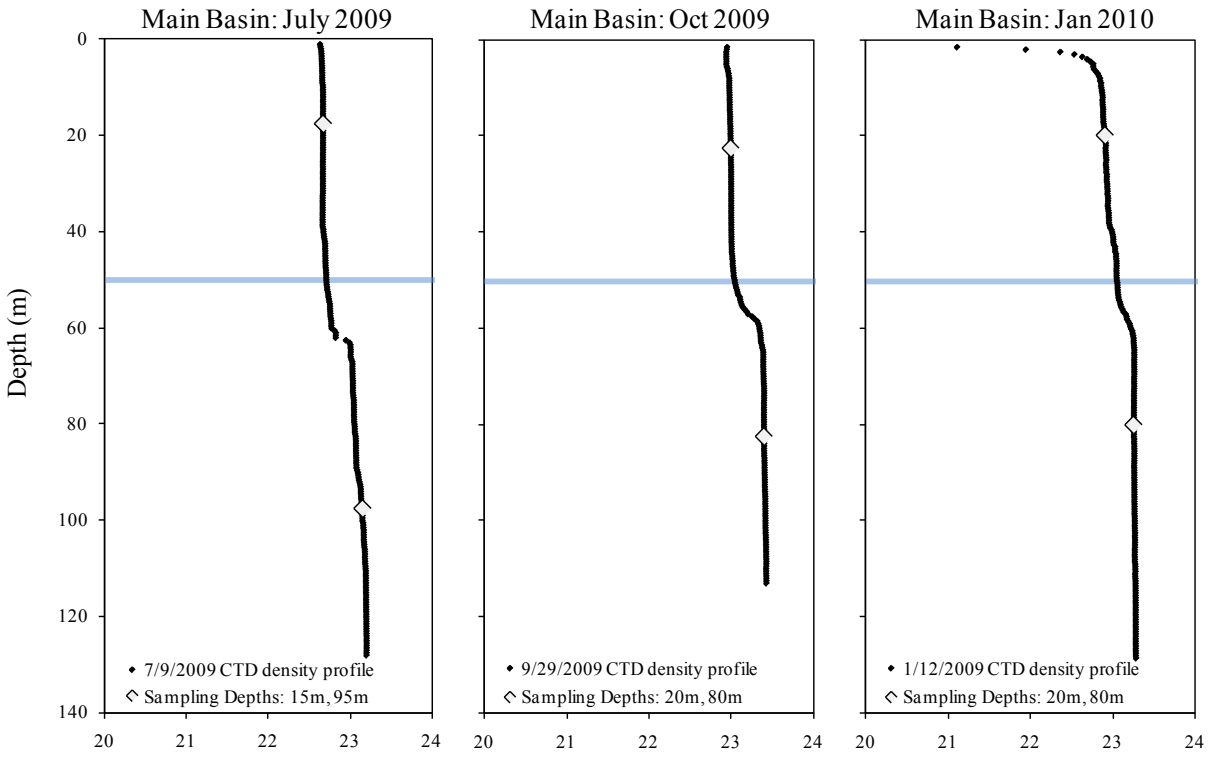

Figure B-4. Main Basin water column sampling depths in relation to density profiles.
Density (x-axis) given in kg/m^3. Depth of the division between Box Model layers is shown at 50m.

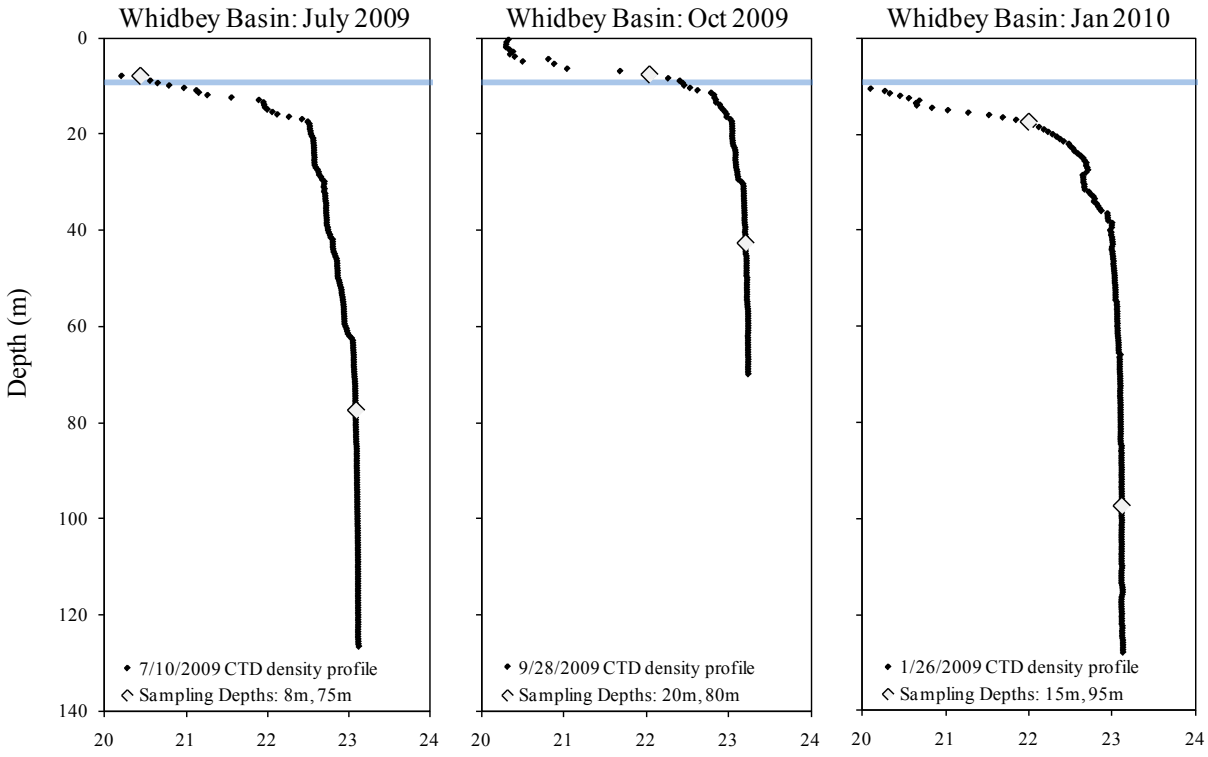

Figure B-5. Whidbey Basin water column sampling depths in relation to density profiles.
Density (x-axis) given in kg/m^3. Depth of the division between Box Model layers is shown at 9m.

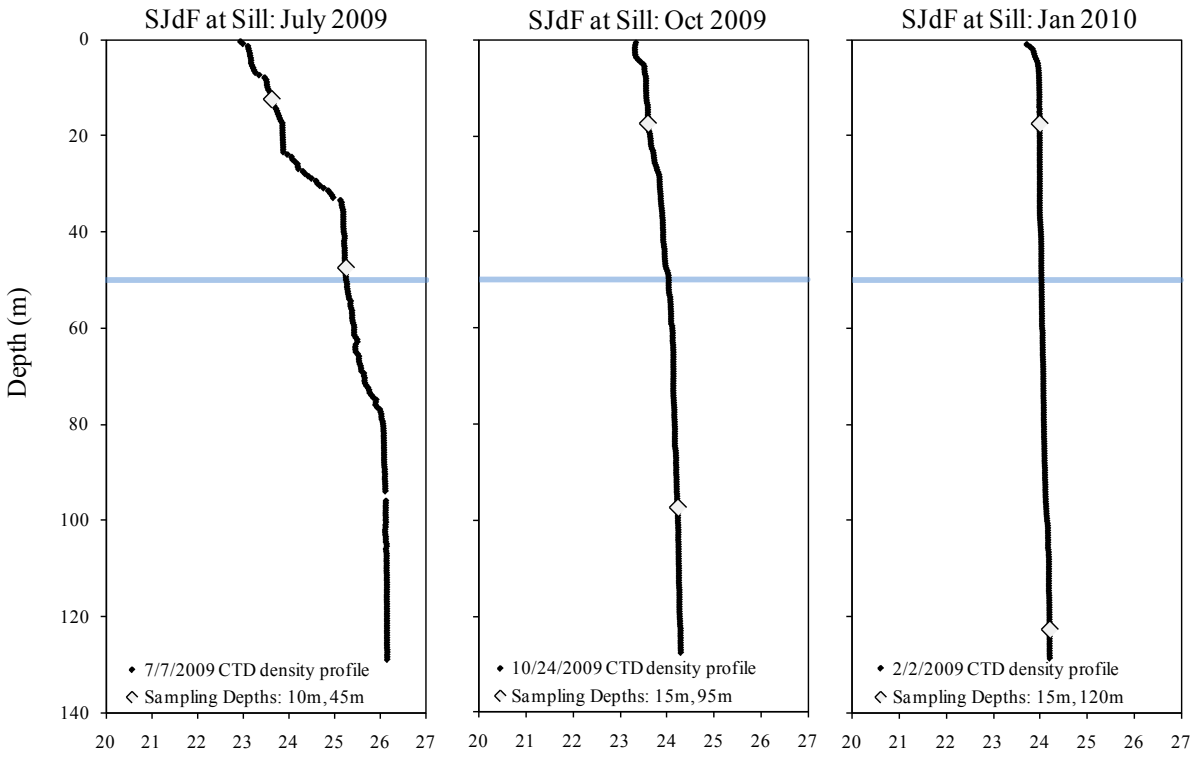

Figure B-6. SJdF at Sill water column sampling depths in relation to density profiles.
Density (x-axis) given in kg/m^3. Depth of the division between Box Model layers is shown at 50m.

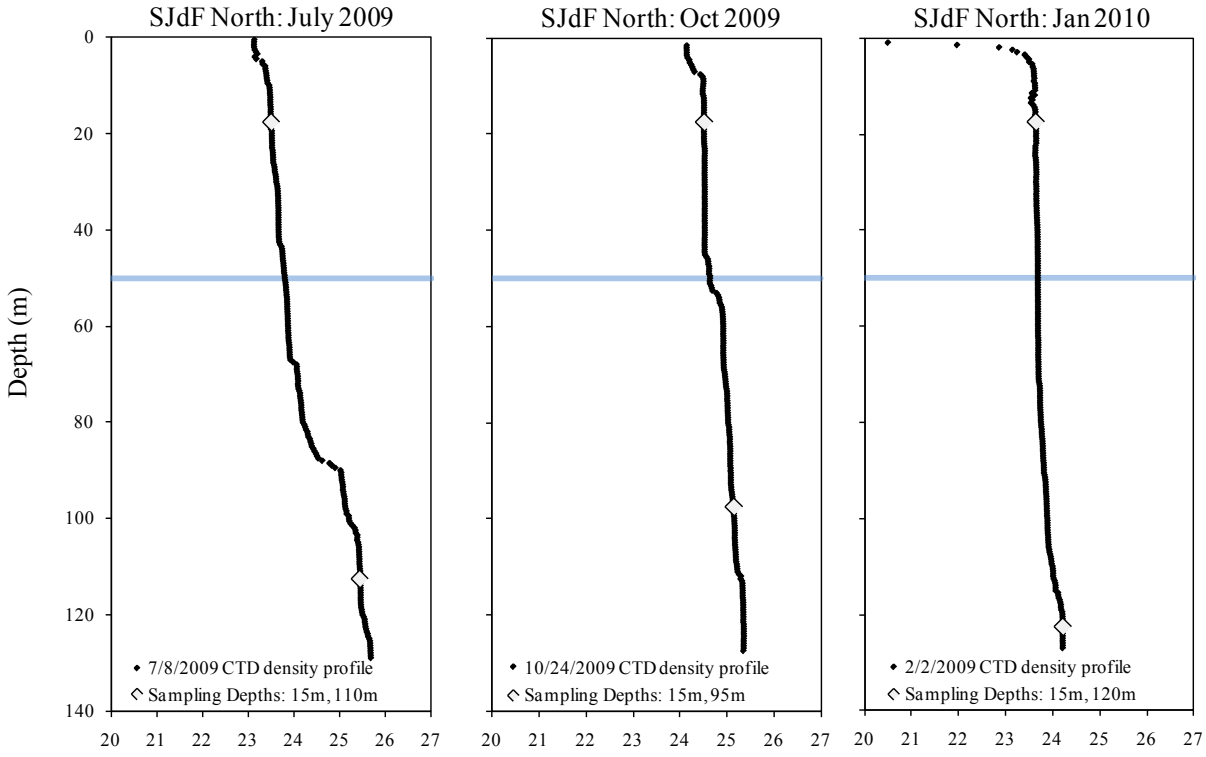

Figure B-7. SJdF North water column sampling depths in relation to density profiles.
Density (x-axis) given in kg/m^3. Depth of the division between Box Model layers is shown at 50m.

Figure B-8. Haro Strait water column sampling depths in relation to density profiles.
Density (x-axis) given in kg/m^3. Depth of the division between Box Model layers is shown at 50m.

Marine SPM Sampling

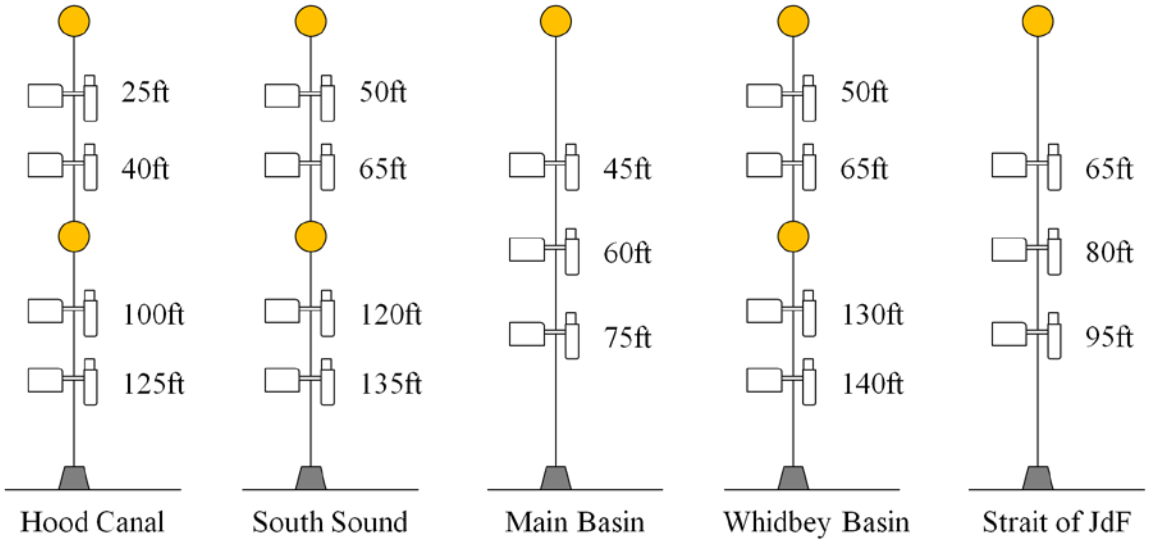

Figure B-9. Configuration of sediment trap deployments at each mooring location.

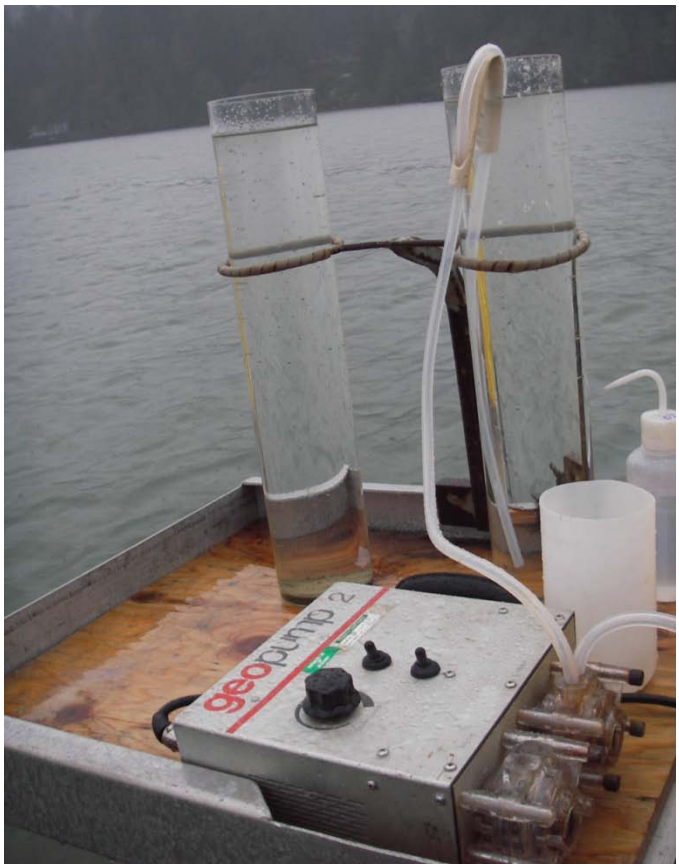

Figure B-10. Drawing overlying water from glass sediment trap cylinders.

River Water Sampling

Table B-3. Summary of water sampling activities at the five major rivers discharging to Puget Sound.

River	Date	Start Time	End Time	Channel Depths Sampled (ft)				Mean Daily Flow [1]		Flow Type	Conditions/Notes
				Left	Center	Pump/ (Channel)	Right	ft^3/s (cfs)	$m^{3/}s$ (cms)		
Nooksack	7/21/09	0928	1200	5.5	5.7	-	6.6	1,840 [2]	52.1	Base	USGS predicted flow of 1,760 cfs.
Skagit	7/21/09	1603	1932	5.2	4.1	-	8.4	10,500	297	Base	Approx. 50% of long-term mean flow for July [4].
Stillaguamish	7/22/09	0900	1125	11.7	8.7	-	6.4	470 [2]	13.3	Base	USGS predicted flow of 333 cfs.
Snohomish	7/22/09	1417	1711	15	13.2	-	17.6	3,470	98.3	Base	Current slowing with flood tide near end of sampling.
Puyallup	7/23/09	0907	1225	2.6	4.2	-	7.5	2,380	67.4	-- [3]	Water chalky brown except near small tributary. Glacial silts from late seasonal snow melt?
QA REP											
Nooksack	10/12/09	1353	1625	4.3	4.8	-	5.4	590	16.7	Base	Flow 38% of long-term mean October baseflow
Skagit	10/13/09	0823	1153	2.8	3.3	-	6.3	5,400	153	Runoff	Low flow, quite shallow. 44% of long-term mean flow for October [4].
Stillaguamish	10/19/09	1129	1300	14.8	11.5	-	8.6	3,240	91.8	Base	Falling stage. Still five times monthly mean baseflow [4].
Snohomish	10/20/09	1030	1211	20.5	23.6	-	26	4,940	140	Runoff	Falling stage of runoff event.
Puyallup	10/15/09	0847	1043	2.9	5.5	-	7	1,000	28.3	Runoff	Early phase runoff.
QA REP		1304	1522								
Nooksack	01/06/10	1039	1222	8.7	11.1	6 (10-10.5)	11.2	7,880	223	Runoff	Strong current, high turbidity. Flow based on USGS 15-minute records. Discharge 300% mean baseflow [4].
Skagit	12/17/09	0921	1110	9.0	7.5	***~4.5*** (7.5)	7.5	13,850	392	Runoff	Water clear initially, turning visibly turbid later.
Stillaguamish	12/08/09	1326	1534	13.2	11.3	7.8 (13.2)	8.7	~1,900	53.8	Runoff	Clear and cold, with ice on banks and in river. USGS 15-minute flow records, stage variable.
Snohomish	12/22/09	1525	1733	≤18.0	≤25.1	9-11 (32)	≤30.5	18,400	521	Base	Swift current, changing water levels.
Puyallup	12/14/09	0949	1147	3.5	4.8	4.2 (7)	6.7	1,860	52.7	Base	Light rain throughout evening. Becoming colder – morning frost.
QA REP		1355	1510	3.4	5.3		6.5				

[1] Flow predicted from stage height recorded at nearby USGS gaging station.
[2] Flow measured by Ecology stream monitoring staff on day of sampling.
[3] Sampling conditions reflected neither baseflow nor runoff related to recent precipitation. Suspended solids were related to seasonal runoff from glaciers, not from recent precipitation events.
[4] From Sinclair and Pitz (1999).
QA REP = Quality assurance replicate.

Figure B-11. Skagit River sampling site.

Top: Aerial view of Riverside Drive (Old Highway 99) bridge over the Skagit River. Bottom: Photograph taken from the northwest, just downstream (shown as star at top).

Figure B-12. Snohomish River sampling site.

Top: Aerial view of Airport Way / Avenue D bridge over the Snohomish River in the City of Snohomish.

Bottom: Photograph taken from the north side of the river just downstream of the bridge (shown as star at top).

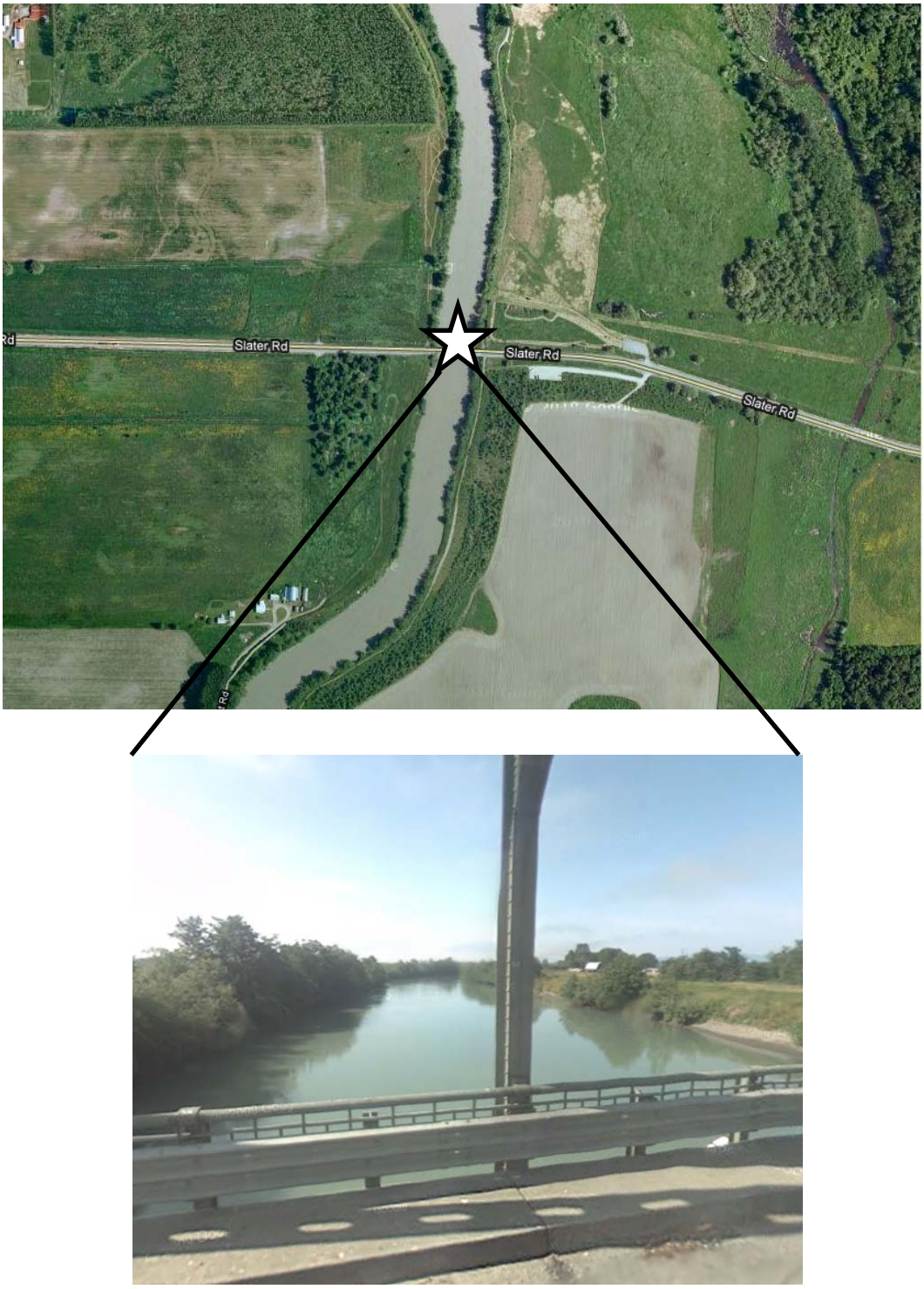

Figure B-13. Nooksack River sampling site.

Top: Aerial view of the Slater Road bridge over the Nooksack River (south of Ferndale, Washington).

Bottom: Photograph taken from the bridge deck looking approximately south (downstream).

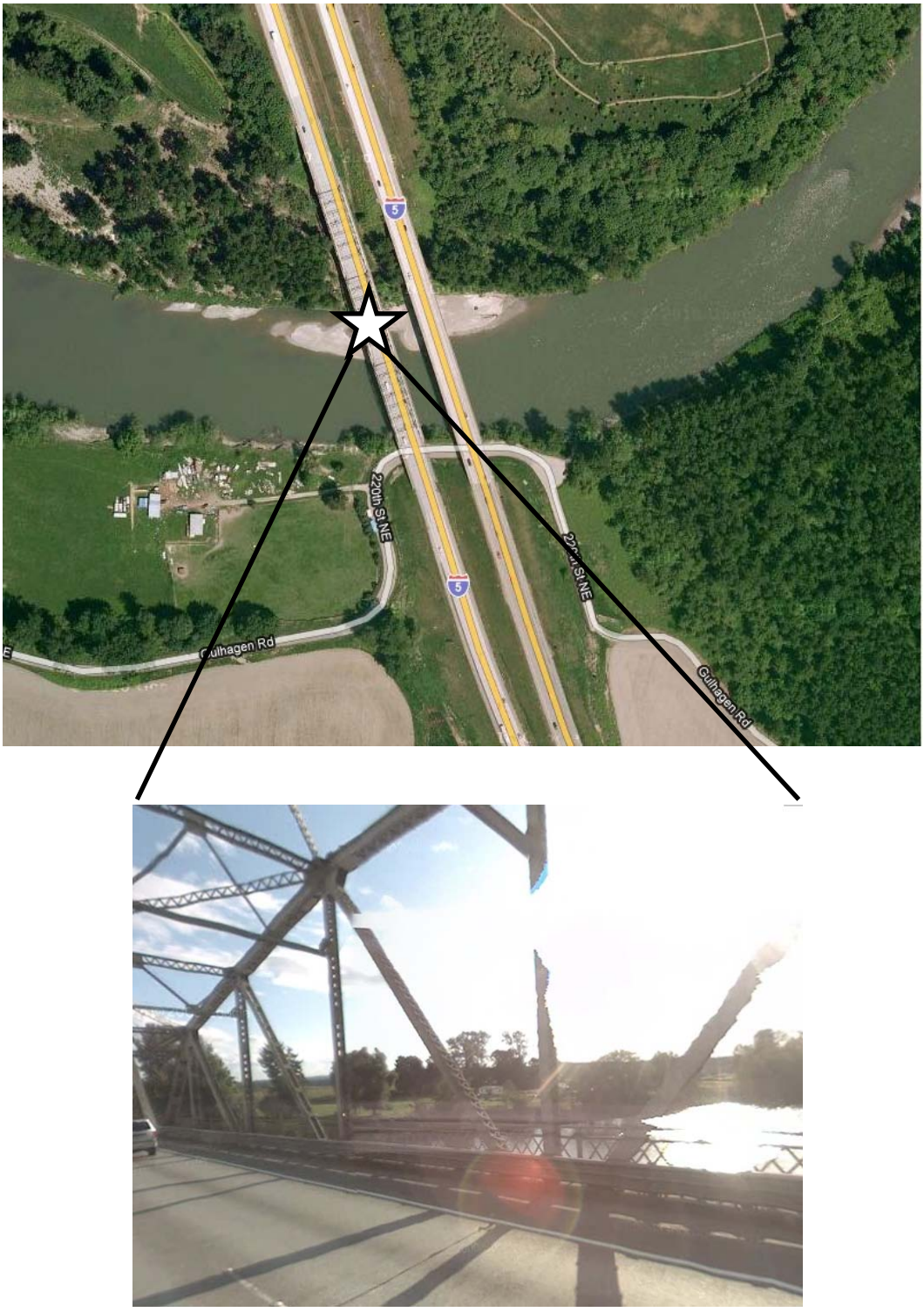

Figure B-14. Stillaguamish River sampling site.

Top: Aerial view of the Interstate-5 bridges over the Stillaguamish River near Silvana (west of Arlington, Washington).

Bottom: Photograph taken from the western (southbound) span of the bridge looking southwest.

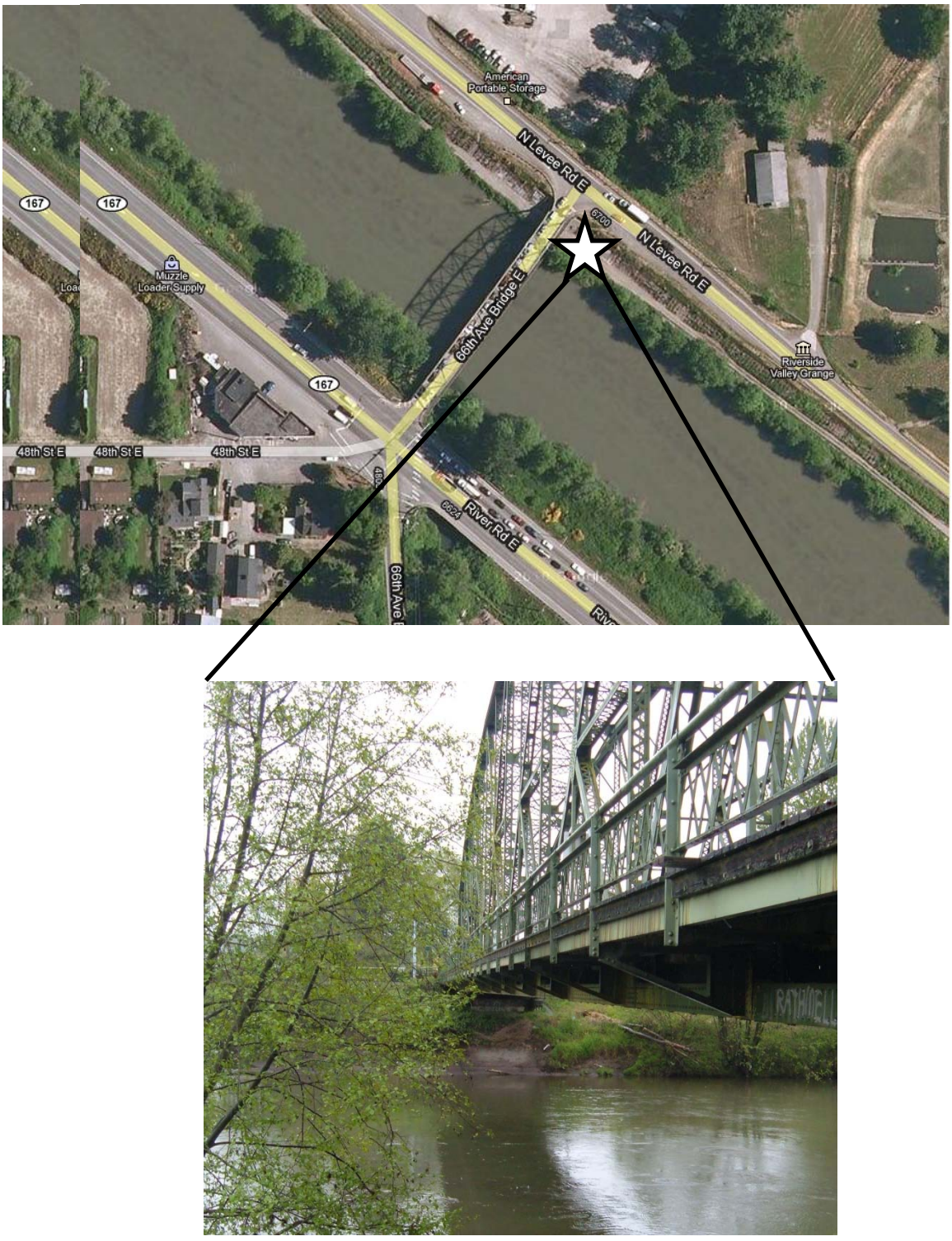

Figure B-15. Puyallup River sampling site.

Top: Aerial view of the 66th Avenue bridge over the Puyallup River west of the City of Puyallup.

Bottom: Photograph taken from the north bank of the river, just upstream of the bridge (location shown as star at the top).

Appendix C. Sampling and Analysis Methods

Sampling for Trace Levels of Analytes in Marine Waters using GO-FLO Samplers

Sampling Marine Waters for Organic Carbon

Sample Containers, Preservation, and Holding Times

Analytical Methods

Sampling for Trace Levels of Analytes in Marine Waters using GO-FLO Samplers

Effective control of contamination during the collection and handling of marine water column samples is of paramount importance. Many of the target analytes are ubiquitous on the sampling platform and equipment, often at several orders of magnitude higher than concentrations expected in ambient waters. Introduction of contamination at this stage will negate all care taken in subsequent analytical steps.

These field protocols are intended to provide a step-by-step procedure for the collection of contamination-free water samples from depth in marine waters. Guidance was taken from the sampling literature, and to the extent possible EPA *clean hands / dirty hands* techniques are employed (EPA, 1996). Performance of these protocols should be routinely measured through the collection and analysis of field blanks and replicates.

Overview

While there is no "standard" method for obtaining at-depth samples of marine waters for trace analyses, a proven and widespread technique involves the deployment of one or more Teflon-coated GO-FLO samplers (General Oceanics, Inc.) on a non-metallic hydrowire (typically Kevlar). The sampling procedures employed in the present study are based on this "standard" foundation as follows:

Two Teflon-coated GO-FLO samplers are mounted back-to-back (or several meters apart) on a non-metallic Vectran rope and are lowered by hand into the water with their end caps *closed* to avoid potential contamination from the microlayer at the water surface. The samplers open automatically by hydrostatic pressure release at a depth of approximately 10 meters. Site water flushes through the open samplers as they are lowered to the predetermined sampling depth. The samplers are remotely triggered by Teflon-coated messengers. A non-metallic windlass drum and Acetal sheave facilitate recovery of the GO-FLO samplers and ensure that the rope does not contact potentially contaminating materials. Once on-board, the sampler end caps are kept covered by polyethylene bags to minimize atmospheric exposure, and the samplers are secured in a purpose-built storage cabinet.

Subsampling activities are conducted within a simple portable glove box. Water samples are decanted from each GO-FLO sampler via clean Teflon tubing that connects to the sampler drain valve inside the storage cabinet and to a Teflon petcock inside the glove box. In this way, sample bottles for the various analytes are filled in an environment isolated from major air- and ship-borne contamination sources. If the project lead judges the protection of a glove box to be unnecessary, the GO-FLO samplers may simply be drained through Teflon tubing and into the various analyte sample bottles (with minimal exposure to potential atmospheric contaminants).

At the completion of a sampling cruise, the GO-FLO samplers undergo cleaning and storage procedures.

Principal equipment

- 10-liter GO-FLO samplers (2) – Teflon-coated with Teflon drain valves and air vent screws; spare parts kit.
- Vectran 12-strand rope (600 ft) – marked at 1- and 5-meter increments.
- Teflon-coated messengers.
- Snatch block and non-metal sheave – Ronstan single snatch block with Trunnion head and Acetal sheave.
- Non-metallic line weight – 20-lb. lead weight encased in epoxy resin.
- Cabinet for clean storage and transportation of GO-FLO samplers – constructed of UHMW polyethylene and Teflon materials.
- Large polyethylene bags capable of completely enclosing a single 10-liter GO-FLO sampler.
- Elasticized polyethylene "shower caps" (Saranwrap Quick Covers) or 2-gallon Ziplock bags.
- Talc-free Nitrile gloves.
- Clinometer or like instrument.
- Metals tubing train – 2-in. segment of MasterFlex 73 (3/8" O.D.) connects to GO-FLO drain valve, 6-ft segment of Teflon tubing (3/16" I.D.), and 2-ft segment of MasterFlex 73 tubing (3/8" O.D.) at peristaltic pump.
- Metals filter – in-line Gelman capsule filter, 0.45 μm.
- Peristaltic pump.

General rules

- Personnel must wear clean Nitrile gloves during all sampling and subsampling operations. If glove contamination is detected or suspected, work must be halted, the contaminated gloves removed, and a new pair of clean gloves put on. Wearing multiple layers of clean gloves allows the old pair to be quickly stripped with minimal disruption to the work activity.
- The upper ball valve of each GO-FLO sampler must be covered with an elasticized polyethylene "shower cap" at all times except during active deployment. The drain valve of each GO-FLO sampler must be covered with a Nitrile glove at all times except during active deployment and sample decanting.
- Samplers are transported around the vessel within polyethylene bags when possible, and are handled only by gloved personnel. The samplers should never be placed directly on deck or any hard surface where foreign particles might be lodged in the ball valves and cause contamination of subsequent samples. Improper use and handling of GO-FLO samplers can result in permanent contamination.
- Ensure at all times that the Vectran 12-strand rope does not make contact with any part of the vessel (other than the Acetal sheave and windlass drum). When not in use, remove the rope from the snatch block and coil it inside a clean polyethylene bag. Place the bagged rope within a sealed plastic container to minimize exposure to air- and ship-borne contaminants.
- Store the snatch block, line weights, and messengers in clean polyethylene bags when not in use.

- All polyethylene storage bags are considered "one-time use." That is, once a piece of equipment is removed from its storage bag, a separate clean bag must be used for subsequent storage.

Preparation

- Upon arrival at the sampling location, turn the engine off and wait 10 minutes before placing any sampling equipment in the water. Allow the vessel to drift during all sampling operations and conduct all sampling on the windward side of the vessel to minimize contamination from shipboard sources.
- Remove the snatch block from its polyethylene storage bag and secure it to the A-frame.
- Tie off the bitter end of the Vectran rope to a plastic cleat to secure it in case of mishap. Feed the working end of the rope over the sheave, being careful not to touch any metal objects that could embed foreign particles in the braid. Keep as much standing rope inside the covered plastic container as possible.
- Remove the line weights from storage bags and attach the weights to the loop eye at the working end of the Vectran rope. Lift the weights overboard and lower them into the water so that at least 10 meters of rope extend above the weights. Secure the rope to a plastic cleat to maintain this configuration, and replace any extra rope into the rope storage box.
- Arm the GO-FLO samplers and secure each to the Vectran rope – *This is a 2-person activity and personnel must wear clean gloves*. Layering of gloves is recommended to facilitate rapid discarding of dirty/contaminated gloves. Technicians should work carefully but quickly, striving to minimize the duration of atmospheric exposure for GO-FLO samplers secured to the Vectran rope. Follow the procedures listed below for the first GO-FLO sampler, and then repeat the procedure to arm and secure the second GO-FLO sampler.
    - Technician #1 (T1) removes the sampler from the storage cabinet (keeping it inside the polyethylene bag in which it was stored).
    - Technician #2 (T2) places a clean polyethylene bag flat on a stable surface away from contamination sources. T1 places the GO-FLO sampler (still inside its polyethylene storage bag) on the bag.
    - T2 puts on clean gloves and reaches inside the storage bag to arm the GO-FLO sampler; contact with the GO-FLO sampler is only made by T2. T1 assists by stabilizing the sampler and manipulating the storage bag for T2.
        - Reverse the spring over the pulley to release tension.
        - Pull the pressure release valve all the way out and position the lanyard poly-balls on either side between the valve and the stainless steel frame.
        - Attach the lanyard to the plunger mechanism by inserting the slack loop into the trip release.
        - Re-span the spring by rotating it over the pulley so that the spring and the lanyards are under tension.
        - *Optional:* Test the closing mechanism to verify that it functions properly.
            - Push the pressure release valve to cause the ball valves to move to the open position.
            - Press the plunger to release the lanyard, which results in bottle closure.
            - Re-arm the GO-FLO sampler after this check.

- T1 carries the armed sampler (still inside the storage bag) to the Vectran rope. T2 reaches inside the storage bag and checks that the protective "shower cap" and Nitrile glove are securely covering the upper ball valve and drain valve, respectively. T2 then removes the GO-FLO sampler from the storage bag. T1 discards the storage bag and secures the GO-FLO sampler to the Vectran rope at the 10-meter marking above the line weights.
- T1 puts on clean gloves, and the above procedure is repeated for the remaining GO-FLO sampler. Mount the second sampler above the first and note the distance between the vertical centers of the samplers. Samplers are typically spaced two to five meters apart to ensure triggering of the lower sampler by a serial messenger.

- To prepare the samplers for serial firing, attach a Teflon-coated messenger by its lanyard to the plunger mechanisms of the upper GO-FLO sampler, and then snap the messenger onto the Vectran rope between the two samplers.

Deployment

- GO-FLO samplers armed using the above procedures are set to be deployed in a *closed* position to avoid potential contamination from the surface microlayer. If the number of line weights needed to overcome the buoyancy of the air trapped in the GO-FLO samplers becomes prohibitive, consider deploying the samplers in the *open* position. The ball valves can be easily released to the *open* position by depressing the pressure release piston. Note that the poly-balls on the lanyards are under tension and will snap quite suddenly when the pressure release piston is pressed in. Keep hands well clear of the poly-balls, and use a pen wrapped in either a polyethylene bag or a clean glove to depress the pressure valve.
- By convention, at the water surface the GO-FLO samplers are at 0 meters depth. Record the depth marking at which the GO-FLO samplers are mounted on the Vectran rope. This length of rope between each sampler and the line weights is called the "Weight Segment". In calm conditions when the rope angle (deviation from vertical) is negligible, the length of rope from the depth of the GO-FLO samplers in the water column to the surface (called the Sampler Segment) is equal to the total length of rope payed out (Total Length) minus the Weight Segment.

  Sampler Segment = (Total Length) – (Weight Segment)

- Immediately before deployment, remove the protective "shower cap" from the upper ball valve and the Nitrile glove from the drain valve of each GO-FLO sampler. Wearing clean gloves, check that all drain valves and air vent screws are tightly closed.
- Lower the samplers quickly and completely through the water surface to minimize contact with the surface microlayer. Once submerged, slowly lower the GO-FLO samplers by hand to ~15-20 meters depth. The hydrostatic pressure release valve should cause the ball valves to open at approximately 10 meters.
- Verify that the ball valves have opened properly: the parcel of air trapped in each sampler will be visible as it bubbles to the surface. If bubbles are not seen and there is concern that a sampler did not open, raise the rope slowly until the status of the ball valves can be assessed visually. However, note that contamination risks increase as the samplers approach the surface and the vessel. If water conditions are turbid or rough, assume that the bottle is open

and accept that redeployment may be necessary. The weight of a retrieved sampler will be indicative of it being empty or filled with water.

- Lower the GO-FLO samplers to the desired sampling depth.
- Pay out additional rope as needed to adjust for significant rope angles (e.g., caused by strong currents or wind).
  - Read the Total Length and subtract the Weight Segment to determine the Sampler Segment.
  - Measure the angle of the rope from vertical (called Rope Angle) using a clinometer.
  - Calculate the actual depth of the GO-FLO samplers, the "Sampler Depth":

    (Sampler Depth) = (Sampler Segment) x cosine (Rope Angle)

  - Use the vessel's depth sounder for general verification (GO-FLO samplers should be detected by the sounder).
- Remove a Teflon-coated messenger from its storage bag, attach it to the Vectran rope, and release. This messenger will trigger closure of the upper GO-FLO sampler, followed by release of the serial messenger and subsequent triggering of the lower GO-FLO sampler.
- Allow adequate time for the messenger to reach the GO-FLO samplers before retrieval.

Recovery

- Use the windlass to recover the GO-FLO samplers, and feed the rope into the storage container as it is collected to minimize the potential for contact with contamination sources. It may be necessary to have the vessel's engine running to avoid complete draw-down of the battery by the windlass. In that case, engine assistance may only be used to raise the samplers to a depth of 10 meters. Above (i.e., shallower than) 10 meters depth, the engine must be off to avoid introducing excess contamination to the water column through which the GO-FLO samplers will travel. After the engine is off, allow at least one minute for ship-influenced water to dissipate before resuming sampler recovery.
- Once the GO-FLO samplers are retrieved to deck level, quickly inspect for leakage. If leakage is detected or suspected, prepare all samplers for re-deployment as follows:
  - Empty each GO-FLO sampler.
  - Rinse the sample chamber, the drain valve, and the air vent screw with de-ionized water.
  - Wearing clean gloves, and with the GO-FLO samplers still mounted on the Vectran rope, re-arm the samplers.
  - Re-deploy the GO-FLO samplers.
- If no leakage is apparent, immediately place clean polyethylene "shower caps" on the GO-FLO samplers' top ball valves. Rinse the samplers' drain valves with de-ionized water and cover each with a Nitrile glove.
- Remove the messengers and place them in a polyethylene bag for storage.
- Disengage the GO-FLO samplers individually and transport each to the storage cabinet. *This is a 2-person activity and all personnel must wear clean gloves*. Follow the steps below for the first GO-FLO sampler, and then repeat for the second sampler.

- T1 supports the GO-FLO sampler to be removed, and T2 releases the screws that secure the sampler to the line.
- While T1 holds the GO-FLO sampler, T2 places a clean polyethylene bag over the unit. T1 adjusts so that the sampler is completely contained in the bag.
- T1 carries the GO-FLO sampler to the storage cabinet; T2 acts as a spotter. The sampler should not make contact with any part of the vessel.
- T1 places the GO-FLO sampler inside the storage cabinet in an upright position (it should remain in the polyethylene bag). T1 secures the GO-FLO sampler inside the cabinet using bungee cords.
- T2 puts on clean gloves, opens the GO-FLO sampler's air vent screw, and removes the glove from the drain valve.
- Inside the glove box (situated under the cabinet), T1 removes a clean Teflon tubing/ petcock assembly from its storage bag. The open end of the tubing remains covered with foil, and the petcock remains protected by a Nitrile glove until subsampling activities commence. T1 feeds the tubing from inside the glove box to the GO-FLO sampler cabinet, and checks that the petcock inside the glove box is closed.
- T2 receives the Teflon tubing at the storage cabinet, removes the foil from the end, and connects the tubing to the drain valve's compression fitting. T2 opens the drain valve, and T1 makes sure that the petcock isn't leaking in the glove box.

- Wearing clean gloves, remove the line weights and place them in polyethylene bags for storage. Release the Vectran rope from the snatch block. Coil the rope, place it in a polyethylene bag, and store it within the sealed container to protect against air- and ship-borne contaminants. Place the snatch block in a polyethylene bag for storage.

Subsampling

- Begin decanting from the GO-FLO samplers as soon as possible to prevent settling, biological activity, or adsorptive losses.
- Prior to the cruise, pre-labeled bottles for a specific sampling location and depth (henceforth called a "set") will have been assembled in two large, layered polyethylene bags. Wearing clean gloves, remove the outer polyethylene bag and transfer the set (still contained in the inner polyethylene bag) to the inside of the glove box.
- Place a wide-mouthed waste container inside the glove box.
- The flow of water from a GO-FLO sampler is controlled from inside the glove box using the Teflon petcock. Remove the protective Nitrile glove to access a petcock. Be extremely careful, and ensure that nothing in the glove box makes contact with the exposed petcock at any time.
- Drain the first 0.5 liters of water from each GO-FLO sampler into the waste container before decanting sample water for chemical analyses.
- Decant whole-water subsamples.
  - Remove the analyte bottle(s) from the set bag as they are needed, and follow analyte-specific handling procedures (e.g. bottle rinses).
  - The recommended sequence for decanting analyte samples is as follows:

- GO-FLO sampler #1:
  1. Total Suspended Solids – 2 L
  2. DOC and POC – 1 L
  3. PCB Congeners – 2.5 L
  4. PBDE Congeners – 1 L
  5. Chlorinated Pesticides – 1 L
  6. Backup volume in case of mishap – 1 L
- GO-FLO sampler #2:
  7. PAHs – 1 L
  8. BNAs – 3.5 L

  - Filtration for DOC and POC is carried out immediately after their 1-liter subsample is decanted from the GO-FLO sampler (i.e., while other analyte subsamples are still being drained from the samplers). Filtration protocols are detailed elsewhere in this Appendix.
  - After each analyte bottle is filled, attach a sample tag with the required identification information (e.g., sample I.D., date/time, location, analyte, etc.). Seal the individual bottle inside a polyethylene bag and then inside another polyethylene bag.
  - *Do not* allow the mouth of an analyte bottle to contact the petcock at any time.
  - *Do not* swirl or shake the GO-FLO samplers to re-suspend settled material, as this can alter partitioning between dissolved and particulate size fractions.
- Observing *clean hands / dirty hands* guidelines, set up a clean tubing train for collecting metals samples from GO-FLO #2.
  - Use the peristaltic pump to flush 250 mL of sample water through the tubing train before rinsing and filling the total metals bottle. Label and double-bag the bottle.
  - Attach the in-line metals filter to the tubing train. Remove the end of the tubing train from the drain valve of GO-FLO #2 and place it in a bottle of laboratory-provided reagent water. Use the peristaltic pump to flush the filter with 750 mL of reagent water. Re-connect the end of the tubing train to the drain valve of sampler #2, and flush the filter with 250 mL of sample water before rinsing and filling the dissolved metals bottle with filtrate. Label and double-bag the bottle.
- Remove the set of subsample bottles from the glove box and place them in a cooler on ice.

Between stations or sampling events

- To minimize the risk of contamination to the GO-FLO samplers during short-term storage, adhere to the following precautions:
  - Store the samplers in polyethylene bag(s) inside the storage cabinet, and only remove a sampler just prior to deployment.
  - All valves (i.e., ball valves, air vent screws, drain valves) should be stored in their final closed position.
  - Cover the upper ball valve with an elasticized "shower cap," even when the sampler is inside a polyethylene storage bag.
  - Protect the drain valve by storing it covered by a Nitrile glove.
- If contamination of any GO-FLO sampler is suspected, stop using the sampler and return it to the lab for a thorough cleaning.

Extended storage

- Prior to long-term storage, rinse the GO-FLO samplers with de-ionized water.
- Ensure that all valves are in their final closed position.
- Cover the upper ball valve with a clean elasticized "shower cap," and place a clean Nitrile glove over the drain valve.
- Store the GO-FLO samplers in one or more clean polyethylene bag(s) and secure them in the storage cabinet.
- If GO-FLO samplers are not to be used within 30-60 days, return the samplers to the lab and schedule a thorough cleaning and maintenance. Procedures will be guided by existing standard techniques for the cleaning of Teflon-coated sampling equipment for priority pollutant sampling.

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Sampling Marine Waters for Organic Carbon

The following standard operating procedures (SOPs) represent a modified version of those used by Horn Point Marine Laboratory, University of Maryland (Lane, 2000).

Procedure for collecting particulate organic carbon (POC) samples

Equipment

- All-glass filter apparatus, pre-washed with 10% HCl (400 mL capacity filter column, scintered filter support with silicone stopper for 1000 ml side arm flask).
- Stainless steel forceps, similarly pre-cleaned.
- Certified pre-cleaned 30-50 ml amber glass DOC storage vials.
- GFF filters (25 mm diameter, 0.7 μm pore size), pre-combusted at 450°C for 90 min, handled with clean forceps only, and stored in aluminum foil packets on which the filter number is pre-recorded.

Filtration Procedure

- Assemble filtration apparatus with pre-combusted filter in place (unpatterned side up) between scintered support and funnel.
- Connect side arm flask to hand pump using pharmaceutical grade tubing.
- Apply gentle vacuum with hand pump (<10 inches Hg or <5 psi) and, ideally, filter water sample for no more than 5 minutes.
  - Volumes requiring 5 minutes filtration may be estimated by filtering incremental volumes of sample water through a discardable filter.
  - Multiple filtrations/filters may be needed to collect sufficient filtrate for DOC analysis.
- Record *total volume filtered* to 3 significant places (e.g., 1020 ml, 102 ml, 10.2 ml).
- Use clean forceps to fold used filter, still on scintered column, in half (top side of filter with POC is folded in on itself).
- Enclose individual used filters in aluminum foil packets.
- Record date/time, sample identification number, and filtrate volume legibly on exterior of aluminum foil packet with a permanent marker (CAUTION: do not puncture foil packet).
- Store aluminum foil packet in a plastic bag and refrigerate in the dark.

Drying Filters

- Within 48 hours, transfer POC filter in aluminum foil packets to laboratory environment.
- Partially open packets using cleaned forceps, place in convection oven, and dry overnight at 60°C.
- Close aluminum foil packet and place in dry plastic bag for shipment.
- Re-label aluminum foil packet if any information on label is no longer visible.

Procedure for collecting dissolved organic carbon (DOC) samples
(DOC is also referred to as NPOC or non-purgeable organic carbon)

- Collect one duplicate sample for every 10 samples to increase precision.
- Rinse side arm flask with approximately ½ sample volume expected to be filtered for POC.
- Remove filter column from flask (leaving filter in place between support and funnel), swirl filtrate thoroughly in flask and discard.
- Reassemble apparatus.
- Filter remaining volume for POC.
- Record station, date, and total volume filtered through filter for POC procedure (see above).
- Remove filter (described above).
- Rinse sample vial(s):
  - Transfer a few milliliters filtrate vial and cap.
  - Shake filtrate and discard.
- Fill vial with at least 20 mLs filtrate.
- Store vial in refrigerator in the dark (4°C).
- DO NOT FREEZE OR ADD ACID!
- Ship overnight within 2 weeks, using ice packs to keep samples cold but not frozen.

Sample Containers, Preservation, and Holding Times

Table C-1. Sample containers, requested volumes, preservation, and holding times for marine water column samples.

Parameter	Bottle Type and Volume	Sample Volume Requested	Preservation	Holding Time
TSS	1 L Poly	2 L	Cool to $\leq 6^{o}$ C	7 days
DOC	40 mL Amber Glass	40 mL	Filter in field w/ 0.7 µm GFF filter; Cool to $\leq 6^{o}$ C	28 days
POC	1 L Amber Glass	variable	Dry filter w/in 2 days; Cool to $\leq 6^{o}$ C	28 days
Total Metals	1000 mL HDPE	1 L	HNO_3 to pH < 2; Cool to $\leq 6^{o}$ C *	6 months
Dissolved Metals	1000 mL HDPE	1 L	Filter in field w/ 0.45 µm filter; HNO_3 to pH < 2; Cool to $\leq 6^{o}$ C *	6 months
Semivolatiles (BNA)	1 Gallon Glass	3 L	Cool to $\leq 6^{o}$ C	7 days
PAHs	1 L Amber Glass	1 L	Cool to $\leq 6^{o}$ C	7 days
Chlorinated Pesticides	1 L Amber Glass	1 L	Cool to $\leq 6^{o}$ C	7 days
PCB Congeners	2.5 L Amber Glass	2.5 L	Cool to $\leq 6^{o}$ C	1 year
PBDE Congeners	1 L Amber Glass	1 L	Cool to $\leq 6^{o}$ C	1 year
Total 13.54 L				

* Metals samples were acidified at the analyzing laboratory to avoid introducing contamination in the field and for safety of staff.

Table C-2. Sample containers, requested mass, preservation, and holding times for marine particulate samples.

Parameter	Bottle Type and Volume	Sample Mass Requested * (wet weight)	Preservation	Holding Time
Percent Solids	2 oz Glass	50 Grams	Cool to $\leq 6^{o}$ C	7 days
TOC			Cool to $\leq 6^{o}$ C; may freeze at -18^{o}C	14 days; 6 months frozen
Total Recoverable Metals			Cool to $\leq 6^{o}$ C; may freeze at -18^{o}C	6 months
Semivolatiles (BNA)	8 oz Glass	250 Grams	Cool to $\leq 6^{o}$ C	14 days; 1 year frozen
PAHs				
Chlorinated Pesticides		250 Grams	Cool to $\leq 6^{o}$ C	14 days; 1 year frozen
PCB Congeners		50 Grams	Cool to $\leq 6^{o}$ C; may freeze at -18^{o}C	1 year
PBDE Congeners		50 Grams	Cool to $\leq 6^{o}$ C; may freeze at -18^{o}C	1 year
Total 650 Grams				

* The minimum mass required to obtain specified detection limits for each analysis is less than the mass requested by analytical laboratories listed here and in the QA Project Plan.

Table C-3. Sample containers, requested volumes, preservation, and holding times for river water samples.

Parameter	Bottle Type and Volume	Sample Volume Requested	Preservation	Holding Time
TSS	1 L Poly	2 L	Cool to $\leq 6^{o}$ C	7 days
TOC	60 mL Poly	50 mL	1:1 HCl to pH < 2; Cool to $\leq 6^{o}$ C	28 days
DOC	60 mL Poly	50 mL	Field filter w/ 0.45 µm; 1:1 HCl to pH < 2; Cool to $\leq 6^{o}$ C	28 days
Hardness	125 mL Poly	100 mL	H_2SO_4 to pH <2; Cool to $\leq 6^{o}$ C	6 months
Nutrients: Ortho-phosphate	125 mL Amber Poly	125 mL	Field filter w/ 0.45 µm; Cool to $\leq 6^{o}$ C	48 hours
Nutrients: Total phosphorus	60 mL Poly	50 mL	1:1 HCl to pH < 2; Cool to $\leq 6^{o}$ C	28 days
Nutrients: Ammonia, Nitrate+Nitrite, and Total Nitrogen	125 mL Clear Poly	125 mL	Pre-acidify w/ H_2SO_4; Cool to $\leq 6^{o}$ C	28 days
Total Metals	500 mL HDPE	350 mL	HNO_3 to pH < 2; Cool to $\leq 6^{o}$ C	6 months
Dissolved Metals	500 mL HDPE	350 mL	Field filter w/ 0.45 µm; HNO_3 to pH < 2; Cool to $\leq 6^{o}$ C	6 months
TPH-D	1 L Amber Glass	3 L	Cool to $\leq 6^{o}$ C	14 days
TPH-G	40 mL VOAs	360 mL	1:1 HCl to pH < 2; Cool to $\leq 6^{o}$ C	14 days
Oil and grease	1 L Glass	3 L	1:1 HCl, pH < 2; Cool to $\leq 6^{o}$ C	28 days
BNAs	1 Gallon Glass	3 L	Cool to $\leq 6^{o}$ C	7 days
PAHs	1 L Amber Glass	1 L	Cool to $\leq 6^{o}$ C	7 days
Chlorinated Pesticides	1 L Amber Glass	1 L	Cool to $\leq 6^{o}$ C	7 days
PCB Congeners	2.5 L Amber Glass	2.5 L	Cool to $\leq 6^{o}$ C	1 year
PBDE Congeners	1 L Amber Glass	1 L	Cool to $\leq 6^{o}$ C	1 year
Total 18.06 L				

Table C-4. Sample containers, requested mass, preservation, and holding times for river particulate samples.

Parameter	Bottle Type and Volume	Sample Mass Requested * (wet weight)	Preservation	Holding Time
Percent Solids	2 oz Glass	50 Grams	Cool to ≤ 6° C	7 days
TOC			Cool to ≤ 6° C; may freeze at -18°C	14 days; 6 months frozen
Metals Total Recoverable			Cool to ≤ 6° C; may freeze at -18°C	6 months; 2 years frozen
BNAs **	8 oz Glass	250 Grams	Cool to ≤ 6° C; may freeze at -18°C	14 days; 1 year frozen
PAHs **				
TPH-D **			Cool to ≤ 6° C	14 days
PCB Congeners		50 Grams	Cool to ≤ 6° C; may freeze at -18°C	1 year
PBDE Congeners		50 Grams	Cool to ≤ 6° C; may freeze at -18°C	1 year
Total 450 Grams				

* The minimum mass required to obtain specified detection limits for each analysis is less than the mass requested by analytical laboratories listed here and in the QA Project Plan.

** Insufficient particle mass was collected at the Stillaguamish River to conduct these analyses.

Analytical Methods

Table C-5. Summary of marine water column sample analyses.

Number of samples analyzed includes field QA samples.

Parameter	Samples Analyzed	Final Reporting Limits	Preparation/ Extraction	Cleanup	Analytical Method	Method Description
Conventionals (mg/L)						
TSS	48	0.5 - 2.0	-	-	SM 2540 D	Gravimetric
POC	48	0.015 *	Acidification of dried samples	-	SM 5310	Combustion/oxidation Thermal conductivity
DOC	42	0.018 *	Filter 0.7 µm GFF	-		Combustion, Infrared detection
Total Recoverable and Dissolved Metals (µg/L)						
Arsenic	48 (total) and 47 (diss.)	0.05	• Reductive co-precipitation • Acid Digest • For dissolved metals, prefilter through 1.2 µm glass microfiber filters	-	FGS 054	ICP-MS
Cadmium		0.01				
Copper		0.05				
Lead		0.05				
Zinc		0.25				
Organic Compounds (µg/L unless noted otherwise)						
BNAs	48	0.08 - 3.6	Extraction	-	EPA 8270	Capillary GC/MS
PAHs	47	0.01- 0.02	Solid Phase	-	EPA 8270 SIM	GC/MS
Chlor. Pesticides (ng/L)	46	0.2 - 1.0	EPA 3510	-	EPA 8081	GC/ECD
PCB Congeners (pg/L)	53	3.9 - 0.6	Dichloromethane	Acid/base wash	EPA 1668A	GC/HRMS
PBDE Congeners (pg/L)	47	24 - 255			EPA 1614	

* These values are detection limits. The detection limit for POC is based on filtering 0.75 liters of seawater.

EPA = U.S. Environmental Protection Agency
FGS = Frontier GeoSciences
GC/HRMS = Gas Chromatography / High Resolution Mass Spectrometry
GC/MS = Gas Chromatography / Mass Spectrometry
ICP-MS = Inductively-coupled plasma detector, mass spectrometer confirmation
SIM = Selective Ion Monitoring
SM = Standard Methods (APHA, 2005)

Table C-6. Summary of river water sample analyses.

Number of samples analyzed includes field QA samples.

Parameter	Samples Analyzed	Final Reporting Limits	Preparation Method	Cleanup Method	Analytical Method	Method Description
Conventionals, Nutrients, and Hardness (mg/L)						
TSS	18	0.6 - 4.3	-	-	SM 2540 D	Gravimetric
TOC		1.0	Acidification	-	SM 5310 C	Combustion to CO_2 Infrared detection
DOC			Filtration (0.45 μm), Acidification			
Nutrients *	17	0.003 - 0.025	Reaction, Reduction or Digestion	-	SM 4500	Colorimetric
Hardness	18	0.3	Acidification	-	EPA 200.7	ICP, Calculation
Petroleum Products (mg/L)						
Oil and Grease	18	1.6 - 5.6	Hexane extraction	-	EPA 1664A	Gravimetric
TPH-D		0.02 - 0.13	Extraction	Acid/ silica	ECY 97-602	GC/FID
TPH-G	30	0.14	Acidification and Extraction			Purge and Trap GC/FID
Total Recoverable and Dissolved Metals (µg/L)						
Arsenic, Copper	21 (total) and 21 (diss.)	0.10	Acidification and Filtration (0.45um) + Acidification	-	EPA 200.8	ICP - MS
Cadmium, Lead		0.02 - 0.10				
Zinc		1.0 - 5.0				
Organic Compounds (µg/L unless noted otherwise)						
BNAs	19	0.08 - 3.4	Extraction	-	EPA 8270	Capillary GC/MS
PAHs	19	0.01 - 0.02	Solid Phase Extraction	-	EPA 8270 SIM	GC/MS
Chlorinated Pesticides (ng/L)	19	0.2 - 11	Extraction, EPA 3510	-	EPA 8081	GC/ECD
PCBs (pg/L)	21	3.8 - 11.4	Dichloromethane Extraction	Acid/ base wash	EPA 1668A	High Resolution GC/MS
PBDEs (pg/L)	20	12 - 280			EPA 1614	

* Total persulfate, nitrite plus nitrate, and ammonia nitrogen; total available and ortho-phosphate.
GC/FID = Gas chromatography/flame ionization detection
GC/ECD = Gas chromatography/electron capture detection

Table C-7. Summary of analyses for SPM collected from marine sediment traps and rivers.

Parameter	Sediment Trap Samples	Suspended River Solids	Final Reporting Limits	Sample Preparation Method	Sample Cleanup Method	Analytical Method	Method Description
Conventional parameters (%)							
Percent Solids	1	5	1	-	-	EPA 160.3	
TOC			0.1	-	-	PSEP, 1986/1997 EPA 415.1	
Metals - Total Recoverable (mg/Kg)							
Arsenic, Cadmium, Copper, Lead	2	5	0.05 - 0.1	SW-846 3050B	-	EPA 200.8	ICP - MS
Zinc			2.5 - 5.0				
Organic compounds (µg/Kg unless noted otherwise)							
TPH-D (mg/Kg)	-	4	10 - 44	SW-846 Extraction	-	EPA 8270	GC/FID
BNAs			21 - 740				Capillary GC/MS
PAHs			1.4 - 14	Soxhtherm Extraction	Silica Gel	EPA 8270 SIM	GC/MS
Chlorinated Pesticides			0.12 – 3.2	Extraction EPA 3541	-	EPA 8081	GC/ECD
PCB Congeners (ng/Kg)	2	5	4 - 22	Soxhlet Extraction	Acid/base wash	EPA 1668A	High Resolution GC/MS
PBDE Congeners (ng/Kg)			14 - 174			EPA 1614	

Appendix D. Data Quality

Study-Specific Data Quality Rules

Chemical Qualifier Code Revisions

Field QA Sample Descriptions and Results

Study-Specific Data Quality Rules

Assigning chemical qualifiers

- No chemical qualifier code was assigned when:
  - a concentration was greater or equal to the estimated quantitation limit (EQL), practical quantitation limit (PQL), or reporting limit (RL) listed by the laboratory, *and*
  - all or nearly all lab QC sample results were within specified control limits, *and*
  - the analyte of interest was positively identified.
- An "N" qualifier code was assigned to an otherwise unqualified result when the analyte could not be positively identified but there was evidence it was present [third condition above not met].
- A "J" qualifier code, indicating an estimated concentration, was assigned when:
  - a result was greater than or equal to the EQL, PQL, or RL, *and*
  - some lab QC sample results were outside specified control limit, *and*
  - the analyte of interest was positively identified.
- An "NJ" was assigned to an estimated concentration of a tentatively identified analyte.
- A "J" qualifier code, indicating an estimated concentration, was assigned when a detected concentration was less than the EQL, PQL or RL, but greater than or equal to the estimated detection limit (EDL) or method detection limit (MDL) listed by the laboratory. Concentrations were reported down to the listed EDL or MDL whenever possible.
- Valid EIM result data qualifiers (e.g., "G" or "L") that preserve evidence of low or high analytical bias were not assigned.
- An "REJ" qualifier code was assigned when the presence or absence of an analyte was not verified because of serious problems associated with the sample analysis or lab QC sample performance (results consistently or well outside of control limits). The result was unusable.
- A "U" was assigned when the analyte was not detected at or above a defined numeric value. Depending on the parameter and analytical purpose, nondetect values were set at the quantitation limit (EQL, PQL, or RL) or the detection limit (EDL or MDL). Sometimes results were presented using both methods of assigning concentrations to nondetect results.
- A "UJ" qualifier code was assigned to an individual analytical result for a variety of reasons:
  - The analyte was not detected at or above a quantification limit that is uncertain.
  - Initial or ongoing instrument calibrations were unacceptable.
  - Results for one or more lab QC samples were outside control limits.
  - The analyte was also detected in the lab method blank (see below).

Assigning chemical qualifiers and data flags due to elevated method blank concentrations

- No chemical qualifier code was assigned to a sample concentration that was ≥ a quantitation limit (EQL, PQL, or RL) and ≥ 10 times the concentration in the associated method blank.
- A "J" qualifier code was assigned to a sample concentration greater than or equal to three times (≥3 X) and less than or equal to ten times (≤ 10X) the concentration detected in the associated method blank. A "B" flag was entered into the associated EIM comment field to indicate that "J" was assigned because of the elevated blank concentration.
- A "UJ" qualifier code was assigned to a sample concentration ≥ EDL or MDL and less than three times (< 3X) the concentration detected in the associated method blank. A "B" flag was entered into the associated EIM comment field to indicate that "UJ" was assigned because of the elevated blank concentration and that the result may be used for some purposes.

Correcting for analytes detected in method blanks

Sample concentration results were not corrected for the presence of the same analyte in the batch-specific method blank. Exceptions included the following marine water column sample results:

- DOC. The mass of carbon (µg C) measured on batch-specific filter adsorption blanks was added to the µg C measured in filtered marine water column samples.
- POC. The µg C measured on batch-specific filter trip blanks was subtracted from the µg C measured on marine water column sample filters. The resulting sample concentration was then adjusted for the µg C (DOC) measured on batch-specific filter adsorption blanks.
- Metals. The contract laboratory adjusted the measured concentrations of metals in marine water column samples by subtracting the mean concentration measured in 3 batch-specific "preparation" (method) blanks. Ecology staff derived the original (uncorrected) lab result by adding the mean preparation blank concentration to the reported results. A different chemical qualifier code was then assigned if appropriate.

Correcting for analytes detected in field blanks

Sample results were not modified when field blanks (bottle, filter, transfer, and sampler blanks) showed presence of the same analyte. This decision was based on the following lines of evidence:

- Field blanks, although attempting to mimic sampling processes, were exposed to sources of contamination that the marine and river water samples were not.
  - Marine water column samples were thoroughly pre-rinsed with seawater.
  - Marine water column and river water samples were not exposed to ambient air to the same extent as were field blanks.
- The "fingerprint" of organic compounds (PCB and PBDE congeners) in field blanks was different from that found in field samples.

Summing analytes to estimate total concentrations

Summing rules were developed from Ecology internal *Guidance for Calculating Total Values of Selected Analytes for the EAP Toxics Studies Unit and EIM Parameter Names to Use (2008):*

- If some of the individual analytes were detected (greater than or equal to EDL or MDL), then only detected concentrations were summed to represent the total concentration.
- If none of the individual analytes was detected (greater than or equal to EDL or MDL), then various alternatives were taken:
  - For summed PAH values, ½ the RL was assigned to each PAH compound.
  - For summed PAH values, the MDL was assigned to each PAH compound.
  - For total PCBs and total PBDEs, the largest nondetect concentration (RL) for an individual congener was used.

Using nondetect values

Descriptive statistics and other statistical analyses, as well as estimates of annual mass exchange and loading of toxic chemicals, sometimes involved chemicals or chemical classes that were never or seldom detected in the water samples collected. Therefore, it was important to determine how to use nondetect ("U") values in statistics and calculations.

Several options were considered for using nondetect values for toxic chemicals such as petroleum-related compounds, BNAs, PAHs, chlorinated pesticides, and PBDEs. For statistical summaries and analyses, nondetect values were not used unless stated otherwise in the report. For calculations of annual mass fluxes and loadings, based on multiplying mean water concentrations by predicted water flux or river flow, nondetect values were used as follows:

- When all or most samples had detected concentrations, nondetect values were not used to calculate mean water concentrations.
- When a parameter was never or seldom detected, flux and loading calculations were based on:
  - Nondetects = 1/2 the RL.
  - Nondetects = the detection limit (EDL or MDL), if available.

Chemical Qualifier Code Revisions

Table D-1. Summary of data qualifier changes made to marine water column results (not including field QA samples) during project staff review.

QC Code Change	TSS	POC	DOC	As	As dissolved	Cd total	Cd dissolved	Cu total	Cu dissolved	Pb total	Pb dissolved	Zn total	Zn dissolved	Chlor Pest	BNAs	PAHs	PCBs	PBDEs	Total Changes
"_" → J	-	-	-	-	-	-	-	1	3	2	1	35	31	-	-	-	-	-	73
"_" → UJ	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
J → "_"	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	3
J → UJ	-	-	-	-	-	-	-	-	-	5	3	-	2	-	1	-	-	-	11
U → J	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	3
U → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
U1 → U2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
B → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	10
UJ → "_"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2
UJ → J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	7
B Flag *	-	-	-	-	-	-	-	1	3	8	8	38	37	51	37	2	38	110	333
Total Changes	0	0	0	0	0	0	0	2	6	17	16	73	71	51	38	2	48	119	443

* Entered into EIM, separate from chemical qualifier codes, to clearly denote presence of analyte in method blank(s).

Table D-2. Summary of data qualifier changes made to marine water field QA sample results during project staff review.

QC Code Change	TSS	POC	DOC	As	As dissolved	Cd total	Cd dissolved	Cu total	Cu dissolved	Pb total	Pb dissolved	Zn total	Zn dissolved	Chlor Pest	BNAs	PAHs	PCBs	PBDEs	Total Changes
"_" → J	-	-	-	-	-	-	-	-	1	-	-	5	4	-	-	-	-	-	10
"_" → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
J → "_"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
J → UJ	-	-	-	-	-	-	-	2	1	1	1	1	-	-	-	-	-	-	6
U → J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
U → UJ	-	-	-	-	-	-	-	1	1	1	1	-	1	-	-	-	-	-	5
U1 → U2	-	2	3	3	3	3	3	-	-	-	1	-	-	-	-	-	-	-	18
B → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	6
UJ → "_"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
UJ → J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
B Flag *	-	-	-	-	-	-	-	3	3	2	2	6	5	4	6	-	10	14	55
Total Changes	0	2	3	3	3	3	3	6	6	4	5	12	10	4	6	0	16	15	101

* Entered into EIM, separate from chemical qualifier codes, to clearly denote presence of analyte in method blank(s).

Table D-3. Summary of data qualifier changes made to river water results (not including field QA samples) during project staff review.

QC Code Change	TSS	TOC	DOC	Ammonia	Nitrate+Nitrite	Total N (TN)	Total P (TP8)	Ortho-P	Hardness	As total	As dissolved	Cd total	Cd dissolved	Cu total	Cu dissolved	Pb total	Pb dissolved	Zn total	Zn dissolved	HEM	TPH-D	TPH-G	Chlor Pest	BNAs	PAHs	PCBs	PBDEs	Total Changes
"_" → J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	2	-	-	-	-	-	-	-	-	-	5
"_" → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
J → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
U → "_"	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	3
U → J	-	7	6	2	-	-	-	-	-	-	-	15	8	-	-	3	2	7	4	5	-	-	-	-	-	-	-	59
U → UJ	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-	-	-	-	-	-	-	-	3
U1 → U2	-	-	-	5	-	-	-	-	-	-	-	-	5	-	-	-	4	-	-	-	-	-	-	-	-	-	-	14
B Flag *	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	8	-	7	-	-	-	-	16	12	10	15	27	96
Total Changes	0	7	7	8	0	0	0	0	0	0	0	15	15	0	0	16	6	17	5	5	0	0	16	12	11	15	27	182

* Entered into EIM, separate from chemical qualifier codes, to clearly denote presence of analyte in method blank(s).

Table D-4. Summary of data qualifier changes made to river water QC sample results during project staff review.

QC Code Change	TSS	TOC	DOC	Ammonia	Nitrate+Nitrite	Total N (TN)	Total P (TP8)	Ortho-P	Hardness	As total	As dissolved	Cd total	Cd dissolved	Cu total	Cu dissolved	Pb total	Pb dissolved	Zn total	Zn dissolved	HEM	TPH-D	TPH-G	Chlor Pest	BNAs	PAHs	PCBs	PBDEs	Total Changes
"_" → J	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
"_" → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
J → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
U → "_"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
U → J	-	1	1	1	-	-	-	-	-	-	-	3	2	-	1	1	1	3	1	1	-	-	-	-	-	-	-	16
U → UJ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	2	-	-	-	-	-	-	-	-	-	5
U1 → U2	-	-	-	-	-	-	-	-	-	3	3	3	4	1	-	-	2	-	-	-	-	-	-	-	-	-	-	16
B Flag *	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	4	-	4	-	-	-	-	5	3	4	8	7	36
Total Changes	0	1	1	1	0	0	0	0	0	3	3	6	6	3	1	8	3	9	1	1	0	0	5	3	4	8	7	74

* Entered into EIM, separate from chemical qualifier codes, to clearly denote presence of analyte in method blank(s).

Field Quality Control Sample Descriptions and Results

Field replicates

Replicate sampling involved the analysis of two samples collected in an identical manner and in close spatial and temporal proximity. Field replicates provide a measure of field precision and allow for the assessment of the environmental variability of concentrations of target parameters.

Marine water column field replicates

- Parameters analyzed: All.
- Procedure: Following water collection from a regular sampling site, the GO-FLO samplers were immediately redeployed and collection was repeated at the same location and depth.

River water field replicates

- Parameters analyzed: All.
- Procedure: First, the complete set of depth-integrated river water samples was collected (compositing from three quarter points). After these samples were processed and stored, the river was sampled a second time using a new, acid-cleaned sampler.

Results for each replicate sample are presented beside the regular station sample results in Tables D-5, D-7, and D-8 for marine water, and in Tables D-11, D-13, and D-14 for river water. Replicate results were in good agreement with their corresponding station sample results for most parameters, as indicated by low relative percent difference (RPD) values. Marine water POC, marine water dissolved lead, and river water total cadmium occasionally had elevated RPDs that were attributable to low measured concentrations (i.e., near the analytical method detection limit) that exaggerated differences.

Elevated RPDs for other parameters suggested environmental variability. Slightly elevated RPDs for total PCB replicate sample pairs in both marine and river waters showed that samples collected in close spatial and temporal proximity may yield slightly variable concentration measurements, likely as a consequence of the affinity of these chemicals for particulates. Marine total lead and freshwater dissolved copper replicate pairs also had instances of anomalously high RPDs, but the observed variability was nowhere above what might be expected for samples collected up to three hours apart in dynamic bodies of water. As such, replicate results did not warrant the re-qualification of any project data.

For the purposes of this report, field replicates were used for QA assessment only; field replicate results were not averaged with their corresponding station sample results for data analyses presented in this document.

Field Duplicates

Duplicate sampling involved the analysis of two samples obtained from a single water collection. Field duplicates allow for the evaluation of analytical variability, or lab precision.

Marine water column field duplicates

- Parameters analyzed: TSS, DOC, POC, and PCB congeners.
- Procedure: Two samples for a given parameter were decanted from a single GO-FLO water collection. Organic carbon samples were processed simultaneously on separate clean filtration apparatuses.

Results for each duplicate sample are presented beside their corresponding station samples in Tables D-6 and D-7. These pairs of results generally agreed very well, as indicated by their low RPDs. Thus, duplicates were not used to re-qualify any project data.

For the purposes of this report, the results of the field duplicate analyses were not averaged with their corresponding station sample results.

Bottle and transfer blanks

Bottle blanks involved the analysis of analyte-specific blank water that was carried unopened into the field and treated as a sample. Transfer blanks involved pouring the same lab-provided blank water into a sample bottle in the field. These types of blanks allow for the evaluation of contamination arising from the sample bottles themselves, from general bottle handling, and from the atmosphere during sample transfers. Results also allow evaluation of the cleanliness of the blank water that was used for other field QA samples, such as equipment blanks.

Marine water column bottle blanks

- Parameters analyzed: PCB congeners.
- Procedure: Lab blank water obtained from Analytical Perspectives was brought unopened into the field and treated as a sample.

River water transfer blanks

- Parameters analyzed: Total metals, chlorinated pesticides, BNAs, PAHs, PCB congeners, and PBDE congeners.
- Procedure: For total metals, blank water from MEL's metals lab was transferred (by pouring) to an acidified sample bottle. For organics, blank water from MEL's organics lab was carried in 1-gallon glass containers and transferred into individual sample bottles.

Results for the two marine PCB bottle blanks are presented in Table D-10. Both bottle blanks showed low concentrations of four PCB congeners in Analytical Perspectives reagent water. These congeners were not detected in the corresponding method blanks, suggesting that the detected contamination was associated with bottle transport and handling. From only two blanks it was unclear whether this congener-specific contamination might be pervasive throughout the marine water column samples. For the purposes of this project, results were not re-qualified at the congener level based on this potential contamination.

Results for the freshwater transfer blanks are given in Tables D-12 and D-14. A low concentration of zinc was detected in the total metals transfer blank, likely attributable to atmospheric exposure during the unprotected transfer process. No contamination was detected in the transfer blanks for chlorinated pesticides and BNAs, and only a low concentration of naphthalene was detected in the PAH transfer blank. The results for both PCB and PBDE

transfer blanks were deemed unusable due to the improper creation of these samples (blank water should have come from Analytical Perspectives and Pacific Rim laboratories, not MEL). Overall, transfer blanks for river water sampling did not warrant re-qualification of project results.

Tubing and filter blanks

Tubing and filter blanks were created by mimicking transfers through tubing and contact with filtration apparatuses that occur during regular sampling. These blanks help assess metals contamination arising from the pumping and filtration systems.

Marine water column tubing and filter blanks

- Parameters analyzed: Total and dissolved metals.
- Procedure: Metals reagent water (supplied by Frontier Geosciences) was drawn directly from its bottle using a peristaltic pump and a clean tubing train. The tubing train was flushed with 250-500 mL of reagent water before rinsing and filling the tubing blank bottle. A new, clean filter was connected in-line and the filter was flushed with at least 500 mL of blank water before filling the filter blank bottle.

River water filter blanks

- Parameters analyzed: Dissolved metals.
- Procedure: Reagent water from MEL's metals lab was filtered through a clean filtration apparatus, and the filtrate was poured into a pre-acidified sample bottle.

Results for tubing and filter blanks from marine sampling are presented in Table D-9. Lead and zinc were detected in the tubing blank. It had been necessary to modify the tubing train in the field prior to conducting this tubing blank (using a Teflon-coated tubing cutter of uncertain cleanliness), and the detected lead and zinc were likely attributable to that adjustment. Project results for marine metals were not re-qualified based on tubing and filter blanks.

Results for the freshwater filter blank are shown in Table D-12. Very low concentrations of dissolved copper and zinc were detected in the blank, but these were deemed insufficient to warrant the re-qualification of project results for river water metals.

Sampler blanks

Sampler blanks involved the placement of analyte-specific laboratory reagent water into the sampling gear (GO-FLO samplers for marine water, DH-95 bottle/cap/nozzle set-up for river water) to mimic sample water contact with the collection equipment. These blanks allow assessment of contamination arising from pre-cleaning methods, the sampling equipment itself, and sample decanting procedures.

Marine water column sampler blanks

- Parameters analyzed: All.
- Procedure: GO-FLO samplers were rinsed thoroughly with analyte-specific blank water and emptied, re-filled with blank water, and then a subsample was decanted through clean Teflon tubing following standard procedures. Sampler blanks were conducted using GO-FLO

samplers immediately after acid-cleaning, as well as samplers that had been used (or "conditioned") by previous deployments to collect site water.

River water sampler blanks

- Parameters analyzed: Total and dissolved metals, chlorinated pesticides, BNAs, PAHs, PCB congeners, and PBDE congeners.
- Procedure: The DH-95 bottle/cap/nozzle was rinsed with analyte-specific blank water and emptied, re-filled, assembled, and left for two minutes to approximate the duration that a typical water collection would be in contact with the sampling gear. In September 2009 the sampler was left exposed to the bridge atmosphere for the two minutes, while in December 2009 the opening of the bottle/cap/nozzle was covered with a nitrile glove to minimize exposure to airborne contaminants.

Results for marine sampler blanks are presented in Tables D-9 and D-10. All parameter results for the July 2009 "used" sampler blank were discarded, for these blanks were improperly created using blank water that was not obtained from the appropriate analytical laboratories. Blanks created immediately after acid-cleaning the sampling equipment detected low concentrations of total and dissolved lead and zinc, as well as several BNA and PAH compounds and a number of PCB congeners. However, "used" sampler blanks revealed that nearly all of these contaminants were absent after normal use of the equipment during sampling. During deployment the GO-FLO samplers were flushed with site water as they were lowered to the collection depth, and this appeared to be sufficient to remove residual contamination from pre-cleaning procedures.

Potential PCB contamination from marine sampling gear was investigated in January 2010. A blank was first created using an acid-cleaned sampler. Next the sampler was deployed to a depth of 60 meters (flushing to depth) where site water was collected. Finally a "used" (or "conditioned") sampler blank was created. A bottle blank was also conducted to determine the presence of congener-specific contamination from the laboratory reagent water used in the creation of the sampler blanks. After accounting for congener-specific, low-level contamination from the lab water and from cleaning procedures (i.e., contamination that was noted to "wash away" during deployment), only three to six PCB congeners appeared to persist in the "conditioned" sampler blank. These lines of evidence suggested that much of the residual contamination from pre-cleaning procedures was removed by the thorough flushing of the sampler during deployment.

Results for river sampler blanks are shown in Tables D-12 and D-14. September 2009 sampler blanks appeared to have been influenced by exposure to the bridge atmosphere during creation. This exposure was well in excess of that experienced by regular samples during standard collection procedures, and so the results of these sampler blanks were deemed unrepresentative. Despite precautions in December 2009, those sampler blanks also appear to have been exposed to contamination sources not experienced during normal sampling activities.

This contention is supported by PCB congener *fingerprints*, which showed that field blanks tended to contain greater abundance of mono- to tri-chlorinated congeners and relatively lower concentrations of tetra- to hepta-chlorinated congeners. This was not the pattern for river water or marine water column samples. If PCBs in water samples were derived from the same sources as field blanks, then similar total concentrations and similar congener compositions would be

expected. Therefore, the sources of elevated PCB congener concentrations in field blanks were different from the sources of PCBs in marine water column or river water samples.

One explanation is that the high-quality de-ionized water used to create most field blanks (<15 pg/L) effectively scavenged PCBs from the ambient air (to which field blanks were exposed longer than actual water samples).

Overall, it was concluded that sampler blanks did not exactly reproduce conditions encountered during normal sampling procedures. Sampler blanks reflected opportunities for contamination not shared with actual marine and river water samples, and so sampler blank results were not used to further interpret or qualify sample results.

Organic Carbon Blanks

A variety of field blanks were created to evaluate the newly developed protocols for marine organic carbon sampling. These included the following:

Laboratory filter blanks

- Purpose: Quantification of the mass of "background" carbon inherent in a typical filter.
- Procedure: The analytical lab (Horn Point) retained and analyzed several clean, unused filters from the batch that was sent for field sampling.

Filter trip blanks

- Purpose: Quantification of the mass of carbon that accumulated on a filter during typical transport and handling activities.
- Procedure: A filter from the batch provided by the analytical lab was carried unopened into the field and treated as a POC sample. During October 2009 and January 2010 sampling, a total of eight filter trip blanks were conducted.

Adsorption blanks

- Purpose: Determination of the concentration of carbon that was adsorbed to a typical filter during filtration.
- Procedure: Standard marine carbon filtration procedures were followed, but using two "stacked" filters. After subtracting the background carbon mass inherent in a typical filter, the mass of carbon measured on the lower filter and the volume of sample water filtered were used to calculate the concentration of adsorbed carbon. The mass of carbon adsorbed was assumed to increase linearly with the volume of sample filtered.

Results for the various organic carbon blanks were used to blank-correct marine sample results. The average mass of background carbon inherent in a filter was 8.40 μg C, and the average mass accumulated during transport and handling was 4.84 μg C. That combined mass of carbon (13.24 μg C) accounted for an average of 25% of each regular project sample's total measured (i.e., uncorrected) POC. After these "filter effects" were subtracted from POC measurements, the average carbon concentration contributed by adsorption of DOC to the filter (mg C per liter filtered) was 0.0045 mg/L C, accounting for approximately 7% of the remaining total measured POC. This adsorbed carbon was also subtracted from the total measured POC to arrive at a final

result. For DOC, the only blank correction needed was to add the carbon that was lost due to adsorption during filtration (proportional to the volume filtered).

Example series of measurements and calculations for blank-correction of POC results

a) The POC sample was obtained by filtering 600 mL of sample water.
b) The instrument-measured carbon signal of the sample filter = 1445 µVolts.
c) The average carbon signal measured in three lab filter blanks = 168 µVolts.
d) Sample filter carbon signal, corrected for average lab filter blank carbon signal, equals:
   1445 – 168 = 1277 µVolts.
e) Average carbon signal measured in three filter trip blanks = 74.7 µVolts.
f) Sample filter carbon signal, corrected for average filter trip blank carbon signal, equals:
   1277 – 74.7 = 1202.3 µVolts.
g) "K-factor" (provided by the lab) allows conversion of a carbon signal to mass:
   "K-factor" = 23.0 µVolts / µg carbon.
h) Mass of carbon on filter, corrected for lab and field filter blanks, equals:
   1202.3 / 23.0 = 53.6 µg carbon.
i) Calculate the carbon concentration of the three individual adsorption blanks. For example, the creation of one adsorption blank had involved "stacked" filtration of 435 mL of sample water. After correcting the measured carbon signal for lab and field filter blanks and then applying the K-factor, the mass of adsorbed carbon was 2.51 µg carbon. Thus, the carbon adsorbed to the filter was:
   2.51 / 435 = 0.006 mg/L carbon.
   That is, 0.006 mg carbon was adsorbed to the filter for every liter filtered.
j) The average carbon concentration of the three adsorption blanks = 0.0045 mg/L carbon.
k) The mass of carbon adsorbed for the sample of interest equals:
   600 mL filtered X 0.0045 mg/L carbon = 2.70 µg carbon.
l) The mass of carbon on the filter, corrected for the adsorbed mass, equals:
   53.6 – 2.7 = 50.9 µg carbon.
m) Finally, the concentration of POC in the sample water equals:
   50.9 µg carbon / 600 mL filtered = 0.085 mg/L POC.

Table D-5. Summary of field replicate results for marine water samplings.

Non-detect values for the listed BNA compounds are given at the reporting limit (RL). Total PCB values are sums of detected congeners (unqualified and J-qualified results). PCB homolog and congener results for field replicates are detailed in Tables D-7 and D-8, respectively.

Parameter	Field Replicates									
	July 2009			Sept 2009			Jan 2010			Mean RPD
	Sample	QA Rep	RPD	Sample	QA Rep	RPD	Sample	QA Rep	RPD	
Conventional Parameters (mg/L)										
TSS	3.5	2.1	50	1.1	1.1	0.0	0.8	1.0	22	24
POC	-	-	-	0.093	0.063	38	0.071	0.028	86	62
DOC	-	-	-	0.756	0.747	1.1	0.771	0.799	3.6	2.4
Metals (µg/L)										
Arsenic, total	1.46	1.44	1.4	1.47	1.36	7.8	1.53	1.56	1.9	3.7
Arsenic, dissolved	1.54	1.46	5.3	1.40	1.35	3.6	-	-	-	4.5
Cadmium, total	0.085	0.085	0.0	0.092	0.080	14	0.082	0.080	2.5	5.5
Cadmium, dissolved	0.086	0.086	0.0	0.077	0.093	19	-	-	-	9.0
Copper, total	0.49	0.45	8.5	0.34	0.31	9.2	0.48	0.47	2.1	7.1
Copper, dissolved	0.41	0.39	5.8	0.31	0.30	4.2	-	-	-	5.0
Lead, total	0.114	0.056	68	0.046 J	0.025 UJ	-	0.033 J	0.048 J	37	53
Lead, dissolved	0.033 J	0.021 J	44	0.018 J	0.021 UJ	-	-	-	-	44
Zinc, total	0.74 J	0.99 J	29	0.91 J	0.48 J	62	0.88 J	0.76 J	15	35
Zinc, dissolved	0.69 J	0.72 J	4.3	0.70 J	0.46 J	42	-	-	-	23
Chlorinated Pesticides (ng/L)										
All 33 chlorinated pesticide compounds	ND	ND	-	ND	ND	-	ND	ND	-	-
BNAs (µg/L)										
4-Chloro-3-Methylphenol	0.91 UJ	0.006 J	-	0.8 UJ	0.85 UJ	-	-	-	-	-
Cholesterol	0.91 UJ	0.84 U	-	0.7 J	0.74 J	5.6	-	-	-	5.6
54 other BNA compounds	ND	ND	-	ND	ND	-	-	-	-	-
PAHs (µg/L)										
All 22 PAH compounds	ND	ND	-	ND	ND	-	ND	ND	-	-
PCB Congeners (pg/L)										
Total PCBs	43.92 J	31.12 J	34	33.583 J	19.058 J	55	18.39 J	22.59 J	20	36
PBDE Congeners (pg/L)										
BDE-099	10.9 UJ	53.9 J	-	17.9 UJ	14.1 UJ	-	-	-	-	-
BDE-100	10 UJ	19.4 J	-	10 UJ	10 UJ	-	-	-	-	-
34 other PBDE congeners	ND	ND	-	ND	ND	-	-	-	-	-
Total PBDEs	127.6 U	73.3 J	-	122.5 U	130.2 U	-	-	-	-	-

Table D-6. Summary of field duplicate results for marine water samplings.

Non-detect values for POC are given at the method detection limit (MDL). Total PCB values are sums of detected congeners (unqualified and J-qualified results). PCB homolog and congener results for field duplicates are detailed in Tables D-7 and D-8, respectively.

Parameter	Field Duplicates									
	July 2009			Sept 2009			Jan 2010			Mean RPD
	Sample	QA Dup	RPD	Sample	QA Dup	RPD	Sample	QA Dup	RPD	
TSS (mg/L)	2.6	2.4	8.0	1.1	0.9	20	-	-	-	14
	3.5	2.5	33	-	-	-	-	-	-	33
POC (mg/L)	-	-	-	0.063	0.068	7.6	0.028	0.049	55	31
	-	-	-	0.058	0.051	13	0.011 U	0.011 U	-	13
DOC (mg/L)	-	-	-	0.035	0.045	25	0.799	0.757	5.4	15
	-	-	-	0.802	0.722	11	0.084	0.162	63	37
Total PCBs (pg/L)	31.12 J	30.31 J	2.6	-	-	-	-	-	-	2.6

Table D-7. Summary of PCB homolog totals in field replicates and field duplicates for marine water samplings.

Homolog totals and Total PCB values are sums of detected congeners (unqualified and J-qualified results). PCB congener results for field replicates and field duplicates are detailed in Table D-8.

PCB Homolog (pg/L)	Field Replicates										Field Duplicates		
	July 2009			Sept 2009			Jan 2010			Mean RPD	July 2009		
	Sample	QA Rep	RPD	Sample	QA Rep	RPD	Sample	QA Rep	RPD		Sample	QA Dup	RPD
Mono-CBs	5.21 U	10.2 U	-	2.793 J	5 U	-	3.91 U	4.15 U	-	-	10.2 U	10.3 U	-
Di-CBs	4.09 J	3.15 J	26	3.783 J	2.14 J	55	3.91 U	1.7 J	-	41	3.15 J	2.6 J	19
Tri-CBs	4.87 J	10.2 U	-	4.814 J	0.798 J	143	3.91 U	1.28 J	-	143	10.2 U	1.84 J	-
Tetra-CBs	18.748 J	11.34 J	49	14.27 J	11.58 J	21	15.96	11.99 J	28	33	11.34 J	14.58 J	25
Penta-CBs	8.822 J	9.73 J	9.8	6.623 J	3.45 J	63	2.43 J	2.55 J	4.8	26	9.73 J	8.72 J	11
Hexa-CBs	7.39 J	6.9 J	6.9	1.3 J	1.09 J	18	3.91 U	5.07 J	-	12	6.9 J	2.57 J	91
Hepta-CBs	5.21 U	10.2 U	-	4.13 U	5 U	-	3.91 U	4.15 U	-	-	10.2 U	10.3 U	-
Octa-CBs	5.21 U	10.2 U	-	4.13 U	5 U	-	3.91 U	4.15 U	-	-	10.2 U	10.3 U	-
Nona-CBs	5.21 U	10.2 U	-	4.13 U	5 U	-	3.91 U	4.15 U	-	-	10.2 U	10.3 U	-
PCB-209	5.21 U	10.2 U	-	4.13 U	5 U	-	3.91 U	4.15 U	-	-	10.2 U	10.3 U	-
Total PCBs	43.92 J	31.12 J	34	33.583 J	19.058 J	55	18.39 J	22.59 J	20	36	31.12 J	30.31 J	3

Table D-8. Summary of PCB congener detects in field replicates and duplicates for marine water samplings.

Congener concentrations are listed only if detected in at least one of these blanks. U- and UJ-qualified results are not shown.

PCB Congener (pg/L)	Field Replicates						Field Duplicates	
	July 2009		Sept 2009		Jan 2010		July 2009	
	Sample	QA Rep	Sample	QA Rep	Sample	QA Rep	Sample	QA Dup
PCB-001	1.3 NJ		2.46 NJ					
PCB-002	1.4 NJ		0.336 NJ					
PCB-003	1.82 NJ		0.399 J					
PCB-004	2.27 J		1.62 J	1.35 J		1.7 J		
PCB-006			0.397 J					
PCB-008	1.82 J	3.15 J	1.41 J	0.79 J			3.15 J	2.6 J
PCB-016			0.503 J					
PCB-017	2.43 J		0.687 NJ			0.935 NJ		
PCB-018/030	2.44 J		1.12 J	0.877 NJ	1.22 NJ	1.28 J		1.8 NJ
PCB-019			0.348 J					
PCB-020/028			1.06 J	0.798 J		0.949 NJ		1.84 J
PCB-021/033			0.595 J					
PCB-022			0.35 J					
PCB-031			0.822 J			0.854 NJ		
PCB-032			0.34 NJ					
PCB-040/071	0.731 J							0.775 NJ
PCB-044/047/065	6.5	5.42 J	5.48 J	5.39 J	14.6	6.57 J	5.42 J	5.67 J
PCB-049/069	1.26 J	1.36 NJ	0.482 NJ	0.654 NJ	1.36 J	1.22 J	1.36 NJ	1.32 J
PCB-051	3.74 J	3.16 J	4.01 J	3.6 J	8.69 NJ	3.78 NJ	3.16 J	3.77 J
PCB-052	2.51 J	2.76 J	1.24 J	1.54 J	2.28 NJ	2.67 J	2.76 J	2.59 J
PCB-061/070/074/076	1.54 J		1.05 J					
PCB-064								0.594 NJ
PCB-066	0.867 J							
PCB-068	1.6 J		0.96 J	1.05 J	2.71 NJ	1.53 J		1.23 J
PCB-086/087/097/108/119/125	1.29 NJ		0.903 J					
PCB-090/101/113	3.01 J	2.75 J	1.09 J	1.87 J	2.43 J		2.75 J	3.47 J
PCB-095	2.35 J	2.34 J	0.933 J	1.58 J		2.55 J	2.34 J	3.01 J
PCB-099	0.974 NJ							
PCB-105	0.932 J		0.371 NJ					
PCB-110	2.53 J	2.63 J	0.841 J	0.867 NJ	1.52 NJ	1.12 NJ	2.63 J	1.85 NJ
PCB-118	1.42 NJ	2.01 J	0.573 J	0.852 NJ			2.01 J	2.24 J
PCB-129/138/163	2.98 J	2.49 J	0.609 J	1.09 J		2.15 J	2.49 J	2.25 NJ
PCB-147/149	1.94 J	2.19 J	0.366 NJ			1.41 J	2.19 J	1.64 NJ
PCB-153/168	2.47 J	2.22 J	0.383 J	0.642 NJ	1.11 NJ	1.51 J	2.22 J	2.57 J
PCB-169			0.337 J					
PCB-194				0.806 NJ				1.41 NJ
Total PCBs								
…including N,NJ	52.124 J	32.48 J	34.756 J	23.756 J	35.92 J	30.228 J	32.48 J	40.629 J
…excluding N,NJ	43.92 J	31.12 J	33.583 J	19.058 J	18.39 J	22.59 J	31.12 J	30.31 J

Table D-9. Summary of equipment blank results for marine water samplings.

Non-detect values for POC and metals are given at the method detection limit (MDL). Non-detect values for organic compounds are given at the reporting limit (RL).

Parameter	Tubing	Filter	Used Sampler		Acid-Cleaned Sampler	
	July 2009	July 2009	July 2009	Sept 2009	Sept 2009	Jan 2010
Conventional Parameters (mg/L)						
POC	-	-	-	-	0.063	0.011 U
	-	-	-	-	0.068 (Dup)	0.011 U (Dup)
DOC	-	-	-	-	0.035	0.084
Metals (µg/L)						
Arsenic, total	0.006 U	-	-	0.006 U	-	0.006 U
Arsenic, dissolved	-	0.006 U	-	0.006 U	-	0.006 U
Cadmium, total	0.003 U	-	-	0.003 U	-	0.003 U
Cadmium, dissolved	-	0.003 U	-	0.003 U	-	0.003 U
Copper, total	0.023 UJ	-	-	0.027 UJ	-	0.029 UJ
Copper, dissolved	-	0.033 UJ	-	0.08 J	-	0.05 UJ
Lead, total	0.015 J	-	-	0.012 UJ	-	1.85
Lead, dissolved	-	0.005 U	-	0.010 UJ	-	1.81
Zinc, total	0.440 J	-	-	0.250 UJ	-	0.350 J
Zinc, dissolved	-	0.130 UJ	-	0.510 J	-	0.390 J
Chlorinated Pesticides (ng/L)						
All 33 chlor pest compounds	-	-	ND	-	ND	-
BNAs (µg/L)						
2-Methylphenol	-	-	0.02 J	0.81 U	0.013 J	0.82 U
4-Chloro-3-Methylphenol	-	-	0.04 J	0.81 UJ	0.82 UJ	0.82 U
4-Methylphenol	-	-	0.03 J	0.81 U	0.82 U	0.82 U
Bis(2-Ethylhexyl) Phthalate	-	-	5.8	0.16 U	0.083 J	0.16 U
Bisphenol A	-	-	0.24 J	0.33 U	0.08 J	0.33 U
Butyl benzyl phthalate	-	-	2	0.33 U	0.33 U	0.33 U
Diethyl phthalate	-	-	1.1	0.16 U	0.16 U	0.16 U
Dimethyl phthalate	-	-	0.04 J	0.16 U	0.16 U	0.16 U
Ethanol, 2-Chloro-, Phosphate (3:1)	-	-	0.11 NJ	0.081 UJ	0.082 UJ	0.082 U
Phenol	-	-	0.06 J	0.33 U	0.33 U	0.33 U
Triclosan	-	-	0.17 NJ	0.057 J	0.082 U	0.082 U
45 other BNA compounds	-	-	ND	ND	ND	ND
PAHs (µg/L)						
1-Methylnaphthalene	-	-	0.037	-	0.01 U	0.01 U
2-Methylnaphthalene	-	-	0.061	-	0.01 U	0.01 U
Fluorene	-	-	0.016	-	0.01 U	0.01 UJ
Naphthalene	-	-	0.096	-	0.049	0.01 U
Phenanthrene	-	-	0.021	-	0.01 U	0.01 U
17 other PAH compounds	-	-	ND	-	ND	ND
PBDE congeners (pg/L)						
All 36 PBDE congeners	-	-	ND	-	ND	ND

Table D-10. Summary of PCB congener detects in equipment blanks for marine water samplings.

Congener concentrations are listed only if detected in at least one of these blanks. Table continues on the following page.

PCB Congener (pg/L)	July 2009	September 2009		January 2010			
	Used Sampler	Bottle Blank	Acid-Cleaned Sampler	Bottle Blank	Acid-Cleaned Sampler	Site Reference	Used Sampler
PCB-001	15.4	2.5 J	2.35 NJ	2.01 J	3.06 J		2.57 J
PCB-002	3.65 NJ	3.21 NJ	1.17 NJ	2.41 J	2.1 NJ	1.22 NJ	2.45 J
PCB-003	10.4 N	4.36 NJ	2.37 NJ	2.84 J	4.71 J	0.885 NJ	4.34 NJ
PCB-004	33.6		6.83		4.03 J		2.69 J
PCB-006	9.09		1.15 J				
PCB-007	3.37 J						
PCB-008	38.5		5.66		4.01 J	1.45 J	2.75 J
PCB-009	2.88 J						
PCB-011	46						
PCB-012/013	6.36						
PCB-015	24.6		1.55 J				
PCB-016	25.6		1.84 J		0.849 NJ		
PCB-017	26.9		3.79 J		2.19 J		2.06 NJ
PCB-018/030	48.6	0.968 J	3.58 NJ	1.3 J	2.66 J	1.45 NJ	2 J
PCB-019	8.42		1.09 NJ				
PCB-020/028	29.4		2.48 J		1.27 J	1.3 NJ	
PCB-021/033	25		3.2 J				
PCB-022	13.6						
PCB-025	4.99 J						
PCB-026/029	6.97						
PCB-027	4.58 J						
PCB-031	34		2.51 J		1.76 J	0.82 NJ	
PCB-032	13.9		1.22 NJ		0.719 NJ		
PCB-035	3.2 NJ						
PCB-037	27.4						
PCB-040/071	13.8						
PCB-041	3.37 J						
PCB-042	8.32						
PCB-044/047/065	212		101		35.7	6.76 J	19.7
PCB-046	3.04 J						
PCB-048	5.93						
PCB-049/069	34		2.99 J		1.12 NJ	1.23 J	
PCB-050/053	11.9						
PCB-051	124		75.1		24.8	3.33 J	15.9
PCB-052	157		6.94	1.11 NJ	2.88 J	2.68 J	1.61 NJ
PCB-056	8.47						
PCB-059/062/075	1.66 NJ						
PCB-060	3.27 J						
PCB-061/070/074/076	78		5.83 J				
PCB-064	18.5						
PCB-066	11.6 N		1.67 J				
PCB-068	28.5		18.2		4.22 NJ		3.57 NJ
PCB-077	16.3						
PCB-082	8.93						
PCB-083	4.99 NJ						
PCB-084	44.4		2.63 J				
PCB-085/116	12.4						
PCB-086/087/097/108/119/125	63.6		8.5 J				

PCB Congener (pg/L)	July 2009	September 2009		January 2010			
	Used Sampler	Bottle Blank	Acid-Cleaned Sampler	Bottle Blank	Acid-Cleaned Sampler	Site Reference	Used Sampler
PCB-090/101/113	105		10.8 J		2.24 NJ	2.65 NJ	
PCB-091	11.2 N						
PCB-092	18.7						
PCB-095	134		7.24 NJ		1.55 J	2.05 NJ	
PCB-096	1.89 NJ						
PCB-099	27		2.81 NJ				
PCB-105	13.9		3.1 NJ				
PCB-107/124	2.06 NJ						
PCB-109	3.11 J						
PCB-110	84.1		9.37		1.51 NJ		
PCB-118	32.5		6.33		0.946 NJ	1.63 J	
PCB-128/166	4.16 NJ						
PCB-129/138/163	26.7		5.95 J			1.49 NJ	
PCB-130	2.52 NJ						
PCB-132	14.4 N		2.93 NJ				
PCB-134	3.01 J						
PCB-135/151	14.8						
PCB-136	11.3						
PCB-137	1.67 J						
PCB-139/140	0.966 NJ						
PCB-141	5.4						
PCB-144	2.03 NJ						
PCB-146	3.22 J						
PCB-147/149	31.9		3.98 NJ			1.44 NJ	
PCB-153/168	16.1		2.28 NJ			2.31 J	
PCB-156/157	2 J						
PCB-158	2.4 NJ						
PCB-164	1.62 NJ						
PCB-170	1.39 NJ						
PCB-174	1.9 NJ						
PCB-179	1.62 NJ						
PCB-180/193	2.72 NJ						
PCB-183	1.19 NJ						
PCB-187	1.62 NJ						
Total PCBs							
…including N,NJ	1928.486	11.038 J	318.44 J	9.67 J	102.324 J	32.695 J	59.64 J
…excluding N,NJ	1839.3	3.468 J	284.32 J	8.56 J	88.62 J	19.39 J	48.06 J

Table D-11. Summary of field replicate results for river water samplings.

Total PCB and PBDE values are sums of detected congeners (unqualified and J-qualified results). PCB homolog and congener results for field replicates are detailed in Tables D-13 and D-14, respectively.

Parameter	Field Replicates									
	July 2009			Sept 2009			Dec 2009			Mean
	Sample	QA Rep	RPD	Sample	QA Rep	RPD	Sample	QA Rep	RPD	RPD
Conventional Parameters (mg/L)										
TSS	233	235	0.85	38.7	40.5	4.6	11.9	13.2	10	5.2
TOC	0.5 J	0.4 J	22	1.1	1.3	17	1.3	1.2	8.0	16
DOC	0.8 J	0.9 J	12	1.4	1.3	7.4	1.2	1.2	0.0	6.5
Ammonia	0.01	0.009 J	11	0.162	0.179	10	-	-	-	11
Nitrate+Nitrite	0.11	0.105	4.7	0.309	0.320	3.5	-	-	-	4.1
Total Nitrogen	0.137	0.132	3.7	0.545	0.580	6.2	-	-	-	5.0
Total Phosphorus	0.250	0.197	24	0.0795	0.110	32	-	-	-	28
Ortho-phosphate	0.0287	0.0319	11	0.0478	0.0527	9.8	-	-	-	10
Hardness	27.7	28.1	1.4	40.8	39.5	3.2	33.2	33.5	0.90	1.8
Metals (µg/L) [1]										
Arsenic, total	0.92	0.98	6.3	0.6	0.68	13	0.52	0.53	1.9	7.1
Arsenic, dissolved	0.46	0.47	2.2	0.62	0.64	3.2	0.5	0.49	2.0	2.5
Cadmium, total	0.01 J	0.02 J	67	0.006 J	0.006 J	0.0	0.005 J	0.006 J	18	28
Cadmium, dissolved	0.003 J	0.002 U	-	0.003 J	0.003 J	0.0	0.002 U	0.002 J	-	0.0
Copper , total	11.6	11.6	0.0	1.81	2.16	18	1.32	1.22	7.9	8.6
Copper, dissolved	4.19	0.78	137	0.91	0.73	22	0.63	1.64	89	83
Lead, total	1.42	1.49	4.8	0.2	0.28	33	0.11 UJ	0.08 UJ	-	19
Lead, dissolved	0.006 U	0.006 U	-	0.035	0.034	2.9	0.024	0.022	8.7	5.8
Zinc, total	11.6	22.2	63	3.7 J	3.4 J	8.5	2.7 UJ	2.8 UJ	-	36
Zinc, dissolved	2	4.2	71	1.2	1.5	22	1	2	67	53
Petroleum-related Products (mg/L) [2]										
Oil and grease	0.9 J	1 J	11	1.8 U	1.8 U	-	5.5 U	5.5 U	-	11
TPH-D #2 Diesel	0.05 U	0.05 U	-	0.05 U	0.05 U	-	0.02 U	0.02 U	-	-
TPH-D Lube Oil	0.13 U	0.13 U	-	0.12 U	0.12 U	-	0.04 U	0.04 U	-	-
TPH-G	0.14 U	0.14 U	-	0.14 U	0.14 U	-	0.14 U	0.14 U	-	-
Chlorinated Pesticides (ng/L) [2]										
All 33 chlorinated pesticide compounds	ND	ND	-	ND	ND	-	-	-	-	-
BNAs (µg/L) [2]										
2-Methylphenol	0.0058 J	0.81 U	-	0.8 U	0.78 U	-	-	-	-	-
Cholesterol	0.79 U	0.81 U	-	1.4	1.4	0.0	-	-	-	0.0
Di-N-Octyl Phthalate	0.16 U	0.16 U	-	0.16 U	0.16 J	-	-	-	-	-
Pentachlorophenol	0.079 UJ	0.081 UJ	-	0.083 NJ	0.081 NJ	2.4	-	-	-	2.4
Triclosan	0.079 U	0.081 U	-	0.08 U	0.081	-	-	-	-	-
Triethyl citrate	0.31 U	0.33 U	-	0.32 U	0.31 J	-	-	-	-	-
49 other BNA compounds	ND	ND	-	ND	ND	-	-	-	-	-
PAHs (µg/L) [2]										
1-Methylnaphthalene	0.01 UJ	0.01 U	-	0.01 U	0.0034 J	-	-	-	-	-
21 other PAH compounds	ND	ND	-	ND	ND	-	-	-	-	-
PCB Congeners (pg/L) [2]										
Total PCBs	2.61 J	6.701 J	88	40.18 J	33.35 J	19	21.497 J	23.509 J	8.9	39
PBDE Congeners (pg/L) [2]										
BDE-100	10.9 J	10.8 J	0.92	11.1 UJ	10 UJ	-	10 UJ	10.7 UJ	-	0.92
BDE-209	250 U	250 UJ	-	260	260		250 U	250 U	-	-
34 other PBDE congeners	ND	ND	-	ND	ND	-	ND	ND	-	-
Total PBDEs	10.9 J	10.8 J	0.92	265.18	260	2.0	250 U	250 U	-	1.5

[1] Non-detect results for metals are given at the method detection limit (MDL).

[2] Non-detect results for petroleum-related products, chlorinated pesticides, BNAs, PAHs, PCB congeners, and PBDE congeners are given at the reporting limit (RL).

Table D-12. Summary of field QA sample results for river water samplings.

Total PCB and PBDE values are sums of detected congeners (unqualified and J-qualified results).

Parameter	Bottle / Filter Blanks	Acid-Cleaned Sampler Blanks	
	July 2009	Sept 2009	Dec 2009
Metals (µg/L) [1]			
Arsenic, total	0.05 U	0.05 U	0.05 U
Arsenic, dissolved	0.03 U	0.03 U	0.03 U
Cadmium, total	0.003 U	0.003 U	0.003 U
Cadmium, dissolved	0.002 U	0.002 U	0.002 U
Copper, total	0.02 U	0.12 J	0.33
Copper, dissolved	0.04 J	0.26	0.31
Lead, total	0.02 UJ	0.01 UJ	0.02 J
Lead, dissolved	0.006 U	0.007 J	0.037
Zinc, total	2.8 J	2.3 UJ	2.3 J
Zinc, dissolved	0.3 J	1.4	2.8
Chlorinated Pesticides (ng/L) [2]			
All 33 chlorinated pesticide compounds	ND	ND	-
BNAs (µg/L) [2]			
2-Methylphenol	0.82 U	0.82 U	-
Cholesterol	0.82 U	0.82 UJ	-
Di-N-Octyl Phthalate	0.16 U	0.16 U	-
Pentachlorophenol	0.082 UJ	0.082 U	-
Triclosan	0.082 U	0.082 U	-
Triethyl citrate	0.33 U	0.33 U	-
49 other BNA compounds	ND	ND	-
PAHs (µg/L) [2]			
1-Methylnaphthalene	0.01 U	0.01 U	-
Naphthalene	0.01	0.01 U	-
20 other PAH compounds	ND	ND	-
PCB Congeners (pg/L) [2]			
Total PCBs	11.2 U	47.066 J	13.959 J
PBDE Congeners (pg/L) [2]			
BDE-099	382	22.8 UJ	-
BDE-100	81.9	10 UJ	-
BDE-154	18.3 NJ	10 UJ	-
33 other PBDE congeners	ND	ND	-
Total PBDEs	807.9	124 U	-

[1] Non-detect results for metals are given at the method detection limit (MDL).
[2] Non-detect results for petroleum-related products, chlorinated pesticides, BNAs, PAHs, PCB congeners, and PBDE congeners are given at the reporting limit (RL).

Table D-13. Summary of PCB homolog totals in field replicates for river water samplings.

Homolog totals and Total PCB values are sums of detected congeners (unqualified and J-qualified results). PCB congener results for field replicates are detailed in Table D-14.

PCB Homolog (pg/L)	Field Replicates									
	July 2009			Sept 2009			Dec 2009			Mean RPD
	Sample	QA Rep	RPD	Sample	QA Rep	RPD	Sample	QA Rep	RPD	
Mono-CBs	10.3 U	10.2 U	-	1.8 J	0.779 J	79	2.726 J	0.688 J	119	99
Di-CBs	10.3 U	10.2 U	-	2.04 J	4.8 J	81	3.91 U	1.39 J	-	81
Tri-CBs	10.3 U	10.2 U	-	5.2 J	5.696 J	9.1	3.557 J	5.232 J	38	24
Tetra-CBs	1.45 J	10.2 U	-	5.89 J	3.22 J	59	5.467 J	6.641 J	19	39
Penta-CBs	1.16 J	4.52 J	118	15.11 J	9.76 J	43	6.487 J	4.245 J	42	68
Hexa-CBs	10.3 U	0.761 J	-	8.63 J	7.59 J	13	3.26 J	4.7 J	36	25
Hepta-CBs	10.3 U	10.2 U	-	1.51 J	0.756 J	67	3.91 U	0.613 J	-	67
Octa-CBs	10.3 U	1.42 J	-	5 U	0.749 J	-	3.91 U	4.17 U	-	-
Nona-CBs	10.3 U	10.2 U	-	5 U	5 U	-	3.91 U	4.17 U	-	-
PCB-209	10.3 U	10.2 U	-	5 U	5 U	-	3.91 U	4.17 U	-	-
Total PCBs	2.61 J	6.701 J	88	40.18 J	33.35 J	19	21.497 J	23.509 J	8.9	39

Table D-14. Summary of PCB congener detects in field QA results for river water sampling.

Congener concentrations are listed only if detected in at least one of these blanks.

PCB Congener (pg/L)	Field Replicates						Bottle Blank	Acid-Cleaned Sampler Blanks	
	July 2009		September 2009		December 2009		July '09	Sept '09	Dec '09
	Sample	QA Rep	Sample	QA Rep	Sample	QA Rep	Result	Result	Result
PCB-001				0.779 J	0.976 J			2.99 J	0.752 NJ
PCB-002					1.73 NJ	0.832 NJ		0.956 J	
PCB-003			1.8 J		1.75 J	0.688 J		3.64 J	1.76 J
PCB-004				1.85 J				3 J	
PCB-005								0.469 J	
PCB-006				0.489 J				1.53 J	0.971 J
PCB-007								0.65 J	
PCB-008			2.04 J	1.72 J				5.37	2.4 J
PCB-009								0.734 J	
PCB-012/013								0.781 J	
PCB-015				0.741 J		1.39 J		2.19 J	1.2 J
PCB-016								2.98 J	0.66 J
PCB-017				0.826 J		0.885 NJ		2.39 J	0.943 J
PCB-018/030		10.2 NJ	1.69 J	1.86 J	1.49 J	1.98 J		4.43 J	1.55 J
PCB-019								0.744 J	
PCB-020/028	10.3 NJ	10.2 NJ	1.77 J	1.57 J	1.04 NJ	1.32 NJ		1.98 J	1.31 J
PCB-021/033				0.442 NJ	0.897 J	0.851 J		1.95 J	0.936 J
PCB-022				0.45 NJ		0.661 J		1.09 J	0.424 NJ
PCB-026/029								0.453 NJ	
PCB-027								0.406 NJ	
PCB-031	10.3 NJ		1.74 J	1.44 J	1.17 J	1.74 J		2.03 J	1.18 J
PCB-032				0.471 NJ		4.17 NJ		1.5 J	0.516 J
PCB-039				0.314 NJ					
PCB-040/071								0.568 NJ	3.75 NJ
PCB-044/047/065				1.75 NJ	1.57 J	1.95 J		1.74 J	0.726 NJ
PCB-049/069			1.27 NJ	1.06 J	0.751 J	0.988 J		0.891 NJ	0.533 J
PCB-052	1.45 J	10.2 NJ	2.76 J	2.16 J				1.65 J	0.974 UJ
PCB-061/070/074/076			3.13 J	1.72 NJ	1.72 J	2.31 J			
PCB-064					0.585 J	0.551 J		0.391 NJ	
PCB-066				0.641 NJ	0.841 J	0.842 J			
PCB-086/087/097/108/119/125				2.02 J		0.794 NJ			
PCB-090/101/113	10.3 NJ	1.69 J	3.04 J	2.65 J	1.76 J	2.11 J		0.601 NJ	
PCB-095			3.37 J	1.9 NJ	1.4 J	1.35 NJ		1.1 J	
PCB-099			1.63 J	1.08 J	0.497 J	0.48 NJ			
PCB-105			1.86 J	1.05 NJ		0.585 J			
PCB-110	1.16 J	1.44 J	2.66 J	2.28 J	1.58 J	1.55 J		0.519 J	0.434 NJ
PCB-118		1.39 J	2.55 J	1.73 J	1.25 J	1.11 NJ			
PCB-128/166						4.17 NJ			
PCB-129/138/163		10.2 NJ	3.19 J	2.67 J	1.85 J	1.92 J		0.653 J	
PCB-132				1.05 J					
PCB-135/151				1.04 NJ					
PCB-147/149			2.43 J	1.97 J	1.41 J	1.42 J			
PCB-153/168			3.01 J	1.9 J	1.17 NJ	1.36 J			
PCB-169		0.761 J							
PCB-177				0.765 NJ				0.686 NJ	
PCB-180/193				0.757 NJ		0.923 NJ			
PCB-187			1.51 J	0.756 J		0.613 J		0.707 NJ	0.616 NJ
PCB-194		1.42 J		0.749 J				0.442 NJ	
Total PCBs									
…including N,NJ	33.51 J	47.501 J	41.45 J	49.65 J	25.437 J	39.543 J	11.2 U	57.211 J	20.661 J
…excluding N,NJ	2.61 J	6.701 J	40.18 J	33.35 J	21.497 J	23.509 J	11.2 U	47.066 J	13.959 J

Appendix E. Analytical Results - Marine Water Column

Table E-1. Summary of Marine Water Results for Conventionals and Metals.

Non-detect results were assigned the method detection limit (MDL) value. POC and DOC samples were not collected in July 2009.

July 2009:

Parameter	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
Conventional Parameters (mg/L)														
TSS	1.9	1.5	2.2	1.7	1.6	1.6	1.6	2.0	2.6	3.5	1.4	1.4	1.6	1.4
POC	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DOC	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Metals (µg/L)														
Arsenic, total	1.30	1.37	1.52	1.49	1.39	1.52	1.46	1.54	1.34	1.46	1.34	1.41	1.41	1.41
Arsenic, dissolved	1.34	1.47	1.48	1.50	1.35	1.61	1.42	1.56	1.32	1.54	1.34	1.46	1.35	1.34
Cadmium, total	0.072	0.076	0.091	0.091	0.087	0.098	0.090	0.097	0.079	0.085	0.076	0.080	0.077	0.076
Cadmium, dissolved	0.067	0.068	0.089	0.091	0.078	0.102	0.079	0.098	0.068	0.086	0.072	0.081	0.068	0.073
Copper, total	0.48	1.37	0.29	0.28	0.37	0.21	0.25	0.25	0.44	0.49	0.39	0.37	0.44	0.41
Copper, dissolved	0.45	0.51	0.22	0.26	0.25	0.20	0.27	0.23	0.37	0.41	0.35	0.34	0.39	0.37
Lead, total	0.129	0.177	0.091	0.230	0.052	0.109	0.025 J	0.116	0.061	0.114	0.049 J	0.088	0.039 J	0.050
Lead, dissolved	0.119	0.064	0.056	0.153	0.060	0.056	0.050	0.131	0.043 J	0.033 J	0.028 J	0.035 J	0.084	0.090
Zinc, total	0.69 J	7.44	0.59 J	0.79 J	0.75 J	0.45 J	0.56 J	0.52 J	0.70 J	0.74 J	0.84 J	0.53 J	0.64 J	0.48 J
Zinc, dissolved	1.25	2.30	0.70 J	0.72 J	0.36 J	0.51 J	0.36 J	0.63 J	1.78	0.69 J	0.62 J	0.50 J	0.41 J	0.68 J

October 2009:

Parameter	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
Conventional Parameters (mg/L)														
TSS	1.2	1.1	1.3	1.2	1.1	1.2	1.1	1.0	5.5	1.2	0.9	1.7	0.9	0.8
POC	0.216	0.093	0.08	0.049	0.058	0.068	0.051	0.039	1.78	0.061	0.123	0.086	0.184	0.114
DOC	0.874	0.756	0.805	0.611	0.802	0.625	0.697	0.716	0.969	0.968	0.773	0.755	0.844	0.831
Metals (µg/L)														
Arsenic, total	1.22	1.47	1.31	1.46	1.31	1.44	1.33	1.36	1.45	1.47	1.40	1.40	1.28	1.16
Arsenic, dissolved	1.26	1.40	1.38	1.44	1.36	1.49	1.36	1.43	1.37	1.42	1.38	1.46	1.26	1.29
Cadmium, total	0.099	0.092	0.089	0.096	0.089	0.105	0.082	0.092	0.087	0.081	0.081	0.081	0.076	0.059
Cadmium, dissolved	0.076	0.077	0.083	0.111	0.081	0.105	0.087	0.096	0.074	0.079	0.074	0.081	0.069	0.074
Copper, total	0.35	0.34	0.20	0.19 J	0.25	0.63	0.24	0.24	0.38	0.35	0.35	0.34	0.38	0.26
Copper, dissolved	0.29	0.31	0.17 J	0.16 J	0.22	0.19 J	0.21	0.23	0.33	0.33	0.28	0.28	0.30	0.32
Lead, total	0.015 J	0.046 J	0.035 UJ	0.035 UJ	0.042 UJ	0.070 J	0.058 J	0.108 J	0.098	0.095	0.090	0.143	0.025 UJ	0.024 UJ
Lead, dissolved	0.013 J	0.018 J	0.030 UJ	0.042 UJ	0.045 J	0.057 J	0.058 J	0.068 J	0.235	0.133	0.078	0.048 J	0.039 UJ	0.045 J
Zinc, total	0.52 J	0.91 J	0.41 J	0.53 J	0.45 J	0.64 J	0.47 J	0.88 J	0.69 J	0.58 J	0.86 J	0.79 J	0.69 J	0.53 J
Zinc, dissolved	0.38 UJ	0.70 J	0.45 J	0.43 J	0.58 J	0.47 J	0.71 J	0.66 J	1.42 J	1.06 J	0.46 UJ	0.69 J	0.73 J	0.36 J

Table E-1, continued. Summary of Marine Water Results for Conventionals and Metals.

Non-detect results were assigned the method detection limit (MDL) value.

January 2010:

Parameter	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
Conventional Parameters (mg/L)														
TSS	1.3	1.1	2.2	2.3	2.3	6.0	1.9	1.6	0.8	2.0	1.6	1.4	1.3	1.6
POC	0.072	0.031	0.051	0.07	0.046	0.108	0.037	0.041	0.071	0.048	0.028	0.034	0.05	0.047
DOC	0.705	0.712	0.691	0.646	0.705	0.667	0.697	0.702	0.771	0.808	0.754	0.724	0.811	0.786
Metals (µg/L)														
Arsenic, total	1.46	1.50	1.52	1.50	1.36	1.56	1.39	1.34	1.53	1.54	1.39	1.41	1.49	1.41
Arsenic, dissolved	1.44	1.70	1.42	1.42	1.38	1.43	1.31	1.37	1.44	1.50	1.48	1.43	1.35	1.45
Cadmium, total	0.082	0.088	0.080	0.087	0.087	0.092	0.082	0.080	0.082	0.112	0.077	0.089	0.069	0.074
Cadmium, dissolved	0.086	0.079	0.095	0.093	0.089	0.081	0.091	0.081	0.080	0.090	0.079	0.084	0.081	0.072
Copper, total	0.38	0.40	0.38	0.45	0.31	0.41	0.72	0.38	0.48	0.51	0.40	1.03	0.42	0.44
Copper, dissolved	0.35	0.33	0.24	0.24	0.26	0.27	0.28	0.27	0.41	0.43	0.36	0.37	0.39	0.38
Lead, total	0.189	0.035 J	0.049 J	0.152	0.036 J	0.093	0.043 J	0.052	0.033 J	0.109	0.031 J	0.206	0.031 J	0.042 J
Lead, dissolved	0.010 J	0.019 J	0.016 J	0.056	0.025 J	0.033 J	0.030 J	0.050 J	0.045 J	0.063	0.007 J	0.012 J	0.006 J	0.007 J
Zinc, total	0.62 J	0.55 J	0.57 J	0.68 J	0.56 J	1.44	0.99	1.07	0.88 J	1.05 J	0.71 J	1.04 J	0.73 J	0.77 J
Zinc, dissolved	0.54 J	0.54 J	0.40 UJ	0.41 J	0.46 J	0.73	0.65	0.43 J	0.81 J	0.76 J	0.75 J	0.59 J	0.59 J	0.69 J

Table E-2. July 2009 Chlorinated Pesticides Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4'-DDE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4'-DDT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4,4'-DDD	0.20 U	0.18	0.20 U	0.17	0.20 U	0.17	0.20 U	0.18	0.20 U	0.17	0.21 U	0.18	0.21 U	0.18	0.20 U	0.17
4,4'-DDE	0.20 U	0.17	0.20 U	0.17	0.20 U	0.17	0.20 U	0.17	0.20 U	0.17	0.21 U	0.18	0.21 U	0.18	0.20 U	0.17
4,4'-DDT	0.20 U	-	0.20 U	-	0.20 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-
Aldrin	0.20 U	0.062	0.20 U	0.06	0.20 U	0.06	0.20 U	0.062	0.20 U	0.06	0.21 U	0.065	0.21 U	0.064	0.20 U	0.061
Alpha-BHC	0.20 U	0.041	0.20 U	0.04	0.20 U	0.04	0.20 U	0.041	0.20 U	0.04	0.21 U	0.043	0.21 U	0.043	0.20 U	0.041
Beta-BHC	0.20 U	0.15	0.20 U	0.14	0.20 U	0.14	0.20 U	0.15	0.20 U	0.14	0.21 U	0.15	0.21 U	0.15	0.20 U	0.14
Chlorpyriphos	0.20 U	-	0.21 UJ	-	0.56 UJ	-	0.25 UJ	-	0.24 UJ	-	0.32 UJ	-	0.21 U	-	0.20 U	-
cis-Chlordane	0.20 U	0.092	0.20 U	0.089	0.20 U	0.089	0.20 U	0.092	0.20 U	0.089	0.21 U	0.096	0.21 U	0.095	0.20 U	0.09
Cis-Nonachlor	0.20 U	0.13	0.20 U	0.13	0.20 U	0.12	0.20 U	0.13	0.20 U	0.13	0.21 U	0.14	0.21 U	0.13	0.20 U	0.13
Dacthal (DCPA)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DDMU	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Delta-BHC	0.20 U	0.041	0.20 U	0.04	0.20 U	0.039	0.20 U	0.041	0.20 U	0.04	0.21 U	0.043	0.21 U	0.042	0.20 U	0.04
Dieldrin	0.51 U	0.21	0.50 U	0.2	0.49 U	0.2	0.51 U	0.21	0.50 U	0.2	0.53 U	0.21	0.53 U	0.21	0.50 U	0.2
Endosulfan I	0.20 U	0.092	0.20 U	0.09	0.20 U	0.089	0.20 U	0.092	0.20 U	0.09	0.21 U	0.096	0.21 U	0.095	0.20 U	0.091
Endosulfan II	0.20 U	0.075	0.20 U	0.074	0.20 U	0.073	0.20 U	0.075	0.31 UJ	0.074	0.21 U	0.079	0.25 UJ	0.078	0.20 U	0.074
Endosulfan Sulfate	0.20 U	0.16	0.20 U	0.16	0.20 U	0.16	0.20 U	0.16	0.20 U	0.16	0.21 U	0.17	0.21 U	0.17	0.20 U	0.16
Endrin	0.51 U	0.22	0.50 U	0.21	0.49 U	0.21	0.51 U	0.22	0.50 U	0.21	0.53 U	0.23	0.53 U	0.23	0.50 U	0.22
Endrin Aldehyde	0.20 U	0.15	0.20 U	0.15	0.20 U	0.15	0.20 U	0.15	0.20 U	0.15	0.21 U	0.16	0.21 U	0.16	0.20 U	0.15
Endrin Ketone	0.76 U	0.61	0.74 U	0.6	0.74 U	0.59	0.76 U	0.61	0.74 U	0.6	0.80 U	0.64	0.79 U	0.64	0.75 U	0.61
Gamma-BHC (Lindane)	13 UJ	0.26	2.6 UJ	0.05	2.9 UJ	0.049	3.7 UJ	0.051	2.8 UJ	0.05	3.0 UJ	0.054	3.3 UJ	0.053	2.8 UJ	0.05
Heptachlor	0.20 U	0.089	0.20 U	0.087	0.20 U	0.086	0.20 U	0.089	0.20 U	0.087	0.21 U	0.093	0.21 U	0.092	0.20 U	0.088
Heptachlor Epoxide	0.20 U	0.12	0.20 U	0.12	0.20 U	0.12	0.20 U	0.12	0.20 U	0.12	0.21 U	0.13	0.21 U	0.13	0.20 U	0.12
Hexachlorobenzene	0.20 U	-	0.20 U	-	0.20 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-
Methoxychlor	0.51 U	0.26	0.50 U	0.25	0.49 U	0.25	0.51 U	0.26	0.50 U	0.25	0.53 U	0.27	0.53 U	0.27	0.50 U	0.25
Mirex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxychlordane	0.20 U	0.074	0.20 U	0.072	0.20 U	0.072	0.20 U	0.074	0.20 U	0.072	0.21 U	0.078	0.21 U	0.077	0.20 U	0.073
Pentachloroanisole	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxaphene	1.0 U	-	0.98 U	-	0.97 U	-	1.0 U	-	0.98 U	-	1.1 U	-	1.0 U	-	0.99 U	-
trans-Chlordane	0.20 U	0.15	0.20 U	0.15	0.20 U	0.14	0.20 U	0.15	0.20 U	0.15	0.21 U	0.16	0.21 U	0.16	0.20 U	0.15
Trans-Nonachlor	0.20 U	-	0.20 U	-	0.20 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-

Table E-3. July 2009 Chlorinated Pesticides Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	-	-	-	-	-	-	-	-	-	-	-	-
2,4'-DDE	-	-	-	-	-	-	-	-	-	-	-	-
2,4'-DDT	-	-	-	-	-	-	-	-	-	-	-	-
4,4'-DDD	0.20 U	0.17	0.20 U	0.17	0.21 U	0.18	0.20 U	0.17	0.21 U	0.18	0.21 U	0.18
4,4'-DDE	0.20 U	0.17	0.20 U	0.17	0.21 J	0.17	0.39	0.17	0.21 U	0.18	0.21	0.18
4,4'-DDT	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-
Aldrin	0.20 U	0.062	0.20 U	0.061	0.21 U	0.062	0.20 U	0.062	0.21 U	0.063	0.21 U	0.064
Alpha-BHC	0.20 U	0.041	0.20 U	0.041	0.21 U	0.041	0.20 U	0.041	0.21 U	0.042	0.21 U	0.042
Beta-BHC	0.20 U	0.15	0.20 U	0.14	0.21 U	0.15	0.20 U	0.15	0.21 U	0.15	0.21 U	0.15
Chlorpyriphos	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-
cis-Chlordane	0.20 U	0.091	0.20 U	0.09	0.21 U	0.092	0.20 U	0.091	0.21 U	0.094	0.21 U	0.094
Cis-Nonachlor	0.20 U	0.13	0.20 U	0.13	0.21 U	0.13	0.20 U	0.13	0.21 U	0.13	0.21 U	0.13
Dacthal (DCPA)	-	-	-	-	-	-	-	-	-	-	-	-
DDMU	-	-	-	-	-	-	-	-	-	-	-	-
Delta-BHC	0.20 U	0.04	0.20 U	0.04	0.21 UJ	0.041	0.20 U	0.04	0.21 U	0.041	0.21 U	0.042
Dieldrin	0.51 U	0.2	0.50 U	0.2	0.51 U	0.21	0.51 U	0.2	0.52 U	0.21	0.52 U	0.21
Endosulfan I	0.20 U	0.092	0.20 U	0.091	0.21 U	0.093	0.20 U	0.092	0.21 U	0.094	0.21 U	0.094
Endosulfan II	0.20 U	0.075	0.20 U	0.074	0.21 U	0.076	0.20 U	0.075	0.21 U	0.077	0.21 U	0.077
Endosulfan Sulfate	0.20 U	0.16	0.20 U	0.16	0.21 U	0.16	0.20 U	0.16	0.21 U	0.17	0.21 U	0.17
Endrin	0.51 U	0.22	0.50 U	0.22	0.51 U	0.22	0.51 U	0.22	0.52 U	0.22	0.52 U	0.22
Endrin Aldehyde	0.20 U	0.15	0.20 U	0.15	0.21 U	0.15	0.20 U	0.15	0.21 U	0.16	0.21 U	0.16
Endrin Ketone	0.76 U	0.61	0.75 U	0.61	0.77 U	0.62	0.76 U	0.61	0.78 U	0.63	0.78 U	0.63
Gamma-BHC (Lindane)	9.4 UJ	0.051	3.0 UJ	0.05	2.8 UJ	0.051	1.8 UJ	0.051	4.2 UJ	0.052	6.4 UJ	0.052
Heptachlor	0.20 U	0.089	0.20 U	0.088	0.21 U	0.09	0.20 U	0.089	0.21 U	0.091	0.21 U	0.091
Heptachlor Epoxide	0.20 U	0.12	0.20 U	0.12	0.21 U	0.13	0.20 U	0.12	0.21 U	0.13	0.21 U	0.13
Hexachlorobenzene	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-
Methoxychlor	0.51 U	0.26	0.50 U	0.25	0.51 U	0.26	0.51 U	0.26	0.52 U	0.26	0.52 U	0.26
Mirex	-	-	-	-	-	-	-	-	-	-	-	-
Oxychlordane	0.20 U	0.074	0.20 U	0.073	0.21 U	0.075	0.20 U	0.074	0.21 U	0.076	0.21 U	0.076
Pentachloroanisole	-	-	-	-	-	-	-	-	-	-	-	-
Toxaphene	1.0 U	-	0.99 U	-	1.0 U	-	1.0 U	-	1.0 U	-	1.0 U	-
trans-Chlordane	0.20 U	0.15	0.20 U	0.15	0.21 U	0.15	0.20 U	0.15	0.21 U	0.15	0.21 U	0.15
Trans-Nonachlor	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-

Table E-4. September 2009 Chlorinated Pesticides Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
2,4'-DDE	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
2,4'-DDT	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
4,4'-DDD	0.21 U	0.18	0.21 U	0.18	0.23 U	0.2	0.20 U	0.18	0.21 U	0.18	0.20 U	0.17	0.20 U	0.17	0.20 U	0.17
4,4'-DDE	0.21 U	0.17	0.21 U	0.17	0.23 U	0.19	0.20 U	0.17	0.21 U	0.17	0.20 U	0.17	0.20 U	0.17	0.20 U	0.17
4,4'-DDT	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
Aldrin	0.21 UJ	0.062	0.21 UJ	0.062	0.23 UJ	0.069	0.20 UJ	0.062	0.21 UJ	0.062	0.20 UJ	0.062	0.20 UJ	0.061	0.20 UJ	0.061
Alpha-BHC	0.21 U	0.041	0.21 U	0.041	0.23 U	0.046	0.21	0.041	0.21 U	0.041	0.20 U	0.041	0.20 U	0.041	0.20 U	0.041
Beta-BHC	0.21 U	0.15	0.21 U	0.15	0.23 U	0.16	0.32	0.15	0.21 U	0.15	0.20 U	0.15	0.20 U	0.14	0.20 U	0.14
Chlorpyriphos	14 UJ	-	0.21 U	-	0.23 U	-	1.9 UJ	-	1.1 UJ	-	3.0 UJ	-	0.93 UJ	-	1.8 UJ	-
cis-Chlordane	0.21 U	0.092	0.21 U	0.092	0.23 U	0.1	0.20 U	0.092	0.21 U	0.092	0.20 U	0.091	0.20 U	0.09	0.20 U	0.09
Cis-Nonachlor	0.21 U	0.13	0.21 U	0.13	0.23 U	0.14	0.20 U	0.13	0.21 U	0.13	0.20 U	0.13	0.20 U	0.13	0.20 U	0.13
Dacthal (DCPA)	0.21 U	-	0.21 U	-	0.23 U	-	0.24 UJ	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
DDMU	0.21 U	-	0.21 U	-	0.23 U	-	0.38 UJ	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
Delta-BHC	0.21 U	0.041	0.21 U	0.041	0.23 U	0.045	0.25 J	0.041	0.21 U	0.041	0.20 U	0.04	0.20 U	0.04	0.20 U	0.04
Dieldrin	0.51 U	0.21	0.51 U	0.21	0.57 U	0.23	0.51 U	0.21	0.51 U	0.21	0.51 U	0.2	0.50 U	0.2	0.50 U	0.2
Endosulfan I	0.21 U	0.093	0.21 U	0.093	0.23 U	0.1	0.20 U	0.092	0.21 U	0.093	0.20 U	0.092	0.20 U	0.091	0.20 U	0.091
Endosulfan II	0.21 UJ	0.076	0.21 UJ	0.076	0.31 UJ	0.084	0.20 UJ	0.075	0.21 UJ	0.076	0.20 UJ	0.075	0.20 UJ	0.074	0.20 UJ	0.074
Endosulfan Sulfate	0.21 UJ	0.16	0.21 UJ	0.16	0.23 UJ	0.18	0.20 UJ	0.16	0.21 UJ	0.16	0.20 UJ	0.16	0.20 UJ	0.16	0.20 UJ	0.16
Endrin	0.51 UJ	0.22	0.51 UJ	0.22	0.57 UJ	0.24	0.51 UJ	0.22	0.51 UJ	0.22	0.51 UJ	0.22	0.50 UJ	0.22	0.50 UJ	0.22
Endrin Aldehyde	0.38 UJ	0.15	0.49 UJ	0.15	0.68 UJ	0.17	0.37 UJ	0.15	0.40 UJ	0.15	0.32 UJ	0.15	0.46 UJ	0.15	0.42 UJ	0.15
Endrin Ketone	0.77 U	0.62	0.77 U	0.62	0.85 U	0.69	0.76 U	0.61	0.77 U	0.62	0.76 U	0.61	0.75 U	0.61	0.75 U	0.61
Gamma-BHC (Lindane)	2.4 UJ	0.051	1.3 UJ	0.051	2.5 UJ	0.057	2.4 UJ	0.051	1.9 UJ	0.051	2.0 UJ	0.051	3.5 UJ	0.05	3.3 UJ	0.05
Heptachlor	0.21 U	0.09	0.21 U	0.09	0.23 U	0.1	0.20 U	0.089	0.21 U	0.09	0.20 U	0.089	0.20 U	0.088	0.20 U	0.088
Heptachlor Epoxide	0.21 U	0.13	0.21 U	0.13	0.23 U	0.14	0.20 U	0.12	0.21 U	0.13	0.20 U	0.12	0.20 U	0.12	0.20 U	0.12
Hexachlorobenzene	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
Methoxychlor	0.51 UJ	0.26	1.1 UJ	0.26	0.57 UJ	0.29	0.51 UJ	0.26	0.51 UJ	0.26	0.51 UJ	0.26	0.50 UJ	0.25	0.50 UJ	0.25
Mirex	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
Oxychlordane	0.21 U	0.075	0.21 U	0.075	0.23 U	0.083	0.20 U	0.074	0.21 U	0.075	0.20 U	0.074	0.20 U	0.073	0.20 U	0.073
Pentachloroanisole	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-
Toxaphene	10 U	-	10 U	-	11 U	-	10 U	-	10 U	-	10 U	-	9.9 U	-	9.9 U	-
trans-Chlordane	0.21 U	0.15	0.21 U	0.15	0.23 U	0.17	0.20 U	0.15	0.21 U	0.15	0.20 U	0.15	0.20 U	0.15	0.20 U	0.15
Trans-Nonachlor	0.21 U	-	0.21 U	-	0.23 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.20 U	-

Table E-5. September 2009 Chlorinated Pesticides Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
2,4'-DDE	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
2,4'-DDT	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
4,4'-DDD	0.21 U	0.18	0.20 U	0.17	0.21 U	0.18	0.21 U	0.18	0.21 U	0.18	0.20 U	0.17
4,4'-DDE	0.21 U	0.18	0.20 U	0.17	0.21 U	0.18	0.21 U	0.17	0.21 U	0.18	0.20 U	0.17
4,4'-DDT	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
Aldrin	0.21 U	0.063	0.20 U	0.062	0.21 U	0.063	0.21 U	0.062	0.21 U	0.064	0.20 U	0.062
Alpha-BHC	0.21 U	0.042	0.20 U	0.041	0.21 U	0.042	0.21 U	0.041	0.21 U	0.042	0.20 U	0.041
Beta-BHC	0.21 U	0.15	0.20 U	0.15	0.21 U	0.15	0.21 U	0.15	0.21 U	0.15	0.20 U	0.15
Chlorpyriphos	0.53 UJ	-	0.20 U	-	0.76 UJ	-	0.36 UJ	-	0.64 UJ	-	0.54 UJ	-
cis-Chlordane	0.21 U	0.093	0.20 U	0.091	0.21 U	0.094	0.21 U	0.092	0.21 U	0.094	0.20 U	0.091
Cis-Nonachlor	0.21 U	0.13	0.20 U	0.13	0.21 U	0.13	0.21 U	0.13	0.21 U	0.13	0.20 U	0.13
Dacthal (DCPA)	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
DDMU	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
Delta-BHC	0.21 U	0.041	0.20 U	0.04	0.21 U	0.041	0.21 U	0.041	0.21 U	0.042	0.20 U	0.04
Dieldrin	0.52 U	0.21	0.51 U	0.2	0.52 U	0.21	0.51 U	0.21	0.52 U	0.21	0.51 U	0.2
Endosulfan I	0.21 U	0.093	0.20 U	0.092	0.21 U	0.094	0.21 U	0.093	0.21 U	0.094	0.20 U	0.092
Endosulfan II	0.30 UJ	0.077	0.21 UJ	0.075	0.21 UJ	0.077	0.23 UJ	0.076	0.22 UJ	0.077	0.29 UJ	0.075
Endosulfan Sulfate	0.21 UJ	0.17	0.20 UJ	0.16	0.21 UJ	0.17	0.26 UJ	0.16	0.21 UJ	0.17	0.20 UJ	0.16
Endrin	0.52 UJ	0.22	0.51 UJ	0.22	0.52 UJ	0.22	0.51 UJ	0.22	0.52 UJ	0.22	0.51 UJ	0.22
Endrin Aldehyde	0.62 UJ	0.16	0.52 UJ	0.15	0.66 UJ	0.16	0.59 UJ	0.15	0.52 UJ	0.16	0.42 UJ	0.15
Endrin Ketone	0.77 U	0.62	0.76 U	0.61	0.78 U	0.63	0.77 U	0.62	0.78 U	0.63	0.76 U	0.61
Gamma-BHC (Lindane)	3.6 UJ	0.052	2.2 UJ	0.051	3.6 UJ	0.052	4.2 UJ	0.051	1.5 UJ	0.052	4.0 UJ	0.051
Heptachlor	0.21 U	0.09	0.20 U	0.089	0.21 U	0.091	0.21 U	0.09	0.21 U	0.091	0.20 U	0.089
Heptachlor Epoxide	0.21 U	0.13	0.20 U	0.12	0.21 U	0.13	0.21 U	0.13	0.21 U	0.13	0.20 U	0.12
Hexachlorobenzene	0.21 U	-	0.20 U	-	0.21	-	0.21 U	-	0.21 U	-	0.20 U	-
Methoxychlor	0.52 UJ	0.26	0.51 UJ	0.26	0.52 UJ	0.26	0.51 UJ	0.26	0.52 UJ	0.26	0.51 UJ	0.26
Mirex	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
Oxychlordane	0.21 U	0.075	0.20 U	0.074	0.21 U	0.076	0.21 U	0.075	0.21 U	0.076	0.20 U	0.074
Pentachloroanisole	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-
Toxaphene	10 U	-	10 U	-	10 U	-	10 U	-	10 U	-	10 U	-
trans-Chlordane	0.21 U	0.15	0.20 U	0.15	0.21 U	0.15	0.21 U	0.15	0.21 U	0.15	0.20 U	0.15
Trans-Nonachlor	0.21 U	-	0.20 U	-	0.21 U	-	0.21 U	-	0.21 U	-	0.20 U	-

Table E-6. January 2010 Chlorinated Pesticides Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
2,4'-DDE	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
2,4'-DDT	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
4,4'-DDD	0.20 U	0.17	0.21 U	0.18	0.20 U	0.17	0.20 U	0.17	0.21 U	0.18	0.20 U	0.18	0.21 U	0.18	0.20 U	0.17
4,4'-DDE	0.20 U	0.17	0.21 U	0.17	0.20 U	0.17	0.20 UJ	0.17	0.21 U	0.17	0.20 U	0.17	0.21 U	0.18	0.20 U	0.17
4,4'-DDT	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
Aldrin	0.20 UJ	0.062	0.21 UJ	0.063	0.20 U	0.062	0.20 U	0.06	0.21 UJ	0.062	0.20 UJ	0.062	0.21 UJ	0.064	0.20 UJ	0.06
Alpha-BHC	0.20 UJ	0.041	0.21 UJ	0.042	0.20 U	0.041	0.20 U	0.04	0.21 UJ	0.041	0.20 UJ	0.041	0.21 UJ	0.042	0.20 UJ	0.04
Beta-BHC	0.20 U	0.15	0.21 U	0.15	0.20 U	0.15	0.20 U	0.14	0.21 U	0.15	0.20 U	0.15	0.21 U	0.15	0.20 U	0.14
Chlorpyriphos	0.20 U	-	0.21 U	-	0.20 U	-	0.22 UJ	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
cis-Chlordane	0.20 U	0.091	0.21 U	0.093	0.20 U	0.091	0.20 U	0.089	0.21 U	0.092	0.20 U	0.092	0.21 U	0.094	0.20 U	0.089
Cis-Nonachlor	0.20 U	0.13	0.21 U	0.13	0.20 U	0.13	0.20 U	0.12	0.21 U	0.13	0.20 U	0.13	0.21 U	0.13	0.20 U	0.13
Dacthal (DCPA)	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
DDMU	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
Delta-BHC	0.20 U	0.04	0.21 U	0.041	0.20 U	0.04	0.20 U	0.039	0.21 U	0.041	0.20 U	0.041	0.21 U	0.042	0.20 U	0.039
Dieldrin	0.51 U	0.2	0.51 U	0.21	0.51 U	0.2	0.49 U	0.2	0.51 U	0.21	0.51 U	0.21	0.52 U	0.21	0.49 U	0.2
Endosulfan I	0.20 U	0.092	0.21 U	0.093	0.20 UJ	0.092	0.20 UJ	0.089	0.21 U	0.093	0.20 U	0.092	0.21 U	0.094	0.20 U	0.089
Endosulfan II	0.20 U	0.075	0.21 U	0.076	0.20 U	0.075	0.20 U	0.073	0.21 U	0.076	0.20 U	0.075	0.21 U	0.077	0.20 U	0.073
Endosulfan Sulfate	0.20 U	0.16	0.21 U	0.17	0.20 U	0.16	0.20 U	0.16	0.21 U	0.16	0.20 U	0.16	0.21 U	0.17	0.20 U	0.16
Endrin	0.51 U	0.22	0.51 U	0.22	0.51 U	0.22	0.49 U	0.21	0.51 U	0.22	0.51 U	0.22	0.52 U	0.22	0.49 U	0.21
Endrin Aldehyde	0.20 U	0.15	0.21 U	0.16	0.20 U	0.15	0.20 U	0.15	0.21 U	0.15	0.20 U	0.15	0.21 U	0.16	0.20 U	0.15
Endrin Ketone	0.76 U	0.61	0.77 U	0.62	0.76 U	0.61	0.74 U	0.59	0.77 U	0.62	0.76 U	0.61	0.78 U	0.63	0.74 U	0.6
Gamma-BHC (Lindane)	0.43 UJ	0.051	0.21 UJ	0.052	0.40 UJ	0.051	0.31 UJ	0.049	0.21 U	0.051	0.20 U	0.051	0.21 U	0.052	0.20 U	0.05
Heptachlor	0.20 U	0.089	0.21 U	0.09	0.20 U	0.089	0.20 U	0.086	0.21 U	0.09	0.20 U	0.089	0.21 U	0.091	0.20 U	0.086
Heptachlor Epoxide	0.20 U	0.12	0.21 U	0.13	0.20 UJ	0.12	0.20 UJ	0.12	0.21 U	0.13	0.20 U	0.12	0.21 U	0.13	0.20 U	0.12
Hexachlorobenzene	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
Methoxychlor	0.51 U	0.26	0.51 U	0.26	0.51 U	0.26	0.49 UJ	0.25	0.51 U	0.26	0.51 U	0.26	0.52 U	0.26	0.49 U	0.25
Mirex	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
Oxychlordane	0.20 U	0.074	0.21 U	0.075	0.20 U	0.074	0.20 U	0.072	0.21 U	0.075	0.20 U	0.074	0.21 U	0.076	0.20 U	0.072
Pentachloroanisole	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-
Toxaphene	10 U	-	10 U	-	10 U	-	9.7 U	-	10 U	-	10 U	-	10 U	-	9.8 U	-
trans-Chlordane	0.20 U	0.15	0.21 U	0.15	0.20 U	0.15	0.20 U	0.14	0.21 U	0.15	0.20 U	0.15	0.21 U	0.15	0.20 U	0.15
Trans-Nonachlor	0.20 U	-	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.20 U	-	0.21 U	-	0.20 U	-

Table E-7. January 2010 Chlorinated Pesticides Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.20 UJ	-
2,4'-DDE	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.25 UJ	-	0.21 UJ	-	0.20 UJ	-
2,4'-DDT	0.21 UJ	-	0.21 UJ	-	0.21 UJ	-	0.24 UJ	-	0.21 UJ	-	0.25 UJ	-
4,4'-DDD	0.21 UJ	0.18	0.21 U	0.18	0.21 UJ	0.18	0.21 U	0.18	0.21 UJ	0.18	0.20 UJ	0.17
4,4'-DDE	0.21 UJ	0.17	0.21 UJ	0.18	0.21 UJ	0.18	0.21 UJ	0.18	0.21 UJ	0.17	0.20 UJ	0.17
4,4'-DDT	0.21 UJ	-	0.21 UJ	-	0.21 UJ	-	0.21 UJ	-	0.33 UJ	-	0.20 UJ	-
Aldrin	0.21 UJ	0.062	0.28 UJ	0.063	0.23 UJ	0.064	0.27 UJ	0.064	0.23 UJ	0.062	0.20 UJ	0.061
Alpha-BHC	0.21 UJ	0.041	0.21 U	0.042	0.21 UJ	0.042	0.21 U	0.042	0.21 UJ	0.041	0.20 UJ	0.041
Beta-BHC	0.21 UJ	0.15	0.21 U	0.15	0.21 UJ	0.15	0.21 U	0.15	0.21 UJ	0.15	0.20 UJ	0.14
Chlorpyriphos	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.20 UJ	-
cis-Chlordane	0.21 UJ	0.092	0.21 U	0.094	0.21 UJ	0.094	0.21 U	0.094	0.21 UJ	0.092	0.20 UJ	0.09
Cis-Nonachlor	0.21 UJ	0.13	0.21 U	0.13	0.21 UJ	0.13	0.21 U	0.13	0.21 UJ	0.13	0.20 UJ	0.13
Dacthal (DCPA)	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.20 UJ	-
DDMU	0.36 UJ	-	0.62 UJ	-	0.21 UJ	-	0.59 UJ	-	0.21 UJ	-	0.20 UJ	-
Delta-BHC	0.21 UJ	0.041	0.21 UJ	0.041	0.21 UJ	0.042	0.21 UJ	0.042	0.21 UJ	0.041	0.20 UJ	0.04
Dieldrin	0.51 UJ	0.21	0.52 UJ	0.21	0.52 UJ	0.21	0.52 UJ	0.21	0.51 UJ	0.21	0.50 UJ	0.2
Endosulfan I	0.21 UJ	0.093	0.21 UJ	0.094	0.21 UJ	0.094	0.21 UJ	0.094	0.21 UJ	0.093	0.20 UJ	0.091
Endosulfan II	0.21 UJ	0.076	0.21 UJ	0.077	0.21 UJ	0.077	0.21 UJ	0.077	0.21 UJ	0.076	0.20 UJ	0.074
Endosulfan Sulfate	0.21 UJ	0.16	0.21 UJ	0.17	0.21 UJ	0.17	0.22 UJ	0.17	0.21 UJ	0.16	0.20 UJ	0.16
Endrin	0.51 UJ	0.22	0.52 UJ	0.22	0.52 UJ	0.22	0.52 UJ	0.22	0.51 UJ	0.22	0.50 UJ	0.22
Endrin Aldehyde	0.21 UJ	0.15	0.21 U	0.16	0.21 UJ	0.16	0.21 U	0.16	0.21 UJ	0.15	0.20 UJ	0.15
Endrin Ketone	0.77 UJ	0.62	0.78 U	0.63	0.78 UJ	0.63	0.78 U	0.63	0.77 UJ	0.62	0.75 UJ	0.61
Gamma-BHC (Lindane)	0.39 UJ	0.051	0.29 UJ	0.052	0.57 UJ	0.052	0.47 UJ	0.052	0.33 UJ	0.051	0.33 UJ	0.05
Heptachlor	0.21 UJ	0.09	0.21 UJ	0.091	0.21 UJ	0.091	0.21 UJ	0.091	0.21 UJ	0.09	0.20 UJ	0.088
Heptachlor Epoxide	0.21 UJ	0.13	0.21 UJ	0.13	0.21 UJ	0.13	0.21 UJ	0.13	0.21 UJ	0.13	0.20 UJ	0.12
Hexachlorobenzene	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.20 UJ	-
Methoxychlor	0.51 UJ	0.26	0.52 UJ	0.26	0.52 UJ	0.26	0.52 UJ	0.26	0.51 UJ	0.26	0.50 UJ	0.25
Mirex	0.49 UJ	-	0.53 UJ	-	0.51 UJ	-	0.51 UJ	-	0.49 UJ	-	0.32 UJ	-
Oxychlordane	0.21 UJ	0.075	0.21 U	0.076	0.21 UJ	0.076	0.21 U	0.076	0.21 UJ	0.075	0.20 UJ	0.073
Pentachloroanisole	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.20 UJ	-
Toxaphene	10 UJ	-	10 U	-	10 UJ	-	10 U	-	10 UJ	-	9.9 UJ	-
trans-Chlordane	0.79 UJ	0.15	1.1 UJ	0.15	1.1 UJ	0.15	1.4 UJ	0.15	0.77 UJ	0.15	0.75 UJ	0.15
Trans-Nonachlor	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.21 U	-	0.21 UJ	-	0.20 UJ	-

Table E-8. July 2009 PAH Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.010 U	0.011	0.0099 U	0.010	0.0098 U	0.010	0.010 U	0.011	0.010 U	0.010	0.010 UJ	0.010	0.0099 U	0.010	0.010 U	0.010
2-Chloronaphthalene	0.010 U	0.0096	0.0099 U	0.0092	0.0098 U	0.0091	0.010 U	0.0097	0.010 U	0.0095	0.010 UJ	0.0095	0.0099 U	0.0092	0.010 U	0.0095
2-Methylnaphthalene	0.010 U	0.0089	0.0099 U	0.0085	0.0098 U	0.0084	0.010 U	0.0090	0.010 U	0.0088	0.010 UJ	0.0088	0.0099 U	0.0085	0.010 U	0.0088
Acenaphthene	0.010 U	0.0088	0.0099 U	0.0085	0.0098 U	0.0084	0.010 U	0.0089	0.010 U	0.0088	0.010 U	0.0088	0.0099 U	0.0085	0.010 U	0.0088
Acenaphthylene	0.010 U	0.0087	0.0099 U	0.0084	0.0098 U	0.0083	0.010 U	0.0088	0.010 U	0.0086	0.010 U	0.0086	0.0099 U	0.0084	0.010 U	0.0086
Anthracene	0.010 U	0.0052	0.0099 U	0.0050	0.0098 U	0.0050	0.010 U	0.0053	0.010 U	0.0052	0.010 U	0.0052	0.0099 U	0.0050	0.010 U	0.0052
Benzo(a)anthracene	0.010 U	0.0009	0.0099 U	0.0009	0.0098 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.020 U	0.0009	0.020 U	0.0009
Benzo(a)pyrene	0.010 UJ	0.0017	0.0099 UJ	0.0016	0.0098 UJ	0.0016	0.010 UJ	0.0017	0.010 UJ	0.0017	0.010 UJ	0.0017	0.020 UJ	0.0016	0.020 UJ	0.0017
Benzo(b)fluoranthene	0.010 U	0.0011	0.0099 U	0.0010	0.0098 UJ	0.0010	0.010 UJ	0.0011	0.010 UJ	0.0010	0.010 UJ	0.0010	0.020 UJ	0.0010	0.020 UJ	0.0010
Benzo(ghi)perylene	0.010 UJ	0.0016	0.0099 UJ	0.0016	0.0098 UJ	0.0016	0.010 UJ	0.0017	0.010 UJ	0.0016	0.010 UJ	0.0016	0.020 U	0.0016	0.020 U	0.0016
Benzo(k)fluoranthene	0.010 U	0.0005	0.0099 UJ	0.0005	0.0098 U	0.0005	0.010 U	0.0006	0.010 U	0.0005	0.010 U	0.0005	0.020 UJ	0.0005	0.020 UJ	0.0005
Carbazole	0.010 U	0.0015	0.0099 U	0.0015	0.0098 U	0.0014	0.010 U	0.0015	0.010 U	0.0015	0.010 U	0.0015	0.0099 U	0.0015	0.010 U	0.0015
Chrysene	0.010 U	0.0009	0.0099 U	0.0008	0.0098 U	0.0008	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.020 U	0.0008	0.020 U	0.0009
Dibenzo(a,h)anthracene	0.010 UJ	0.0014	0.0099 UJ	0.0014	0.0098 UJ	0.0014	0.010 UJ	0.0015	0.010 UJ	0.0014	0.010 UJ	0.0014	0.020 UJ	0.0014	0.020 UJ	0.0014
Dibenzofuran	0.010 U	0.0081	0.0099 U	0.0078	0.0098 U	0.0077	0.010 U	0.0082	0.010 U	0.0081	0.010 U	0.0081	0.0099 U	0.0078	0.010 U	0.0081
Fluoranthene	0.010 U	0.0016	0.0099 U	0.0015	0.0098 U	0.0015	0.010 U	0.0016	0.010 U	0.0016	0.010 U	0.0016	0.0099 U	0.0015	0.010 U	0.0016
Fluorene	0.010 U	0.0076	0.0099 U	0.0073	0.0098 U	0.0072	0.010 U	0.0077	0.010 U	0.0076	0.010 U	0.0076	0.0099 U	0.0073	0.010 U	0.0076
Indeno(1,2,3-cd)pyrene	0.010 U	0.0020	0.0099 U	0.0020	0.0098 U	0.0019	0.010 U	0.0021	0.010 U	0.0020	0.010 UJ	0.0020	0.020 UJ	0.0020	0.020 U	0.0020
Naphthalene	0.010 U	0.032	0.0099 U	0.031	0.0098 U	0.031	0.010 U	0.033	0.010 U	0.032	0.010 UJ	0.032	0.0099 U	0.031	0.010 U	0.032
Phenanthrene	0.010 U	0.0063	0.0099 U	0.0060	0.0098 U	0.0060	0.010 U	0.0063	0.010 U	0.0062	0.010 U	0.0062	0.0099 U	0.0060	0.010 U	0.0062
Pyrene	0.010 U	0.0018	0.0099 U	0.0018	0.0098 U	0.0017	0.010 U	0.0019	0.010 U	0.0018	0.010 U	0.0018	0.020 U	0.0018	0.020 U	0.0018
Retene	0.010 U	0.0010	0.0099 U	0.0009	0.0098 U	0.0009	0.010 U	0.0010	0.010 U	0.0010	0.010 U	0.0010	0.020 U	0.0009	0.020 U	0.0010
Total PAHs																
…ND at ½ RL	0.11 U		0.11 U		0.11 U		0.11 U		0.11 U		0.11 U		0.16 U		0.16 U	
…ND at MDL	0.12 U		0.12 U		0.12 U		0.12 U		0.12 U		0.12 U		0.12 U		0.12 U	
Total cPAHs*																
…ND at ½ RL	0.035 U		0.035 U		0.034 U		0.035 U		0.035 U		0.035 U		0.070 U		0.070 U	
…ND at MDL	0.0085 U		0.0082 U		0.0081 U		0.0088 U		0.0084 U		0.0084 U		0.0082 U		0.0084 U	

* The carcinogenic PAH compounds (cPAHs) are: benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Table E-9. July 2009 PAH Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.010 U	0.010	0.010 U	0.010	0.010 U	0.010	0.010 U	0.010	0.010 U	0.010	0.010 U	0.011
2-Chloronaphthalene	0.010 U	0.0093	0.010 U	0.0095	0.010 U	0.0093	0.010 U	0.0094	0.010 U	0.0095	0.010 U	0.0096
2-Methylnaphthalene	0.010 U	0.0086	0.010 U	0.0088	0.010 U	0.0086	0.010 U	0.0087	0.010 U	0.0088	0.010 U	0.0089
Acenaphthene	0.010 U	0.0086	0.010 U	0.0088	0.010 U	0.0086	0.010 U	0.0087	0.010 U	0.0087	0.010 U	0.0089
Acenaphthylene	0.010 U	0.0085	0.010 U	0.0086	0.010 U	0.0084	0.010 U	0.0085	0.010 U	0.0086	0.010 U	0.0087
Anthracene	0.010 U	0.0051	0.010 U	0.0052	0.010 U	0.0051	0.010 U	0.0051	0.010 U	0.0052	0.010 U	0.0053
Benzo(a)anthracene	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009
Benzo(a)pyrene	0.010 UJ	0.0016	0.010 UJ	0.0017	0.010 UJ	0.0016	0.010 UJ	0.0016	0.010 UJ	0.0017	0.010 UJ	0.0017
Benzo(b)fluoranthene	0.010 UJ	0.0010	0.010 UJ	0.0010	0.010 UJ	0.0010	0.010 UJ	0.0010	0.010 UJ	0.0010	0.010 UJ	0.0011
Benzo(ghi)perylene	0.010 UJ	0.0016	0.010 UJ	0.0016	0.010 UJ	0.0016	0.010 UJ	0.0016	0.010 UJ	0.0016	0.010 UJ	0.0017
Benzo(k)fluoranthene	0.010 U	0.0005	0.010 U	0.0005	0.010 U	0.0005	0.010 U	0.0005	0.010 U	0.0005	0.010 U	0.0005
Carbazole	0.010 U	0.0015	0.010 U	0.0015	0.010 U	0.0015	0.010 U	0.0015	0.010 U	0.0015	0.010 U	0.0015
Chrysene	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009
Dibenzo(a,h)anthracene	0.010 UJ	0.0014	0.010 UJ	0.0014	0.010 UJ	0.0014	0.010 UJ	0.0014	0.010 UJ	0.0014	0.010 UJ	0.0015
Dibenzofuran	0.010 U	0.0079	0.010 U	0.0081	0.010 U	0.0079	0.010 U	0.0079	0.010 U	0.0080	0.010 U	0.0081
Fluoranthene	0.010 U	0.0015	0.010 U	0.0016	0.010 U	0.0015	0.010 U	0.0016	0.010 U	0.0016	0.010 U	0.0016
Fluorene	0.010 U	0.0074	0.010 U	0.0076	0.010 U	0.0074	0.010 U	0.0075	0.010 U	0.0075	0.010 U	0.0077
Indeno(1,2,3-cd)pyrene	0.010 U	0.0020	0.010 U	0.0020	0.010 U	0.0020	0.010 U	0.0020	0.010 U	0.0020	0.010 U	0.0020
Naphthalene	0.010 U	0.032	0.010 U	0.032	0.010 U	0.031	0.010 U	0.032	0.010 U	0.032	0.010 U	0.033
Phenanthrene	0.010 U	0.0061	0.010 U	0.0062	0.010 U	0.0061	0.010 U	0.0061	0.010 U	0.0062	0.010 U	0.0063
Pyrene	0.010 U	0.0018	0.010 U	0.0018	0.010 U	0.0018	0.010 U	0.0018	0.010 U	0.0018	0.010 U	0.0018
Retene	0.010 U	0.0010	0.010 U	0.0010	0.010 U	0.0010	0.010 U	0.0010	0.010 U	0.0010	0.010 U	0.0010
Total PAHs												
…ND at ½ RL	0.11 U		0.11 U		0.11 U		0.11 U		0.11 U		0.11 U	
…ND at MDL	0.12 U		0.12 U		0.12 U		0.12 U		0.12 U		0.12 U	
Total cPAHs												
…ND at ½ RL	0.035 U		0.035 U		0.035 U		0.035 U		0.035 U		0.035 U	
…ND at MDL	0.0083 U		0.0084 U		0.0083 U		0.0083 U		0.0084 U		0.0086 U	

Table E-10. September 2009 PAH Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.010 U	0.0010	0.010 U	0.0010	0.0098 U	0.0010	0.0099 U	0.0010	0.0099 U	0.0010	0.0099 U	0.0010	0.010 U	0.0010	0.010 U	0.0010
2-Chloronaphthalene	0.010 U	0.0093	0.010 U	0.0093	0.0098 U	0.0092	0.0099 U	0.0092	0.0099 U	0.0092	0.0099 U	0.0092	0.010 U	0.0096	0.010 U	0.0095
2-Methylnaphthalene	0.010 U	0.0086	0.010 U	0.0086	0.0098 U	0.0085	0.0099 U	0.0085	0.0099 U	0.0085	0.0099 U	0.0086	0.010 U	0.0089	0.010 U	0.0088
Acenaphthene	0.010 U	0.0086	0.010 U	0.0086	0.0098 U	0.0084	0.0099 U	0.0085	0.0099 U	0.0085	0.0099 U	0.0085	0.010 U	0.0089	0.010 U	0.0088
Acenaphthylene	0.010 UJ	0.0085	0.010 UJ	0.0084	0.0098 UJ	0.0083	0.0099 UJ	0.0084	0.0099 UJ	0.0084	0.0099 UJ	0.0084	0.010 UJ	0.0087	0.010 UJ	0.0086
Anthracene	0.010 U	0.0051	0.010 U	0.0051	0.0098 U	0.0050	0.0099 U	0.0050	0.0099 U	0.0050	0.0099 U	0.0051	0.010 U	0.0053	0.010 U	0.0052
Benzo(a)anthracene	0.010 U	0.0009	0.010 U	0.0009	0.0098 U	0.0009	0.0099 U	0.0009	0.0099 U	0.0009	0.0099 U	0.0009	0.010 U	0.0009	0.010 U	0.0009
Benzo(a)pyrene	0.010 U	0.0016	0.010 U	0.0016	0.0098 U	0.0016	0.0099 U	0.0016	0.0099 U	0.0016	0.0099 U	0.0016	0.010 U	0.0017	0.010 U	0.0017
Benzo(b)fluoranthene	0.010 U	0.0010	0.010 U	0.0010	0.0098 U	0.0010	0.0099 U	0.0010	0.0099 U	0.0010	0.0099 U	0.0010	0.010 U	0.0011	0.010 U	0.0010
Benzo(ghi)perylene	0.010 U	0.0016	0.010 U	0.0016	0.0098 U	0.0016	0.0099 U	0.0016	0.0099 U	0.0016	0.0099 U	0.0016	0.010 U	0.0017	0.010 U	0.0016
Benzo(k)fluoranthene	0.010 U	0.0005	0.010 U	0.0005	0.0098 U	0.0005	0.0099 U	0.0005	0.0099 U	0.0005	0.0099 U	0.0005	0.010 U	0.0005	0.010 U	0.0005
Carbazole	0.010 UJ	0.0015	0.010 UJ	0.0015	0.0098 UJ	0.0015	0.0099 UJ	0.0015	0.0099 UJ	0.0015	0.0099 UJ	0.0015	0.010 UJ	0.0015	0.010 UJ	0.0015
Chrysene	0.010 U	0.0009	0.010 U	0.0009	0.0098 U	0.0008	0.0099 U	0.0008	0.0099 U	0.0008	0.0099 U	0.0008	0.010 U	0.0009	0.010 U	0.0009
Dibenzo(a,h)anthracene	0.010 U	0.0014	0.010 U	0.0014	0.0098 U	0.0014	0.0099 U	0.0014	0.0099 U	0.0014	0.0099 U	0.0014	0.010 U	0.0015	0.010 U	0.0014
Dibenzofuran	0.010 U	0.0079	0.010 U	0.0079	0.0098 U	0.0077	0.0099 U	0.0078	0.0099 U	0.0078	0.0099 U	0.0078	0.010 U	0.0081	0.010 U	0.0081
Fluoranthene	0.010 U	0.0015	0.010 U	0.0015	0.0098 U	0.0015	0.0099 U	0.0015	0.0099 U	0.0015	0.0099 U	0.0015	0.010 U	0.0016	0.010 U	0.0016
Fluorene	0.010 U	0.0074	0.010 U	0.0074	0.0098 U	0.0073	0.0099 U	0.0073	0.0099 U	0.0073	0.0099 U	0.0074	0.010 U	0.0077	0.010 U	0.0076
Indeno(1,2,3-cd)pyrene	0.010 U	0.0020	0.010 U	0.0020	0.0098 U	0.0019	0.0099 U	0.0020	0.0099 U	0.0020	0.0099 U	0.0020	0.010 U	0.0020	0.010 U	0.0020
Naphthalene	0.010 U	0.0011	0.010 U	0.0011	0.0098 U	0.0011	0.0099 U	0.0011	0.0099 U	0.0011	0.0099 U	0.0011	0.010 U	0.0012	0.010 U	0.0011
Phenanthrene	0.010 U	0.0061	0.010 U	0.0061	0.0098 U	0.0060	0.0099 U	0.0060	0.0099 U	0.0060	0.0099 U	0.0060	0.010 U	0.0063	0.010 U	0.0062
Pyrene	0.010 U	0.0018	0.010 U	0.0018	0.0098 U	0.0018	0.0099 U	0.0018	0.0099 U	0.0018	0.0099 U	0.0018	0.010 U	0.0018	0.010 U	0.0018
Retene	0.010 U	0.0010	0.010 U	0.0010	0.0098 U	0.0009	0.0099 U	0.0009	0.0099 U	0.0009	0.0099 U	0.0009	0.010 U	0.0010	0.010 U	0.0010
Total PAHs																
…ND at ½ RL	0.11 U		0.11 U		0.11 U		0.11 U		0.11 U		0.11 U		0.11 U		0.11 U	
…ND at MDL	0.079 U		0.079 U		0.078 U		0.078 U		0.078 U		0.079 U		0.082 U		0.081 U	
Total cPAHs*																
…ND at ½ RL	0.035 U		0.035 U		0.034 U		0.035 U		0.035 U		0.035 U		0.035 U		0.035 U	
…ND at MDL	0.0083 U		0.0083 U		0.0081 U		0.0082 U		0.0082 U		0.0082 U		0.0086 U		0.0084 U	

* The carcinogenic PAH compounds (cPAHs) are: benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Table E-11. September 2009 PAH Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.0098 U	0.0010	0.010 U	0.0010	0.0099 U	0.0010	0.0099 U	0.0010	0.010 U	0.0010	0.0098 U	0.0010
2-Chloronaphthalene	0.0098 U	0.0092	0.010 U	0.0093	0.0099 U	0.0092	0.0099 U	0.0092	0.010 U	0.0096	0.0098 U	0.0092
2-Methylnaphthalene	0.0098 U	0.0085	0.010 U	0.0086	0.0099 U	0.0085	0.0099 U	0.0086	0.010 U	0.0089	0.0098 U	0.0085
Acenaphthene	0.0098 U	0.0084	0.010 U	0.0086	0.0099 U	0.0085	0.0099 U	0.0085	0.010 U	0.0089	0.0098 U	0.0084
Acenaphthylene	0.0098 U	0.0083	0.010 U	0.0084	0.0099 U	0.0084	0.0099 U	0.0084	0.010 U	0.0087	0.0098 U	0.0083
Anthracene	0.0098 U	0.0050	0.010 U	0.0051	0.0099 U	0.0050	0.0099 U	0.0051	0.010 U	0.0053	0.0098 U	0.0050
Benzo(a)anthracene	0.0098 U	0.0009	0.010 U	0.0009	0.0099 U	0.0009	0.0099 U	0.0009	0.010 U	0.0009	0.0098 U	0.0009
Benzo(a)pyrene	0.0098 U	0.0016	0.010 U	0.0016	0.0099 U	0.0016	0.0099 U	0.0016	0.010 U	0.0017	0.0098 U	0.0016
Benzo(b)fluoranthene	0.0098 U	0.0010	0.010 U	0.0010	0.0099 U	0.0010	0.0099 U	0.0010	0.010 U	0.0011	0.0098 U	0.0010
Benzo(ghi)perylene	0.0098 U	0.0016	0.010 U	0.0016	0.0099 U	0.0016	0.0099 U	0.0016	0.010 U	0.0017	0.0098 U	0.0016
Benzo(k)fluoranthene	0.0098 U	0.0005	0.010 U	0.0005	0.0099 U	0.0005	0.0099 U	0.0005	0.010 U	0.0005	0.0098 U	0.0005
Carbazole	0.0098 UJ	0.0015	0.010 UJ	0.0015	0.0099 UJ	0.0015	0.0099 UJ	0.0015	0.010 UJ	0.0015	0.0098 UJ	0.0015
Chrysene	0.0098 U	0.0008	0.010 U	0.0009	0.0099 U	0.0008	0.0099 U	0.0008	0.010 U	0.0009	0.0098 U	0.0008
Dibenzo(a,h)anthracene	0.0098 U	0.0014	0.010 U	0.0014	0.0099 U	0.0014	0.0099 U	0.0014	0.010 U	0.0015	0.0098 U	0.0014
Dibenzofuran	0.0098 U	0.0077	0.010 U	0.0079	0.0099 U	0.0078	0.0099 U	0.0078	0.010 U	0.0081	0.0098 U	0.0077
Fluoranthene	0.0098 U	0.0015	0.010 U	0.0015	0.0099 U	0.0015	0.0099 U	0.0015	0.010 U	0.0016	0.0098 U	0.0015
Fluorene	0.0098 U	0.0073	0.010 U	0.0074	0.0099 U	0.0073	0.0099 U	0.0074	0.010 U	0.0077	0.0098 U	0.0073
Indeno(1,2,3-cd)pyrene	0.0098 U	0.0019	0.010 U	0.0020	0.0099 U	0.0020	0.0099 U	0.0020	0.010 U	0.0020	0.0098 U	0.0019
Naphthalene	0.0098 U	0.0011	0.010 U	0.0011	0.0099 U	0.0011	0.0099 U	0.0011	0.010 U	0.0012	0.0098 U	0.0011
Phenanthrene	0.0098 U	0.0060	0.010 U	0.0061	0.0099 U	0.0060	0.0099 U	0.0060	0.010 U	0.0063	0.0098 U	0.0060
Pyrene	0.0098 U	0.0018	0.010 U	0.0018	0.0099 U	0.0018	0.0099 U	0.0018	0.010 U	0.0018	0.0098 U	0.0018
Retene	0.0098 U	0.0009	0.010 U	0.0010	0.0099 U	0.0009	0.0099 U	0.0009	0.010 U	0.0010	0.0098 U	0.0009
Total PAHs												
…ND at ½ RL	0.11 U		0.11 U		0.11 U		0.11 U		0.11 U		0.11 U	
…ND at MDL	0.078 U		0.079 U		0.078 U		0.079 U		0.082 U		0.078 U	
Total cPAHs												
…ND at ½ RL	0.034 U		0.035 U		0.035 U		0.035 U		0.035 U		0.034 U	
…ND at MDL	0.0081 U		0.0083 U		0.0082 U		0.0082 U		0.0086 U		0.0081 U	

Table E-12. January 2010 PAH Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.0099 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.010 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010
2-Chloronaphthalene	0.0099 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.010 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0009	0.0099 U	0.0010
2-Methylnaphthalene	0.0099 U	0.0013	0.0099 U	0.0013	0.0097 U	0.0013	0.010 U	0.0013	0.0097 U	0.0013	0.0099 U	0.0013	0.0097 U	0.0013	0.0099 U	0.0013
Acenaphthene	0.0099 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.010 U	0.0011	0.0097 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010
Acenaphthylene	0.0099 U	0.0018	0.0099 U	0.0018	0.0097 UJ	0.0018	0.010 UJ	0.0019	0.0097 UJ	0.0018	0.0099 UJ	0.0018	0.0097 UJ	0.0018	0.0099 UJ	0.0018
Anthracene	0.0099 U	0.0023	0.0099 U	0.0023	0.0097 U	0.0022	0.010 U	0.0023	0.0097 U	0.0022	0.0099 U	0.0022	0.0097 U	0.0022	0.0099 U	0.0022
Benzo(a)anthracene	0.0099 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.010 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010
Benzo(a)pyrene	0.020 U	0.0018	0.020 U	0.0018	0.019 U	0.0018	0.020 U	0.0019	0.019 U	0.0018	0.020 U	0.0018	0.019 U	0.0018	0.020 U	0.0018
Benzo(b)fluoranthene	0.0099 U	0.0011	0.0099 U	0.0011	0.0097 U	0.0011	0.010 U	0.0011	0.0097 U	0.0011	0.0099 U	0.0011	0.0097 U	0.0011	0.0099 U	0.0011
Benzo(ghi)perylene	0.0099 U	0.0017	0.0099 U	0.0017	0.0097 UJ	0.0017	0.010 UJ	0.0017	0.0097 UJ	0.0017	0.0099 UJ	0.0017	0.0097 UJ	0.0017	0.0099 UJ	0.0017
Benzo(k)fluoranthene	0.0099 U	0.0006	0.0099 U	0.0006	0.0097 U	0.0006	0.010 U	0.0006	0.0097 U	0.0006	0.0099 U	0.0006	0.0097 U	0.0006	0.0099 U	0.0006
Carbazole	0.0099 U	0.0013	0.0099 U	0.0013	0.0097 U	0.0012	0.010 U	0.0013	0.0097 U	0.0012	0.0099 U	0.0012	0.0097 U	0.0012	0.0099 U	0.0012
Chrysene	0.0099 U	0.0009	0.0099 U	0.0009	0.0097 U	0.0009	0.010 U	0.0009	0.0097 U	0.0009	0.0099 U	0.0009	0.0097 U	0.0009	0.0099 U	0.0009
Dibenzo(a,h)anthracene	0.0099 U	0.0015	0.0099 U	0.0015	0.0097 UJ	0.0015	0.010 UJ	0.0015	0.0097 UJ	0.0015	0.0099 UJ	0.0015	0.0097 UJ	0.0015	0.0099 UJ	0.0015
Dibenzofuran	0.0099 U	0.0009	0.0099 U	0.0009	0.0097 U	0.0009	0.010 U	0.0009	0.0097 U	0.0009	0.0099 U	0.0009	0.0097 U	0.0009	0.0099 U	0.0009
Fluoranthene	0.0099 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.010 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010	0.0097 U	0.0010	0.0099 U	0.0010
Fluorene	0.0099 U	0.0007	0.0099 U	0.0007	0.0097 U	0.0007	0.010 U	0.0007	0.0097 U	0.0007	0.0099 U	0.0007	0.0097 U	0.0007	0.0099 UJ	0.0007
Indeno(1,2,3-cd)pyrene	0.0099 U	0.0020	0.0099 U	0.0020	0.0097 U	0.0020	0.010 U	0.0021	0.0097 U	0.0020	0.0099 U	0.0020	0.0097 U	0.0020	0.0099 U	0.0020
Naphthalene	0.0099 U	0.0011	0.0099 U	0.0011	0.0097 U	0.0011	0.010 U	0.0011	0.0097 U	0.0011	0.0099 U	0.0011	0.0097 U	0.0011	0.0099 U	0.0011
Phenanthrene	0.0099 U	0.0024	0.0099 U	0.0024	0.0097 U	0.0023	0.010 U	0.0025	0.0097 U	0.0023	0.0099 U	0.0024	0.0097 U	0.0023	0.0099 U	0.0024
Pyrene	0.0099 U	0.0020	0.0099 U	0.0020	0.0097 U	0.0019	0.010 U	0.0020	0.0097 U	0.0019	0.0099 U	0.0020	0.0097 U	0.0019	0.0099 U	0.0020
Retene	0.0099 U	0.0011	0.0099 U	0.0011	0.0097 U	0.0011	0.010 U	0.0011	0.0097 U	0.0011	0.0099 U	0.0011	0.0097 U	0.0010	0.0099 U	0.0011

Total PAHs																
…ND at ½ RL	0.11 U		0.11 U		0.11 U		0.12 U		0.11 U		0.11 U		0.11 U		0.11 U	
…ND at MDL	0.030 U		0.030 U		0.029 U		0.030 U		0.029 U		0.029 U		0.029 U		0.029 U	

Total cPAHs*																
…ND at ½ RL	0.040 U		0.040 U		0.039 U		0.040 U		0.039 U		0.040 U		0.039 U		0.040 U	
…ND at MDL	0.0089 U		0.0089 U		0.0089 U		0.0091 U		0.0089 U		0.0089 U		0.0089 U		0.0089 U	

* The carcinogenic PAH compounds (cPAHs) are: benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Table E-13. January 2010 PAH Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.0098 UJ	0.0010	0.011 U	0.0011	0.0099 U	0.0010	0.010 UJ	0.0010	0.0098 U	0.0010	0.0098 U	0.0010
2-Chloronaphthalene	0.0098 U	0.0010	0.011 U	0.0010	0.0099 U	0.0010	0.010 U	0.0010	0.0098 U	0.0010	0.0098 U	0.0010
2-Methylnaphthalene	0.0098 UJ	0.0013	0.011 U	0.0014	0.0099 U	0.0013	0.010 UJ	0.0013	0.0098 U	0.0013	0.0098 U	0.0013
Acenaphthene	0.0098 U	0.0010	0.011 U	0.0011	0.0099 U	0.0010	0.010 U	0.0011	0.0098 U	0.0010	0.0098 U	0.0010
Acenaphthylene	0.0098 U	0.0018	0.011 U	0.0019	0.0099 U	0.0018	0.010 U	0.0019	0.0098 U	0.0018	0.0098 U	0.0018
Anthracene	0.0098 U	0.0022	0.011 U	0.0024	0.0099 U	0.0023	0.010 U	0.0023	0.0098 U	0.0022	0.0098 U	0.0022
Benzo(a)anthracene	0.0098 U	0.0010	0.011 U	0.0011	0.0099 U	0.0010	0.010 U	0.0010	0.0098 U	0.0010	0.0098 U	0.0010
Benzo(a)pyrene	0.020 U	0.0018	0.021 U	0.0020	0.020 U	0.0018	0.021 U	0.0019	0.020 U	0.0018	0.020 U	0.0018
Benzo(b)fluoranthene	0.0098 U	0.0011	0.011 U	0.0012	0.0099 U	0.0011	0.010 U	0.0012	0.0098 U	0.0011	0.0098 U	0.0011
Benzo(ghi)perylene	0.0098 U	0.0017	0.011 U	0.0018	0.0099 U	0.0017	0.010 U	0.0018	0.0098 U	0.0017	0.0098 U	0.0017
Benzo(k)fluoranthene	0.0098 U	0.0006	0.011 U	0.0006	0.0099 U	0.0006	0.010 U	0.0006	0.0098 U	0.0006	0.0098 U	0.0006
Carbazole	0.0098 U	0.0012	0.011 U	0.0013	0.0099 U	0.0013	0.010 U	0.0013	0.0098 U	0.0012	0.0098 U	0.0012
Chrysene	0.0098 U	0.0009	0.011 U	0.0010	0.0099 U	0.0009	0.010 U	0.0009	0.0098 U	0.0009	0.0098 U	0.0009
Dibenzo(a,h)anthracene	0.0098 UJ	0.0015	0.011 UJ	0.0016	0.0099 UJ	0.0015	0.010 UJ	0.0016	0.0098 UJ	0.0015	0.0098 UJ	0.0015
Dibenzofuran	0.0098 U	0.0009	0.011 U	0.0010	0.0099 U	0.0009	0.010 U	0.0009	0.0098 U	0.0009	0.0098 U	0.0009
Fluoranthene	0.0098 U	0.0010	0.011 U	0.0011	0.0099 U	0.0010	0.010 U	0.0010	0.0098 U	0.0010	0.0098 U	0.0010
Fluorene	0.0098 U	0.0007	0.011 U	0.0007	0.0099 U	0.0007	0.010 U	0.0007	0.0098 U	0.0007	0.0098 U	0.0007
Indeno(1,2,3-cd)pyrene	0.0098 U	0.0020	0.011 U	0.0021	0.0099 U	0.0020	0.010 U	0.0021	0.0098 U	0.0020	0.0098 U	0.0020
Naphthalene	0.0098 UJ	0.0011	0.011 U	0.0012	0.0099 U	0.0011	0.010 UJ	0.0012	0.0098 U	0.0011	0.0098 U	0.0011
Phenanthrene	0.0098 U	0.0024	0.011 U	0.0025	0.0099 U	0.0024	0.010 U	0.0025	0.0098 U	0.0024	0.0098 U	0.0024
Pyrene	0.0098 U	0.0020	0.011 U	0.0021	0.0099 U	0.0020	0.010 U	0.0021	0.0098 U	0.0020	0.0098 U	0.0020
Retene	0.0098 U	0.0011	0.011 U	0.0011	0.0099 U	0.0011	0.010 U	0.0011	0.0098 U	0.0011	0.0098 U	0.0011
Total PAHs												
…ND at ½ RL	0.11 U		0.13 U		0.11 U		0.12 U		0.11 U		0.11 U	
…ND at MDL	0.029 U		0.031 U		0.030 U		0.031 U		0.029 U		0.029 U	
Total cPAHs												
…ND at ½ RL	0.039 U		0.044 U		0.040 U		0.041 U		0.039 U		0.039 U	
…ND at MDL	0.0089 U		0.0096 U		0.0089 U		0.0093 U		0.0089 U		0.0089 U	

Table E-14. July 2009 BNA Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
1,2-Dichlorobenzene	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
1,2-Diphenylhydrazine	0.083 U	-	0.088 UJ	-	0.089 UJ	-	0.091 UJ	-	0.086 UJ	-	0.086 UJ	-	0.090 UJ	-	0.085 UJ	-
1,3-Dichlorobenzene	0.083 UJ	-	0.088 UJ	-	0.089 UJ	-	0.091 UJ	-	0.086 UJ	-	0.086 UJ	-	0.090 UJ	-	0.085 UJ	-
1,4-Dichlorobenzene	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
2,2'-Oxybis[1-chloropropane]	0.08 U	-	0.09 U	-	0.09 U	-	0.09 U	-	0.09 U	-	0.09 U	-	0.09 U	-	0.08 U	-
2,4,5-Trichlorophenol	0.33 U	-	0.35 U	-	0.36 U	-	0.36 U	-	0.34 U	-	0.34 U	-	0.36 U	-	0.34 U	-
2,4,6-Trichlorophenol	0.33 UJ	-	0.35 UJ	-	0.36 UJ	-	0.36 UJ	-	0.34 UJ	-	0.34 UJ	-	0.36 UJ	-	0.34 UJ	-
2,4-Dichlorophenol	0.062 J	-	0.16 J	-	0.043 J	-	0.91 U	-	0.86 U	-	0.86 U	-	0.90 U	-	0.85 U	-
2,4-Dimethylphenol	0.83 U	-	0.88 U	-	0.89 U	-	0.91 U	-	0.86 U	-	0.86 U	-	0.90 U	-	0.85 U	-
2,4-Dinitrophenol	0.83 U	-	0.88 U	-	0.89 U	-	0.91 U	-	0.86 U	-	0.86 U	-	0.90 U	-	0.85 U	-
2,4-Dinitrotoluene	0.33 UJ	-	0.35 UJ	-	0.36 UJ	-	0.36 UJ	-	0.34 UJ	-	0.34 U	-	0.36 U	-	0.34 U	-
2,6-Dinitrotoluene	0.33 U	-	0.35 U	-	0.36 U	-	0.36 U	-	0.34 U	-	0.34 U	-	0.36 U	-	0.34 U	-
2-Chlorophenol	0.33 U	-	0.35 U	-	0.36 U	-	0.36 U	-	0.34 U	-	0.34 U	-	0.36 U	-	0.34 U	-
2-Methylphenol	0.011 J	-	0.037 J	-	0.010 J	-	0.91 U	-	0.86 U	-	0.86 U	-	0.90 U	-	0.85 U	-
2-Nitroaniline	1.7 U	-	1.8 U	-	1.8 U	-	1.8 U	-	1.7 U	-	1.7 U	-	1.8 U	-	1.7 U	-
2-Nitrophenol	0.17 UJ	-	0.18 UJ	-	0.18 UJ	-	0.18 UJ	-	0.17 UJ	-	0.17 UJ	-	0.18 UJ	-	0.17 UJ	-
3,3'-Dichlorobenzidine	0.17 UJ	-	0.18 UJ	-	0.18 UJ	-	0.18 UJ	-	0.17 UJ	-	0.17 U	-	0.18 U	-	0.17 U	-
3B-Coprostanol	1.2 J	-	0.88 UJ	-	0.89 UJ	-	0.91 UJ	-	0.86 UJ	-	0.86 U	-	0.90 U	-	0.85 U	-
3-Nitroaniline	0.33 U	-	0.35 U	-	0.36 U	-	0.36 U	-	0.34 U	-	0.34 U	-	0.36 U	-	0.34 U	-
4,6-Dinitro-2-Methylphenol	0.33 U	-	0.35 U	-	0.36 U	-	0.36 U	-	0.34 U	-	0.34 U	-	0.36 U	-	0.34 U	-
4-Bromophenyl phenyl ether	0.17 U	-	0.18 U	-	0.18 U	-	0.18 U	-	0.17 U	-	0.17 U	-	0.18 U	-	0.17 U	-
4-Chloro-3-Methylphenol	0.060 J	-	0.33 J	-	0.024 J	-	0.91 UJ	-	0.86 UJ	-	0.86 UJ	-	0.90 UJ	-	0.026 J	-
4-Chloroaniline	3.3 REJ	-	3.5 REJ	-	3.6 REJ	-	3.6 REJ	-	3.4 REJ	-	3.4 REJ	-	3.6 REJ	-	3.4 REJ	-
4-Chlorophenyl-Phenylether	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
4-Methylphenol	0.83 U	-	0.88 U	-	0.89 U	-	0.91 U	-	0.86 U	-	0.86 U	-	0.90 U	-	0.85 U	-
4-Nitroaniline	0.33 UJ	-	0.35 UJ	-	0.36 UJ	-	0.36 UJ	-	0.34 UJ	-	0.34 UJ	-	0.36 UJ	-	0.34 UJ	-
4-Nitrophenol	0.83 UJ	-	0.88 UJ	-	0.89 UJ	-	0.91 UJ	-	0.86 UJ	-	0.86 UJ	-	0.90 UJ	-	0.85 UJ	-
4-nonylphenol	0.33 U	0.033	0.35 U	0.035	0.36 U	0.036	0.36 U	0.036	0.34 U	0.034	0.34 U	0.034	0.36 U	0.036	0.34 U	0.034
Benzoic Acid	0.83 UJ	-	0.88 UJ	-	0.89 UJ	-	0.91 UJ	-	0.86 UJ	-	0.86 UJ	-	0.90 UJ	-	0.85 UJ	-
Benzyl Alcohol	0.83 UJ	-	0.88 UJ	-	0.89 UJ	-	0.91 UJ	-	0.86 UJ	-	0.86 UJ	-	0.90 UJ	-	0.85 UJ	-
Bis(2-chloro-1-methylethyl) ether	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
Bis(2-Chloroethoxy)Methane	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
Bis(2-Chloroethyl)Ether	0.17 U	-	0.18 U	-	0.18 U	-	0.18 U	-	0.17 U	-	0.17 U	-	0.18 U	-	0.17 U	-
Bis(2-Ethylhexyl) Phthalate	0.048 J	-	0.012 J	-	0.18 U	-	0.18 U	-	0.17 U	-	0.17 U	-	0.18 U	-	0.17 U	-
Bisphenol A	0.33 UJ	0.033	0.19 J	0.035	0.36 U	0.036	0.36 U	0.036	0.34 U	0.034	0.34 U	0.034	0.36 U	0.036	0.34 U	0.034
Butyl benzyl phthalate	0.069 UJ	0.033	0.35 UJ	0.035	0.36 U	0.036	0.36 U	0.036	0.34 U	0.034	0.34 U	0.034	0.36 U	0.036	0.34 U	0.034
Caffeine	0.17 U	-	0.18 U	-	0.18 U	-	0.18 U	-	0.17 U	-	0.17 U	-	0.029 J	-	0.17 U	-
Cholesterol	0.62 J	-	0.88 UJ	-	0.75 J	-	0.91 UJ	-	0.86 UJ	-	0.86 U	-	0.76 J	-	0.64 J	-

Table E-14, continued. July 2009 BNA Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
Diethyl phthalate	0.17 U	0.033	0.18 U	0.035	0.18 U	0.036	0.18 U	0.036	0.17 U	0.034	0.17 U	0.034	0.18 U	0.036	0.17 U	0.034
Dimethyl phthalate	0.17 U	0.033	0.18 U	0.035	0.18 U	0.036	0.18 U	0.036	0.17 U	0.034	0.17 U	0.034	0.18 U	0.036	0.17 U	0.034
Di-N-Butylphthalate	0.29 UJ	-	0.34 UJ	-	0.23 UJ	-	0.20 UJ	-	0.12 UJ	-	0.14 UJ	-	0.15 UJ	-	0.17 UJ	-
Di-N-Octyl Phthalate	0.17 UJ	-	0.18 UJ	-	0.18 U	-	0.18 U	-	0.17 U	-	0.17 U	-	0.18 U	-	0.17 U	-
Ethanol, 2-Chloro-, Phosphate (3:1)	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.099	-	0.085 U	-
Hexachlorobenzene	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
Hexachlorobutadiene	0.083 UJ	-	0.088 UJ	-	0.089 UJ	-	0.091 UJ	-	0.086 UJ	-	0.086 UJ	-	0.090 UJ	-	0.085 UJ	-
Hexachlorocyclopentadiene	0.33 UJ	-	0.35 UJ	-	0.36 UJ	-	0.36 UJ	-	0.34 UJ	-	0.34 UJ	-	0.36 UJ	-	0.34 UJ	-
Hexachloroethane	0.083 UJ	-	0.088 UJ	-	0.089 UJ	-	0.091 UJ	-	0.086 UJ	-	0.086 UJ	-	0.090 UJ	-	0.085 UJ	-
Isophorone	0.17 U	-	0.18 U	-	0.18 U	-	0.18 U	-	0.17 U	-	0.17 U	-	0.18 U	-	0.17 U	-
Nitrobenzene	0.083 U	-	0.088 U	-	0.089 U	-	0.091 U	-	0.086 U	-	0.086 U	-	0.090 U	-	0.085 U	-
N-Nitrosodi-n-propylamine	0.10 U	-	0.11 U	-	0.11 U	-	0.11 U	-	0.10 U	-	0.10 U	-	0.11 U	-	0.10 U	-
N-Nitrosodiphenylamine	0.17 U	-	0.18 U	-	0.18 U	-	0.18 U	-	0.17 U	-	0.17 UJ	-	0.18 UJ	-	0.17 UJ	-
Pentachlorophenol	0.083 UJ	-	0.088 UJ	-	0.089 UJ	-	0.091 UJ	-	0.086 UJ	-	0.086 UJ	-	0.090 UJ	-	0.085 UJ	-
Phenol	0.33 U	-	0.017 J	-	0.36 U	-	0.36 U	-	0.34 U	-	0.34 U	-	0.36 U	-	0.34 U	-
Triclosan	0.083 UJ	-	0.088 UJ	-	0.089 UJ	-	0.091 UJ	-	0.086 UJ	-	0.086 U	-	0.090 U	-	0.085 U	-
Triethyl citrate	0.33 U	0.033	0.35 U	0.035	0.36 U	0.036	0.36 U	0.036	0.34 U	0.034	0.34 U	0.034	0.36 U	0.036	0.34 U	0.034

Table E-15. July 2009 BNA Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
1,2-Dichlorobenzene	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
1,2-Diphenylhydrazine	0.085 UJ	-	0.079 UJ	-	0.090 UJ	-	0.088 UJ	-	0.082 UJ	-	0.079 UJ	-
1,3-Dichlorobenzene	0.085 UJ	-	0.079 UJ	-	0.090 UJ	-	0.088 UJ	-	0.082 UJ	-	0.079 UJ	-
1,4-Dichlorobenzene	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
2,2'-Oxybis[1-chloropropane]	0.08 U	-	0.08 U	-	0.09 U	-	0.09 U	-	0.08 U	-	0.08 U	-
2,4,5-Trichlorophenol	0.34 U	-	0.32 U	-	0.36 U	-	0.35 U	-	0.33 U	-	0.31 U	-
2,4,6-Trichlorophenol	0.34 UJ	-	0.32 UJ	-	0.36 UJ	-	0.35 UJ	-	0.33 UJ	-	0.31 UJ	-
2,4-Dichlorophenol	0.85 U	-	0.79 U	-	0.90 U	-	0.88 U	-	0.82 U	-	0.063 J	-
2,4-Dimethylphenol	0.85 U	-	0.79 U	-	0.90 U	-	0.88 U	-	0.82 U	-	0.79 U	-
2,4-Dinitrophenol	0.85 U	-	0.79 U	-	0.90 U	-	0.88 U	-	0.82 U	-	0.79 U	-
2,4-Dinitrotoluene	0.34 UJ	-	0.32 UJ	-	0.36 UJ	-	0.35 UJ	-	0.33 UJ	-	0.31 UJ	-
2,6-Dinitrotoluene	0.34 U	-	0.32 U	-	0.36 U	-	0.35 U	-	0.33 U	-	0.31 U	-
2-Chlorophenol	0.34 U	-	0.32 U	-	0.36 U	-	0.35 U	-	0.33 U	-	0.31 U	-
2-Methylphenol	0.85 U	-	0.79 U	-	0.90 U	-	0.88 U	-	0.82 U	-	0.013 J	-
2-Nitroaniline	1.7 U	-	1.6 U	-	1.8 U	-	1.8 U	-	1.6 U	-	1.6 U	-
2-Nitrophenol	0.17 UJ	-	0.16 UJ	-	0.18 UJ	-	0.18 UJ	-	0.16 UJ	-	0.16 UJ	-
3,3'-Dichlorobenzidine	0.17 UJ	-	0.16 UJ	-	0.18 UJ	-	0.18 UJ	-	0.16 UJ	-	0.16 UJ	-
3B-Coprostanol	0.85 UJ	-	0.79 UJ	-	0.90 UJ	-	0.88 UJ	-	0.82 UJ	-	0.79 UJ	-
3-Nitroaniline	0.34 U	-	0.32 U	-	0.36 U	-	0.35 U	-	0.33 U	-	0.31 U	-
4,6-Dinitro-2-Methylphenol	0.34 U	-	0.32 U	-	0.36 U	-	0.35 U	-	0.33 U	-	0.31 U	-
4-Bromophenyl phenyl ether	0.17 U	-	0.16 U	-	0.18 U	-	0.18 U	-	0.16 U	-	0.16 U	-
4-Chloro-3-Methylphenol	0.85 UJ	-	0.025 J	-	0.90 U	-	0.016 J	-	0.82 UJ	-	0.094 J	-
4-Chloroaniline	3.4 REJ	-	3.2 REJ	-	3.6 REJ	-	3.5 REJ	-	3.3 REJ	-	3.1 REJ	-
4-Chlorophenyl-Phenylether	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
4-Methylphenol	0.85 U	-	0.79 U	-	0.90 U	-	0.88 U	-	0.82 U	-	0.79 U	-
4-Nitroaniline	0.34 UJ	-	0.32 UJ	-	0.36 UJ	-	0.35 UJ	-	0.33 UJ	-	0.31 UJ	-
4-Nitrophenol	0.85 UJ	-	0.79 UJ	-	0.90 UJ	-	0.88 UJ	-	0.82 UJ	-	0.79 UJ	-
4-nonylphenol	0.34 U	0.034	0.32 U	0.032	0.36 U	0.036	0.35 U	0.035	0.33 U	0.033	0.31 U	0.031
Benzoic Acid	0.85 UJ	-	0.79 UJ	-	0.90 UJ	-	0.88 UJ	-	0.82 UJ	-	0.79 UJ	-
Benzyl Alcohol	0.85 UJ	-	0.79 UJ	-	0.90 UJ	-	0.88 UJ	-	0.82 UJ	-	0.79 UJ	-
Bis(2-chloro-1-methylethyl) ether	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
Bis(2-Chloroethoxy)Methane	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
Bis(2-Chloroethyl)Ether	0.17 U	-	0.16 U	-	0.18 U	-	0.18 U	-	0.16 U	-	0.16 U	-
Bis(2-Ethylhexyl) Phthalate	0.17 U	-	0.16 UJ	-	0.18 UJ	-	0.18 UJ	-	0.16 U	-	0.059 J	-
Bisphenol A	0.34 U	0.034	0.32 UJ	0.032	0.36 UJ	0.036	0.35 UJ	0.035	0.33 U	0.033	0.31 UJ	0.031
Butyl benzyl phthalate	0.34 U	0.034	0.32 UJ	0.032	0.36 UJ	0.036	0.35 UJ	0.035	0.33 U	0.033	0.31 UJ	0.031
Caffeine	0.17 U	-	0.16 U	-	0.18 U	-	0.18 U	-	0.16 U	-	0.16 U	-
Cholesterol	0.85 UJ	-	0.79 UJ	-	0.90 UJ	-	0.88 UJ	-	0.82 UJ	-	0.79 UJ	-
Diethyl phthalate	0.17 U	0.034	0.16 U	0.032	0.18 U	0.036	0.18 U	0.035	0.16 U	0.033	0.16 U	0.031
Dimethyl phthalate	0.17 U	0.034	0.16 U	0.032	0.18 U	0.036	0.18 U	0.035	0.16 U	0.033	0.16 U	0.031
Di-N-Butylphthalate	0.19 UJ	-	0.23 UJ	-	0.21 UJ	-	0.16 UJ	-	0.13 UJ	-	0.17 UJ	-
Di-N-Octyl Phthalate	0.17 U	-	0.16 UJ	-	0.18 UJ	-	0.18 UJ	-	0.16 U	-	0.16 UJ	-
Ethanol, 2-Chloro-, Phosphate (3:1)	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
Hexachlorobenzene	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
Hexachlorobutadiene	0.085 UJ	-	0.079 UJ	-	0.090 UJ	-	0.088 UJ	-	0.082 UJ	-	0.079 UJ	-
Hexachlorocyclopentadiene	0.34 UJ	-	0.32 UJ	-	0.36 UJ	-	0.35 UJ	-	0.33 UJ	-	0.31 UJ	-
Hexachloroethane	0.085 UJ	-	0.079 UJ	-	0.090 UJ	-	0.088 UJ	-	0.082 UJ	-	0.079 UJ	-
Isophorone	0.17 U	-	0.16 U	-	0.18 U	-	0.18 U	-	0.16 U	-	0.16 U	-
Nitrobenzene	0.085 U	-	0.079 U	-	0.090 U	-	0.088 U	-	0.082 U	-	0.079 U	-
N-Nitrosodi-n-propylamine	0.10 U	-	0.095 U	-	0.11 U	-	0.11 U	-	0.098 U	-	0.094 U	-
N-Nitrosodiphenylamine	0.17 U	-	0.16 U	-	0.18 U	-	0.18 U	-	0.16 U	-	0.16 U	-
Pentachlorophenol	0.085 UJ	-	0.079 UJ	-	0.090 UJ	-	0.088 UJ	-	0.082 UJ	-	0.079 UJ	-
Phenol	0.34 U	-	0.32 U	-	0.36 U	-	0.35 U	-	0.33 U	-	0.31 U	-
Triclosan	0.085 UJ	-	0.079 UJ	-	0.090 UJ	-	0.088 UJ	-	0.082 UJ	-	0.079 UJ	-
Triethyl citrate	0.34 U	0.034	0.32 U	0.032	0.36 U	0.036	0.35 U	0.035	0.33 U	0.033	0.31 U	0.031

Table E-16. September 2009 BNA Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
1,2-Dichlorobenzene	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
1,2-Diphenylhydrazine	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
1,3-Dichlorobenzene	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 UJ	-	0.079 UJ	-
1,4-Dichlorobenzene	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
2,2'-Oxybis[1-chloropropane]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trichlorophenol	0.33 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-	0.31 U	-	0.32 U	-
2,4,6-Trichlorophenol	0.33 U	-	0.32 U	-	0.33 UJ	-	0.32 UJ	-	0.32 UJ	-	0.32 UJ	-	0.31 UJ	-	0.32 UJ	-
2,4-Dichlorophenol	0.82 U	-	0.80 U	-	0.81 U	-	0.80 U	-	0.81 U	-	0.79 U	-	0.77 U	-	0.79 U	-
2,4-Dimethylphenol	0.82 U	-	0.80 U	-	0.81 U	-	0.80 U	-	0.81 U	-	0.79 U	-	0.77 U	-	0.79 U	-
2,4-Dinitrophenol	0.82 U	-	0.80 U	-	0.81 U	-	0.80 U	-	0.81 U	-	0.79 U	-	0.77 U	-	0.79 U	-
2,4-Dinitrotoluene	0.33 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-	0.31 U	-	0.32 U	-
2,6-Dinitrotoluene	0.33 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-	0.31 U	-	0.32 U	-
2-Chlorophenol	0.33 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-	0.31 U	-	0.32 U	-
2-Methylphenol	0.82 U	-	0.80 U	-	0.81 U	-	0.80 U	-	0.81 U	-	0.79 U	-	0.77 U	-	0.79 U	-
2-Nitroaniline	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-	1.5 U	-	1.6 U	-
2-Nitrophenol	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.15 U	-	0.16 U	-
3,3'-Dichlorobenzidine	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.15 UJ	-	0.16 UJ	-
3B-Coprostanol	0.82 U	-	0.80 U	-	0.81 U	-	0.80 U	-	0.81 U	-	0.79 U	-	0.77 U	-	0.79 U	-
3-Nitroaniline	0.33 UJ	-	0.32 UJ	-	0.33 UJ	-	0.32 UJ	-	0.32 UJ	-	0.32 UJ	-	0.31 UJ	-	0.32 UJ	-
4,6-Dinitro-2-Methylphenol	0.33 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-	0.31 U	-	0.32 U	-
4-Bromophenyl phenyl ether	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.15 U	-	0.16 U	-
4-Chloro-3-Methylphenol	0.82 UJ	-	0.80 UJ	-	0.81 UJ	-	0.80 UJ	-	0.81 UJ	-	0.79 UJ	-	0.77 UJ	-	0.79 UJ	-
4-Chloroaniline	3.3 REJ	-	3.2 REJ	-	3.3 REJ	-	3.2 REJ	-	3.2 REJ	-	3.2 REJ	-	3.1 REJ	-	3.2 REJ	-
4-Chlorophenyl-Phenylether	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
4-Methylphenol	0.82 U	-	0.80 U	-	0.81 U	-	0.80 U	-	0.81 U	-	0.79 U	-	0.77 U	-	0.79 U	-
4-Nitroaniline	0.33 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-	0.31 U	-	0.32 U	-
4-Nitrophenol	0.82 U	-	0.80 U	-	0.81 U	-	0.80 U	-	0.81 U	-	0.79 U	-	0.77 U	-	0.79 U	-
4-nonylphenol	0.33 U	0.033	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.32 U	0.032	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032
Benzoic Acid	0.82 U	-	0.80 U	-	0.81 UJ	-	0.80 UJ	-	0.81 UJ	-	0.79 UJ	-	0.77 UJ	-	0.79 UJ	-
Benzyl Alcohol	0.82 U	-	0.80 U	-	0.81 UJ	-	0.80 UJ	-	0.81 UJ	-	0.79 UJ	-	0.77 UJ	-	0.79 UJ	-
Bis(2-chloro-1-methylethyl) ether	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
Bis(2-Chloroethoxy)Methane	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
Bis(2-Chloroethyl)Ether	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.15 U	-	0.16 U	-
Bis(2-Ethylhexyl) Phthalate	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.15 U	-	0.19 UJ	-
Bisphenol A	0.33 U	0.033	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.32 U	0.032	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032
Butyl benzyl phthalate	0.33 U	0.033	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.32 U	0.032	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032
Caffeine	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.15 U	-	0.16 U	-
Cholesterol	0.77 J	-	0.70 J	-	1.1	-	0.73 J	-	0.73 J	-	0.71 J	-	0.73 J	-	0.73 J	-

Table E-16, continued. September 2009 BNA Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
Diethyl phthalate	0.16 U	0.033	0.16 U	0.032	0.16 U	0.033	0.16 U	0.032	0.16 U	0.032	0.16 U	0.032	0.15 U	0.031	0.16 U	0.032
Dimethyl phthalate	0.16 U	0.033	0.16 U	0.032	0.16 U	0.033	0.16 U	0.032	0.16 U	0.032	0.16 U	0.032	0.15 U	0.031	0.16 U	0.032
Di-N-Butylphthalate	0.27 UJ	-	0.23 UJ	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
Di-N-Octyl Phthalate	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.15 UJ	-	0.16 UJ	-
Ethanol, 2-Chloro-, Phosphate (3:1)	0.082 UJ	-	0.080 UJ	-	0.081 UJ	-	0.080 UJ	-	0.081 UJ	-	0.079 UJ	-	0.077 UJ	-	0.079 UJ	-
Hexachlorobenzene	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
Hexachlorobutadiene	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 UJ	-	0.079 UJ	-
Hexachlorocyclopentadiene	0.33 UJ	-	0.32 UJ	-	0.33 UJ	-	0.32 UJ	-	0.32 UJ	-	0.32 UJ	-	0.31 UJ	-	0.32 UJ	-
Hexachloroethane	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 UJ	-	0.079 UJ	-
Isophorone	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.15 U	-	0.16 U	-
Nitrobenzene	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
N-Nitrosodi-n-propylamine	0.098 U	-	0.096 U	-	0.098 U	-	0.096 U	-	0.097 U	-	0.095 U	-	0.092 U	-	0.095 U	-
N-Nitrosodiphenylamine	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.15 UJ	-	0.16 UJ	-
Pentachlorophenol	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
Phenol	0.33 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-	0.31 U	-	0.32 U	-
Triclosan	0.082 U	-	0.080 U	-	0.081 U	-	0.080 U	-	0.081 U	-	0.079 U	-	0.077 U	-	0.079 U	-
Triethyl citrate	0.33 UJ	0.033	0.32 UJ	0.032	0.33 UJ	0.033	0.32 UJ	0.032	0.32 UJ	0.032	0.32 UJ	0.032	0.31 UJ	0.031	0.32 UJ	0.032

Table E-17. September 2009 BNA Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
1,2-Dichlorobenzene	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
1,2-Diphenylhydrazine	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
1,3-Dichlorobenzene	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
1,4-Dichlorobenzene	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
2,2'-Oxybis[1-chloropropane]	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trichlorophenol	0.32 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-
2,4,6-Trichlorophenol	0.32 UJ	-	0.32 UJ	-	0.33 UJ	-	0.32 UJ	-	0.32 UJ	-	0.32 UJ	-
2,4-Dichlorophenol	0.80 U	-	0.81 U	-	0.82 U	-	0.81 U	-	0.81 U	-	0.81 U	-
2,4-Dimethylphenol	0.80 U	-	0.81 U	-	0.82 U	-	0.81 U	-	0.81 U	-	0.81 U	-
2,4-Dinitrophenol	0.80 U	-	0.81 U	-	0.82 U	-	0.81 U	-	0.81 U	-	0.81 U	-
2,4-Dinitrotoluene	0.32 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-
2,6-Dinitrotoluene	0.32 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-
2-Chlorophenol	0.32 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-
2-Methylphenol	0.80 U	-	0.81 U	-	0.82 U	-	0.81 U	-	0.81 U	-	0.81 U	-
2-Nitroaniline	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-
2-Nitrophenol	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
3,3'-Dichlorobenzidine	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-
3B-Coprostanol	0.80 U	-	0.81 U	-	0.82 U	-	0.81 U	-	0.81 U	-	0.81 U	-
3-Nitroaniline	0.32 UJ	-	0.32 UJ	-	0.33 UJ	-	0.32 UJ	-	0.32 UJ	-	0.32 UJ	-
4,6-Dinitro-2-Methylphenol	0.32 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-
4-Bromophenyl phenyl ether	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
4-Chloro-3-Methylphenol	0.80 UJ	-	0.81 UJ	-	0.82 UJ	-	0.81 UJ	-	0.81 UJ	-	0.81 UJ	-
4-Chloroaniline	3.2 REJ	-	3.2 REJ	-	3.3 REJ	-	3.2 REJ	-	3.2 REJ	-	3.2 REJ	-
4-Chlorophenyl-Phenylether	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
4-Methylphenol	0.80 U	-	0.81 U	-	0.82 U	-	0.81 U	-	0.81 U	-	0.81 U	-
4-Nitroaniline	0.32 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-
4-Nitrophenol	0.80 U	-	0.81 U	-	0.82 U	-	0.81 U	-	0.81 U	-	0.81 U	-
4-nonylphenol	0.32 U	0.032	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.32 U	0.032	0.32 U	0.032
Benzoic Acid	0.80 UJ	-	0.81 UJ	-	0.82 UJ	-	0.81 UJ	-	0.81 UJ	-	0.81 UJ	-
Benzyl Alcohol	0.80 UJ	-	0.81 UJ	-	0.82 UJ	-	0.81 UJ	-	0.81 UJ	-	0.81 UJ	-
Bis(2-chloro-1-methylethyl) ether	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
Bis(2-Chloroethoxy)Methane	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
Bis(2-Chloroethyl)Ether	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Bis(2-Ethylhexyl) Phthalate	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Bisphenol A	0.32 U	0.032	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.32 U	0.032	0.32 U	0.032
Butyl benzyl phthalate	0.32 U	0.032	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.32 U	0.032	0.32 U	0.032
Caffeine	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Cholesterol	0.73 J	-	0.71 J	-	0.73 J	-	0.72 J	-	0.81 U	-	0.74 J	-
Diethyl phthalate	0.16 U	0.032	0.16 U	0.032	0.16 U	0.033	0.16 U	0.032	0.16 U	0.032	0.16 U	0.032
Dimethyl phthalate	0.16 U	0.032	0.16 U	0.032	0.16 U	0.033	0.16 U	0.032	0.16 U	0.032	0.16 U	0.032
Di-N-Butylphthalate	0.080 U	-	0.081 U	-	0.082 U	-	0.30 UJ	-	0.081 U	-	0.081 U	-
Di-N-Octyl Phthalate	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-
Ethanol, 2-Chloro-, Phosphate (3:1)	0.080 UJ	-	0.081 UJ	-	0.082 UJ	-	0.081 UJ	-	0.081 UJ	-	0.081 UJ	-
Hexachlorobenzene	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
Hexachlorobutadiene	0.080 UJ	-	0.081 UJ	-	0.082 UJ	-	0.081 UJ	-	0.081 UJ	-	0.081 UJ	-
Hexachlorocyclopentadiene	0.32 UJ	-	0.32 UJ	-	0.33 UJ	-	0.32 UJ	-	0.32 UJ	-	0.32 UJ	-
Hexachloroethane	0.080 UJ	-	0.081 UJ	-	0.082 UJ	-	0.081 UJ	-	0.081 UJ	-	0.081 UJ	-
Isophorone	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Nitrobenzene	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
N-Nitrosodi-n-propylamine	0.096 U	-	0.097 U	-	0.098 U	-	0.097 U	-	0.097 U	-	0.097 U	-
N-Nitrosodiphenylamine	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-
Pentachlorophenol	0.080 U	-	0.081 U	-	0.082 U	-	0.081 U	-	0.081 U	-	0.081 U	-
Phenol	0.32 U	-	0.32 U	-	0.33 U	-	0.32 U	-	0.32 U	-	0.32 U	-
Triclosan	0.048 J	-	0.048 J	-	0.051 J	-	0.050 J	-	0.047 J	-	0.051 J	-
Triethyl citrate	0.32 UJ	0.032	0.32 UJ	0.032	0.33 UJ	0.033	0.32 UJ	0.032	0.32 UJ	0.032	0.32 UJ	0.032

Table E-18. January 2010 BNA Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.079 U	0.020	0.082 U	0.020	0.079 U	0.020	0.079 U	0.019	0.079 U	0.020	0.079 U	0.019	0.080 U	0.020	0.081 U	0.020
1,2-Dichlorobenzene	0.079 U	0.019	0.082 U	0.019	0.079 U	0.019	0.079 U	0.019	0.079 U	0.019	0.079 U	0.019	0.080 U	0.019	0.081 U	0.019
1,2-Diphenylhydrazine	0.079 U	0.051	0.082 U	0.052	0.079 U	0.051	0.079 U	0.050	0.079 U	0.050	0.079 U	0.050	0.080 U	0.051	0.081 U	0.051
1,3-Dichlorobenzene	0.079 UJ	0.016	0.082 UJ	0.017	0.079 U	0.016	0.079 U	0.016	0.079 UJ	0.016	0.079 UJ	0.016	0.080 UJ	0.016	0.081 UJ	0.016
1,4-Dichlorobenzene	0.079 U	0.017	0.082 U	0.018	0.079 U	0.017	0.079 U	0.017	0.079 U	0.017	0.079 U	0.017	0.080 U	0.017	0.081 U	0.018
2,2'-Oxybis[1-chloropropane]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trichlorophenol	0.32 U	0.063	0.33 U	0.065	0.32 U	0.063	0.31 U	0.062	0.32 U	0.063	0.31 U	0.062	0.32 U	0.063	0.32 U	0.064
2,4,6-Trichlorophenol	0.32 U	0.048	0.33 U	0.050	0.32 U	0.048	0.31 U	0.048	0.32 U	0.048	0.31 U	0.048	0.32 U	0.048	0.32 U	0.049
2,4-Dichlorophenol	0.79 U	0.042	0.82 U	0.043	0.79 U	0.042	0.79 U	0.041	0.79 U	0.041	0.79 U	0.041	0.80 U	0.042	0.81 U	0.042
2,4-Dimethylphenol	0.79 U	0.047	0.82 U	0.048	0.79 U	0.047	0.79 U	0.046	0.79 U	0.047	0.79 U	0.046	0.80 U	0.047	0.81 U	0.048
2,4-Dinitrophenol	0.79 U	-	0.82 U	-	0.79 U	-	0.79 U	-	0.79 U	-	0.79 U	-	0.80 U	-	0.81 U	-
2,4-Dinitrotoluene	0.32 U	0.045	0.33 U	0.046	0.32 U	0.045	0.31 U	0.044	0.32 U	0.045	0.31 U	0.044	0.32 U	0.045	0.32 U	0.046
2,6-Dinitrotoluene	0.32 U	0.054	0.33 U	0.056	0.32 U	0.054	0.31 U	0.054	0.32 U	0.054	0.31 U	0.054	0.32 U	0.054	0.32 U	0.055
2-Chlorophenol	0.32 U	0.041	0.33 U	0.043	0.32 U	0.041	0.31 U	0.041	0.32 U	0.041	0.31 U	0.041	0.32 U	0.042	0.32 U	0.042
2-Methylphenol	0.79 U	0.040	0.82 U	0.041	0.79 U	0.040	0.79 U	0.040	0.79 U	0.040	0.79 U	0.040	0.80 U	0.040	0.81 U	0.041
2-Nitroaniline	1.6 UJ	0.053	1.6 UJ	0.055	1.6 UJ	0.053	1.6 UJ	0.053	1.6 UJ	0.053	1.6 UJ	0.053	1.6 UJ	0.053	1.6 UJ	0.054
2-Nitrophenol	0.16 UJ	0.036	0.16 UJ	0.037	0.16 UJ	0.036	0.16 UJ	0.035	0.16 UJ	0.036	0.16 UJ	0.035	0.16 UJ	0.036	0.16 UJ	0.036
3,3'-Dichlorobenzidine	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-
3B-Coprostanol	0.79 UJ	-	0.82 UJ	-	0.79 UJ	-	0.79 UJ	-	0.79 UJ	-	0.79 UJ	-	0.80 UJ	-	0.81 UJ	-
3-Nitroaniline	0.32 REJ	0.046	0.33 REJ	0.047	0.32 REJ	0.046	0.31 REJ	0.045	0.32 REJ	0.045	0.31 REJ	0.045	0.32 REJ	0.046	0.32 REJ	0.046
4,6-Dinitro-2-Methylphenol	1.6 U	0.53	1.6 U	0.55	1.6 U	0.53	1.6 U	0.53	1.6 U	0.53	1.6 U	0.53	1.6 U	0.53	1.6 U	0.54
4-Bromophenyl phenyl ether	0.16 U	0.071	0.16 U	0.074	0.16 U	0.071	0.16 U	0.071	0.16 U	0.071	0.16 U	0.071	0.16 U	0.072	0.16 U	0.072
4-Chloro-3-Methylphenol	0.79 UJ	0.063	0.82 UJ	0.065	0.79 UJ	0.063	0.79 UJ	0.062	0.79 UJ	0.063	0.79 UJ	0.062	0.80 UJ	0.063	0.81 UJ	0.064
4-Chloroaniline	3.2 REJ	0.13	3.3 REJ	0.13	3.2 REJ	0.13	3.1 REJ	0.13	3.2 REJ	0.13	3.1 REJ	0.13	3.2 REJ	0.13	3.2 REJ	0.13
4-Chlorophenyl-Phenylether	0.079 U	0.071	0.082 U	0.073	0.079 U	0.071	0.079 U	0.070	0.079 U	0.071	0.079 U	0.070	0.080 U	0.071	0.081 U	0.072
4-Methylphenol	0.79 U	0.039	0.82 U	0.041	0.79 U	0.039	0.79 U	0.039	0.79 U	0.039	0.79 U	0.039	0.80 U	0.040	0.81 U	0.040
4-Nitroaniline	0.32 UJ	-	0.33 UJ	-	0.32 UJ	-	0.31 UJ	-	0.32 UJ	-	0.31 UJ	-	0.32 UJ	-	0.32 UJ	-
4-Nitrophenol	0.79 U	-	0.82 U	-	0.79 U	-	0.79 U	-	0.79 U	-	0.79 U	-	0.80 U	-	0.81 U	-
4-nonylphenol	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032	0.32 U	0.032
Benzoic Acid	0.79 UJ	-	0.82 UJ	-	0.79 UJ	-	0.79 UJ	-	0.79 UJ	-	0.79 UJ	-	0.80 UJ	-	0.81 UJ	-
Benzyl Alcohol	0.79 UJ	0.028	0.82 UJ	0.029	0.79 UJ	0.028	0.79 UJ	0.028	0.79 UJ	0.028	0.79 UJ	0.028	0.80 UJ	0.028	0.81 UJ	0.028
Bis(2-chloro-1-methylethyl) ether	0.079 U	0.053	0.082 U	0.055	0.079 U	0.053	0.079 U	0.053	0.079 U	0.053	0.079 U	0.053	0.080 U	0.053	0.081 U	0.054
Bis(2-Chloroethoxy)Methane	0.079 U	0.066	0.082 U	0.068	0.079 U	0.066	0.079 U	0.065	0.079 U	0.066	0.079 U	0.065	0.080 U	0.066	0.081 U	0.067
Bis(2-Chloroethyl)Ether	0.16 U	0.046	0.16 U	0.047	0.16 U	0.046	0.16 U	0.045	0.16 U	0.045	0.16 U	0.045	0.16 U	0.046	0.16 U	0.046
Bis(2-Ethylhexyl) Phthalate	0.16 U	0.048	0.16 U	0.049	0.16 U	0.048	0.16 U	0.047	0.16 U	0.048	0.16 U	0.047	0.16 U	0.048	0.16 U	0.048
Bisphenol A	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032	0.32 U	0.032
Butyl benzyl phthalate	0.32 UJ	0.037	0.33 UJ	0.038	0.32 UJ	0.037	0.31 UJ	0.037	0.32 UJ	0.037	0.31 UJ	0.037	0.32 UJ	0.037	0.32 UJ	0.038
Caffeine	0.16 U	0.062	0.16 U	0.064	0.16 U	0.062	0.16 U	0.061	0.16 U	0.061	0.16 U	0.061	0.16 U	0.062	0.16 U	0.063
Cholesterol	0.79 UJ	0.075	0.82 UJ	0.078	0.79 UJ	0.075	0.79 UJ	0.075	0.79 UJ	0.075	0.79 UJ	0.075	0.80 UJ	0.076	0.81 UJ	0.077

Table E-18, continued. January 2010 BNA Results for Marine Water Samples from Puget Sound Basin Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Hood Canal				Whidbey Basin				Main Basin				South Sound			
	Surface		Deep		Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
Diethyl phthalate	0.16 U	0.078	0.16 U	0.081	0.16 U	0.078	0.16 U	0.078	0.16 U	0.078	0.16 U	0.078	0.16 U	0.079	0.16 U	0.080
Dimethyl phthalate	0.16 U	0.069	0.16 U	0.071	0.16 U	0.069	0.16 U	0.068	0.16 U	0.068	0.16 U	0.068	0.16 U	0.069	0.16 U	0.070
Di-N-Butylphthalate	0.11 UJ	0.058	0.19 UJ	0.060	0.13 UJ	0.058	0.15 UJ	0.058	0.23 UJ	0.058	0.21 UJ	0.058	0.17 UJ	0.058	0.25 UJ	0.059
Di-N-Octyl Phthalate	0.16 U	0.071	0.16 U	0.073	0.16 U	0.071	0.16 U	0.070	0.16 U	0.070	0.16 U	0.070	0.16 U	0.071	0.16 U	0.072
Ethanol, 2-Chloro-, Phosphate (3:1)	0.079 U	0.032	0.082 U	0.033	0.079 U	0.032	0.079 U	0.031	0.079 U	0.032	0.079 U	0.031	0.080 U	0.032	0.081 U	0.032
Hexachlorobenzene	0.079 U	0.039	0.082 U	0.040	0.079 U	0.039	0.079 U	0.039	0.079 U	0.039	0.079 U	0.039	0.080 U	0.039	0.081 U	0.040
Hexachlorobutadiene	0.079 UJ	0.012	0.082 UJ	0.012	0.079 U	0.012	0.079 U	0.012	0.079 UJ	0.012	0.079 UJ	0.012	0.080 UJ	0.012	0.081 UJ	0.012
Hexachlorocyclopentadiene	0.32 UJ	0.010	0.33 UJ	0.010	0.32 UJ	0.010	0.31 UJ	0.0099	0.32 UJ	0.0099	0.31 UJ	0.0099	0.32 UJ	0.010	0.32 UJ	0.010
Hexachloroethane	0.079 UJ	-	0.082 UJ	-	0.079 U	-	0.079 U	-	0.079 UJ	-	0.079 UJ	-	0.080 UJ	-	0.081 UJ	-
Isophorone	0.16 U	0.073	0.16 U	0.076	0.16 U	0.073	0.16 U	0.073	0.16 U	0.073	0.16 U	0.073	0.16 U	0.074	0.16 U	0.075
Nitrobenzene	0.079 U	0.066	0.082 U	0.068	0.079 U	0.066	0.079 U	0.065	0.079 U	0.065	0.079 U	0.065	0.080 U	0.066	0.081 U	0.067
N-Nitrosodi-n-propylamine	0.095 U	0.070	0.098 U	0.073	0.095 U	0.070	0.094 U	0.070	0.095 U	0.070	0.094 U	0.070	0.096 U	0.071	0.097 U	0.071
N-Nitrosodiphenylamine	0.16 U	0.033	0.16 U	0.034	0.16 U	0.033	0.16 U	0.033	0.16 U	0.033	0.16 U	0.033	0.16 U	0.033	0.16 U	0.034
Pentachlorophenol	0.079 UJ	-	0.082 UJ	-	0.079 UJ	-	0.079 UJ	-	0.079 UJ	-	0.079 UJ	-	0.080 UJ	-	0.081 UJ	-
Phenol	0.32 U	0.025	0.33 U	0.026	0.32 U	0.025	0.31 U	0.025	0.32 U	0.025	0.31 U	0.025	0.32 U	0.025	0.32 U	0.026
Triclosan	0.079 U	0.032	0.082 U	0.033	0.079 U	0.032	0.079 U	0.031	0.079 U	0.032	0.079 U	0.031	0.080 U	0.032	0.081 U	0.032
Triethyl citrate	0.32 U	0.032	0.33 U	0.033	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032	0.31 U	0.031	0.32 U	0.032	0.32 U	0.032

Table E-19. January 2010 BNA Results for Marine Water Samples from Boundary Water Sites.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	SJdF at Sill				SJdF North				Haro Strait			
	Surface		Deep		Surface		Deep		Surface		Deep	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.082 U	0.020	0.087 U	0.021	0.083 U	0.020	0.084 U	0.021	0.081 U	0.020	0.082 U	0.020
1,2-Dichlorobenzene	0.082 U	0.019	0.087 U	0.021	0.083 U	0.020	0.084 U	0.020	0.081 U	0.019	0.082 U	0.019
1,2-Diphenylhydrazine	0.082 U	0.052	0.087 U	0.055	0.083 U	0.053	0.084 U	0.053	0.081 U	0.052	0.082 U	0.052
1,3-Dichlorobenzene	0.082 U	0.017	0.087 U	0.018	0.083 U	0.017	0.084 U	0.017	0.081 U	0.017	0.082 U	0.017
1,4-Dichlorobenzene	0.082 U	0.018	0.087 U	0.019	0.083 U	0.018	0.084 U	0.018	0.081 U	0.018	0.082 U	0.018
2,2'-Oxybis[1-chloropropane]	-	-	-	-	-	-	-	-	-	-	-	-
2,4,5-Trichlorophenol	0.33 U	0.065	0.35 U	0.069	0.33 U	0.066	0.33 U	0.066	0.32 U	0.064	0.33 U	0.065
2,4,6-Trichlorophenol	0.33 U	0.050	0.35 U	0.053	0.33 U	0.050	0.33 U	0.051	0.32 U	0.049	0.33 U	0.050
2,4-Dichlorophenol	0.82 U	0.043	0.87 U	0.045	0.83 U	0.043	0.84 U	0.044	0.81 U	0.042	0.82 U	0.043
2,4-Dimethylphenol	0.82 U	0.048	0.87 U	0.051	0.83 U	0.049	0.84 U	0.049	0.81 U	0.048	0.82 U	0.049
2,4-Dinitrophenol	0.82 U	-	0.87 U	-	0.83 U	-	0.84 U	-	0.81 U	-	0.82 U	-
2,4-Dinitrotoluene	0.33 U	0.046	0.35 U	0.049	0.33 U	0.047	0.33 U	0.047	0.32 U	0.046	0.33 U	0.046
2,6-Dinitrotoluene	0.33 U	0.056	0.35 U	0.059	0.33 U	0.057	0.33 U	0.057	0.32 U	0.055	0.33 U	0.056
2-Chlorophenol	0.33 U	0.043	0.35 U	0.045	0.33 U	0.043	0.33 U	0.044	0.32 U	0.042	0.33 U	0.043
2-Methylphenol	0.82 U	0.041	0.87 U	0.044	0.83 U	0.042	0.84 U	0.042	0.81 U	0.041	0.82 U	0.042
2-Nitroaniline	1.6 UJ	0.055	1.7 UJ	0.058	1.7 UJ	0.055	1.7 UJ	0.056	1.6 UJ	0.054	1.6 UJ	0.055
2-Nitrophenol	0.16 UJ	0.037	0.17 UJ	0.039	0.17 UJ	0.037	0.17 UJ	0.038	0.16 UJ	0.036	0.16 UJ	0.037
3,3'-Dichlorobenzidine	0.16 UJ	-	0.17 UJ	-	0.17 UJ	-	0.17 UJ	-	0.16 UJ	-	0.16 UJ	-
3B-Coprostanol	0.82 UJ	-	0.87 UJ	-	0.83 UJ	-	0.84 UJ	-	0.81 UJ	-	0.82 UJ	-
3-Nitroaniline	0.33 REJ	0.047	0.35 REJ	0.050	0.33 REJ	0.048	0.33 REJ	0.048	0.32 REJ	0.047	0.33 REJ	0.047
4,6-Dinitro-2-Methylphenol	1.6 U	0.55	1.7 U	0.58	1.7 U	0.55	1.7 U	0.56	1.6 U	0.54	1.6 U	0.55
4-Bromophenyl phenyl ether	0.16 U	0.074	0.17 U	0.078	0.17 U	0.075	0.17 U	0.075	0.16 U	0.073	0.16 U	0.074
4-Chloro-3-Methylphenol	0.82 UJ	0.065	0.87 UJ	0.069	0.83 UJ	0.066	0.84 UJ	0.066	0.81 UJ	0.064	0.82 UJ	0.065
4-Chloroaniline	3.3 REJ	0.13	3.5 REJ	0.14	3.3 REJ	0.13	3.3 REJ	0.13	3.2 REJ	0.13	3.3 REJ	0.13
4-Chlorophenyl-Phenylether	0.082 U	0.073	0.087 U	0.078	0.083 U	0.074	0.084 U	0.075	0.081 U	0.073	0.082 U	0.073
4-Methylphenol	0.82 U	0.041	0.87 U	0.043	0.83 U	0.041	0.84 U	0.041	0.81 U	0.040	0.82 U	0.041
4-Nitroaniline	0.33 UJ	-	0.35 UJ	-	0.33 UJ	-	0.33 UJ	-	0.32 UJ	-	0.33 UJ	-
4-Nitrophenol	0.82 U	-	0.87 U	-	0.83 U	-	0.84 U	-	0.81 U	-	0.82 U	-
4-nonylphenol	0.33 U	0.033	0.35 U	0.035	0.33 U	0.033	0.33 U	0.033	0.32 U	0.032	0.33 U	0.033
Benzoic Acid	0.82 UJ	-	0.87 UJ	-	0.83 UJ	-	0.84 UJ	-	0.81 UJ	-	0.82 UJ	-
Benzyl Alcohol	0.82 UJ	0.029	0.87 UJ	0.031	0.83 UJ	0.029	0.84 UJ	0.029	0.81 UJ	0.029	0.82 UJ	0.029
Bis(2-chloro-1-methylethyl) ether	0.082 U	0.055	0.087 U	0.058	0.083 U	0.055	0.084 U	0.056	0.081 U	0.054	0.082 U	0.055
Bis(2-Chloroethoxy)Methane	0.082 U	0.068	0.087 U	0.072	0.083 U	0.069	0.084 U	0.069	0.081 U	0.067	0.082 U	0.068
Bis(2-Chloroethyl)Ether	0.16 U	0.047	0.17 U	0.050	0.17 U	0.048	0.17 U	0.048	0.16 U	0.047	0.16 U	0.047
Bis(2-Ethylhexyl) Phthalate	0.16 U	0.049	0.17 U	0.052	0.17 U	0.050	0.17 U	0.050	0.16 U	0.049	0.16 U	0.049
Bisphenol A	0.33 U	0.033	0.35 U	0.035	0.33 U	0.033	0.33 U	0.033	0.32 U	0.032	0.33 U	0.033
Butyl benzyl phthalate	0.33 UJ	0.038	0.35 UJ	0.041	0.33 UJ	0.039	0.33 UJ	0.039	0.32 UJ	0.038	0.33 UJ	0.038
Caffeine	0.16 U	0.064	0.17 U	0.067	0.17 U	0.064	0.17 U	0.065	0.16 U	0.063	0.16 U	0.064
Cholesterol	0.82 UJ	0.078	0.87 UJ	0.083	0.83 UJ	0.079	0.84 UJ	0.079	0.81 UJ	0.077	0.82 UJ	0.078
Diethyl phthalate	0.16 U	0.081	0.17 U	0.086	0.17 U	0.082	0.17 U	0.082	0.16 U	0.080	0.16 U	0.081
Dimethyl phthalate	0.16 U	0.071	0.17 U	0.075	0.17 U	0.072	0.17 U	0.072	0.16 U	0.070	0.16 U	0.071
Di-N-Butylphthalate	0.29 UJ	0.060	0.26 UJ	0.064	0.21 UJ	0.061	0.24 UJ	0.061	0.30 UJ	0.059	0.28 UJ	0.060
Di-N-Octyl Phthalate	0.16 U	0.073	0.17 U	0.077	0.17 U	0.074	0.17 U	0.074	0.16 U	0.072	0.16 U	0.073
Ethanol, 2-Chloro-, Phosphate (3:1)	0.082 U	0.033	0.087 U	0.035	0.083 U	0.033	0.084 U	0.033	0.081 U	0.032	0.082 U	0.033
Hexachlorobenzene	0.082 U	0.040	0.087 U	0.043	0.083 U	0.041	0.084 U	0.041	0.081 U	0.040	0.082 U	0.041
Hexachlorobutadiene	0.082 U	0.012	0.087 U	0.013	0.083 U	0.013	0.084 U	0.013	0.081 U	0.012	0.082 U	0.012
Hexachlorocyclopentadiene	0.33 UJ	0.010	0.35 UJ	0.011	0.33 UJ	0.010	0.33 UJ	0.011	0.32 UJ	0.010	0.33 UJ	0.010
Hexachloroethane	0.082 UJ	-	0.087 UJ	-	0.083 UJ	-	0.084 UJ	-	0.081 UJ	-	0.082 UJ	-
Isophorone	0.16 U	0.076	0.17 U	0.080	0.17 U	0.077	0.17 U	0.077	0.16 U	0.075	0.16 U	0.076
Nitrobenzene	0.082 U	0.068	0.087 U	0.072	0.083 U	0.069	0.084 U	0.069	0.081 U	0.067	0.082 U	0.068
N-Nitrosodi-n-propylamine	0.098 U	0.073	0.10 U	0.077	0.10 U	0.074	0.10 U	0.074	0.097 U	0.072	0.099 U	0.073
N-Nitrosodiphenylamine	0.16 U	0.034	0.17 U	0.036	0.17 U	0.035	0.17 U	0.035	0.16 U	0.034	0.16 U	0.034
Pentachlorophenol	0.082 U	-	0.087 U	-	0.083 U	-	0.084 U	-	0.081 U	-	0.082 U	-
Phenol	0.33 U	0.026	0.35 U	0.028	0.33 U	0.026	0.33 U	0.027	0.32 U	0.026	0.33 U	0.026
Triclosan	0.082 U	0.033	0.087 U	0.035	0.083 U	0.033	0.084 U	0.033	0.081 U	0.032	0.082 U	0.033
Triethyl citrate	0.33 U	0.033	0.35 U	0.035	0.33 U	0.033	0.33 U	0.033	0.32 U	0.032	0.33 U	0.033

Table E-20. July 2009 Detected PCB Congeners for Marine Water Samples.

PCB Congener (pg/L)	Homolog	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
		Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
PCB-001	mono-									3.07 NJ	1.3 NJ				
PCB-002	mono-										1.4 NJ				
PCB-003	mono-									3.19 NJ	1.82 NJ				
PCB-004	di-		3 J								2.27 J	1.72 J			2.9 J
PCB-008	di-		3.22 J					1.03 J			1.82 J	1.84 J	1.44 J		2.52 J
PCB-017	tri-		2.41 J								2.43 J				
PCB-018/030	tri-		2.69 NJ								2.44 J			2.12 J	
PCB-020/028	tri-		1.79 NJ											1.16 J	
PCB-031	tri-		1.78 NJ									1.96 J		1.06 J	
PCB-040/071	tetra-										0.731 J				
PCB-044/047/065	tetra-	5.82 J	10.8	6.68 J	4.99 J	6.63	4.66 J	5.02 J	7.58	6.81 N	6.5	5.94	6.29	6.09	13.6
PCB-049/069	tetra-		1.22 NJ								1.26 J	1.07 NJ	0.935 J	0.946 J	
PCB-051	tetra-	2.7 NJ	9.14 J	3.91 J	3.3 J	5.45	3.71 J	3.34 J	5.87	6.72	3.74 J	3.77 J	4.04 J	3.58 J	10.6
PCB-052	tetra-	2.6 J	4.02 J			1.23 NJ	1.15 J	0.838 J	1.17 J	2.01 J	2.51 J	2.63 J	1.95 J	2.06 J	2.52 J
PCB-061/070/074/076	tetra-		2.24 NJ			0.933 NJ	0.967 J				1.54 J			1 J	
PCB-066	tetra-										0.867 J				
PCB-068	tetra-		1.66 NJ			1.74 J	1.45 J	1.42 J	1.87 NJ	2.43 NJ	1.6 J		1.57 J	1.12 J	4.57 J
PCB-086/087/097/108/119/125	penta-		2.4 NJ								1.29 NJ	1.16 NJ			
PCB-090/101/113	penta-	2.29 NJ	4.37 J			0.91 J		1.02 J	1.04 NJ	2.03 NJ	3.01 J	2.34 J	1.59 J	2.04 J	2.48 J
PCB-095	penta-		4.55 J			0.864 NJ			1 NJ		2.35 J	1.97 NJ	1.18 NJ	2.01 J	1.55 NJ
PCB-099	penta-										0.974 NJ				0.883 NJ
PCB-105	penta-										0.932 J				
PCB-110	penta-	2.14 J	2.56 NJ			0.675 NJ	0.677 NJ	0.698 NJ	0.767 NJ		2.53 J	1.42 NJ	1.72 J	1.38 J	1.5 NJ
PCB-118	penta-	1.65 J	1.97 NJ			0.679 J		0.817 J			1.42 NJ	1.47 J	0.909 NJ	1.14 NJ	1.57 J
PCB-128/166	hexa-						0.532 J								
PCB-129/138/163	hexa-		2.13 J				1.74 J				2.98 J	1.52 J	1.51 NJ	1.04 J	
PCB-147/149	hexa-		1.53 NJ				0.539 NJ				1.94 J	1.03 NJ	1.29 NJ	0.944 J	1.49 J
PCB-153/168	hexa-		1.25 J								2.47 J	1.3 J	0.99 NJ	1.07 NJ	1.23 J
PCB-156/157	hexa-						0.715 NJ								
PCB-194	octa-								0.763 NJ						

Total PCBs														
…including N,NJ	17.2 J	64.73 J	10.59 J	8.29 J	19.111 J	16.14 J	14.183 J	20.06 J	26.26 J	52.124 J	31.14 J	25.414 J	28.76 J	47.413 J
…excluding N,NJ	12.21 J	44.89 J	10.59 J	8.29 J	15.409 J	14.209 J	13.485 J	14.62	8.73 J	43.92 J	24.49 J	19.535 J	26.55 J	43.48 J

Table E-21. September 2009 Detected PCB Congeners for Marine Water Samples.

PCB Congener (pg/L)	Homolog	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
		Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
PCB-001	mono-	2.46 NJ	0.403 J		0.81 J	0.387 J	0.407 J		1.3 NJ	2.38 J					
PCB-002	mono-	0.336 NJ	1.21 J		0.498 J				0.958 J	7.17					
PCB-003	mono-	0.399 J	1.18 J		1.05 J	0.569 J	0.455 J		1.9 J	4.87 J					
PCB-004	di-	1.62 J	1.65 J	1.08 J	1.36 J	1.32 J	1.93 J	0.977 J	1.87 J	4.05 J	3.08 J	2.67 J	4.05 J	2.25 J	2.51 J
PCB-006	di-	0.397 J	0.386 J			0.404 J	0.411 J	0.299 J		0.826 J	5 U		1.37 J		
PCB-008	di-	1.41 J	1.16 J		1.03 J	0.857 J	1.28 J	0.78 J	1.36 J	2.43 J	1.44 J	1.19 J	1.75 J	1.34 J	1.48 J
PCB-015	di-		0.587 J												
PCB-016	tri-	0.503 J					0.475 J	0.301 NJ							
PCB-017	tri-	0.687 NJ	0.849 J	0.625 J	0.934 J	0.614 J	0.895 J	0.555 J	0.913 NJ	1.74 J	2.46 J	1.54 J	1.52 J	5 U	1.22 J
PCB-018/030	tri-	1.12 J	1.16 J	0.941 J	1.12 J	0.734 J	1.07 J	0.745 J	1.02 NJ	2.6 J	2.1 J	1.75 J	2.23 J	1.2 NJ	1.71 J
PCB-019	tri-	0.348 J					0.315 J	0.405 J		1.02 J					
PCB-020/028	tri-	1.06 J	0.993 J	0.723 J	0.676 NJ	0.656 J	0.757 J	0.506 NJ	0.709 J	1.1 J	1.14 NJ	0.995 NJ	1.16 J	5 U	0.976 J
PCB-021/033	tri-	0.595 J	0.563 J		0.579 J		0.478 NJ	0.348 J		0.963 J					
PCB-022	tri-	0.35 J													
PCB-031	tri-	0.822 J	0.868 J		0.713 NJ	0.535 J	0.685 J	0.519 NJ	0.758 J	1.37 J	1.06 NJ	0.891 J	1.11 J		
PCB-032	tri-	0.34 NJ	0.381 J				0.302 J			0.629 NJ	1.04 J	5 U			
PCB-039	tri-						0.308 J	0.199 NJ				5 U			
PCB-044/047/065	tetra-	5.48 J	6.12 J	5.93 J	12.6	5.73 J	9.7 J	4.94 J	9.55 J	14.5 J	17.1	6.76 J	13 J	6.32 J	8.25 J
PCB-049/069	tetra-	0.482 NJ	0.631 NJ		0.874 J		0.54 J	0.438 J		1.21 J	1.34 J	5 U		0.909 J	1.34 J
PCB-051	tetra-	4.01 J	4.2	3.54 J	9.76	4.1	6.71	3.33 J	8.62	11.7	12.4	4.84 J	10.4	4.44 J	6.61
PCB-052	tetra-	1.24 J	1.45 J	0.984 J	1.56 J	1.1 J	1.14 J	0.972 J	1.95 J	2.86 J	2.55 NJ	1.85 J	2.43 J	1.6 J	2.12 J
PCB-061/070/074/076	tetra-	1.05 J	1.07 J	0.656 J			0.837 J	0.728 J		1.58 NJ		1.41 NJ			
PCB-068	tetra-	0.96 J	1.43 J	1.11 J	2.79 J	1.07 J	2.16 J	0.93 J	2.29 J	2.45 J	6.26	1.78 NJ	2.77 J	1.13 NJ	2.45 J
PCB-086/087/097/108/119/125	penta-	0.903 J	1.28 J		1.14 J		0.808 J	0.723 J		2.1 J				2.4 J	
PCB-090/101/113	penta-	1.09 J	1.67 J	0.883 J		0.816 NJ	0.897 J	0.733 J	1.38 J	2.28 NJ	1.82 NJ	2.6 NJ	3.28 NJ		2.11 J
PCB-095	penta-	0.933 J	1.65 J	0.976 J		0.979 J	0.986 NJ	0.598 J	1.06 NJ	2.43 J	2.55 J	1.8 NJ	2.19 NJ	2.04 J	2.09 NJ
PCB-099	penta-						0.358 J								
PCB-105	penta-	0.371 NJ						0.413 NJ		0.935 NJ	1.31 NJ		1.06 NJ		
PCB-110	penta-	0.841 J	1.2 J	0.711 J	1.22 J	0.635 NJ	0.847 J	0.454 NJ	1.19 J	2.11 J	2.1 NJ	1.24 NJ	2.34 J	1.39 J	1.39 J
PCB-118	penta-	0.573 J	0.823 J	0.505 J	0.935 J		0.61 J	0.473 J		1.44 NJ	1.59 J	0.862 NJ	1.64 NJ	1.44 J	1.12 NJ
PCB-129/138/163	hexa-	0.609 J	1.3 J		1.14 J		0.44 J	0.473 J		1.04 NJ	1.44 J	1.75 J	2.01 J		1.9 J
PCB-147/149	hexa-	0.366 NJ	4.13 U				0.434 J	0.254 J		1.2 J	1.68 J	1.18 NJ	2.17 J	1.26 J	1.48 J
PCB-153/168	hexa-	0.383 J	0.542 NJ		0.732 NJ		0.366 J	0.302 J		1.02 J	1.29 NJ	0.865 J	1.86 J		1.26 J
PCB-169	hexa-	0.337 J													
PCB-177	hepta-												2.06 J		
PCB-187	hepta-									3.04 J	1.63 J				
PCB-194	octa-							0.287 J				1.27 J			1.53 NJ
Total PCBs															
…including N,NJ		32.075 J	34.756 J	18.664 J	41.521 J	20.506 J	36.882 J	21.682 J	36.828 J	83.043 J	68.83 J	37.243 J	60.4 J	27.719 J	41.546 J
…excluding N,NJ		27.033 J	33.583 J	18.664 J	39.4 J	19.055 J	35.418 J	19.29 J	32.535 J	75.139 J	57.56 J	25.376 J	52.23 J	25.389 J	36.806 J

Table E-22. January 2010 Detected PCB Congeners for Marine Water Samples.

PCB Congener (pg/L)	Homolog	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
		Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
PCB-001	mono-				0.818 J								4.22		1.04 NJ
PCB-002	mono-												7.82	1.07 J	0.973 J
PCB-003	mono-				0.916 J								6.65	1.41 NJ	1.21 NJ
PCB-004	di-				1.67 J						2.15 J				
PCB-008	di-				1.28 J						0.858 J				
PCB-017	tri-				0.975 NJ						1.17 J			0.883 NJ	
PCB-018/030	tri-	1.14 J		0.939 J	0.808 NJ	1.03 NJ	1.39 J	1.11 J	0.958 NJ	1.22 NJ	1.5 J	1.68 NJ	1.26 NJ	1.42 NJ	1.22 J
PCB-020/028	tri-	0.629 NJ		0.62 J	0.67 J	0.855 J	0.908 J	0.644 J			1.05 J		1.24 J	1.24 J	
PCB-021/033	tri-			0.444 NJ	0.443 NJ										
PCB-031	tri-			0.53 NJ	0.521 NJ			0.587 NJ			0.883 NJ		1.11 J	1.11 NJ	
PCB-032	tri-										0.843 J				
PCB-040/071	tetra-										0.576 NJ				
PCB-044/047/065	tetra-	4.32 NJ	9.42 J	4.83 J	14.4	4.66 NJ	11.6 J	5.87 J	11.5 J	14.6	6.49 J	7.32 J	7.28 J	6.25 J	7.08 J
PCB-049/069	tetra-			0.714 NJ		1.04 NJ		0.569 NJ		1.36 J	1.09 J	1.58 J	1.35 J	0.982 NJ	
PCB-051	tetra-	3 NJ	6.82	3.3 J	9.99	3.61 J	8.36	3.78 J	8.01	8.69 NJ	3.9 J	4.36	4.65	2.53 NJ	4.93
PCB-052	tetra-	2.84 J	2.67 J	1.95 J	2.1 J	1.88 J	1.75 J	1.77 J	1.72 J	2.28 NJ	2.76 J	2.86 NJ	3.33 J	3.18 J	2.45 NJ
PCB-061/070/074/076	tetra-										1.35 NJ				
PCB-068	tetra-		1.27 NJ	0.696 NJ	2.89 J		2.4 J	0.983 J	2.36 J	2.71 NJ	0.923 J		0.916 NJ		0.856 J
PCB-084	penta-										0.818 J				
PCB-086/087/097/108/119/125	penta-										1.42 J				
PCB-090/101/113	penta-	2.11 J		1.42 J	1.12 J			0.944 J		2.43 J	2.81 J		1.95 NJ	2.86 J	2.57 J
PCB-095	penta-				1.44 NJ		1.4 NJ	1.3 J			2.76 NJ		1.82 NJ	1.84 NJ	2.65 J
PCB-099	penta-										0.969 J				
PCB-105	penta-				0.384 J						0.665 J				
PCB-110	penta-			1.15 J	0.935 J			0.803 NJ		1.52 NJ	2.13 J		1.29 NJ	2.07 J	1.47 NJ
PCB-118	penta-				0.649 J						1.56 NJ		1.33 J	1.37 J	
PCB-129/138/163	hexa-			0.595 NJ	0.872 J						2.68 J		1.6 NJ		2.48 J
PCB-132	hexa-										0.851 J				
PCB-135/151	hexa-										0.978 J				
PCB-147/149	hexa-	0.783 NJ						0.675 J			1.59 NJ		1.49 NJ	1.59 J	1.92 J
PCB-153/168	hexa-			0.545 NJ				0.582 J		1.11 NJ	1.83 J		1.04 NJ	1.54 NJ	1.63 J
PCB-169	hexa-				0.457 NJ										
PCB-180/193	hepta-										0.526 NJ				
PCB-187	hepta-										0.739 NJ				

Total PCBs														
…including N,NJ	14.822 J	20.18 J	17.733 J	43.338 J	13.075 J	27.808 J	19.617 J	24.548 J	35.92 J	47.869 J	17.8 J	50.346 J	31.345 J	32.479 J
…excluding N,NJ	6.09 J	18.91 J	14.209 J	38.694 J	6.345 J	26.408 J	17.658 J	23.59 J	18.39 J	37.885 J	13.26 J	38.98 J	19.63 J	26.309 J

Table E-23. PCB Homolog Totals for Marine Water Samples.

Results qualified as N or NJ were not included in homolog sums or Total PCB calculations.

Sampling Date	PCB Homolog (pg/L)	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
		Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
July 2009	Mono-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Di-CBs	0	6.22 J	0	0	0	0	1.03 J	0	0	4.09 J	3.56 J	1.44 J	0	5.42 J
	Tri-CBs	0	2.41 J	0	0	0	0	0	0	0	4.87 J	1.96 J	0	4.34 J	0
	Tetra-CBs	8.42 J	23.96 J	10.59 J	8.29 J	13.82 J	11.937 J	10.618 J	14.62	8.73 J	18.748 J	12.34 J	14.785 J	14.796 J	31.29 J
	Penta-CBs	3.79 J	8.92 J	0	0	1.589 J	0	1.837 J	0	0	8.822 J	3.81 J	3.31 J	5.43 J	4.05 J
	Hexa-CBs	0	3.38 J	0	0	0	2.272 J	0	0	0	7.39 J	2.82 J	0	1.984 J	2.72 J
	Hepta-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Octa-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nona-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PCB-209	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total PCBs	12.21 J	44.89 J	10.59 J	8.29 J	15.409 J	14.209 J	13.485 J	14.62	8.73 J	43.92 J	24.49 J	19.535 J	26.55 J	43.48 J
September 2009	Mono-CBs	0.399 J	2.793 J	0	2.358 J	0.956 J	0.862 J	0	2.858 J	14.42 J	0	0	0	0	0
	Di-CBs	3.427 J	3.783 J	1.08 J	2.39 J	2.581 J	3.621 J	2.056 J	3.23 J	7.306 J	4.52 J	3.86 J	7.17 J	3.59 J	3.99 J
	Tri-CBs	4.798 J	4.814 J	2.289 J	2.633 J	2.539 J	4.807 J	2.053 J	1.467 J	8.793 J	7.05 J	4.181 J	6.02 J	0	3.906 J
	Tetra-CBs	12.74 J	14.27 J	12.22 J	27.584 J	12 J	21.368 J	11.338 J	22.41 J	32.72 J	37.1	13.45 J	28.6 J	13.269 J	20.77 J
	Penta-CBs	4.34 J	6.623 J	3.075 J	3.295 J	0.979 J	3.52 J	2.527 J	2.57 J	6.64 J	4.14 J	0	2.34 J	7.27 J	3.5 J
	Hexa-CBs	1.329 J	1.3 J	0	1.14 J	0	1.24 J	1.029 J	0	2.22 J	3.12 J	2.615 J	6.04 J	1.26 J	4.64 J
	Hepta-CBs	0	0	0	0	0	0	0	0	3.04 J	1.63 J	0	2.06 J	0	0
	Octa-CBs	0	0	0	0	0	0	0.287 J	0	0	0	1.27 J	0	0	0
	Nona-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PCB-209	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total PCBs	27.033 J	33.583 J	18.664 J	39.4 J	19.055 J	35.418 J	19.29 J	32.535 J	75.139 J	57.56 J	25.376 J	52.23 J	25.389 J	36.806 J
January 2010	Mono-CBs	0	0	0	1.734 J	0	0	0	0	0	0	0	18.69	1.07 J	0.973 J
	Di-CBs	0	0	0	2.95 J	0	0	0	0	0	3.008 J	0	0	0	0
	Tri-CBs	1.14 J	0	1.559 J	0.67 J	0.855 J	2.298 J	1.754 J	0	0	4.563 J	0	2.35 J	1.24 J	1.22 J
	Tetra-CBs	2.84 J	18.91 J	10.08 J	29.38 J	5.49 J	24.11 J	12.403 J	23.59 J	15.96	15.163 J	13.26 J	16.61 J	9.43 J	12.866 J
	Penta-CBs	2.11 J	0	2.57 J	3.088 J	0	0	2.244 J	0	2.43 J	8.812 J	0	1.33 J	6.3 J	5.22 J
	Hexa-CBs	0	0	0	0.872 J	0	0	1.257 J	0	0	6.339 J	0	0	1.59 J	6.03 J
	Hepta-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Octa-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nona-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PCB-209	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total PCBs	6.09 J	18.91 J	14.209 J	38.694 J	6.345 J	26.408 J	17.658 J	23.59 J	18.39 J	37.885 J	13.26 J	38.98 J	19.63 J	26.309 J

Table E-24. Detected PBDE Congeners for Marine Water Samples.

Samples for which all congener results were nondetects (U- or UJ-qualified) were assigned a total PBDE value equal to the highest congener reporting limit (RL).

Sampling Date	PBDE Homolog [1]	PBDE Congener (pg/L)	Hood Canal		SJdF at Sill		SJdF North		Haro Strait		Whidbey Basin		Main Basin		South Sound	
			Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep	Surface	Deep
July 2009	Tetra-	PBDE-047				163 J										
	Penta-	PBDE-085				25.6										
	Penta-	PBDE-099				184										
	Penta-	PBDE-100				50 N										
	Total PBDEs															
	…including N, NJ		120.2 U	120.2 U	128.9 U	422.6 J	122.5 U	134.4 U	125 U	129.5 U	135.9 U	127.6 U	120.2 U	121.4 U	130.2 U	128.9 U
	…excluding N, NJ		120.2 U	120.2 U	128.9 U	372.6 J	122.5 U	134.4 U	125 U	129.5 U	135.9 U	127.6 U	120.2 U	121.4 U	130.2 U	128.9 U
September 2009	Tri-	PBDE-028													10.7 J	
	Tetra-	PBDE-047					87.5 J		556							
	Tetra-	PBDE-049							29.7							
	Penta-	PBDE-085							56.9				28.3		23 J	
	Penta-	PBDE-099					152	51 J	1080						424 J	
	Penta-	PBDE-100					26.4		238				63.2 J		74.3 J	
	Hexa-	PBDE-139							21.5 J				12.3 J			
	Hexa-	PBDE-153							115				32.6		33.1	
	Hexa-	PBDE-154							87.6				49.3		28	
	Octa-	PBDE-201							43 J							
	Deca-	PBDE-209							959							
	Total PBDEs															
	…including N, NJ		123 U	122.5 U	123.8 U	122.5 U	265.9 J	51 J	3186.7	134 U	121.4 U	120.2 U	185.7 J	121.4 U	593.1 J	127.6 U
	…excluding N, NJ		123 U	122.5 U	123.8 U	122.5 U	265.9 J	51 J	3186.7	134 U	121.4 U	120.2 U	185.7 J	121.4 U	593.1 J	127.6 U
January 2010	Tetra-	PBDE-066		12.8 NJ												
	Octa-	PBDE-196								40.8 J						
	Octa-	PBDE-201								50.3 J						
	Octa-	PBDE-203								108						
	Nona-	PBDE-206				80 J				822						
	Nona-	PBDE-207				166 J				1240						
	Nona-	PBDE-208				153 J				1270	101 NJ					
	Deca-	PBDE-209				2700				15200 J	1300 J				904	
	Total PBDEs															
	…including N, NJ		245 U	12.8 NJ	243 U	3099 J	253 U	253 U	255 U	18691 J	1401 J	245 U	240 U	245 U	904	238 U
	…excluding N, NJ		245 U	240 U	243 U	3099 J	253 U	253 U	255 U	18691 J	1300 J	245 U	240 U	245 U	904	238 U

[1] The following 36 congeners were measured (listed by homolog group):
Di-brominated congeners = PBDEs 007, 010, and 015; tri-brominated congeners = PBDEs 017, 028, and 030; tetra-brominated congeners = PBDEs 047, 049, 066, 071, and 077; penta-brominated congeners = PBDEs 085, 099, 100, 119, and 126; hexa-brominated congeners are PBDEs 138-140, 153, 154, and 156/169; hepta-brominated congeners are PBDEs 171, 180, 183, 184, and 191; octa-brominated congeners are PBDEs 196, 197/204, 201, 203, and 205; nona-brominated congeners are PBDEs 206-208; the deca-brominated congener is PBDE 209.

Appendix F. Analytical Results - Marine SPM

Table F-1. Summary of Results for Marine Particulate Samples.

All results for the Case+Carr Inlet sample were J-qualified due to analysis beyond holding time. PBDE results show only detected congeners.

Parameter	Hood Canal (Deep)	Case+Carr (Mid-water)
Conventional Parameters (%)		
TOC	2.75	n/a
Total Recoverable Metals (mg/Kg dry)		
Arsenic	7.53	5.72 J
Cadmium	0.87	1.04 J
Copper	82.0	18.5 J
Lead	9.13	8.78 J
Zinc	90.0	72.0 J
PBDE s (ng/Kg dry)		
BDE-017		28.6 J
BDE-028	10.2 J	40.1 J
BDE-047	120	438 J
BDE-049	17.8 J	59.6 J
BDE-099	104	184 J
BDE-100	27.1 J	84.8 J
BDE-139		10.4 J
BDE-153	29.6	18.2 J
BDE-154	14 J	29.8 J
BDE-183	54.1 J	41.2 J
BDE-197/204	36.7 J	28.4 J
BDE-203	20.6 J	
BDE-206		92.1 J
BDE-207	103 J	
BDE-208	167	
BDE-209	879	
Total PBDEs	1583.1 J	1055.2 J

Table F-2. Summary of Detected PCB Congeners in Marine Particulate Samples.
All detected results for the Case+Carr sample were J-qualified due to analysis beyond holding time.

PCB Congener (ng/Kg dry)	Hood Canal (Deep)	Case+Carr (Mid-water)
PCB-001		19 NJ
PCB-002		13.3 J
PCB-003		22 J
PCB-004		18.8 NJ
PCB-005/008	71.9	165 J
PCB-006		12.4 NJ
PCB-007	10.1 NJ	
PCB-011	305	571 J
PCB-012/013		58.5 N
PCB-015	52.5	104 J
PCB-016	13.5 NJ	60.7 J
PCB-017	22.9	61.5 J
PCB-018	42.6	143 J
PCB-020/033	34.9	172 J
PCB-022	26.4	111 J
PCB-025		28 J
PCB-026		34.5 J
PCB-027		11.7 J
PCB-028	56.6	381 J
PCB-031	52.5	243 J
PCB-032		47.1 J
PCB-037	44.2	57.5 N
PCB-042	20.5 J	21.4 NJ
PCB-043/049	43.7	150 J
PCB-044	53.1	97.8 J
PCB-045		15.8 NJ
PCB-046	31.8 N	
PCB-047/048	32.8	87.1J
PCB-050		
PCB-051		12.6 NJ
PCB-052/069		187 J
PCB-053		18.3 J
PCB-056	12.3 NJ	65.8 J
PCB-060		39.9 J
PCB-064/072	20.1 J	30 J
PCB-066	55.2	186 J
PCB-070	73	218 J
PCB-071	11.9 J	16.4 J
PCB-074	32.3	102 J
PCB-076		11.8 NJ
PCB-077		33.8 J
PCB-081	12.9 NJ	
PCB-082		32.1 N
PCB-083		19.1 NJ
PCB-084		75.7 J
PCB-085		72.5 J
PCB-086/097/117	54.1	86.3 J
PCB-087/115	50.6 N	103 J
PCB-090		15.8 J
PCB-091		50.2 J
PCB-092	39.7	72 J
PCB-093/095/098/102	134	283 J
PCB-099	124	214 J
PCB-101	171	365 J

PCB Congener (ng/Kg dry)	Hood Canal (Deep)	Case+Carr (Mid-water)
PCB-105	61.9	133 J
PCB-107/108		42.7 J
PCB-110	201	368 J
PCB-112/119		13.3 J
PCB-118	128	384 J
PCB-121	22 J	
PCB-123	12.5 J	11.7 J
PCB-124	11.5 NJ	
PCB-128	22.9 N	72.4 J
PCB-129		12.1 NJ
PCB-130		49.5 N
PCB-132	45.4	158 J
PCB-134		27.1 J
PCB-135	36	97.1 J
PCB-136	24.1 N	93.9 J
PCB-137		20 J
PCB-138	147	534 J
PCB-139/149	176	535 J
PCB-141		61.8 J
PCB-144		41.2 J
PCB-146	25 N	127 J
PCB-151	20.9 NJ	145 J
PCB-153	170	690 J
PCB-154		11.9 NJ
PCB-156	13.1 J	35.4 J
PCB-157		11.6 J
PCB-158	10.6 J	37.6 J
PCB-163/164	44.3	206 J
PCB-167		25.7 J
PCB-170	38.1	85 J
PCB-171		39.4 J
PCB-172		11.8 J
PCB-174	31.5 N	52.9 J
PCB-176		12 J
PCB-177	31.2	85.1 J
PCB-178		55.5 J
PCB-179	27.4	63.3 J
PCB-180	92.4	202 J
PCB-182/187	94.8	254 J
PCB-183	21.4 NJ	47.7 J
PCB-190		13.8 NJ
PCB-194		37.6 J
PCB-195		25.8 J
PCB-196		25.1 J
PCB-199	26.4 N	92.2 J
PCB-201		15.4 NJ
PCB-202		28.7 J
PCB-203	11.6 J	39.7 J
PCB-206	20.3 NJ	53.4 J
PCB-208	23.2 N	21.1 NJ
PCB-209	27.8	32.3 J
Total PCBs		
…including N,NJ	3324.4 J	10256.2 J
…excluding N,NJ	2966	9853.4 J

Appendix G. Analytical Results - Rivers

Table G-1. Conventionals and Metals Results for River Water Samples.

Non-detect values are given at the method detection limit (MDL).

Parameter	Nooksack			Skagit			Stillaguamish			Snohomish			Puyallup		
	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec
Conventional Parameters (mg/L)															
TSS	10.9	3.7	76.3 J	7.2	6.4	60.8 J	2.6	41.3	3.7	4.7	13.6	54.5	233	38.7	11.9
TOC	0.6 J	0.8 J	2.8	0.6 J	0.6 J	1.7	0.8 J	3.3	1.1	0.6 J	2.1	2.1	0.5 J	1.1	1.3
DOC	0.8 J	1	2.9	0.6 J	0.9 J	1.6	0.9 J	4	1	0.7 J	2.2	2.1	0.8 J	1.4	1.2
Ammonia	0.002 U	0.002 U	0.022	0.002 U	0.046	0.002 U	0.011	0.039	0.007 J	0.002 U	0.079	0.008 J	0.01	0.162	0.027
Nitrate+Nitrite	0.087	0.344	0.544	0.045	0.084	0.126	0.088	0.341	0.301	0.077	0.281	0.276	0.11	0.309	0.301
Total Nitrogen	0.106	0.376	0.656	0.057	0.163	0.157	0.147	0.418	0.332	0.102	0.389	0.321	0.137	0.545	0.37
Total Phosphorus	0.0212	0.0257	0.0904	0.0073 J	0.0059	0.0855	0.0172	0.0718	0.0155	0.0092 J	0.0324	0.0532	0.25	0.0795	0.0437
Ortho-phosphate	0.0082 J	0.0209	0.0099	0.0042	0.0032	0.0045	0.0141	0.0112 J	0.0075	0.0047	0.0144	0.0041	0.0287	0.0478	0.0211
Hardness	38.1	62.0 J	38.5	21.8	29.9 J	27.6	31.9	19.2	29.9	17.4	15.7	13.2	27.7	40.8	33.2
Metals (µg/L)															
Arsenic, total	0.37	0.26	1.01	0.57	0.43	1.24	0.73	1.12	0.52	0.92	0.94	1.14	0.92	0.6	0.52
Arsenic, dissolved	0.31	0.37	0.3	0.5	0.47	0.5	0.75	0.51	0.48	0.86	0.71	0.52	0.46	0.62	0.5
Cadmium, total	0.005 J	0.005 J	0.04 J	0.009 J	0.006 J	0.02 J	0.005 J	0.02 J	0.007 J	0.005 J	0.01 J	0.03 J	0.01 J	0.006 J	0.005 J
Cadmium, dissolved	0.002 U	0.007 J	0.006 UJ	0.002 U	0.006 J	0.035	0.002 U	0.003 J	0.005 J	0.002 U	0.003 J	0.010 J	0.003 J	0.003 J	0.002 U
Copper, total	2.08	0.75 J	4.41	0.77	0.86	4.56	1.16	6.58	1.12	1.35	2.36	4.08	11.6	1.81	1.32
Copper, dissolved	0.38	0.41	2.09	0.52	0.35	1.04	1.22	1.69	0.68	1.71	1.17	1	4.19	0.91	0.63
Lead, total	0.10 J	0.05 J	0.82	0.11 J	0.05 J	0.78	0.03 UJ	0.79	0.37 J	0.09 J	0.3	0.63	1.42	0.2	0.11 UJ
Lead, dissolved	0.006 U	0.018 J	0.281	0.006 U	0.014 J	0.046	0.006 U	0.052	0.04	0.048	0.037	0.054	0.006 U	0.035	0.024
Zinc, total	5.1	3.2 J	9.7	2.4 J	2.4 J	10.6	4.0 J	17.7	5.2 J	2.5 J	3.3 J	8.3 J	11.6	3.7 J	2.7 UJ
Zinc, dissolved	1.4	1	3.4	1.5	0.7 J	0.9 J	2.2	0.7 J	3.2	4.4	3.7	0.9 J	2	1.2	1

Table G-2. Petroleum-Related Products Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Sampling Date	Parameter (mg/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
		Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
July 2009	Oil and Grease	1.4 J	0.5	1.4 J	0.5	1.4 J	0.5	2.8	0.5	0.9 J	0.5
	TPH-D #2 Diesel	0.05 U	0.002	0.05 U	0.002	0.05 U	0.002	0.05 U	0.002	0.05 U	0.002
	TPH-D Lube Oil	0.12 U	0.004	0.13 U	0.004	0.13 U	0.004	0.13 U	0.004	0.13 U	0.004
	TPH-G [1]	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014
October 2009	Oil and Grease	1.8 U	0.5	1.9 U	0.5	1.8 U	0.5	1.8 U	0.5	1.8 U	0.5
	TPH-D #2 Diesel	0.05 U	0.002	0.05 U	0.002	0.05 U	0.002	0.05 U	0.002	0.05 U	0.002
	TPH-D Lube Oil	0.12 U	0.004	0.12 U	0.004	0.13 U	0.004	0.12 U	0.004	0.12 U	0.004
	TPH-G	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014
December 2009	Oil and Grease	5.5 U	1.5	5.4 U	1.5	5.4 U	1.5	1.6 J	1.5	5.5 U	1.5
	TPH-D #2 Diesel	0.02 U	0.0005	0.02 U	0.0006	0.05 U	0.002	0.02 U	0.0006	0.02 U	0.0006
	TPH-D Lube Oil	0.04 U	0.001	0.04 U	0.001	0.12 U	0.004	0.04 U	0.001	0.04 U	0.004
	TPH-G	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014	0.14 U	0.014

[1] TPH-G results for July represent the average of three quarter point samples (none were detected).

Table G-3. July 2009 Chlorinated Pesticides Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	-	-	-	-	-	-	-	-	-	-
2,4'-DDE	-	-	-	-	-	-	-	-	-	-
2,4'-DDT	-	-	-	-	-	-	-	-	-	-
4,4'-DDD	0.20 U	0.17	0.21 U	0.18	0.21 U	0.18	0.20 U	0.17	0.21 UJ	0.18
4,4'-DDE	0.28 UJ	0.17	0.21 U	0.18	0.26 UJ	0.17	0.21 UJ	0.17	0.21 UJ	0.17
4,4'-DDT	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 UJ	-
Aldrin	0.20 UJ	0.061	0.21 UJ	0.065	0.21 UJ	0.062	0.20 UJ	0.061	0.21 UJ	0.063
Alpha-BHC	0.20 U	0.041	0.21 U	0.043	0.21 U	0.041	0.20 U	0.040	0.21 UJ	0.042
Beta-BHC	0.20 U	0.14	0.21 U	0.15	0.21 U	0.15	0.20 U	0.14	0.21 UJ	0.15
Chlorpyriphos	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
cis-Chlordane	0.20 U	0.090	0.21 U	0.096	0.21 U	0.092	0.20 U	0.090	0.21 UJ	0.093
Cis-Nonachlor	0.20 U	0.13	0.21 U	0.14	0.21 U	0.13	0.20 U	0.13	0.21 UJ	0.13
Dacthal (DCPA)	-	-	-	-	-	-	-	-	-	-
DDMU	-	-	-	-	-	-	-	-	-	-
Delta-BHC	0.20 UJ	0.040	0.21 UJ	0.043	0.21 UJ	0.041	0.20 UJ	0.040	0.21 UJ	0.041
Dieldrin	0.50 U	0.20	0.53 U	0.21	0.51 U	0.21	0.50 U	0.20	0.51 U	0.21
Endosulfan I	0.20 U	0.091	0.21 U	0.096	0.21 U	0.093	0.20 U	0.090	0.21 U	0.093
Endosulfan II	0.20 U	0.074	0.21 U	0.079	0.21 U	0.076	0.20 U	0.074	0.21 U	0.076
Endosulfan Sulfate	0.20 U	0.16	0.21 U	0.17	0.21 U	0.16	0.20 U	0.16	0.21 U	0.17
Endrin	0.50 U	0.22	0.53 U	0.23	0.51 U	0.22	0.50 U	0.21	0.51 U	0.22
Endrin Aldehyde	0.20 U	0.15	0.21 U	0.16	0.21 U	0.15	0.20 U	0.15	0.21 U	0.16
Endrin Ketone	0.75 U	0.61	0.80 U	0.64	0.77 U	0.62	0.75 U	0.60	0.77 U	0.62
Gamma-BHC (Lindane)	1.0 UJ	0.050	1.2 UJ	0.054	0.87 UJ	0.051	1.2 UJ	0.050	2.1 UJ	0.052
Heptachlor	0.20 UJ	0.088	0.21 UJ	0.093	0.21 UJ	0.090	0.20 UJ	0.087	0.21 UJ	0.090
Heptachlor Epoxide	0.20 U	0.12	0.21 U	0.13	0.21 U	0.13	0.20 U	0.12	0.21 U	0.13
Hexachlorobenzene	0.20 UJ	-	0.21 UJ	-	0.21 UJ	-	0.20 UJ	-	0.21 UJ	-
Methoxychlor	0.50 U	0.25	0.53 U	0.27	0.51 U	0.26	0.50 U	0.25	0.51 U	0.26
Mirex	-	-	-	-	-	-	-	-	-	-
Oxychlordane	0.20 U	0.073	0.21 U	0.078	0.21 U	0.075	0.20 U	0.073	0.21 UJ	0.075
Pentachloroanisole	-	-	-	-	-	-	-	-	-	-
Toxaphene	9.9 U	-	11 U	-	10 U	-	9.9 U	-	10 UJ	-
trans-Chlordane	0.20 U	0.15	0.21 U	0.16	0.21 U	0.15	0.20 U	0.15	0.21 UJ	0.15
Trans-Nonachlor	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 UJ	-

Table G-4. October 2009 Chlorinated Pesticides Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
2,4'-DDE	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
2,4'-DDT	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
4,4'-DDD	0.21 U	0.18	0.20 U	0.17	0.20 U	0.17	0.21 U	0.18	0.21 U	0.18
4,4'-DDE	0.21 U	0.17	0.20 U	0.17	0.20 U	0.17	0.21 U	0.17	0.21 U	0.18
4,4'-DDT	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
Aldrin	0.21 UJ	0.062	0.20 UJ	0.062	0.20 UJ	0.061	0.21 UJ	0.063	0.21 UJ	0.063
Alpha-BHC	0.21 U	0.041	0.20 U	0.041	0.20 UJ	0.041	0.21 UJ	0.042	0.21 U	0.042
Beta-BHC	0.21 U	0.15	0.20 U	0.15	0.20 U	0.15	0.21 U	0.15	0.21 U	0.15
Chlorpyriphos	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
cis-Chlordane	0.21 U	0.092	0.20 U	0.091	0.20 U	0.091	0.21 U	0.093	0.21 U	0.093
Cis-Nonachlor	0.21 U	0.13	0.20 U	0.13	0.20 U	0.13	0.21 U	0.13	0.21 U	0.13
Dacthal (DCPA)	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
DDMU	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
Delta-BHC	0.21 U	0.041	0.20 U	0.040	0.20 U	0.040	0.21 U	0.041	0.21 U	0.041
Dieldrin	0.51 U	0.21	0.51 U	0.20	0.50 U	0.20	0.51 U	0.21	0.52 U	0.21
Endosulfan I	0.21 U	0.093	0.20 U	0.092	0.20 U	0.091	0.21 U	0.093	0.21 U	0.093
Endosulfan II	0.21 U	0.076	0.20 U	0.075	0.20 U	0.075	0.21 U	0.076	0.21 U	0.077
Endosulfan Sulfate	0.21 U	0.16	0.25 UJ	0.16	0.20 U	0.16	0.23 UJ	0.17	0.32 UJ	0.17
Endrin	0.51 U	0.22	0.51 U	0.22	0.50 U	0.22	0.51 U	0.22	0.52 U	0.22
Endrin Aldehyde	0.44 UJ	0.15	0.36 UJ	0.15	0.36 UJ	0.15	0.52 UJ	0.16	0.46 UJ	0.16
Endrin Ketone	0.77 U	0.62	0.76 U	0.61	0.75 U	0.61	0.77 U	0.62	0.77 U	0.62
Gamma-BHC (Lindane)	8.6 UJ	0.051	5.6 UJ	0.051	4.4 UJ	0.051	5.2 UJ	0.052	26 UJ	0.26
Heptachlor	0.21 U	0.090	0.20 U	0.089	0.20 U	0.088	0.21 U	0.090	0.21 U	0.090
Heptachlor Epoxide	0.21 U	0.13	0.20 U	0.12	0.20 U	0.12	0.21 U	0.13	0.21 U	0.13
Hexachlorobenzene	0.21 U	-	0.20 U	-	1.6	-	0.21 U	-	0.21 U	-
Methoxychlor	0.51 U	0.26	0.51 U	0.26	0.50 U	0.25	0.51 U	0.26	0.52 U	0.26
Mirex	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
Oxychlordane	0.21 U	0.075	0.20 U	0.074	0.20 U	0.073	0.21 U	0.075	0.21 U	0.075
Pentachloroanisole	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-
Toxaphene	10 U	-	10 U	-	9.9 U	-	10 U	-	10 U	-
trans-Chlordane	0.21 U	0.15	0.20 U	0.15	0.20 U	0.15	0.21 U	0.15	0.21 U	0.15
Trans-Nonachlor	0.21 U	-	0.20 U	-	0.20 U	-	0.21 U	-	0.21 U	-

Table G-5. December 2009 Chlorinated Pesticides Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (ng/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
2,4'-DDE	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
2,4'-DDT	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
4,4'-DDD	0.20 U	0.17	0.21 U	0.18	0.21 U	0.18	0.20 U	0.17	0.21 U	0.18
4,4'-DDE	0.20 U	0.17	0.21 U	0.17	0.21 U	0.18	0.20 U	0.17	0.21 U	0.18
4,4'-DDT	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
Aldrin	0.20 U	0.061	0.21 UJ	0.062	0.21 U	0.065	0.20 U	0.061	0.21 UJ	0.064
Alpha-BHC	0.20 U	0.041	0.21 U	0.041	0.21 U	0.043	0.20 U	0.041	0.21 U	0.042
Beta-BHC	0.20 U	0.15	0.21 U	0.15	0.21 U	0.15	0.20 U	0.14	0.21 U	0.15
Chlorpyriphos	0.21 UJ	-	0.23 UJ	-	0.21 U	-	0.20 U	-	0.21 UJ	-
cis-Chlordane	0.20 U	0.091	0.21 U	0.092	0.21 U	0.096	0.20 U	0.090	0.21 U	0.094
Cis-Nonachlor	0.20 U	0.13	0.21 U	0.13	0.21 U	0.14	0.20 U	0.13	0.21 U	0.13
Dacthal (DCPA)	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
DDMU	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
Delta-BHC	0.20 U	0.040	0.21 U	0.041	0.21 U	0.043	0.20 U	0.040	0.21 U	0.042
Dieldrin	0.50 U	0.20	0.51 U	0.21	0.53 U	0.21	0.50 U	0.20	0.52 U	0.21
Endosulfan I	0.20 U	0.091	0.21 U	0.093	0.21 U	0.096	0.20 U	0.091	0.21 U	0.094
Endosulfan II	0.20 U	0.075	0.21 U	0.076	0.21 U	0.079	0.20 U	0.074	0.21 U	0.077
Endosulfan Sulfate	0.42	0.16	0.21 U	0.16	0.21 U	0.17	0.20 U	0.16	0.21 U	0.17
Endrin	0.50 U	0.22	0.51 U	0.22	0.53 U	0.23	0.50 U	0.22	0.52 U	0.22
Endrin Aldehyde	0.20 U	0.15	0.21 U	0.15	0.21 U	0.16	0.20 U	0.15	0.21 U	0.16
Endrin Ketone	0.75 U	0.61	0.77 U	0.62	0.80 U	0.64	0.75 U	0.61	0.78 U	0.63
Gamma-BHC (Lindane)	0.20 U	0.051	0.40 UJ	0.051	0.56 UJ	0.054	0.47 UJ	0.050	0.42 UJ	0.052
Heptachlor	0.20 U	0.088	0.21 U	0.090	0.21 U	0.093	0.20 U	0.088	0.21 U	0.091
Heptachlor Epoxide	0.20 U	0.12	0.21 U	0.13	0.21 U	0.13	0.20 U	0.12	0.21 U	0.13
Hexachlorobenzene	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
Methoxychlor	0.50 U	0.25	0.51 U	0.26	0.53 U	0.27	0.50 U	0.25	0.52 U	0.26
Mirex	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
Oxychlordane	0.20 U	0.073	0.21 U	0.075	0.21 U	0.078	0.20 U	0.073	0.21 U	0.076
Pentachloroanisole	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-
Toxaphene	9.9 U	-	10 U	-	11 U	-	9.9 U	-	10 U	-
trans-Chlordane	0.20 U	0.15	0.21 U	0.15	0.21 U	0.16	0.20 U	0.15	0.21 U	0.15
Trans-Nonachlor	0.20 U	-	0.21 U	-	0.21 U	-	0.20 U	-	0.21 U	-

Table G-6. July 2009 PAH Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.011 U	0.011	0.011 U	0.011	0.0099 U	0.010	0.010 U	0.010	0.010 UJ	0.010
2-Chloronaphthalene	0.011 U	0.010	0.011 U	0.010	0.0099 U	0.0092	0.010 U	0.0094	0.010 UJ	0.0093
2-Methylnaphthalene	0.011 U	0.0095	0.011 U	0.0095	0.0099 U	0.0085	0.010 U	0.0087	0.010 UJ	0.0086
Acenaphthene	0.011 U	0.0095	0.011 U	0.0095	0.0099 U	0.0085	0.010 U	0.0087	0.010 UJ	0.0086
Acenaphthylene	0.011 U	0.0094	0.011 U	0.0094	0.0099 U	0.0084	0.010 U	0.0085	0.010 UJ	0.0084
Anthracene	0.011 U	0.0056	0.011 U	0.0056	0.0099 U	0.0051	0.010 U	0.0051	0.010 UJ	0.0051
Benzo(a)anthracene	0.018 UJ	0.0010	0.018 UJ	0.0010	0.016 UJ	0.0009	0.016 UJ	0.0009	0.016 UJ	0.0009
Benzo(a)pyrene	0.011 UJ	0.0018	0.011 UJ	0.0018	0.0099 UJ	0.0016	0.010 UJ	0.0016	0.010 UJ	0.0016
Benzo(b)fluoranthene	0.011 U	0.0011	0.011 U	0.0011	0.0099 U	0.0010	0.010 U	0.0010	0.010 UJ	0.0010
Benzo(ghi)perylene	0.011 UJ	0.0018	0.011 UJ	0.0018	0.0099 UJ	0.0016	0.010 UJ	0.0016	0.010 UJ	0.0016
Benzo(k)fluoranthene	0.011 U	0.0006	0.011 U	0.0006	0.0099 U	0.0005	0.010 U	0.0005	0.012 UJ	0.0005
Carbazole	0.011 U	0.0016	0.011 U	0.0016	0.0099 U	0.0015	0.010 U	0.0015	0.010 UJ	0.0015
Chrysene	0.011 UJ	0.0009	0.011 UJ	0.0009	0.0099 UJ	0.0008	0.010 UJ	0.0009	0.010 UJ	0.0009
Dibenzo(a,h)anthracene	0.011 U	0.0016	0.011 U	0.0016	0.0099 U	0.0014	0.010 U	0.0014	0.010 UJ	0.0014
Dibenzofuran	0.011 U	0.0087	0.011 U	0.0087	0.0099 U	0.0078	0.010 U	0.0079	0.010 UJ	0.0079
Fluoranthene	0.011 U	0.0017	0.011 U	0.0017	0.0099 U	0.0015	0.010 U	0.0016	0.010 UJ	0.0015
Fluorene	0.011 U	0.0082	0.011 U	0.0082	0.0099 U	0.0074	0.010 U	0.0075	0.010 UJ	0.0074
Indeno(1,2,3-cd)pyrene	0.011 U	0.0022	0.011 U	0.0022	0.0099 U	0.0020	0.010 U	0.0020	0.010 UJ	0.0020
Naphthalene	0.011 U	0.035	0.011 U	0.035	0.0099 U	0.031	0.010	0.032	0.010 UJ	0.031
Phenanthrene	0.011 U	0.0067	0.011 U	0.0067	0.0099 U	0.0060	0.010 U	0.0061	0.010 UJ	0.0061
Pyrene	0.011 U	0.0020	0.011 U	0.0020	0.0099 U	0.0018	0.010 U	0.0018	0.010 UJ	0.0018
Retene	0.011 U	0.0011	0.011 U	0.0011	0.0099 U	0.0009	0.010 U	0.0010	0.010 UJ	0.0010

Table G-7. October 2009 PAH Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.0039 J	0.0010	0.0049 J	0.0010	0.010 U	0.0010	0.0098 U	0.0010	0.010 U	0.0010
2-Chloronaphthalene	0.010 UJ	0.0093	0.010 U	0.0095	0.010 U	0.0093	0.0098 U	0.0091	0.010 U	0.0093
2-Methylnaphthalene	0.010 UJ	0.0086	0.0089 J	0.0087	0.010 U	0.0086	0.0098 U	0.0084	0.010 U	0.0086
Acenaphthene	0.010 UJ	0.0086	0.010 U	0.0087	0.010 U	0.0086	0.0098 U	0.0084	0.010 U	0.0086
Acenaphthylene	0.010 UJ	0.0085	0.010 U	0.0086	0.010 U	0.0085	0.0098 U	0.0083	0.010 U	0.0084
Anthracene	0.010 UJ	0.0051	0.010 U	0.0052	0.010 U	0.0051	0.0098 U	0.0050	0.010 U	0.0051
Benzo(a)anthracene	0.010 UJ	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.0098 U	0.0009	0.010 U	0.0009
Benzo(a)pyrene	0.020 UJ	0.0016	0.020 UJ	0.0017	0.020 UJ	0.0016	0.020 UJ	0.0016	0.020 UJ	0.0016
Benzo(b)fluoranthene	0.010 UJ	0.0010	0.010 U	0.0010	0.010 U	0.0010	0.0098 U	0.0010	0.010 U	0.0010
Benzo(ghi)perylene	0.010 UJ	0.0016	0.010 U	0.0016	0.010 U	0.0016	0.0098 U	0.0016	0.010 U	0.0016
Benzo(k)fluoranthene	0.010 UJ	0.0005	0.010 U	0.0005	0.010 U	0.0005	0.0098 U	0.0005	0.010 U	0.0005
Carbazole	0.010 UJ	0.0015	0.010 U	0.0015	0.010 U	0.0015	0.0098 U	0.0014	0.010 U	0.0015
Chrysene	0.010 UJ	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.0098 U	0.0008	0.010 U	0.0009
Dibenzo(a,h)anthracene	0.010 UJ	0.0014	0.010 U	0.0014	0.010 U	0.0014	0.0098 U	0.0014	0.010 U	0.0014
Dibenzofuran	0.010 UJ	0.0079	0.010 U	0.0080	0.010 U	0.0079	0.0098 U	0.0077	0.010 U	0.0079
Fluoranthene	0.010 UJ	0.0015	0.010 U	0.0016	0.010 U	0.0015	0.0098 U	0.0015	0.010 U	0.0015
Fluorene	0.010 UJ	0.0074	0.010 U	0.0075	0.010 U	0.0074	0.0098 U	0.0072	0.010 U	0.0074
Indeno(1,2,3-cd)pyrene	0.010 UJ	0.0020	0.010 U	0.0020	0.010 U	0.0020	0.0098 U	0.0019	0.010 U	0.0020
Naphthalene	0.012 UJ	0.0011	0.015 UJ	0.0011	0.010 U	0.0011	0.010 UJ	0.0011	0.012 UJ	0.0011
Phenanthrene	0.010 UJ	0.0061	0.010 U	0.0062	0.010 U	0.0061	0.0098 U	0.0060	0.010 U	0.0061
Pyrene	0.010 UJ	0.0018	0.010 U	0.0018	0.010 U	0.0018	0.0098 U	0.0017	0.010 U	0.0018
Retene	0.010 UJ	0.0010	0.010 U	0.0010	0.010 U	0.0010	0.0098 U	0.0009	0.010 U	0.0010

Table G-8. December 2009 PAH Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	0.010 U	0.010	0.010 U	0.011	0.010 U	0.0010	0.010 U	0.010	0.011 U	0.011
2-Chloronaphthalene	0.010 REJ	0.0094	0.010 REJ	0.0096	0.010 U	0.0010	0.010 REJ	0.0093	0.011 U	0.0098
2-Methylnaphthalene	0.010 U	0.0087	0.010 U	0.0089	0.010 U	0.0011	0.010 U	0.0086	0.011 U	0.0091
Acenaphthene	0.010 U	0.0087	0.010 U	0.0089	0.010 U	0.0011	0.010 U	0.0086	0.011 U	0.0091
Acenaphthylene	0.010 U	0.0086	0.010 U	0.0087	0.010 U	0.0018	0.010 U	0.0085	0.011 REJ	0.0089
Anthracene	0.010 U	0.0052	0.010 U	0.0053	0.010 U	0.0023	0.010 U	0.0051	0.011 U	0.0054
Benzo(a)anthracene	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0010	0.0009 J	0.0009	0.011 U	0.0009
Benzo(a)pyrene	0.010 U	0.0016	0.010 U	0.0017	0.010 U	0.0018	0.010 U	0.0016	0.011 U	0.0017
Benzo(b)fluoranthene	0.010 U	0.0010	0.010 U	0.0011	0.010 U	0.0011	0.010 U	0.0010	0.011 U	0.0011
Benzo(ghi)perylene	0.010 U	0.0016	0.010 U	0.0017	0.010 U	0.0017	0.010 U	0.0016	0.011 U	0.0017
Benzo(k)fluoranthene	0.010 U	0.0005	0.010 U	0.0005	0.010 U	0.0006	0.010 U	0.0005	0.011 U	0.0006
Carbazole	0.010 U	0.0015	0.010 U	0.0015	0.010 U	0.0013	0.010 U	0.0015	0.011 U	0.0016
Chrysene	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.010 U	0.0009	0.011 U	0.0009
Dibenzo(a,h)anthracene	0.010 UJ	0.0014	0.010 U	0.0015	0.010 UJ	0.0015	0.010 U	0.0014	0.011 UJ	0.0015
Dibenzofuran	0.010 U	0.0080	0.010 U	0.0081	0.010 U	0.0009	0.010 U	0.0079	0.011 U	0.0083
Fluoranthene	0.010 U	0.0016	0.010 U	0.0016	0.010 U	0.0010	0.010 U	0.0015	0.011 U	0.0016
Fluorene	0.010 U	0.0075	0.010 U	0.0077	0.010 U	0.0007	0.010 U	0.0074	0.011 U	0.0078
Indeno(1,2,3-cd)pyrene	0.010 U	0.0020	0.010 U	0.0020	0.010 U	0.0020	0.010 U	0.0020	0.011 U	0.0021
Naphthalene	0.010 U	0.0081	0.010 U	0.0082	0.010 U	0.0011	0.010 U	0.0080	0.024	0.0084
Phenanthrene	0.010 U	0.0062	0.010 U	0.0063	0.010 U	0.0024	0.010 U	0.0061	0.011 U	0.0064
Pyrene	0.010 U	0.0018	0.010 U	0.0018	0.010 U	0.0020	0.010 U	0.0018	0.011 U	0.0019
Retene	0.0097 J	0.0010	0.11	0.0010	0.010 U	0.0011	0.0030 J	0.0010	0.0015 J	0.0010

Table G-9. Total PAH and Total cPAH Results for River Water Samples.

Sampling Date	Parameter (µg/L)	Nooksack	Skagit	Stillaguamish	Snohomish	Puyallup
July 2009	Total PAHs					
	…ND at ½ RL	0.12 U	0.12 U	0.11 U	0.010	0.11 UJ
	…ND at MDL	0.13 U	0.13 U	0.12 U	0.010	0.12 UJ
	Total cPAHs					
	…ND at ½ RL	0.039 U	0.039 U	0.035 U	0.035 U	0.035 UJ
	…ND at MDL	0.0092 U	0.0092 U	0.0082 U	0.0083 U	0.0083 UJ
October 2009	Total PAHs					
	…ND at ½ RL	0.0039 J	0.014 J	0.12 U	0.11 U	0.12 U
	…ND at MDL	0.0039 J	0.014 J	0.079 U	0.077 U	0.079 U
	Total cPAHs					
	…ND at ½ RL	0.040 UJ	0.040 U	0.040 U	0.039 U	0.040 U
	…ND at MDL	0.0083 UJ	0.0084 U	0.0083 U	0.0081 U	0.0083 U
December 2009	Total PAHs					
	…ND at ½ RL	0.0097 J	0.11	0.11 U	0.0039 J	0.026
	…ND at MDL	0.0097 J	0.11	0.029 U	0.0039 J	0.026
	Total cPAHs					
	…ND at ½ RL	0.035 U	0.035 U	0.035 U	0.0009 J	0.039 U
	…ND at MDL	0.0083 U	0.0086 U	0.0089 U	0.0009 J	0.0088 U

Table G-10. Summary of July 2009 BNA Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
1,2-Dichlorobenzene	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
1,2-Diphenylhydrazine	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
1,3-Dichlorobenzene	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
1,4-Dichlorobenzene	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
2,4,5-Trichlorophenol	0.32 U	-	0.31 U	-	0.31 U	-	0.33 U	-	0.31 U	-
2,4,6-Trichlorophenol	0.32 UJ	-	0.31 UJ	-	0.31 UJ	-	0.33 UJ	-	0.31 UJ	-
2,4-Dichlorophenol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
2,4-Dimethylphenol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
2,4-Dinitrophenol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
2,4-Dinitrotoluene	0.32 U	-	0.31 U	-	0.31 U	-	0.33 U	-	0.31 U	-
2,6-Dinitrotoluene	0.32 U	-	0.31 U	-	0.31 U	-	0.33 U	-	0.31 U	-
2-Chlorophenol	0.32 U	-	0.31 U	-	0.31 U	-	0.33 U	-	0.31 U	-
2-Methylphenol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.0058 J	-
2-Nitroaniline	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-	1.6 U	-
2-Nitrophenol	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
3,3'-Dichlorobenzidine	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-
3B-Coprostanol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
3-Nitroaniline	0.32 U	-	0.31 U	-	0.31 U	-	0.33 U	-	0.31 U	-
4,6-Dinitro-2-Methylphenol	0.32 U	-	0.31 U	-	0.31 U	-	0.33 U	-	0.31 U	-
4-Bromophenyl phenyl ether	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
4-Chloro-3-Methylphenol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
4-Chloroaniline	3.2 REJ	-	3.1 REJ	-	3.1 REJ	-	3.3 REJ	-	3.1 REJ	-
4-Chlorophenyl-Phenylether	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
4-Methylphenol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
4-Nitroaniline	0.32 UJ	-	0.31 UJ	-	0.31 UJ	-	0.33 UJ	-	0.31 UJ	-
4-Nitrophenol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
4-nonylphenol	0.32 U	0.032	0.31 U	0.031	0.31 U	0.031	0.33 U	0.033	0.31 U	0.031
Benzoic Acid	0.81 UJ	-	0.79 UJ	-	0.78 UJ	-	0.81 UJ	-	0.79 UJ	-
Benzyl Alcohol	0.81 UJ	-	0.79 UJ	-	0.78 UJ	-	0.81 UJ	-	0.79 UJ	-
Bis(2-chloro-1-methylethyl) ether	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
Bis(2-Chloroethoxy)Methane	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
Bis(2-Chloroethyl)Ether	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Bis(2-Ethylhexyl) Phthalate	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Bisphenol A	0.32 U	0.032	0.31 U	0.031	0.31 U	0.031	0.33 U	0.033	0.31 U	0.031
Butyl benzyl phthalate	0.32 U	0.032	0.31 U	0.031	0.31 U	0.031	0.33 U	0.033	0.31 U	0.031
Caffeine	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Cholesterol	0.81 U	-	0.79 U	-	0.78 U	-	0.81 U	-	0.79 U	-
Diethyl phthalate	0.16 U	0.032	0.16 U	0.031	0.16 U	0.031	0.16 U	0.033	0.16 U	0.031
Dimethyl phthalate	0.16 U	0.032	0.16 U	0.031	0.16 U	0.031	0.16 U	0.033	0.16 U	0.031
Di-N-Butylphthalate	0.12 UJ	-	0.18 UJ	-	0.19 UJ	-	0.16 UJ	-	0.17 UJ	-
Di-N-Octyl Phthalate	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Ethanol, 2-Chloro-, Phosphate (3:1)	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
Hexachlorobenzene	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
Hexachlorobutadiene	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
Hexachlorocyclopentadiene	0.32 UJ	-	0.31 UJ	-	0.31 UJ	-	0.33 UJ	-	0.31 UJ	-
Hexachloroethane	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
Isophorone	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Nitrobenzene	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
N-Nitrosodi-n-propylamine	0.097 U	-	0.094 U	-	0.094 U	-	0.098 U	-	0.094 U	-
N-Nitrosodiphenylamine	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-	0.16 U	-
Pentachlorophenol	0.081 UJ	-	0.079 UJ	-	0.078 UJ	-	0.081 UJ	-	0.079 UJ	-
Phenol	0.32 U	-	0.31 U	-	0.31 U	-	0.33 U	-	0.31 U	-
Triclosan	0.081 U	-	0.079 U	-	0.078 U	-	0.081 U	-	0.079 U	-
Triethyl citrate	0.32 U	0.032	0.31 U	0.031	0.31 U	0.031	0.33 U	0.033	0.31 U	0.031

Table G-11. Summary of October 2009 BNA Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.079 U	0.020	0.080 U	0.020	0.079 U	0.019	0.083 U	0.020	0.080 U	0.020
1,2-Dichlorobenzene	0.079 U	0.019	0.080 U	0.019	0.079 U	0.019	0.083 U	0.020	0.080 U	0.019
1,2-Diphenylhydrazine	0.079 U	0.051	0.080 U	0.051	0.079 U	0.050	0.083 U	0.053	0.080 U	0.051
1,3-Dichlorobenzene	0.079 U	0.016	0.080 U	0.016	0.079 U	0.016	0.083 U	0.017	0.080 U	0.016
1,4-Dichlorobenzene	0.079 U	0.017	0.080 U	0.018	0.079 U	0.017	0.083 U	0.018	0.080 U	0.018
2,4,5-Trichlorophenol	-	-	-	-	-	-	-	-	-	-
2,4,6-Trichlorophenol	-	-	-	-	-	-	-	-	-	-
2,4-Dichlorophenol	0.79 U	0.042	0.80 U	0.042	0.79 U	0.041	0.83 U	0.043	0.80 U	0.042
2,4-Dimethylphenol	0.79 U	0.047	0.80 U	0.047	0.79 U	0.046	0.83 U	0.049	0.80 U	0.047
2,4-Dinitrophenol	0.79 U	-	0.80 U	-	0.79 U	-	0.83 U	-	0.80 U	-
2,4-Dinitrotoluene	0.32 U	0.045	0.32 U	0.045	0.31 U	0.044	0.33 U	0.047	0.32 U	0.045
2,6-Dinitrotoluene	0.32 U	0.054	0.32 U	0.054	0.31 U	0.054	0.33 U	0.056	0.32 U	0.054
2-Chlorophenol	0.32 U	0.041	0.32 U	0.042	0.31 U	0.041	0.33 U	0.043	0.32 U	0.042
2-Methylphenol	0.79 U	0.040	0.80 U	0.040	0.79 U	0.040	0.83 U	0.042	0.80 U	0.040
2-Nitroaniline	1.6 U	0.053	1.6 U	0.053	1.6 U	0.053	1.7 U	0.055	1.6 U	0.053
2-Nitrophenol	0.16 U	0.036	0.16 U	0.036	0.16 U	0.035	0.17 U	0.037	0.16 U	0.036
3,3'-Dichlorobenzidine	0.16 UJ	-	0.16 UJ	-	0.16 UJ	-	0.17 UJ	-	0.16 UJ	-
3B-Coprostanol	-	-	-	-	-	-	-	-	-	-
3-Nitroaniline	0.32 UJ	0.046	0.32 UJ	0.046	0.31 UJ	0.045	0.33 UJ	0.047	0.32 UJ	0.046
4,6-Dinitro-2-Methylphenol	1.6 U	0.53	1.6 U	0.53	1.6 U	0.53	1.7 U	0.55	1.6 U	0.53
4-Bromophenyl phenyl ether	0.16 U	0.071	0.16 U	0.072	0.16 U	0.071	0.17 U	0.074	0.16 U	0.072
4-Chloro-3-Methylphenol	0.79 U	0.063	0.80 U	0.063	0.79 U	0.062	0.83 U	0.065	0.80 U	0.063
4-Chloroaniline	3.2 U	0.13	3.2 U	0.13	3.1 UJ	0.13	3.3 UJ	0.13	3.2 U	0.13
4-Chlorophenyl-Phenylether	0.079 U	0.071	0.080 U	0.071	0.079 U	0.070	0.083 U	0.074	0.080 U	0.071
4-Methylphenol	0.79 U	0.039	0.80 U	0.040	0.050 J	0.039	0.093 J	0.041	0.80 U	0.040
4-Nitroaniline	0.32 U	-	0.32 U	-	0.31 U	-	0.33 U	-	0.32 U	-
4-Nitrophenol	-	-	-	-	-	-	-	-	-	-
4-nonylphenol	0.32 U	0.032	0.32 U	0.032	0.31 U	0.031	0.33 U	0.033	0.32 U	0.032
Benzoic Acid	-	-	-	-	-	-	-	-	-	-
Benzyl Alcohol	-	-	-	-	-	-	-	-	-	-
Bis(2-chloro-1-methylethyl) ether	-	-	-	-	-	-	-	-	-	-
Bis(2-Chloroethoxy)Methane	0.079 U	0.066	0.080 U	0.066	0.079 U	0.065	0.083 U	0.069	0.080 U	0.066
Bis(2-Chloroethyl)Ether	0.16 U	0.046	0.16 U	0.046	0.16 U	0.045	0.17 U	0.047	0.16 U	0.046
Bis(2-Ethylhexyl) Phthalate	0.16 U	0.048	0.16 U	0.048	0.16 U	0.047	0.17 U	0.050	0.16 U	0.048
Bisphenol A	0.32 U	0.032	0.32 U	0.032	0.072 J	0.031	0.33 U	0.033	0.32 U	0.032
Butyl benzyl phthalate	0.32 U	0.037	0.32 U	0.037	0.31 U	0.037	0.33 U	0.039	0.32 U	0.037
Caffeine	0.16 U	0.062	0.16 U	0.062	0.16 U	0.061	0.17 U	0.064	0.16 U	0.062
Cholesterol	0.13 NJ	0.075	0.63 J	0.076	0.49 J	0.075	0.73 J	0.078	1.4	0.076
Diethyl phthalate	0.16 U	0.078	0.16 U	0.079	0.16 U	0.078	0.17 U	0.081	0.16 U	0.079
Dimethyl phthalate	0.16 U	0.069	0.16 U	0.069	0.16 U	0.068	0.17 U	0.071	0.16 U	0.069
Di-N-Butylphthalate	0.13 UJ	0.058	0.12 UJ	0.058	0.079 U	0.058	0.083 U	0.060	0.14 UJ	0.058
Di-N-Octyl Phthalate	0.16 U	0.071	0.16 U	0.071	0.16 U	0.070	0.17 U	0.074	0.16 U	0.071
Ethanol, 2-Chloro-, Phosphate (3:1)	-	-	-	-	-	-	-	-	-	-
Hexachlorobenzene	0.079 U	0.039	0.080 U	0.039	0.079 U	0.039	0.083 U	0.041	0.080 U	0.039
Hexachlorobutadiene	0.079 U	0.012	0.080 U	0.012	0.079 UJ	0.012	0.083 UJ	0.013	0.080 U	0.012
Hexachlorocyclopentadiene	0.32 UJ	0.010	0.32 UJ	0.010	0.31 UJ	0.0099	0.33 UJ	0.010	0.32 UJ	0.010
Hexachloroethane	0.079 UJ	-	0.080 UJ	-	0.079 UJ	-	0.083 UJ	-	0.080 UJ	-
Isophorone	0.16 U	0.073	0.16 U	0.074	0.16 U	0.073	0.17 U	0.076	0.16 U	0.074
Nitrobenzene	0.079 U	0.066	0.080 U	0.066	-	-	0.083 U	0.068	0.080 U	0.066
N-Nitrosodi-n-propylamine	0.095 U	0.070	0.096 U	0.071	0.094 U	0.070	0.099 U	0.073	0.096 U	0.071
N-Nitrosodiphenylamine	0.16 UJ	0.033	0.16 UJ	0.034	0.16 UJ	0.033	0.17 UJ	0.035	0.16 UJ	0.034
Pentachlorophenol	0.079 U	-	0.080 U	-	0.079 U	-	0.083 U	-	0.083 NJ	-
Phenol	0.32 U	0.025	0.32 U	0.025	0.31 U	0.025	0.33 U	0.026	0.32 U	0.025
Triclosan	0.079 U	0.032	0.080 U	0.032	0.079 U	0.031	0.083 U	0.033	0.080 U	0.032
Triethyl citrate	0.060 J	0.032	0.058 J	0.032	0.31 U	0.031	0.33 U	0.033	0.32 U	0.032

Table G-12. Summary of December 2009 BNA Results for River Water Samples.

Non-detect values are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter (µg/L)	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	0.078 UJ	0.019	0.084 U	0.021	0.079 UJ	0.019	0.084 U	0.021	0.076 UJ	0.019
1,2-Dichlorobenzene	0.078 UJ	0.018	0.084 U	0.020	0.079 U	0.019	0.084 U	0.020	0.076 UJ	0.018
1,2-Diphenylhydrazine	0.078 U	0.049	0.084 U	0.053	0.079 U	0.050	0.084 U	0.053	0.076 U	0.049
1,3-Dichlorobenzene	0.078 UJ	0.016	0.084 U	0.017	0.079 UJ	0.016	0.084 U	0.017	0.076 UJ	0.016
1,4-Dichlorobenzene	0.078 UJ	0.017	0.084 U	0.018	0.079 UJ	0.017	0.084 U	0.018	0.076 UJ	0.017
2,4,5-Trichlorophenol	0.31 U	0.061	0.34 U	0.066	0.31 U	0.062	0.34 U	0.066	-	-
2,4,6-Trichlorophenol	0.31 UJ	0.047	0.34 UJ	0.051	0.31 UJ	0.048	0.34 UJ	0.051	-	-
2,4-Dichlorophenol	0.78 U	0.041	0.84 U	0.044	0.79 U	0.041	0.84 U	0.044	0.76 U	0.040
2,4-Dimethylphenol	-	-	0.84 U	0.049	0.79 U	0.046	0.84 U	0.049	0.76 U	0.045
2,4-Dinitrophenol	0.78 U	-	0.84 U	-	0.79 U	-	0.84 U	-	0.76 U	-
2,4-Dinitrotoluene	0.31 U	0.044	0.34 U	0.047	0.31 UJ	0.044	0.34 U	0.047	0.31 UJ	0.043
2,6-Dinitrotoluene	0.31 U	0.053	0.34 U	0.057	0.31 U	0.054	0.34 U	0.057	0.31 U	0.052
2-Chlorophenol	0.31 U	0.040	0.34 U	0.044	0.31 U	0.041	0.34 U	0.044	0.31 U	0.040
2-Methylphenol	0.78 U	0.039	0.84 U	0.042	0.79 U	0.040	0.84 U	0.042	0.76 U	0.039
2-Nitroaniline	1.6 UJ	0.052	1.7 UJ	0.056	1.6 UJ	0.053	1.7 UJ	0.056	1.5 UJ	0.051
2-Nitrophenol	0.16 U	0.035	0.17 U	0.038	0.16 UJ	0.035	0.17 UJ	0.038	0.15 UJ	0.034
3,3'-Dichlorobenzidine	0.16 UJ	-	0.17 UJ	-	0.16 UJ	-	0.17 UJ	-	0.15 UJ	-
3B-Coprostanol	0.78 UJ	-	0.84 UJ	-	0.79 UJ	-	0.84 UJ	-	0.76 UJ	-
3-Nitroaniline	0.31 REJ	0.045	0.34 REJ	0.048	0.31 REJ	0.045	0.34 REJ	0.048	0.31 REJ	0.044
4,6-Dinitro-2-Methylphenol	1.6 U	0.52	1.7 U	0.56	1.6 U	0.53	1.7 U	0.56	1.5 U	0.51
4-Bromophenyl phenyl ether	0.16 U	0.070	0.17 U	0.075	0.16 U	0.071	0.17 U	0.075	0.15 U	0.069
4-Chloro-3-Methylphenol	0.78 UJ	0.061	0.84 UJ	0.066	0.79 UJ	0.062	0.84 UJ	0.066	0.76 UJ	0.060
4-Chloroaniline	3.1 REJ	0.12	3.4 REJ	0.13	3.1 REJ	0.13	3.4 REJ	0.13	3.1 REJ	0.12
4-Chlorophenyl-Phenylether	0.078 U	0.069	0.084 U	0.075	0.079 U	0.070	0.084 U	0.075	0.076 U	0.068
4-Methylphenol	0.78 U	0.038	0.84 U	0.042	0.13 J	0.039	0.84 U	0.042	0.76 U	0.038
4-Nitroaniline	0.31 UJ	-	0.34 UJ	-	0.31 UJ	-	0.34 UJ	-	0.31 UJ	-
4-Nitrophenol	0.78 U	-	0.84 U	-	0.79 U	-	0.84 U	-	0.76 U	-
4-nonylphenol	0.31 U	0.031	0.052 J	0.034	0.31 U	0.031	0.34 U	0.034	0.31 U	0.031
Benzoic Acid	0.78 REJ	-	0.84 UJ	-	0.79 U	-	0.84 UJ	-	0.76 UJ	-
Benzyl Alcohol	0.78 UJ	0.027	0.84 UJ	0.030	0.79 UJ	0.028	0.84 UJ	0.030	0.76 UJ	0.027
Bis(2-chloro-1-methylethyl) ether	0.078 U	0.052	0.084 U	0.056	0.079 U	0.053	0.084 U	0.056	0.076 U	0.051
Bis(2-Chloroethoxy)Methane	0.078 U	0.064	0.084 U	0.070	0.079 U	0.065	0.084 U	0.070	0.076 U	0.063
Bis(2-Chloroethyl)Ether	0.16 U	0.044	0.17 U	0.048	0.16 U	0.045	0.17 U	0.048	0.15 U	0.044
Bis(2-Ethylhexyl) Phthalate	0.16 U	0.047	0.17 U	0.050	0.16 U	0.047	0.17 U	0.050	0.074 J	0.046
Bisphenol A	0.31 U	0.031	0.34 UJ	0.034	0.31 UJ	0.031	0.34 U	0.034	0.31 UJ	0.031
Butyl benzyl phthalate	0.31 U	0.036	0.34 UJ	0.039	0.31 UJ	0.037	0.34 UJ	0.039	0.31 U	0.036
Caffeine	0.16 U	0.060	0.17 U	0.065	0.16 U	0.061	0.17 U	0.065	0.15 U	0.059
Cholesterol	0.78 UJ	0.074	0.56 J	0.079	0.51 J	0.075	0.84 UJ	0.079	0.57 J	0.072
Diethyl phthalate	0.16 U	0.076	0.17 U	0.083	0.16 U	0.078	0.17 U	0.083	0.15 U	0.075
Dimethyl phthalate	0.16 U	0.067	0.17 U	0.072	0.16 U	0.068	0.17 U	0.072	0.15 U	0.066
Di-N-Butylphthalate	0.41 UJ	0.057	0.27 UJ	0.061	0.12 UJ	0.058	0.084 U	0.061	0.18 UJ	0.056
Di-N-Octyl Phthalate	0.16 U	0.069	0.17 U	0.075	0.16 U	0.070	0.17 U	0.075	0.15 U	0.068
Ethanol, 2-Chloro-, Phosphate (3:1)	0.078 U	0.031	0.084 U	0.034	0.079 U	0.031	0.084 U	0.034	0.076 U	0.031
Hexachlorobenzene	0.078 U	0.038	0.084 U	0.041	0.079 U	0.039	0.084 U	0.041	0.076 U	0.038
Hexachlorobutadiene	0.078 UJ	0.012	0.084 UJ	0.013	0.079 UJ	0.012	0.084 UJ	0.013	0.076 UJ	0.012
Hexachlorocyclopentadiene	0.31 UJ	0.0097	0.34 UJ	0.011	0.31 UJ	0.0099	0.34 UJ	0.011	0.31 UJ	0.0096
Hexachloroethane	0.078 UJ	-	0.084 UJ	-	0.079 UJ	-	0.084 UJ	-	0.076 UJ	-
Isophorone	0.16 U	0.072	0.17 U	0.077	0.16 U	0.073	0.17 U	0.077	0.15 U	0.071
Nitrobenzene	0.078 U	0.064	0.084 U	0.069	0.079 U	0.065	0.084 U	0.069	0.076 U	0.063
N-Nitrosodi-n-propylamine	0.093 U	0.069	0.10 U	0.074	0.094 U	0.070	0.10 U	0.074	0.092 U	0.068
N-Nitrosodiphenylamine	0.16 UJ	0.032	0.17 UJ	0.035	0.16 UJ	0.033	0.17 UJ	0.035	0.15 REJ	0.032
Pentachlorophenol	0.078 UJ	-	0.084 U	-	0.079 U	-	0.084 UJ	-	0.076 U	-
Phenol	0.31 U	0.025	0.34 U	0.027	0.31 U	0.025	0.34 U	0.027	0.31 U	0.024
Triclosan	0.078 UJ	0.031	0.084 U	0.034	0.079 U	0.031	0.084 U	0.034	0.076 U	0.031
Triethyl citrate	0.31 U	0.031	0.34 U	0.034	0.31 U	0.031	0.34 U	0.034	0.31 U	0.031

Table G-13. Detected PCB Congeners for River Water Samples.

PCB Congener (pg/L)	Nooksack			Skagit			Stillaguamish			Snohomish			Puyallup		
	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec
PCB-001		0.861 NJ						0.86 NJ							0.976 J
PCB-002		1.46 NJ		1.71 J		0.595 NJ		1.26 NJ							1.73 NJ
PCB-003	11.4 NJ	2.14 J		10.5 NJ		0.677 NJ		1.75 J						1.8 J	1.75 J
PCB-006		0.391 J													
PCB-008	3.18 J	0.878 J		1.94 J		0.842 J	2.98 J	1.55 J		2.45 J				2.04 J	
PCB-015		0.513 J			0.709 J	0.532 J		0.948 J		3.69 J					
PCB-017					0.463 J	0.561 NJ									
PCB-018/030		0.742 J	0.688 NJ	2.17 J	0.902 J	1.16 J	3.17 J	1.28 J	1.11 J	2.84 J	1.02 NJ	0.801 J		1.69 J	1.49 J
PCB-020/028		0.666 NJ	0.756 NJ	1.51 J	1.04 J	0.988 J	2.19 J	1.59 J	0.625 J	2.54 J	1.29 J	0.5 NJ	10.3 NJ	1.77 J	1.04 NJ
PCB-021/033		0.286 J				0.496 J	1.63 J	0.651 NJ							0.897 J
PCB-022						0.297 J									
PCB-031	2.11 J	0.629 NJ			0.964 J	0.971 J	2.69 J	1.37 NJ		2.38 J	1.12 J		10.3 NJ	1.74 J	1.17 J
PCB-037		0.32 J													
PCB-039		0.255 NJ													
PCB-044/047/065		0.78 J	0.64 NJ		0.763 J	1.08 J		2.67 J	1.628 J	1.64 J		0.902 J			1.57 J
PCB-049/069		0.317 NJ	0.539 J			0.519 J		1.36 J				0.448 J		1.27 NJ	0.751 J
PCB-052		1.15 J			1.08 J		10.5 NJ	4.31 J			1.35 J		1.45 J	2.76 J	
PCB-056						0.217 J									
PCB-061/070/074/076		0.952 J	0.692 NJ		0.702 J	1.01 J		5.63 J				0.656 NJ		3.13 J	1.72 J
PCB-064						0.298 J		1.04 J							0.585 J
PCB-066						0.397 NJ		1.45 J							0.841 J
PCB-084								2.19 J							
PCB-085/116								0.806 NJ							
PCB-086/087/097/108/119/125		1.28 J			0.733 J	0.592 J		4.45 NJ							
PCB-090/101/113		1.39 J	1.39 NJ		0.847 J	0.974 J	1.87 J	7.03 J	0.821 J	11 NJ		1 NJ	10.3 NJ	3.04 J	1.76 J
PCB-095		1.11 J	0.685 NJ		0.688 NJ	0.848 NJ	1.18 J	5.87				1.19 J		3.37 J	1.4 J
PCB-099		0.39 J	0.382 NJ			0.355 J		2.32 J						1.63 J	0.497 J
PCB-105		0.566 J			0.469 NJ	0.294 J		2.45 NJ						1.86 J	
PCB-110	1.12 J	1 J	0.806 J		0.721 J	0.811 J	10.5 NJ	6.69		1.19 J		0.796 J	1.16 J	2.66 J	1.58 J
PCB-118		1.03 J	0.691 NJ		0.44 J	0.674 J	1.21 J	4.62 J				0.572 NJ		2.55 J	1.25 J
PCB-129/138/163		0.868 J	1.95 J		0.597 J	1.3 J	1.07 J	3.21 J	0.807 J	1.09 J	1.17 J	1.33 J		3.19 J	1.85 J
PCB-132						0.332 NJ		1.12 NJ							
PCB-135/151						0.55 J									
PCB-146						0.24 J									
PCB-147/149		0.69 J	0.979 J			0.656 NJ		2.03 NJ				0.829 J		2.43 J	1.41 J
PCB-153/168	11.4 NJ	0.704 J	1.52 J		0.405 NJ	0.974 J		2.33 J				0.997 J		3.01 J	1.17 NJ
PCB-169										0.961 J					
PCB-180/193						0.717 J						0.647 NJ			
PCB-187						0.523 NJ								1.51 J	
PCB-194						0.272 NJ	1.28 J	1.14 J							
PCB-198/199						0.292 NJ									
PCB-209						1.09 J									

Table G-14. Total PCBs for River Water Samples.

Total concentrations were calculated by summing the congener detects, as described in Appendix D.

Total PCBs (pg/L)	Nooksack			Skagit			Stillaguamish			Snohomish			Puyallup		
	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec
…including N,NJ	29.21 J	21.37 J	11.72 J	17.83 J	11.52 J	22.13 J	40.27 J	73.98 J	4.99 J	29.78 J	5.95 J	10.67 J	35.31 J	41.45 J	25.44 J
…excluding N,NJ	6.41 J	17.18 J	5.79 J	7.33 J	9.96 J	16.98 J	19.27 J	58.98 J	4/99 J	18.78 J	4.93 J	7.29 J	2.61 J	40.18 J	21.5 J

Table G-15. PCB Homolog Totals for River Water Samples.

Results qualified as N or NJ were not included when summing homologs to calculate total PCBs.

PCB Homolog (pg/L)	Nooksack			Skagit			Stillaguamish			Snohomish			Puyallup		
	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec
Mono-CBs	0	2.14 J	0	1.71 J	0	0	0	1.75 J	0	0	0	0	0	1.8 J	2.726 J
Di-CBs	3.18 J	1.782 J	0	1.94 J	0.709 J	1.374 J	2.98 J	2.498 J	0	6.14 J	0	0	0	2.04 J	0
Tri-CBs	2.11 J	1.348 J	0	3.68 J	3.369 J	3.912 J	9.68 J	2.87 J	1.735 J	7.76 J	2.41 J	0.801 J	0	5.2 J	3.557 J
Tetra-CBs	0	2.882 J	0.539 J	0	2.545 J	3.124 J	0	16.46 J	1.628 J	1.64 J	1.35 J	1.35 J	1.45 J	5.89 J	5.467 J
Penta-CBs	1.12 J	6.766 J	0.806 J	0	2.741 J	3.7 J	4.26 J	28.72 J	0.821 J	1.19 J	0	1.986 J	1.16 J	15.11 J	6.487 J
Hexa-CBs	0	2.262 J	4.449 J	0	0.597 J	3.064 J	1.07 J	5.54 J	0.807 J	2.051 J	1.17 J	3.156 J	0	8.63 J	3.26 J
Hepta-CBs	0	0	0	0	0	0.717 J	0	0	0	0	0	0	0	1.51 J	0
Octa-CBs	0	0	0	0	0	0	1.28 J	1.14 J	0	0	0	0	0	0	0
Nona-CBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCB-209	0	0	0	0	0	1.09 J	0	0	0	0	0	0	0	0	0
Total PCBs	6.41 J	17.18 J	5.794 J	7.33 J	9.961 J	16.98 J	19.27 J	58.98 J	4.991 J	18.78 J	4.93 J	7.293 J	2.61 J	40.18 J	21.50 J

Table G-16. Detected PBDE Congeners for River Water Samples.

Samples for which all congener results were nondetects (U- or UJ-qualified) were assigned a total PBDE value equal to the highest congener reporting limit (RL).

PBDE Congener (pg/L)	Nooksack			Skagit			Stillaguamish			Snohomish			Puyallup		
	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec	July	Oct	Dec
BDE-017		5.19 J													
BDE-028		7.32 J		13.3 J			10.7 J			5.7 NJ				5.18 J	
BDE-030							5.2 NJ								
BDE-049		17 J													
BDE-100	34.2 J						11.6 J			13.7 J			10.9 J		
BDE-209														260	
Total PBDEs															
…including N, NJ	34.2 J	29.51 J	250 U	13.3 J	250 U	250 U	27.5 J	250 U	250 UJ	19.4 J	250 U	250 U	10.9 J	265.18	250 U
…excluding N,NJ	34.2 J	29.51 J	250 U	13.3 J	250 U	250 U	22.3 J	250 U	250 UJ	13.7 J	250 U	250 U	10.9 J	265.18	250 U

Appendix H. Analytical Results - River SPM

Table H-1. Results for Conventionals, Metals, and Petroleum-Related Products in River Particulate Samples.

All samples were collected in December 2009. Non-detect petroleum results are given at the reporting limit (RL).

Parameter	Nooksack	Skagit	Stillaguamish	Snohomish	Puyallup
Conventional Parameters (%)					
Percent Solids	69.0	60.6	43.9	56.7	73.3
TOC	0.96	1.46	1.88	1.49	0.36
Metals (mg/Kg dry)					
Arsenic	6.62	6.46	11.1	13.3	1.45
Cadmium	0.17	0.13	0.24	0.20	0.04 J
Copper	33.0	27.1	53.5	51.6	17.2
Lead	5.35	4.46	9.55	8.36	1.57
Zinc	77.4	53.8	106	86.0	20.3
Petroleum-Related Products (mg/Kg dry)					
TPH-D #2 Diesel	14 U	16 U	23 U	17 U	13 U
TPH-D Lube Oil	36 U	41 U	57 U	44 U	33 U

Table H-2. December 2009 Chlorinated Pesticides Results for River Particulate Samples.

Non-detect results are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
(µg/Kg dry)	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
2,4'-DDD	0.13 U	0.027	0.13 U	0.027	0.32 U	0.069	0.13 U	0.027	0.12 U	0.027
2,4'-DDE	0.13 U	0.068	0.13 U	0.068	0.32 U	0.17	0.13 U	0.069	0.12 U	0.067
2,4'-DDT	0.13 U	0.051	0.13 U	0.051	0.32 U	0.13	0.13 U	0.051	0.12 U	0.050
4,4'-DDD	0.13 U	0.032	0.13 U	0.032	0.32 U	0.082	0.13 U	0.032	0.12 U	0.032
4,4'-DDE	0.38	0.069	0.13 U	0.069	0.32 U	0.18	0.13 U	0.070	0.12 U	0.068
4,4'-DDT	0.39	0.053	0.13 U	0.054	0.32 U	0.14	0.13 U	0.054	0.12 U	0.053
Aldrin	0.13 U	0.057	0.13 U	0.057	0.32 U	0.15	0.13 U	0.058	0.12 U	0.056
Alpha-BHC	0.13 U	0.033	0.13 U	0.033	0.32 U	0.084	0.13 U	0.033	0.12 U	0.032
Beta-BHC	0.13 U	0.027	0.13 U	0.027	0.32 U	0.068	0.13 U	0.027	0.12 U	0.026
Chlordane, technical	1.3 U	-	1.3 U	-	3.2 U	-	1.3 U	-	1.2 U	-
Chlorpyriphos	0.13 U	0.029	0.13 U	0.029	0.32 U	0.073	0.13 U	0.029	0.12 U	0.028
cis-Chlordane	0.13 U	0.041	0.13 U	0.041	0.32 U	0.10	0.13 U	0.041	0.12 U	0.040
Cis-Nonachlor	0.13 U	0.046	0.13 U	0.046	0.32 U	0.12	0.13 U	0.047	0.12 U	0.045
Dacthal	0.13 U	0.021	0.13 U	0.021	0.32 U	0.053	0.13 U	0.021	0.12 U	0.020
DDMU	0.13 U	0.032	0.13 U	0.032	0.32 U	0.082	0.13 U	0.033	0.12 U	0.032
Delta-BHC	0.13 U	0.029	0.13 U	0.029	0.32 U	0.075	0.13 U	0.030	0.12 U	0.029
Dieldrin	0.13 U	0.0052	0.13 U	0.0052	0.32 U	0.013	0.13 U	0.0052	0.12 U	0.0051
Endosulfan I	0.13 U	0.056	0.13 U	0.056	0.32 U	0.14	0.13 U	0.057	0.12 U	0.055
Endosulfan II	0.13 U	0.010	0.13 U	0.010	0.32 U	0.026	0.13 U	0.010	0.12 U	0.0099
Endosulfan Sulfate	0.72 UJ	0.045	0.26 UJ	0.045	0.32 U	0.11	0.30 UJ	0.045	0.32 UJ	0.044
Endrin	0.13 U	0.0056	0.13 U	0.0056	0.32 U	0.014	0.13 U	0.0057	0.12 U	0.0055
Endrin Aldehyde	0.13 UJ	0.083	0.13 UJ	0.083	0.32 UJ	0.21	0.13 UJ	0.084	0.12 UJ	0.082
Endrin Ketone	0.13 U	0.029	0.13 U	0.029	0.32 U	0.074	0.13 U	0.029	0.12 U	0.029
Gamma-BHC	0.52 UJ	0.028	0.58 UJ	0.029	2.0 UJ	0.073	0.47 UJ	0.029	0.72 UJ	0.028
Heptachlor	0.13 U	0.034	0.13 U	0.034	0.32 U	0.086	0.13 U	0.034	0.12 U	0.033
Heptachlor Epoxide	0.13 U	0.060	0.13 U	0.061	0.32 U	0.15	0.13 U	0.061	0.12 U	0.060
Hexachlorobenzene	0.41	0.065	0.13 U	0.065	0.32 U	0.17	0.13 U	0.066	0.12 U	0.064
Methoxychlor	0.13 U	0.066	0.13 U	0.066	0.32 U	0.17	0.13 U	0.066	0.12 U	0.065
Mirex	0.13 U	0.067	0.13 U	0.067	0.32 U	0.17	0.13 U	0.068	0.12 U	0.066
Oxychlordane	0.13 U	0.037	0.13 U	0.037	0.32 U	0.095	0.13 U	0.037	0.12 U	0.037
Pentachloroanisole	0.17	0.120	0.13 U	0.12	0.32 U	0.31	0.13 U	0.12	0.12 U	0.12
Toxaphene	1.3 U	0.043	1.3 U	0.043	3.2 U	0.11	1.3 U	0.043	1.2 U	0.042
trans-Chlordane	0.13 U	0.037	0.13 U	0.037	0.32 U	0.095	0.13 U	0.037	0.12 U	0.037
Trans-Nonachlor	0.13 U	0.060	0.13 U	0.060	0.32 U	0.15	0.13 U	0.061	0.12 U	0.059

Table H-3. December 2009 PAH Results for River Particulate Samples.

Non-detect results are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
(µg/Kg dry)	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1-Methylnaphthalene	13	0.81	3.6	0.93	18	3.2	6.4	0.99	5.3	0.77
2-Chloronaphthalene	3.6 U	2.4	4.1 U	2.7	14 U	9.3	4.4 U	2.9	3.4 U	2.3
2-Methylnaphthalene	21		6.1		30		11		7.8	
Acenaphthene	1.4 U	2.1	1.6 U	2.4	5.6 U	8.0	1.7 U	2.5	1.4 U	2.0
Acenaphthylene	1.4 U	0.74	1.6 U	0.85	5.6 U	2.9	1.7 U	0.90	1.4 U	0.70
Anthracene	1.5	1.4	1.6 U	1.6	6.6	5.3	2.6	1.7	1.5	1.3
Benzo(a)anthracene	3.6	0.80	1.6 U	0.92	6.9	3.1	4.6	0.97	1.6	0.76
Benzo(a)pyrene	2.8 J	1.6	3.3 U	1.8	6.9 J	6.1	3.7	1.9	2.7 U	1.5
Benzo(b)fluoranthene	8.0	1.9	1.6 U	2.2	14	7.3	11	2.3	2.0	1.8
Benzo(ghi)perylene	5.2 J	1.2	1.8 J	1.3	12 J	4.5	7.7 J	1.4	2.0 J	1.1
Benzo(k)fluoranthene	2.1	2.0	1.6 U	2.2	5.6 U	7.6	1.7	2.4	1.4 U	1.8
Carbazole	3.6 U	4.1	4.1 U	4.6	14 U	16	4.4 U	4.9	3.4 U	3.8
Chrysene	12	1.3	2.3	1.5	15	4.9	9.6	1.5	2.8	1.2
Dibenzo(a,h)anthracene	0.94 J	0.78	1.6 U	0.89	5.6 U	3.0	1.1 J	0.94	1.4 U	0.73
Dibenzofuran	4.3		1.4 J		8.8		3.2		1.6	
Fluoranthene	18	0.94	2.1	1.1	13	3.6	8.9	1.1	3.2	0.88
Fluorene	3.9 J	0.89	1.1 J	1.0	7.6	3.5	4.3	1.1	1.4 U	0.84
Indeno(1,2,3-cd)pyrene	3.1 J	0.73	0.92 J	0.84	7.5 J	2.8	5.0 J	0.89	1.3 J	0.69
Naphthalene	11	1.7	3.4	2.0	19	6.7	8.8	2.1	2.7	1.6
Phenanthrene	28	0.77	6.7	0.88	36	3.0	22	0.94	6.7	0.73
Pyrene	18	2.1	3.5	2.4	18	8.2	11	2.6	4.4	2.0
Retene	100	2.3	280 J	5.2	310	8.8	400 J	11	60	2.1
Total PAHs	260		310 J		530		520 J		100	
Total cPAHs*	33 J		3.2 J		50 J		37 J		7.7 J	

*The carcinogenic PAH compounds (cPAHs) are: benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Table H-4. December 2009 BNA Results for River Particulate Samples.

Non-detect results are given at the reporting limit (RL). The method detection limit (MDL) is presented for comparison.

Parameter	Nooksack		Skagit		Stillaguamish		Snohomish		Puyallup	
(µg/Kg dry)	Result	MDL	Result	MDL	Result	MDL	Result	MDL	Result	MDL
1,2,4-Trichlorobenzene	47 U	39	53 U	44	74 U	61	57 U	47	43 U	35
1,2-Dichlorobenzene	94 U	41	110 U	46	150 U	64	110 U	49	85 U	37
1,2-Diphenylhydrazine	23 U	17	27 U	20	37 U	27	28 U	21	21 U	16
1,3-Dichlorobenzene	94 U	39	110 U	45	150 U	62	110 U	48	85 U	36
1,4-Dichlorobenzene	94 U	39	110 U	44	150 U	61	110 U	47	85 U	35
2,4,5-Trichlorophenol	94 U	15	110 U	17	150 U	23	110 U	18	85 U	13
2,4,6-Trichlorophenol	94 U	11	110 U	13	150 U	17	110 U	13	85 U	10
2,4-Dichlorophenol	230 U	16	270 U	18	370 U	25	280 U	19	210 U	15
2,4-Dimethylphenol	230 U	16	270 U	18	370 U	25	280 U	19	210 U	15
2,4-Dinitrophenol	230 REJ		270 REJ		370 REJ		280 REJ		210 REJ	
2,4-Dinitrotoluene	94 UJ	8.9	110 UJ	10	150 UJ	14	110 UJ	11	85 UJ	8.0
2,6-Dinitrotoluene	94 U	8.5	110 U	9.7	150 U	13	110 U	10	85 U	7.7
2-Chlorophenol	94 U	19	110 U	21	150 U	29	110 U	23	85 U	17
2-Methylphenol	230 U	17	270 U	19	370 U	26	280 U	20	210 U	15
2-Nitroaniline	470 UJ	22	530 UJ	25	740 UJ	34	570 UJ	26	430 UJ	20
2-Nitrophenol	47 UJ	15	53 UJ	17	74 UJ	23	57 UJ	18	43 UJ	14
3,3'-Dichlorobenzidine	94 UJ	5.2	110 UJ	5.9	150 UJ	8.1	110 UJ	6.2	85 UJ	4.7
3B-Coprostanol	260 J	12	220 J	13	670 J	18	240 J	14	310 J	11
3-Nitroaniline	94 REJ	23	110 REJ	26	150 REJ	36	110 REJ	28	85 REJ	21
4,6-Dinitro-2-Methylphenol	94 REJ		110 REJ		150 REJ		110 REJ		85 REJ	
4-Bromophenyl phenyl ether	47 U	9.8	53 U	11	74 U	15	57 U	12	43 U	8.9
4-Chloro-3-Methylphenol	230 U	14	270 U	16	370 U	22	280 U	17	210 U	13
4-Chloroaniline	940 REJ	23	1100 REJ	27	1500 REJ	37	1100 REJ	28	850 REJ	21
4-Chlorophenyl-Phenylether	23 U	12	27 U	14	37 U	19	28 U	15	21 U	11
4-Methylphenol	230 U	30	78 J	34	52 J	47	43 J	36	210 U	27
4-Nitroaniline	94 UJ	9.1	110 UJ	10	150 UJ	14	110 UJ	11	85 UJ	8.2
4-Nitrophenol	230 UJ	9.0	270 UJ	10	370 UJ	14	280 UJ	11	210 UJ	8.2
4-nonylphenol	15 J	2.3	27 U	2.7	37 U	3.7	28 U	2.8	21 U	2.1
Benzoic Acid	230 UJ	9.1	270 UJ	10	370 UJ	14	310 J	11	210 UJ	8.3
Benzyl Alcohol	230 UJ	39	270 UJ	44	370 UJ	61	280 UJ	47	210 UJ	35
Bis(2-chloro-1-methylethyl) ether	23 U	21	27 U	24	37 U	33	28 U	25	21 U	19
Bis(2-Chloroethoxy)Methane	23 U	16	27 U	18	37 U	24	28 U	19	21 U	14
Bis(2-Chloroethyl)Ether	47 U	16	53 U	18	74 U	25	57 U	19	43 U	14
Bis(2-Ethylhexyl) Phthalate	540	5.9	510	6.7	230 J	9.2	170 J	7.1	1000	5.3
Bisphenol A	20 J	2.3	27 U	2.7	37 U	3.7	28 U	2.8	21 U	2.1
Butyl benzyl phthalate	47 UJ	4.4	53 UJ	5.0	74 UJ	7.0	57 UJ	5.4	43 UJ	4.0
Caffeine	47 UJ	24	53 UJ	27	74 UJ	38	57 UJ	29	43 UJ	22
Cholesterol	410 J	2.3	1100 J	2.7	8600 J	3.7	1300 J	2.8	1400 J	2.1
Diethyl phthalate	23 U	8.6	27 U	9.8	37 U	13	28 U	10	21 U	7.8
Dimethyl phthalate	23 U	11	27 U	12	37 U	17	28 U	13	21 U	9.7
Di-N-Butylphthalate	58 UJ	6.0	54 UJ	6.8	70 UJ	9.4	40 UJ	7.2	33 UJ	5.4
Di-N-Octyl Phthalate	47 U	3.8	53 U	4.3	74 U	6.0	57 U	4.6	43 U	3.5
Ethanol, 2-Chloro-, Phosphate (3:1)	23 U	2.3	27 U	2.7	37 U	3.7	28 U	2.8	21 U	2.1
Hexachlorobenzene	23 U	8.3	27 U	9.4	37 U	13	28 U	10	21 U	7.5
Hexachlorobutadiene	94 U	42	110 U	47	150 U	65	110 U	50	85 U	38
Hexachlorocyclopentadiene	94 UJ		110 UJ		150 UJ		110 UJ		85 UJ	
Hexachloroethane	23 U	15	27 U	17	37 U	23	28 U	18	21 U	14
Isophorone	47 U	13	53 U	15	74 U	21	57 U	16	43 U	12
Nitrobenzene	23 U	20	27 U	23	37 U	32	28 U	24	21 U	18
N-Nitrosodi-n-propylamine	23 U	15	27 U	17	37 U	24	28 U	18	21 U	14
N-Nitrosodiphenylamine	47 UJ	9.4	53 UJ	11	74 UJ	15	57 UJ	11	43 UJ	8.5
Pentachlorophenol	230 UJ	4.8	270 UJ	5.4	370 UJ	7.5	280 UJ	5.8	210 UJ	4.3
Phenol	94 U	20	26 NJ	23	150 U	32	110 U	25	26 J	18
Triclosan	23 UJ	2.3	27 UJ	2.7	37 UJ	3.7	28 UJ	2.8	21 UJ	2.1
Triethyl citrate	23 REJ	2.3	27 REJ	2.7	37 REJ	3.7	28 REJ	2.8	21 REJ	2.1

Table H-5. Detected PCB Congeners for River Particulate Samples Collected in December 2009.

PCB Congener (ng/Kg dry)	Nooksack	Skagit	Stillaguamish	Snohomish	Puyallup
PCB-003		3.52 J	5.34 J		
PCB-005/008	15.8	11.7	25.7	20.8	8.59
PCB-006			8.23		
PCB-007				5.96	
PCB-011	86.8	35.5	121	86.4	26.1
PCB-015	5.69	9.91	13.3	10.2	4.63
PCB-016	3.44 J		4.86 NJ		
PCB-017	5.6	4.06	5.54 J	5.02	
PCB-018	12.1	8.76	16.9	11.5	5.51
PCB-020/033	8.02	6.86	15.2	7.85	3.63 J
PCB-022	4.83	5.54	9.99	4.06 N	
PCB-028	11.3	10.9	18.6	11.3	6.56
PCB-031	9.56	8.32	18	10	4.15
PCB-037	4.76	7.95	15.7	6.6	4.63 N
PCB-042			5.63 J		
PCB-043/049	5.33		9.36	5.21	
PCB-044	5.7		13.1	3.97 NJ	
PCB-047/048	4.97		5.35 J	3.36 J	
PCB-052/069	8.56	4.64	18.4	10.2	3.93 J
PCB-056			3.81 J	3.33 J	
PCB-060			3.95 NJ		
PCB-064/072	3.1 J		5.22 J		
PCB-066	7.21	4.42	12.5	7.01	
PCB-070	11.6	4.36 N	19.5	10.4	5.58
PCB-074	4.38		7.67	4.78	
PCB-082			4.22 NJ		
PCB-084			3.79 J		
PCB-085		3.42 J	8.49		
PCB-086/097/117	4.57		13.6	5.95	3.08 J
PCB-087/115	6.43 N	3.75 J	19.3	6.07	6.16
PCB-092	5.16		6.18 N	3.07 J	
PCB-093/095/098/102	21.1	6.91 N	36.3	20.7	7.17
PCB-099	6.99		17.6	7.99	
PCB-101	16.9 N	7.05	39.2	19	8.03
PCB-105	5.22	5.49	15.4	5.74	3.43 J
PCB-110	22	12.7	45.3	22.4	12.3
PCB-118	10.1	11.1	33.4	13.2	7.84
PCB-128			7.15 N	4.37	
PCB-132			7 N	4.55 N	
PCB-135			6.48		
PCB-136	4.22		8.88	5.25	
PCB-138	9.8	8.7	34.6	20.4	6.96
PCB-139/149	18.1	10.5	37.7	24.3	9.74 N
PCB-141			7.13	3.26 NJ	
PCB-146			3.67 NJ	3.45 J	
PCB-151	6.66		14.6	6.57	
PCB-153	13.2	8.6	29.4	20.2	6.36
PCB-156			3.69 J		
PCB-158			3.2 J		
PCB-163/164			9.18 N	7.85	
PCB-170		4.91	10.8	3.58 NJ	
PCB-174	3.15 J		15.2	7.43	4.33
PCB-177			9.02	5.04	
PCB-179			3.37 NJ		

PCB Congener (ng/Kg dry)	Nooksack	Skagit	Stillaguamish	Snohomish	Puyallup
PCB-180	6.72	7.94	29.9	12.3	6.89
PCB-182/187	4.58	4.88	16	10.4	4.13
PCB-183			4.89 J		
PCB-190			3.67 J		
PCB-199		4.7	8.52	7.25	
PCB-203			7.05	3.42 J	
PCB-206			8.31 N	5.81 N	
PCB-209		5.12	7.46	4.32	
Total PCBs					
…including N,NJ	383.65	232.21	922.5 J	491.82	162.73 J
…excluding N,NJ	360.32	220.94	864.61	466.59	145.36

Table H-6. PCB Homolog Totals for River Particulate Samples Collected in December 2009.

Results qualified as N or NJ were not included in homolog sums or Total PCB calculations.

PCB Homolog (ng/Kg dry)	Nooksack	Skagit	Stillaguamish	Snohomish	Puyallup
Mono-CBs	0	3.52 J	5.34 J	0	0
Di-CBs	108.29	57.11	168.23	123.36	39.32
Tri-CBs	59.61	52.39	99.93	52.27	19.85 J
Tetra-CBs	50.85	9.06	100.54 J	44.29 J	9.51 J
Penta-CBs	75.14	43.51 J	232.38	104.12	48.01 J
Hexa-CBs	51.98	27.8	145.68	92.39	13.32
Hepta-CBs	14.45 J	17.73	89.48	35.17	15.35
Octa-CBs	0	4.7	15.57	10.67 J	0
Nona-CBs	0	0	0	0	0
Deca-CBs (PCB-209)	0	5.12	7.46	4.32	0
Total PCBs	360.32	220.94	864.61	466.59	145.36

Table H-7. Detected PBDE Congeners for River Particulate Samples Collected in December 2009.

PBDE Congener (ng/Kg dry)	Nooksack	Skagit	Stillaguamish	Snohomish	Puyallup
BDE-017	6.02		4.69 J		
BDE-028	5.62	3.51	18.9	2.28 J	4.08
BDE-047	126	18.9 J	442	53.4	77.5
BDE-049	24.8		24	4.94 J	5.96
BDE-066	6.15		25.3	3.09 J	3.57 J
BDE-071	2.2 J		5.01 J		
BDE-085	6.05		20.4	2.86 J	4.87
BDE-099	155	19	499	60	84.4
BDE-100	40.5		114	15.8	19.9
BDE-119			6.17 J		
BDE-138	3.73 J		3.19 J		
BDE-139	2.64 J		4.01 NJ		
BDE-140			3.62 J		
BDE-153	17.9		46.2	7.3	9.33
BDE-154	18.7	3.41 J	51.5	5.02 J	4.87
BDE-156/169			2.97 J		
BDE-183	5 J		9.74 J		
BDE-196	9.18	4.24 J	31.4		8.2 J
BDE-197/204	6.56 J		29.3 J		5.58 NJ
BDE-201	8.01 J	7.08 J	38.6	6.31 J	8.9 J
BDE-203	12.9	10.6	66.9	6.63 J	13.9
BDE-206	84	14.3 J	268	52.5	69.4
BDE-207	88.2	68.7	308	55.7	115
BDE-208	96.2	50.1	397	69.9	133
BDE-209	683	322	2280	375	470
Total PBDEs					
…including N,NJ	1408.36	521.84	4699.9	720.73	1038.46
…excluding N,NJ	1408.36	521.84	4695.89	720.73	1032.88

Table H-8. PBDE Homolog Totals for River Particulate Samples Collected in December 2009.

Results qualified as N or NJ were not included in homolog sums or total PBDE calculations.

PBDE Homolog (ng/Kg dry)	Nooksack	Skagit	Stillaguamish	Snohomish	Puyallup
Mono-BDEs	-	-	-	-	-
Di-BDEs	0	0	0	0	0
Tri-BDEs	11.64	3.51	23.59 J	2.28	4.08
Tetra-BDEs	159.2	18.9 J	496.3	61.43 J	87.03
Penta-BDEs	201.6	19	639.6	78.66	109.2
Hexa-BDEs	42.97 J	3.41 J	107.5 J	12.32 J	14.2
Hepta-BDEs	5 J	0	9.74 J	0	0
Octa-BDEs	36.65 J	21.92 J	166.2 J	12.94 J	31 J
Nona-BDEs	268.4	133.1 J	973	178.1	317.4
Deca-BDEs (PBDE-209)	683	322	2280	375	470
Total PBDEs	1408.36	521.84	4695.89	720.73	1032.88

Appendix I. 2009-2010 Results Compared to Historical Data

Table I-1. Marine water column results for conventional parameters compared to historical data.

Parameter (mg/L)	Number	Median	Mean	Stdev	Low	High	Data Source*
TSS	42	1.6	1.75	1.05	0.8	6.0	Present Study
	18	4.5	4.9	1.6	2	9	Johnson (2009)
	19185	~2.5	~3.0	~2.47	0.0	64.1	Pelletier and Mohamedali (2009)
POC	28	0.059	0.133	0.326	0.028	1.780	Present Study
	~472	~0.08	~0.11	~0.03	~0.01	~0.36	Johannessen et al. (2008)
	(calc'd)	~2.84	~5.12	-	-	-	Pelletier and Mohamedali (2009)
DOC	28	0.754	0.757	0.089	0.611	0.969	Present Study
	~472	~0.64	~0.66	~0.02	~0.44	~0.91	Johannessen et al. (2008)
	24	1.06	1.23	-	0.70	2.16	Pelletier and Mohamedali (2009)
TOC	28	0.807	0.891	0.379	0.660	2.749	Present Study
	~472	~0.71	~0.77	~0.03	~0.48	~1.2	Johannessen et al. (2008)
	348	4.00	~6.35	-	0.85	79.0	Pelletier and Mohamedali (2009)

* Data sources:
Johannessen et al. (2008) data from Straits of Juan de Fuca and Georgia, 2003.
Johnson (2009) data from Strait of Juan de Fuca, Guemes Channel, and Commencement Bay, 2008-2009.
Pelletier and Mohamedali (2009) summary of EIM data for various Box Model regions; POC calculated as the difference of TOC and DOC.

Table I-2. Marine water column results for PCBs and PBDEs compared to historical data.

Parameter (pg/L)	Number	Median	Mean	Stdev	Low	High	Data Source*
Total PCBs	42	24.0	26.3	14.9	6.09	75.1	Present Study
	~14	-	~42	-	40.3	43.5	Dangerfield (2007)
Total PBDEs	10	749	2865	5678	51	18691	Present Study
	~14	-	~19	-	14.8	23.4	Dangerfield (2007)

* Data source:
Dangerfield et al. (2007) data from Boundary Pass and Rosario Strait, Strait of Georgia.

Table I-3 (presented on the following page). Marine water column metals results compared to historical data.

* Data sources:
Crecelius (1998) data from Cherry Point, Strait of Georgia and from March Point, Strait of Juan de Fuca, 1997.
Johnson (2009) data from Strait of Juan de Fuca, Guemes Channel, and Commencement Bay, 2008-2009.
Johnson (2009) summary of KCDNR data from Strait of Juan de Fuca, 1997-2000 (King County, 2001).
Johnson (2009) summary of Johnson and Summers (1999) data from Commencement Bay, 1997-1998.
Serdar (2008) summary of KCDNR data from Puget Sound region, 1996-2002; summary of EIM data from Puget Sound, 1995-2007.

Table I-3. Marine water column metals results compared to historical data.

Parameter (µg/L)	Number	Median	Mean	Stdev	Low	High	Data Source
Arsenic Total	42	1.41	1.42	0.091	1.16	1.56	Present Study
	10	0.457	0.468	0.044	0.410	0.567	Crecelius (1998) – Cherry Point
	10	1.03	1.03	0.081	0.856	1.16	Crecelius (1998) – March Point
	1927	~1.1	-	-	-	-	Serdar (2008) – KCDNR
	~130	~1	-	-	0.5	2.0	Serdar (2008) – EIM
Arsenic Dissolved	42	1.42	1.42	0.089	1.26	1.70	Present Study
	10	0.444	0.464	0.057	0.417	0.579	Crecelius (1998) – Cherry Point
	10	1.06	1.06	0.682	0.965	1.18	Crecelius (1998) – March Point
	1927	~1.1	-	-	-	-	Serdar (2008) – KCDNR
	~125	~1	-	-	0.5	2.0	Serdar (2008) – EIM
Cadmium Total	42	0.084	0.085	0.0097	0.059	0.112	Present Study
	10	0.0455	0.0451	0.0026	0.040	0.0480	Crecelius (1998) – Cherry Point
	10	0.0713	0.0703	0.0041	0.0616	0.0746	Crecelius (1998) – March Point
	~2227	~0.06	-	-	-	-	Serdar (2008) – KCDNR & EIM
Cadmium Dissolved	42	0.081	0.083	0.0105	0.067	0.111	Present Study
	10	0.0373	0.0365	0.0033	0.0306	0.0408	Crecelius (1998) – Cherry Point
	10	0.0696	0.0694	0.0047	0.0626	0.0759	Crecelius (1998) – March Point
	~2227	~0.06	-	-	-	-	Serdar (2008) – KCDNR & EIM
Copper Total	42	0.38	0.41	0.212	0.19	1.37	Present Study
	10	0.673	0.666	0.051	0.556	0.733	Crecelius (1998) – Cherry Point
	10	0.508	0.500	0.029	0.444	0.535	Crecelius (1998) – March Point
	17	0.45	0.53	0.30	0.19	1.3	Johnson (2009) /King County (2001)
	3 to 5	-	0.45	-	-	-	Johnson (2009)/King County (2001)
	1935	0.55	-	-	-	-	Serdar (2008) – KCDNR
	340	0.8	-	-	-	-	Serdar (2008) – EIM
Copper Dissolved	42	0.30	0.31	0.079	0.16	0.51	Present Study
	10	0.606	0.594	0.034	0.525	0.637	Crecelius (1998) – Cherry Point
	10	0.425	0.425	0.022	0.387	0.451	Crecelius (1998) – March Point
	12	0.38	0.48	0.21	0.31	1.0	Johnson (2009) /King County (2001)
	3 to 5	-	0.37	-	-	-	Johnson (2009) /King County (2001)
	3	-	0.61	-	-	-	Johnson and Summers (1999)
	1935	~0.39	-	-	-	-	Serdar (2008) – KCDNR
Lead Total	37	0.070	0.085	0.0541	0.015	0.230	Present Study
	10	0.0146	0.0144	0.0025	0.0101	0.0189	Crecelius (1998) – Cherry Point
	10	0.0380	0.0389	0.0057	0.0309	0.0507	Crecelius (1998) – March Point
	18	0.039	0.034	0.021	< 0.006	0.069	Johnson (2009)
	7 to 14	-	0.015	-	-	-	Johnson (2009) /King County (2001)
	1953	~0.045	-	-	-	-	Serdar (2008) – KCDNR
	< 274	~0.08	-	-	-	-	Serdar (2008) – EIM
Lead Dissolved	39	0.048	0.056	0.0464	0.006	0.235	Present Study
	10	0.0061	0.0083	0.0070	0.0061	0.0281	Crecelius (1998) – Cherry Point
	10	0.0089	0.0096	0.0032	0.0061	0.0182	Crecelius (1998) – March Point
	16	< 0.006	< 0.008	0.007	< 0.006	0.033	Johnson (2009)
	7 to 14	-	< 0.005	-	-	-	Johnson (2009)/King County (2001)
	3	-	0.018	-	-	-	Johnson and Summers (1999)
	1953	~0.008	-	-	-	-	Serdar (2008) – KCDNR
	< 274	~0.03	-	-	-	-	Serdar (2008) – EIM
Zinc Total	42	0.69	0.86	1.060	0.41	7.44	Present Study
	10	0.832	0.846	0.194	0.574	1.30	Crecelius (1998) – Cherry Point
	10	0.336	0.447	0.218	0.336	1.01	Crecelius (1998) – March Point
	18	0.75	0.90	0.64	0.20	2.9	Johnson (2009)/King County (2001)
	7 to 24	-	0.42	-	-	-	Johnson (2009) – KCDNR
	1954	0.87	-	-	-	-	Serdar (2008) – KCDNR
Zinc Dissolved	39	0.65	0.71	0.388	0.36	2.30	Present Study
	10	0.500	0.552	0.150	0.336	0.836	Crecelius (1998) – Cherry Point
	10	0.336	0.581	0.776	0.336	2.79	Crecelius (1998) – March Point
	14	0.60	0.80	0.59	0.31	2.6	Johnson (2009)/King County (2001)
	3	-	2.0	-	-	-	Johnson and Summers (1999)
	1954	0.73	0.73	-	-	-	Serdar (2008) – KCDNR
	< 574	2	-	-	-	-	Serdar (2008) – EIM

Table I-4. Concentrations of conventional parameters and nutrients in major rivers discharging to Puget Sound compared to historical data.

River	Study/ Data Source	TSS	TOC	DOC	Total N	Nitrite/ Nitrate - N	Ammonia - N	Total P	Ortho-P
Skagit	Present Study Mean (n=3 except as noted) and Range	24.8 6.4 - 60.8	1.0 0.6-1.7	1.0 0.6-1.6	0.13 0.057-0.163	0.08 0.045-0.126	0.046 (1) --	0.033 0.006-0.086	0.004 0.003-0.005
	EIM Mean (n) and Range [1]	42.4 (401) 1.0-1230	2.1 (42) 0.5-7.0	--	0.140 (209) 0.033-0.48	0.097 (64) 0.020-0.200	0.041 (252) 0.010-2.65	0.032 (359) 0.003-0.737	0.007 (105) 0.001-0.030
	Wise et al., 2007 Range for annual mean [2]	13.6 - 78.5	--	--	0.13 - 0.17	--	--	0.02 -0.05	--
Snohomish	Present Study	24.3 4.7-54.5	1.6 0.6-2.1	1.7 0.7-2.2	0.271 0.102-0.389	0.211 0.077-0.281	0.044 0.008-0.079	0.032 0.009-0.053	0.008 0.004-0.014
	EIM	15.2 (392) 1.0-260	1.85 (21) 0.8-6.1	--	0.304 (205) 0.030-0.840	0.219 (21) 0.073-0.368	0.040 (306) 0.010-0.780	0.025 (429) 0.005-0.160	0.011 (207) 0.002-0.100
	Wise et al., 2007	9.7 - 42.4	--	--	0.32 - 0.34	--	--	0.02 - 0.03	--
Nooksack	Present Study	30.3 3.7-76.3	1.4 0.6-2.8	1.6 0.8-2.9	0.379 0.106-0.656	0.325 0.087-0.544	0.022 (1) --	0.046 0.021-0.090	0.013 0.009-0.021
	EIM	97.5 (382) 1.0-2600	--	--	0.437 (233) 0.097-1.22	0.331 (20) 0.076-0.684	0.057 (408) 0.010-0.510	0.066 (562) 0.009-0.132	0.013 (324) 0.004-0.121
	Embrey & Frans, 2003 [3] *Median* and range	70 8-2,890	2.2 0.7-6.8	--	--	0.35 0.13-0.94	0.03 <0.02-0.08	0.04 <0.01-.3	0.008 <0.01 - 0.02
	Wise et al., 2007	48 - 301	--	--	0.49 -0.55	--	--	0.05 - 0.20	--
Stillaguamish	Present Study	15.9 2.6-41.3	1.7 0.8-3.3	2.0 0.9-4.0	0.299 0.147-0.418	0.243 0.088-0.341	0.019 0.007-0.039	0.035 0.016-0.072	0.011 0.008-0.014
	EIM	73.1 (758) 0.1-2700	1.7 (2) 1.4-2.0	--	0.275 (389) 0.054-0.767	0.208 (410) 0.010-0.728	0.044 (500) 0.010-0.760	0.046 (615) 0.008-0.698	0.010 (393) 0.002-0.110
Puyallup	Present Study	94.5 11.9-233	1.0 0.5-1.3	1.1 0.8-1.4	0.351 0.137-0.545	0.240 0.110-0.309	0.066 0.010-0.162	0.124 0.044-0.250	0.033 0.021-0.048
	EIM	138 (483) 1.0-2890	3.0 (63) 0.9-9.1	1.7 (16) 1.1-3.2	0.305 (274) 0.074-0.826	0.225 (21) 0.056-0.399	0.064 (542) 0.004-0.580	0.104 (585) 0.010-1.66	0.018 (526) 0.007-0.120
	Wise et al., 2007	77.1 - 407	--	--	0.27 - 0.41	--	--	0.09 - 0.15	--

[1] Derived from EIM data representing similar locations in each river and equivalent and analytical methods.
[2] Flow-weighted annual mean concentrations for 1997, 2000, and 2001 based on LOADEST model annual loads and annual flows.
[3] Based on approximately 40 samples collected near Brennan, Washington, in 1996-1998.

Table I-5. Hardness and concentrations of metals in major rivers discharging to Puget Sound compared to historical data.

River	Study/ Data Source	Hardness	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Zinc
		mg/L	μg/L				
Skagit	Present Study Mean (n=3 except as noted) and Range	26.4 21.8-29.9	0.75 0.43 - 1.24	0.012 0.006-0.020	2.06 0.77-4.56	0.31 0.05-0.78	5.1 2.4-10.6
	EIM Mean (n) and Range [1]	22.6 (218) 13-48	0.65 (12) 0.45-1.09	--	1.39 (19) 0.280-12.0	0.165 (9) 0.023-0.47	3.09 (8) 0.55-9.34
Snohomish	Present Study	15.4 13.2-17.4	1.00 0.92-1.14	0.015 0.005-0.030	2.60 1.35-4.08	0.34 0.09-0.63	4.7 2.5-8.3
	EIM	18.2 (368) 3.0-52.0	0.82 (23) 0.48-1.9	0.03 (1) --	1.06 (42) 0.39-5.9	0.271 (29) 0.020-1.50	5.49 (30) 0.61-33.9
Nooksack	Present Study	46.2 38.1-62.0	0.55 0.26-1.01	0.017 0.005-0.040	2.41 0.75-4.41	0.32 0.05-0.82	6.0 3.2-9.7
	EIM	39.8 (306) 10.0-71.0	0.725 (18) 0.23-5.22	--	2.03 (29) 0.27-21	0.368 (22) 0.020-3.86	5.0 (24) 0.34-35.3
Stillaguamish	Present Study	27.0 19.2-31.9	0.79 0.52-1.12	0.011 0.005-0.020	2.95 1.16-6.58	0.58 (2) 0.37-0.79	9.0 4.0-17.7
	EIM	22.3 (178) 11.0-43.0	0.90 (18) 0.37-2.65	0.102 (1) --	2.15 (18) 0.50-18.0	0.08 (12) 0.020-0.450	4.2 (10) 0.45-20
Puyallup	Present Study	33.9 27.7-40.8	0.68 0.52-0.92	0.007 0.005-0.010	4.91 1.32-11.6	0.81 (2) 0.20-1.42	7.7 (2) 3.7-11.6
	EIM	25.5 (273) 14.0-60.4	0.68 (38) 0.33-1.16	0.073 (22) 0.003-0.200	4.82 (73) 0.45-41.4	0.77 (45) 0.022-6.30	7.5 (57) 0.21-43.5
Green/Duwamish	King County (2007) [1,2] Mean (n) and range	--	0.71 (11) 0.34-2.4	--	13.1	--	21.3
Surface Runoff	PSTLA (Ecology, 2010) [3] Range for 5% - 95% probability of exceedance concentrations	--	0.2 -14.9	0.0002 - 9.2	0.1 - 110	0.02 - 309	0.28 - 527

[1] King County, personal communication, April 2009. Arsenic data from 2006-2008.
[2] Mean copper and zinc concentrations derived from 2003-2005 total annual loads and discharges listed in King County (2007), Table 5-9.
[3] Range of values from Ecology (2010), Table 2: Probability of exceedance concentrations applied to major land-use types and highways.

Table I-6. Comparison of concentration ranges for organic compounds measured for the present study and others.

River	Study/ Data Source	Oil and Grease		Total PAH	cPAH *	Total PCBs	Total PBDEs
		Including ND=MDL/2	Detects only	Including ND = MDL/2			
		µg/L				pg/L	
Skagit, Snohomish, Nooksack, Stillaguamish, and Puyallup	Present Study Mean (n) and Range	920 (15) 250-2800	1600 (6) 900-2800	0.032 (15) 0.012 - 0.055	0.011 (15) 0.009 - 0.014	16.1 (15) 2.6 - 59.0	55.6 (7) 10.9 - 265
Green/Duwamish	Williston (2009) [1] Mean (n) and Range	--		0.026 (11) 0.015 - 0.05	0.001 (18) <0.001 - 0.003	410 (22) 38 - 2360	--
	Gries and Sloan (2009) [2] Est. range for annual mean	--		--	1.2-14.3	140 - 1,600	--
Total Surface Runoff	PSTLA (Ecology 2010) [3] Concentration Range	3.7 - 26,400		0.001- 56.6	0.0002 - 11.8	16 - 810,000	0.30 - 810

* Carcinogenic PAH compounds (cPAH) include benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene

[1] King County, personal communication, April 2009. PAH data from 2008.

[2] Estimated range for annual flow-weighted mean concentrations.

[3] Range of values from Ecology (2010), Table 2: Probability of exceedance concentrations applied to major land uses types and highways.

Appendix J. Statistical Results

Marine Water Column Statistics

Table J-1. Data distributions/outliers

Table J-2. Nonparametric analysis of variance (ANOVA) results

Table J-3. Spearman rank correlations

River Water Statistics

Table J-4. Data distributions/outliers

Table J-5. Nonparametric ANOVA results

Table J-6. Nonparametric ANOVA results, excluding summer 2009 Puyallup River results

Table J-7. Spearman rank correlations

Table J-1. Data distributions and potential outliers for marine water column sample results.

Parentheses indicate that some distributions change when outliers are removed from the data set.

Parameter	Normal Distribution	Log Normal Distribution	Gamma Distribution	Statistical Outliers
TSS	x (Y)	x (Y)	x (Y)	6.0, 5.5, 3.5
DOC	Y	Y	Y	--
POC	x (x)	x (Y)	x (Y)	1.78, 0.22, 0.18
Arsenic, Total	x	x	Y	--
Arsenic, Dissolved	x (Y)	x (Y)	Y	1.704
Cadmium, Total	x	x	Y	--
Cadmium, Dissolved	x	x	Y	--
Copper, Total	x (Y)	x (Y)	x (Y)	1.37, 1.03, 0.72
Copper, Dissolved	x	x	Y	--
Lead, Total	x	Y	Y	--
Lead, Dissolved	x (x)	Y	Y	0.235
Zinc, Total	x (Y)	x (Y)	x (Y)	7.44, 1.44
Zinc, Dissolved	x (x)	x (x)	x (Y)	2.3, 1.78, 1.42, 1.25, 1.06
Mono-chlorinated PCBs	x	Y	X	18.7, 0.399
Di-chlorinated PCBs	Y	Y	Y	7.31, 1.03
Tri-chlorinated PCBs	x	Y	Y	--
Tetra-chlorinated PCBs	x	x	Y	--
Penta-chlorinated PCBs	x	Y	Y	--
Hexa-chlorinated PCBs	x	Y	Y	7.39, 0.872
Total PCBs *	x (Y)	x	Y	75.1
Total PBDEs *	x	Y	Y	18700, 51

* Insufficient number of detected results (n<8) to evaluate distributions for PCB homologs with more than 6 chlorines or any PBDE homologs.

Table J-2. Results of nonparametric ANOVA (Kruskal Wallis Test and Test of Means) for all marine water column results.

Independent Categorical Variable → / Chemical Name ↓	Puget Sound (PS) Vs. Ocean Boundary (OB)	Summer, Fall, Winter: Kruskal Wallis Test & Test of Medians	Stations Kruskal Wallis Test & Test of Medians	Surface vs. Deep Layer Kruskal Wallis Test & Test of Medians
TSS		p<0.002, TSS lowest in Fall		
DOC	p<0.001, PS>OB	p<0.024*, Fall > Winter	p<0.014, greatest at Whidbey Basin & South Sound stations	
POC		p<0.004, Fall > Winter		
TOC	p<0.001, PS>OB	p<0.031, Fall > Winter	p<0.034, see DOC	
Arsenic, Total		p<0.020, lowest in Fall		p<0.031, Surface < Deep
Arsenic, Dissolved				p<0.001, Surface < Deep
Cadmium, Total	p<0.001, PS<OB		p<0.003, greatest at Juan de Fuca & Hood Canal stations	(p<0.13, Surface < Deep)
Cadmium, Dissolved	p<0.001, PS<OB		p<0.002, see total cadmium	
Copper, Total	p<0.005, PS>OB	p<0.003, lowest in Fall		
Copper, Dissolved	p<0.001, PS>OB	p<0.042, lowest in Fall	p<0.001, lowest at Juan de Fuca & Hood Canal stations	
Lead, Total				p<0.005, Surface < Deep
Di-chlorinated PCBs	p<0.001, PS>OB			
Tri-chlorinated PCBs		p<0.002, lowest in Winter		
Tetra-chlorinated PCBs				P<0.001, Surface < Deep
Penta-chlorinated PCBs	p<0.002, PS>OB		p<0.015, greatest at Haro Strait, Whidbey Basin, and South Sound stations	
Hexa-chlorinated PCBs			p<0.044, greatest at Main and Whidbey basin stations	
Total PCBs	p<0.027, PS>OB	p<0.020, greatest in fall		p<0.001, Surface < Deep
Total PBDEs		p<0.034*, greatest in winter		

* Identified as significant only by Test of Medians.

Table J-3. Spearman rank correlation coefficients between pairs of parameters measured in marine water column samples.

Units of measure are mg/L for conventionals, µ/L for metals, and pg/L for total PCBs and PBDEs.
Values in bold are significant at p<0.05. The 3 italicized values are significant only at p<0.10.

	TSS	DOC	POC	TOC	Arsenic , Total	Arsenic , Dissolved	Cadmium , Total	Cadmium , Dissolved	Copper , Total	Copper , Dissolved	Lead , Total	Lead , Dissolved	Zinc , Total	Zinc , Dissolved	Total PCBs	Total PBDEs
TSS	1.00															
DOC	**-0.67**	1.00														
POC	**-0.49**	*0.32*	1.00													
TOC	**-0.76**	**0.96**	*0.36*	1.00												
Arsenic, Total	0.20	**-0.57**	0.11	**-0.61**	1.00											
Arsenic, Dissolved	0.27	**-0.70**	0.02	**-0.76**	**0.88**	1.00										
Cadmium, Total	0.27	**-0.54**	-0.07	**-0.50**	**0.39**	**0.63**	1.00									
Cadmium, Dissolved	**0.45**	**-0.88**	-0.13	**-0.78**	**0.52**	**0.66**	**0.79**	1.00								
Copper, Total	0.16	**-0.46**	**0.36**	**-0.57**	**0.75**	**0.88**	**0.43**	**0.40**	1.00							
Copper, Dissolved	**-0.45**	**0.64**	**0.50**	**0.54**	0.14	-0.16	**-0.61**	**-0.72**	0.11	1.00						
Lead, Total	**0.83**	**-0.93**	**-0.39**	**-0.89**	**0.43**	**0.51**	**0.54**	**0.85**	0.25	**-0.68**	1.00					
Lead, Dissolved	**0.54**	**-0.88**	**-0.56**	**-0.78**	0.31	**0.39**	**0.36**	**0.78**	0.04	**-0.76**	**0.85**	1.00				
Zinc, Total	-0.02	0.25	0.21	0.04	**0.32**	0.20	**-0.46**	**-0.54**	**0.46**	**0.79**	**-0.36**	**-0.51**	1.00			
Zinc, Dissolved	**-0.99**	**0.61**	**0.46**	**0.71**	-0.18	-0.27	**-0.32**	**-0.41**	-0.18	**0.43**	**-0.79**	**-0.45**	0.00	1.00		
Total PCBs	**0.70**	**-0.54**	0.14	**-0.57**	0.04	0.16	0.11	**0.38**	**0.32**	**-0.32**	**0.61**	**0.31**	0.00	**-0.68**	1.00	
Total PBDEs	0.29	-0.07	-0.46	-0.11	0.14	-0.18	*-0.61*	-0.25	-0.32	0.29	0.14	0.25	0.32	-0.21	-0.07	1.00

Table J-4. Data distributions and potential outliers for river water sample results.

Chemical	Normal Distribution	Log Normal Distribution	Gamma Distribution	Statistical Outliers
TSS	x (x)	Y	Y	233
TOC	x	Y	Y	--
DOC	x (x)	Y	Y	0.56
Total Nitrogen	Y	Y	Y	--
Nitrate+Nitrite Nitrogen	x	Y	x	--
Ammonia Nitrogen	x (Y)	Y	Y	0.162
Total Phosphorus	x (Y)	Y	Y	0.250
Ortho-phosphate	x (Y)	Y	Y	0.0478
Hardness	Y	Y	Y	62
Arsenic, Total	Y	Y	Y	--
Arsenic, Dissolved	Y	Y	Y	--
Cadmium, Total	x	x	x (Y)	0.04
Cadmium, Dissolved	x (Y)	x (Y)	Y	0.035 *
Copper, Total	x (x)	Y	Y	11.6
Copper, Dissolved	x (x)	Y	Y	4.19
Lead, Total	x	Y	Y	--
Lead, Dissolved	x (Y)	Y	x (Y)	0.281
Zinc, Total	x	Y	Y	--
Zinc, Dissolved	x	Y	Y	--
Oil & Grease	Y	Y	Y	2.8
Mono-chlorinated PCBs	Y	Y	Y	--
Di-chlorinated PCBs	Y	Y	Y	6.14
Tri-chlorinated PCBs	Y	Y	Y	9.68
Tetra-chlorinated PCBs	x (x)	Y	Y	16.5
Penta-chlorinated PCBs	x (x)	Y	Y	28.7
Hexa-chlorinated PCBs	Y	Y	Y	--
Total PCBs	x (x)	Y	Y	59.0
Tri-brominated PBDEs	--	--	--	--
Penta-brominated PBDEs	--	--	--	34.2
Total PBDEs	x (Y)	x (Y)	x (Y)	265.2

* Outlier removed for analysis because dissolved cadmium >> total cadmium.

Table J-5. Results of nonparametric ANOVA (Kruskal Wallis Test and Test of Medians) for all river water results.

Independent Categorical Variable → / Chemical Name ↓	Season: Summer vs. Fall vs. Winter	River/Station	Flow Regime: Baseflow vs. Runoff Event
TSS	--	--	--
DOC	p<0.011; summer low	--	--
TOC	p<0.019; summer low	--	--
Total Nitrogen	p<0.008; summer low	--	--
Ammonia Nitrogen	p<0.038; fall high	--	--
Nitrate+Nitrite Nitrogen	p<0.026; summer low	--	--
Total Phosphorus	--	--	--
Ortho-phosphate	--	P<0.034; Skagit lowest, Puyallup highest	--
Hardness	--	P<0.026; Snohomish lowest, Nooksack/Puyallup highest	--
Arsenic, Total	--	--	--
Arsenic, Dissolved	--	P<0.041; Nooksack lowest	--
Cadmium, Total	--	--	--
Cadmium, Dissolved	--	--	--
Copper, Total	--	--	--
Copper, Dissolved	--	--	--
Lead, Total	p<0.034*; summer/fall low, winter high	--	--
Lead, Dissolved	--	--	--
Zinc, Total	p<0.050*; fall low, winter high	--	--
Zinc, Dissolved	--	--	--
Oil and Grease	--	--	--
Total PCBs	--	--	(p<0.094; baseflow higher)
Total PBDEs	--	--	--

* Identified as significant only by Test of Medians.

Table J-6. Results of nonparametric ANOVA (Kruskal Wallis Test and Test of Medians) excluding summer Puyallup River results.

Independent Categorical Variable → / Chemical Name ↓	Season: Summer vs. Fall vs. Winter	River/Station	Flow Regime: Baseflow vs. Runoff Event
TSS	p<0.050*; summer low, winter high	--	--
DOC	p<0.022; summer low, winter high	--	--
TOC	p<0.038; summer low, winter high	--	--
Total Nitrogen	p<0.015; summer low, fall high	--	--
Ammonia Nitrogen	p<0.050, fall high, winter low	--	--
Nitrate+Nitrite Nitrogen	p<0.039; summer low, fall high	--	--
Total Phosphorus	0.050*; summer low, winter high	--	--
Ortho-phosphate	--	--	--
Hardness	--	p<0.022, Nooksack/Puyallup high, Skagit/Snohomish low	--
Arsenic, Total	--	--	--
Arsenic, Dissolved	--	P<0.044, Nooksack/Skagit low, Snohomish high	--
Cadmium, Total	--	--	--
Cadmium, Dissolved	--	--	--
Copper, Total	--	--	--
Copper, Dissolved	--	--	--
Lead, Total	0.027*; summer low, winter high	--	--
Lead, Dissolved	--	--	--
Zinc, Total	p<0.050*; winter high, summer/fall low	--	--
Zinc, Dissolved	p<0.034*; summer high, fall low	--	--
Oil and Grease	--	--	--
Total PCBs	--	--	--
Total PBDEs	--	--	--

* Identified as significant only by Test of Medians.

Table J-7. Spearman rank correlation coefficients between paired parameters measured in river water samples.

Units of measure are mg/L for conventionals, nutrients, and hardness; µg/L for all metals; mg/L for oil and grease, and pg/L for PCBs. Values in bold are significant at p<0.05.

	Flow	TSS	TOC	DOC	Total Nitrogen (N)	Nitrate+Nitrite N	Ammonia N	Total Phosphorus	Ortho-phosphate	Hardness	Arsenic , Total	Arsenic , Dissolved	Cadmium , Total	Cadmium , Dissolved	Copper , Total	Copper , Dissolved	Lead , Total	Lead , Dissolved	Zinc , Total	Zinc , Dissolved
Flow (cfs)	1.00																			
TSS	0.50	1.00																		
TOC	0.28	0.39	1.00																	
DOC	0.22	0.50	**0.95**	1.00																
Total Nitrogen	-0.11	0.29	**0.76**	**0.85**	1.00															
Nitrate+Nitrite Nitrogen	-0.22	0.28	**0.71**	**0.78**	**0.92**	1.00														
Ammonia Nitrogen	-0.09	-0.04	0.14	0.31	0.49	0.17	1.00													
Total Phosphorus	0.09	**0.85**	0.47	**0.59**	0.49	**0.59**	0.02	1.00												
Ortho-phosphate	**-0.70**	0.13	0.05	0.17	0.44	0.52	0.36	0.50	1.00											
Hardness	**-0.64**	-0.02	-0.17	-0.08	0.29	0.30	0.30	0.25	0.50	1.00										
Arsenic, Total	**0.61**	**0.67**	**0.59**	**0.56**	0.17	0.13	-0.16	**0.58**	-0.14	**-0.52**	1.00									
Arsenic, Dissolved	0.00	-0.20	0.16	0.06	-0.08	-0.24	0.29	-0.18	0.02	-0.46	0.39	1.00								
Cadmium, Total	**0.74**	**0.76**	**0.59**	**0.62**	0.34	0.30	-0.21	**0.57**	-0.24	-0.32	**0.77**	-0.11	1.00							
Cadmium, Dissolved	0.51	0.01	0.01	-0.03	-0.33	-0.10	-0.47	-0.14	**-0.65**	-0.15	0.22	-0.31	0.19	1.00						
Copper, Total	0.33	**0.86**	0.41	0.50	0.20	0.22	-0.07	**0.81**	0.17	-0.16	**0.77**	0.01	**0.66**	-0.21	1.00					
Copper, Dissolved	0.15	0.48	0.28	0.28	0.13	0.18	-0.20	**0.57**	0.27	-0.20	**0.74**	0.30	0.46	-0.36	**0.69**	1.00				
Lead, Total	0.47	**0.86**	0.48	**0.53**	0.34	0.41	-0.35	**0.78**	0.11	-0.10	**0.67**	-0.21	**0.85**	-0.14	**0.81**	**0.57**	1.00			
Lead, Dissolved	0.56	**0.64**	**0.66**	0.58	0.12	0.11	-0.55	0.54	-0.28	-0.32	**0.81**	0.16	**0.74**	0.17	**0.77**	**0.85**	**0.83**	1.00		
Zinc, Total	0.10	**0.63**	0.45	0.52	0.28	0.43	-0.47	**0.76**	0.17	0.02	**0.60**	-0.19	**0.62**	-0.13	**0.82**	**0.57**	**0.78**	**0.70**	1.00	
Zinc, Dissolved	-0.13	-0.19	-0.17	-0.26	-0.14	-0.11	-0.13	-0.11	0.20	0.01	0.02	0.17	-0.13	-0.34	-0.04	0.44	-0.01	0.17	-0.12	1.00

Table J-7 (continued). Spearman rank correlation coefficients between paired parameters measured in river water samples.

Units of measure are mg/L for conventionals, nutrients, and hardness; µg/L for all metals; mg/L for oil and grease; pg/L for all summed PCBs. There were no significant correlations involving PBDE results for river water. Values in bold are significant at p<0.05.

	Total PCBs	Hexa-chlorinated PCBs	Penta-chlorinated PCBs	Tetra-chlorinated PCBs	Tri-chlorinated PCBs	Di-chlorinated PCBs	Mono-chlorinated PCBs	Oil & Grease
Flow	-0.34	0.04	-0.35	-0.49	-0.15	-0.40	**-0.70**	0.46
TSS	-0.24	**0.67**	-0.15	-0.24	-0.11	-0.20	-0.20	-0.40
TOC	0.17	**0.60**	0.24	-0.03	-0.28	-0.18	0.30	0.55
DOC	0.12	**0.65**	0.31	-0.02	-0.32	-0.34	0.10	0.03
Total Nitrogen (N)	0.17	**0.63**	0.34	0.07	-0.30	-0.35	0.10	-0.03
Nitrate+Nitrite N	0.14	**0.61**	0.26	0.13	-0.39	-0.18	0.30	-0.15
Ammonia N	0.43	0.37	**0.67**	0.34	0.41	**-0.80**	-0.50	-0.50
Total Phosphorus	-0.07	**0.83**	0.06	-0.07	-0.06	-0.05	0.20	-0.40
Ortho-phosphate	0.17	0.43	0.39	0.26	0.12	0.33	**0.70**	-0.70
Hardness	0.14	0.37	-0.11	0.22	0.28	-0.18	**0.60**	-0.64
Arsenic , Total	-0.04	0.40	-0.03	-0.21	0.25	0.15	**-0.60**	0.37
Arsenic , Dissolved	0.43	-0.03	0.46	0.16	**0.55**	0.45	-0.31	0.70
Cadmium , Total	-0.37	0.34	-0.24	-0.45	-0.29	-0.50	**-0.87**	-0.16
Cadmium , Dissolved	0.14	-0.20	-0.15	-0.12	-0.27	**-0.67**	**0.87**	**1.00**
Copper , Total	-0.19	**0.64**	-0.12	-0.14	-0.02	0.30	-0.20	-0.21
Copper , Dissolved	-0.10	0.29	-0.18	-0.39	0.41	**0.53**	-0.20	-0.09
Lead , Total	-0.37	**0.54**	-0.26	-0.30	-0.28	-0.05	-0.41	-0.40
Lead , Dissolved	-0.14	0.39	-0.38	-0.39	-0.08	**0.77**	**-0.80**	**-1.00**
Zinc , Total	-0.18	0.46	-0.14	-0.06	-0.27	0.24	0.00	-0.40
Zinc , Dissolved	-0.44	-0.17	**-0.60**	**-0.54**	0.25	**0.70**	-0.36	0.09
Oil & Grease	0.52	0.50	0.31	0.50	-0.11	**0.78**	.	1.00
1-Cl PCBs	0.10	**-0.60**	**-1.00**	-0.40	-0.30	-0.40	1.00	
2-Cl PCBs	0.23	0.07	-0.29	0.09	0.30	1.00		
3-Cl PCBs	**0.54**	0.03	0.21	0.45	1.00			
4-Cl PCBs	**0.84**	0.40	**0.89**	1.00				
5-Cl PCBs	**0.88**	0.44	1.00					
6-Cl PCBs	0.51	1.00						
Total PCBs	1.00							

THE ADMINISTRATOR OF THE ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

DEC - 1 2014

MEMORANDUM

SUBJECT: Commemorating the 30th Anniversary of the EPA's Indian Policy

FROM: Gina McCarthy

TO: All EPA Employees

I am proud to recognize the U.S. Environmental Protection Agency's 30th anniversary of its Indian policy, and I want to thank everyone who has worked diligently to establish and sustain the agency's Indian program. As we mark this milestone, I also want to convey gratitude to our tribal-government partners for all their time, expertise and effort in building this important partnership with the EPA.

On November 8, 1984, the EPA issued its *Policy for the Administration of Environmental Programs on Indian Reservations*. In doing so, the EPA became the first federal agency to adopt a formal Indian policy to guide its relations with tribal governments in the administration of its programs. The 1984 Indian Policy represented – and continues to represent – a bold statement on the EPA's commitment to our partnership with federally recognized Indian tribes and to tribal self-governance in implementing environmental-protection programs.

The underlying principles of the 1984 Indian policy continue to guide our unique relationship with, and the federal trust responsibility to, federally recognized Indian tribes as expressed in treaties, statutes, executive orders and court decisions. The agency remains fully committed to engaging tribes as sovereign governments with a right to self-governance, which is a commitment the EPA made and has kept since our agency's founding.

Tribal Treaty Rights

Under the U.S. Constitution, treaties have the same legal force as federal statutes. And the United States' government-to-government relationship with and trust responsibility to federally recognized Indian tribes reinforces the importance of honoring these treaty rights. As such, the EPA has an obligation to honor and respect tribal rights and resources protected by treaties. While treaties do not expand the EPA's authority, the EPA must ensure its actions do not conflict with tribal treaty rights. In addition, EPA programs should be implemented to enhance protection of tribal treaty rights and treaty-covered resources when we have discretion to do so. To help guide the agency's decisions when treaty rights should be considered, the Office of General Counsel and the American Indian Environmental Office will develop an analytical framework, with input and consultation from other EPA offices and tribal governments.

Intergovernmental Cooperation

Good governance demands that the EPA increase our efforts to work in concert with other federal agencies, tribes, states and local governments to protect human health and the environment. Coming together to set priorities and define mutual roles and responsibilities regarding the administration of environmental-protection programs will build stronger, more efficient and effective partnerships. The EPA remains committed to continue building on the following notable Indian program efforts:

- engaging tribal-elected officials on key environmental and public-health issues through an annual tribal leaders' listening session;
- coordinating with the Environmental Council of the States to include tribal governments in key discussions as co-regulators;
- using the Council for the Commission for Environmental Cooperation to ensure that the U.S., Canada and Mexico continue to work with indigenous communities across North America and recognize the importance of the traditional ecological knowledge and practices of indigenous communities; and
- working with the Department of the Interior to build tribal resiliency regarding the impacts of climate change.

The EPA this year also celebrates the 20th anniversary of the Indian Environmental General Assistance Program. Through this program, the EPA has provided more than $1 billion in direct funding to federally recognized tribes and intertribal consortia to build strong, sustainable tribal environmental-protection program capacity.

Thank you all once more for your hard work and your commitment. I look forward to working with you to achieve much more in the months ahead.

DEPARTMENT OF
ECOLOGY
State of Washington

Fish Consumption Rates

Technical Support Document

A Review of Data and Information about Fish Consumption in Washington

Version 2.0

Final

January 2013
Publication No. 12-09-058

05398

Publication and Contact Information

This report is available on the Department of Ecology's website at
www.ecy.wa.gov/biblio/1209058.html

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Fish Consumption Rates

Technical Support Document

A Review of Data and Information about Fish Consumption in Washington

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Final

Toxics Cleanup Program
Washington State Department of Ecology
Olympia, Washington

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Acronyms and Abbreviations

API	Asian and Pacific Islander
ATSDR	Agency for Toxic Substances and Disease Registry
BAF	bioaccumulation factor
BCF	bioconcentration factor
bw	body weight
BRFSS	Behavioral Risk Factor Surveillance System
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRITFC	Columbia River Inter-Tribal Fish Commission
CSFII	Continuing Survey of Food Intakes by Individuals
CWA	Clean Water Act
DDT	dichlorodiphenyltrichloroethane
DOH	Washington State Department of Health
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
g/day	grams per day
g/kg	grams per kilogram
IHS	Indian Health Service
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µg/mg	micrograms per milligram
MTCA	Model Toxics Control Act
NCI	National Cancer Institute
NHANES	National Health and Nutrition Examination Survey
NOAA	National Oceanic and Atmospheric Administration
Oregon DEQ	Oregon Department of Environmental Quality
OFM	Office of Financial Management
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PBT	persistent bioaccumulative toxic
PCB	polychlorinated biphenyl
POP	persistent organic pollutant
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RME	reasonable maximum exposure
SaSI	Salmonid Stock Inventory
SMS	Sediment Management Standards
U.S.	United States

USDA	U.S. Department of Agriculture
WAC	Washington Administrative Code
WDF	Washington Department of Fisheries
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area

Acknowledgments

The Washington State Department of Ecology wishes to thank the many people who have participated in the ongoing dialogue on fish consumption rates. There have been many conversations through the years, with a great many people providing insight and input, answering questions, reviewing draft documents, and clarifying various issues. In particular, Ecology wishes to acknowledge the following people. Persons listed here provided constructive input and feedback; they were not, however, asked to endorse the final product, and did not see the final report before its release.

University of Washington

- Dr. William (Bill) Daniell, Associate Professor, Environmental and Occupational Health Sciences
- Dr. Elaine Faustman, Professor, Environmental Health
- Dr. William (Bill) Griffith, Principal Research Scientist and Director of the Risk Assessment Core of the Institute for Risk Analysis and Risk Communication
- Alison Scherer, Research Scientist, Environmental and Occupational Health Sciences
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- Dr. Thomas M. Burbacher, Professor, Environmental Health
- Dr. Vincent F. Gallucci, Professor, Aquatic and Fishery Sciences
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- Catherine A. O'Neill, Professor of Law
- Doug Nash, Professor of Law and member of Nez Perce Tribe

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- Don Hurst and Patti Bailey, Confederated Tribes of the Colville Reservation
- Fran Wilshusen, Northwest Indian Fisheries Commission
- Denice Taylor, Suquamish Tribe

- Dianne C. Barton and Aja DeCoteau, Columbia River Inter-Tribal Fish Commission (CRITFC)

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- Yi Zhao, Chief Demographer

Washington Department of Fish and Wildlife

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Selected members of the Human Health Focus Group, Oregon Dept of Environmental Quality

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Preface to Version 2.0

Washington's marine and fresh waters are home to rich stocks of finfish and shellfish, and these resources are vital to the well-being of the peoples of our state.[1] Several years ago the Washington State Department of Ecology (Ecology) began work reviewing fish consumption rates as part of updating environmental cleanup regulations, and subsequently produced a draft Technical Support Document. The evaluations presented in that document followed similar evaluations done in Oregon. Ecology received several hundred comments on the draft document and has made revisions based on input received. Additional analyses were performed and supplemental information was gathered to support preparation of this revised version.

Regulatory context plays a role in this topic, and Ecology will be addressing both the scientific and policy questions associated with fish consumption rates. This Technical Support Document, however, does not address the policy questions. It focuses quite specifically on the issue of how much and what types of fish are consumed by the people of Washington, and what data are available about fish consumption rates.

It is appropriate and necessary to review and, if needed, update exposure parameters used in various regulatory contexts, and this document is offered as one part of the effort to consider fish consumption rates. Readers may notice that this document has evolved. Ecology produced the *Fish Consumption Rates Technical Support Document: A Review of Data and Information about Fish Consumption in Washington, Version 1.0* to support dialogue related to updating the default fish consumption rates used in Washington environmental regulations. At that time, Ecology was focused on updating the Sediment Management Standards, with updates to water quality standards to follow at a later time. It was a draft document that posed several questions and was distributed for public review and input in October 2011. Although scheduled to end December 31, 2011, the comment period was extended until January 18, 2012.[2]

In Version 1.0 of the Technical Support Document, Ecology collected data about fish consumers in Washington and looked at national data about fish consumption in the United States. We reviewed this information as a first step in addressing how to establish a fish consumption rate for use in Washington. Ecology then considered how to systematically and scientifically determine a default rate appropriate for use in a regulatory context. Multiple questions arose, including: How should the data be combined in a statistically correct manner? Is it appropriate to establish a single default rate for use in multiple settings? How should salmon be included in the default fish consumption rate?

[1] In most places in this document, unless noted otherwise, fish refers to both finfish and shellfish.

[2] Due to a winter storm that caused statewide power outages during that week, Ecology accepted all late comments.

Ecology received over 300 comments on Version 1.0 of the Technical Support Document. Comments were posted on the Ecology website in the order in which they were received. Ecology announced that a response to comments would be prepared.

In order to respond to comments and to update the document based on public input, Ecology performed a number of additional analyses. The additional work in response to comments falls generally into the following categories:

- Technical analyses to more accurately characterize fish-consuming populations, including statistical review of data and methodologies.
- Research of relevant supporting information (for example, regarding recreational fish consumption, health benefits and risks from eating finfish and shellfish, and life strategies for different fish species).

Purpose

The purpose of this Technical Support Document (Version 2.0) is to compile and evaluate available information on fish consumption in Washington State. It is a technical document, and is not designed to resolve policy issues associated with using that information to make regulatory decisions. Those issues will be dealt with in separate rulemaking documents and processes. However, in order to assist readers, this document does provide a certain amount of context and identifies some of the policy questions that are relevant to the topic of fish consumption rates.

This document is narrower in scope than Version 1.0 of the Technical Support Document (distributed in October 2011). At that time, Ecology planned to adopt a default fish consumption rate in the Sediment Management Standards (SMS) rule. One purpose of the Technical Support Document (Version 1.0) was to identify a recommended range of fish consumption rates for consideration in the SMS rule revision process. Since that time, Ecology has decided not to propose a default fish consumption rate in the SMS rule. Instead Ecology is proposing to use a *reasonable maximum exposure* as the sediment cleanup standard for protecting fish consumers. Ecology is also beginning the process to revise the Water Quality Standards for Surface Waters and adopt human health criteria.

Instead of identifying a fish consumption rate appropriate for use in a particular regulatory context, this document compiles relevant data and information. Ecology acknowledges the complexity of this topic and offers this Technical Support Document to provide a thorough, rigorous, and comprehensive review of the available technical information about fish and fish consumers in Washington.

Executive Summary

Problem statement

Washington's aquatic resources provide tremendous benefit to the people of the state. Large quantities of finfish and shellfish are caught each year, both recreationally and commercially, and many residents eat seafood harvested from our waters. In addition, tribal populations enjoy treaty fishing rights, and harvesting and eating seafood plays a significant role in their cultures. Finfish and shellfish are important parts of a healthy diet.

Polychlorinated biphenyls (PCBs), dioxins, mercury, and other persistent chemicals can accumulate in fish tissue and harm the health of people who consume fish. Those who may be particularly vulnerable include adults who eat large amounts of finfish or shellfish, as well as children and other sensitive populations. Current fish consumption rates used by Ecology to make regulatory decisions are not consistent with data about fish consumption by Washington populations for which fish consumption survey information is available.[3]

Ecology currently identifies two separate default fish consumption rates that have been used to establish regulatory requirements:

- Washington's Model Toxics Control Act (MTCA) Cleanup Regulation includes a default fish consumption rate of 54 grams (1.9 ounces) per day. This value was established in 1991. It is based on information from a survey of Washington recreational anglers in Commencement Bay (Pierce et al., 1981).
- Washington is covered under a federal regulation – the National Toxics Rule. Washington's Water Quality Standards for Surface Waters currently rely on the 1992 National Toxics Rule (57 Fed. Reg. 60848-60923 codified at 40 CFR 131.36), which includes Water Quality Standards for human health protection based on a fish consumption rate of 6.5 grams (0.22 ounce) per day.

There have been many scientific and regulatory developments related to fish consumption rates over the past 20 years. The review of Washington fish consumption in this Technical Support Document is offered to provide data and information pertinent to ongoing public dialogue concerning regulatory issues. This report reviews recent scientific data, noting the uncertainty and variability associated with those data.

[3] Ecology has the ability to make site-specific decisions and use site-specific information, including fish consumption rates protective of tribal populations.

The aquatic environment challenge

Many different species of finfish and shellfish are harvested from Washington waters. Each species has a unique life history and preferred habitat. Some finfish and shellfish are exposed to contaminants, but determining how much or where that exposure occurs is difficult. In an aquatic environment, contaminants move between water and sediment and from one location to another. In addition, the various salmon species, like other anadromous fish, migrate between river and open ocean environments, spending only a portion of their life cycle near shore.

The issues surrounding salmon life history are particularly complex. Most salmon leave freshwater streams when they are juveniles, only a couple of inches long, and spend varying amounts of time in coastal waters. Salmon spend most of their life cycle in the open ocean, and return to Washington waters at the end of their life cycle. Salmon are the most frequently consumed fish in Washington, but how to account for the complexity they present when considering questions related to water and sediment quality is a challenge. This document does not resolve these questions. Instead it offers information that will be useful as readers think through various options.

Washington fish resources

A large variety of fish and shellfish are available for harvesting in Washington, including more than 50 species of edible freshwater fish and almost as many in marine waters (WDFW, 2010).

Commercial fish landings from Washington non-treaty fisheries totaled over 109 million pounds of finfish and shellfish in 2006, including over 25 million pounds of shellfish and over 11 million pounds of salmon.

Recreationally caught finfish in Washington include albacore, bottomfish, Pacific halibut, salmon, steelhead, and sturgeon, with the 2006 catch totaling over 840,000 fish. Over 113,000 pounds of shellfish were collected from Washington waters in 2006, primarily Dungeness crab and razor clams.

Washington fish consumers

Ecology estimates that between 1.4 and 3.8 million Washington adults and 290,000 children consume some amount of fish as part of their diet.[4]

[4] The term *fish* in this document may refer to finfish or to both finfish and shellfish. The term *fish consumption* usually refers to consumption of both finfish and shellfish. The intent should be clear from the context; where appropriate the distinction is noted.

Recreational fishers may consume more fish than the general Washington population. Some population groups consume especially large amounts of finfish and shellfish as part of traditionally influenced diets. These include Native Americans and Asian and Pacific Islanders.

Fish consumption surveys

Information about fish consumption can be collected in a variety of ways. This document describes the different methodologies used to collect information about fish consumption. To identify robust and defensible surveys relevant to Washington, Ecology reviewed survey methodologies and survey results by considering measures of technical defensibility.

Ecology reviewed general population data from national surveys. Statistical methodology used by the National Cancer Institute (NCI) was applied to the national survey data to better estimate long-term consumption rates using short-term dietary records.

Ecology reviewed available information on fish consumption in Washington. Certain dietary recall surveys are identified as well-designed and well-conducted. The following studies meet measures of technical defensibility and contain data directly applicable to Washington population groups:

- *A Fish Consumption Survey of the Umatilla, Nez Perce, Yakama, and Warm Springs Tribes of the Columbia River Basin* (CRITFC, 1994).
- *A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region* (Toy et al., 1996).
- *Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservations, Puget Sound Region* (The Suquamish Tribe, 2000).

The *Asian and Pacific Islander Seafood Consumption Study* (Sechena et al., 1999, including EPA's 2005 re-evaluation) is a well-designed and conducted study, but it represents a very small sample of each of the Asian and Pacific Islander populations surveyed, and statewide populations may differ.

Data on recreational fishing provide another piece of information about fish consumers in Washington. However, this information is collected from creel surveys and is therefore less useful than dietary recall surveys for estimating consumption rates for a population. (The data are included with the table below for convenience only.)

Survey information for the general population, Pacific Northwest populations, and recreational fishers is summarized in Table 1.

Table 1. Summary of Fish Consumption Data, All Finfish and Shellfish (g/day)

Population	Source of Fish	Number of Adults Surveyed	Mean	Percentiles		
				50th	90th	95th
General population (consumers only)	All sources: EPA method All sources: NCI method	2,853 6,465	56 19	38 13	128 43	168 57
Columbia River Tribes	All sources Columbia River	464 –	63 56	41 36	130 114	194 171
Tulalip Tribes	All sources Puget Sound	73 71	82 60	45 30	193 139	268 237
Squaxin Island Tribe	All sources Puget Sound	117 –	84 56	45 30	206 139	280 189
Suquamish Tribe	All sources Puget Sound	92 91	214 165	132 58	489 397	797 767
Recreational Fishers (compilation of multiple studies)	Marine waters, WA State Freshwater, WA State	– –	11–53 6.0–22	1.0–21 –	13–246 42–67	

Sources: Adapted from Polissar et al., 2012, Table E-1. Data for recreational fishers is from Table 3, Technical Issue Paper: *Recreational Fish Consumption Rates* (Ecology, 2012). General population data are for consumers only, as opposed to per capita. See Chapters 4 and 6.

Key technical findings

Key findings of this Technical Support Document include the following:

- Significant numbers of people in Washington consume finfish and shellfish. Ecology estimates that between 1.4 and 3.8 million adults in Washington eat finfish or shellfish at least occasionally.
- No survey data currently exist about fish consumption rates specific to the general population in Washington. Statistical evaluation of national fish consumption data may provide useful information about fish consumption among the general population. For estimates based on national data, the methodology developed by the National Cancer Institute provides improved accuracy for episodically consumed foods.
- Regional-specific fish dietary surveys provide technically defensible information about high fish-consuming populations in the Pacific Northwest.

In response to public review comments received by Ecology on Version 1.0 of this Technical Support Document, supplementary information (provided as separate Technical Issue Papers) has been prepared to provide additional detail on topics of specific relevance to the evaluation of fish consumption rates. These topics include:

* Estimating annual fish consumption rates using data from short-term surveys.
* Recreational fish consumption rates.
* Health benefits and risks of consuming finfish and shellfish.
* Chemical contaminants in dietary protein sources.
* Salmon life history and body burdens.

These Technical Issue Papers are provided in Ecology, 2012 (*Supplemental Information to Support the Fish Consumption Rates Technical Support Document*).

Supporting information

In addition to the key findings, this document includes information that allows a more comprehensive understanding of fish consumption patterns in Washington. This information, taken collectively, provides multiple lines of evidence about fish consumption in Washington. For example, water body-specific evaluations, predominantly creel surveys, do provide additional information about fish consumption.

In addition, this document looks at identifying species that are locally harvested[5] and consumed.

- About 68 percent of total fish consumed by the Squaxin Island tribal population is locally harvested. The percentage of total fish consumed that is locally harvested is somewhat higher for the other tribal populations surveyed: approximately 88 percent for the Columbia River Tribes, 72 to 88 percent for the Tulalip Tribes, and 81 to 96 percent for the Suquamish tribe.
- Where possible, data on types of fish consumed and where the fish were obtained are provided, allowing a regional look at fish consumption patterns.
- About 62 percent of shellfish consumed by Squaxin Island tribal populations are locally harvested. The percentage of shellfish that is locally harvested is somewhat higher for the Suquamish Tribe (81 percent), and highest for the Tulalip Tribes (98 percent or higher).

[5] The term *locally harvested* is used to identify the source of fish. It is used to distinguish fish harvested locally from fish purchased and coming from unknown and potentially non-local (out of state) sources.

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Chapter 1: Introduction and Purpose

1.1 Introduction

This report addresses fish consumption among Washington fish consumers, including the general population, tribal populations, and other groups, such as Asian and Pacific Islanders and recreational anglers, who are known to eat large amounts of fish.[6]

The Washington State Department of Ecology (Ecology) currently recognizes two separate default fish consumption rates used to establish regulatory requirements:

- Washington's Model Toxics Control Act (MTCA) Cleanup Regulation includes a default fish consumption rate of 54 grams (1.9 ounces) per day. This value was established in 1991. It is based on information from a survey of Washington recreational anglers in Commencement Bay (Pierce et al., 1981).
- Washington is covered under a federal regulation – the National Toxics Rule. Washington's Water Quality Standards for Surface Waters currently rely on the 1992 National Toxics Rule (57 Fed. Reg. 60848-60923 codified at 40 CFR 131.36), which includes Water Quality Standards for human health protection based on a fish consumption rate of 6.5 grams (0.22 ounce) per day.[7] This value is based on technical evaluations completed by the U.S. Environmental Protection Agency (EPA) in the mid-1980s. It represents the low estimate of national average per capita consumption of fish and shellfish from estuarine and fresh waters (45 Fed. Reg. 79348; U.S. EPA, 1980).[8]

The methods used to develop these two rates included a number of differing assumptions about exposures. The MTCA fish consumption rate of 54 grams per day (g/day) is a recreational rate based on a creel survey from Commencement Bay. The Water Quality Standards default fish consumption rate of 6.5 g/day is the average per capita consumption rate of all (contaminated and non-contaminated) freshwater and estuarine fish for the U.S. population (57 Fed. Reg. 60848-60923 codified at 40 CFR 131.36). This average includes people who never eat fish.

To estimate the average per capita intake of a pollutant due to consumption of contaminated fish and shellfish, the results of an early 1980s seafood dietary survey (U.S. EPA, 1980) were analyzed to calculate the average consumption of freshwater and estuarine fish and shellfish (45

[6] For the purposes of this report, *fish consumers* include all people in Washington who eat finfish or shellfish. While there is variability among how much fish is consumed by—both within and among—various population groups, some people never include fish in their diets. These people are considered non-consumers.

[7] The 6.5 grams per day contaminated fish consumption value is equivalent to the average per-capita consumption rate of all (contaminated and non-contaminated) freshwater and estuarine fish for the U.S. population (57 Fed. Reg. 60863).

[8] Moderate and high average fish consumption estimates for the U.S. national population were based on the consumption of fish and shellfish from fresh, estuarine, and marine waters (U.S. EPA, 1989a).

Fed. Reg. 79348). In the absence of estimates of fish dietary information from local fish-consuming populations, an EPA companion guidance document to the National Toxics Rule proposed the following average consumption rates:

- 6.5 g/day to represent a low estimate of average consumption of fish and shellfish from estuarine and fresh waters by the U.S. population.
- 20 g/day to represent a moderate estimate of the average consumption of fish and shellfish from marine, estuarine, and fresh waters by the U.S. population.
- 165 g/day to represent a high estimate of the average consumption of fish and shellfish from marine, estuarine, and fresh waters by the 99.9th percentile of the U.S. population.

In contrast to the low average estimate, the moderate and high average fish consumption estimates for the U.S. population is based on the consumption of fish and shellfish not only from fresh and estuarine waters but also from marine waters (U.S. EPA, 1989a, page 58 and Table 7, page 71).

There have been many scientific and regulatory developments related to fish consumption rates over the past 20 years. These include:

- Acquisition of recent scientific data on finfish and shellfish consumption rates for different population groups.
- Updated approaches used by other state and federal agencies.
- Analysis of uncertainty and variability in finfish and shellfish consumption rates for different population groups and individuals within those groups.
- Analysis of current and potential future exposures resulting from finfish and shellfish consumption.
- Revision of state laws and policies, including MTCA and the Water Pollution Control Act.
- Assertion of tribal fishing rights by tribes.

1.2 Intended audience

Ecology will use this document to engage multiple audiences in discussions on issues related to fish consumption rates.[9] This report is meant to facilitate discussions with interested parties and persons throughout Washington.

To facilitate these discussions, it is important to understand the different ways we express fish consumption rates in this Technical Support Document. In general, a fish consumption rate is presented as grams of fish consumed per day (g/day). For many readers, it is easier to understand a fish consumption rate expressed in ounces per day, or number of 8-ounce meals per week. (An

[9] The term *fish* includes all types of finfish and shellfish. When discussing the species that are consumed, fish are categorized by species groupings.

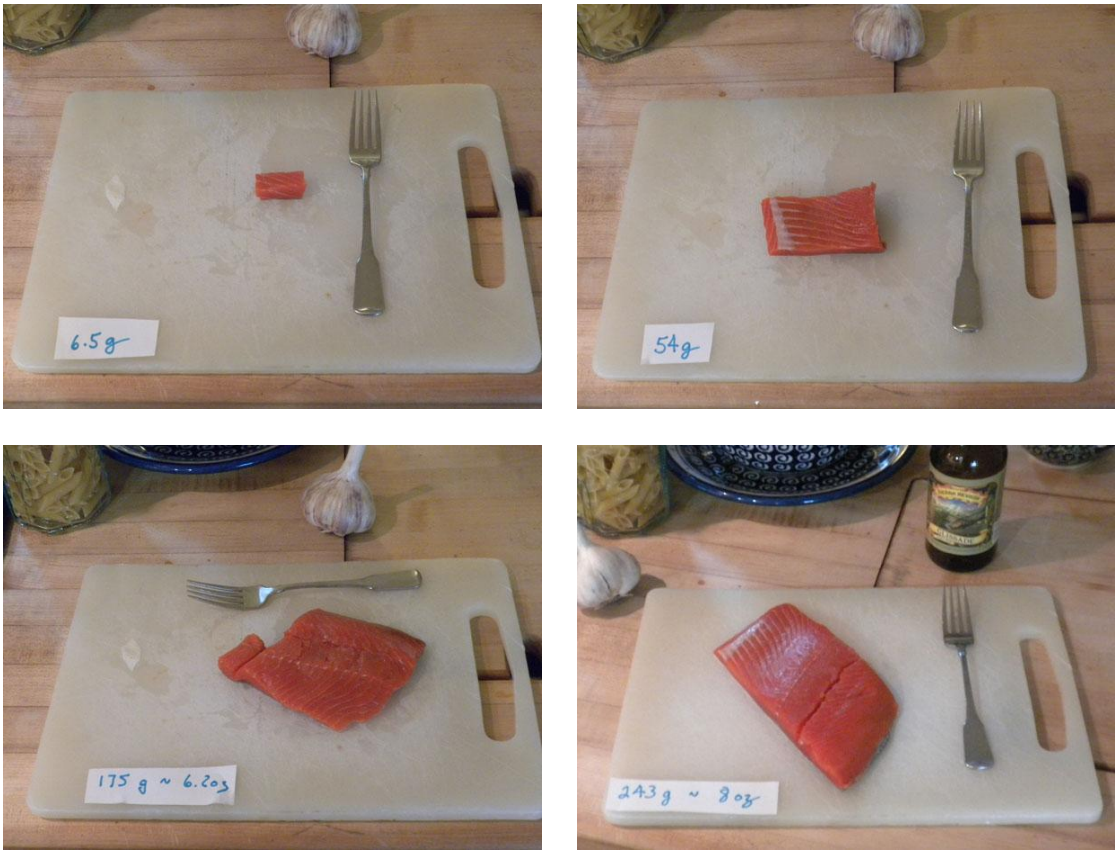
8-ounce meal corresponds to approximately 227 grams.) Another way to express fish consumption is in terms of the frequency of an 8-ounce meal (e.g., once per month, three times per week), or as total pounds of fish per year. Table 2 summarizes the different metrics that are used to describe fish consumption rates.

Table 2. Different Metrics Used to Describe Fish Consumption Rates

Consumption Rate Metric	Examples of Consumption Rates For Each Metric						
Grams per day	6.5	17.5	50	100	260	500	620
Ounces per day	0.23	0.62	1.8	3.5	10	18	22
Number of 8-ounce meals per week	0.2	0.5	1.5	3	8	15	17
Frequency of 8-ounce meals	< one 8-ounce meal per month	Two 8-ounce meals per month	One to two 8-ounce meals per week	Three 8-ounce meals per week	Every day or ½ pound per day	Twice per day or 1 pound per day	1 pound per day plus other forms and uses
Pounds per year	5	15	40	80	200	400	500

Source: Adapted from Swinomish Tribe, 2006, Table 30.

In the absence of population-specific fish dietary information, the U.S. EPA suggest using a default value of 8 ounces (227 grams) as an average meal size for the general adult population (72-kilogram person) for exposure assessments and fish advisories (U.S. EPA, 2000d).



Fish portion sizes (6.5, 54, 175, and 243 grams)

1.3 Purpose of this document

The purpose of this Technical Support Document (Version 2.0) is to compile and evaluate existing data on fish consumption in Washington State. It is a technical document, and is not designed to resolve policy issues associated with using that information to make regulatory decisions. Those issues will be dealt with in separate rulemaking documents and processes.

This Technical Support Document provides useful background information for discussions related to finfish and shellfish consumption rates. The primary question addressed in this document is:

- What is currently known about fish consumption habits and rates for people in Washington?

Specifically, what types of data are available, how much fish do people in various population groups eat, what kinds of fish do they eat, and where do they obtain the fish?

Ecology recognizes that many other considerations factor into calculating protective standards, including acceptable risk levels and exposure parameters (such as exposure duration). These considerations may be relevant to various regulatory discussions. This particular document, however, focuses primarily on technical information related to fish consumption rates.

1.4 Document history

Ecology distributed the *Fish Consumption Rates Technical Support Document, Version 1.0,* for public review in September 2011. The document was prepared to support discussion on whether and how to revise the fish consumption rates in the Sediment Management Standards (SMS) rule. Ecology held several public workshops to discuss the draft report and regulatory implications.

Ecology received several hundred written comments on the draft report. Ecology has reviewed those comments and prepared written responses that are compiled in a separate document. As part of that review, Ecology also performed additional technical analyses to address several issues raised during the public comment period.

Ecology has considered the comments and analyses when revising this Technical Support Document. Significant revisions include the following:

- *General population studies.* Several people recommended that Ecology provide information on fish consumption rates for the general population. Ecology has worked with the University of Washington to review national dietary surveys that provide information on fish consumption rates for the general population, and has included the results of that review in the revised document.
- *Recreational fisher studies.* Several people recommended that Ecology provide information on fish consumption rates for recreational fishers. Ecology reviewed available studies on recreational fishers. Based on that review, Ecology has conducted an

independent assessment, provided in a separate Technical Issue Paper (Ecology, 2012), that details recreational fish consumption studies conducted in Washington. Ecology has incorporated the results of that review into this revised Technical Support Document.

- *Asian Pacific Islander (API) studies.* Several people recommended that Ecology consider additional information on the fish dietary habits of API populations. Ecology has incorporated additional information on API populations into this revised Technical Support Document.
- *Estimating long-term consumption rates.* Several people expressed concerns about using the results from short-term episodic dietary studies to estimate long-term upper percentile fish consumption rates. Ecology has reviewed and evaluated methods for adjusting short-term episodic dietary information to provide fish consumption estimates and percentiles. These statistical corrections were used to estimate annual fish consumption rates for the general population from 2-day national survey data.
- *Salmon.* Ecology received a wide range of comments on salmon, their life cycles and survival strategies, and salmon contaminant body burdens. This document provides fish consumption estimates with and without salmon from several fish dietary surveys of Pacific Northwest populations. Where available, fish consumption estimates are tabulated for anadromous and non-anadromous species. Additional information on salmon contaminant body burdens is provided in Appendix C and in the Technical Issue Paper, *Salmon Life History and Contaminant Body Burdens* (Ecology, 2012).
- *Analysis of regional fish dietary information*. In Version 1.0 of this Technical Support Document, Ecology provided the results of a statistical evaluation from fish dietary surveys of Pacific Northwest populations. Ecology's evaluation provided fish consumption estimates between the 80^{th} and 95^{th} percentiles of the fish consumption distribution. Several people provided comments regarding policy choices embedded in this evaluation. Ecology has reviewed these comments, and in order to facilitate broad consideration in the process of revising the Water Quality Standards for Surface Waters, this version of the Technical Support Document does not provide a recommended range for fish consumption rates. Discussion is provided in Chapter 4.
- *Policy statements and recommendations.* This Technical Support Document is focused on finfish and shellfish resources in the Pacific Northwest, and Washington State fish-consuming populations. It includes information from fish dietary surveys of Pacific Northwest populations and national general population data. Ecology acknowledges that there are many policy decisions associated with estimating fish consumption rates for Washington State fish-consuming populations. Some of these policy issues are noted in Chapter 6. This document, however, does not provide a thorough discussion of policy choices. The issues are identified only to assist readers in a broader understanding of the context in which fish consumption rates are considered.

1.5 Organization of this document

The remainder of this document is organized as follows.

Chapter 2: Washington Fish Resources and Fish-Consuming Populations

Available information indicates that some Washington residents consume locally harvested finfish and/or shellfish. In addition, several population subgroups (including Native Americans and Asian and Pacific Islanders) consume large amounts of finfish and shellfish. This chapter summarizes available information on state water resources that support fishing practices. Regional differences are acknowledged and the size and demographic characteristics of Washington finfish and shellfish consumers and consuming populations are identified.

Chapter 3: Methodology for Assessing Fish Consumption Rate Information

Several approaches are available for developing estimates of finfish and shellfish consumption. Although surveys are generally considered to be the best approach for developing these estimates, a number of design features determine whether a particular survey provides a technically defensible basis for agency decision making. This chapter reviews those design features and outlines the factors considered when evaluating studies.

Chapter 4: Fish Consumption Survey Data that Apply to Washington Fish Consumers

This chapter reviews and analyzes available fish consumption survey data for the general population, Pacific Northwest Native American tribes, Asian and Pacific Islanders, and recreational fishers. It includes a discussion of variability and uncertainty in the survey data, and summarizes key findings.

Chapter 5: Sources of Uncertainty and Variability

When making regulatory decisions, it is important to consider the uncertainties associated with available data and the variability across individuals, fish species, and geographic areas. This chapter provides a high-level summary of important sources of uncertainty and variability in fish consumption surveys used to estimate finfish and shellfish consumption rates.

Chapter 6: Using Scientific Data to Support Regulatory Decisions

This chapter highlights some of the policy choices that will be needed when using fish consumption rates to support regulatory decisions. The discussion includes brief descriptions of particular regulatory issues and a range of examples to illustrate how agencies have resolved each issue.

Appendices

Included here is other fish consumption information used for regulatory decision making including fish species found in Washington, information on additional tribal studies, correspondence from the Columbia River Inter-Tribal Fish Commission and University of Washington, further discussion on the challenges of risk assessment and salmon consumption, a glossary of terms, and a complete list of reference citations presented alphabetically by author.

Chapter 2: Washington Fish Resources and Fish-Consuming Populations

2.1 Introduction

Washington is home to a wide range of water resources that support commercial, recreational, and subsistence fishing and harvesting. Many Washington residents consume some local finfish or shellfish. Several population groups consume larger amounts of finfish and shellfish than the general population. These include members of Native American tribal nations, Asian and Pacific Islanders, and people who fish recreationally (recreational fishers).

Ecology's review of available data on fish harvests identified the commercial, tribal, and recreational harvesting of multiple species, including groundfish, Pacific halibut, coastal pelagic species, highly migratory species, salmon, other anadromous species and eggs, and shellfish. Similarly, recreational sport fishing is structured around a multispecies fishery, and hundreds of thousands of sport anglers harvest fish throughout Washington.

Salmon are of particular importance in Washington, and questions about salmon are discussed at several points in this report. Salmon are harvested from both fresh and marine waters. The Puget Sound basin and the Columbia River basin dominate the areas of harvest. Steelhead and salmon (from both fresh and marine waters) accounted for about half of the recreational sport harvest (close to 400,000 fish) in 2006.

This chapter is organized into the following sections:

- *Fish resources.* A summary of finfish and shellfish resources in Washington.
- *Estimated number of Washington fish consumers.* This section provides rough estimates on the number of adults and children in Washington who regularly eat finfish and/or shellfish.
- *High fish-consuming populations.* This section defines *high fish consumers* and identifies and describes subpopulations in Washington generally known to be high fish consumers.

Washington waters support large finfish and shellfish populations and commercial, tribal, and recreational harvests.

2.2 Washington fish resources

Washington has more than 500 miles of Pacific coast shoreline and over 2,000 combined miles of Puget Sound, San Juan Islands, Strait of Juan de Fuca, and Hood Canal shoreline. This shoreline provides habitat for marine finfish and shellfish. In addition, the state has 4,000 rivers

and streams, stretching over 50,000 miles. Many streams and rivers have seasonal salmon and steelhead runs. State waters also include more than 7,000 lakes, with over 2,500 lakes at alpine elevations, and more than 200 reservoirs that provide additional fishing opportunities. Many freshwater areas are open for fishing year-round (WDFW, 2010).

A large variety of finfish and shellfish are available for harvesting in Washington (WDFW, 2010, p. 17–30). The Washington Department of Fish and Wildlife (WDFW) has identified more than 50 species of edible freshwater fish and almost as many in marine waters (WDFW, 2010, p. 17–30). (See Appendix C for information on finfish and shellfish species harvested in Washington.)

A study to summarize the economic benefits of Washington's non-treaty commercial and recreational fisheries provides information on the valuation and numbers of commercial and recreational finfish and shellfish harvested throughout Washington. In 2006, commercial fish landings from non-treaty fisheries totaled more than 109 million pounds. The Washington coastal area is the largest contributor to commercial fish harvesting, accounting for 85 percent of total pounds landed (WDFW, 2008a).

The fish consumption rate tabulations in this technical support document are derived from national fish dietary data and from fish dietary surveys from the Pacific Northwest. The tribal fish dietary surveys from the Pacific Northwest document fish locally harvested and consumed. Independent and separate documentation from three different Washington State agencies (WDFW, Washington State Department of Health [DOH], and Ecology) document the harvest and consumption of local aquatic resources, including finfish and shellfish. However, data gaps remain regarding the exact locations of where fish and shellfish are harvested in Washington and how the fish are then made commercially available for consumption.

2.2.1 Washington's commercial fisheries

Washington's commercial fisheries include harvest of groundfish, Pacific halibut, coastal pelagic species, highly migratory species, salmon (including eggs), other anadromous species, and shellfish. In 2006, nontribal commercial fish landings from Washington fisheries totaled approximately 109.4 million pounds.

In 2006, groundfish (bottom-dwelling fish or bottomfish) composed the state's largest commercial fishery. Groundfish accounted for 54 percent of the commercial catch from Washington waters, with approximately 59.2 million pounds landed. Shellfish landings represented the state's second-largest commercial fishery, accounting for almost 25 percent of the commercial catch, with approximately 25.8 million pounds landed in 2006.

Salmon is a major contributor to Washington's commercial fishing industry. Salmon landings from Washington waters totaled about 11 million pounds, accounting for about 10 percent of the commercial catch in 2006.

Table 3 illustrates the extent of Washington's commercial fisheries, showing pounds of fish harvested from Washington non-treaty fisheries in 2006.

Table 3. Commercial Fish Landings from Washington Non-treaty Fisheries in 2006

Species	Pounds Landed
Groundfish (excluding halibut)	59,217,924
Total shellfish	25,789,641
Salmon	11,020,228
Coastal pelagic species	8,233,078
Highly migratory species	4,802,666
Other anadromous fish and eggs	158,621
Pacific halibut	135,868
Total commercial pounds landed of finfish/shellfish	109,358,026

Source: Adapted from WDFW, 2008a, Table 1, p. 6.

2.2.2 Washington's recreational fisheries

Traditionally, Washington's most intense freshwater fishing activity begins during the last weekend in April. Based on estimates from WDFW, over 300,000 anglers fish during opening weekend of the lowland lakes season. To meet this demand, WDFW stocks about 19 million trout and kokanee fry annually. Another 3 million catchable trout are planted in lakes and streams. In addition, many lakes receive additional sterile rainbow trout. Most rivers and streams throughout Washington are managed to produce wild trout, coastal and west slope cutthroat, salmon, and steelhead (WDFW, 2010).

An estimated total of 824,000 people fished in Washington in 2006, including both finfishing and shellfishing. Of these, an estimated 725,000 anglers (88 percent of the total) were state residents who fished a combined total of about 8.5 million days that year. This equals 93 percent of all fishing days available for licensed recreational sport fishing (WDFW, 2008a).

Marine recreational fishing and shellfishing occurs along more than 500 miles of the Pacific Coast shoreline and more than 2,000 combined miles of shoreline throughout Puget Sound, the San Juan Islands, the Strait of Juan de Fuca, and Hood Canal (WDFW, 2008a). As previously noted, freshwater recreational fish inhabit more than 4,000 rivers and streams extending over 50,000 miles, 7,000 lakes, and 200 reservoirs (WDFW, 2010, 2012). The following are selected highlights of recreational sport fishing and shellfishing that identify the species available for recreational anglers across Washington:

- Recreational fishing for shad on the Columbia River with several million shad passing through Bonneville Dam annually.
- WDFW lists state record catches for more than 50 freshwater species of fish (e.g., rainbow trout, Beardslee rainbow trout, brown trout, and numerous other trout species).
- Recreational sturgeon fishing on the Columbia River.
- Marine recreational seasonal fishing for lingcod, halibut, and rockfish as well as other marine bottomfish.
- Recreational shellfishing for oysters, clams, shrimp, and crab throughout Puget Sound, Hood Canal, the San Juan Islands, and the Strait of Juan de Fuca.

Recreational sport fishers harvest finfish in fresh and marine waters and shellfish along marine shorelines. Approximately 22 million trout and kokanee are stocked annually in lakes and inland streams and are available to recreational anglers. Tables 4 and 5 list information on the 2006 sport finfish and shellfish harvests, respectively. These numbers demonstrate the extent of recreational fishing in Washington.

Approximately two-thirds of the 2006 catch for bottomfish was harvested in coastal waters, with the remaining one-third harvested from the marine waters of Puget Sound.[10] Approximately 74 percent of the steelhead and 95 percent of the sturgeon harvested from Washington waters in 2006 were from the Columbia River and its tributaries.

Table 4. Number of Recreational Finfish Caught in Washington Waters in 2006 by Species and Region

Species/Group	Number of Finfish Harvested from each Catch Region				
	Puget Sound	Coast	Columbia River*	Unknown	Total
Bottomfish	112,457	295,151	---	---	407,608
Salmon – freshwater	98,576	7,186	65,817	1,227	172,806
Steelhead	12,709	15,415	80,294	477	108,895
Salmon – marine	65,423	43,027	---	---	108,450
Albacore	---	18,941	---	---	18,941
Sturgeon	203	456	15,695	182	16,536
Pacific halibut	2,727	6,977	692	---	10,400
Total	292,095	387,153	162,498	1,886	843,636

Source: Adapted from WDFW, 2008a, Table 6, p. 17.

* Columbia River region includes the Columbia River and all tributaries and the Snake River.

[10] The term *coastal waters* refers to waters having a coastline that forms the boundary between land and freshwaters and marine and/or estuarine waters. This term encompasses all freshwaters of statewide significance (lakes, rivers, streams, etc.) and those marine and/or estuarine waters extending from the landward edge of a barrier beach or shoreline of coastal bay to the outer extent of the continental shelf.

Table 5. Pounds of Shellfish Taken Recreationally From Washington Waters in 2006, by Species and Region

Species/Group	Pounds of Shellfish Harvested from each Catch Region					
	North Puget Sound	South Puget Sound	Strait	Coast	Columbia River	Totals
Dungeness crab	3,330,004	271,167	261,540	---	---	3,862,711
Razor clams	---	---	---	3,601,000		3,601,000
Oysters	19,129	632,966	---	---	---	652,095
Other clams	93,038	252,628	---	---	---	345,666
Shrimp	23,520	87,996	1,950	---	---	113,466

Source: Adapted from WDFW, 2008a, Table 7, p. 17.

All values are in pounds except oysters, which are in number of oysters harvested.

Salmon were harvested in both fresh and marine waters, with approximately 60 percent of the salmon harvest occurring in marine waters. Puget Sound salmon accounted for approximately 60 percent of all salmon harvested in marine waters. In fresh water, approximately 57 percent of salmon are harvested in Puget Sound streams and 38 percent are from the Columbia River and its tributaries.

Dungeness crab taken from north Puget Sound waters accounted for more than 85 percent of the 2006 statewide harvest. Razor clams are only harvested from coastal beaches. Tens of thousands of recreational sport clammers harvest razor clams on weekends during clamming season (WDFW, 2008a).

2.3 Washington fish-consuming population

Washington is home to a culturally and ethnically diverse population that is projected to become more diversified over the next 20 years. The Washington Office of Financial Management (OFM) provides the following demographic information (U.S. Census Bureau, 2000, 2010)[11]:

- Total Washington Population as of April 1, 2010 — 6.72 million
  - Adults (74 percent of the population is estimated at over 18) — 5.14 million
  - Children (between 0 and 18 years of age) — 1.71 million

OFM projects that the Washington population will increase by 1.8 million people in the next 20 years: [12]

[11] Population estimates are based on census data, and may vary depending on the census accounting procedures used to generate estimates for specific subpopulations. Therefore, subpopulation estimates and totals may not align perfectly.

[12] Population projections are provided for illustrative purposes; they are not intended as precise estimates. Population projections presented in this document do not reflect 2012 redistricting updates.

- Projected Total Washington Population, 2030 8.54 million
  Projected children (between 0 and 18 years of age) 2030 2.06 million

2.3.1 Estimated number of fish consumers in Washington

The general population is made up of people with a variety of dietary preferences. Some consume fish frequently, some infrequently, and some potentially never. (However, even people who report they don't eat fish may consume some fish in processed foods like salad dressing, Worcestershire sauce, and cheese spread.) Per capita rates that take into account the entire population will differ from rates derived from consideration of so-called *consumer only* data. For protection of people who eat fish, the population of interest is generally considered to be fish consumers (CalEPA 2001, page 13; Oregon DEQ 2008; U.S.EPA 2002b).

People consume finfish and shellfish obtained from a variety of sources. Information about fish consumed by the general Washington population is available only through estimates.[13] While there are uncertainties associated with these estimates, they are useful in providing context to the discussion about fish consumption rates.

First, the total number of fish consumers was estimated. A *fish consumer* is someone who eats finfish or shellfish at least occasionally. Then a definition of *high fish consumer* was used to suggest the number of people in the general population at the high end of the exposure distribution. These estimates provide only a rough number of fish consumers and no information about the source of the fish. Ecology also reviewed available information on certain ethnic groups that consume fish from local waters.

To estimate the number of fish consumers in Washington, and how much fish they consume, Ecology considered multiple estimation methods. This is consistent with the approach taken by the Oregon Department of Environmental Quality (Oregon DEQ) Human Health Focus Group.

Using 2010 demographic information provided by the Washington OFM, Ecology estimates that between 1.4 and 3.8 million Washington adults (and approximately 290,000 Washington children 0 to 18 years old) are fish consumers. These upper and lower estimates were developed using two different methods, as described below:

- *Low Estimate: Based on national survey data.* The first approach resulted in the lower of the two estimates. It was developed using Washington population data and information on the percentage of fish consumers reported in *Estimated Per Capita Fish Consumption*

[13] These estimates use the EPA 2002 data and are consistent with the methodology used by the Oregon Human Health Focus Group. They do not use the National Health and Nutrition Examination Survey (NHANES) results because these estimates were developed before that work was complete.

in the United States (U.S. EPA, 2002a).[14] For this estimate of fish consumers in Washington, Ecology assumed that Washington dietary habits are similar to those for the United States as a whole. The Oregon DEQ Human Health Focus Group used this approach to prepare estimates of fish consumers in Oregon.[15] (See Chapter 4 for additional information on estimated United States per capita fish consumption.)

- *Adults.* EPA found that 28 percent of adults interviewed in the national survey were fish consumers (U.S. EPA, 2002a, Section 5.1.1.1, Table 4). Assuming that a similar percentage of Washington's 5.1 million adults also consume fish, Ecology estimates that approximately 1.4 million adults in Washington currently eat some amount of fish.
- *Children.* EPA found that 16 to 19 percent of children (ages 0 to 18) included in the national survey were fish consumers (Moya, 2011, personal communication).[16] Assuming that 17 percent of Washington's 1.7 million children also consume fish, Ecology estimates that there are approximately 290,000 children in Washington who currently eat some amount of fish.

- *High Estimate: Based on Washington State Department of Health survey.* The second approach resulted in the higher estimate. It was developed using Washington population data and information compiled by the DOH. DOH used the Behavioral Risk Factor Surveillance System (BRFSS) to compile information on fish consumption habits of randomly selected Washington residents.[17] This work was done over a 4-year period; it was designed to improve DOH's understanding of the percent of the Washington population that consumes fish.

Washington State Behavioral Risk Factor Surveillance System

The BRFSS telephone survey is a valuable health management tool used by DOH to collect health-based information and monitor the public's behavioral risk factors that may contribute to a person's health. The BRFSS primarily collects data on chronic diseases, injuries, infectious illnesses, and the behavioral factors underlying these conditions.

[14] This percent value may underestimate the fraction of fish consumers in Washington State because other parts of the United States do not have the fisheries resources available in Washington State.

[15] Ecology acknowledges the limitations of the national fish dietary data; this approach employed a 2-day dietary recall survey methodology where respondents who did not report eating fish on one of the two survey days were counted as non-consumers and averaged with consumers as a zero. As noted by the EPA 2011 *Exposure Factors Handbook*, p. 10-16, "… short-term consumption data may not accurately reflect long-term eating patterns and may under-represent infrequent consumers of a given fish species. This is particularly true for the tails (extremes) of the distribution of food intake. Because these are 2-day averages, consumption estimates at the upper end of the intake distribution may be underestimated are used to assess acute (i.e., short-term) exposures."

[16] Approximately 18 percent of the U.S. general population ages 16 – 21 are fish consumers; approximately 31 percent of the U.S. general population ages 20 – 50 are fish consumers. Information is based on EPA's reexamination of the National Health and Nutrition Examination Survey (NHANES) and the 2002 per capita fish consumption report.

[17] The BRFSS is sponsored by the U.S. Centers for Disease Control and Prevention (CDC) and is a probability-based telephone survey of non-institutionalized adults, ages 18 years and over.

- DOH found that in 2002 and 2004, 78 percent and 74 percent, respectively, of adults in Washington consumed store-bought fish. In 2005, 57 percent of the adults surveyed reported eating fresh fish purchased at a local grocery store or fish market (frozen fish excluded). Among Washington fish consumers, 44 percent consumed salmon, 20 percent consumed halibut, 13 percent consumed cod, and 6 percent consumed tuna.
- Although these data were intended for use by DOH in developing fish consumption advisory programs, Ecology, after consultation with DOH, determined that the information is appropriate for estimating the total number of fish consumers in Washington as needed for this report.
- Working with DOH, Ecology estimated that between 2.9 and 3.8 million Washington adults currently consume some amount of finfish and/or shellfish. Table 6 provides estimates of Washington fish consumers calculated by Ecology using the DOH data.

Table 6. Estimated Washington Fish Consumers Based on Washington DOH Survey Data

Years for Projected Population Estimates	Estimated number of Washington adults who consume:		
	Store-bought fish	Fish from local stores or markets	Salmon
2010	3.80 million [a]	2.93 million [b]	1.67 million
2030	4.88 million	3.76 million	2.90 million

a. This estimate assumes 74 percent of the total adult population consuming store-bought fish, per the DOH 2004 data.
b. This estimate assumes 57 percent of the total adult population consuming fresh fish from local stores or markets, per the DOH 2005 data.

Population projections are included to illustrate that estimates of total fish consumers in Washington are expected to increase as the population grows.

2.3.2 Estimated number of high fish-consuming adults

Pacific Northwest fish dietary information shows that certain populations—Native American tribes, Asian Pacific Islanders, and recreational fishers—consume fish at much higher rates than the average U.S. consumer and at higher rates than those used to establish surface water cleanup standards. Because these populations consume fish at higher rates than the national rates used in Ecology's regulations, their exposure to contaminants in fish may be underestimated and these populations may therefore be at a higher risk. For this reason, Ecology has estimated the number of high fish consumers in the general population. The estimate is intended only to provide

Fish consumption-related BRFSS telephone survey questions

BRFSS telephone survey questions related to fish dietary habits provide DOH with information on:

* Types and frequency of finfish consumption.
* Perceptions about the benefits of eating fish (are fish healthy to eat).
* How, where, or in what form the public receives information about fish health advisories that limit fish consumption based on mercury contamination.
* Whether people are following the fish advisories.
* Regional differences regarding frequency and types of fish consumed.

context; it does not provide information on where these consumers obtain their fish and shellfish. Specifically, it does not address the question of whether this is locally harvested.[18]

Information elsewhere in this report notes that many people in Washington consume fish from local waters—for example, recreational anglers.

For purposes of this estimate, *high fish consumers* are persons who consume fish at or above the 90th percentile of the national per capita fish consumption rate. The fish consumption rate that corresponds to the 90th percentile national per capita consumption depends on the dataset and statistical method used. The choice for defining high fish consumers this way was made for illustrative purposes. It is consistent with EPA regulatory policy and procedures and is the definition used by the Oregon Human Health Focus Group.

Selected results from BRFSS telephone survey

* In 2005, about 44 percent of all adults surveyed consumed salmon in the past 30 days.
* In 2005, about 20 percent of all adults surveyed consumed halibut in the past 30 days.
* In 2005, about 13 percent of all adults surveyed consumed cod in the past 30 days. All other species were consumed by <10 percent of survey participants.
* In 2004, about 74 percent of all adults surveyed followed fish advisories when they thought the fish advice applied to them. However, only about 44 percent of all adults surveyed thought the fish advisory applied to them.
* In 2004, about 98 percent of the pregnant women surveyed followed fish advisories when they thought the fish advice applied to them. However, only about 48 percent of the pregnant women surveyed thought the fish advisory applied to them.
* In 2004, about 35 percent of all adults surveyed reported eating sport fish in the past year harvested from Washington State waters. Among different races, about 47 percent of adult American Indians, 38 percent of Pacific Islanders, 23 percent of Asians, and 19 percent of Blacks reported eating sport fish in the past year.
* In 2004, about 35 percent of adults living in Western Washington counties (Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Pierce, San Juan, Skagit, Skamania, Snohomish, Thurston, Wahkiakum, and Whatcom) reported eating any sport fish in the past year. About 40 percent of adults living in counties along the Columbia River reported eating any sport fish in the past year, while 34 percent of adults living in Puget Sound counties and 57 percent of adults living in outer coastal counties reported eating sport fish in the past year.

[18] The term *locally harvested* is used to identify the source of fish. It is used to distinguish fish harvested locally from fish purchased and coming from unknown and potentially non-local (out of state) sources.

Based on EPA's *Estimated Per Capita Fish Consumption in the United States*, the 90th percentile of the estimated national fish consumption rate for adult fish consumers only corresponds to 250 g/day (U.S. EPA, 2002a).[19] (250 grams is approximately 0.55 pound or 8.8 ounces.) This value is used to define high fish-consuming adults in this Technical Support Document. (See Chapter 6 for a discussion of per capita vs. consumer-only fish consumption rates.)

Ecology has also evaluated national fish dietary information using data from the U.S. Department of Agriculture's National Health and Nutrition Examination Survey (NHANES), 2003–2006. This analysis is discussed in Chapter 4. Based on this evaluation, the 90th percentile of the estimated national per capita fish consumption for adult consumers is in the range of 42.5 g/day to 128 g/day, depending on the statistical method used.

Ecology estimates that between approximately 140,000 and 380,000 Washington adults are high fish consumers (Table 7). Based on OFM population projections, this number could increase by 27 percent over the next 20 years.

2.3.3 Assumptions

This estimate is based on a number of assumptions that Ecology believes to be reasonable:

- Between approximately 1.4 million and 3.8 million Washington adults consume some amount of fish on a regular basis. As described in the previous sections, this range is based on current population data and estimates indicating that between 28 and 74 percent of Washington adults regularly consume fish.[20]
- *High fish consumers* are defined as people who consume more than the 90th percentile estimate of finfish and/or shellfish per day.[21] The 90th percentile of the fish consumption distribution may be based on national data as evaluated by EPA in 2002 or by Ecology in 2012 using the 2003–2006 NHANES data. Estimates of adult fish consumption rates vary depending on the statistical methodology used to evaluate the data.
- The dietary habits and patterns for Washington fish consumers are similar to those reported for the United States fish consumers.[22]

[19] Corresponds to the 90th percentile intake of finfish and shellfish for adult consumers only, based on uncooked fish weight. See U.S. EPA, 2002a, Section 5.2.1.1, Table 4.

[20] The 2003 – 2006 NHANES dietary information provides reasonably comparable low end percent estimates of fish consumers as evaluated in EPA, 2002, and Polissar et al., 2012.

[21] Unless otherwise noted, in this document the term *fish consumption rate* refers to consumption of both finfish and shellfish.

[22] This assumption is discussed further in the conclusions to this chapter.

Table 7. Estimated Number of Fish Consumers among the General Washington Adult Population

Year	Total Population of Washington Adults	Estimated Number of Washington Adult Fish Consumers		Estimated Number of Washington Adults who are High Fish Consumers (90th percentile or above)	
		Low Estimate	High Estimate	Low Estimate	High Estimate
2010	5.14 million	1.44 million	3.81 million	144,000	381,000
2030	6.59 million	1.85 million	4.88 million	185,000	488,000

As noted, estimates of fish consumption that correspond to the 90th percentile of the distribution may vary depending on the statistical methods used to evaluate the national data. Regardless of the national dataset used and the statistical methodology used to evaluate the national data, population estimates for Washington State fish-consuming adults based on the 90th percentile of the fish consumption distribution indicate that there are a large number of adults in Washington who consume fish (for adult low and high estimates approximating 30 to 75 percent of the total Washington State population). Note that the information used for estimates of fish consumption among the general adult population is for total fish consumed from all sources.

2.3.4 Estimated number of high fish-consuming children

For purposes of this report, Ecology defines children as high fish consumers if they consume fish at or above the 90th percentile of the estimated national per capita fish consumption rate for children. As discussed above, the fish consumption rate that corresponds to the 90th percentile depends on the dataset and statistical method used to evaluate the data. Based on EPA's *Estimated Per Capita Fish Consumption in the United States*, the 90th percentile of the estimated national per capita fish consumption rate for children who eat fish corresponds to 190 g/day (U.S. EPA, 2002a).[23] (190 grams is approximately 0.42 pound or 6.7 ounces.) Ecology's evaluation of the NHANES 2003–2006 data, as described in Section 4.2.2, did not include estimation of fish consumption rates for children.

Ecology estimates that there are approximately 29,000 Washington children who are high fish consumers (Table 8). Based on OFM population projections, this number could increase by 83 percent over the next 20 years.

This estimate is based on the following assumptions that Ecology believes to be reasonable:

- Approximately 290,000 Washington children eat some amount of fish on a regular basis. As discussed in an earlier section, this estimate is based on current population estimates and national survey results that indicate that 16 to 19 percent of children reported eating some amount of finfish or shellfish.

[23] Corresponds to the 90th percentile intake of finfish and shellfish for consumers only, age 14 and under. Based on uncooked fish weight.

- Children are defined as high fish consumers when they consume more than the 90th percentile estimate of finfish and/or shellfish per day. The 90th percentile of the fish consumption distribution to define a high fish consumer may be applied to the national data as evaluated by the EPA (U.S. EPA, 2002a, Section 5.2.1.1, Table 4) or to the 2003–2006 NHANES data. Estimates of children's fish consumption will vary depending on the statistical methodology used to evaluate the data. The information in Table 8 suggests that about 20 percent of the total children in Washington State are fish consumers.
- The dietary habits and patterns for Washington fish consumers are similar to those reported for the United States fish consumers.

Table 8. Estimated Number of Child Fish Consumers among the General Washington Population

(Children Younger Than 18 Years Consuming Large Amounts of Finfish or Shellfish)

Year	Total Population of Children (18 and younger)	Estimated Number of Washington Child Fish Consumers	Estimated Number of Washington Children who are High Fish Consumers (90th percentile or above)
2010	1.71 million	290,000	29,000
2030	2.06 million	350,000	35,000

2.4 High fish-consuming populations

Some population groups consume especially large amounts of finfish and shellfish as part of traditionally influenced diets. These include Native Americans and Asian, Pacific Islanders, and subsistence and recreational fishers.

2.4.1 Washington Native American Tribes

Washington is home to 29 federally recognized and seven non-federally recognized Native American tribes (Governor's Office of Indian Affairs, 2010). Traditional fishing areas for tribes cover essentially all of Washington.

The Washington OFM estimates there are approximately 104,000 American Indian and Alaska natives in Washington. Approximately 70 percent of the American Indian and Alaska native population is 18 years of age or older (73,500 adults) (U.S. Census Bureau, 2000, Table 2). OFM estimates there are 33,600 American Indian and Alaska natives between the ages of 0 and 18 years.

OFM projects that the total number of Native Americans in Washington will increase from 104,000 in 2010 to approximately 146,000 by the year 2030:[24]

[24] 2010 population numbers are based on the 2010 Census redistricting data. 2030 estimates are as of the OFM 2006 Population Projections by Age, Sex, and Race.

- Population of American Indian and Alaska natives in Washington 104,000
  Adults (70 percent of population is estimated at over 18) 73,500
  Children (between 0 and 18 years of age) 33,600
- 2030 Population Projection 146,000

2.4.2 Asian and Pacific Islanders

Asian and Pacific Islander (API) populations include Native Hawaiians and peoples from other Pacific islands. The Washington OFM estimates there are approximately 522,000 Asian and Pacific Islanders currently residing in Washington (U.S. Census Bureau, 2000, Table 2). Finfish and shellfish consumption among this population in Washington has been documented. Approximately 75 percent of the current API population is 18 years of age or older (405,000 adults) (Sechena et al., 1999). There are 138,000 Asian and Pacific Islanders between the ages of 0 and 18 years.

OFM projects that the total number of Asian and Pacific Islanders in Washington will increase from 522,000 in 2010 to approximately 825,000 by the year 2030:[25]

- Population of Asian and Pacific Islanders in Washington 522,000
  Adults (75 percent of the population is estimated at over 18) 405,000
  Children (between 0 and 18 years of age) 138,000
- 2030 API Population Projection 825,000

2.4.3 Subsistence and recreational fishers

Approximately 824,000 people fished in Washington State during 2006; of these, 725,000 were Washington residents and 99,000 were nonresidents. Washington residents fished a total of 8.5 million days in 2006, an average of 12 days per angler (U.S. Department of the Interior and U.S. Department of Commerce, 2008).

Washington is home to some number of persons engaged in a subsistence lifestyle. Considerations related to subsistence fishing for Native American tribes in the Pacific Northwest have been identified (Donatuto and Harper, 2008; Harper and Harris, 2008). However, due to a lack of data, at this time Ecology is unable to estimate the number of subsistence fishers in Washington.

[25] 2010 population numbers are based on the 2010 Census redistricting data. 2030 estimates are as of the OFM 2006 Population Projections by Age, Sex, and Race.

2.5 Sources of Fish Consumed

Fish consumption rate tabulations in this technical support document are derived from national fish dietary data and fish dietary surveys from the Pacific Northwest. The tribal fish dietary surveys from the Pacific Northwest provide information about the types of fish that are locally harvested and consumed. These tribal fish dietary surveys document locally harvested fish from usual and accustomed tribal treaty areas throughout the Columbia River basin and throughout Puget Sound.

For example, the 1994 Columbia River Inter-Tribal Fish Consumption Survey reflects fish harvest rates throughout the Columbia River basin for over 80% of the respondents.

Independent and separate documentation from three different Washington State agencies (WDFW, DOH, and Ecology) document the harvest and consumption of local abundant aquatic resources, including finfish and shellfish. For example, WDFW has documented the amounts of different shellfish harvested from various regions in Washington State (see Table 5).

Data gaps remain regarding exact locations where fish and shellfish are harvested in Washington State, and information about their commercial availability in state-wide grocery stores and local food markets.

2.6 Summary

From current demographic information, Ecology has estimated the total number of Washington fish consumers. Ecology reached its estimate after working with OFM to use census data and applying national and Washington fish consumption rate estimates to the general Washington population. There may be some variation in the adult and child fish-consuming population estimates for Washington State depending on the dataset and statistical methods used to evaluate national fish dietary information. Adult and child fish-consuming population estimates presented in this report are based on a similar analysis conducted by the 2008 Oregon DEQ Human Health Focus Group Report (Oregon DEQ, 2008).

Ecology believes that the population estimates for Washington State adult and child fish consumers provided in this report are reasonable estimates that help gauge and approximate the number of fish consumers. There are a large number of adults and children in Washington State who routinely consume finfish and shellfish.

According to Ecology's analysis, there are between 1.4 and 3.8 million Washington adults (18 years of age or older) who are fish consumers.[26] The number of adult fish consumers is

[26] This includes a large number of recreational anglers. For example, the Washington Department of Fish and Wildlife estimates there were 824,000 recreational anglers (both finfishing and shellfishing) in Washington in 2006.

projected to increase by up to 27 percent as Washington's population grows over the next 20 years.

Ecology estimates that approximately 290,000 Washington children (0 to 18 years of age) consume fish. It should be noted that this estimate was developed using national survey data for the general population. Studies have shown that people living in coastal states tend to consume finfish and shellfish at a higher frequency and higher rates than inland states (Moya, 2004).[27] Ecology is not aware of Washington surveys that have examined child fish consumption frequency for the general population. The number of Washington children who eat some type of fish is also projected to increase as Washington's population grows over the next 20 years.

For this report, Ecology defined *high fish consumers* as all Washington adults and children who consume finfish and/or shellfish at or above the 90th percentile estimates from surveys of national per capita consumption. Based on data presented by the EPA (U.S. EPA, 2002a), these estimates correspond to 250 g/day and 190 g/day for adults and children, respectively.

- Ecology estimates that there are between 140,000 and 380,000 Washington adults who are high fish consumers. Ecology believes that the high end of this range provides a reasonable estimate of the number of high fish consumers in Washington. The high end of the range is based on information collected by the Department of Health on fish consumption habits of Washington residents.
- Ecology estimates that there are approximately 29,000 Washington children who are high fish consumers.

Certain population groups, including Native Americans and Asian and Pacific Islanders, consume large amounts of finfish and shellfish.[28]

- According to OFM estimates, there are approximately 104,000 Native American and Alaska natives in Washington.
- According to OFM estimates, approximately 522,000 Asian and Pacific Islanders live in Washington.

In summary, considerable quantities of finfish and shellfish are harvested for consumption in Washington, both recreationally and commercially. Many Washington residents harvest and presumably consume finfish and shellfish from local waters (WDFW, 2008a, 2012). High fish consumers include several population groups known to consume larger amounts of finfish and shellfish than the general population.

[27] National fish consumption studies are typically carried out over a broad geographical area, including multiple states. Consequently, national studies may underestimate the rates and frequencies for states like Washington.

[28] Chapter 4 discusses further the consumption rates, patterns, and species consumed by Native Americans and Asian and Pacific Islanders.

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Chapter 3: Methodology for Assessing Fish Consumption Rate Information

3.1 Introduction

Researchers use a variety of methods for estimating the amount of finfish and shellfish consumed. Surveys are generally considered to be the best approach for collecting data; however, a number of design features determine whether a particular survey will provide a technically defensible basis for agency decision making. *Technical defensibility* means that the survey stands up to technical and scientific scrutiny and provides a solid technical basis for regulatory decisions. Among other factors, a survey that is technically defensible: (1) uses sound scientific methods and survey methods that have been peer reviewed and tested; (2) employs interviewers who are trained and/or questionnaires that follow accepted guidance; (3) presents clear reporting and conclusions that are supported by the data; (4) studies sample populations that represent the population of concern and consider temporal, geographic, and cultural aspects of fish consumption; (5) uses current information; and (6) provides results that can be used to support regulatory decision making. The measures of technical defensibility are described in more detail at the end of this chapter.

Different surveys are designed for different purposes. This chapter reviews the design features of various methods for collecting information about finfish and shellfish consumption. The purpose of this review is to identify the specific factors that Ecology considered when evaluating fish consumption surveys.

Regional-specific dietary information about people who eat finfish and shellfish is useful in providing a weight of evidence for evaluating the fish-consuming habits and patterns of fish consumers in Washington. Fish dietary information from the Pacific Northwest indicates that Washington State's fish-consuming populations eat more fish than what is reflected in the rates used to establish regulatory standards.

To provide more information when making risk management decisions, Ecology understands that it would be desirable to have *statewide* fish dietary data and information regarding the fish consumption habits and patterns of *all* Washington State fish consumers. However, in the absence of a statewide fish dietary survey, Ecology believes that the fish dietary information from Pacific Northwest fish-consuming populations such as tribal populations is useful and relevant for making sound risk management decisions that protect Washington State's residents. Ecology believes that there is sufficient credible fish dietary information to provide fish consumption estimates for fish-consuming populations in Washington State. If the assumption is made that the fish consumption habits and patterns among the Washington State general fish-consuming population are similar to those of the U.S. general population of fish consumers, then

the fish dietary estimates for the U.S. general population may be used to provide estimates for the Washington general population. Ecology notes that differences between the Washington population and the U.S. general population do exist: for example, status as a coastal state has the possibility of affecting fish consumption patterns.

The Pacific Northwest surveys have all followed a similar design: dietary recall complemented by food frequency questionnaires; they have been scientifically peer-reviewed (CRITFC, 2012; University of Washington, 2012), and have included reviews of study design and analysis of the results of the dietary surveys. The surveys have been considered and utilized by EPA on both a regional and national basis for environmental regulation as well as by the State of Oregon. These fish dietary surveys, together with other dietary information, provide a reasonable and technically sound basis to estimate the fish consumption habits and patterns for Washington State fish consumers.

This chapter is organized into three sections:

- *Surveys and other approaches used to estimate fish consumption.* This section reviews the various methods that have been used or are available for collecting data about dietary habits and patterns surrounding fish consumption.
- *Factors to consider when evaluating survey results.* This section identifies key design or implementation features that impact the quality of individual surveys.
- *Establishing technical defensibility.* This section describes the methodology Ecology used in assessing the technical defensibility of fish consumption survey information and results. The methodology explained here is then applied in the next chapter to surveys pertinent to Washington.

3.2 Surveys and other approaches used to estimate fish consumption

The various approaches to collecting information on finfish/shellfish dietary habits and patterns include telephone surveys, mail surveys, food diaries, personal interviews, and creel surveys (U.S. EPA, 1992). Each method has certain limitations, including bias, error, and variability (U.S. EPA, 1992; Moya et al., 2008). Ecology thoroughly examined the methodology used in fish consumption surveys. To determine quality and ensure utility for each survey examined, Ecology evaluated experimental design, target population, sample size, location, and potential bias (Ecology, 1999). This analysis aids general understanding and identifies the limitations and utility of the available data.

Fish dietary survey methodologies and limitations, as described in this report, are consistent with EPA guidance for conducting fish consumption surveys (U.S. EPA, 1992, 1998). Another approach, a dietary *market basket* survey, is used by EPA's Office of Pesticide Programs to

evaluate aggregate exposure to pesticide residues in food to which consumers may be exposed. This is a different approach that analyzes exposure to a single chemical by multiple pathways and routes of exposure. Market basket surveys conducted by EPA's Office of Pesticide Programs are statistically designed and executed on a single-serving basis at the point of sale to the consumer (U.S. EPA, 2000a).

Five fish consumption survey methods, and the strengths and weaknesses of each approach, are briefly described below.

3.2.1 Creel surveys

Creel surveys estimate fish consumption by interviewing anglers[29] on site. Using the number of fish caught at a given location divided by the number of people who will consume the catch, creel surveys can determine a fish consumption rate (Moya, 2004). The Technical Issue Paper entitled *Recreational Fish Consumption Rates* (Ecology, 2012) provides a more detailed review and analysis of fish consumption rates for recreational fishers.

A number of creel surveys have been conducted in Washington. Examples are:

- Landolt, M.L., Hafer, F.R., Nevissi, A., Van Belle, G., Van Ness, K., and Rockwell, C. 1985. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. NOAA Technical Memorandum NOS OMA 23. November 1985.
- Landolt, M.L., Kalman, D.L., Nevissi, A., Van Belle, G., Van Ness, K., and Hafer, F.R. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. NOAA Technical Memorandum NOS OMA 33. As cited in Tetra Tech 1988.
- Mayfield, D.B., Robinson, S., and Simmonds, J. 2007. Survey of fish consumption patterns of King County (Washington) recreational anglers. *Journal of Exposure Analysis and Environmental Epidemiology*, 17:604-612.
- McCallum, M. 1985. Recreational and subsistence catch and consumption of seafood from three urban industrial bays of Puget Sound: Port Gardner, Elliott Bay and Sinclair Inlet. Washington State Division of Health, Epidemiology Section. January 1985.
- Parametrix. 2003. Results of a human use survey for shoreline areas of Lake Union, Lake Washington, and Lake Sammamish. Sammamish-Washington Analysis and Modeling Program (SWAMP). Prepared for King County Department of Natural Resources. September 2003.

[29] The term *fisher* denotes a person who fishes for any type of seafood by any method, including finfish and shellfish. The term *angler* refers to a person who fishes with hook and line.

- Pierce, D., Noviello, D.T., and Rogers, S.H. 1981. Commencement Bay seafood consumption study. Preliminary Report. Tacoma-Pierce County Health Department, Tacoma, Washington. December 1981.
- Price, P., Su, S., and Gray, M. 1994. The effects of sampling bias on estimates of angler consumption rates in creel surveys. *Journal of Exposure Analysis and Environmental Epidemiology* 4:355-371. As cited in U.S. EPA, 2011.

As with any type of survey, creel surveys have both strengths and weaknesses (see Table 9) (U.S. EPA, 1992).

Table 9. Strengths and Weaknesses of Creel Surveys

Strengths	Weaknesses
* Can assess site-specific consumption rates. * Can target specific at-risk populations who fish at contaminated sites. * The interviewer can observe the participant's fishing behaviors and catch as well as the condition of the interview site. * Recall bias is minimized by using visual aids and by having the interviewer refer to the fish caught around the time of the interview as a reference. * Results can be verified by looking at the daily catch of the participant. * Response rate is high. * More information can be gained by using visual aids and probing questions. * Creel surveys are routinely done for fishery management purposes; adding fish consumption questions to the surveys can be done with little added cost.	* Only a limited number and types of questions are used to minimize survey time. * Language barriers may exist between participants and interviewers. * Surveys require well-trained staff that must be monitored for quality control. * If interviews are occurring at fishing sites, answers about consumption are hypothetical because the fish have not yet been consumed. * Participants who fish more frequently are more likely to be interviewed than those who fish less frequently. [a] * Survey results cannot be generalized to the entire population. * May miss anglers if not all fishing locations and times are surveyed. * May under- or overestimate yearly consumption if survey is not conducted throughout the year. * Pilot testing for a target population is not as effective as is the case with personal interview surveys. * Anglers may not be as receptive to engaging in interviews as preselected personal interview survey interviewees. * Fears of contact with government officials may inhibit responses of minority groups. * Anglers in the field may not be as inclined or ready to respond as individuals that have been contacted and readied to participate in a personal interview survey. * Visual aids for unique seafood preparations are difficult to develop without knowledge of the target population. * If the water body is known to have chemical contamination, rates may be impacted by a suppression effect (i.e., the suppression of the harvest and consumption of fish), and hence may not result in protective risk estimates or cleanup levels. * It may difficult to know who actually consumes the fish.

a. Moya et al., 2008.

3.2.2 Personal interviews

Personal interviews can be used to estimate fish consumption rates by asking participants questions about their dietary patterns, particularly about how much fish they consume over a given amount of time (Table 10). A useful type of personal interview survey considers 24-hour dietary recall. In this type of interview, participants are asked by a trained interviewer to report what they ate during the previous 24 hours. Although the 24-hour dietary recall format avoids recall bias, the short time period of recall is unable to show consumption variation over the course of a year (U.S. EPA, 1992). Some survey designs have addressed this by interviewing the same individual multiple times or by staggering interviews of the survey population over the course of a year. Other personal interviews may ask a participant to provide information about their consumption of finfish and shellfish over longer time periods, such as 2 weeks, a month, a season, or a year. Examples of personal interview surveys include the Native American fish consumption surveys conducted for tribes residing along the Columbia River basin and throughout Puget Sound (see Chapter 4).

Table 10. Strengths and Weaknesses of Personal Interviews

Strengths	Weaknesses
* Can assess site-specific consumption rates. * Can identify and get information from vulnerable subpopulations (those populations at a disproportionate risk) by collecting data from participants who are close to contaminated sites and by asking community agencies who should be interviewed. * Responses can be validated and supported with information gathered by the interviewer. * Literacy and language barriers are minimized by face-to-face interaction. * Visual aids can be used to estimate meal size or fish species, reducing recall bias. * High response rate. * Interviewer can clarify questions for respondents. * Possible to select a random sample that is representative of the population. * Pilot testing of interview with target population is possible. * Possible to incorporate culturally unique seafood preparations and considerations into the dietary survey. * Possible to tailor survey to specific groups. * Avoids issues associated with missing fishing locations or times that are encountered in creel surveys.	* Only a limited number and types of questions are used to minimize survey time. * Requires coordinated and supervised interviewers. * If interviews are occurring at fishing sites, answers about consumption are hypothetical because the fish have not yet been consumed. * Responses may be biased by fishing practices at the time the interview is being administered. * Uncertainty introduced when individuals are asked to recall consumption throughout the year.

3.2.3 Diary surveys

Diary surveys use questionnaires, in the form of logbooks, diaries, or catch cards, to record fish consumption over time. Information is filled out by the participant ideally at the end of a fishing day or at the time of consumption, to minimize possible recall bias (Table 11).

The Connecticut Department of Environmental Protection used diary surveys to find out about fish meals and portion sizes eaten by Connecticut families. The families received the surveys in the mail (U.S. EPA, 1992; Moya et al., 2008).

Table 11. Strengths and Weaknesses of the Diary Method

Strengths	Weaknesses
* Can assess site-specific consumption rates. * Information collected over long periods of time. * Less expensive than personal interviews. * Large numbers of participants possible. * Recall bias is reduced. * Visual aids can be used to improve accuracy of answers.	* Respondents must be taught how to complete the survey by a trained interviewer. * Participants must be literate. * Participants must be monitored during the study to maintain consistency. * Keeping a dietary record may change a participant's dietary practices. * Participants may not maintain daily record keeping. * Language barriers may affect how participants are recruited and how their diary responses are interpreted. * Questionnaire design is more complicated than other types of surveys.

3.2.4 Telephone surveys

Telephone interview surveys estimate recent fish consumption or information about recent fishing trips. Answers are recorded on preprinted questionnaires (Table 12) (U.S. EPA, 1992).

Table 12. Strengths and Weaknesses of Telephone Surveys

Strengths	Weaknesses
* Can assess region-specific consumption rates. * Can target and identify specific subpopulations of concern. * Less expensive and time-consuming than personal interviews. * High rate of success for completion of interviews. * Sensitive information may be obtained more easily. * Provides immediate response to questions.	* Interviewers cannot reach people who do not have phones. * Interviews are limited in scope and length. * Difficult to verify information. * Cannot use visual aids. * Inability to reach people by phone may be of concern for low-income individuals who harvest more fish than more affluent people. * Language barriers may pose limitations.

3.2.5 Recall mail surveys

Recall mail surveys are self-administered questionnaires used to estimate fish consumption. Most commonly they are used to obtain information from recreational anglers (Table 13) (U.S. EPA, 1992).

Table 13. Strengths and Weaknesses of Recall Mail Surveys

Strengths	Weaknesses
* Can assess region-specific consumption rates. * Can target and identify specific subpopulations of concern. * Least expensive since no interviewers are required. * Large numbers of respondents may be contacted over a large area. * Most likely to provide honest answers. * Complex technical data may be obtained if respondent takes the time to consider the questions and/or consult other sources. * Survey can cover broad areas of inquiry.	* Cannot reach people without mailing addresses. * Questions must be carefully designed to compensate for lack of personal interaction. * Questions should be limited in scope and complexity. * Requires substantial follow-up efforts or incentives to achieve reasonable response rate. * Higher number of inaccurate and incomplete responses. * May miss respondents who are illiterate, or have difficulty in understanding questions, or who cannot read the language.

3.3 Survey selection criteria

Both dietary recall interviews and creel surveys have been used in Washington in various contexts to estimate fish consumption rates (see Chapter 4, Table 14).

Certain criteria are useful for comparing survey methodologies, and key factors influence the selection of a particular survey type (U.S. EPA, 1998). These selection criteria assist in discriminating between different survey approaches. In addition, how different survey methodologies compare based on these criteria highlights the various strengths and weaknesses.

Consistent with this approach, Ecology established key considerations for selection criteria: time frame, resources, target populations, subpopulations, accuracy, and harvest characteristics. Although many of these considerations are discussed separately, Table 14 provides a useful tool for comparing different survey methodologies.

Table 14. Comparison of Five Consumption Survey Methodologies Using EPA's Selection Criteria

Survey Type Selection Criteria	Telephone	Mail	Diary	Interview	Creel
Time Frame					
Immediate data from respondent	Yes	No	No	Yes	Yes
Resources					
Interviewer burden	Moderate	Low	Low	High	High
Respondent burden	Low	Moderate	High	Low	Low
Relative cost	Moderate	Low/moderate	Low	High	High
Target Populations/Subpopulations					
Survey sample known prior to conducting survey	Yes/no [a]	Yes	Yes	Yes/no [b]	Yes/no [c]
Can be used with low literacy populations	Yes	No	No	Yes	Yes
Accuracy [d, e]					
Reliability: Potential for response reliability	Moderate/high	Low/moderate	Low/moderate	Moderate/high	Moderate/high
Validity: Validity of consumption estimates	Low	Low/high [f]	Moderate	Moderate [g]	Low/moderate [g]
Validity: Validity of species identification	Low	Moderate	Moderate	Moderate/high [h]	High
Bias: Potential to minimize recall bias	Moderate	Low/high [f]	Moderate	Moderate/high [h]	Not applicable [i]
Bias: Potential to minimize prestige bias	Moderate	Low	Low	Moderate	Moderate
Measurement error: opportunity for respondent to ask for clarification	Moderate/high	Low	Low	High	High
Measurement error: potential for respondent participation	Moderate	Moderate	Low	High	High
Harvest Characteristics					
Many access points	Yes	Yes	Yes	Yes/no [b]	Yes/no [j]
High fishing or hunting pressure	Yes/no [k]	Yes	No	Yes	Yes/no [l]
Large geographic area	Yes	Yes	Yes	Yes [m]	No
Account for seasons and times	Yes	Yes	Yes	Yes	No [n]

Source: U.S. EPA, 1998, Table 3, p. 3-3.

a. Yes if phone numbers are obtained after sample population has been preselected; no if random digit dialing.

b. No for interviews conducted at fish/hunting access points; yes for off-site interviews.

c. Depends on ability to estimate total site usage using random sampling of all access points.

d. Given sufficient resources, all five survey approaches can generate accurate data.

e. For minority and tribal populations a sense of trust and cultural identity between interviewer and interviewee is particularly important.

f. Dependent on the recall method employed.

g. On-site interviews result in valid catch estimates, but consumption estimates are hypothetical because they measure only the intent to consume. Off-site interviews result in catch and consumption estimates with potentially low validity depending on the period of recall.

h. Moderate for off-site interviews; high for on-site interviews. Administering the survey at regular intervals can reduce bias associated with the availability of different seafood resources throughout the year.

i. Creel surveys may minimize recall bias but the responses only represent the point of time the individual starts fishing to the time the individual is interviewed.

j. Yes for roving creel survey; no for access point survey.

k. Yes for random telephone numbers; no for known telephone numbers.

l. Yes for access point survey; no for roving creel survey.

m. Yes when interviewees are preselected so they can tell interviewer where they have fished.

n. A creel survey may be designed to account for seasons and times; however, creel surveys seeking to develop health protective estimates of fish consumption may only be conducted during high harvest time periods.

3.4 Evaluating survey vehicles

Large differences in survey objectives combined with the high variability in fish consumption patterns make it difficult to make generalizations about surveys. To compare and evaluate both the survey vehicle (that is, the questionnaire or interview process) and the data obtained, a number of factors should be considered. Also, to establish whether a particular survey is appropriate to use, each factor needs to be evaluated and documented. Moya, 2004, and U.S. EPA, 1992 and 1998, identify important elements of survey design.

Also of significance is whether a survey is designed to look at short-term or long-term behaviors. This is especially relevant when comparing results of different surveys.

3.4.1 General survey design

Survey design is fundamental to the accuracy and success of a survey, and identifying the target population is important both when both choosing a survey method and effectively executing the survey (Table 15). The design establishes the type of information collected and the level of detail provided (Moya, 2004). Survey accuracy improves when the following factors are considered during the design phase. Ecology considered these as essential in a well-designed survey.

Table 15. Survey Design Evaluation Criteria

Criteria	Description
1. Timing of interviews	For a survey to adequately capture fish consumption, an appropriate time frame must have been chosen that minimizes the effect of recall bias yet captures the dietary variations.[a] (Additional discussion on survey recall error and bias are provided in the Glossary, Appendix D.)
2. Training of interviewers	Interviewers should be trained for the study protocol to avoid potential interviewer bias. Interviewers must adhere to the questionnaire wording and format and be culturally sensitive when interacting with the study participants. If possible, interviews should be conducted by members of the target population to avoid adverse impacts associated with cultural differences, language barriers, and participation refusals. [a]
3. Consideration of all fish species	The types of fish consumed can be highly variable depending on seasonal and geographic availability, market prices, and cultural preferences. Surveys should identify and record each type of fish consumed and any unique preparation methods. [a]
4. Identification of the source	If known, either the water body where the fish was caught or the purchase location (for example, grocery store or fish market) should be identified. To improve exposure assessment, both locally caught fish and store bought fish should be included in fish consumption rate estimates. This distinction allows the risk assessor to better account for regional and seasonal variations in fish consumption estimates. [b]
5. Random selection of participants, sample size, and statistical analysis	During the planning phase, statistical analysis helps identify the ideal sample size and how to randomly select participants. This analysis helps minimize bias and sampling error and ensures statistical rigor. After the data have been collected, sound descriptive statistical analysis should ensure that the data are presented accurately. The range of data should be presented with confidence intervals and appropriate distribution values. Weighting schemes should be clearly described in order to apply survey results to populations of interest. Statistical treatment of perceived outliers should be discussed.

Criteria	Description
6. Appropriate quality assurance and quality control	The study design should include appropriate quality assurance and quality controls into the planning and execution of the survey. For example, types of quality control measures would include checking questionnaires for completeness and proper entry of recorded responses, verifying correct data entry, and checking the manual coding operations and comparisons of results and error rates. This reduces bias and random error, improving accuracy. [c]
7. Accuracy and precision	The study design can affect the overall accuracy of the study. Accuracy can be split into five components. Reliability (the variability or repeatability of the response), validity (the ability of the respondent to provide the correct answer), measurement errors (which are associated with the interviewer, the respondent, the questionnaire, and the mode of data collection), bias (the consistent overestimation or underestimation due to survey design and sample selection), and random errors. [c]

Sources:

a. Ecology, 1999.

b. Ebert et al., 1994.

c. U.S. EPA, 1998.

3.4.2 Survey questions

The following information should be collected from study respondents and is necessary for understanding what they eat (Strauss, 2004).[30]

- Frequency and quantity (how much fish is consumed per day, week, or month).
- Parts of the fish consumed.
- Species consumed.
- Source of the fish.
- Seafood preparation and cooking methods.
- Respondent's body weight.
- Exposure duration.
- Approximate age (child or adult).

Survey questions should be clearly worded, unambiguous, and well understood to obtain clear and correct answers from respondents.

[30] See this 2004 article by Strauss for details regarding complexities and variability.

3.4.3 Population surveyed

The sample population must represent the target population. This is particularly important because fish consumption rates may be affected by the socio-demographic characteristics of a population. Furthermore, the type of survey used may influence or determine a number of things, including what population will respond to the survey, the response rates, and the level of detail obtained (Moya, 2004).

3.4.4 Description of water body

The survey must identify and understand the characteristics of all relevant water bodies, including location, size, species inhabiting the water, and fish advisory status. These characteristics influence the quantity of fish available. In addition, this information is critical to producing results that can be used to compare with or extrapolate to other populations (Moya, 2004).

3.4.5 Survey results

Ecology considered it important to evaluate how the survey results are presented and what they are meant to represent. This included identifying and considering goals of the survey.

Estimating the size of a meal is subject to error, especially when a survey vehicle (questionnaire or interview) does not include visual aids. Also, quantities of seafood may be part of stews, soups, and other recipes that may or may not be accounted for in fish dietary survey design.

Sound descriptive statistical analysis is required to ensure that the data are presented accurately. The range of data should be presented with confidence intervals and appropriate distribution values (Moya, 2004). Weighting schemes should be clearly described in order to apply survey results to populations of interest. Statistical treatment of perceived outliers should be discussed.

3.4.6 Factors to consider

Ecology identified the following factors as appropriate and necessary when evaluating survey results:

- *Cultural factors.* Does the population group of interest (for example, Native Americans or Asian and Pacific Islanders) have cultural characteristics that should be considered when designing a fish consumption survey? Native American ways of life may influence fish consumption habits and patterns; salmon is of particular significance in the diet of Northwest Pacific Native American tribal peoples. Asian and Pacific Islanders may consume parts of organisms that differ from those preferred by other populations. Also, is the survey designed to identify subsistence fishing practices?

- *Fish diet fraction (the portion of fish consumed that comes from the site).* Have sources of fish tissue contamination been considered in the design and/or evaluation of the survey? Are the fish consumed harvested from local waters? Does the survey distinguish between store-bought fish or fish consumed in restaurants and fish harvested from local waters?
- *Types of seafood (finfish and shellfish) consumed from marine, freshwater, and estuarine habitats.* This information may be useful in characterizing risks for consumption of aquatic biota that have different contaminant levels as a result of their feeding behaviors (for example, bottom feeding fish or top predator species). Has the fish consumption survey considered both the range of types of finfish/shellfish consumed and where they are harvested?
- *Cooking methods.* Use of cooked weights or uncooked weights to measure fish consumed must be standardized. Generally, uncooked weights are preferred because environmental contaminants are usually analytically determined for wet weight. Cooking fish can reduce the weight of a fillet by 20 percent or more (U.S. EPA, 1998). Have the methods of food preparation and cooking been considered in the fish consumption survey design and/or evaluating the survey?
- *Are there historical and traditional fishing areas and practices that should be identified?*
- *Environmental justice.* How have historically underrepresented populations and disproportionately impacted communities been considered in the design and evaluation of fish consumption surveys?

3.5 Measures of technical defensibility

For purposes of this report, Ecology developed several *measures of technical defensibility* to help guide the evaluation of individual surveys. These measures of technical defensibility ensure that a survey can stand up to technical and scientific scrutiny and are described in Table 16. They represent an expansion of the two selection criterion used by the June 2008 Oregon Human Health Focus Group-Oregon Fish and Shellfish Consumption Rate Project

Collectively, these measures of technical defensibility provide an assessment of overall technical suitability to support regulatory decision making (for example, they provide information about whether the survey results are suitable and appropriate in a regulatory context for establishing risk-based standards).

The measures of technical defensibility are based on:

- EPA *Exposure Factors Handbook*, 2009 Update (U.S. EPA, 2009a).
- EPA *Exposure Factors Handbook*, 2011 Edition (U.S. EPA, 2011a).
- EPA *Guidance for Conducting Fish and Wildlife Consumption Surveys* (U.S. EPA, 1992, 1998).
- Consultations with the University of Washington, Environmental and Occupational Health Sciences.[31]

Ecology applied these measures of technical defensibility to selected fish dietary surveys performed in Washington State. Ecology has not applied these measures of technical defensibility to all surveys conducted in Washington; many of these surveys were conducted for specific water bodies to help support fish advisories, or were used to assess risks to specific ethnic populations.

Water body-specific fish dietary surveys are limited in scope because they evaluate very specific populations, usually recreational anglers and specific ethnic groups, which harvest and consume fish from a particular water body within a specific county or jurisdiction in Washington State. Each serves a useful purpose to help evaluate and assess potential health risks from consuming contaminated finfish and shellfish; however, their methodology does not allow for the projection of longer term estimates of fish consumption.

The additional fish dietary information provided in Table 32 and Appendix B, although not meeting the measures of technical defensibility described in this chapter, provides support, using a weight-of-evidence approach, to the idea that people in Washington State harvest and consume considerable amounts of fish.

[31] Ecology acknowledges input from the University of Washington, Seattle, Environmental and Occupational Health Sciences and Departments of Medicine and Internal Medicine.

Table 16. Measures of Technical Defensibility

Measure	Description
1. Survey Method Development	* Was the survey design based on sound scientific survey methods recognized either in guidance or other technical publications? * For surveys dealing with unique populations (for example, tribes or ethnic minorities), was the survey vehicle reviewed by tribal staff and tribal governments? Did it include review and collaboration with state and federal agencies? * Was the survey tested and modified before it was conducted? * Did the survey design evaluate the essential elements provided in Table 15?
2. Survey Execution	* Was the execution of the survey based on sound survey methods recognized either in guidance or other technical publications? * Were the personnel conducting interviews provided adequate training? * Were finfish/shellfish models used as visual aids to help participants estimate approximate amounts and types of fish consumed?
3. Publication of Results	* Was the publication of survey results based on sound survey methods recognized either in guidance or other technical publications? * Was the study methodology clearly defined and reported? * Is there a discussion of the consistency of the survey's methodology with accepted practices? * Was the study methodology consistent with sound survey practices? * Were the survey results tabulated and reported clearly? * Were statistical approaches (including weighting and treatment of outliers) clearly explained? * Were the study conclusions clearly reported and supported by study findings? * Were variability and uncertainty recognized? * Were uncertainties identified and reported? * Did the survey design take into account and/or discuss factors that might contribute to bias in the study results?
4. Applicability and Utility for Regulatory Decision Making	* Is the sample population representative of the population of concern, and does the survey provide sufficient information about the sample population to characterize the population being studied? * Is it reasonable to apply the results of the surveyed population to populations of concern? * Are the water bodies/fisheries resources upon which the surveyed population relies similar to the water bodies being regulated? * Is the information current and is suppression effects on fish dietary habits recognized and accounted for? * Are fish consumption rate statistics commonly used for regulatory purposes presented and supported? * Are data sufficient for descriptive statistics to define statistical fish consumption rate distributions?

3.6 Custody of fish dietary survey data

Most fish dietary surveys that address the habits and patterns of ethnic groups (Asian and Pacific Islanders, Native American populations) are funded either through state or federal cooperative agreements or grants. Survey questionnaires are generally developed in close collaboration with an organization that represents the ethnic group or technical personnel associated with the tribal governments or tribal natural resource offices. Surveys are conducted by trained tribal personnel or people representative of the ethnic population being surveyed. The resulting data may be owned by the tribal government or the ethnic group that collaborated on the survey. The survey design and methodology are generally reviewed by the funding organization (federal or state) and technical personnel or representatives from the tribe or ethnic group.

The custody of survey data by tribal governments is related to their concerns with maintaining and sustaining tribal sovereignty and honoring confidentiality agreements with individual participants surveyed. The tribal governments have employed various methods to establish data quality without releasing individual response data to entities other than tribal governments. Ecology acknowledges that further evaluations would be possible using individual level response data.

Pacific Northwest Native American fish consumption surveys are designed and executed as government-to-government collaboration with state and federal governments. They are generally published under the authority of the tribal governments.

There are a number of ways to establish the defensibility of data. Scientific journals use peer review to establish scientific defensibility of reported results. A recent *Science Magazine* editorial (Hanson et al., 2011) noted the importance of making data available for scrutiny so that other researchers can verify results and test conclusions. Using independent statisticians for review and analysis may circumvent the need to release the raw data.

Many Pacific Northwest tribal organizations or tribal governments do not provide their raw seafood dietary data to researchers outside of their sovereign tribal government or organizations. They may consider survey data as confidential and not allow independent evaluations. Data evaluation typically occurs through government-to-government agreements or tribal technical personnel.

For example, the fish consumption survey of the four tribes that reside throughout the Columbia River basin was initiated through a cooperative agreement between EPA and the CRITFC. The development, design, and execution of the CRITFC fish consumption survey vehicle were conducted through the respective tribal governments that compose CRITFC. The fish consumption data were collected and evaluated by tribal members and technical staff and are retained by CRITFC. Other Pacific Northwest Indian tribes follow a similar pattern where the data are retained by tribal governments or Pacific Northwest Indian commissions.

Ecology evaluated the Native American fish consumption surveys, as well as other available surveys conducted in the Pacific Northwest, based on the measures of technical defensibility discussed above. That evaluation is described in the following chapter.

Chapter 4: Fish Consumption Survey Data that Apply to Washington Fish Consumers

4.1 Introduction

Over the last several years, Ecology has evaluated available fish consumption surveys to support site-specific regulatory decisions.

Fish consumption survey data are identified, discussed, and evaluated against the measures of technical defensibility presented in Chapter 3. The purpose of this chapter is to identify those surveys that are most appropriate for assessing fish consumption rates in Washington. A word of caution is appropriate. Many sources of data are available and provide information that may be appropriate for answering particular questions. The question being considered in this chapter is identification of data appropriate for use in a regulatory context to characterize fish-consuming populations across Washington State.

Ecology considered a range of information that describes fish consumption rates and patterns for fish consumers in Washington. In general, Ecology examined:

- General population surveys conducted at the national level.
- Dietary surveys of Washington Native American populations.
- A dietary survey of Asian and Pacific Islander populations in King County.
- Washington water body-specific evaluations, assessments, or health advisories issued by DOH.[32]
- Technical publications, assessments, and/or evaluations of fish consumption specific to the Pacific Northwest.
- Various evaluations or assessments used to make regulatory decisions. For example, the baseline human health risk assessment performed for the Lower Duwamish Waterway, which refers to the EPA Region 10 Framework and Kissinger re-evaluation (Windward Environmental, 2007; U.S. EPA, 2007b; Kissinger, 2005).[33]

[32] Washington State Department of Health fish consumption advisories by water body located at the following web link: http://www.doh.wa.gov/CommunityandEnvironment/Food/Fish/Advisories.aspx, and Port Angeles: http://www.ecy.wa.gov/news/2012/052.html

[33] Besides the Lower Duwamish Waterway Remedial Investigation Report, Ecology also considered the Port Angeles and Port Gamble sediment cleanup:

Port Angeles: http://www.ecy.wa.gov/programs/tcp/sites_brochure/portAngelesHarborSed/paSed_hp.htm

Port Gamble: http://www.ecy.wa.gov/programs/tcp/sites_brochure/psi/portGamble/psi_portGamble.html

These data were examined and assessed to identify technically defensible studies appropriate for use in characterizing fish-consuming populations in Washington.

To provide a more detailed look at fish consumption patterns across the state, where possible, fish consumption data and descriptive statistics have been tabulated for both locally harvested fish, and for fish consumed from all sources including stores and restaurants. Where available, additional fish consumption estimates from Pacific Northwest fish dietary surveys are included for groups of fish species, such as finfish, shellfish, anadromous finish, and non-anadromous finfish.

4.2 General population data

Currently, there are no fish dietary data available for the general fish-consuming populations in Washington State. That is, there is not a survey of fish consumption of the entire population of Washington State. Ecology examined information on fish consumption among the U.S. national general population.

Ecology notes that national data show that people who live in coastal areas consume fish at higher rates than those living in other areas (Moya, 2004) and that EPA recommends using regional-specific data, when available (U.S. EPA, 2000b, 2007b, 2011a).

4.2.1 Continuing Survey of Food Intakes by Individuals

In 2000, the EPA developed national estimates of fish consumption based on an analysis of the U.S. Department of Agriculture's (USDA) 1994–1996 *Continuing Survey of Food Intakes by Individuals* (CSFII) and its 1998 *Children's Supplement* (U.S. EPA, 2002a). (These USDA reports are collectively referred to as CSFII 1994–1996, 1998).

The USDA surveys were designed to provide estimates of food consumption across the United States and were conducted in all 50 states and Washington, D.C. They include fish consumers and non-consumers, and provide data for federal activities related to the nutritional status of the U.S. population.[34] The national fish dietary information is not representative of some Washington State fish-consuming populations, such as Asian-Pacific Islanders and Native Americans.

Over 20,000 survey participants each provided dietary information during two non-consecutive 24-hour periods. The survey was designed so that the second interview occurred 3 to 10 days after the first interview but not on the same day of the week. The dietary recall surveys were administered over a period of 4 years.

[34] By definition, per capita fish consumption includes consumers and non-consumers of fish. The per capita survey methodology is different than the Pacific Northwest fish dietary recall studies and is discussed below.

The CSFII was conducted by interviewing respondents according to a stratified design that accounted for geographic location, degree of urbanization, and socioeconomics. Eligibility for the survey was limited to households with gross incomes at or less than 130 percent of the federal poverty guidelines. Survey weights were assigned to this dataset to make it representative of the U.S. population.

The CSFII is the primary source of food consumption data used in dietary risk assessments. It is well suited to national-level dietary risk assessments, because it is statistically designed to sample individuals of all ages and major ethnic subgroups to reflect various demographics. The CSFII is statistically designed so that the national estimate of consumption is not biased by seasons of the year or regions of the country (U.S. EPA, 2001). The CSFII may be considered a variation of the dietary market basket survey approach but on a larger-scale with a more sophisticated design and execution.

Ecology notes, however, that the survey methodology limits its use. In particular, participants who did not eat fish on either of the two days surveyed would be considered non-consumers. The rate of fish consumption (or non-consumption) for individual consumers during the two days surveyed was assumed to represent their consumption rate for the entire year. In other words, someone who did not eat fish during the two days of the survey was assumed to consume no fish at all during the year. The resulting values may not be representative of long-term consumption rates that have been averaged over time and presented as a daily rate.

By definition, per capita fish consumption rates reflect fish dietary habits averaged over the general U.S. population, including people who never eat fish. Hence, per capita fish consumption rates do not necessarily describe actual fish consumption by consumers of finfish and shellfish.

Although fish consumption rates derived for consumers would be preferable to per capita rates in describing the consumption of finfish and shellfish in the United States, there are limitations when "consumer only" rates are derived from national per capita surveys:

- During the two non-consecutive days of the survey period, the amount of fish and shellfish that a respondent ate on a given day would not be equivalent to the gram per day value obtained when the amount of fish consumed over a longer survey period is divided by the number of survey-period days for a more comprehensive fish dietary recall survey.
- People who typically consume finfish and shellfish, but did not do so during one of the two non-consecutive days of the survey period, were not captured by the survey and therefore are not included in national fish consumption estimates for consumers.
- It is not possible to determine the percentage of the finfish- and shellfish-consuming population that was missed, or whether the respondents who did consume finfish or shellfish during the survey's two-non-consecutive-day reporting period are adequately representative of the U.S. fish-consuming population.

Ecology acknowledges the difficulty in evaluating the data from the EPA 2002 per capita estimates. We have considered this information in helping to estimate the number of fish consumers in Washington but not in estimating a fish consumption rate. We have also used the per capita data to define high fish consumers in order to approximate the number of high fish consumers among the general population.

Table 17. General Population: Adult Respondents, Consumers Only, Based on CSFII 1994 to 1996

Population	Number of Adults Surveyed	Descriptive Statistics (g/day)					
		Mean	Median	Percentiles			
				75th	90th	95th	99th
U.S General Population (consumers only)	2585	127	99	-	248	334	519

Source: Adapted from Oregon DEQ, 2008, Table 3, based on EPA 2002 and CSFII dietary data. Persons interested in further details on the CSFII are referred to U.S. EPA, 2002.

4.2.2 National Health and Nutrition Examination Survey, 2003 to 2006

The EPA 2011 national estimates for fish consumption are based on analysis of the USDA National Health and Nutrition Examination Survey (NHANES) from 2003 to 2006. The fish consumption estimates from the NHANES 2003–2006 data are available in Chapter 10 of EPA's Exposure Factors Handbook, 2011 (U.S. EPA, 2011a).

Designed to assess the health and nutritional status of adults and children in the United States, starting in 1999, NHANES is a continuous program that interviews nationally representative samples of about 7,000 people annually. The survey is administered for two non-consecutive 24-hour periods of dietary intake. Data for the first day is collected in-person, while data for the second day is collected by telephone about 3 to 10 days later. Using the 2000 U.S. population census estimates to develop the sampling frame, the NHANES 2003–2006 surveys are probability-based and county-based population samples from across the United States.

The EPA's Office of Pesticide Programs used NHANES 2003–2006 data to update the CSFII 1994–1996, 1998 study (as presented in EPA's 2002 *Estimated Per Capita Fish Consumption in the United States*). Summary statistics were developed for fish consumers only and on a per capita basis. Dietary rates were derived for finfish, shellfish, and finfish and shellfish combined (shown for consumers only in Table 18 and Figure 1 below). Two-day average dietary fish consumption rates were calculated for all respondents who provided dietary information for two days of the survey. If a respondent reported consuming fish on one of the two days of the survey, then their 2-day average would be half the amount reported for the one day of consumption.

The EPA 2011 *Exposure Factors Handbook* (U.S. EPA, 2011a, p. 10–16) qualifies the fish dietary estimates as follows:

…it should be noted that the distribution of average daily intake rates generated using short-term data (e.g., 2-day) does not necessarily reflect the long-term distribution of average daily intake rates. The distributions generated from short-term and long-term data will differ to the extent that each individual's intake varies from day to day…

…Short-term consumption data may not accurately reflect long-term eating patterns and may under-represent infrequent consumers of a given fish species. This is particularly true for the tails (extremes) of the distribution of food intake.

Table 18. General Population: Adult Respondents, Consumers Only, Based on NHANES 2003–2006, Using Standard Statistical Survey Methodology

Population	Species Group	Descriptive Statistics (g/day)				
		50th Percentile	Mean	75th Percentile	90th Percentile	95th Percentile
National Estimates from NHANES 2003–2006 (consumers only)	All Fish	37.9	56.0	78.8	128	168
	Finfish	34.6	49.9	68.9	115	150
	Shellfish	25.7	43.0	54.4	101	147

See Polissar et al., 2012. Estimates based on statistical methodology defining *fish consumers* as those who consumed fish on at least one of the two dietary recall days.

Ecology reevaluated the NHANES fish dietary data using the National Cancer Institute's (NCI) statistical methodology (Polissar et al., 2012). The NCI method estimates usual intake of episodically consumed foods by accounting for day-to-day variations (Tooze et al., 2006). The national dietary information (CSFII and NHANES) consists of two detailed 24-hour dietary recalls conducted for a large, randomly selected U.S. population. Although 24-hour dietary recall surveys capture detailed information on a person's food consumption, this dietary assessment method does not adequately measure the usual intake of foods that are not consumed nearly every day (i.e., episodically consumed foods such as fish). The NCI method uses statistical modeling to combine food frequency questionnaire data with 24-hour dietary recall data to project long-term food consumption estimates. Results are shown in Table 19 and Figure 2 below.

Table 19. General Population: Adult Respondents, Consumers Only, Based on NHANES 2003–2006, Using NCI Statistical Survey Methodology

Population	Species Group	Descriptive Statistics (g/day)				
		50th Percentile	Mean	75th Percentile	90th Percentile	95th Percentile
National Estimates from NHANES 2003–2006 (consumers only)	All Fish	12.7	18.8	24.8	43.3	56.6
	Finfish	9.0	14.0	18.1	31.8	43.3
	Shellfish	2.4	5.4	6.0	13.2	20.5

See Polissar et al., 2012. Estimates based on NCI statistical methodology (Tooze et al., 2006) that models two days of fish consumption from 24-hour episodic dietary recall and fish dietary information from the food frequency questionnaire.

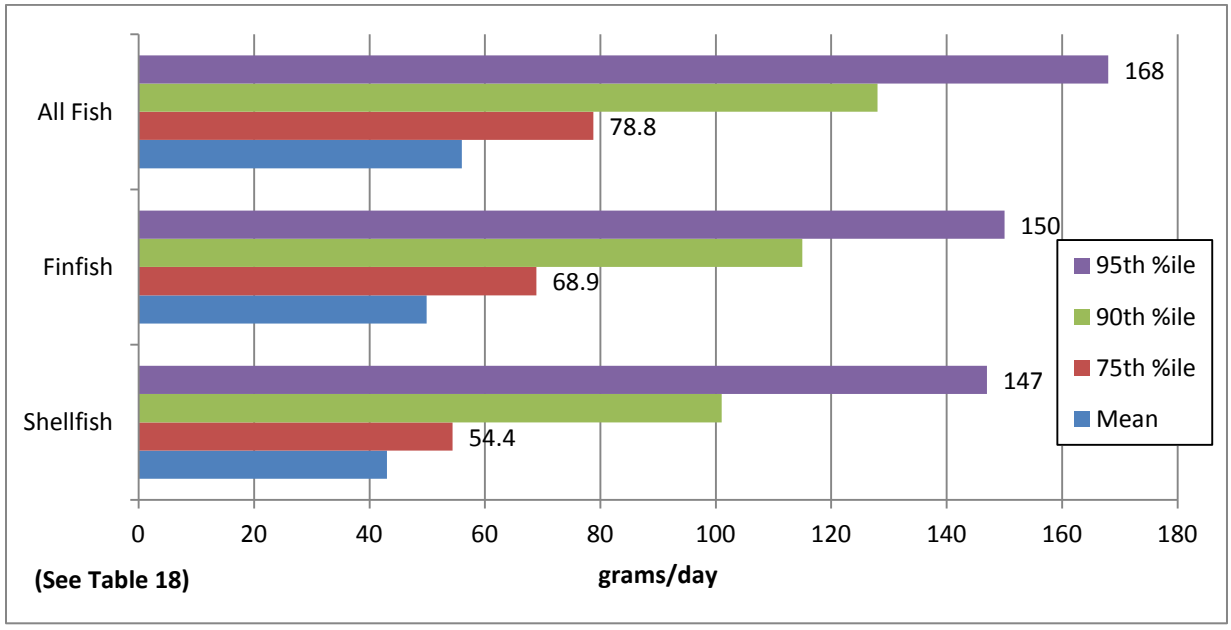


Figure 1. General Population Adult Fish Consumption Rates, Consumers Only, NHANES 2003–2006, Using Standard Statistical Survey Methodology

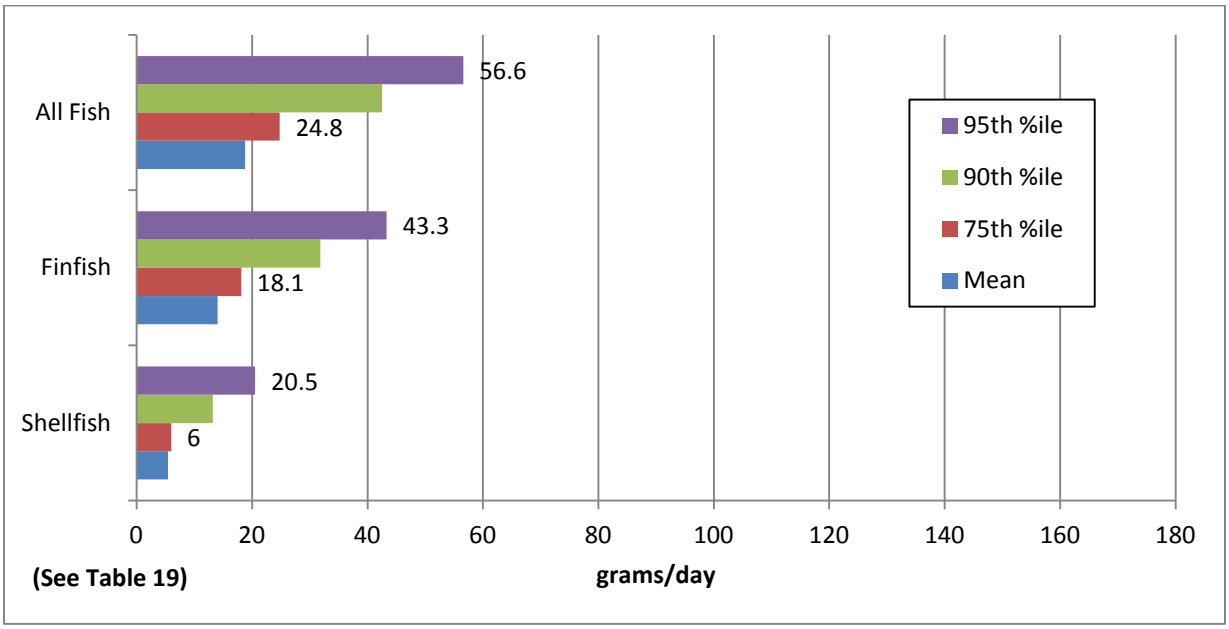


Figure 2. General Population Adult Fish Consumption Rates, Consumers Only, NHANES 2003–2006, Using NCI Statistical Survey Methodology

Technical defensibility

As summarized in Table 20 below, Ecology has determined that the national surveys of the general population are relevant to Washington and satisfy measures of technical defensibility.

Table 20. Technical Defensibility of National (General Population) Fish Dietary Information

Metric	Observations and Comments	Evaluation
1. Survey Method Development		
Description of survey vehicle	Survey methodology and analysis of survey data independently conducted by two federal agencies	Survey methodology, design and analysis described in detail; sample size very large to provide good dietary information for the general U.S. population
Description of sample population	Large sample size, randomly selected, and sample geographically representative of national general population	
2. Survey execution		
Survey method	Survey data based on recent 2-day dietary recall; data collected over short duration and independent collection periods	Nationwide survey with sample selection based on randomized selection; two non-consecutive-day recall supports development of per capita consumption estimates; high level of peer review on methodology design and execution
Bias	Good response rate (> 70%)	
Review and evaluations	Quality assurance/quality control (QA/QC) standards are high and documented	
Review and evaluations	National Center for Health Statistics	

Metric	Observations and Comments	Evaluation
3. Publication of results		
Where published and clear information	Published by USDA, EPA, and other agencies	Accessible through large number of venues and publications
Survey methodology	Two non-consecutive-day dietary recall	
Applicability for regulatory decision making		
Currency of information	CSFII 1994–1996 and 1998 2003–2006 NHANES	Suitable for average intake rates of general population; not intended to substitute for regional-specific fish dietary information [a]
Representative of target population	Representative of the general U.S. population	
4. Overall technical suitability for regulatory decision making		
Range of technical defensibility	Survey method designed to provide average intake rates for general populations	Not designed to capture long-term dietary intake
Appropriateness for use in risk-based standards	Designed to provide average dietary intake rates	Not a substitute for regional-specific dietary information

Sources: U.S. EPA, 2011a; USDA CSFII 1994–1996, 1998.

a. Study design may bias high upper percentile consumer only fish consumption estimate; however, use of national fish dietary information underestimates fish consumption estimates for areas with more fisheries and resources (i.e., Washington State).

4.3 Pacific Northwest Native American fish consumption data

As of the writing of this report, results of three tribal-specific finfish/shellfish dietary surveys of tribes along the Columbia River basin and in the Puget Sound area of Washington were available for review.

In addition, several technical publications provide information on tribal fish consumption (Harper et al., 2002, p. 513–526; Harris and Harper, 1997, 2001). These publications have been used to define a tribal reasonable maximum exposure (RME) for various regulatory decisions.[35]

Although these technical publications provide useful information for specific regulatory decisions, it is the published tribal fish consumption surveys that provide the relevant information on fish consumption. The surveys employed a well-defined, standardized, dietary survey methodology, data analysis, and reporting of results.

Tribal fish dietary surveys provide relevant fish dietary information for Washington State fish consumers because these surveys include: (1) respondents that are fish consumers from Washington State; (2) locally harvested and consumed finfish and shellfish; (3) well-defined, standardized, dietary survey methodology, data analysis, defined measures of quality assurance and quality control, and reporting of results; (4) close collaboration with and support from academia and state and federal health and resource agencies; (5) minimized recall bias in the

[35] In Harper et al., 2002, Table 11, p. 521 notes 885 – 1,000 g/day for those with a high fish diet (fish consumers) and 175 g/day for shellfish consumption for fish consumers and non-consumers of fish.

surveys due to dietary and culturally based dependence on fish consumption; and (6) the well-supported assumption that *locally harvested fish* includes fish from large freshwater, estuarine, and marine water areas of Washington State because tribal reserved rights include harvesting fish and consuming fish from all watersheds throughout the state.

Ecology reviewed and analyzed the data from these surveys, looking specifically at species consumed and where the fish were obtained (Polissar et al., 2012). The fish dietary surveys provide credible information on the types and amounts of fish consumed by Native American populations in Washington State. Generally, the fish dietary surveys indicate that these populations consume large amounts of finfish and shellfish harvested from marine and freshwater environments throughout Washington.

This section describes the surveys, along with an evaluation of technical defensibility.

4.3.1 Columbia River Inter-Tribal Fish Commission survey: the Umatilla, Nez Perce, Yakama, and Warm Springs Tribes of the Columbia River Basin

The Columbia River Inter-Tribal Fish Commission (CRITFC) surveyed fish consumption among four Native American tribes that reside along the Columbia River basin (CRITFC, 1994). The survey of adult tribal members who lived on or near the Yakama, Warm Springs, Umatilla, or Nez Perce Reservations was conducted during the fall and winter of 1991–1992.[36]

The survey identified individual tribal members' consumption rates, habits, and food preparation methods for anadromous and resident fish species caught from the Columbia River basin. A random sampling was taken based on respondents selected from patient registration files of the Indian Health Service. The survey questionnaire included a 24-hour dietary recall and questions regarding seasonal and annual fish consumption. Food models were used to help respondents estimate the amounts of fish consumed.

Information obtained included age-specific fish consumption rates, the fish species and parts of the fish consumed, and the methods used to prepare the fish for consumption.

Personal interviews conducted on the four tribal reservations achieved an overall response rate of 69 percent from a sample size of 513 tribal members 18 years of age or older. Tribal adult respondents provided information for 204 children 5 years of age or younger. Since tribal population sizes were unequal, demographic weighting factors were applied to the pooled data in proportion to tribal population size, so that survey results would reflect the overall population of adult members of the four tribes. An unweighted analysis was performed for children, since the sample size was small. To derive consumption rates that represented the adult tribal population as a whole, the survey averaged the fish consumption for both consumers and non-consumers.

[36] As noted in the survey, conducting interviews over this period of time biased the consumption estimates low because of low availability of fish to harvest during that seasonal period of time.

All interviews were conducted at tribal offices, which could potentially select against individuals with mobility problems. It is possible that tribal elders, who may be more likely to practice subsistence consumption, were omitted from the survey. Since adults answered questions regarding children's fish consumption, the adult respondents may have mistakenly answered questions as if they were providing their own survey responses. Selected outliers were removed from the datasets.

CRITFC consumption rates represent consumption from all sources. Salmon and steelhead were consumed by the largest number of adult respondents, followed by trout, lamprey, and smelt. A seasonal variation in fish consumption was observed, with the most fish consumed April through July. The mean fish consumption rate was 108 g/day. There was a large seasonal variation in fish consumption. The reported mean rate of consumption during the high months (April–July) was three times the mean rate of consumption in low months (November–February).

The mean fish consumption rate for all surveyed tribal adults (consumers and non-consumers) throughout the year was 58.7 g/day. Seven percent of survey respondents did not consume fish. Excluding non-consumers of fish, the mean fish consumption rate for surveyed tribal adult fish consumers was 63.2 g/day. The average consumption rate for children (5 years old and younger) was 24.8 g/day. About 83 percent of the 204 children consumed fish. The 99th percentile fish consumption rates of adults and children (5 and younger) who consume fish were 389 g/day and 162 g/day, respectively.

Reanalysis of the CRITFC survey report by Ecology provides estimates of anadromous, non-anadromous, all finfish consumption estimates, and source of harvest (Table 21, Figures 3 and 4). Slight variations between can be attributed to procedures used to estimate rates and percentiles (Polissar et al., 2012).

Table 21. CRITFC Adult Fish Consumption Rates by Species Group and Source, Consumers Only

Population Tribal	Species Group	Harvest Source of Fish	Descriptive Statistics (g/day)				
			50th Percentile	Mean	75th Percentile	90th Percentile	95th Percentile
The 4 Tribes Affiliated With The Columbia River Inter-Tribal Fish Commission	All finfish	all	40.5	63.2	64.8	130.0	194.0
	Non-anadromous	all	20.9	32.6	33.4	67.0	99.9
	Anadromous	all	19.6	30.6	31.4	63.1	94.1
	All finfish	Columbia River Basin	35.6	55.6	57.0	114	171
	Non-anadromous	Columbia River Basin	18.4	28.6	29.4	58.9	87.9
	Anadromous	Columbia River Basin	17.3	27.0	27.7	55.5	82.8

See Polissar et al., 2012, Table E-1.

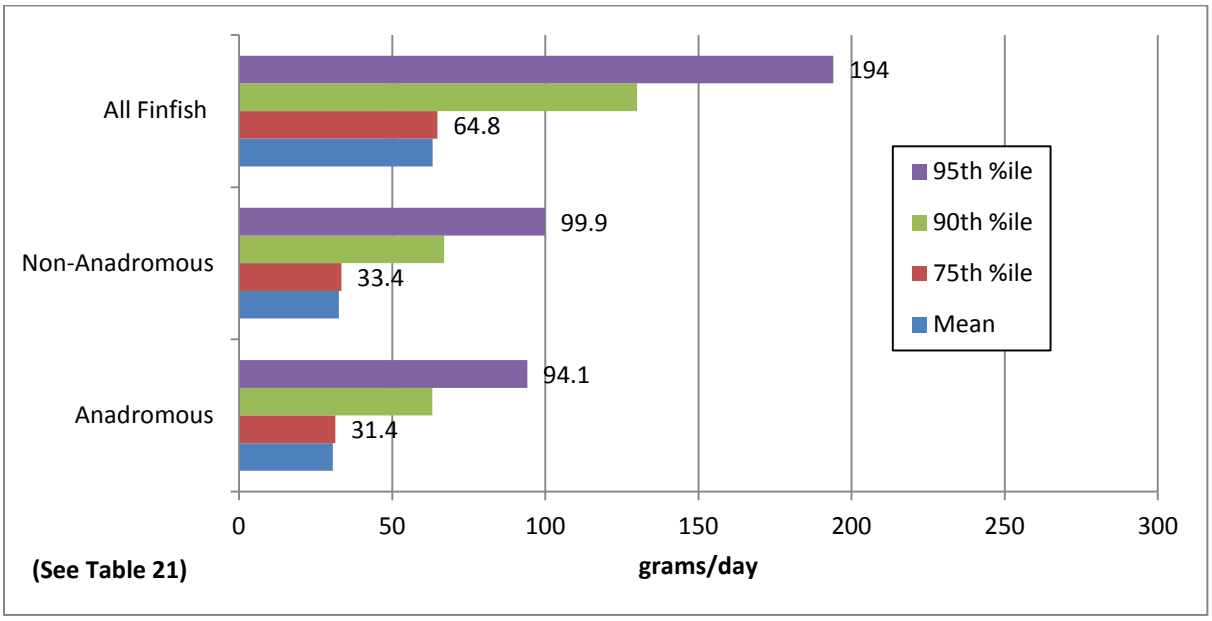


Figure 3. CRITFC Adult Fish Consumption Rates, Harvested from All Sources

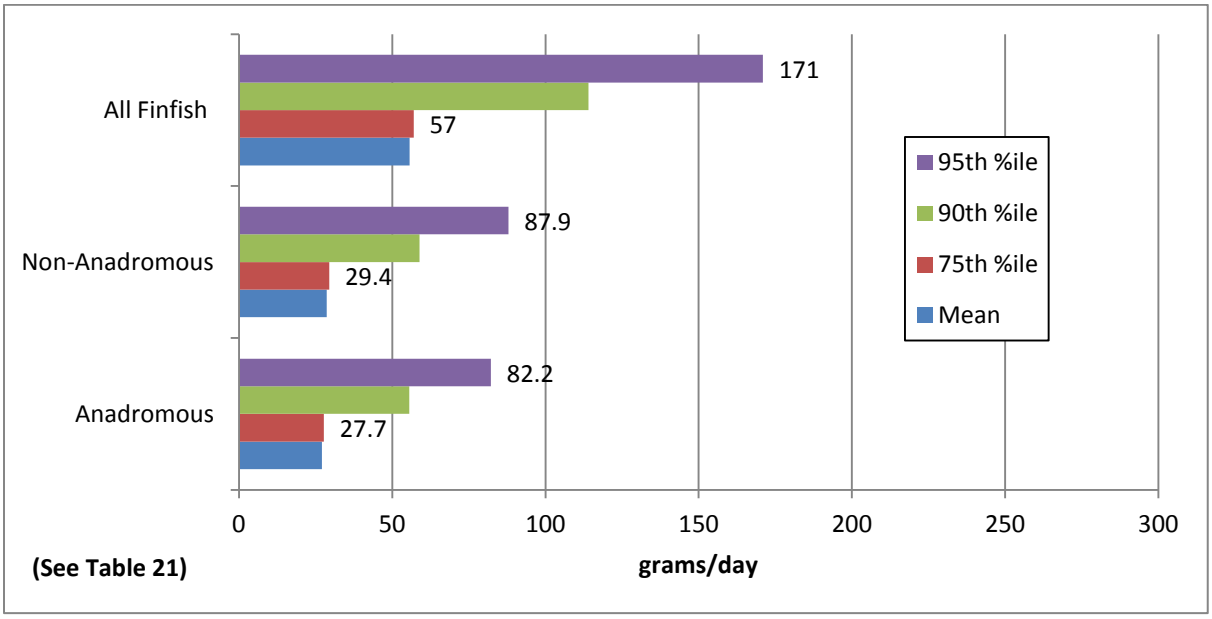


Figure 4. CRITFC Adult Fish Consumption Rates, Harvested from Columbia River Basin

Technical defensibility

As summarized in Table 22 below, Ecology has determined that the 1994 CRITFC survey is relevant to Washington and satisfies measures of technical defensibility.

Table 22. Columbia River Inter-Tribal Fish Commission Consumption Survey

Metric	Observations and Comments	Evaluation
1. Survey Method Development		
a. Type and description of survey vehicle	24-hour and seasonal dietary recall personal interview survey; respondents were randomly selected from Indian Health Service records; a large range of fish was considered in the survey (salmon, lamprey, smelt.)	The survey method and vehicle were developed in a technically defensible manner.
b. Collaboration and review	CRITFC staff developed the survey in collaboration with Washington DOH, EPA HQ & Region 10 staff, Indian Health Service staff; it was reviewed by tribal governments of the CRITFC member tribes (Nez Perce Tribe, Confederated Tribes and Bands of the Yakama Indian Nation, Confederated Tribes of the Warm Springs and Umatilla Indian Reservations).	
c. Beta testing	The survey was tested by tribal staff in consultation with EPA.	
2. Survey execution		
a. Establish and document execution standards	Execution of survey vehicle by native population documented; data gathered on adult respondents 18 years or older and children 5 years or younger.	The survey vehicle was appropriately executed and documented; use of fish models was documented.
b. Document staff training	Native staff trained personnel in collaboration with and with technical oversight provided by state/federal agencies.	
c. Finish/shellfish models used	Fish models were employed to aid in identifying the amount of finfish and shellfish consumed.	
3. Publication of results		
a. Where were results published? Are they clear and complete?	Results were published in a CRITFC tribal government publication. The population surveyed, method used, conclusions, and tabulations were well-defined, presented, and documented. The highest fish consumers were considered outliers and were dropped from the survey data and, therefore, were not statistically evaluated.	The data presented are sufficient to develop consumption distributions with percentiles.
b. Methodology reported	The methodology used is clearly described and documented.	
c. Results tabulated and stated	Survey results are reported and summarized in a tabular format suitable for distributional descriptive statistics; the report documents an acceptable response rate (69%).	
d. Conclusions clearly reported	Conclusions are stated and correspond to data tabulated.	
e. Variability and uncertainty	Variability and uncertainty were qualitatively recognized and noted.	
f. How is the potential for bias addressed?	Different types of bias were identified and discussed in the survey.	
4. Applicability and utility for regulatory decision making		
a. Representation of target population	The survey provides a reasonable estimate of fish consumption for CRITFC member Native populations within the Columbia River Basin (Nez Perce Tribe, Confederated Tribes and Bands of the Yakama Indian Nation, Confederated Tribes of the Warm Springs & Umatilla Indian Reservations).	This survey meets the standards of relevance, applicability, and utility and is appropriate for use in regulatory decision making. Rigorous
b. Currency of information	Surveys were conducted in the early to mid-1990s; more recently, the CRITFC estimates were used by Oregon DEQ for developing water quality standards (2011).	

Metric	Observations and Comments	Evaluation
c. Sufficiency of data	The fish consumption estimates are sufficient to provide descriptive statistics for defined distributions and percentiles for risk-based decision making. However, it is unclear what portion of seafood consumed is harvested from local sources. CRITFC fish consumption rates are for seafood from all sources and include anadromous (migratory) species.	
5. Overall technical suitability for regulatory decision making		
a. Range of technical defensibility	Survey design, development of methodology, execution of survey, data interpretation, and conclusions for fish consumption provide a reasonable quantitative exposure estimate of fish consumption rates for target populations.	Ecology concludes survey is technically defensible.
b. Appropriateness for use in risk-based standards	The data are sufficient to provide distribution, average, and percentile estimates of fish consumption as required for risk-based decision making.	

Source: CRITFC, 1994.

The CRITFC fish dietary survey was one of the first tribal dietary surveys conducted in the Pacific Northwest. The technical rigor applied to the design and conduct of this survey has been mirrored by other regional-specific surveys conducted in Washington State. The March 19, 2012, correspondence from Babtist Paul Lumley, Executive Director of CRITFC, to Ted Sturdevant, Director, Washington State Department of Ecology, summarizes the efforts that support the scientific defensibility of the CRITFC fish dietary survey (CRITFC, 2012). As described in this correspondence, the salient features of the 1994 CRITFC survey design and analysis are provided below:

- A technical panel was established to assist in designing and implementing the survey. The panel consisted of 17 members and included technical staff from CRITFC, as well as toxicologists, epidemiologists, health scientists, and environmental scientists from the Indian Health Service (IHS), the Centers for Disease Control and Prevention (CDC), Washington and Oregon State health departments, EPA Region 10, and EPA Headquarters.
- During a three-day session, the CDC trained interviewers and instructed them in procedures and techniques for conducting surveys. The instructors reviewed each question on the questionnaire with the interviewers and helped them practice conducting interviews. Models of finfish and shellfish were used as visual aids to help identify types and amounts of fish consumed.
- A total of 513 tribal members at least 18 years old were directly surveyed. These respondents provided information for 204 children age 5 or younger (one child per household). The CDC used a systematic probability sampling method to randomly select respondents from Indian Health Service client lists of tribal members. Stratified systematic sampling was used to collect survey data, with each of the four tribes considered an independent stratum.

- Survey data were transferred from the questionnaires to an electronic database, and all data entries were reviewed for missing answers or mistakes. The CDC's statistical database package for analysis of epidemiological data was used to analyze the survey data. A private consulting firm conducted a second complete audit of the database, which involved a question-by-question review of each survey. Appropriate statistical tests were used to evaluate the data. The Shapiro-Wilk test was used because the sample size was less than 2,000 and indicated that the dataset was not a purely random distribution, but rather reflected meaningful trends. In the 1994 CRITFC analysis, outliers whose data points seemed unreasonably high due to discontinuity in distribution were ignored on all calculations. For highly positively skewed distributions, removing statistical outliers from the dataset may bias the upper percentile fish consumption estimates low.
- The study design, implementation strategy, and analyses were submitted to an independent peer review panel. The peer review panel consisted of the following members: Dr. Patrick West, Ph.D., University of Michigan; Dr. Douglas Robeson, Ph.D., Ottawa, Ontario; Dr. Clayton Stunkard, Silver Spring, MD; Dr. H. Joseph Sekerke, Jr., State of Florida Department of Health and Rehabilitation Services; Dr. Mary Yoshiko Hama, Ph.D., U.S. Department of Agriculture, Food Consumption Research Branch; Dr. Kenneth Rudo, Ph.D., State of North Carolina, Department of Environmental Health, Division of Epidemiology; Dr. Yasmin Cypel, Ph.D., U.S. Department of Agriculture, Food Consumption Research Branch; Dr. Rolf Hartung, Ph.D., Department of Environmental and Industrial Health, University of Michigan; and Dr. Dale Hattis, Ph.D., Clark University.
- The CRITFC survey design's credibility is further supported by its use as a template for other Pacific Northwest dietary surveys, with refinements specific for the populations being surveyed. In addition, the CRITFC survey has been referred to in national guidance for policies and procedures for evaluating exposures (EPA's Exposure Factors Handbook 2009 Update and 2011 Edition).

Additional information reviewed

- Harris and Harper (1997) report that a fish consumption rate of 540 g/day represents a reasonable subsistence fish consumption rate for CRITFC's member tribes who pursue a traditional lifestyle. They base this on their review of several nonsubsistence Native American studies, two subsistence studies, and personal interviews of members of the Umatilla and Yakama Tribes.
- A further examination of Columbia River basin tribal populations used information and data collected from the 1994 Columbia River Inter-Tribal Fish Commission's fish consumption survey (Sun Rhodes, 2006). Because of concerns due to chemical contaminants in water and fish for tribal fish-consuming populations along the Columbia River basin, the tribal populations' characteristics were examined for children, women of

child-bearing age, and tribal elders who may be susceptible to adverse health effects from exposure to contaminants due to high fish consumption. A multivariate analysis showed a positive association between fish consumption rates and factors including breastfeeding after the most recent births, percent of fish obtained non-commercially for women who recently gave birth, living off the reservation, and fish consumption for children and the elderly. About 50 percent of women, 80 percent of tribal elders, and at least 40 percent of children consume nonfillet fish parts. Although this reevaluation did not result in any changes or corrections in Columbia River basin tribal consumption rates, it provided additional information regarding susceptible tribal populations that consume fish.

4.3.2 Tulalip and Squaxin Island Tribes of the Puget Sound Region

A survey of finfish and shellfish consumption for the Tulalip and Squaxin Island Tribes living in the Puget Sound region was conducted in 1994 (Toy et al., 1996).

The target populations included adult tribal members (18 years or older), randomly selected from tribal enrollments who lived on or within a 50-mile radius of the reservation, and children aged 5 years or younger who lived in the enrolled member's household. The survey reported consumption rates of anadromous, pelagic, bottomfish, and shellfish in grams per kilogram body weight per day (g/kg bw/day) over a 1-year period and the portion size of each meal. Adults who did not consume fish (less than 1 percent of those contacted) were not included in the survey. Finfish/shellfish models were used to estimate portion sizes. Finfish/shellfish preparation methods were identified, and sources of finfish and shellfish consumed were reported by tribe and species groups.

Species groups included:

- *Anadromous fish (Group A).* Salmon (Chinook, pink, sockeye, coho, chum); smelt; steelhead.
- *Pelagic fish (Group B).* Cod, dogfish, greenling, herring, perch, pollock, rockfish, sablefish, spiny.
- *Bottomfish (Group C).* Halibut, sole/flounder, sturgeon.
- *Shellfish (Group D).* Butter clam, clams (manila/littleneck), cockles, Dungeness crab, horse clam, moon snail, mussels, oyster, scallops, sea cucumber, sea urchin, shrimp, squid.
- *Other (Groups E and F).* Abalone, barnacles, bullhead, chitons, crayfish, eel, geoduck, grunters, limpets, lobster, mackerel, manta ray, octopus, razor clam, shark, skate, trout.

A total of 190 successful interviews were completed from February 25 through mid-May for adult tribal respondents. A tribal parent or guardian answered questions about the fish consumption for children from the same household. Only one child per household, selected randomly, was included in the survey, for a total of 69 children. Results from half of the adult respondents in the Tulalip Tribes were dropped because one of the tribal interviewers did not follow the survey interview protocol. However, repeat interviews were conducted by telephone as a follow-up with 10 percent of the survey respondents. The timing of the survey period may bias the fish consumption estimates. Salmon are present in Puget Sound during different times of the year. The survey was administered during a low season for anadromous (salmon) fish harvest but prior to and during the shellfish harvest season. Because of the timing of the survey, respondents may have underestimated their salmon consumption and overestimated shellfish consumption.

Anadromous finfish and shellfish were most frequently consumed. The main source for the most frequently consumed fish (anadromous finfish and shellfish) was local water bodies of Puget Sound. Fish fillets with skin were consumed by up to 40 percent of the tribal respondents, with mean percent consumption of fish parts (head, bones, eggs, organs, and skin) for up to 11 percent of tribal respondents consuming anadromous fish. Although the survey identified fish parts consumed by respondents, it did not include complex tribal seafood recipes.

Weight adjusted consumption rates were calculated and reported by tribe, age, gender, income, and species group. The adult mean and median consumption rates for all forms of fish combined were 0.89 and 0.55 g/kg bw/day for the Tulalip Tribes and 0.89 and 0.52 g/kg bw/day for the Squaxin Island Tribe, respectively. Age-adjusted median fish consumption rates for the Tulalip Tribes were 53 g/day for males and 34 g/day for females. Age adjusted median fish consumption rates for the Squaxin Island Tribe were 66 g/day for males and 25 g/day for females. The mean and median consumption rate for children, 5 years and younger for both tribes combined, were 0.53 and 0.17 g/kg bw/day, respectively.

Ecology's statistical analysis of the Tulalip survey data (individual level respondent data) provides estimates of anadromous, non-anadromous, shellfish, all finfish/shellfish consumption estimates, and source of harvest (Table 23, Figures 5 and 6).

Table 23. Tulalip Tribal Adult Fish Consumption Rates by Species Group and Source

Population Tribal	Species Group	Harvest Source of Fish	Descriptive Statistics (g/day)				
			50th Percentile	Mean	75th Percentile	90th Percentile	95th Percentile
Tulalip	All Fish	All Sources	44.5	82.2	94.2	193	268
	Finfish	All Sources	22.3	44.1	49.1	110	204
	Shellfish	All Sources	15.4	42.6	40.1	113	141
	Non-anadromous	All Sources	20.1	45.9	52.4	118	151
	Anadromous	All Sources	16.8	38.1	43.3	92.1	191
	All	Puget Sound	29.9	59.5	75.0	139	237
	Finfish	Puget Sound	13.0	31.9	33.1	78.4	146
	Shellfish	Puget Sound	14.2	36.9	40.1	111	148
	Non-anadromous	Puget Sound	14.8	35.5	38.8	109	145
	Anadromous	Puget Sound	11.8	30.4	32.4	66.0	148

See Polissar et al., 2012, Table E-1.

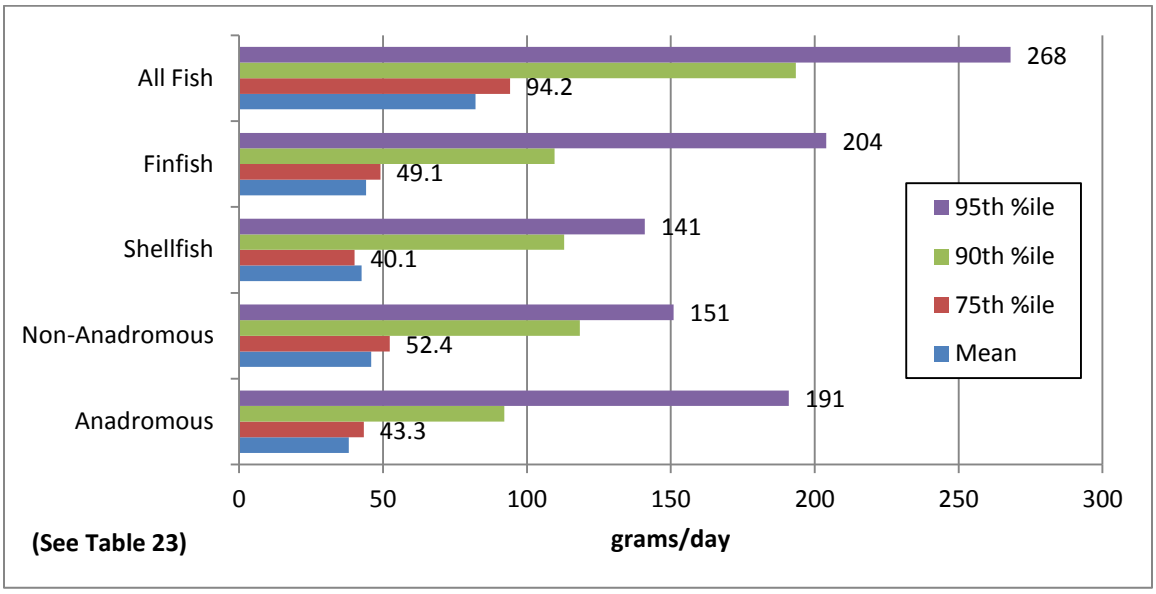


Figure 5. Tulalip Tribal Adult Fish Consumption Rates, Harvested from All Sources

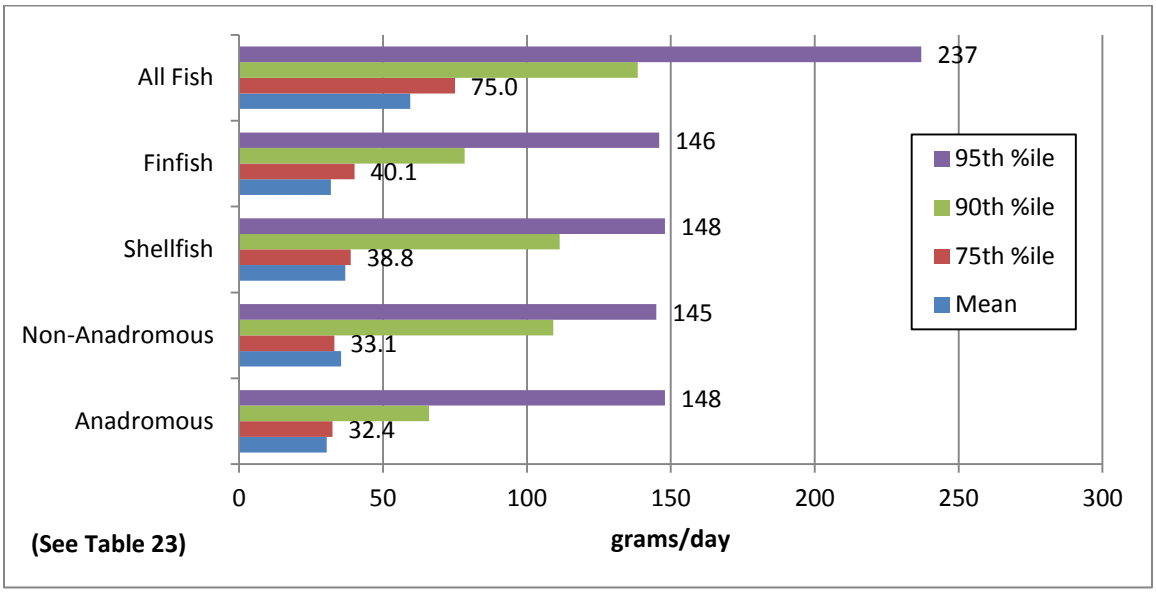


Figure 6. Tulalip Tribal Adult Fish Consumption Rates, Harvested from Puget Sound

Ecology's statistical analysis of the Squaxin Island survey data provides consumption estimates for anadromous, non-anadromous, shellfish, and all finfish/shellfish, and data on source of harvest (Table 24, Figures 7 and 8). Consumption rate estimates for the Squaxin Island adult fish consumers are based on published results of the fish dietary survey.

Table 24. Squaxin Island Tribal Adult Fish Consumption Rates by Species Group and Source

Population Tribal	Species Group	Harvest Source of Fish	Descriptive Statistics (g/day)				
			50th Percentile	Mean	75th Percentile	90th Percentile	95th Percentile
Squaxin Island	All fish	All	44.5	83.7	94.4	206	280
	Finfish	All	31.4	65.5	82.3	150	208
	Shellfish	All	10.3	23.1	23.9	54.0	83.6
	Non-anadromous	All	15.2	28.7	32.3	70.5	95.9
	Anadromous	All	25.3	55.1	65.8	128	171
	All fish	Puget Sound	30.0	56.4	63.5	139	189
	Finfish	Puget Sound	21.6	45.0	56.5	103	143
	Shellfish	Puget Sound	6.4	14.3	14.8	33.5	51.9
	Non-anadromous	Puget Sound	6.5	12.3	13.9	30.3	41.2
	Anadromous	Puget Sound	20.2	44.1	52.6	103	137

See Polissar et al., 2012, Table E-1.

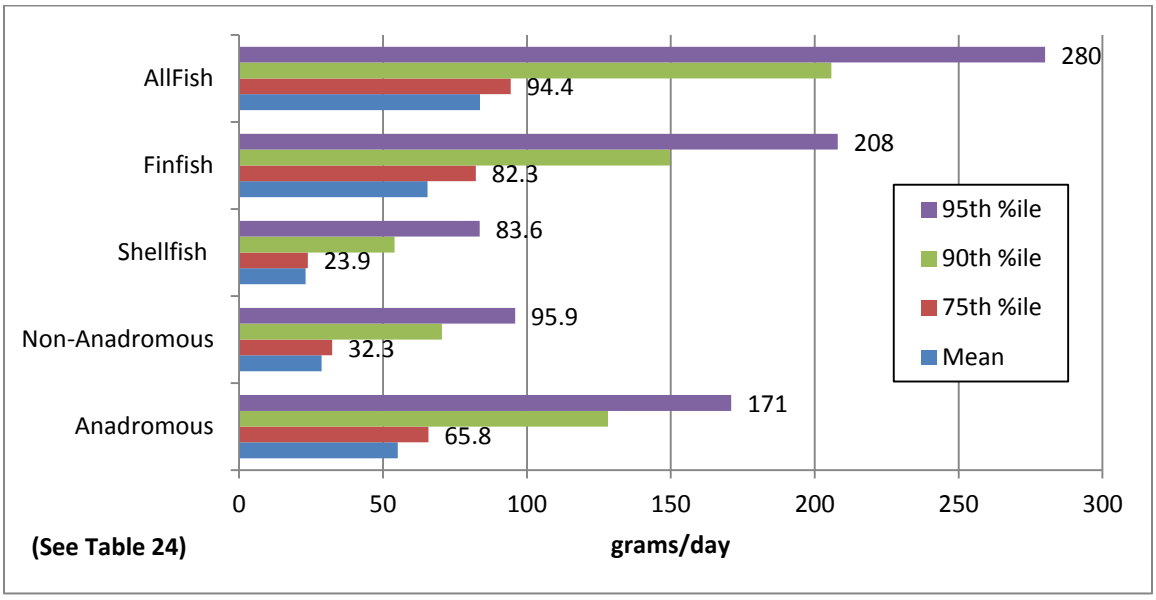


Figure 7. Squaxin Island Tribal Adult Fish Consumption Rates, Harvested from All Sources

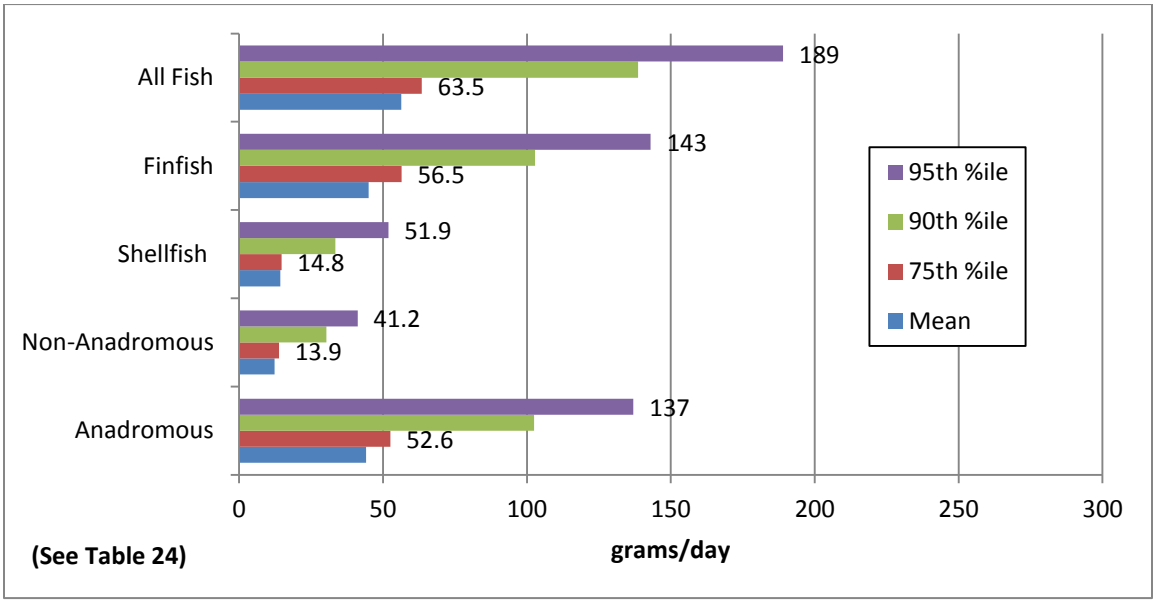


Figure 8. Squaxin Island Tribal Adult Fish Consumption Rates, Harvested from Puget Sound

Technical defensibility

As summarized in Table 25 below, Ecology has determined that the survey of Tulalip and Squaxin Island Tribes of the Puget Sound Region is relevant to Washington and satisfies measures of technically defensibility (Toy et al., 1996).

Table 25. Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region

Metric	Observations and Comments	Evaluation
1. Survey method development		
a. Type and description of survey vehicle	Personal interview survey; 24-hour and seasonal dietary recall; finfish/shellfish identification, portion, frequency, preparation, and harvest locations.	The survey method and vehicle were developed in a technically defensible manner.
b. Collaboration and review	Survey was developed in collaboration with Washington DOH, Ecology, EPA Region 10, Tulalip Tribal Department of Environment, Suquamish Tribal Fisheries Department, Board of Directors for Tulalip and Squaxin Island Tribes, Columbia River Inter-Tribal Fish Commission, and Fred Hutchinson Cancer Research Center in Seattle.	
c. Beta testing	Pilot survey and repeat interviews conducted	
2. Survey execution		
a. Establish and document execution standards	Execution of survey questionnaire documented with identifiable QA/QC procedures.	The survey vehicle was appropriately executed and documented; use of fish models was documented.
b. Document staff training	Two members from each tribe trained to conduct interviews.	
c. Finfish/shellfish models used	Finfish and shellfish models used for multiple species.	
3. Publication of results		
a. Where were results published? Are they clear and complete?	Finfish/shellfish identification, portion, frequency, preparation, and harvest locations documented and reported.	The data presented in the joint Tulalip and Squaxin Island tribal publication are sufficient to develop consumption distributions with percentiles.
b. Methodology reported	All phases of method development documented and reported.	
c. Results tabulated and stated	Tabulated species-specific consumption with descriptive statistics.	
d. Conclusions clearly reported	Conclusions reported with follow-up interviews for reliability and representation	
f. Variability and uncertainty	Noted and documented with note of “outliers” with reported rates for Tulalip and Squaxin Island Tribes.	
g. How is the potential for bias addressed?	The possibility for bias in the survey methodology is recognized and discussed. Survey results from one interview did not follow protocol and were eliminated.	
4. Applicability and utility for regulatory decision making		
a. Representation of target population	Included range of different rates for enrolled Tulalip and Squaxin Island tribal members	This survey meets the standards of relevance, applicability, and utility and is appropriate for use in regulatory decision making.
b. Currency of information	Survey conducted in 1996; more recently the consumption estimates were used by Oregon DEQ in developing water quality standards (2011). EPA Region 10 has also utilized the Suquamish survey in its internal policy on assessing tribal seafood consumption risks.	
c. Sufficiency of data	The data are sufficient to provide distribution and percentile estimates of fish consumption for Tulalip and Squaxin Island tribal populations.	

Metric	Observations and Comments	Evaluation
5. Overall technical suitability for regulatory decision making		
a. Range of technical defensibility	Technically defensible dietary survey of the Squaxin Island Tribe.	Ecology concludes the survey is technically defensible.
b. Appropriateness for use in risk-based standards	Data were reanalyzed by Nayak L. Polissar, Ph.D., to provide consumer-only consumption rates. It is sufficient to provide distribution and percentile estimates of fish consumption as required for risk-based decision making.	

Source: Toy et al., 1996.

The technical rigor applied to the design and conduct of the Tulalip and Squaxin Island tribal fish dietary survey illustrates a high level of collaboration across state and federal agencies and tribal governments, and closely parallels the CRITFC fish dietary survey. The salient features of this survey are noted below:

- A Technical Advisory Panel was formed to provide assistance and oversight for planning, developing methods, and conducting the dietary survey. Panelists included numerous professionals from the Washington State Departments of Health and Ecology, U.S. Environmental Protection Agency, and the U.S. Public Health Service.
- Tulalip and Squaxin Island tribal staff assisted with organizing and executing the survey. They also provided tribal consultations with other tribal governments and organizations including the Columbia River Inter-Tribal Fish Commission, Portland, Oregon.
- A toxicologist, epidemiologist, tribal biologists, and statistical consultants provided professional guidance and consultations.

4.3.3 Suquamish Tribe

The Suquamish Tribal Council conducted a fish consumption survey during July, August, and September 1998 of Suquamish tribal members living on and near the Port Madison Indian reservation in the Puget Sound area (The Suquamish Tribe, 2000). The survey was conducted to determine the finfish/shellfish consumption rates, habits, and patterns of the Suquamish Tribe. Also, the study was conducted to identify fish consumption-related cultural practices and tribal characteristics that might affect fish consumption rates, patterns, and habits. The survey was administered during months of high availability of fisheries, which may have had a positive bias on the reported fish consumption estimates.

Consumption data were based on a random sample of adults (16 years and older) selected from the tribal enrollment roster. Of 425 tribal members of all ages living on or near the reservation, 284 adults were identified as eligible to participate in the survey. Of these, 142 adults were randomly selected and 92 participated in the survey, for a 64.8 percent participation rate. Consumption data were collected for 31 children under the age of 6 who were living in the same household with adult respondents at the time of the survey. Some households had more than one child who was surveyed. The survey questionnaire was administered by trained tribal members

using personal interviews and included two parts: a 24-hour dietary recall, and an assessment of fish consumption over the course of a year.[37] In addition, the survey included information on:

- Fish species identification, portion sizes, frequency of consumption, methods of preparation, harvest locations.
- Shellfish consumption, methods of preparation, harvest location.
- Changes in consumption over time, cultural information, physical information, and socioeconomic information.

Finfish/shellfish models were used to assist tribal respondents regarding amounts and types consumed. Booklets were used to assist in identifying harvest locations of seafood consumed. Finfish/shellfish were grouped into categories based on similarities in life history and practices of tribal members who fish for subsistence, ceremonial, and commercial purposes. The majority of finfish/shellfish consumed by the Suquamish Tribe was harvested from Puget Sound, with Pacific salmon and shellfish consumed more than other fish.

All 92 adult tribal respondents reported consuming some type of fish; hence, no non-consumers of fish were surveyed. Survey results were recorded as grams per kilogram per day (g/kg/day) along with the respondent's body weight. Adult respondents reported a mean consumption rate of all finfish and shellfish consumption rate of 2.71 g/kg/day. For children under 6 years old, the mean consumption of all finfish and shellfish was 1.48 g/kg/day. Below are weight-adjusted survey results for Suquamish adult fish consumers.

Ecology's statistical analysis of the Suquamish dietary data for Suquamish tribal adult fish consumers provides finfish, shellfish, and non-anadromous consumption rates by species groups and sources of fish consumed (Table 26, Figures 9 and 10).

[37] Estimates of maximum amounts of fish consumed, either as a rate or portion size, from a highly positively skewed dataset can be very large with estimates of several pounds of fish consumed. These maximum fish consumption estimates reflect the maximum amount of fish consumed by a subset of fish consumers within a larger indigenous fish-consuming population. Harper, Harris, and Donatuto have indicated that these very high fish consumers are true subsistence populations (fish consumption rate exceeding 454 g/day or 1 pound/day) within the larger indigenous fish-consuming populations (Harris and Harper, 1997; Harper and Harris, 2008; Donatuto and Harper, 2008).

Table 26. Suquamish Tribal Adult Fish Consumption Rates by Species Group and Source

Population Tribal	Species Group	Harvest Source of Fish	Descriptive Statistics (g/day)				
			50th Percentile	Mean	75th Percentile	90th Percentile	95th Percentile
Suquamish Tribe	All	All Sources	132	214	284	489	797
	Shellfish	All Sources	64.7	134	145	363	615
	Non-anadromous*	All Sources	102	169	219	377	615
	Anadromous	All Sources	27.6	48.8	79.1	133	172
	All	Puget Sound	57.5	165	221	397	767
	Shellfish	Puget Sound	52.4	109	118	294	499
	Non-anadromous*	Puget Sound	49.1	126	116	380	674
	Anadromous	Puget Sound	21.8	38.6	62.5	105	136

See Polissar et al., 2012

*Based on an assumed n = 90 consumers.

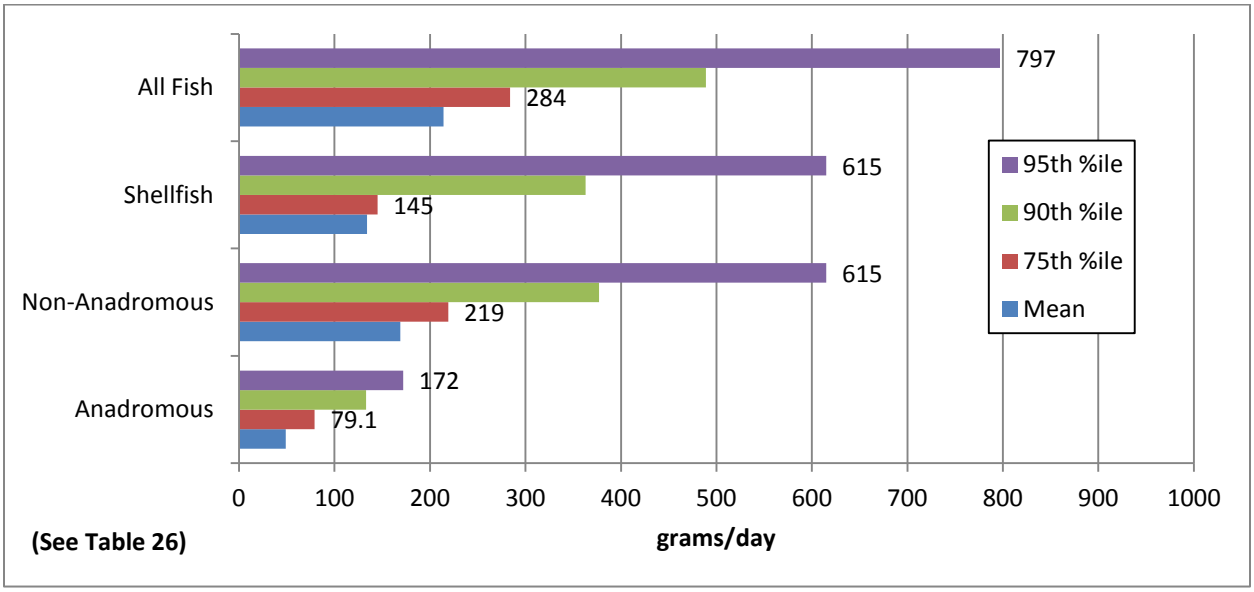


Figure 9. Suquamish Tribal Adult Fish Consumption Rates, Harvested from All Sources

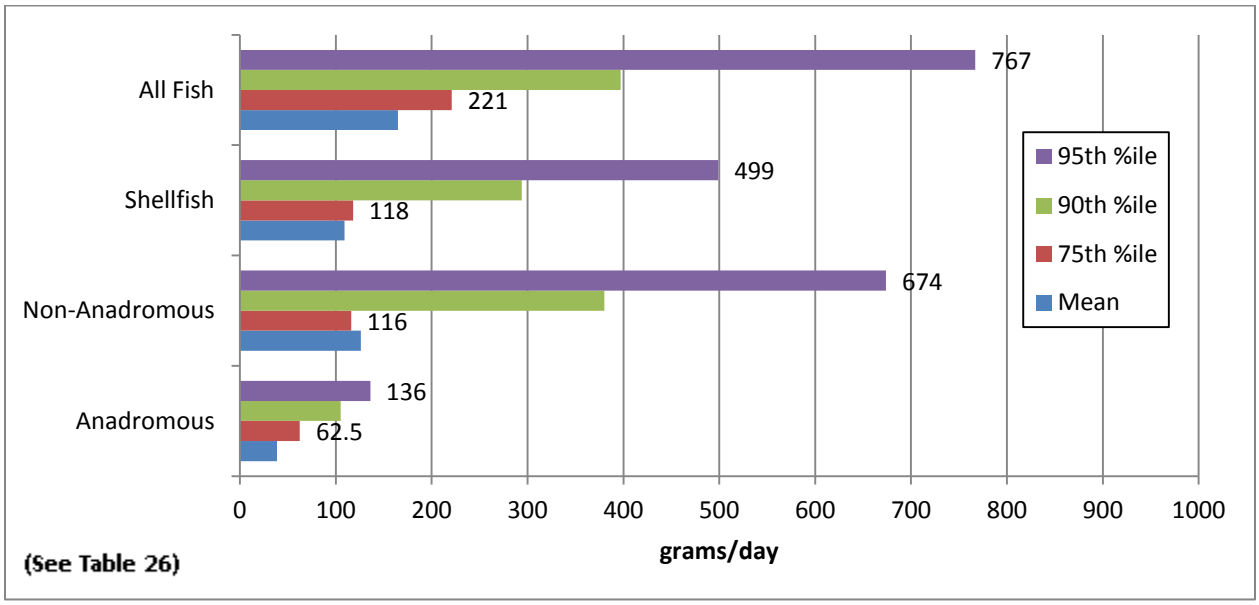


Figure 10. Suquamish Tribal Adult Fish Consumption Rates, Harvested from Puget Sound

Technical defensibility

As summarized in Table 27 below, Ecology has determined that the 2000 survey of the Suquamish Indian Tribe of the Port Madison Indian Reservations of Puget Sound is relevant to Washington and satisfies measures of technical defensibility.

Table 27. Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservation, Puget Sound Region

Metric	Observations and Comments	Evaluation
1. Survey method development		
a. Type and description of survey vehicle	Personal interview survey; 24-hour and seasonal dietary recall; finfish/shellfish identification, portion, frequency, preparation, and harvest locations.	The survey method and vehicle were developed in a technically defensible manner.
b. Collaboration and review	Survey was developed in collaboration with Washington DOH, Ecology, Agency for Toxic Substances and Disease Registry, University of Washington, EPA Region 10, and Suquamish Tribal Fisheries Department.	
c. Beta testing	Beta testing documented.	
2. Survey execution		
a. Establish and document execution standards	Execution of survey questionnaire documented with identifiable QA/QC procedures.	The survey vehicle was appropriately executed and documented; use of fish models was documented.
b. Document staff training	Training of personnel was conducted by trained Suquamish Tribe members.	
c. Finfish/shellfish models used	Seafood models and a display booklet of seafood illustrations for multiple species were used to aid in identifying the amount of seafood consumed.	

Metric	Observations and Comments	Evaluation
3. Publication of results		
a. Where were results published? Are they clear and complete?	Finfish/shellfish identification, portion, frequency, preparation, and harvest locations were documented and reported.	Suquamish Tribe publication with well-defined method, analysis of species consumed, clear data analysis and interpretation.
b. Methodology reported	The methodology used is clearly described and documented.	
c. Results tabulated and stated	Survey results are reported and summarized in a tabular format suitable for distributional descriptive statistics.	
d. Conclusions clearly reported	Conclusion reported with follow-up interviews for reliability and representation.	
e. Variability and uncertainty	Noted and documented with "outliers" identified and determined impact of outliers on consumption rate statistics of interest.	
f. How is the potential for bias addressed?	The possibility for bias in the survey methodology is recognized and discussed.	
4. Applicability and utility for regulatory decision making		
a. Representation of target population	Included range of different rates for enrolled Suquamish Tribe members.	This survey meets the standards of relevance, applicability, and utility and is appropriate for use in regulatory decision making.
b. Currency of information	The survey was conducted in 1999; more recently, the consumption estimates were used by Oregon DEQ for developing water quality standards (2011).	
c. Sufficiency of data	The fish-consumption estimates are sufficient to provide descriptive statistics for defined distributions and percentiles for Suquamish Tribal population. EPA Region 10 has also utilized the Suquamish survey information in its internal policy on assessing tribal seafood consumption risks.	
5. Overall technical suitability for regulatory decision making		
a. Range of technical defensibility	Technically defensible dietary survey of the Suquamish Tribe.	The survey is technically defensible with rates and portion sizes reinforced by independent technical documentation (Harper and Harris, 1997, 2008; Donatuto and Harper, 2008).
b. Appropriateness for use in risk-based standards	The data are sufficient to provide distribution and percentile estimates of fish consumption as required for risk-based decision making. Seafood consumption data provided are for consumption of seafood from all sources. EPA Region 10's tribal seafood consumption framework provides an approach for developing consumption rates of regionally harvested seafood.	

Source: The Suquamish Tribe, 2000.

Many features of the Suquamish tribal member dietary survey are similar to and reflect the experience gained during the development and conduct of the CRITFC dietary survey. These features were identified and described in the survey report, which confers and supports the technical defensibility of the study design, dietary methodology, execution of the survey, and results and conclusions drawn from the dietary survey (The Suquamish Tribe, 2000). The salient features of the technical review procedures for the Suquamish dietary review are noted below:

- The survey was funded through the Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Health and Human Services, and Washington State Department of Health with collaboration regarding the survey questionnaire design to elicit useful dietary information from tribal respondents.
- Technical review and oversight of the planning, design, execution, and evaluation of the data included biologists, epidemiologists, toxicologists, and statisticians from multiple agencies.
- The Suquamish Tribal staff included interviewers, biologists, and a principle investigator.
- Technical collaboration, consultations, and reviews were conducted by the Washington Departments of Ecology and Health, University of Washington, U.S. Department of Health and Human Services, Fred Hutchinson Cancer Research Institute, and the U.S. Environmental Protection Agency.
- Data analysis and review were conducted by two Seattle statistical consulting firms, Mountain-Whisper-Light Statistics and StatPro Consultants.

4.4 Asian and Pacific Islanders

An Asian and Pacific Islander (API) seafood consumption study was conducted during the spring and summer of 1997 in King County, Washington, to obtain information on consumption rates, species and seafood parts consumed, and preparation methods for first- or second-generation members of the API community (Sechena et al., 1999). Survey participants were API seafood consumers 18 years or older. The study was conducted in three phases:

- *Phase I:* Identify target API ethnic groups and develop appropriate questionnaires in the language required to administer the questionnaire to each API ethnic group.
- *Phase II:* Characterize seafood consumption for 10 API ethnic groups within the King County study area.[38]
- *Phase III:* Develop culturally appropriate health messages on risks related to seafood consumption and disseminate to API community.

Of the 202 respondents, 89 percent were first API generation (born outside the United States). API participants were interviewed by trained representatives from each of the 10 API ethnic communities represented and asked to report on the number of annual servings and portion size of the servings. Participants reported their own body weights. Fish consumption rate results were reported as grams per kilogram per day. Because the survey was based on dietary recall, the authors selected 20 API respondents to interview a second time, to assess the reliability of the

[38] The 10 API ethnic groups are Cambodian, Chinese, Filipino, Hmong, Japanese, Korean, Laotian, Mien, Samoan, and Vietnamese.

responses. The results suggest that the estimated consumption rates are reliable for the API community study area.

Table 28 provides the weight-adjusted survey results for API adult fish consumers.

Table 28. Adult Respondents to the Asian and Pacific Islander Survey

	Number of Adults Surveyed	Descriptive Statistics (g/day)					
		Mean	Median	Percentiles			
				75th	90th	95th	99th
Asian and Pacific Islanders	202	117	78	139	236	306	-

Source: Adapted from Oregon DEQ, 2008, Table 3. See also Polissar et al., 2012; Sechena et al.,1999, 2003.

Survey results indicate that shellfish were consumed more by the API community than any other group of fish. More than 75 percent of the respondents consumed shrimp, crab, and squid. Salmon and tuna were the most frequently consumed finfish. For all fish groups, 79 to 97 percent of the seafood consumed came from either groceries/street vendors or restaurants. Japanese consume a greater percentage of finfish than shellfish (52 percent), while Vietnamese consume more shellfish (50 percent). The mean and median consumption rates for all seafood combined for the 10 API ethnic groups were 1.9 g/kg bw/day and 1.4 g/kg bw/day, respectively. The average shellfish consumption rate for the API community was 0.87 g/kg bw/day. The API community consumed more shellfish than all of the combined categories of finfish consumed (average finfish consumption is 0.82 g/kg bw/day).

Technical defensibility

As summarized in Table 29 below, Ecology has determined that the 1999 survey of King County Asian and Pacific Islanders is relevant to Washington and satisfies measures of technical defensibility. The King County, Washington, API fish consumption survey is considered an outstanding model (gold standard) for culturally sensitive fish dietary surveys.

The fish dietary survey was administered in two phases:

- *Phase 1:* Identification of appropriate API ethnic groups to survey, design culturally sensitive fish dietary survey questionnaire, and then translate and pilot test the questionnaire for each API ethnic group.
- *Phase 2:* Established partnership between the Refugee Federation Service Center and the University of Washington's Environmental Health Department to help support the University of Washington Human Subjects Committee for the design, survey instruments, and execution of the survey.

Table 29. Asian and Pacific Islander Seafood Consumption Study

Metric	Observations and Comments	Evaluation
1. Survey method development		
a. Type and description of survey vehicle	Personal interview survey; 24-hour dietary recall; conducted in three phases.	The survey method and vehicle were developed in a technically defensible manner.
b. Collaboration and review	Survey was developed in collaboration with a Community Steering Committee (representatives of the API community, Washington DOH, Ecology, EPA Region 10, University of Washington, and Seattle Refugee Federation Service Center).	
c. Beta testing	The testing of the survey was conducted in phases with follow-up interviews to assess reliability of responses.	
2. Survey execution		
a. Establish & document execution standards	Seafood consumption studies for 10 API groups in King County, Washington. Technical execution guided by Community Steering, Technical, and Advisory Committees.	The survey was appropriately executed and documented; use of fish models was documented.
b. Document staff training	Trained bilingual interviewers from API community.	
c. Finfish/shellfish models used	Seafood models were used to represent approximate portion sizes.	
3. Publication of results		
a. Where were results published? Are they clear and complete?	Information on types of seafood consumed, source of seafood, preparation methods, frequency and portion size consumed, demographic information clearly reported.	Robust analysis and evaluation of API community fish consumption habits and patterns
b. Methodology reported	Phase II (fish consumption) followed from identification target API populations with ethnic and language-specific questionnaires.	
c. Results tabulated and stated	Tabulated species-specific consumption across 10 different API ethnic populations; included food preparation methods.	
d. Conclusions clearly reported	Conclusions clearly reported with follow-up interviews.	
e. Variability and uncertainty	Variability and uncertainty were qualitatively recognized and noted.	
f. How is the potential for bias addressed?	The possibility for bias in the survey methodology is recognized and discussed.	
4. Applicability and utility for regulatory decision making		
a. Representation of target population	The survey included a range of different API ethnic groups to evaluate consumption representative of API population.	This survey meets the standards of relevance, applicability, and utility and is appropriate for use in regulatory decision making.
b. Currency of information	The survey was conducted in 1999; more recently, the consumption estimates were used by Oregon DEQ in developing water quality standards (2011).	
c. Sufficiency of data	The consumption estimates are sufficient to provide descriptive statistics for defined distributions and percentiles for different API populations.	
5. Overall technical suitability for regulatory decision making		
a. Range of technical defensibility	Technically defensible dietary survey of API populations in King County, Washington.	Ecology concludes the survey is technically defensible.
b. Appropriateness for use in risk-based standards	The data are sufficient to provide distribution and percentile estimates of fish consumption as required for risk-based decision making. The API survey did not correct for cooking weight loss or regionally harvested seafood. See write-up on EPA Region 10's reanalysis of the API survey (Kissinger, 2005).	

Source: Sechena et al., 1999.

Sechena et al., 2003 provides a detailed description of the API fish dietary survey. Detailed descriptions of the survey methodology include:

- A methodology overview.
- Survey instruments.
- Sampling strategy including respondent selection criteria, API ethnic representation and recruitment, questionnaire administration, data analyses.
- Statistical methods used to derive fish consumption rates, treatment of outliers, hypothesis testing, and statistical significance and descriptive statistics.
- Results and discussion with tabulated results in g/kg/day for upper percentile estimates.

4.4.1 Reanalysis by EPA Region 10

EPA Region 10 reanalyzed the API data to correct for cooking weight loss, regional seafood harvest, and extrapolation from the survey to King County API populations (Kissinger, 2005). This reanalysis was used to establish cleanup levels in the Lower Duwamish Waterway (Windward Environmental, 2007). The EPA Region 10 reanalysis of the API 1999 survey included only data for individuals consuming seafood from King County. Weighting factors for King County consumers for various ethnic groups were a function of the percentage of that ethnic group as determined in the census and the number of individuals in that ethnic group that consumed seafood from King County. The 95th percentile ingestion rate (defined as the reasonable maximum exposure [RME] scenario) was developed from the consumer-only dataset of weighted ingestion rates. Adjustments were made to account for some of the shellfish consumption reported on a cooked-weight basis rather than on a wet-weight basis. Revised estimates of average raw shellfish consumption were made by using 25 and 50 percent cooking loss correction factors for those shellfish species for which consumption was reported on a cooked-weight basis. EPA calculated demographically weighted mean ingestion rates for each seafood category for individuals who consumed some seafood caught in King County. Demographically weighted mean ingestion rates were used to derive the percentage of consumption of each seafood category. These percentages were then applied to the total consumption rate (95th percentile of total King County API seafood consumption of 57.1 g/day) to derive consumption rates for each seafood category.

Anadromous fish were not included in the fish consumption scenario because it is problematic to apportion salmon (anadromous fish) contaminant body burden to site-specific chemical contaminants. To estimate the API central tendency consumption rate, the 50th percentile of total King County API consumption was multiplied by the percentage of consumption for the various seafood categories. Total non-anadromous seafood consumption for the API exposure scenarios was 51.1 g/day and 5.3 g/day for the RME and central tendency estimates, respectively.

Reanalysis of the consumption of shellfish (mussels, crabs, and clams) for the API exposures used average demographically weighted consumption of these shellfish species harvested only from King County. These shellfish consumption estimates were used to calculate the percentage of each shellfish type consumed. The demographic weighting factor was used to estimate the consumption of clams, mussels, and crabs. The crab consumption rates were apportioned among crab whole body and edible meat, and the benthic (demersal) fish consumption rates were apportioned among benthic fish fillet and whole body. EPA Region 10 provided demographically weighted average percentages of crab whole-body and crab edible-meat consumption by API populations consuming at least some King County seafood. Also, EPA Region 10 provided average demographically weighted percentages of whole-body and fillet consumption by API members consuming at least some King County seafood.

Technical defensibility

Ecology has determined that the EPA Region 10 reanalysis of the 1999 API survey is a relevant and technically defensible approach for a site-specific evaluation (Lower Duwamish Waterway).

Reanalysis of the API data by EPA Region 10 for King County API adult consumers provided central and upper bound estimates of fish consumption (Table 30). The reported consumption estimates include no adjustment for cooking and may be slightly biased low (i.e., underestimated).

The Kissinger (2005) demographic weighting methodology is not recommended for projecting fish dietary patterns for API populations beyond King County. Because of the small number of respondents for each API ethnic group, there would be a high level of uncertainty in projecting statewide API fish dietary patterns from King County API fish dietary information.

It should be noted that Asian and Pacific Islanders include a broad range of ethnicities[39] and that the Kissinger (2005) analysis presents fish consumption estimates determined from aggregating fish consumption data for small numbers of individuals from these varied ethnic groups. Future fish consumption survey efforts should consider more comprehensive analysis of quantitative fish consumption and cultural factors associated with fish consumption by individual ethnic groups.

[39] For the ethnicities listed here, the first number is the number of respondents from that ethnic group; the second number is the percentage of the total number of respondents represented by that group (Sechena et al., 2003, Table 1).

Cambodian	20/≈10%	Mien	10/≈5%
Chinese	30/≈14%	Hmong	5/≈2%
Filipino	30/≈14%	Samoan	10/≈5%
Japanese	29/≈14%	Vietnamese	26/≈13%
Korean	22/≈10%	All API Ethnicity	202
Laotian	20/≈10%		

Table 30. API Adult Seafood Consumption Rates by Species Group and Source

Population API	Species Group	Source of Fish	Descriptive Statistics (g/day)		
			50th Percentile	90th Percentile	95th Percentile
Asian-Pacific Islander (API)	Total seafood consumption	All sources	74.0	227	286
	All species	Harvested anywhere	6.5	25.9	58.8
	All species	Harvested from King County	5.7	22.2	48.4
	Non-anadromous species	Harvested anywhere	6.2	37.9	54.1
	Non-anadromous species	Harvested from King County	6.0	20.1	45.5

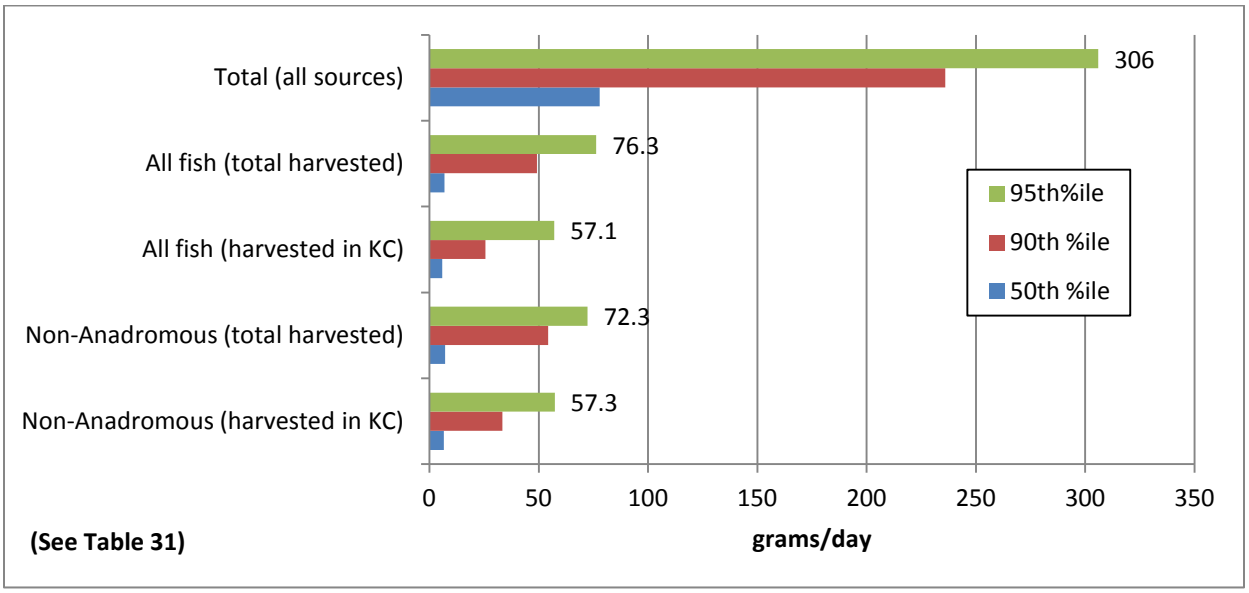
Sources: Adapted from Kissinger, 2005, Table 5. See also Polissar et al., 2012.

In recommending fish consumption estimates for API populations, EPA Region 10 proposed using estimates that accounted for weight lost during cooking. The EPA Region 10 rates included adjustments to account for cooking loss (Table 31).

Table 31. API Seafood Consumption Rates Adjusted for Cooking Loss

Population API	Species Group	Source of Fish	Descriptive Statistics (g/day)		
			50th Percentile	90th Percentile	95th Percentile
Asian-Pacific Islander (API)	Total seafood consumption	All sources	77.8	236	306
	All species	Harvested anywhere	6.9	49.1	76.3
	All species	Harvested from King County	5.8	25.5	57.1
	Non-anadromous species	Harvested anywhere	7.1	54.2	72.3
	Non-anadromous species	Harvested from King County	6.6	33.4	57.3

Source: Adapted from Kissinger, 2005, Table 8. See also Polissar et al., 2012.



Source: Adapted from Kissinger, 2005, Table 8. See also Polissar et al., 2012.

Figure 11. API Adult Fish Consumption Rates, Harvested from King County (KC) and Other Sources, Adjusted for Cooking Loss

4.5 Recreational fishers

Recreational fishing is a popular activity and consideration of recreational fishers provides additional information about fish consumption from Washington waters. Although data for the general population is useful for evaluating fish consumption rates, data on recreational fishing are needed to assess exposure to individuals with potentially higher fish consumption levels. Recreational fishers may consume fish more frequently, and may consume larger portions at each meal, than the general population. In addition, they may frequently fish from a single contaminated source. These factors may put recreational fishers at higher risk of exposure to contaminants in finfish and shellfish.

Several studies have been conducted in Washington State to evaluate the fish consumption of recreational anglers. The Technical Issue Paper *Recreational Fish Consumption Rates* provides detailed information on these surveys and their findings. Many of the available recreational angler surveys were done in the 1980s and are not as current as the other surveys noted above. Additionally, recreational surveys are generally creel, rather than personal interview surveys. These fish consumption surveys can be used to provide an estimate of mean and upper (90^{th} to 95^{th}) percentile marine/estuarine and freshwater fish consumption rates for recreational fishers in Washington State, as follows:

- Mean consumption rates for both freshwater and marine/estuarine finfish and shellfish are in the range of 20 to 60 g/day.
- Upper percentile consumption rates are in the range of 200 to 250 g/day for marine/ estuarine finfish and shellfish, and in the range of 100 to 150 g/day for freshwater fish.

Ecology believes that recreational angler surveys employing a creel methodology are far less appropriate for regulatory use than surveys that utilize a personal interview approach (see Tables 9 and 10).

4.6 Additional fish consumption rate information evaluated by Ecology

In addition to the studies summarized in Section 4.1 to 4.5 above, Ecology considered a range of other sources of information about fish consumption in Washington, as listed in Table 32. These sources provide information on resource use and historical information about fish consumption, which provides a larger and more complete view of finfish and shellfish harvest and consumption in Washington. Appendix B provides a summary of additional tribal fish consumption evaluations reviewed during preparation of this Technical Support Document.

Table 32. Fish Consumption Information Relevant to Washington and Considered by Ecology

Tribal Surveys	Description
A Fish Consumption Survey of the Umatilla, Nez Perce, Yakama, and Warm Springs Tribes of the Columbia River Basin [a]	Fish consumption habits & patterns of selected Native American tribes that reside and harvest fish in the Columbia River Basin. Includes Yakama and Umatilla tribes from Washington; Nez Perce and Warm Springs tribes from Oregon State.
A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region [b]	Puget Sound regional survey for two tribes. Provides information on both finfish and shellfish consumption.
Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservations, Puget Sound Region [c]	Puget Sound regional survey for two tribes. Provides information on both finfish and shellfish consumption.
Survey of Asian and Pacific Islander	
Asian and Pacific Islander Seafood Consumption Study [d]	King County specific fish consumption estimates for Asian and Pacific Islanders. Survey information has been used by EPA Region 10 to estimate rates for Asian and Pacific Islanders for other Puget Sound areas. Using Sechena et al., 1999, EPA Region 10 reanalyzed data to support Ecology in developing site-specific MTCA cleanup standards and risk assessment for the Lower Duwamish Waterway and Elliott Bay.[e]
U.S. General Population	
Estimated Per Capita Fish Consumption in the United States [f]	Includes fish consumers and non-consumers. (These data were used by Oregon DEQ to estimate the percentage of fish consumers and non-consumers in Oregon.)
State Assessments, Evaluations, and Advisories	
Washington State Department of Health Fish Advisories	Various water body-specific fish consumption rates. DOH advisories provide information on fish meals that should be avoided or can be safely eaten for analytically determined contaminant levels in fish tissue.
Lower Duwamish Waterway Baseline Human Health Risk Assessment [g]	Provides fish consumption information derived from Puget Sound surveys as incorporated in the EPA Region 10 framework describing tribal seafood consumption risk assessment for Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup sites in Puget Sound and modified by tribal consultation. Develops sediment cleanup standards based on tribal RME scenarios.
Lower Elwha Klallam Tribe/Port Angeles [h, i]	In collaboration with Ecology and using the EPA Region 10 framework developed tribal fish consumption rate. Cleanup standards are based on a tribal RME.
Lake Roosevelt, DOH [j]	DOH in cooperation with the Spokane Tribe, water body- and angler-specific creel survey; 42 fish meals/year; assuming 8-ounce meal. This is approximately 26 g/day.
Sinclair Inlet Bremerton Naval Complex [k]	Risk-based screening levels based on Suquamish Tribe adult and children finfish/shellfish ingestion rates and recreational sport fishers (see Appendix A).
Lake Whatcom, DOH [l]	Provided estimated species-specific fish meals sizes for commonly caught and consumed Lake Whatcom fish species (crayfish, cutthroat trout, kokanee, yellow perch, smallmouth bass) with median rates in g/meal; from low (crayfish) of 24 g/meal and high (smallmouth bass) of 220 g/meal.
Rhone-Poulenc [m]	Cleanup standards based on Tulalip tribal and Asian and Pacific Islander seafood consumption data. Range of fish consumption rates referred to and documented in Lower Duwamish Waterway Human Health Risk Assessment.
South Aberdeen-Cosmopolis Area [n]	Chinook, coho, chum; anadromous steelhead and cutthroat trout commonly found and available for harvest. Evaluates fish habitat and recommends habitat restoration and enhancement.
Naval Base Kitsap – Keyport, Washington [o]	Based on Suquamish Tribe shellfish (clams, mussels, crabs, oysters) consumption rate. Based on U.S. general population rate 54 g/day to Suquamish rate 632 g/day for clams.
Oakland Bay, Shelton [p]	Water body-specific evaluation. A range of shellfish consumption rates used, 17.5, 60, 175, 260 g/day; based in part on Squaxin Island tribal consultations.
Umatilla Tribal Water Quality Standard [q]	Consumption rate of 389 g/day approved by EPA Feb. 2010. (Lummi Nation, Shoshone-Bannock Tribe and the Swinomish Tribe are eligible to adopt tribal water quality for their respective reservations.)
Lake Washington [r]	Anglers rate 10.8 g/day; angler 95th percentile 30.2 g/day; children anglers 9.5 g/day with 95th percentile 86.2 g/day. Allowable meal limits determined for northern pikeminnow, yellow perch, cutthroat trout, sockeye salmon.

Table Sources:

a. CRITFC, 1994.
b. Toy et al., 1996.
c. The Suquamish Tribe, 2000.
d. Sechena et al., 1999.
e. Kissinger, 2005.
f. U.S. EPA, 2002a.
g. Windward Environmental, 2007.
h. Lower Elwha Klallam Tribe, 2007.
i. Lower Elwha Klallam Tribe, 2008.
j. Washington DOH, 1997.
k. Naval Facilities Engineering Command Northwest, 2010.
l. Washington DOH, 2001.
m. U.S. EPA, 2006.
n. U.S. Department of the Interior, Fish and Wildlife Service, 1994.
o. ATSDR, 2009.
p. Washington DOH, 2010.
q. U.S. EPA, 2011b.
r. Washington DOH, 2004.

4.7 Key Findings

Ecology reviewed finfish/shellfish dietary surveys and related information relevant to fish-consuming populations in Washington, including general population data from national surveys and regional fish consumption surveys.

1. *National survey data*

   Ecology analyzed general population survey data from national studies. A statistical methodology used by the National Cancer Institute (NCI) was applied to the national survey data to estimate long-term consumption rates from the short-term dietary records collected by these studies. It is noted, however, that national survey data may underestimate fish consumption in coastal states, such as Washington, which have large fish resources available for harvest and consumption.

2. *Regional survey data*

   Ecology identified the following Pacific Northwest tribal surveys as well-designed and well-conducted. They meet measures of technical defensibility and are directly applicable to Washington population groups.

   - *A Fish Consumption Survey of the Umatilla, Nez Perce, Yakama, and Warm Springs Tribes of the Columbia River Basin* (CRITFC, 1994).
   - *A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region* (Toy et al., 1996).
   - *Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservations, Puget Sound Region* (The Suquamish Tribe, 2000).

   These surveys provide finfish and shellfish dietary information for Washington fish-consuming populations and identify and quantify consumption habits. Ecology believes that these surveys provide credible information about fish consumption in Washington..

3. *Asian and Pacific Islander survey data*

   The *Asian and Pacific Islander Seafood Consumption Study* (Sechena et al., 1999, including EPA's 2005 re-evaluation) is well-designed and conducted, but represents only a very small sample of each of the Asian and Pacific Islander populations surveyed. Because of the differences in API populations across the state, it may not be appropriate to apply these results statewide.

4. *Recreational survey data*

   Recreational fish consumption surveys conducted in Washington were generally older and were conducted using less technically defensible methods (creel surveys).

Ecology has reviewed other surveys and fish consumption information used for health assessments for specific populations groups and water bodies throughout Washington State (see Appendix B). Although these surveys are technically sound and help support an evaluation and assessment of potential adverse effects from consuming contaminated fish from specific water bodies, their methodology does not allow for the projection of longer term estimates of fish consumption. Hence, these estimates are tabulated in this chapter to provide multiple lines of evidence, as a weight-of-evidence approach, that people in Washington State harvest and consume large amounts of fish.

Fish consumption rates for the general population and from the three Pacific Northwest tribal surveys identified above are listed in Table 33 below. The dietary survey methodologies employed for these studies are well documented and provide quantifiable dietary information. Ecology applied measures of technical defensibility to these fish dietary surveys to assess their suitability for estimating long-term fish consumption rates for Washington State fish-consuming populations. Ecology believes that these surveys provide credible information about fish consumption in Washington.

Table 33. Summary of Fish Consumption Rates from Studies Meeting the Measures of Technical Defensibility, All Finfish and Shellfish (g/day)

Population	Source of Fish	Number of Adults Surveyed	Mean	Percentiles			
				50th	75th	90th	95th
General population (consumers only)	All sources: EPA method	2,853	56	38	79	128	168
	All sources: NCI method	6,465	19	13	25	43	57
Columbia River Tribes	All sources	464	63	41	65	130	194
	Columbia River	–	56	36	57	114	171
Tulalip Tribes	All sources	73	82	45	94	193	268
	Puget Sound	71	60	30	75	139	237
Squaxin Island Tribe	All sources	117	84	45	94	206	280
	Puget Sound	–	56	30	63	139	189
Suquamish Tribe	All sources	92	214	132	284	489	797
	Puget Sound	91	165	58	221	397	767

See also Polissar et al., 2012

Discussion

Based on the fish dietary surveys for Puget Sound and the Columbia River basin, fish-consuming populations within the Pacific Northwest consume comparable amounts of fish. The average fish consumption rates from all sources for the Columbia River, Tulalip, and Squaxin Island tribes are within a very small range of one another, about 60 to 80 g/day. Central tendency estimates of consumption, either average or median estimates, for Asian-Pacific Islanders, recreational anglers, and national (based on EPA information) estimates are also within this range. Fish consumption estimates from local harvests for tribal fish-consuming populations show a similar

but slightly lower trend, around 55 to 60 g/day. The Puget Sound fish-consuming population that consumes the largest amount of fish is the Squamish Tribe, with higher central tendency estimates of consumption of about 130 to 215 g/day. For these fish-consuming populations, the trend for the upper 90th and 95th percentile fish consumption estimates shows a convergence that illustrates a consistently high rate of fish consumption.

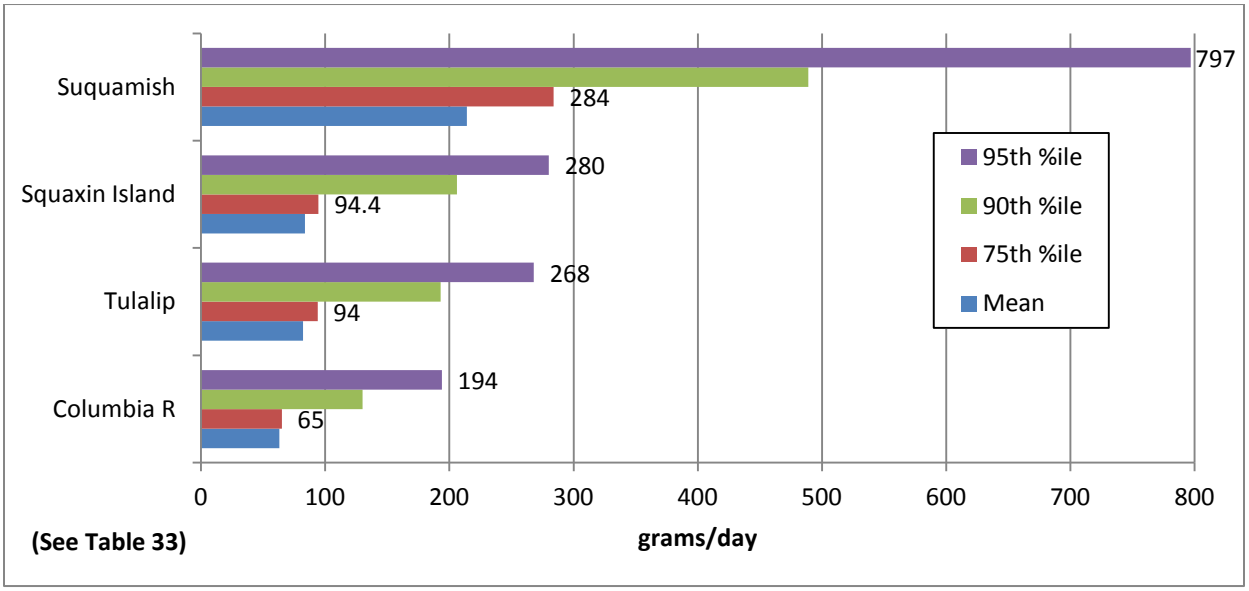


Figure 12. Regional-specific Adult Fish Consumption Rates, Harvested from All Sources

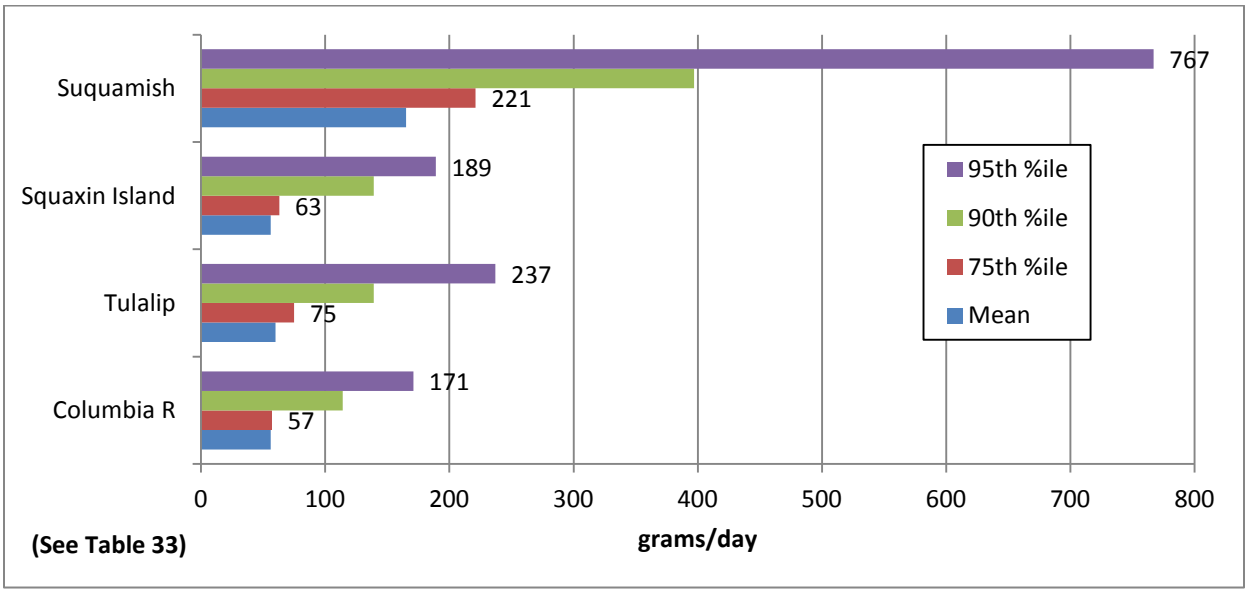


Figure 13. Regional-specific Adult Fish Consumption Rates, Harvested from Local Sources

Computations for all percent estimates of local fish harvests are based on estimates of fish consumption for tribal populations from Table 33. Percent estimates are derived based on upper percentile estimates of fish consumption from all sources compared with sources of fish harvested locally, such as Puget Sound or the Columbia River basin.

For all fish consumed. About 67 to 68 percent of total fish consumed by the Squaxin Island tribal population are locally harvested. The percentage of total fish consumed that is locally harvested is somewhat higher for the other tribal populations surveyed: approximately 88 percent for the Columbia River Tribes, 72 to 88 percent for the Tulalip Tribe, and 81 to 96 percent for the Suquamish Tribe.

Table 34. Percent of Tribal Fish Consumption Rate (All Sources) that is Locally Harvested

Population	At the 90th Percentile	At the 95th Percentile
Columbia River Tribes	88%	88%
Tulalip Tribes	72%	88%
Squaxin Island Tribe	67%	68%
Suquamish Tribe	81%	96%

For anadromous fish consumed. About 72 to 77 percent of anadromous fish consumed by the Tulalip tribal population are locally harvested. The percentage of anadromous fish consumed that is locally harvested is somewhat higher for the other tribal populations surveyed: approximately 88 to 89 percent for the Columbia River Tribes, and 80 percent for the Squaxin Island Tribe. Insufficient data were available on locally harvested anadromous fish consumption for the Suquamish Tribe.

Table 35. Percent of Tribal Anadromous Fish Consumption Rate (All Sources) that is Locally Harvested

Population	At the 90th Percentile	At the 95th Percentile
Columbia River Tribes	88%	89%
Tulalip Tribes	72%	77%
Squaxin Island Tribe	80%	80%
Suquamish Tribe	NA	NA

For shellfish consumed. About 62 to 63 percent of shellfish consumed by Squaxin Island tribal populations are locally harvested. The percentage of shellfish that is locally harvested is somewhat higher for the Suquamish Tribe (81 percent), and highest for the Tulalip Tribes (98 to over 99 percent).

Table 36. Percent of Tribal Shellfish Consumption (All Sources) that is Locally Harvested

Percent of tribal shellfish consumption (all sources) that is locally harvested		
Population	At the 90th Percentile	At the 95th Percentile
Columbia River Tribes	NA	NA
Tulalip Tribes	98%	>99%
Squaxin Island Tribe	63%	62%
Suquamish Tribe	81%	81%

Chapter 5: Sources of Uncertainty and Variability

Ecology and other agencies regularly use available scientific information on finfish and shellfish consumption rates to support regulatory decisions. In these situations, Ecology must generally select a particular value from a range of values. When making these decisions, it is appropriate to identify, recognize, and consider both the uncertainties associated with available data and the variability across individuals, fish species, and geographic areas.

Sometimes these two terms, uncertainty and variability, are lumped together. However, the nature of the errors (and consequences of over- or underestimating results) that arise due to uncertainty in the data is different than those errors that arise as a result of variability across populations, geographic areas, and time. Environmental agencies' responses to uncertainty are inherently different than responses to variability. Specifically:

- *Variability.* With variability, people and organizations know that there is a range of actual values for the parameter in question. In these situations, environmental agencies must simply decide how to characterize the range of values.
- *Uncertainty.* With uncertainty, people and organizations have limited knowledge on the magnitude and range of the parameter in question. In these situations, environmental agencies must decide how to address gaps in information and/or scientific knowledge.

This chapter summarizes important sources of uncertainty and variability in the scientific information used to estimate finfish and shellfish consumption rates.

- Uncertainty associated with dietary intake survey methods.
- Variability in consumption rates for individuals within a specific study population.
- Geographic variations and uncertainties associated with extrapolating survey results to different population groups and different areas.
- Temporal variability and uncertainties associated with estimating long-term exposure.
- Uncertainties associated with estimating future consumption rates and patterns.
- Uncertainties and variability in the relationships between cooked and uncooked tissue weights.
- Uncertainties and variability in sources of finfish and shellfish.
- Temporal variability in the availability of finfish and shellfish.

This chapter is designed to provide a high-level summary. There are several excellent resources that provide information on general sources of uncertainty and variability in risk assessments

(National Research Council, 1994, 2009; U.S. EPA, 2011a). In addition, other agencies and organizations (U.S. EPA, 2007b; Oregon DEQ, 2008; Windward Environmental, 2007) have evaluated sources of uncertainty and variability in fish consumption rates.[40] (Much of the information in this chapter is directly from the sources cited.) See also CalEPA (2001) for a particularly good discussion of sources of variability in fish consumption estimates.

5.1 Survey methodology

Dietary recall surveys are dependent on many factors, and the careful design and execution can minimize or eliminate sources of certain types of errors.

Chapter 3 discusses survey methodology, execution, publication of results, applicability and utility for regulatory decision making, and overall technical suitability to support regulatory decision making. Fish consumption surveys selected as applicable to Washington fish consumers were evaluated in Chapter 4.

Factors contributing to measurement error and bias include:

- Survey design (for example, accurate representation of the target population). Considers attributes of the survey relative to attaining accuracy and precision (e.g., are all species included, are visual aids utilized for portion sizes, will the survey be administered over an entire fishing season, are an appropriate number of individuals interviewed).
- Survey methodology (for example, considers the interaction between the survey methodology chosen and attributes of the target population taking into account literacy, language barriers, and cultural sensitivity).
- Survey execution (for example, coding errors, interviewer bias, recall bias).[41]
- Method of analysis (for example, if and how systematic error is identified and estimated; treatment of outliers and weighting factors).

Various survey types have inherent biases, strengths, and weaknesses that may contribute to variable results demonstrated across these different surveys. It should be noted that regulatory policies (for example, what questions are the surveys designed to answer) can influence the planning and design phases, which can in turn influence the results and conclusions. Furthermore, policy choices may not be consistent across various federal and state agencies and academic institutions.

[40] See also the National Cancer Institute discussions of measurement error related to dietary surveys. http://riskfactor.cancer.gov/measurementerror/

[41] Recall bias occurs when factors exist that may affect the respondent's memory of an event. For example, an individual that consumed fish in the last 24 hours may provide greater estimates of fish consumption on a seasonal or yearly basis.

EPA examined different fish consumption survey methods, identifying important considerations for survey design, selection of respondents, quality assurance, and statistical analysis (U.S. EPA, 1992). Additional guidance on fish and wildlife consumption surveys thoroughly examines survey instrument design, execution, and analysis (U.S. EPA, 1998).

Limited resources and differing objectives for organizations and groups interested in determining fish consumption rates can influence the design of the survey and how it is conducted. Plausible objectives for fish consumption surveys include: determining average consumption rates, fishing pressure on water bodies, and maximum consumption during the fishing season. Surveys designed to meet one objective may not be suitable for another. Ecology must consider a fish consumption survey's objectives, execution, and evaluation to determine the utility of a survey's use by Ecology for environmental regulation.

5.1.1 Differences due to survey design, terminology, and definitions

Some fish dietary surveys may not include all relevant species in the questionnaire. Terminology across different fish consumption surveys may be highly variable. A lack of a consistent terminology can contribute to variability and uncertainty. For example, *shellfish* usually refers to aquatic invertebrate organisms with a shell. Clams and oysters are easily identified as shellfish. However, selected aquatic animals (squid) have evolved such that the shell has become internal and/or reduced, while in others, the shell has disappeared (octopus). Furthermore, crustaceans (crayfish) have exoskeletons instead of true shells.

Seafood consumption may include finfish and/or shellfish obtained from a variety of sources. Surveys may not differentiate the sources of the finfish and/or shellfish. Indeed, some surveys may consider consumption of fish harvested from a single water body (e.g., Commencement Bay) while other studies determine rates for fish consumption from multiple water bodies. Also, consumption rates reported in different studies may or may not distinguish between consumption of marine, estuarine, and freshwater finfish and shellfish. These differences and their contributions to variability were summarized in a study published in the *Journal of Exposure Analysis and Environmental Epidemiology* (Ebert et al., 1994). This study noted that the consumption rate of an individual comprises the sum of the rates from different sources. It does not differentiate among sources of seafood. Estimates may vary substantially depending on how these different sources are evaluated.

5.1.2 Types of data and methods of collection

The method used to collect dietary information may lead to uncertainty. For example, data collected from creel surveys involve interviewing anglers at fishing locations to provide water body-specific data about fishing frequency, fish species, and sizes caught and/or consumed. Hence, the creel survey method may only provide data about specific species available during specific seasons. Creel surveys, like other surveys methods, are subject to biases. Poor catches, catches

below legal size limits, or catches above total allowable limits may not be reported. Persons fishing without a license may avoid participating. See Table 9 for issues associated with creel surveys.

5.1.3 Cooked and uncooked tissue weights

A number of researchers have noted the uncertainty introduced by inconsistency regarding reporting of finfish and shellfish using cooked vs. uncooked weight. Raw fish tissue samples are used to determine chemical contaminant levels for use in human health risk assessments.

The EPA Region 10 Framework recommends that risk assessments be performed using the weight of uncooked fish, with no modification for potential contaminant losses or gains during cooking. This is consistent with the fact that uncooked fish consumption rates were measured in the tribal finfish and shellfish consumption studies cited. EPA notes:

> *Because of the many ways in which fish may be served, quantitative assumptions regarding preparation methods and their effects on contaminant concentrations would be unreliable. Depending upon the preparation and cooking procedures, and upon the nature of the contaminants in the fish, concentrations may decrease or increase [U.S. EPA, 1998]. For fat-soluble compounds such as PCBs, trimming and removing adipose tissue reduces the mass of contaminants in the consumed portion of the fish. Similarly, broiling, frying, or grilling fish is likely to result in reductions of fat-soluble compounds [Sherer and Price, 1993]. Cooking is not likely to change the level of exposure to mercury because it is bound to muscle tissue and is not lost by cooking, which mostly removes moisture and fat [Morgan et al., 1997]. Fish cooked with no prior preparation, as in a stew, might show negligible loss of contaminants, except perhaps for volatile contaminants. Because lead concentrates in bones, preparations where bones are discarded are likely to result in reductions in lead exposure [Ay et al., 1999].*

5.1.4 Variability within a population

A number of factors may contribute to variability in finfish and shellfish consumption survey results (Ebert et al., 1994). Dietary patterns vary within a population and between populations. Different population groups may have different fish consumption rates related to cultural or regional differences. Family preferences, recipes, and individual taste are sources of variability within a population; access to resources, tradition, and custom are sources of variability between populations.

5.1.5 Data analysis and statistical considerations

Without careful definition of the target population, it is possible to bias survey results. For example, to avoid characterizing the consumption for a population that is not at risk from consuming contaminated fish, surveys are designed to evaluate consumers only, with questions allowing identification of persons who never (or rarely) consume fish.

Various statistical techniques have been described to analyze consumption data. For example, different methods of treating missing data or non-response data may contribute to bias. Identification and treatment of potential outliers may contribute to biased datasets (this includes recording outliers as multiples of standard deviations above the mean or eliminating them from the dataset).

Defining subgroups within a larger population (stratification) differently can affect survey results and introduce different levels of bias. An important element of survey design is how well the survey sample population represents the selected target population or population of concern. Weighting schemes designed to make a sample more representative of the population should be carefully defined. Statistical methods should consider sampling rate, differences in sampling days, and other factors that may influence the results.

The fish consumption rates for a fish-consuming population should be sufficiently characterized to provide a population distribution and statistics that contribute to an understanding of the nature of a population exposure distribution such as the mean, median, and upper percentiles (90^{th} or 95^{th} percentile) or bounding estimates (99^{th} or 99.9^{th} percentile). It is essential to understand how these distributions were derived as distributions derived from consumers and non-consumers of fish have different meanings and applications.

It should be noted that 24-hour dietary recall surveys that include food frequency questionnaires enable calculating the upper percentiles with greater confidence (U.S. EPA 1992, 1998). Consistent with federal guidance on fish dietary survey methodologies, all regional Pacific Northwest fish dietary surveys (Tribal and Asian-Pacific Islander populations) employ some permutation of a food frequency questionnaire in their survey methodology to project long-term consumption estimates.

Fish dietary information may be reported as point estimates, usually a mean or median value to represent central tendency estimates of consumption, or as a distribution of values. When the estimates of fish consumption are normally distributed in a population, the mean and median will be close or approximately equal. When the distribution is skewed (e.g., lognormal distribution), the mean and median may be substantially different. The mean fish consumption estimate represents the average value for the sampled population and in a skewed distribution the mean will either be a higher or lower value than the median value. For a highly positively skewed distribution, as found in the Pacific Northwest fish-consuming populations, the mean is higher than the median estimates of consumption. The median value represents the 50^{th} percentile (or midpoint) of the distribution where half of the sampled population consumes more and half consumes less fish, than the median value (Helsel and Hirsch, 2002).

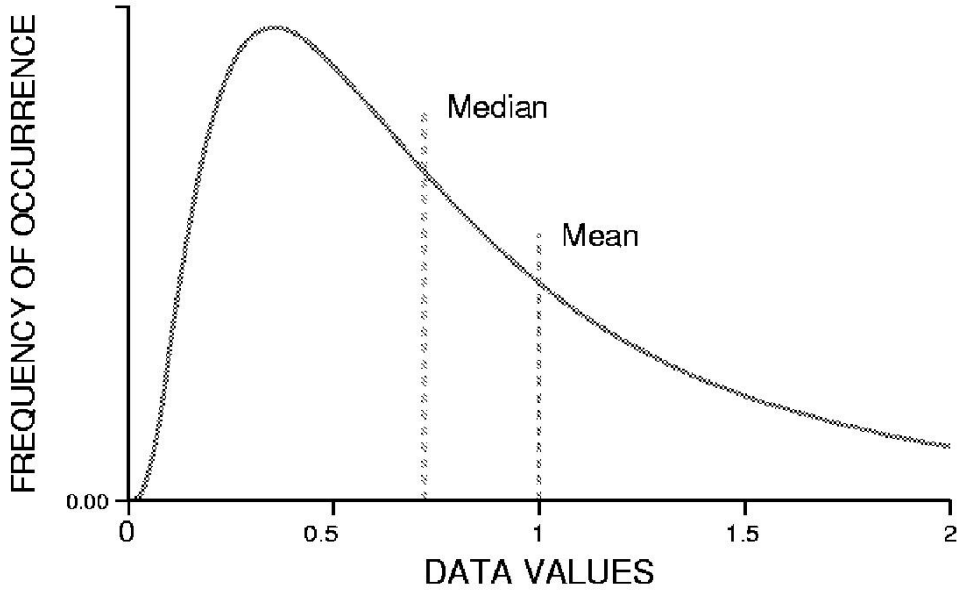


Figure 14. Density function for a positively skewed lognormal distribution

5.1.6 Target populations and characteristics of populations

Different population groups may have different fish consumption rates. Recognizing differences between fish consumption rates for whole populations (including both consumers and non-consumers) and consumption rates in actual consumers of fish is a critical distinction. For example, Oregon's Human Health Focus Group made the clear distinction between per capita fish consumption based on consumers and non-consumers of fish. High fish consumers make up a relatively small portion of the whole population, and may represent extreme upper percentiles in a distribution that includes both consumers and non-consumers of fish.

A distinction is generally made between (a) national per capita consumption estimates inclusive of both consumers and nonconsumers of fish and (b) estimates of fish consumption from local fish consuming populations (EPA Region-10 Framework, 2007; EPA, 2000; CalEPA, 2001; Oregon DEQ HHFG Report, 2008):

- "Per capita rates are primarily useful for trend analyses rather than representing actual consumption. Average per capita rates derived from national surveys for consumption of fish and shellfish by the general population ranged from 10 to 17.9 grams per day. Several analyses of data used to estimate per capita consumption of fish and shellfish found an

increase of approximately 25% between 1970 and the early 1990s, indicating that the U.S. population as a whole consumed more fish in more recent years" (CalEPA, 2001, page 3).

- "Consumption rates derived for consumers are preferable to per capita rate for use in describing actual consumption of fish and shellfish in the U.S." (CalEPA, 2001, page 3).

Further distinctions are made between national per capita fish consumption estimates and consumer-only estimates by how consumers of fish and/or shellfish are defined. CalEPA, 2001, provides further insights regarding consumption estimates for populations that consume fish compared to estimates for the general national population as follows:

> *Rates reported for the general national population, usually referred to as per capita rates, differ from those reported for subpopulations such as individuals who catch and consume their own catch of fish and shellfish. It is essential to consider whether rates that apply on a per capita basis are appropriate to the study question or whether rates specific to particular subpopulations are needed. For example, some consumption rates have been derived by averaging over both consumers and nonconsumers, as compared to consumers only. These per capita estimates would not be representative of consumption by actual consumers or other specific subpopulations. Thus, exposure assessments and evaluation of potential risks to consumers must consider consumption rates appropriate for actual consumers.*
>
> *For groups of individuals who consume sport fish and/or shellfish, there is a continuum ranging from intermittent fishers, who may eat fish only occasionally, to those who fish regularly and/or heavily and consume large quantities of the fish that they catch. These "high-end consumers" could include recreational fishers with high rates of success and subsistence fishers who rely on their catch to feed themselves and their families. Therefore, within the subset of the population that fishes (i.e., fishers) there is likely to be a wide range of fishing effort and success, and a single value is unlikely to adequately describe consumption by the entire fishing population (CalEPA, 2001, page 13).*

5.2 Geographic differences

5.2.1 Variation and uncertainty associated with regional differences

Fish consumption surveys conducted across the United States have shown regional variations. There are differences between coastal areas and inland areas and regional preferences for certain types of finfish and/or shellfish. Local variations in climate, fishing regulations, accessibility to fisheries, and seasonal differences in availability of fish contribute to the variability in reported fish consumption rates (Ebert et al., 1994; Moya et al., 2008). Differences in habitat may be relevant (U.S. EPA, 2007b).

Comparing the results of surveys from different geographic locations, each with regional effects plus different methodologies, time frames, or other different survey design elements, makes the interpretation of differences between surveys problematic.

5.2.2 Uncertainty associated with extrapolating survey results to different population groups and different locations

The use of surrogate consumption rates can misrepresent actual finfish and shellfish consumption rates. For example, Puget Sound-harvested finfish and shellfish consumption rates derived using Tulalip and Suquamish tribal data as a surrogate for another tribe could lead to either an overestimate or an underestimate of the actual finfish and shellfish consumption.

For many reasons populations surveyed in a particular study may eat different quantities and ratios of finfish and shellfish than do those who harvest elsewhere. For example, differences in habitat type and quality between fishing grounds can affect the quantity of finfish and shellfish available for harvest.

The EPA Region 10 framework takes this into account. For purposes of the framework, if certain species or types of finfish and shellfish are not present, or will not be present in the future, tribal members are assumed to substitute other species or types of finfish or shellfish that may be equally affected by the site. This assumption of resource switching among local finfish and shellfish is incorporated into the framework by holding constant the total amount of finfish and shellfish consumed.

EPA's policy decision to assume that resource switching occurs is supported by limited data and examples in Puget Sound. For example, individuals in the Suquamish Tribe study (The Suquamish Tribe, 2000) eat "more geoduck now, because they are more available to us, but we used to dry oysters and clams...." Two other respondents reported "reduced consumption of butter clams, cockles, and other clams and shellfish due to pollution," but that this "reduced consumption was offset by the higher availability of geoducks from the Suquamish Tribe." Resource switching has been documented in other areas affected by contamination, such as Alaska (Fall and Utermohle, 1999).

The use of fisheries resources is important to tribes for economic, dietary, and cultural reasons. Tribes will likely use whatever fisheries resources are available to them.

The following observation is made in the National Environmental Justice Advisory Council Meeting report (U.S. EPA, 2002b):

> *For many communities of color, low-income communities, Tribes, and other indigenous peoples, there are no real alternatives to eating and using fish, aquatic plants, and wildlife. For members of these groups it is entirely impractical to "switch" to "substitutes" when the fish and other resources on which they rely have become*

> *contaminated. There are numerous and often insurmountable obstacles to seeking alternatives (e.g., fishing "elsewhere," throwing back "undesirable" species of fish, adopting different preparation methods, or substituting beef, chicken or tofu). For some, not fishing and not eating fish are unimaginable for cultural, traditional, or religious reasons. For the fishing peoples of the Pacific Northwest, for example, fish and fishing are necessary for survival as a people – they are vital as a matter of cultural flourishing and self-determination.*

If certain types of finfish or shellfish preferred by tribal members are not present in their usual and accustomed areas, the framework assumes that tribal members will substitute alternative local types of finfish or shellfish in their diets, generally within the same category of fish or shellfish. Thus, the total consumption rate remains the same, regardless of the availability of a particular type of finfish or shellfish. This is a reasonable and protective assumption for tribal members who, for economic, ceremonial, religious, or personal preference reasons, are likely to substitute one species for another.

The assumption that resources will be switched is likely to result in an overestimate of risks for other tribal members who may decrease their overall finfish and shellfish consumption rate because their preferred types are unavailable. Risks may be underestimated if the actual dietary practices of a tribe would result in consumption of species that have higher contaminant levels than the preferred or assumed types of finfish or shellfish.

5.2.3 Availability of finfish and shellfish

The abundance of finfish and shellfish resources available to a given population may be a source of uncertainty. Different water bodies vary in their capacity to support and sustain different species of finfish and shellfish. Furthermore, the capacity of the water body to support fish resources may change over time, for both natural and human caused reasons.

Regarding the use of surrogate data, the EPA Region 10 framework notes:

> *Although the degree to which site-related risks could be overestimated by the use of any of the fish and shellfish consumption rates presented in this Framework cannot be known precisely, these methods are preferable to alternatives that would be likely to underestimate site-related risks, such as basing a consumption rate (or site-related estimates of risk) on the size of the cleanup site, or reducing the site's estimated contribution to fish and shellfish contamination because nearby sites or sources are associated with similar contaminants. This Framework includes the assumption that the selected Tribal fish and shellfish consumption rates and their associated risk estimates will not be reduced based on consideration of the size of the cleanup site or the presence of additional sources of contamination.*

The use of a consumption rate based on all finfish and shellfish harvested from Puget Sound as a surrogate for a consumption rate based on finfish and shellfish affected by a cleanup site is likely to overestimate the risk of eating finfish and shellfish from the site, since only a portion of the finfish and shellfish diet will have actually come from the site in question. The degree of overestimation depends upon such factors as size and location of the site, type and degree of contamination, and habits of affected finfish and shellfish.

A potential data gap is the lack of information on commercial routes of distribution for locally harvested fish and/or shellfish to local food markets, restaurants, or other food outlets in Washington State. However, seafood supply availability as an indirect measure of consumption has very limited utility. As noted by CalEPA, 2001 (page 15):

> *Approaches to collecting data on fish consumption include both indirect and direct measures. Indirect measures primarily rely on data pertaining to food availability or food disappearance into marketing channels or households, and are best regarded as a measure of food availability into commercial markets and only a rough indicator of consumption. Data from studies on food availability generally have been collected for purposes other than to estimate consumption rates, and data gaps are most serious at the level of the individual consumer; therefore, these types of data are inappropriate for estimating consumption rates for consumers (Anderson, 1986; U.S. EPA, 1992). Additionally, food availability data do not account for waste or spoilage, and interpretation of the results is highly specialized; however, the results from these types of surveys can be useful to assess trends over time (Anderson, 1986).*

On the other hand, some of the finfish and shellfish consumed in restaurants or obtained in grocery stores may have been harvested in Puget Sound, which could lead to an underestimate of exposure.

5.3 Temporal uncertainty and variability

Although estimates of consumption using short-term dietary recall may be reported as g/day, the values may not be the same as long-term consumption rates averaged over time and presented as a daily rate. Study methodologies that consider fish consumption over a longer period of time may be more likely to represent the fish consumption patterns of the population studied.

5.3.1 Using short-term data to estimate long-term exposure

Current health risk models are designed to evaluate health risks associated with exposure over long periods of time. Risk assessors typically use the results from short-term dietary surveys to characterize the amounts of finfish and shellfish eaten on a regular basis over longer periods of time intervals (years).

This approach works well when average values are used in the health risk model. However, regulatory approaches based on concepts like *reasonable maximum exposure* are typically based on the use of upper percentile values (e.g., 90th percentile or above). In this situation, the use of short-term survey results is complicated because the distribution of estimated fish consumption rates over a short period of time will be more spread out than the actual fish consumption over a longer period of time. This means that estimates of the 95th percentile of the fish consumption rates observed over a short period of time (one or two days) will be higher than the 95th percentile of the average daily fish consumption over the longer periods of time considered in health risk assessments (years). This narrowing of the distribution of estimates is called *regression to the mean*.[42]

5.3.2 Temporal factors biasing estimates of fish consumption

The collection of fish consumption information may be subject to temporal biases. Use of 24-hour recall data to estimate fish consumption rates over longer periods are subject to potential biases from the effects of the day of the week or seasonal variations in the availability of fish. Longer term estimates of fish consumption reported by individuals may be subject to recall bias. Rates will be overestimated if fish consumption habits are surveyed when fish are readily available relative to periods when fish are not readily available. Consumption data obtained on consecutive days may be biased due to the consumer correlation with the fish consumed on adjacent days.

Recall bias for estimates of long-term fish consumption is more of an issue for populations where fish may be infrequently consumed and consumption patterns are episodic in nature. In contrast, recall bias in estimating long-term fish consumption rates is minimized for populations in which fish is a primary dietary protein source, is consumed frequently, and where consumption information is hence easily recalled.

The timing of survey administration may or may not account for the biases introduced by seasonal variations in fish availability. Extrapolating estimates of long-term fish consumption from 24-hour recall data or from evaluations of yearly fish consumption may be improved by interviewing fractions of the survey populations during different seasons or by re-interviewing individuals.

Short-term estimates of food intake rates for infrequently consumed items for the general population (e.g., fish) from national short-term surveys are bimodal, varying between zero and the amount typically consumed at a meal. This results in an overestimate of the prevalence of

[42] Regression to the mean is encountered in many areas of science and everyday life. For example, baseball batting averages have a much larger distribution early in the season compared to the end of the season. The following case study illustrates the implications of this situation. There were 177 major league players with at least 400 plate appearances during the 2011 season. Consider the players' batting averages after their first game and at the end of the 162 game season. The first day estimates for the median and average provide a reasonably good estimate of those values for the whole season. However, the first day estimates for the 90th and 95th percentiles of the distribution of batting averages are much higher than the end-of-the season values. As with many situations, players who did extremely well on the first day of the season also had days where they were hitless. Conversely, players who went hitless on opening day had games later in the season where they had one or more hits.

low and high intake rates relative to those that would be seen over a longer observation period. This variation is particularly relevant for assessments of food chemical exposure where the parameters of interest are at the extremes of the exposure distribution rather than at the center (Lambe, 2002).

Attempts to account for the variability and uncertainty associated with the use of short-term consumption studies have generally included qualitative evaluation of data from a range of sources, coupled with consideration of the intended use of the data. To evaluate long-term (habitual) seafood intake, longer-term survey data are preferable to short-term dietary survey data.

Ecology conducted a statistical reanalysis of short-term national fish consumption data to estimate long-term (usual) national fish consumption rates, using the methodology of Tooze et al., 2006 (as cited in Polissar et al., 2012). National fish consumption rate estimates based on this reanalysis are significantly lower than estimates based on simple extrapolation of the short-term fish consumption data. See also the Technical Issue Paper, *Estimating Annual Fish Consumption Rates Using Data from Short-term Surveys* (Ecology, 2012).

5.3.3 Issues using currently suppressed fish consumption data to predict future fish consumption

The presence (or absence) of finfish and shellfish adversely affected by site-related contamination could suppress consumption rates observed during surveys.

The Oregon DEQ Human Health Focus Group discussed some of the factors that may contribute to depressing fish consumption rates compared to historic rates. They noted (1) significant reductions in fish populations, (2) the belief that fish that reside in polluted waters will bioconcentrate pollutants and are contaminated and unsafe to eat, and (3) the intended impact of local fish advisories or the unintended consequences of national fish advisories of commercial fish species that are not applicable to local waters.

The Human Health Focus Group also noted that some studies excluded or discounted high fish consumers by identifying them as statistical outliers. This would have the effect of underestimating the true range in fish consumption rates. If the rates are already suppressed, the elimination of the highest values may be reporting an artificially low fish consumption rate.

Where tribal members have already reduced their harvest of finfish and shellfish from impaired habitat, the use of current consumption rates could result in underestimations of potential finfish and shellfish consumption rates. As noted in the National Environmental Justice Advisory Council Meeting report (U.S. EPA, 2002b):

> *A suppression effect occurs when a fish consumption rate for a given subpopulation reflects a current level of consumption that is artificially diminished from an appropriate baseline level of consumption for that subpopulation . . . When agencies set environmental standards using a fish consumption rate based upon an artificially diminished*

consumption level, they may set in motion a downward spiral whereby the resulting standards permit further contamination and/or depletion of the fish and aquatic resources.

Cleanup levels in the local aquatic environment, if they are based on current finfish and shellfish consumption rates in the vicinity of the cleanup site, may not reflect the potential for the water body to rebound from its current, relatively contaminated state. This should be considered when deciding whether the use of a surrogate tribal finfish and shellfish consumption rate would better represent potential future consumption rates than would consumption rates that represent only current or near-term contamination and habitat conditions.

Studies indicate that tribal fish consumption rates are suppressed compared with historical rates and presumable rates that would exist given historical fishing stocks. The recommendations in this report, however, were developed using existing data from published studies.

For Native American populations in Washington, evaluating fish consumption rates using common survey methodology may be problematic (Donatuto and Harper, 2008). Surveys and the exposure models they develop provide information only about current consumption patterns. The number of tribal members practicing traditional lifestyles is below known historical levels. Survey data do not provide information on historical fish consumption rates and resource use, which may be more indicative of consumption rates.

Researchers suggest that suppression happens for various reasons (Donatuto and Harper, 2008). Two reasons are contamination and lower abundance. When the fish are contaminated or absent, tribal members may eat less fish and/or substitute other types of fish. While, historically, fish provided the main dietary source of protein, this is true today for only a small subset of the tribal population (Harper et al., 2007; Harper and Harris, 2008; Harris and Harper, 2001). Tribal health experts suggest that current tribal fish consumption rates are suppressed due to diminished access to historical quantities of finfish and shellfish, and some researchers believe that historical rates represent the appropriate baseline level of consumption. Effects of suppression due to chemical contamination should be accounted for in environmental cleanup regulations. However, accounting for suppression in environmental cleanup regulations may be problematic when suppression is due to permanent loss or modification of habitat due to urban infrastructure. Where habitat can be restored, then environmental cleanup regulations need to account for suppression effects in revising fish consumption estimates to help support cleanup decisions.

5.4 Uncertainty in Pacific Northwest fish-consuming populations

Ecology has identified numerous fish dietary surveys in Washington State that reflect high rates of consumption for certain ethnic groups (CRITFC, 1994; Toy et al., 1996; Sechena et al., 1999; The Suquamish Tribe, 2000). Consumption estimates vary among subpopulations by age, sex, mode of harvesting, and by region within Washington State. Washington State fish-consuming

populations have been identified (tribal populations, Asian-Pacific Islanders, recreational fishers) and levels of consumption have been estimated from these surveyed populations. These higher fish-consuming ethnic populations and other high-end fish consumers are represented by upper percentile consumption estimates (90^{th} and 95^{th} percentile) derived from distributional analysis of the fish dietary data (CalEPA, 2001; Polissar et al., 2012).

Many of the Pacific Northwest regional-specific surveys note differences in patterns of fish consumption (e.g., eating different fish parts) and fish harvesting techniques, which demonstrates a level of variability across and among these fish-consuming populations (CalEPA, 2001; CRITFC, 1994; Toy et al., 1996; Sechena et al., 1999; The Suquamish Tribe, 2000; EPA EFH, 2011). Central tendency estimates of consumption for these populations are very similar (all fish from local harvests) with upper percentile estimates (90^{th} and 95^{th} percentile) within an order of magnitude.

There is considerable uncertainty inherent in evaluating and estimating fish consumption rates for northwest fish-consuming populations. Much of the uncertainty is because the available information, although substantial, nonetheless provides only a partial picture of fish consumers in Washington. Sources of uncertainties can include the following:

- Whether the available surveys provide a complete picture of the variety of fish consumption practices among various fish consuming populations.
- Evolving and changing lifestyle patterns for various populations across the state.
- Data gaps around dietary habits for other potentially high fish-consuming populations; for example, various ethnic groups, *pescadarians* (people who eat fish but not meat), subsistence fishers, and low income groups.
- Using information about one group as a surrogate for another group's consumption rate based on evaluation of the similarity or differences in, say, species available or the extent of local shellfish habitat.
- The degree to which lifestyle (ethnic, tribal, subsistence, etc.) is recognized and accounted for in consumption studies.
- Whether or how information from the national fish dietary dataset may be inadequate for understanding fish consumption along coastal states with significant fishery resources.
- Whether and how a particular study addresses consumption of anadromous fish species.

It is expected that as the body of information grows some of these data gaps will be filled and uncertainty about Pacific Northwest fish-consuming populations will decrease.

Chapter 6: Using Scientific Data to Support Regulatory Decisions

The purpose of this Technical Support Document (Version 2.0) is to compile and evaluate available information on fish consumption in Washington State. There are risk management issues related to regulatory decisions based on this information. This is a technical document; it is not designed to resolve policy issues associated with using that information to make regulatory decisions. Ecology will be considering those issues in separate documents and processes.

This chapter is intended to provide context. It offers a brief introduction for people who are interested in the multiple and interrelated questions that arise during regulatory decision making. The Conservation Foundation has stated that it is important that environmental agencies distinguish between scientific and policy choices when making regulatory decisions (Conservation Foundation, 1984, p. 310):

> *A key to understanding the risk assessment process is to distinguish between those aspects of the process that are scientific and those that are matters of policy or personal values, and to appreciate their complex interrelationships …. A risk assessment process that is defensible from both a scientific and a policy standpoint must accurately identify which aspects of the assessment are policy and which are science. The difficulty is that both scientists and policy makers tend to define their realm in the broadest terms.*

The interaction between science and policy in regulatory decision making is complicated. Several equally valid scientific options may resolve a particular issue. In these situations, the regulatory decision essentially represents a policy choice that must take into account statutory directives, implementation issues, and value judgments on how to deal with scientific uncertainty and variability in exposure and susceptibility. As Victor Hugo once wrote, "Science says the first word on everything, and the last word on nothing," (Hugo and O'Rourke, 1907).

Chapters 4 and 5 of this report provide Ecology's evaluation and conclusions regarding current scientific information on fish consumption rates in the Pacific Northwest. As the wealth of knowledge continues to grow, additional information will be available in the future. Science-based regulations may have built-in requirements to periodically review and update standards based on new information. This chapter highlights some of the policy choices that will be needed when using this information to support regulatory decisions. The chapter is organized into sections. Each section provides a brief description of a particular regulatory issue and a range of examples to illustrate how agencies have resolved that issue. The issues are:

- Population groups.
- Individual variability in fish consumption rates.
- Geographic variations in fish consumption rates.
- How anadromous species (e.g., salmon) are included in fish consumption rates used for environmental regulation.
- Locally caught vs. store-bought finfish and shellfish.
- Development of regulatory fish consumption rate estimates from consumer-only vs. per capita surveys.
- Other exposure factors (e.g., body weight and exposure duration).
- Acceptable risk.

This is a partial list. Other issues may hold equal or greater importance for particular decisions. In addition, agencies typically do not consider individual policy choices in isolation from other choices. In other words, a decision on one issue may impact the decisions on other issues. For example, decisions on what constitutes an acceptable level of risk may influence decisions on how to address the uncertainties and variability in fish consumption rates.

6.1 Population groups

When developing a regulatory standard based on health protection, agencies must decide what population groups that standard is designed to protect. This is a policy choice that can be made on a programmatic (or statewide) or site-specific basis. This choice can have large implications given the differences in fish consumption rates calculated using information summarized in Chapter 4.

This policy choice is influenced by many factors including statutory requirements, environmental equity, and the nature of the decision (programmatic vs. site-specific). Options typically considered by agencies include:

- *General population.* Environmental and health agencies have established regulatory requirements or fish advisories that are based on the amount of finfish and shellfish consumed by members of the general population. For example, the EPA has adopted guidance for implementing the Clean Water Act that includes a default fish consumption rate of 17.5 g/day. The data used to establish this rate include individuals who do not eat fish. Several states have used this value to develop state water quality standards and cleanup standards for individual sites.
- *Recreational anglers.* Environmental and health agencies have established regulatory requirements or fish advisories using information on the amount of finfish and shellfish consumed by recreational anglers. For example, Ecology in 1991 adopted a default fish

consumption rate (54 g/day) in the MTCA rule that is based on a recreational fish consumption survey.

- *High exposure population groups.* Environmental and health agencies have established regulatory requirements or fish advisories using information on the amount of finfish and shellfish consumed by members of high exposure population groups (such as Native Americans and Asian Pacific Islanders). For example, the Oregon DEQ has adopted a fish consumption rate (175 g/day) that is based on concerns about tribal populations. Ecology has also established sediment cleanup standards for individual sites that are based on assessing exposure for tribal populations.
- *Susceptible populations.* Environmental agencies also establish regulatory requirements or advisories using information on groups that are more susceptible to the effects of toxic chemicals (e.g., children, pregnant women). For example, EPA and DOH have issued fish advisories that are based on limiting mercury exposure for pregnant women.

6.2 Individual variability in fish consumption rates

No two individuals are exactly alike. Exposure to hazardous substances is influenced by multiple factors and may vary widely among individuals within a given population group. Chapter 4 provides information on the variability in fish consumption rates in several study populations. When using that information to support regulatory decisions, Ecology will need to decide which values within this range of variability to use to characterize fish consumption, and consequently the degree of protectiveness Ecology offers when characterizing exposure and making regulatory decisions.

Ecology has compiled information on the distribution of fish consumption rates among the general population, and for participants in the three primary studies identified in the Technical Support Document. The study results were compiled in Table 37 below.

Table 37. Summary of Fish Consumption Rates, All Finfish and Shellfish

Population	Source of Fish	Number of Adults Surveyed	Mean	Percentiles		
				50th	90th	95th
General population (consumers only)	All sources: EPA method	2,853	56	38	128	168
	All sources: NCI method	6,465	19	13	43	57
Columbia River Tribes	All sources	464	63	41	130	194
	Columbia River	–	56	36	114	171
Tulalip Tribes	All sources	73	82	45	193	268
	Puget Sound	71	60	30	139	237
Squaxin Island Tribe	All sources	117	84	45	206	280
	Puget Sound	–	56	30	139	189
Suquamish Tribe	All sources	92	214	132	489	797
	Puget Sound	91	165	58	397	767

See Polissar et al., 2012, Table E-1.

Choosing a summary measure to characterize population exposure reflects an explicit (or implicit) policy choice on the appropriate balance between over- or underestimating exposure levels for particular individuals within the population group. Agencies typically choose one of two approaches for addressing this issue:

- *High end of the distribution.* Many agencies develop standards that are based on protecting more highly exposed individuals within a population group. For example, state and federal cleanup standards are typically based on a reasonable maximum exposure (RME).[43] The RME is defined as reasonable because it is a product of several factors that are an appropriate mix of average and upper-bound estimates. RME estimates typically fall between the 90th and 99.9th percentile of the exposure distribution. This reflects a policy choice that emphasizes the protection of the more highly exposed individuals in a population group. EPA used a similar approach when updating the Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (U.S. EPA, 2000b). The EPA methodology provides a broader range of fish consumption rate statistics for tribes and states to choose from than does the Superfund (CERCLA) program. The EPA methodology allows for both upper percentile and central tendency policy choices. The Ambient Water Quality Criteria for the Protection of Human Health does include upper bound and central tendency exposure parameter choices that reflect an RME approach (e.g., 90th percentile drinking water ingestion rate and an average body weight). The EPA methodology provides a default fish consumption rate for the general population (based on protection of recreational fishers). This value (17.5 g/day) reflects the 90th percentile values protective of consuming estuarine and freshwater fish. It is derived for adults only using data from the USDA's CSFII Survey for the years 1994 to 1996.
- *Middle of the distribution.* Agencies also develop standards that are based on protecting the "average" person in a population. Under this approach, individual exposure parameters are selected to represent the middle of the exposure distribution, which may be defined in terms of the mode, median, or mean.[44] Ecology applied this policy option

[43] The MTCA Cleanup Regulation defines the RME as "the highest exposure that is reasonably expected to occur at a site under current and potential future site use." The RME is designed to represent a high-end (but not worst-case) estimate of individual exposures.

[44] Several scientific advisory committees (National Research Council, 1994, 2009) and scientists have discussed the use of summary statistics to describe variable quantities. For example, Finkel (1989) noted that "…all summary estimators of an uncertain quantity are value laden. Summary measures are little more than ways to interpret facts in light of a subjective calculus of the costs of error…" (pp. 436-437). He described several common statistical measures, which he observed will strike different balances between overestimating and underestimating a particular value.

- Statistical mode (most frequently measured value), which embodies the value judgment that one should minimize the probability of error, without regard to its type (over- or underestimation) and magnitude.
- Statistical median (the 50th percentile value), which embodies the value judgment that the costs of the two types of errors are exactly equivalent.
- Statistical mean (the average of the measure values), which embodies the value judgment that larger errors are more important than smaller errors independent of the direction of the error. He noted that when dealing with highly skewed distributions, the mean of the

when selecting many of the exposure parameters used to calculate Method C cleanup levels in the MTCA rule.

6.3 Geographic variability

Chapter 4 indicates that there is substantial variation in the amount of finfish and shellfish consumed in different parts of Washington. Several factors contribute to these variations:

- Water body characteristics.
- Fish species (shellfish vs. finfish vs. salmon).
- Local communities.

Ecology believes that a certain amount of flexibility is needed to address this type of geographic variability. The question is where to build in the flexibility and where it is most needed. Flexibility is important for considering questions around current and future habitat and resource abundance, as well as the variability of fish species present at a site and their life cycle, including where contaminants are obtained. Ecology also acknowledges that some (but not all) water bodies are large enough to sustain moderate to high fish consumption rates.

Agencies have several options for addressing the geographic variations in fish consumption rates. These options include:

- *Single statewide fish consumption rate.* Regulatory agencies may adopt uniform statewide values that do not fully account for geographic variability in fish consumption rates. (For example, the current Water Quality Standards for Surface Waters are based upon a single fish consumption rate of 6.5 grams/day. Similarly, the MTCA Cleanup Regulation includes a single default fish consumption rate of 54 grams/day.) However, this approach ultimately requires several policy choices regarding the appropriate statewide value.
- *Multiple regional fish consumption rates.* Regulatory agencies may adopt regulatory requirements that use several fish consumption rates that reflect the diversity of fish consumption from various water bodies in Washington. Several people who provided comments on Version 1.0 of this Technical Support Document recommended that Ecology consider this option.
- *Site-specific fish consumption rates.* Regulatory agencies develop site-specific fish consumption rates that are used to establish regulatory requirements that are applicable to specific cleanup sites or dischargers. This approach can be implemented in combination with a default value established on a programmatic basis. As noted above, the MTCA

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distribution will often (but not always) fall at the upper end of the distribution. In some cases, the mean may approach the 95th percentile of the distribution.

Cleanup Regulation includes a default fish consumption rate (54 g/day) that is used to calculate site-specific cleanup standards. However, the rule also provides the flexibility to establish cleanup standards using a site-specific fish consumption rate.

6.4 Salmon

Information about salmon is discussed in various places throughout this Technical Support Document, including Chapter 4, Chapter 6, and Appendix C. In addition, a more detailed discussion of salmon is presented in the Technical Issue Paper, *Salmon Life History and Contaminant Body Burdens* (Ecology, 2012). This is an artifact of the ongoing dialogue in response to comments as Ecology continues to consider the various scientific, policy, and regulatory issues.

Ecology has evaluated current information on salmon consumption and life cycles in Chapter 4 and Appendix C of this report. Ecology also prepared a separate report that provides additional information and evaluation of this topic. Two main points emerged from those analyses:

- Salmon are a primary fish species consumed by Washington fish consumers.
- In contrast to other species, a significant part of salmon body burden is potentially received in waters and from sources outside of individual MTCA sites or the waters of the state[45] that are regulated under the Clean Water Act (CWA)-based criteria.

There are several important issues associated with deciding whether and how consumption of salmon should be taken into account when developing default fish consumption rates used in regulatory decisions. Two key questions are:

- How should the default rates take into account the consumption of fish species like salmon that spend much of their life outside of Washington waters?
- How should the complex life cycle and biology of the different anadromous species like salmon be considered when making regulatory decisions?

Several different approaches are available for resolving these questions. Although others exist, options typically considered by state and federal agencies include:

- *Salmon considered.* Some agencies have established regulatory requirements that are based on fish consumption rates that take into account consumption of all types of finfish and shellfish. In other words, the regulatory requirement is based on a fish consumption rate that includes finfish, shellfish, and anadromous fish. For example, the Oregon DEQ has adopted a fish consumption rate (175 g/day) that includes salmon.
- *Salmon considered when establishing regional rates.* Ecology could establish regional fish consumption rates that reflect the diversity of water bodies, species, and fish consumption patterns. Under this approach, Ecology could include salmon in the rates

[45] *Waters of the state* include lakes, rivers, ponds, streams, inland waters, underground waters, salt waters, and all other surface waters and watercourses within the jurisdiction of the state of Washington (RCW 90.48.020).

applicable to some water bodies while excluding salmon in the rates for other water bodies. Ecology is not aware of examples where this approach has been used.

- *Salmon considered when establishing site-specific rates.* Ecology could establish site-specific fish consumption rates that include salmon for some (but not all) cleanup sites. Under this approach, Ecology would consider the cleanup site's contribution to salmon body burden when establishing site-specific cleanup standards.
- *Salmon NOT considered.* Some agencies have established regulatory requirements that are based on fish consumption rates that do not include salmon. For example, the EPA used this approach when establishing the default fish consumption rates that are included in the EPA Region 10 framework. Most states have adopted human health-based water quality criteria that do not include anadromous salmon in the fish consumption rate.

6.5 Sources of finfish/shellfish

In some surveys, people are asked to provide information on the source of the finfish and shellfish they have consumed. Sources of finfish and shellfish are generally categorized as self-harvested or purchased from stores or restaurants. Not all locally harvested fish may be affected by site-specific contamination. Chapter 4 summarizes information from the four key regional fish consumption surveys conducted in the Pacific Northwest. Section 4.7 summarizes available information on the source of finfish and shellfish. For these tribal populations, locally or regionally harvested finfish and shellfish represents 67 to 96 percent of total finfish and shellfish consumed.

Several different approaches are used by federal and state regulatory programs to account for patterns of exposure from different sources. Options typically considered by agencies include:

- *Fish consumption rates based on consumption of all finfish and shellfish.* Some agencies establish default and site-specific fish consumption rates using study results that reflect the total amount of finfish and shellfish consumed by study participants (independent of whether the finfish/shellfish were locally harvested or store-bought). For example, the Oregon DEQ used this approach when they revised Oregon's Water Quality Standards for Surface Waters.
- *Fish consumption rates based on consumption of locally harvested finfish and shellfish.* Some agencies establish default and site-specific fish consumption rates using study results that reflect locally harvested finfish and shellfish consumed by study participants. For example, the EPA Region 10 framework explicitly recognizes source contribution issues by adjusting total fish consumption rates to account for fish harvested and consumed from Puget Sound (U.S. EPA, 2007b).
- *Fish diet fraction.* Some agencies make site-specific adjustments to account for the amount of locally harvested finfish and shellfish caught at or near an individual sediment cleanup site. For example, the MTCA rule currently considers the fish diet fraction when

calculating site-specific surface water cleanup standards. The fish diet fraction is defined in the MTCA rule as "….the percentage of the total finfish and/or shellfish in an individual's diet that is obtained or has the potential to be obtained from the site" (WAC 173-340-708(10)(b)). Applying the 0.5 default fish diet fraction under MTCA to the 54 g/day default fish consumption rate (see Figures 15 and 16) results in an effective fish consumption rate of 27 g/day.

6.6 Consumer vs. per capita

Fish consumption surveys typically include people who eat fish and people who don't eat fish. People who don't eat fish are termed *non-consumers*. Those that do eat fish are considered *consumers*. The proportion of non-consumers included in the survey will vary depending on the population being interviewed.

The results from fish consumption surveys can be reported in terms of *consumer-only* rates and *per capita* rates. Consumer-only intake rates refer to the quantity of finfish and shellfish consumed by individuals during the survey period. These data are generated by averaging intake across only the individuals in the survey who consumed finfish and shellfish during the survey period. Per capita intake rates are generated by averaging intake rates over the entire survey population (including those individuals that reported no intake).

There can be large differences in study results reported on a consumer-only and per-capita basis when a large percentage of study participants report that they did not eat any finfish or shellfish during the survey period. For example, EPA evaluated national data from approximately 20,000 individuals (3 years and older). Approximately 28 percent were fish consumers. When expressed on a per-capita basis, the 90th percentile of the reported results was 17.5 g/day. When expressed on a consumer-only basis, the 90th percentile of the reported results was 250 g/day (U.S. EPA, 2002a).

However, there are much smaller differences in studies where a high percentage of study participants reported they ate some amount of fish during the survey period. For example, the per-capita and consumer-only rates from the CRITFC study are virtually identical.

Federal and state environmental agencies have used both types of information to establish regulatory requirements. Options include:

- *Per capita data.* Environmental agencies have used per capita fish consumption rates to establish regulatory requirements. For example, several states have adopted surface water quality standards that are based on the 90th percentile of 17.5 g/day.
- *Consumer-only data.* Environmental agencies have used consumer-only fish consumption rates to establish regulatory requirements. For example, the EPA Region 10 framework includes several default fish consumption rates that are based on consumer-only information.

6.7 Other exposure variables

Ecology uses a risk assessment approach to establish cleanup standards and water quality standards based on human health protection. Risk-based concentrations can be calculated for both cancer and non-cancer health effects using standard risk assessment equations. This document is not designed to provide a detailed discussion on individual exposure parameters and the relationships between those parameters and the fish consumption rate used to calculate risk-based concentrations. However, when selecting fish consumption rates used in regulatory decisions, it is important to consider the following points:

- Regulatory choices on individual parameters need to be based on a common exposure scenario. It is important that agencies select fish consumption rates that are consistent with other exposure parameters. For example, if risk calculations are performed using a child's body weight, the fish consumption rate should be based on the amount of finfish and shellfish eaten by children.
- Regulatory choices on individual exposure parameters need to recognize the value judgments embedded in those parameters and the cumulative impact of those choices. For example, selecting upper percentile values for all exposure parameters will result in a risk estimate that does not represent a "reasonable" maximum exposure scenario (RME).
- Values should be concordant with the populations chosen to represent regulatory exposure scenarios, for example body weight for tribal populations or particular ethnic groups. Similarly, exposure duration should reflect the duration of times populations selected for evaluation use water bodies for fishing. Tribes have Usual and Accustomed fishing areas they may use over long periods of time. Individuals may relocate over limited geographic areas and still utilize water bodies for fishing with the implication that times in a single residence may not be an appropriate exposure duration.
- How bioaccumulation is accounted for is also a source of uncertainty and variability. The use of bioconcentration factors (BCFs) that relate contaminant concentrations in aquatic biota to those in water are being replaced by bioaccumulation factors (BAFs) that relate contaminant concentrations in aquatic biota to those from all sources.
- Figures 15 and 16 illustrate other exposure parameters. Shown are equations used to establish MTCA surface water cleanup standards based on non-cancer hazard and cancer risks (Figures 15 and 16, respectively). In addition to a default fish consumption rate, the equation includes default values for body weight, exposure duration, and fish diet fraction. A similar (but not identical) equation is used to establish water quality standards. Several of the exposure assumptions used to establish water quality standards are different than those used under the MTCA rule.

$$CUL = \frac{(RfD * ABW * UCF1 * UCF2 * HQ * AT)}{(BCF * FCR * FDF * ED)}$$

Where:

CUL = Surface water cleanup standard (µg/L)

RfD = Reference Dose as specified in WAC 173-340-708(7)

ABW = Average body weight During the exposure duration (70 kg)

UCF1 = Unit conversion factor (1000 µg/mg)

UCF2 = Unit conversion factor (1000 g/liter)

BCF = Bioconcentration factor as defined in WAC 173-340-708(9) (liters/kilogram)

FCF = Fish consumption rate (54 g/day)

FDF = Fish diet fraction (0.5, unitless)

HQ = Hazard quotient (1 unitless)

AT = Averaging times (30 years)

ED = Exposure duration (30 years)

Figure 15. MTCA Surface Water Cleanup Standards Equation (Non-Carcinogenic Hazards)

$$CUL = \frac{(RISK * ABW * AT * UCF1 * UCF2)}{(CPF * BCF * FCR * FDF * ED)}$$

Where:

CUL	=	Surface water cleanup standard (µg/L)
RISK	=	Acceptable cancer risk level (1 in 1,000,000) (unitless)
ABW	=	Average body weight during the exposure duration (70 kg)
AT	=	Averaging time (75 years)
UCF1	=	Unit conversion factor (1,000 µg/mg)
UCF2	=	Unit conversion factor (1,000 grams/liter)
CPF	=	Carcinogenic Potency Factor as specified in WAC 173-340-708(8) (kg-day/mg)
BCF	=	Bioconcentration factor as defined in WAC 173-340-708(9) (liters/kilogram)
FCR	=	Fish consumption rate (54 grams/day)
FDF	=	Fish diet fraction (0.5) (unitless)
ED	=	Exposure duration (30 years)

Figure 16. MTCA Surface Water Cleanup Standards Equation (Carcinogenic Risk)

6.8 Acceptable risk levels

Washington's current Water Quality Standards and MTCA Cleanup Regulation are both based on an acceptable cancer risk of 1 in 1 million and a hazard quotient of one. These are central policy choices that will continue to be discussed and debated. By necessity, decisions on acceptable risk levels are informed by science but require consideration of a wide range of other factors. For example:

- Statutory requirements.
- Social preferences on risk avoidance and distinctions between voluntary and involuntary risks.
- Uncertainties associated with risk assessment methods.
- Risk tradeoffs, including the health benefits associated with eating finfish and shellfish.
- Risk comparisons, including the risks associated with other common activities.
- Economic impacts of attaining target risk levels.

This technical support document focuses on information about fish consumption. It does not provide a detailed discussion on risk policy. Ecology acknowledges that when selecting fish consumption rates for use in regulatory decisions it will be important to consider the relationships and interactions between the various policy choices.

6.9 Summary

Agencies must address many scientific and policy issues when selecting a fish consumption rate for use in particular regulatory situations. Chapters 3 through 5 compile the currently available information on fish consumption rates in Washington. This chapter describes eight policy choices that should be addressed when using this information in a regulatory context. These policy choices must take into account statutory mandates and values that inevitably reflect explicit or implicit choices on how to deal with scientific uncertainty and variability. There are often multiple answers to these questions surrounding these issues. This chapter provides examples of how Ecology or other agencies have resolved those issues in the past.

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Appendices

Appendix A Information on Bioaccumulation, Fish Consumption by Children, and Species Consumed

This appendix includes information on:

1. Bioaccumulation
2. Children's fish consumption rates
3. Data on species consumed

This information is included in this document to provide additional context for considering fish consumption rates. For additional information readers are referred to references cited.

A.1 Bioaccumulation

Bioaccumulation of contaminants in finfish/shellfish

A detailed discussion regarding the bioaccumulation of chemicals in aquatic biota is beyond the scope of this appendix. The EPA's Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) dedicates an entire chapter on the subject of bioaccumulation and changes in methodologies since the 1980s to assess and predict the bioaccumulation of chemicals in aquatic biota. Federal and state guidance documents are available that provide detailed analysis to assess and predict the bioaccumulation of chemicals in aquatic biota (U.S. EPA, 2000b, 2000c, 2007a; State Water Resources Control Board of California, 2004; CalEPA, 2006). An 800-page appendix to EPA's *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment* provides chemical-specific information relevant to the bioaccumulation of chemicals in aquatic biota (U.S. EPA, 2000c, Appendices).

EPA makes a clear distinction between the terms bioaccumulation and bioconcentration. The term bioaccumulation "refers to the uptake and retention of a chemical by an aquatic organism from all surrounding media (e.g., water, food, sediment)." The term bioconcentration "refers to the uptake and retention of a chemical by an aquatic organism from water only" (U.S. EPA, 2000b). The 2000 EPA guidance reflects the use of bioaccumulation factors (BAFs) to reflect the uptake of a contaminant by fish from all sources rather than just from the water column reflected by the use of bioconcentration factors (BCFs). For chemicals that are persistent and hydrophobic, the magnitude of bioaccumulation by aquatic organisms may be substantially greater than the

magnitude of bioconcentration. The 2000 EPA Ambient Water Quality Methodology provides important concepts regarding the bioaccumulation process as follows (U.S. EPA, 2000b, p. 5–2):

> *Another noteworthy aspect of bioaccumulation process is the issue of steady-state conditions. Specifically, both bioaccumulation and bioconcentration can be viewed as the results of competing rates of chemical uptake and depuration (chemical loss) by an aquatic organism. The rates of chemical uptake and depuration can be affected by various factors including the properties of the chemical, the physiology of the organism in question, water quality and conditions, ecological characteristics of the water body (e.g., food web structure), and the concentration and loadings history of the chemicals. When the rates of chemical uptake and depuration are equal, tissue concentrations remain constant over time and the distribution of the chemical between the organism and its sources(s) is said to be at steady-state. For constant chemical exposures and other conditions, the steady-state concentration in the organism represents the highest accumulation potential of the chemical in that organism under those conditions. The time required for a chemical to achieve steady state has been shown to vary according to the properties of the chemical and other factors.*

The EPA further notes that…"criteria for the protection of human health are typically designed to protect humans from harmful lifetime or long-term exposures to waterborne contaminants, the assessment of bioaccumulation that equals or approximates steady-state accumulation is one of the principles underlying the derivation of national BAFs. For some chemicals that require relatively long periods of time to reach steady-state in tissue of aquatic organisms, changes in water column concentrations may occur on a much more rapid time scale compared to the corresponding changes in tissue concentrations. Thus, if the system departs substantially from steady-state conditions and water concentrations are not averaged over a sufficient time period, the ratio of the tissue concentration to a water concentration may have little resemblance to the steady-state ratio and have little predictive value of long-term bioaccumulation potential" (U.S. EPA, 2000b).

There are several important factors that may affect a chemical's bioavailability and influence its bioaccumulation in fish. These factors include a wide range of physical, chemical, and biological characteristics associated with the contaminants, sediments, and aquatic biota (U.S. EPA, 2000c).

Chemical bioavailability. Chemical bioavailability is a complex interplay between the physical-chemical properties of the contaminant as well as the behavior and physiology of the aquatic biota.

Physical factors of sediments affecting bioavailability and bioaccumulation. Sediments are complex and dynamic environments with a wide range of interacting biological and chemical processes that influence a chemical's bioavailability and bioaccumulation into fish tissues.

Variable rates of mixing surficial sediment layers by physical processes of turbulence and bioturbation compete with rates of sedimentation. In addition, resuspension of sediments may also impact the bioavailability of sediment-associated contaminants by exposing filter feeders to contaminated particulates or by increasing the aqueous concentration of a contaminant via desorption from the particulates within the water column.

Chemical factors affecting bioavailability and bioaccumulation. The physical-chemical characteristics of a contaminant (molecular size and polarity) may influence the degree of association with particles and affect the chemical's bioavailability. Many persistent and bioaccumulative toxic chemicals (PBTs) are large, nonpolar compounds, with low water solubilities and a strong tendency to be associated with dissolved and particulate organic matter. Hydrophobic chemicals, those that are strongly lipophilic, are a critical factor in determining the bioaccumulation behavior of organic chemicals in aquatic systems.

Biological factors affecting bioavailability and bioaccumulation. EPA notes that bioaccumulation is a multi-factorial process that combines the chemical with the biological (U.S. EPA, 2000c, p. X):

> *Bioaccumulation is a function of the bioavailability of contaminants in combination with species-specific uptake and elimination processes. Toxicity is determined by the exposure of an animal to bioavailable contaminants in concert with the animal's sensitivity to the contaminant. These processes have been shown to be a function of the organism's lipid content, size, growth rate, gender, diet, and ability to metabolize or transform a given contaminant, as well as the chemical conditions of the surrounding medium. Other biological factors that can affect a contaminant's bioavailability include the burrowing and feeding behavior of the individual organism or species. The depth to which an organism burrows, the type of feeding mechanism it uses (e.g., filter feeding, particle ingestion), the size range of sediment particles it consumes, and its diet all have a large influence on the concentration of contaminant to which the organism will be exposed.*

A.2 Children's fish consumption rates

The *Child-Specific Exposure Factors Handbook* and the *Highlights of the Child-Specific Exposure Factors Handbook* summarize children's fish consumption rates for different age groups. The mean and 95th percentile consumer-only total fish (marine, estuarine, freshwater) consumption rate for 16 to less than18 years of age for the general population is 2.1 grams per kilogram per day (g/kg/day) (136 g/day) and 6.6 g/kg/day (357 g/day), respectively (U.S. EPA, 2008, 2009b). The mean and 95th percentile consumer-only total fish (finfish and shellfish) consumption rate for 3 to under 6 years old for the general population is 4.2 g/kg/day (78 g/day)

and 10 g/kg/day (186 g/day), respectively (U.S. EPA, 2009b, Table 1).[46] The *Interim Report Child-Specific Exposure Factors Handbook* summarizes the fish consumption rates among Native American children (consumers only, 5 or 6 years old or younger) using Pacific Northwest fish consumption survey information (U.S. EPA, 2002a).

Table A-1. Fish Consumption Rates of Native American Children 5 or 6 Years of Age or Less

Survey (Native Populations)	Mean (g/day)	90th Percentile [a] (unless otherwise noted, g/day)	95th Percentile (g/day)
CRITFC, 1994 (Umatilla, Yakama, Nez Perce, Warm Springs)	25	63	73
Toy et al., 1996 (Tulalip and Squaxin Island Tribes) [b]	11	21 (86th percentile)	
Suquamish Tribal Survey, 2000 [c]	21	48	103

a. Values are the 90th percentile unless otherwise noted.

b. Consumption rate calculated using the average body weight of 15.2 kilograms reported in Toy et al., 1996.

c. Consumption rate calculated using the average body weight of 14.1 kilograms from the general population.

Although the age groups and body weights may differ across the general and Native American children population groups, the fish consumption rates for the children begin to approximate one another at the upper percentiles (78 to 186 g/day and 63 to 103 g/day). EPA has noted that there is a high degree of variability in fish consumption rates across the Pacific Northwest tribes (U.S. EPA, 2009a). The 2008 Oregon DEQ Human Health Focus Group Report referenced EPA's *Per Capita Fish Consumption in the U.S.* (2002) as supporting documentation for the children's fish consumption rate (consumers only) of 191 g/day (Oregon DEQ, 2008; U.S. EPA, 2002a, Section 5.2.1.1, Table 4). The same documentation and children's fish consumption rate (190 g/day) is used to recognize the variability expressed by different fish consumption rates for different fish-consuming populations.

The following tables summarize analysis of fish consumption rate data for surveys identified by Ecology as meeting measures of technical defensibility. These tables are included here to show age group data.

[46] This consumption rate uses a body weight of 18.6 kilograms for children 3 to <6 years of age.

Table A-2. Tribal Fish Consumption Rates

Fish Consumption Rate by Age Group From Selected Pacific Northwest Tribes				
Age Group	Mean	50th Percentile	90th Percentile	95th Percentile
Columbia River Basin Tribes (g/day)				
Adults	58.7			
18–39	57.6			
40–59	55.8			
60 and over	74.4			
Tulalip Tribes (g/kg/day)				
0–5	0.2	0.08	0.7	
18–34		0.06	2.0	2.6
35–49		1.0	3.7	4.2
50–64		0.5	1.6	1.6
65 and over		0.2	0.6	0.6
Adults	0.9	0.6	2.9	
Squaxin Island Tribe (g/kg/day)				
0–5	0.8	0.5	2.1	
18–34		0.5	2.3	3.1
35–49		0.5	2.6	3.0
50–64		1.1	3.6	3.6
65 and over		0.8	2.2	2.2
Adults	0.9	0.5	3.0	
Suquamish Tribe (g/kg/day)				
0–6	1.5		3.4	
Adult Males				
16–42	3.3	2.3	8.6	13.0
43–54	5.2	4.6	10.3	
55 and over	1.6	1.4	4.8	
Adult Females				
16–42	1.9	1.0	4.9	10.1
43–54	1.2	0.8		
55 and over	3.7	2.1		

Source: Adapted from Moya, 2004, Table 5, p. 1204.

Table A-3. Fish Consumption Rate Data for Asian and Pacific Islanders

Asian and Pacific Islanders in King County, by Age Group (g/kg/day)	Mean	50th Percentile	90th Percentile	95th Percentile
All respondents	1.9	0.8	2.4	3.9
18–29	1.8		2.1	3.9
30–54	1.6		2.3	3.8
55 and over	2.1		3.2	5.2

Source: Adapted from Moya, 2004, Table 4, p. 1203.

Table A-4. EPA Data on Children's Finfish and Shellfish Consumption Rates for the U.S. General Population

Fish Population Description	Fish Consumption by Age Group (g/kg/day)			
	3 to < 6 years	6 to < 11 years	11 to < 16 years	16 to < 18 years
Total fish				
Mean per capita	0.43	0.28	0.23	0.16
95th percentile per capita	3.0	1.9	1.5	1.3
Mean consumer only	4.2	3.2	2.2	2.1
95th percentile consumer	10	8.7	6.2	6.6
Marine fish				
Mean per capita	0.31	0.20	0.15	0.10
95th percentile per capita	2.3	1.5	1.3	0.46
Mean consumer only	3.7	2.8	2.0	2.0
95th percentile consumer	9.3	8.0	5.2	6.5
Freshwater fish				
Mean per capita	0.12	0.08	0.08	0.07
95th percentile per capita	0.71	0.35	0.48	0.29
Mean consumer only	2.3	1.8	1.3	1.4
95th percentile consumer	7.2	6.2	4.4	3.3

Source: Adapted from U.S. EPA, 2009b, Table 1, p. 20.

A.3 Data on fish species consumed

The EPA Region 10 framework for establishing site-specific fish consumption rates for use at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites provides the following information related to types of seafood consumed.

For adult members of the Tulalip Tribes, a 95th percentile total consumption rate of 194 g/day is obtained after adjusting the total consumption rate of 243 g/day to include only finfish and shellfish harvested from Puget Sound (Table A-5). This is based on information from the EPA Region 10 framework (U.S. EPA, 2007b, as cited in Windward Environmental, 2007, Appendix B).

Table A-5. Seafood Consumed by Adult Members of the Tulalip Tribes

Seafood Category	Examples	Central Tendency Estimate (g/day)	95th Percentile (g/day)	Percent of Fish Diet
Anadromous fish	Salmon/steelhead	14.9	96.4	49.7
Pelagic fish	Smelt, mackerel, cod, perch	1.3	8.1	4.2
Benthic/demersal fish	Halibut, sole, rockfish, snappers	1.2	7.5	3.9
Shellfish	Crabs, clams, mussels, bivalves	12.5	81.9	42.2
	Total ingestion rate	30	194	100

For adult members of the Suquamish Tribe, a 95th percentile total consumption rate of 766.8 g/day is obtained after adjusting the total consumption rate of 796 g/day to include only finfish and shellfish harvested from Puget Sound (Table A-6). This is based on information from the EPA Region 10 framework (U.S. EPA, 2007b, as cited in Windward Environmental, 2007).

Table A-6. Seafood Consumed by Adult Members of the Suquamish Tribe

Seafood Category	Examples	95th Percentile (g/day)	Percent of Fish Diet
Anadromous fish	Salmon/steelhead	183.5	23.9
Pelagic fish	Smelt, mackerel, cod, perch	56.0	7.3
Benthic/demersal fish	Halibut, sole, rockfish, snappers	29.1	3.8
Shellfish	Crabs, clams, mussels, bivalves	498.4	65
	Total ingestion rate	766.8	100

Freshwater fish make up 8.3 percent of the API seafood consumption, based on information from the API fish consumption survey from King County, Washington, as cited in Windward Environmental, 2007 (Table A-7).

Table A-7. Seafood Consumed by Adult Asian-Pacific Islanders (API)

Seafood Category	Central Tendency Estimate (g/day)	95th Percentile (g/day)	Percent of fish diet
Anadromous fish	0.56	5.5	9.6
Pelagic fish	0.5	4.9	8.6
Benthic/demersal fish	0.24	2.4	4.2
Shellfish	4.6	44.2	77.5
Total	5.9	57	99.9

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Appendix B
Additional Fish Consumption Studies

This appendix includes information on additional studies considered by Ecology:

1. Background information
2. Biometric studies of Japanese and Korean populations in Washington State
3. Additional studies evaluated:
    a. Makah Tribe
    b. Port Gamble S'Klallum Tribe
    c. Muckleshoot Indian Tribes
    d. Upper Columbia River Resources Survey – Confederated Tribes of the Colville Reservation
    e. Spokane River Surveys of Selected Ethnic Populations
    f. Swinomish Tribal Study: Bioaccumulative Toxics in Subsistence-Harvested Shellfish – Contaminant Results and Risk Assessment
4. Additional technical publications by Pacific Northwest tribal staff

B.1 Background information

Ecology identified a number of studies that provide information meeting measures of technical defensibility and that are appropriate for consideration of statewide fish consumption rates. Other studies are useful in providing multiple lines of evidence with respect to fish consumption. That is, numerous other studies, designed for various purposes, provide additional information that may be of value for particular evaluations or considerations. Although these studies may not have been conducted to identify specifically fish consumption rates of the population of interest, they assist in providing a robust picture of the importance of finfish and shellfish to the people of Washington.

The studies discussed in this appendix are comprehensive but not exhaustive. For example, from July 2003 through December 2011, The Lands Council as part of the Spokane River Toxics Outreach, completed approximately 5,300 surveys, distributed about 10,000 health advisories, and participated in public education outreach of nearly 16,000 individuals in the Spokane area. This public outreach is to educate and increase public awareness of the health risks of PCBs in the Spokane River fish and heavy metal contamination in the Spokane River sediments. These surveys have targeted Slavic (eastern European, Russian) and Hispanic populations because they frequently harvest and consume fish from the Spokane River. Spokane River fish advisories recommend only one fish meal per month of fish from the river's middle section and avoid

eating any fish from the Spokane River's upper stretches.[47] As noted in Chapters 3 and 4 of this Technical Support Document, these water body-specific surveys provide important information to support health protective advisories for people who harvest and consume fish from specific water bodies. All water body-specific fish dietary surveys, usually some form of a creel survey, are not detailed in this Technical Support Document. For a more detailed review of all of the water body-specific surveys and fish advisory information, the reader is referred to the Washington Department of Health's website on fish advisories.[48] The fish consumption related information provided in this appendix is important and credible information used to evaluate and assess the potential health risks from eating contaminated fish (seafood). The additional fish dietary information provided in Table 33 and this appendix provide multiple lines of evidence, as a weight of evidence approach, that people in Washington State harvest and consume large amounts of fish. The estimates of fish consumption detailed in Chapter 4 are based on fish dietary information based on survey methodology that allows for the projection of fish consumption estimates over a long period of time with descriptive statistics for percentile estimates. This type of information is important to help support health protective decisions to clean up contaminated sediments.

B.2 Biometric studies of Japanese and Korean populations in Washington State

Several studies have been conducted in Washington State to evaluate the fish consumption of Japanese and Korean populations (Tsuchiya et al., 2008a, 2008b, 2009; Cleland et al., 2009). These studies were conducted as part of the Arsenic Mercury Intake Biometric Study in collaboration with the University of Washington's Institute for Risk Analysis and Risk Communication and the Washington State Department of Health. The studies were designed to evaluate mercury exposure within the Japanese and Korean communities and arsenic exposures within the Korean community of Washington State. Japanese and Korean populations in Washington State consume fish at higher rates than the national average (Sechena et al., 1999). These high fish-consuming populations may be exposed to mercury and arsenic from the consumption of finfish and shellfish.

The fish consumption survey was based on surveys previously conducted for several other Pacific Northwest fish-consuming populations (tribal surveys and Sechena et al., 1999). The food frequency questionnaire was a validated dietary tool used and developed by the Fred Hutchinson Cancer Research Center and was self administered by the participants of this study. As part of the fish dietary survey, participants were provided a pictorial fish booklet, printed in three languages, containing pictures with names of various fish species commonly consumed by

[47] Spokane River Toxics Outreach, web location: http://www.landscouncil.org/water/river_toxics.asp?template=false

[48] Washington State Department of Health Fish Advisory Information: http://www.doh.wa.gov/CommunityandEnvironment/Food/Fish.aspx

Japanese and Koreans and seafood commonly found in the Pacific Northwest. Interview questions included frequency of consumption and serving sizes (based on fish models of fish steaks, fillets, sushi pieces, and shellfish samples). Also, participants were asked if they consumed any other fish not listed in the fish booklet. Survey participants were weighed unless they were pregnant. Pregnant women were asked to report their pre-pregnancy body weights.

The survey instrument included a series of questions that allowed for a cross-check of participant response about fish consumption. Mercury fish tissue concentrations were determined from fish commonly consumed by Japanese and Korean communities in the Puget Sound area from local Asian grocery stores. Fish or fish portions were purchased from multiple locations over a 4-week period. Analysis was conducted on skinless edible portions consisting of steaks or fillets.

Results from the Japanese and Korean fish dietary survey are shown in Table B-1 with comparisons made between the mean combined finfish and shellfish consumption rates (in red) with the 95th percentile national consumption rates (in red).

Table B-1. Fish Consumption Rates for Japanese and Korean Washington Populations

Population	Finfish Consumption (g/day)			Shellfish Consumption (g/day)		
	Mean	50th	95th	Mean	50th	95th
Japanese (n = 106)	60	43	159	14	9	59
Korean (n = 108)	59	42	147	23	13	84
Population	**Finfish and Shellfish Combined Consumption (g/day)**					
	Mean	50th	75th	90th	95th	99th
Japanese (n = 106)	73	55	100	164	188	241
Korean (n = 108)	82	64	112	170	230	329
CSFII	14	----	19	47	72	121
NHANES	----	----	0	43	87	----

Source: Adapted from Tsuchiya et al., 2008b, Table 1.

Both Japanese and Korean respondents from this survey consume almost the same amounts of finfish (mean fish consumption of 60 g/day for Japanese and 59 g/day for Koreans). Also, this similarity in fish consumption for Japanese and Koreans is reflected in the finfish consumption distribution with 95th percentiles being 159 g/day for Japanese and 147 g/day for Koreans. Differences in amounts of total fish consumption for these two fish-consuming populations is due to the Koreans consuming nearly 70 percent more shellfish on a daily basis (22.7 g/day/person) compared to the Japanese (13.5 g/day/person). The mean total fish consumption for Japanese (73 g/day) and Koreans (82 g/day) is almost identical to the 95th percentile estimates from CSFII and NHANES national fish dietary data. Based on comparison with national data, the authors noted (Tsuchiya et al., 2008b):

> *The Koreans and Japanese women consume fish in quantities that exceed the national average. Mean values for the average values for the Japanese and Korean cohorts are significantly higher (73 and 82 g/day, respectively). Values of significance within the NHANES and CSFII distributions are the 95th percentile values (87 and 72 g/d, respectively) because the remaining 5% represent many persons. The average consumption values for the Koreans and Japanese approach or exceed these 95th percentile values, indicating that these 2 populations may be contained within the remaining 5th percentile of the NHANES and CSFII distributions. On the basis of the percentile values for the consumption distributions from CSFII and NHANES, the 2 populations investigated by us have central estimate shifts in consumption, leading to distribution patterns displaced to the right and further down the abscissa. Specifically, all the percentile consumption rates representing the national fish consumer were below those determined for the Japanese and Koreans.*

Mean fish consumption estimates for Japanese and Korean women respondents for each of the clinic visits are provided in the table below. Additional details regarding the finfish species consumed and differences in rates from one clinic visit to another are provided in the Technical Issue Paper, *Health Benefits and Risks of Consuming Fish and Shellfish* (Ecology, 2012).

B.3 Additional studies evaluated

Makah Tribe

The Makah Indian reservation is located on the northwestern tip of the Olympia Peninsula in Washington State. The Makah Tribal usual and accustomed areas for harvesting finfish and shellfish extends east to the Elwha River, south to a geographic point between Ozette and the Quileute reservation, and north to the Canadian international border and the Swiftsure Bank. The geographic position of the Makah Indian reservation provides access to diverse terrestrial, freshwater, and marine resources to support subsistence practices.

An examination of the Makah subsistence practices was conducted by the University of Washington, Department of Anthropology, between 1997 and 1999. Jennifer Sepez's 2001 dissertation documents and evaluates the subsistence hunting, fishing, and shellfishing practices of the Makah Indian Tribe. For the purposes of this research, subsistence was defined as "the local harvest of natural resources for local consumption" (Sepez, 2001, p. 9). A random ethnographic survey sample of 15 percent of reservation households provided information on the contemporary subsistence harvests, uses, and consumption of finfish, shellfish, land mammals, marine mammals, and birds. Results indicate that 99 percent of the reservation households participate in some type of subsistence activities. 71 percent of the households engaged in harvesting resources, while 94 percent received resources harvested by another household. This comprehensive examination of Makah Tribal subsistence practices included hunting for deer,

elk, and grouse, and fishing for salmon, halibut, rockfish, black cod, and other species (Table B-2). Low tides in Neah Bay or adjacent tide flats provide areas for tribal harvesting of clams, mussels, barnacles, chitons, urchins, and other shellfish. Seal hunting occurs in conjunction with net fishing and canoeing. Regarding the Makah Tribal subsistence practices, the thesis noted (Sepez, 2001, p. 19):

> *There is no homogeneous or even typical subsistence profile of Makahs. However, there are identifiable patterns of resource use in the community, and an accumulated history of legal, political, and ecological circumstances that frame contemporary subsistence activities as a place-and time-specific manifestation of ongoing traditions.*
>
> *Although land-based subsistence harvesting is important, the majority of resources come from the sea. One saying around town that captures this orientation is "when the tide is out, the table is set."*

Table B-2. Percent of Households Using Subsistence Resources during 1997–1998

Percent of Reservation Households	Subsistence Resource
76–100%	Halibut, salmon, clams, crab
51–75%	Mussels, deer, elk, goosenecks [boots], seal (meat and/or oil), salmon eggs, barnacles
26–50%	Steelhead, lingcod, olive shells, chitons [slippers], octopus, rockfish, smelt, black cod, herring eggs, grouse
1–25%	Urchins [sea eggs], lingcod eggs, local cow, petrale, trout, tuna, bear, scallop, oysters, sole/flatfish, sea cucumber, squid, sturgeon, true cod, shrimp, rabbits, abalone, duck, pigeon, skate, sea lion, small gastropods, wolf eel.

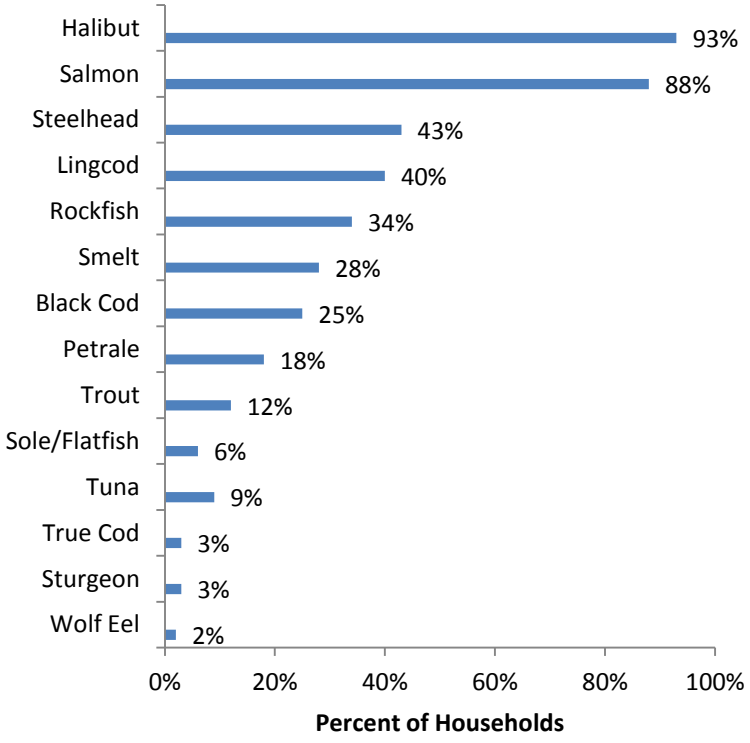
Source: Adapted from Sepez, 2001, Table 4, p. 126.

The Makah tribal subsistence diet is composed mainly of finfish and shellfish. Shellfish contribute 14 percent and finfish contribute 58 percent of the Makah tribal subsistence diet. The percent contribution of fish to the Makah subsistence diet is approximately eight times more than the percent contribution of fish consumed by the average American diet. Halibut is consumed at home by 93 percent of the households. Historical information suggests a strong dietary reliance on halibut, which differentiated the Makah Indian Tribe from other Pacific Northwest tribes whose main fish subsistence resource was salmon. However, 88 percent of the Makah tribal households consume salmon, which surpasses halibut consumption when measured as pounds consumed per household. Table B-3 and Figure B-1 below illustrate the harvest and consumption practices of the Makah Tribe for fish resources in pounds. Salmon and halibut contribute more to the subsistence Makah diet by weight than any other types of fish combined.

Table B-3. Makah Indian Tribe Per Capita Harvest and Consumption of Subsistence Fish (pounds)

Fish Species	Mean per capita harvest (all households)	Mean per capita consumption (all households)	Mean per capita consumption (consumers only)
Halibut	55.6	27.4	28.9
Salmon	49.3	40.1	44.9
Steelhead	3.1	3.8	8.6
Lingcod	2.5	2.9	6.9
Rockfish	2.5	3.3	8.9
Smelt	2.4	2.7	10.0
Black Cod	1.3	1.2	5.9
Trout	0.04	0.1	0.4
Sturgeon	1.0	0.8	28.0
Skates	0.1	NA	NA

Source: Adapted from Sepez, 2001, Table 6, p. 140.



Source: Adapted from Sepez, 2001, Figure 3, p. 139.

Figure B-1.Percent of Makah Tribal Households Consuming Subsistence Fish

The survey vehicle administered to the Makah tribal reservation households obtained subsistence fish harvest and consumption information based on household harvest and consumption practices. Ecology did not use this information because the metrics from the results of the survey of tribal households (percent of tribal household consuming fish) is different than the metrics (grams/day) used for risk-based decision making. Furthermore, since information was not available regarding the number of residents per household, and the residency of the same household may vary depending on the extended family relationship within the Makah Tribe, it is not possible to determine an individual's grams/day fish consumption rate based on this thesis. However, this thesis provides a comprehensive documentation of the composition of subsistence Makah tribal diet and subsistence lifeways and practices.

Port Gamble S'Klallum Tribe

Ecology consulted with the Port Gamble S'Klallam Tribe to determine a tribal fish consumption rate to establish sediment cleanup standards protective of human health. The Port Gamble S'Klallam Tribal fish consumption rates were based on the Suquamish Tribe Fish Consumption Survey using the EPA Tribal Fish Consumption Framework. The daily tribal seafood consumption rate of 499 g/day was determined for selected shellfish only and did not include salmon or other finfish. Tribal consultations are continuing to provide additional information regarding the amounts and types of shellfish consumed. Based on Port Gamble S'Klallam Tribal consultations and the application of the EPA Tribal Fish Consumption Framework, the following shellfish species are consumed:

- Total shellfish consumption (no finfish) is 499 g/day:

Geoduck	96.8 g/day
Littleneck clams	255.9 g/day
Oysters	62.4 g/day
Dungeness crab	83.9 g/day assuming 25% hepatopancreas (20.9 g/day) and 75% meat (62.9 g/day).

Ecology did not use this information to derive a default fish consumption rate because Port Gamble S'Klallam Tribal consultations are continuing to establish an accurate tribal fish consumption rate (Ecology, 2011a).

Muckleshoot Indian Tribes

The Muckleshoot Indian Tribe has not performed a tribal fish consumption survey.[49] However, the Muckleshoot Indian Tribe requested that EPA Region 10 develop a tribal exposure scenario to assist in characterizing the range of seafood consumption risks for the Lower Duwamish Waterway. In consultation with the Muckleshoot and Suquamish Indian Tribes, EPA Region 10

[49] Public Health Assessments and Health Consultations. ATSDR. http://www.atsdr.cdc.gov/hac/pha/pha.asp?docid=1312&pg=2#path

and Ecology used EPA guidance to develop a tribal exposure scenario and derive fish consumption rates based on the Suquamish and Tulalip seafood consumption data. Using the EPA Region 10 guidance framework tribal exposure scenarios were developed for the Lower Duwamish Waterway for tribal adults consuming anadromous and pelagic finfish, benthic/demersal finfish, and shellfish. The Lower Duwamish Waterway Remedial Investigation Report provides a range of tribal consumption rates specific for the risk management decisions for the Lower Duwamish Waterway (Windward Environmental, 2007). The Lower Duwamish Waterway fish consumption rates are not applicable for Washington State high fish-consuming populations. Hence, the Lower Duwamish Waterway fish consumption rates were not used to derive a default MTCA fish consumption rate to establish surface water cleanup standards.

Upper Columbia River Resources Survey–Confederated Tribes of the Colville Reservation

Background information

The Confederated Tribes of the Colville Reservation and the EPA, Region 10 and Headquarters, collaborated on the Upper Columbia River Resources Survey (Confederated Tribes of the Colville Reservation and U.S. EPA, 2012). The upper Columbia River and Lake Roosevelt areas have been affected by contaminants from Teck Cominco lead-zinc smelter operations for over 100 years. Residents of the Colville Reservation, located 50 miles downstream from Teck Cominco mine, may have been exposed to these contaminants and have collaborated with the EPA to assess and measure exposure pathways from the consumption of natural resources (including fish) that may be contaminated from the Teck Cominco operations. This information will be used by the EPA to conduct a human health risk assessment for the Upper Columbia River and Colville reservation residents. The resource use survey was conducted to support efforts to evaluate and assess the human health risks from exposures to contaminants from the Teck Cominco lead-zinc smelter located just north of the U.S. Canadian border.

Survey methodology

The Upper Columbia River Resources Survey is composed of two survey vehicles designed to investigate the food consumed and non-food uses harvested from local resources by residents of the Colville Reservation located in eastern Washington State. The Food Questionnaire was administered by trained personnel to Colville Reservation residents regarding the consumption over the preceding 12-month period of several types of food groups: fish, birds, wild animals, farm animals, dairy products, fruits, vegetables, and wild plants. The Food Questionnaire survey method was a 24-hour dietary recall and included a previous 12-month food frequency recall and non-food use recall associated with resident uses of the reservation's natural resources. Out of a pool of 5,893 people, 1,139 people over the age of 2 responded to the Food Questionnaire—approximately 20 percent of the total resident population. A demographic weighting was applied to each respondent to account for the variance in response rate for residence location and age. The percentages and numbers of consumers provided in the Food Questionnaire data report will

vary from the percentage of individual respondents because of this demographic weighting of each respondent. The demographic weighting allows the calculation of numbers and percentages of Colville Reservation residents over the age of 2 years that consume selected types of foods.

Results

Selected results of the Food Questionnaire related to fish consumption from Upper Columbia River Tribal Exposure Survey are presented in Table B-4.

Table B-4. Summary of Fish Type Consumed, Percentage of Population that Consumed Fish Type, and Percentage Harvest Source from Local Areas by Colville Reservation Residents

Fish Type	Percentage of Residents Consuming Fish Type	Frequency of Consumption (times/year)	Percentage Consumers Harvest from Local Areas
Salmon	73	15	74
Trout	46	13	92
Walleye	13	9	91
Smallmouth Bass	11	21	93
Crawfish	9	13	85
Mussels	8	9	12
Largemouth Bass	7	22	85
Panfish	6	25	79
Burbot	4	9	30
Sturgeon	3	40	68
Lake Whitefish	2	9	91
Mountain Whitefish	1	8	69
Lamprey	1	12	13
Aquatic Animals	1	18	100
Northern Pikeminnow	1	7	87
Other fish/aquatic animal	<1	6	100
Sucker [a]	<1	head/skin/organ/eggs	0%

Source: Adapted from Confederated Tribes of the Colville Reservation and U.S. EPA, 2012, Table 3.

a. Sucker was the only fish for which the head/skin/organ/eggs were reported to be consumed more frequently than the meat of the fish. However, a very low number of respondents reported eating suckers and all respondents were unsure of the harvest source of suckers consumed.

The 24-hour dietary recall survey provides information on food (fish) portion sizes while the previous year recall provides information on frequency of consumption for specific types of food consumed from local resources. Information about specific consumption rates is not yet available. However, important observations can be made from the above table. About 83 percent of the Colville Reservation residents ate fish in the previous year the survey was administered. The average number of local fish species consumed was 3 species with a maximum number of 13 species consumed by residents. 73 percent of Colville Reservation residents ate salmon on an average of 15 times per year. Also, almost 20 percent ate the head, skin, organs, or eggs of

salmon. 61 percent of the respondents noted that all of their salmon was harvested from on or near the Colville Reservation and another 12 percent harvested part of their salmon catch locally.

Freshwater mussels and crawfish are also harvested and consumed by Colville Reservation residents. 8 percent of the Colville Reservation residents ate mussels sometime during the previous year of the administered survey and 9 percent ate crawfish. 13 percent of the mussels were harvested all or partly locally. 81 percent of the crawfish were harvested entirely from local areas.

Many Colville Reservation respondents noted that they do not eat as much local fish as they would prefer because of concerns about smelter contaminants. Suppression of resources and reduced fish consumption remains an important concern by tribal populations. Tribal fish consumption and corresponding rates are artificially reduced due to concerns about contaminants and their associated effects.

Spokane River Surveys of Selected Ethnic Populations

Numerous and different types of surveys have been conducted for the Spokane River by the collaborative efforts of Spokane Regional Health District, Assessment/Epidemiology Center, Washington State's Department of Health, and the Lands Council – Center for Justice. From July 2003 through December 2011, The Lands Council – Center for Justice as part of the Spokane River Toxics Outreach, completed approximately 5,300 surveys, distributed about 10,000 health advisories, and participated in public education outreach of nearly 16, 000 individuals in the Spokane area.[50] Surveys have focused on ethnic populations that may be exposed to legacy contaminants from mining operations (arsenic, lead, cadmium) and PCBs by harvesting and consuming fish from the Spokane River. Two types of surveys are briefly reviewed: (1) 1998 Fish Consumption Survey, Spokane River, Washington (Spokane Regional Health District, 1998), and (2) Lands Council – Center for Justice risk communication and public outreach survey (Robinson Research, 2007), which was directed to specific ethnic communities that harvest and consume fish from the Spokane River.

1998 Fish Consumption Survey, Spokane River

A 1998 Fish Consumption Survey was conducted by the Spokane Regional Health District, Assessment/Epidemiology Center to evaluate how people access the Spokane River for harvesting fish and to assess the fish consumption habits of Russian, Hmong, and Laotian populations. The objectives of the survey were to: (1) identify different types of fish caught from the Spokane River, (2) identify locations where fish are harvested, (3) identify populations who consume fish from the Spokane River, and (4) identify amounts of fish consumed and meal preparation methods. A mail survey questionnaire sampled two fish-consuming populations based on a random sample of Spokane County fishing license holders (2000 sample population)

[50] Spokane River Toxics Outreach, web location: http://www.landscouncil.org/water/river_toxics.asp?template=false

and individuals from a particular Spokane area fishing club (180 sample population from The Walleye Club). Russian and Laotian community representatives were hired by the Spokane Regional Health District to convene a focus group, serve as interpreters, translate the written survey, and coordinate the survey distribution within Russian and Laotian communities. Key findings for each of the two ethnic communities surveyed are provided below.

Key Russian Community Findings:

- Harvest locations: Upriver Dam, the old Walk in the Wild Zoo, River Front Park, downtown Spokane area, T.J Meenach Bridge, Nine Mile Bridge, and Long Lake.
- Fish harvested: rainbow trout, German (brown) trout, suckers, catfish, crayfish, pike minnow, smallmouth bass, and perch.
- Fish consumption: about 4 pounds per month (about 65 g/day or 2.3 ounces of fish per day).

Key Laotian Community Findings:

- Harvest locations: Nine Mile Bridge where the little Spokane and Spokane River meet.
- Fish harvested: catfish, rainbow trout, perch, bass, walleye, and crawdads.
- Fish consumption: two to three meals of Spokane River fish per month (assuming a fish meal equals an 8-ounce serving, then two to three fish meals per month is about 16 to 24 g/day or less than 1 ounce of fish per day).

2007 Spokane River Toxins Survey

Lands Council – Center for Justice conducted a telephone survey for adults living in Spokane, Lincoln, and Stevens Counties who live close to the Spokane River. The purpose of the survey was to evaluate public attitudes and perceptions regarding pollution in the Spokane River. A total of 600 telephone interviews were completed from December 2006 to January 2007 with 67 percent conducted in Spokane County, 17 percent in Lincoln County, and 17 percent in Stevens County. This telephone survey is part of a broader public outreach and education effort by the Lands Council directed to low-income families, indigenous people, and recent immigrant populations (Hmong, Vietnamese, Slavic, and Hispanic populations). Selection of these populations was based on previous work conducted by the Spokane Regional Health District, and State Departments of Health and Ecology, and suggests these ethnic populations may be at potential health risks from exposure to contaminants in fish harvested from the Spokane River.

There are a significant number of people catching and/or eating fish from the Spokane River. For those eating fish, few are taking precautionary measures in preparation of the fish. Results of the Lands Council – Center for Justice provides insights into public outreach and education challenges:

- 19 percent of respondents fish in the Spokane River.
- 12 percent catch and eat fish. Over half eat two or more fish in months they are regularly fishing.
- Of those who said they eat fish from the Spokane River in a typical year, nearly two-thirds (65%) took no precautions in how they prepared the fish for cooking.
- The majority of fishing that includes eating what is caught takes place below Long Lake Dam (80%), where there are no fish advisories regarding consumption.
- Some fish consumption not in accordance with the Washington Department of Health fish advisory is occurring between Lake Spokane and the Idaho Border.

The harvest locations from the Spokane River are as follows:

- 80 percent below Long Lake Dam.
- 10 percent from Spokane Falls to Long Lake Dam.
- 4 percent from Upriver Dam to Spokane Falls.
- 3 percent from the Idaho State Line to Upriver Dam.
- 3 percent reported as Don't Know/Refused.

The Laotian anglers were not evaluated for this survey since fewer than five surveys were returned from the 17 mailed surveys to the Laotian community.

Sampling and analysis reports that evaluated for metals and PCBs in the Spokane River, combined with findings from focus groups, established the questionnaire framework for the development of questions concerning fish harvest location and types of fish harvested. A mail survey questionnaire sampled two fish-consuming populations based on a random sample of Spokane County fishing license holders (2000 sample population) and individuals from a particular Spokane are fishing club (180 sample population from The Walleye Club). The mail survey questionnaire included an introductory letter asking participants to complete the survey if they harvest and consume fish from the Spokane River. A $50 gift certificate was included as an incentive to participate when the survey was completed and returned. There was about a 31 percent response rate to this mail survey.

Swinomish Tribal Study: Bioaccumulative Toxics in Subsistence-Harvested Shellfish – Contaminant Results and Risk Assessment

The Swinomish Indian tribal community is a federally recognized Indian tribe; the Swinomish Indian reservation is located on interior Puget Sound, Skagit County, Washington. The Swinomish Tribal Indian Community is a maritime fishing community with strong cultural and dietary dependence on fish and, particularly, shellfish. Shellfish are an abundant resource

harvested by the Swinomish Tribal Indian Community throughout their usual and accustomed fishing areas.[51]

The Swinomish Tribal Community Office of Planning and Community Development conducted a study to evaluate the toxicity and assess the risks from the consumption of contaminated clams, crabs, and fish (Swinomish Tribe, 2006). Chemicals of concern evaluated in this study include polychlorinated biphenyls (PCBs), arsenic, dioxins/furans, mercury, polycyclic aromatic hydrocarbons (PAHs), and selected chlorinated pesticides and metals. Focused sampling and analysis was conducted for sediments, clams, and crabs from North and South Skagit Bay, Padilla and Fidalgo Bays, and Crescent Harbor.

An ethnographic-style survey (seafood diet interviews to evaluate current consumption pattern) was conducted for the Swinomish Tribal Community. Based on the ethnographic dietary survey, the Swinomish Tribal Indian Community documents 260 g/day (approximates an 8-ounce fish meal) for all seafood consumed harvested locally. The 260 g/day fish consumption rate was used for both adults and children to assess risks of individual clam and crab samples. Cumulative risks were based on a total of 300 g/day associated with the Swinomish Tribal Community consumption of 100 grams consumed daily each of clams, crab, and salmon. The risks from the consumption of contaminated seafood for the Swinomish Tribal Community are provided in Table B-5 below. The report notes "The ingestion rate of a total of 300 gpd [grams per day] is assumed for children as well as adults, which may overestimate intake for younger children. However, children are more sensitive to health effects, so assuming a higher per capita intake more accurately represents risks for younger children than simply scaling down the intake rate but not correcting for children's increased sensitivity." (Swinomish Tribe, 2006, p. 64)

The finfish/shellfish contaminants that contributed the most to human health risks were PCBs, arsenic, and dioxin/furans. Risks attributable from consuming 100 grams (3.5 ounces) of each species daily (total 300 g/day) are in the range of concern with non-cancer risk (HQ) for adults and children above 1 (ranging from 3 to 20), and lifetime cancer risks in the range of 1 in a 1,000.

[51] United States v. Washington, 459 F Supp. 1020, 1049 (W.D. Wash. 1979) "The usual and accustomed fish places of the Swinomish Tribal Community include the Skagit Rivers and its tributaries, the Samish River and its tributaries, and the marine areas of northern Puget Sound from the Fraser River south to and including Whidbey, Camano, Fidalgo, Guemes, Samish, Cypress, and the San Juan Islands, and including Bellingham Bay and Hale Passage adjacent to Lummi Island."

Table B-5. Cumulative Risks to Swinomish Tribal Finfish- and Shellfish-Consuming Populations

Sampling Location and Seafood Type	HQ Child (6 Years)	HQ Adult (70 Years)	Cancer Risk (70 years lifetime)
Clams (Skagit Bay)	4	1	7E-04
Clams (Fidalgo and Padilla Bays)	5	1	9E-04
Crab (Skagit Bay)	3	0.7	8E-05
Crab (Fidalgo and Padilla Bays)	3	0.8	1E-04
Puget Sound Salmon	11	2	5E-04
Total Risk Ranges	17 to 21	3-5	1E-03 to 2E-03

Source: Adapted from Swinomish Tribe, 2006, Table 29.

Lummi Nation

The Lummi Indian nation conducted a survey to estimate seafood consumption for Lummi Indians living on the Lummi Indian Reservation and in surrounding areas of northwestern Washington State (Lummi Natural Resources Department 2012). The survey instrument used in the study was developed by the Lummi Natural Resources Department. The survey instrument used 54 species of seafood with questions on amount, seasonality, and frequency of consumption for each species. Separate information was obtained regarding seafood consumption at home and at tribal gatherings, demographic information, and information about fishing activity and patterns of consumption. The study evaluated historical fish dietary practices and rates in 1985 because current rates for the tribe are suppressed (Lummi Natural Resources Department 2012):

> *The environmental baseline chosen for the Lummi Seafood Consumption Study was 1985, as this was the peak fish harvest year for the Lummi Nation in recent history and a goal of the Lummi Natural Resources Department is to restore fish habitat so that at least the 1985 harvest levels can be sustained. As a result, the Tribal Advisory Committee determined that fish consumption rates from 1985 should be used to develop water quality standards and to support risk assessments of clean-up options for contaminated sites along Bellingham Bay. While not at Treaty-time levels, seafood abundance and availability was less of a limiting factor for seafood consumption during 1985 than in 2012. Consequently, the seafood consumption rate would be less suppressed due to environmental degradation or the lack of available fish. A literature review showed that appropriate data could be elicited in recall studies that reach back 25 years.*

The survey results are summarized below:

- Eighty-two (82) participants were interviewed over the May 2011 through March 2012 survey period.

- Outliers were removed before the final calculation, which reduced the overall sample size used to compute the daily seafood consumption rate to 73 respondents. Outliers were defined by the Tribal Advisory Committee as respondents who reported consumption rates above the 90th percentile of the daily seafood consumption rate of all respondents.
- The resultant average Lummi seafood consumption rate was calculated to be 4.73 grams per kilogram per day (g/kg/day) or approximately 383 grams per day (g/day) (0.84 pounds per day [lb/day] or 13.5 ounces per day [oz/day]) for all seafood consumed.
- The median seafood consumption rate was calculated to be 3.82 g/kg/day or approximately 314 g/day (069 lb/day or 11 oz/day).
- The 90th percentile seafood consumption rate was calculated to be 10.03 g/kg/day or approximately 800 g/day (1.76 lb/day or 28.2 oz/day).
- The 95th percentile seafood consumption rate was calculated to be 11.28 g/kg/day or approximately 918 g/day (2.02 lb/day or 32.4 oz/day).
- The final precision of the survey was ± 16.5%.

B.4 Additional technical publications by Pacific Northwest tribal staff

A Native American exposure scenario

This paper (Harris and Harper, 1997) documents a tribal-based subsistence exposure scenario for a variety of different foods and exposure parameters for use at the Hanford nuclear reservation cleanup. A subsistence fish consumption of 540 g/day is based on selected tribal interview from members of the Confederated Tribes of the Umatilla Indian Reservation and other published studies.

Lifestyles, diets, and Native American exposure factors related to possible lead exposures and toxicity

This article (Harris and Harper, 2001) documents that any assessment of the risk from lead exposure to tribal communities requires an understanding of the tribal community, resource base, and culture. Differences in patterns of exposure between different communities or groups of people are noted with documented additional sources of lead exposure for Native Americans.

A possible approach for setting a mercury risk-based action level based on tribal fish ingestion rates

Risks from the consumption of mercury-contaminated fish were evaluated with a recommended action level for mercury protective of Native American tribes in the Columbia River Basin at 0.1 ppm or less (Harper and Harris, 2008). The recommendation is based on the combined risks from

mercury exposure plus other fish contaminants and exposures, the higher fish consumption rates associated with tribal populations, the existing cultural deficit due to loss of salmon, the health benefits from fish, and the cultural and economic importance of fish to tribal populations. To assess the risks from the consumption of mercury-contaminated fish, Harper and Harris (2008) defined the following fish consumption rates:

- Less than 100 g/day is the low tribal fish ingestion rate.
- 100 to 454 (1 pound per day) g/day is the moderate tribal fish ingestion rate.
- Above 454 g/day is the true tribal subsistence rate.

Non-cancer and cancer risk to tribal populations from the consumption of mercury-contaminated fish was documented and within a risk range of concern.

Issues in evaluating fish consumption rates for Native American tribes

As a continuation and further refinement of the ethnographic survey conducted for the Swinomish Indian tribal community study, *Bioaccumulative Toxics in Subsistence-Harvested Shellfish – Contaminant Results and Risk Assessment*, Donatuto and Harper (2008) provide a Swinomish seafood dietary interview template as an alternative to conventional fish dietary surveys to estimate contemporary consumption. For traditional subsistence tribal fishers, a multidisciplinary method to reconstruct tribal heritage dietary practices and patterns is recommended. Donatuto and Harper identified several problems associated with conventional fish dietary surveys that are insensitive to cultural tribal practices and may lead to tribal misunderstanding about current fish dietary level and underestimate tribal consumption.

Appendix C
The Question of Salmon

Salmon—showcase of the policy dilemma

The question of whether or how to include salmon in a fish consumption rate highlights the policy choices facing a regulatory agency. Multiple regulations—in this case MTCA and CWA—provide differing approaches to account for anadromous fish, with MTCA providing greater flexibility for site-specific modifications to regulatory standards.

Salmonids employ a complex life strategy. Most – but not all – adult salmon spend a portion of their lives outside of Washington waters. The inclusion of Pacific salmon in fish consumption rates is complicated by the question of where and to what extent salmon assume site-specific contaminants that contribute to their body burdens.

Scientific knowledge related to the biology of the life history for the multiple salmon species has increased considerably with efforts to restore salmon in Puget Sound and throughout Washington. This once abundant resource has been reduced, and wild stocks of some species are endangered. Dams are being removed to restore once great salmon runs, and culvert work by necessity now involves salmon friendly design considerations. Effects of riparian zones, temperature, even predators like seals are studied. Understanding has increased of the differing strategies of fall and spring runs from Chinook, chum, coho, sockeye, and pink salmon, and whether they migrate through estuaries or directly from streams to the ocean. The recycling of contaminants means that when uptake occurs in the open ocean those chemicals are deposited by the dying salmon in their natal streams. In the face of this growing and sophisticated body of knowledge the classification of salmon as a *marine species* lacks subtlety and leads to regulatory dilemma.

For example, Ecology's Toxics Cleanup Program will consider several factors related to risk management when deciding how to address the question of salmon. Some of these factors are discussed in this appendix:

- The abundance of salmon.
- Salmon life cycles.
- Chemical contaminants in ambient waters and sediments.
- The unique quality of Puget Sound and other Washington waters.

Considerations of the complex life cycle and survival strategies of anadromous fish species like salmonids complicate and influence many risk management decisions. For example, risk

management cleanup decisions in Port Angeles Harbor and the Lower Duwamish Waterway are influenced by the presence/absences of salmonids in the harbor or waterway, migratory patterns, and contaminant body burdens attributable to site contaminants (Ecology, 2011b; Windward Environmental, 2007). The complication arises because it is difficult to attribute salmon contaminant body burdens to site-specific contaminants.

This appendix describes the life cycle and survival strategies of salmonids. This information is related to policy and technical considerations regarding how to appropriately address the question of salmon when developing fish consumption rates for regulatory purposes.

C.1 Background

Salmon is consumed in abundance. On a global scale, over the last two decades, advances in farmed-salmon production have tripled the world's supply of salmon. In 1985, 6 percent of all salmon consumed around the world was farmed. In 1988, farmed salmon production surpassed wild fisheries. In 2000, 58 percent of all salmon consumed around the world was farmed, almost a tenfold increase from 1985 levels. In the United States, between 1987 and 1999, salmon consumption increased nine times (Institute for Health and the Environment). During that time period, salmon consumption increased annually at a rate of 14 percent in the European Union and 23 percent in the United States (Hites et al., 2004).

Over half the salmon sold globally is farm-raised in Northern Europe, Chile, Canada, and the United States. The annual global production of farmed salmon (Atlantic salmon, *Salmo salar*) has increased from approximately 24,000 to over 1 million metric tons during the past two decades (Institute for Health and the Environment; Charron, 2004, as cited in Hites et al., 2004). Contaminant body burdens in farm-raised salmon have been well documented and compared to wild salmon. European farm-raised salmon have significantly greater organochlorine (dioxin, dioxin-like PCBs, and selected pesticides) contaminant body burdens than those salmon raised in North and South America (Hites et al., 2004).

C.2 Factors influencing the health risk from consuming salmon

There are multiple factors to consider when assessing the risk from consuming salmon. Most Washington salmon spend the largest part of their lives in the open ocean, where exposure to contaminants originating from Washington sources is minimal. Salmon life cycles are complex, and the many species have different survival strategies.

Ecology recognizes that salmon are an available Washington State resource for harvest and consumption. It is appropriate to consider:

- Washington State estimates of recreational and commercial salmon harvests.
- Estimates of Washington State fish-consuming populations.
- Cultural and religious significance of salmon to different Native American fish-consuming populations in Washington State.
- The complexity of the salmon life cycle and survival strategies, local and global salmon contaminant body burdens, and Puget Sound resident and nonresident salmon populations.
- Federal and state regulatory policies and procedures.

Ecology notes that similarities between bioaccumulative and persistent contaminant (organochlorines) salmon body burdens from local and global distributions would preclude the ability to define a chemical fingerprint to attribute salmon body burdens to site-specific bioaccumulative and persistent contaminants

C.3 Information about salmon consumption in Washington

To determine how to appropriately address salmon when developing one or more default fish consumption rates, Ecology examined the regional fish dietary survey information regarding salmon-related consumption. These surveys show that salmon is consumed frequently and in large amounts.

Based on Pacific Northwest regional-specific fish dietary surveys, salmon and selected types of shellfish are the most frequently consumed and consumed in the largest amounts of all seafood. Salmon is the most frequently consumed finfish (more than 90 percent) for all adult respondents from all of the regional-specific fish dietary surveys. (This observation follows the national trend where U.S. salmon consumption grew from 9.5 percent to 15 percent from 1996 to 2005 as a share [percentage] of finfish and shellfish consumption.[52])

For the API populations surveyed, 96 percent of the survey respondents consume anadromous fish comprising greater than 10 percent of all seafood consumed (Sechena et al., 2003, Tables 2 and 5). Also, 99 percent of the survey participants consume shellfish comprising more than 45 percent of all seafood consumed. The API survey participants consume a large variety of finfish and shellfish.

[52] Fish and Shellfish Consumption data from National Marine Fisheries Service, Salmon Consumption data from National Fisheries Institute. Web location: http://www.fas.usda.gov/ffpd/Newsroom/Salmon.pdf, as cited in USDA, 2006.

For the Tulalip Tribes and the Squaxin Island Tribe, 72 to 80 percent of anadromous fish consumed and 62 to 72 percent of shellfish consumed were harvested in the Puget Sound area (Toy et al., 1996). When fish harvests are accounted for outside of the Puget Sound area, greater than 90 percent of the seafood harvested was anadromous. Of both the Tulalip Tribes and the Squaxin Island Tribe surveyed, greater than 90 percent of the survey respondents consume anadromous fish, which comprises almost 50 percent of all seafood consumed. The Tulalip dataset was adjusted for the harvest and consumption of finfish and shellfish from Puget Sound in the EPA Region 10 framework. With the adjusted rates used in the EPA Region 10 framework, salmon and shellfish comprise about 50 percent each of the Tulalip tribal seafood diet, with salmon consumed in slightly greater amounts than shellfish. Hence, if the total fish ingestion rate did not account for salmon consumption, then the fish consumption rate would be reduced by about 50 percent, from 194 g/day to 97.6 g/day (U.S. EPA, 2007b, Appendix B-1, Table B-1).

The Suquamish fish dietary survey identified the largest variety, most frequently consumed, and consumed in the largest amounts of finfish and shellfish for all of the Pacific Northwest tribal fish-consuming populations surveyed (The Suquamish Tribe, 2000). Fifty percent or more of the respondents consumed various types of anadromous fish and about 10 different types of shellfish. The Suquamish dataset was adjusted for the harvest and consumption of finfish and shellfish from Puget Sound in the EPA Region 10 framework. With the adjusted rates used in the EPA Region 10 framework, salmon and shellfish comprise about 25 percent and 65 percent, respectively, of the Suquamish tribal seafood diet. Hence, if the total fish ingestion rate did not account for salmon consumption, then the fish consumption rate would be reduced by about 25 percent, from 766.8 g/day to about 583 g/day (U.S. EPA, 2007b, Appendix B-2, Table B-2).

The fish dietary survey for the Columbia River tribal populations identified a variety of fish harvested and consumed in large amounts (CRITFC, 1994). However, this survey did not include any questions regarding shellfish consumption. Salmon is consumed by the largest number of adult respondents (92 percent), followed by trout (70 percent), lamprey (54 percent), and smelt (52 percent). Using the weighted mean fish consumption rate for adult fish consuming CRITFC tribal populations, salmon would contribute about 50 percent of the tribal seafood diet (≈25/63 g/day). Hence, if the total fish ingestion rate did not account for salmon consumption, then the fish consumption rate would be reduced by more than about 50 percent, from a weighted mean of 63 to about 40 g/day.

C.4 Pacific salmon life cycle and survival strategies

Salmonids have complex life cycles and survival strategies, with large variations across and among different species (Quinn, 2005). The geographic distribution of Pacific salmonids extends

from San Francisco Bay northward along the Canadian and Alaskan coasts to rivers draining into the Arctic Ocean, and southward down the Asian coastal areas of Russia, Japan, and Korea.[53]

Although variation exists, generally, Chinook, coho, and steelhead have migratory patterns along the Pacific continental shelf and remain in freshwater and estuarine environments for longer periods of time than other Pacific salmonid species.

After pink, chum, and sockeye salmon enter the ocean environment, they rapidly migrate northward and westward through coastal waters of North America and are found in the open waters of the North Pacific, Gulf of Alaska, and the Bering Sea by the end of their first year at sea.

Table C-1. Pacific Salmon Life Cycle

Salmonid Life Cycle Environment	← Salmon Species →						
	Chinook	Coho	Sockeye	Chum	Pink	Steelhead	Cutthroat
Riverine rearing	X	X	X			X	X
Estuarine rearing	X	X	X			X	X
Lacustrine rearing			X				X
Nearshore migration	X	X	X	X	X	X	X
Continental shelf migration	X	X				X	
Mid-oceanic migration			X	X	X		

Salmonid contaminant body burden

All seven Pacific salmon species are biotranporters of pollutants to and from the Pacific Ocean and their spawning sites in freshwater (Ewald et al., 1998). During river ascent, salmonids use their muscle lipid and triacyglycerol deposits for energy and gonadal development. Particularly in female salmonids, the organic pollutant body burden redistributes and accumulates in the lipid-rich gonads and salmon roe. Furthermore, the lipid depletions and redistribution during the river ascent are not coupled with a simultaneous elimination of the organic pollutant body burden in the salmonids.

The pollutants in the salmonids are readily available for bioaccumulation, because the migrating salmonids, salmon roe, and salmon carcasses are a direct food source for predators (birds, mammals, and other fish). Hence, salmonids redistribute their pollutant body burdens back to their spawning grounds, to the open-ocean predators, or to the food web as bioaccumulation.

The redistribution, biotransportation, and bioaccumulation of the salmonid pollutant body burden helps contribute to food web contamination.

[53] The definition and usage of terms *freshwater*, *estuarine*, and *marine* may vary according to context, with different writers using the terms differently. Readers should always verify how any terms are being defined.

Persistent bioaccumulative toxics

Persistent bioaccumulative toxics (PBTs) are a group of chemicals that, because of their chemical and physical properties, exist within the environment for long periods of time, are lipophilic and bioaccumulate in fish tissue and animal fat, and are highly toxic to animals and humans (Puget Sound Action Team, 2007). The unique geologic and hydrogeologic nature of Puget Sound, in combination with the bioaccumulative, persistent, and toxic nature of the PBT-type contaminants, creates additional risks to the Puget Sound ecosystem. Some of the PBTs that continue to contaminate, threaten, or harm the Puget Sound ecosystem include PCBs, PAHs, dioxins and furans; polybrominated diphenyl ethers (PBDEs), and hormone-disrupting chemicals (e.g., bisphenol A). PBTs are contaminants throughout the entire pelagic food web in Puget Sound (Puget Sound Action Team, 2007).

Of the different PBTs that permeate the Puget Sound food web, PCBs are well-documented contaminants in coho and Chinook Pacific salmon (O'Neill et al., 1998). Pacific salmon exposure to PBTs, and PCBs in particular, is in part contingent on migratory patterns, residency time in Puget Sound, proximity of the salmon to contaminated sediments and waste sites, and different behavior and dietary patterns as the fish mature (Puget Sound Action Team, 2007; O'Neill et al., 1998). PCBs were detected in composite samples of adult Chinook and coho salmon collected from various in-river and marine locations in Puget Sound. Chinook salmon PCB tissue concentrations were greater than coho salmon PCB concentrations collected from in-river and marine locations.

Table C-2. Average PCB Concentrations for Coho and Chinook Salmon from In-River and Marine Locations, Puget Sound (µg/kg)

Salmon Species	Location		Mean Concentration
	Marine	In-River	
Chinook	74.2	49.1	53.9
Coho	35.1	26.5	28.3
Mean	55.3	38.6	41.85

Source: Adapted from O'Neill et al., 1998. p. 316, Table 1.

The authors of a 1998 study investigating different factors and correlates associated with PCBs in muscle tissue of Chinook and coho salmon from marine and in-river locations in Puget Sound observed "…that Chinook salmon had significantly higher PCB concentrations than coho salmon and within each species, PCB concentrations were higher in fish caught in marine areas than in-river areas" (O'Neill et al., 1998, p. 323). Taking into account differences in their anadromous life cycles, age, and information from other studies evaluating contaminant exposures of salmon in the Puget Sound estuaries, this study suggested "…that Chinook and coho salmon accumulate most of their PCB body-burden in the marine waters of Puget Sound and the ocean, and because

Chinook salmon live longer and stay at sea longer than coho salmon they accumulate higher PCB concentrations in their muscle tissues" (O'Neill et al., 1998).[54] The authors further noted that the salmon contaminant body burden attributable to freshwater and estuarine environments was negligible compared with residency time, growth patterns, and feeding habits of the salmon at sea. A 2005 study on the behavior and ecology of Pacific salmon and trout noted that salmon have high metabolic rates, feed heavily, and grow fast in the ocean (Quinn, 2005).

Salmon can double their body length and increase their body weight tenfold during their first summer at sea. More than 98 percent of the final body weight of most salmon is attained at sea. For example, pink salmon entering the ocean may have a body weight of 0.2 gram but return from the sea weighing 2 kilograms, a ten thousand-fold increase. Further study also associates the percent contaminant body burden with fish biology (O'Neill et al., 2006). Coho and Chinook salmon populations that have more coastal migratory distributions have higher tissue concentrations of PCBs compared with those salmonids with more oceanic migratory distributions (chum, pink, and sockeye). Variations in the contaminant body burdens were noted and attributed to the marine distribution of the species (O'Neill et al., 2006, pp. 3–4):

> *…Chinook salmon returning to Puget Sound had significantly higher concentrations of PCBs and PBDEs compared to other Pacific coast salmon populations we sampled. Furthermore, Chinook salmon that resided in Puget Sound in the winter rather than migrate to the Pacific Ocean ("residents") had the highest concentrations of POPs [persistent organic pollutants], followed by Puget Sound fish populations believed to be more ocean-reared. Fall Chinook from Puget Sound have a more localized marine distribution in Puget Sound and the Georgia Basin than other populations of Chinook from the west coast of North American and are more contaminated with PCBs (2 to 6 times) and PBDEs (5 to 17 times).*

Residence time in Puget Sound

Ecology evaluated a variety of information related to the residence time of salmon in Puget Sound and different river systems of Puget Sound. Several factors have a bearing on the salmon residence time:

- Biological variability exists across and within salmon species regarding migratory habits and behavior patterns.
- The location of rivers or streams within Puget Sound. Locations deep within the sound lengthen the time the salmon reside in the sound.

[54] Chinook and coho salmon occupy three distinct habitat types during their life cycle: (a) Freshwater habitats (eggs hatch and fry develop); (b) Puget Sound (smolts enter marine waters to feed and reside during migration); and (c) Ocean habitat.

- Selected salmonid species do not die after spawning, and may spawn more than once, migrating to and from the same river/stream in Puget Sound.
- With considerable species variability, selected salmonid populations do not migrate to the open ocean and, instead, remain in Puget Sound.

Different residency times of salmon within Puget Sound will result in more or less exposure to chemicals that contaminate the sound and, therefore, contribute to the contaminant body burden of salmon. Some salmon (resident "blackmouth" or Chinook salmon populations) may spend significant portions of their lives in Puget Sound.

Salmon abundance

Interpreting salmon abundance records and historical records on salmon counts is complicated. Salmon are difficult to count because salmon populations are variable due to continual changes in freshwater and marine environments or to the cyclic nature of salmonid behaviors. Very long time-series records (a decade or longer) of catch or escapement are required for detecting large changes (50 percent or greater) in population abundance. Also, long-term changes in abundance may not occur as a continuous linear series of events and, therefore, are not accounted for with standard statistical evaluations. Therefore, records of abundance for short periods of time may suggest an increase or decrease in salmonid populations when, in fact, long-term trends are the reverse. The inherent biological variability of salmonids confers a level of uncertainty about the abundance counts and records associated with the different salmonid species (National Research Council, 1996, pp. 77–79).

Puget Sound salmon

The Puget Sound Basin includes the river systems in Puget Sound, Hood Canal, and the Strait of Juan de Fuca. As shown in the tables below (which provide the status of Washington and Puget Sound Salmon Stocks), there is a wide range of salmon population conditions in Puget Sound ranging from critical to healthy.[55] Generally, for Puget Sound, the Washington Department of Fisheries (now referred to as the Washington Department of Fish and Wildlife) in 1993 classified about 44 percent of the salmon stocks as healthy, about 21 percent as depressed, about 5 percent as critical, and about 30 percent unknown. Puget Sound is considered to have more depressed salmon stocks compared to the Washington coastal regions but fewer depressed stocks than the Columbia River Basin (National Research Council, 1996, pp. 86–90). Many wild salmon, steelhead, and bull trout stocks have been listed under the Endangered Species Act by the National Marine Fisheries Services or the U.S. Fish and Wildlife Service. As of 1998, less than 50 percent of Washington's salmon stocks were considered to be healthy (Governor's Salmon

[55] Stock is defined by Governor's Salmon Recovery Office (http://www.governor.wa.gov/gsr0/glossary/default.asp) as "fish spawning in a particular lake or stream(s) at a particular season which to a substantial degree do not interbreed with any group spawning in a different place at the same time, or in the same place at a different time." The National Research Council (1996, pp. 12–13) notes that salmon stocks refers to a geographic aggregate of salmon populations that includes many local breeding populations of varied size and productivity.

Recovery Office, 1999, pp. II.9 – II.10). The tables below summarize the status of salmon stocks for Puget Sound and Pacific Coastal areas and percentages associated with the different regional salmon stocks.

Table C-3. Status of Washington Salmon Stocks as of 1992

Status	Puget Sound		Washington Coasts		Columbia River		All Of Washington	
	Number of Stocks	%	Number of Stocks	%	Number of Stocks	%	Number of Stocks	%
Healthy	93	44.7	65	56.5	29	26.1	187	43.1
Depressed	44	21.2	8	7.0	70	63.1	122	28.1
Critical	11	5.3	0	0	1	0.9	12	2.8
Unknown	60	28.8	42	36.5	11	9.9	113	26.0
Total	**208**	**100**	**115**	**100**	**111**	**100**	**434**	**100**

Source: Adapted from National Research Council, 1996, Table 4-4. Original data source is WDF et al., 1993.

Note: Status descriptors defined by the Washington Department of Fisheries (status criteria descriptors may change depending on regulatory agency or publication); as used by National Research Council, 1996:

Healthy: Stock of fish experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock.

Depressed: Stock of fish whose production is below expected levels based on available habitat and natural variations in survival rates but above the level where permanent damage to the stock is likely.

Critical: A stock of fish experiencing production levels that are so low that permanent damage to the stock is likely or has already occurred.

Unknown: There is insufficient information to rate stock status.

Table C-4. Status of Puget Sound Salmon Stock as of 1992

Status	Chinook	Chum	Coho	Pink	Sockeye	Steelhead	Total
Healthy	10	38	20	9	0	16	93
Depressed	8	1	16	2	3	14	44
Critical	4	2	1	2	1	1	11
Unknown	7	13	9	2	0	29	60

Source: Adapted from National Research Council, 1996, Table 4-3. Original data source is WDF et al., 1993.

The 1992 Salmonid Stock Inventory (SaSI) recognized 435 stocks of salmon and steelhead, one of which was extinct (WDF et al., 1993). When the 2002 data were published, WDFW made this information available online. Queries were available by Water Resource Inventory Area (WRIA), species, and stock. The 2002 update recognized an additional 54 stocks for a revised total of 489 salmon and steelhead stocks. However, the summary table for these stocks provided by WDFW on the SaSI 2002 update website only included 486 stocks. The 2002 status of these 486 Washington State stocks is provided in Table C-5.

Table C-5. 2002 By-Species Summary Update of WDFW's Salmonid Stock Inventory (SaSI) Status for Washington State Salmon and Steelhead Stock Classifications.

Status	Chinook (2002)	Chum (2002)	Coho (2002)	Pink (2002)	Sockeye (2002)	Steelhead (2002)	Total
Healthy	35	41	47	6	4	33	166
Depressed	39	9	9	4	4	58	123
Critical	14	2	2	2	0	2	22
Extinct	1	8	0	0	0	0	9
Unknown	10	23	34	1	1	97	166
Total	99	83	92	13	9	190	486

Source: http://wdfw.wa.gov/conservation/fisheries/sasi/sasi_2002_introduction.html

When the geographic scale changes from Puget Sound to broader geographic areas of Pacific salmon habitat for the Northwest, the picture of abundance changes but still reflects declining populations. There is a drop in Pacific adult salmon returning to rivers to spawn. Historically, 56 to 65 percent of the Pacific salmon returned to Alaska's streams, 19 to 26 percent returned to streams in British Columbia, and 15 to 16 percent returned to streams in Oregon, Washington, Idaho, and California. Currently in the Pacific Northwest only 1 percent of Pacific salmon are returning (Lichatowich, 1999, pp. 206–207).

WDFW hatchery release estimates to Puget Sound:

WDFW provided Ecology with hatchery releases of yearling Chinook salmon into Puget Sound from 1993 to 2005. Chinook salmon released as yearlings tend to remain in the Sound for their entire life cycle. Although the Chinook salmon release estimates may be subject to revision, the queried data by WDFW provide the most current estimates for Chinook salmon releases in the Puget Sound area and from the Dungeness and Elwha River hatcheries. Total hatchery releases of yearling Chinook salmon into Puget Sound (the Straits and North and South Puget Sound) ranged from a low of 1,835,320 in 2005 to a high of 3,367,106 in 1994 (WDFW, 2008b).

C.5 Chemical contaminants in Puget Sound

Chemical contamination of Puget Sound has occurred over a long period of time (150 years by some estimates) with various chemicals posing risks to the environment, aquatic life, and humans.

Ecology noted at the March 2008 Science Advisory Board meeting, that PBTs pose a significant threat to the Puget Sound ecosystem. This section provides information about the presence, transport, and fate of chemical contaminants in and throughout Puget Sound. These chemicals

may be factors to consider when evaluating the chemical contaminant body burdens of salmon acquired on a site-specific basis.

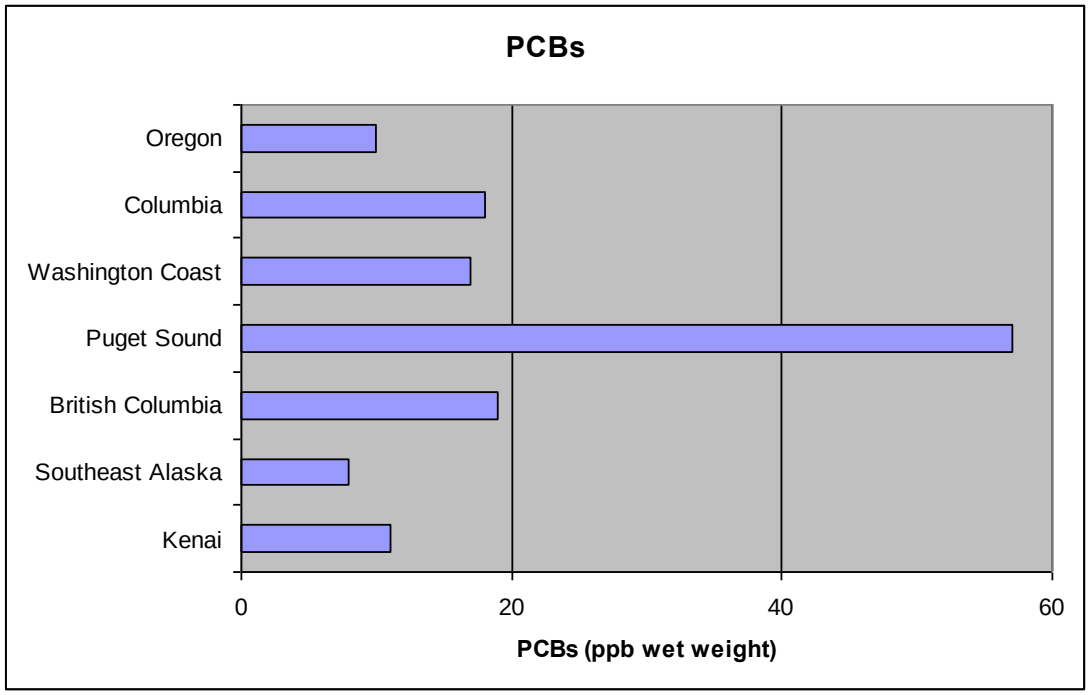
Some of the chemical contaminants of concern for Puget Sound are:

Metals (Inorganic Contaminants)	Organic Contaminants
* Lead	* Polychlorinated biphenyls (PCBs)
* Cadmium	* Polycyclic aromatic hydrocarbons (PAHs)
* Tributyl tins	* Dioxins and furans
* Copper	* Selected pesticides
* Mercury	* Phthalate esters
* Arsenic	* Polybrominated diphenyl ethers (PBDEs)
* Others	* Hormone disrupting chemicals (Bisphenol A)
	* Petroleum and petroleum by-products
	* Pharmaceuticals

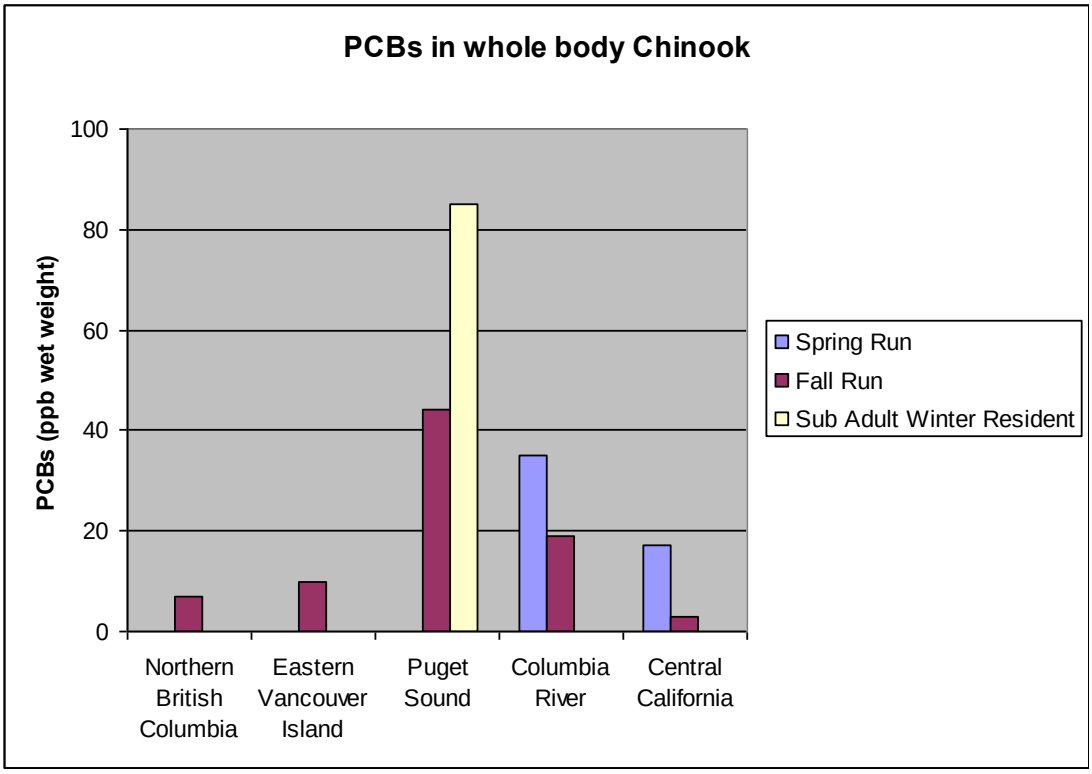
Sources: Puget Sound Action Team, 2007, Table 4-1; West et al., 2011a, 2011b.

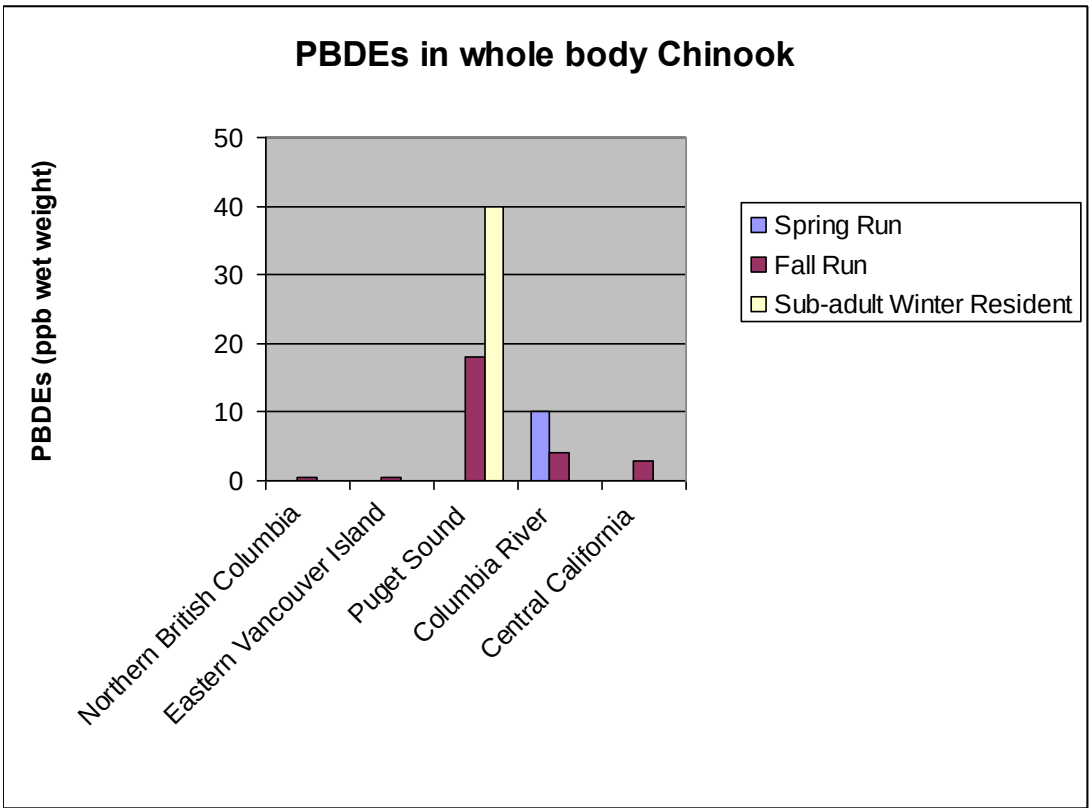
Polychlorinated biphenyls

PCBs are persistent, bioaccumulative, and toxic chemicals found throughout Puget Sound. The bar chart below compares PCBs sampled in Chinook salmon fillets from Puget Sound and Chinook salmon fillets sampled for PCBs from other Pacific west coast areas. Puget Sound Chinook salmon fillets are almost three times more contaminated than fillets of Chinook salmon from other Pacific west coast areas (Puget Sound Action Team, 2007, adapted from Figure 4-18, p. 156).



The bar charts below illustrate differences in contaminant body burdens for salmon from Pacific West Coastal areas. The bar charts illustrate that Puget Sound resident Chinook salmon had the highest contaminant body burden of PCBs and PBDEs compared to other Pacific west coast areas. PCBs and PBDEs in whole body samples of individual summer/fall Chinook salmon from Puget Sound were 2 to 6 times more contaminated with PCBs and 5 to 17 times more contaminated with PBDEs than other populations of Chinook salmon from the Pacific west coast areas (Puget Sound Action Team, 2007, p. 157, Figure 4-19; O'Neill et al., 2006).





C.6 Chemical contaminant transport in and around Puget Sound

Puget Sound has unique geologic qualities among North American estuaries. These unique features confer a greater residence time for contaminants and trap them within the Sound, thereby increasing the potential for exposure.

The transport and fate of site-specific contaminants

Site-specific chemical contaminants in sediments may be relocated throughout Puget Sound by mechanical or biological transport mechanisms. Based on their life cycle, salmon play a unique role in the biological transport of contaminants in and through Puget Sound and contribute to the chemical contamination of the food web.

Hydrodynamic conditions of Puget Sound

Puget Sound is unique among North American estuaries. Shallow sills at the northern and southern ends of central Puget Sound, where water is rapidly transported across the sills by tidal currents, influence circulation patterns. “The sills alter the normal pattern of estuarine circulation by causing mixing and by restricting the exchange of water with adjacent basins” (Ecology, 2007b).

Contaminant residence times

The residence times for contaminants in Puget Sound are extended because the circulation conditions of the Sound, including the shallow sills associated with different inlets, freshwater/marine water gradients, and highly variable flow velocities in different areas of the Sound, all facilitate the trapping and mixing of toxic chemical contaminants. Chemical contaminants spend longer in the Sound increasing exposures to aquatic organisms, humans, and the environment.

Mechanical transport

Plastic debris may be transporting hydrophobic contaminants to sediments and sediment-dwelling (benthic infaunal communities) organisms (Teuten et al., 2007). Representative plastics (polyethylene, polypropylene, and polyvinyl chloride) were used to evaluate the preferential sorption of PAHs in plastics compared to sediments in marine environments. The addition of small amounts of PAH-contaminated plastics to sediments significantly increased the bioaccumulation of PAHs (phenanthrene) in sediment dwelling organisms. In addition, sorption of hydrophobic chemicals to plastics facilitates the transport of the contaminants to other areas in marine environments and to marine aquatic life.

Contaminant dispersal, re-suspension, and transport

Chemical contaminants can be transported and dispersed throughout Puget Sound by a variety of processes. Chemical contaminants within different estuaries and marine water bodies can be transported and dispersed through different watersheds, bay and harbor areas, and inlets. The implications for the transport and dispersion of chemical contaminants throughout these water bodies is an increased potential for exposure to these contaminants by aquatic life and humans, regardless of where the contaminants originated from.

Dispersal

Sediment reservoirs of historically discharged contaminants (metals, PAHs, PCBs, selected pesticides) may be disturbed and distributed by bioadvection, biodiffusion, and physical processes. The sediment-bound contaminants may be moved from the subsurface to upper sediments where the contaminants may undergo further resuspension and redistribution. Benthic infaunal communities (annelids, mollusks, crustaceans), storm events, and tidal influences contribute to the redistribution and dispersion of contaminated sediments (Niedoroda et al., 1996; Stull et al., 1996; Swift et al., 1996).

Resuspension and transport

Historically deposited chemical contaminants buried in sediments may be resuspended in the water column and then transported and redeposited into coastal areas distant from the bay areas where the contaminants originated. Hydrodynamic processes include diffusion, tidal dispersion and transport of chemicals, sediment-water interactions, and adsorption-desorption of chemicals

to and from suspended particulate matter. Models evaluate the transport and fate of chemical contaminants from tidal estuaries and bay areas to other proximate marine environments. Empirical data support modeled outputs related to the remobilization of sediment contaminants, resuspension of the contaminants into the water column, and the subsequent redeposition of the contaminants to distant areas (Zeng and Venkatesan, 1999; Zeng et al., 2005).

Biological transport

All seven Pacific salmon species are biotranporters of pollutants to and from the Pacific Ocean and their spawning sites in freshwater (Ewald, 1998). During river ascent, salmonids use their muscle lipid and triacyglycerol deposits for energy and gonadal development. Particularly in female salmonids, the organic pollutant body burden redistributes and accumulates in the lipid rich gonads and salmon roe. Furthermore, the lipid depletions and redistribution during the river ascent are not coupled with a simultaneous elimination of the organic pollutant body burden in the salmonids. The pollutants in the salmonids are readily available for bioaccumulation because the migrating salmonids, the salmon roe, and salmon carcasses are a direct food source for predators (birds, mammals, and other fish). Hence, salmonids redistribute their pollutant body burdens back to their spawning grounds, to the open-ocean predators, or bioaccumulate in the food web. The redistribution, biotransportation, and bioaccumulation of the salmonid pollutant body burden contribute to food web contamination.

Chemical contaminants are exhibited through the salmon life cycle, which contributes to the transport and distribution of contaminants in Puget Sound:

- Depletion of lipid reserves during upstream migration can cause significant biomagnifications of contaminant body burdens in eggs and gonadal tissues (Kelly et al., 2007).
- Post spawning decay of Chinook salmon carcasses are sources of persistent organic pollutants (POPs), such as PCBs, and dichlorodiphenyltrichloroethanes (DDTs), where body burden contaminants are released into river sediments and, furthermore, are released into the water column of tributary streams (O'Toole et al., 2006).
- Areas in the Pacific Northwest where Chinook salmon are harvested may account for the variations in their PCB body burden concentrations. Although some contamination of the Chinook salmon occurs in the Pacific Ocean, a larger source of the salmon body burden occurs within Puget Sound or along the migratory route within Puget Sound for Chinook salmon (Missildine et al., 2005).
- Chemical contaminants (selected pesticides and POPs) have been documented in outmigrant juvenile Chinook salmon (Johnson et al., 2007).

Life histories and biological variability in life histories of Pacific coast salmonids

The following tables present detailed information on the life histories and biological variability of Pacific coast salmonids.

Additional information on biological transport of contaminants is provided in the following publications:

- Data Report for Lower Columbia Juvenile Salmon Persistent Organic Pollutant Exposure Assessment. NOAA Damage Assessment Center, Portland Harbor Natural Resource Trustees,
- O'Toole, Shaun, Chris Metcalfe, Ian Craine, and Mart Gross. Release of persistent organic contaminants from carcasses of Lake Ontario Chinook salmon (*Oncorhynchus tshawytscha*). *Environmental Pollution* 140 (2006), 102-113.
- Missildine, Brian. Polychlorinated Biphenyl Concentrations in Adult Chinook Salmon (*Oncorhynchus tshawytscha*) Returning to Coastal and Puget Sound Hatcheries. Master of Environmental Studies Thesis. The Evergreen State College. February 2005.
- Missildine, Brian, R., Roger J. Peters, Gerardo Chin-Leo, and Douglas Houck. Polychlorinated Biphenyl Concentrations in Adult Chinook Salmon (*Oncorhynchus tshawytscha*) Returning to Coastal and Puget Sound Hatcheries of Washington State. *Environmental Science & Technology*. 2005, 39, 6944-6951.
- Merna, James W., Contamination of Stream Fishes with Chlorinated Hydrocarbons from Eggs of Great Lakes Salmon. *Transactions of the American Fisheries Society* 115:60-74, 1986.
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Table C-6. Life Histories of Pacific Coast Salmonids

Species	Spawning Migration	Spawning Period	Spawning Area	Life History	Most Common Age at Maturity (Years)
Anadromous Salmon					
Chum salmon	Summer to Winter	Summer to Winter	Usually near tidewater	Fry go directly to sea; 2–5 years ocean	4
Pink salmon	Late summer to early Fall	Late summer to early Fall	Usually near tidewater	Fry go directly to sea; 2 years ocean	2
Sockeye salmon	Spring to fall	Late summer to fall	Tributaries of lakes	1–3 years lake 2–3 years ocean	4–5
Coho salmon	Summer to fall	Fall to early winter	Small headwater streams	1–3 years freshwater 6 months Jack ocean 18 month adult ocean	3
Chinook salmon	Spring to fall	Summer to early winter	Large rivers	3 months to 2 years freshwater 2–5 years ocean	4–5
Anadromous Trout and Char					
Steelhead trout	Summer to winter	Late winter to spring	Small headwater streams	2–3 years freshwater 1–3 years ocean *Repeat spawners*	4–5
Searun cutthroat trout	Fall to winter	Late winter to early spring	Small headwater streams	2–4 years freshwater 2–5 months ocean *Repeat spawners*	3–4
Dolly Varden [a]	Late summer to fall	Fall	Main channels on rivers	2–4 years freshwater 2–4 years ocean *Repeat spawners*	Mature 5–6 Die 6–7
Resident Species					
Kokanee salmon	Late summer to fall	Late summer to fall	Tributaries of lakes, lakeshores	Juveniles migrate to lakes to reside	3–4
Rainbow trout	Spring	Spring	Small headwater streams	Variable residence in natal, streams, rivers, & lakes	2–3
Cutthroat trout	Spring	Spring to early summer	Small headwater streams	Variable residence in natal, streams, rivers, & lakes	3–4
Bull trout [a]	Fall	Fall	Large streams with groundwater infiltration	Juveniles migrate from tributaries to lakes or large streams at about 2 years, highly variable	4–9
Mountain white fish	Fall	Fall	Mid-sized streams, lakes	Reside in streams and lakes	3–4

Source: Spence et al., 1996.

a. On occasion WDFW lumps bull trout and Dolly Varden together because both are listed under the Endangered Species Act and it is hard to differentiate the two species in the field; genetic studies have found bull trout throughout Puget Sound and the Strait (Duncan, 2008, personal communication).

Table C-7. Biological Variability in Life Histories of Pacific Salmonids

Species of Salmon	Life History	Spawns In			Rears In			
		Lakes	Streams	Intertidal	Lakes	Streams	Estuaries	Ocean
Pink salmon	Anadromous		X			X	X	X
	Anadromous		X					X
	Anadromous			X			X	X
Chum salmon	Anadromous		X			X	X	X
	Anadromous		X			X		X
	Anadromous		X					X
	Anadromous			X			X	X
Coho salmon	Anadromous		X			X	X	X
	Anadromous		X			X		X
Sockeye salmon	Anadromous		X		X			X
	Anadromous	X			X			X
Chinook salmon (spring)	Anadromous		X			X	X	X
	Anadromous		X			X		X
Chinook salmon (fall)	Anadromous		X				X	
	Anadromous		X			X		X
Steelhead Trout	Anadromous		X			X		X
Dolly Varden [a]	Anadromous		X			X	X	X
Kokanee salmon	Resident		X		X			
	Resident	X			X			
Cutthroat trout	Resident		X			X		
	Resident		X		X			
Cutthroat trout (searun)	Anadromous		X			X	X	X
	Anadromous		X			X		X
Rainbow trout	Resident		X		X			
	Resident		X		X			
	Resident	X						
Bull trout [a]	Resident		X			X		
	Resident		X		X			
Mountain whitefish	Resident		X			X		
	Resident	X			X			

Source: Spence et al., 1996.

a. On occasion WDFW lumps bull trout and Dolly Varden together because both are listed under the Endangered Species Act and it is hard to differentiate the two species in the field; genetic studies have found bull trout throughout Puget Sound and the Strait (Duncan, 2008, personal communication).

Table C-8. 2001–2002 Freshwater Salmon Sport Catch for Puget Sound River Systems

Catch Area	Species	2001									2002			Total
		April	May	June	July	August	Sept	Oct	Nov	Dec	Jan	Feb	Mar	
Dungeness River	Coho							5,949	597		12			6,558
	Steelhead					9		43	22	107	58	9	4	252
Elwha River	Coho							816	127					943
	Steelhead			5	46	5	5	36						97
Morse Creek	Steelhead							4						4
													Total Salmon Sport Catch	7,854

Source: Adapted from Manning and Smith, 2005, Table 26, p. 42; Table 35, p. 92; and Table 35, p. 90.

Table C-9. 2001–2002 Sport Salmon Catch for East Juan de Fuca (Port Angeles Areas)

Species	2001								2002		Total
	April	May	June	July	August	Sept	Oct	Nov	Feb	Mar	
Chinook	136				18	17	132	171	172	115	761
Coho			10	239	1,492	1,806	199	8			3,754
Pink			21	840	5,742	951					7,554
Sockeye					2						2
Chum						3	3	4			10
Steelhead			6			6					12
										Total Salmon Sport Catch For Area	12,093

Source: Adapted from Manning and Smith, 2005, Table16, p. 25 and Table 35, p. 101.

Table C-10. 2002–2003 Freshwater Salmon Sport Catch for Puget Sound River Systems

Catch Area	Species	2002									2003			Total
		April	May	June	July	August	Sept	Oct	Nov	Dec	Jan	Feb	Mar	
Dungeness River	Coho							398	711	25				1134
	Steelhead							4	3	5	15	15	3	45
Elwha River	Coho							948	175					1123
	Steelhead				2	1	1	9	59	92	17	9	2	192
Morse Creek	Steelhead								3	15	5	10		33
													Total Salmon Sport Catch	2527

Source: Adapted from Kraig and Smith, 2008, Table 25, p. 41; Table 34, p. 87; and Table 34, p. 88.

Table C-11. 2002–2003 Sport Salmon Catch for East Juan de Fuca (Port Angeles Areas)

Species	2002								2003		Total
	April	May	June	July	August	Sept	Oct	Nov	Feb	Mar	
Chinook	55					3	12	59	103	81	313
Coho				43	281	713	35				1072
Pink				21							21
Sockeye											0
Chum							12				12
Steelhead				3			3	3(Dec)	3(Jan)		12
										Total Salmon Sport Catch For Area	1430

Source: Adapted from Kraig and Smith, 2008, Table 16, p. 25 and Table 34, p. 97.

Table C-12. Salmonid Stock Inventory for the Port Angeles Harbor and Adjacent Areas

Anadromous Fish		Total Escapement Estimates		WDFW Designated Status		Comments
Species	Stock	From Year: Est. #	To Year: Est. #	1992	2002	
Chinook	Dungeness Chinook	1986: 238	2003: 640	Critical	Critical	Critical due to chronically low escapements below goal of 925 adults; increased escapement #'s due to continuing hatchery supplementation; spawning mainstream Dungeness River.
	Elwha Chinook	1986: 3,127	2003: 1,045	Healthy	Depressed	Depressed due to long-term negative trend and chronically low escapements since 1992; Spawning lower 4.9 mile of river below Elwha Dam.
Chum	Dungeness Summer Chum	1992: Unknown	2002: Unknown	Not Rated	Unknown	No abundance trend data available; Numbers so low that may not represent a self-sustaining stock; Summer timed limited #'s observed in Dungeness River.
	Dungeness Fall Chum	1992: Unknown	2002: Unknown	Unknown	Unknown	Live + dead counts in one day, one mile section of (Lower Dungeness tributary) Beebe Creek 1997: 303, 1998: 1,025; 2001: 1,062.
	Elwha Fall Chum	1992: Unknown	2002: Unknown	Unknown	Unknown	No abundance trend data available.

Source: WDFW, 2002. Salmon Stock Inventory. Water Resource Inventory Area (WRIA) 18 – Elwha-Dungeness.

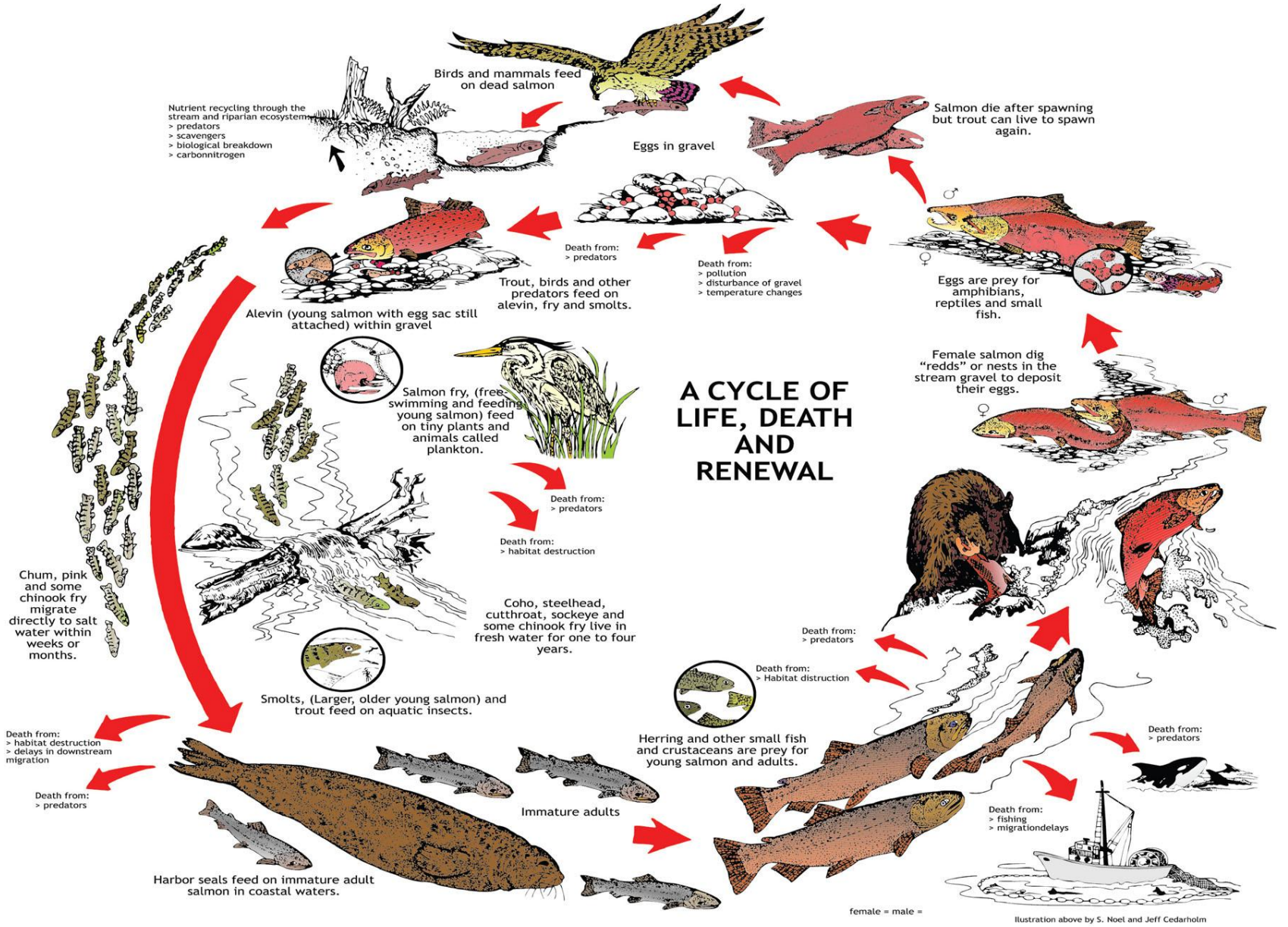
Table C-13. Salmonid Stock Inventory for The Port Angeles Harbor and Adjacent Areas

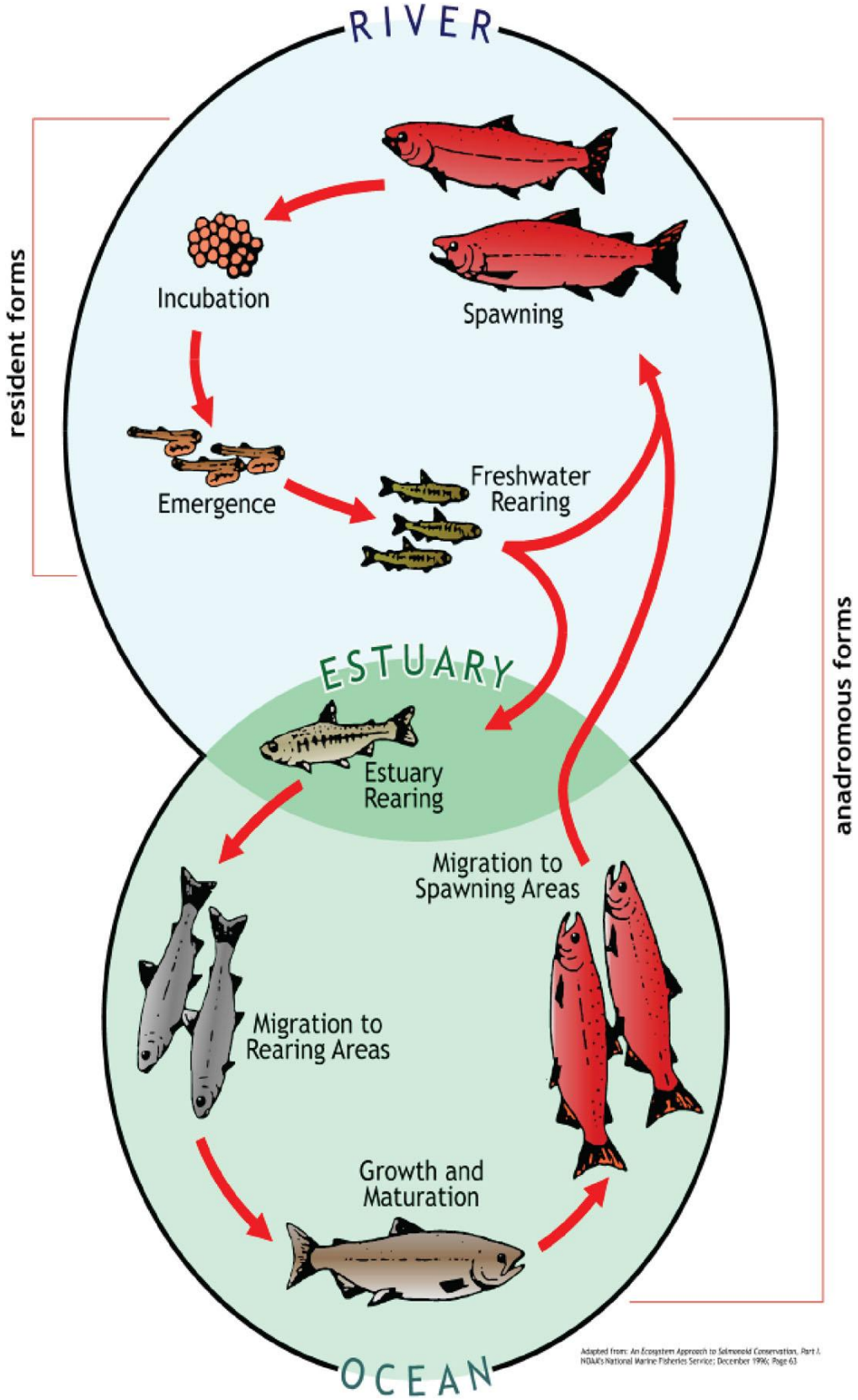
Anadromous Fish		Total Escapement Estimates		WDFW Designated Status		Comments
Species	Stock	From Year: Est. #	To Year: Est. #	1992	2002	
Coho	Dungeness Coho	1992: Depressed	2002: Unknown	Unknown	Unknown	No abundance trend data available; Limited recent-year estimates of smolt production suggest significant natural production Dungeness R. watershed.
	Morse Creek Coho	1998: 488 adults and 511 smolts	2002: 676 adults and 2, 966 smolts	Depressed	Depressed	Spawning distribution: McDonald, Siebert, Morse, Ennis, Valley and Tumwater Creeks; Depressed because of chronically low "redd" counts; mixture of wild and farm-raised stock.
	Elwha Coho	Unknown	Unknown	Healthy	Unknown	No abundance trend data available; Healthy rating based on escapement estimates from Strait of Juan de Fuca tributaries.
Pink	Lower Dungeness Pink	1985: 966	2001: 11,072; 2003: 3,540	Critical	Critical	Estimates based on counts from mainstem of Dungeness R., Gold Creek, and Gray Wolf River; Critical designation due to chronically low escapements.
	Upper Dungeness Pink	1985: 3,764 1989: 10,579	2001: 69,272 2003: 11,576	Depressed	Depressed	Prior to 1981 escapements usually in excess of 20,000; stock status depressed because of chronically low escapements.
	Elwha Pink	1985: 30 1991: 0	2001: 605 2003: 32	Critical	Critical	In early 1970s instantaneous counts over a thousand pinks were made; since 1981 not more than 30 pinks have been seen on any one day; stock status depressed because of chronically low escapements.

Table C-14. Salmonid Stock Inventory for the Port Angeles Harbor and Adjacent Areas

Anadromous Fish		Total Escapement Estimates		WDFW Designated Status		Comments
Species	Stock	From Year: Est. #	To Year: Est. #	1992	2002	
Steelhead	Dungeness Summer Steelhead	Unknown	Unknown	Depressed	Unknown	No abundance trend data available. Due to fisheries closures and low harvest numbers sport harvest is no longer adequate to assess stock status.
	Dungeness Winter Steelhead	1988: 438 1993: 338	2000: 165 2001 183	Depressed	Depressed	Depressed status because of long term negative trends.
	Morse Creek Winter Steelhead	1986: 105 1988: 138	1997: 183 2003: 84	Depressed	Depressed	Escapement estimates based on redd counts; depressed due to chronically low escapements.
	Elwha Summer Steelhead	Depressed	Unknown	Depressed	Unknown	No abundance trend data available.
	Elwha Winter Steelhead	1986: 834 1989: 416	1992: 560 1997: 153	Depressed	Unknown	Access to historic spawning areas blocked by Elwha Dam; Average of 50 redds/year; Lack of systematic abundance trend data.

Source: WDFW, 2002. Salmon Stock Inventory. Water Resource Inventory Area (WRIA) 18 – Elwha-Dungeness.


A CYCLE OF LIFE, DEATH AND RENEWAL
Birds and mammals feed on dead salmon
Nutrient recycling through the stream and riparian ecosystem:
> predators
> scavengers
> biological breakdown
> carbonnitrogen
Eggs in gravel
Salmon die after spawning but trout can live to spawn again.
Death from:
> predators
Death from:
> pollution
> disturbance of gravel
> temperature changes
Eggs are prey for amphibians, reptiles and small fish.
Trout, birds and other predators feed on alevin, fry and smolts.
Alevin (young salmon with egg sac still attached) within gravel
Female salmon dig "redds" or nests in the stream gravel to deposit their eggs.
Salmon fry, (free-swimming and feeding young salmon) feed on tiny plants and animals called plankton.
Death from:
> predators
Death from:
> habitat destruction
Chum, pink and some chinook fry migrate directly to salt water within weeks or months.
Coho, steelhead, cutthroat, sockeye and some chinook fry live in fresh water for one to four years.
Death from:
> predators
Death from:
> Habitat distruction
Smolts, (Larger, older young salmon) and trout feed on aquatic insects.
Herring and other small fish and crustaceans are prey for young salmon and adults.
Death from:
> habitat destruction
> delays in downstream migration
Death from:
> predators
Death from:
> predators
Immature adults
Death from:
> fishing
> migrationdelays
Harbor seals feed on immature adult salmon in coastal waters.
female = male =
Illustration above by S. Noel and Jeff Cedarholm



Source: Adapted from Spence et al., 1996.

Appendix D
Glossary

Anadromous fish: fish that hatch in freshwater, spend a portion of their life maturing in saltwater, then return to freshwater habitats to spawn.

Angler: one who fishes with hook and line, sometimes used to denote "fishers."

Aquatic: from or living in a water body, including both marine and freshwater.

Bottomfish: fish that include Pacific cod, Pacific tomcod, Pacific hake, walleye Pollock, all species of dabs, sole and founders (except Pacific halibut), lingcod and all other species of greenling, ratfish, sablefish, cabezon, buffalo sculpin, great sculpin, red Irish lord, brown Irish lord, Pacific staghorn sculpin, wolf-eel, giant wry mouth, plainfin midshipman, spiny dogfish, six gill shark, soupfin shark and all other species of shark, and all species of skate, rockfish, rattails and surfperches except shiner perch.

Coastal waters: a term that refers to waters having a coastline that forms the boundary between land and freshwaters and marine and/or estuarine waters. This term encompasses all freshwaters of statewide significance (lakes, rivers, streams, etc.) and those marine and/or estuarine waters extending from the landward edge of a barrier beach or shoreline of coastal bay to the outer extent of the Continental Shelf.

Commercial fishers: those individuals who harvest finfish and/or shellfish by any method from Washington State waters (marine, estuarine, and freshwaters) for economic gain as a livelihood.

Creel survey: on-site interview with fishers to obtain information such as species caught; number, length, and weight of catch; location; etc.; typically for use by fisheries managers; may or may not include information on consumption.

Demersal fish: fish that dwell at or near the bottom of a body of water.

Estuarine: from an estuary, i.e., a partly enclosed water body, such as an inlet of the ocean or the mouth of a river where it meets the ocean that contains brackish water (a mixture of salty and freshwater) such as Elliott Bay in Seattle, Washington.

Finfish: fish; a term that is usually applied to the consumption of true fish as opposed to shellfish.

Fish: any of various aquatic animals (belonging to the subphylum Vertebrata) having gills, commonly fins, and bodies usually but not always covered by scales, including those having bony skeletons (bony fishes) and more primitive forms with cartilaginous skeletons (lampreys; hagfishes; and sharks, skates, and rays).

Fish consumers: those individuals who consume finfish and/or shellfish; synonymous with Washington State fish-consuming populations.

Fisher: one who fishes for any type of seafood by any method, inclusive of hook and line and other methods of catching seafood.

Freshwater: water bodies including lakes, ponds, rivers, and streams that contain water with relatively low salinity, i.e., less that 0.5 parts per trillion; species inhabiting freshwater bodies.

Game fish: sport fish that are caught for food.

Indian (Native American) Reservation: land set aside by the federal government for the use, possession, and benefit of a Native American tribe or group of Indians; created by some formal legal directive such as a treaty, statute passed by Congress or an executive Presidential order.

Marine: from, or living in, the ocean; saltwater, with a salinity of approximately 35 parts per trillion.

Native American: a member of the indigenous peoples of the Western Hemisphere. In this technical support document the term "Indian" is used only with reference to the name of a specific Native American tribe.

Noncommercial fisher: one who fishes for recreation and/or home consumption; synonymous with recreational fisher, sport fisher.

Pelagic fish: fish that live near the surface or in the water column of coastal, oceanic, and lake waters.

Reasonable maximum exposure (RME):

The **MTCA definition** of RME (WAC 173-340-200) is as follows:

> *Reasonable maximum exposure means the highest exposure that can be reasonably expected to occur for a human or other living organisms at a site under current and potential future site use.*

The **EPA definition** of RME is as follows:

> *Actions at Superfund sites should be based on an estimate of the **reasonable maximum exposure (RME)** expected to occur under both **current** and **future** land-use conditions. The reasonable maximum exposure is defined here as the highest exposure that is reasonably expected to occur at a site. RMEs are estimated for individual pathways* (U.S. EPA, 1989b, page 6-4 to 6-5).

The worst-case exposure represents an extreme set of exposure conditions, usually not observed in an actual population, which is the maximum possible exposure where everything that can plausibly happen to maximize exposure happens (U.S. EPA Guidelines for Exposure Assessment, Federal Register Notice, Vol. 57, No. 104, May 1992, pages 22888-22938).

The preamble to the **National Contingency Plan** further indicates that the RME will:

> *…result in an overall exposure estimate that is conservative but within a realistic range of exposure. Under this policy, EPA defines "reasonable maximum" such that only potential exposures that are likely to occur will be included in the assessment of exposures. The Superfund program has always designed its remedies to be protective of all individuals and environmental receptors that may be exposed at a site; consequently, EPA believes it is important to include all reasonably expected exposures in its risk assessments…*

Recall bias: Dietary recall surveys may cover specific periods of time or seasons; short term recall surveys may cover a 24-hour food recall to obtain information on the diet of an individual in the prior 24 hours. Dietary surveys that rely on an individual's recall of their diet may undergo some recall errors that introduce an element of bias in the dietary estimates. These recall errors may result in either overestimation or underestimation of fish consumption. Factors that contribute to recall error and bias include how commonly or frequently the food (fish) is consumed, time frames covered by the survey that contribute to seasonal variation in food consumption, survey methods used including provisions to enhance dietary memory or recall (food models), and the desirability or cultural influences on the food consumed. Generally, recall error increases as the length of the recall period increases, with recall periods of 1 year likely to result in the least reliable estimates of consumption. The optimal recall period will be long enough to accurately portray typical dietary (fish consumption) habits and patterns without impairing the ability of respondents to recall their dietary (fish) consumption (Chu et al., 1992).

Recreational fisher: one who fishes primarily for recreational purposes; recreational catch is used primarily for home consumption; synonymous with noncommercial fisher, sport fisher.

Seafood: aquatic organisms that are consumed, including mainly finfish and shellfish, and less frequently, other invertebrate animals or plants or marine mammals.

Shellfish: aquatic invertebrate animals having a shell or exoskeleton, the term usually used in the context of food, including species belonging to the following taxa (some of which have evolved such that the shell has become internal and/or reduced, or has disappeared entirely): (1) mollusks, including bivalves (e.g., clams, oysters, mussels, scallops), gastropods (e.g., snails, limpets, abalone), and cephalopods (e.g., squid, octopods); (2) crustaceans (e.g., crabs, shrimps, lobsters); and (3) echinoderms (e.g., sea urchins, sea cucumbers).

Sport fish: fish that are caught by a sport fisher as opposed to purchased or caught commercially, synonymous with sport-caught, recreationally caught, and noncommercial fish.

Sport fishers: those individuals who harvest finfish and/or shellfish by any method from Washington State waters (marine, estuarine, and freshwaters) for recreation; synonymous with recreational fisher or noncommercial fisher.

Subsistence: Although no single universally accepted definition is available to define what is meant by subsistence or subsistence-based populations, several definitions of subsistence fishers may apply to Washington State ethnic groups and/or fish-consuming populations. It is difficult to define and to quantify subsistence fishers. Definitions and perceptions of what constitute subsistence fishers and fishing may vary among regions and cultures. The 1994 Presidential Executive Order 12898, Section 4-4. Subsistence Consumption of Fish and Wildlife noted differential patterns of subsistence consumption of fish and wildlife for populations who principally rely on fish and/or wildlife for subsistence.[56] Differential patterns of subsistence consumption of fish and wildlife relates to subsistence and differential patterns of subsistence, and means differences in rates and/or patterns of fish, water, vegetation and/or wildlife consumption among minority populations, low-income populations, or Native American tribes, as compared to the general populations. As a response to Executive Order 12898, the 1999 National Academy of Sciences publication noted the following (Institute of Medicine, 1999, p. 17):

> *… differences in behavior, employment, and lifestyles among subgroups in the population may result in differences in exposure. For example, among the Alutiiq, Yup'ik, and Inupiat Alaskan Native peoples, the yearly intake of wild foods per person is between 171 and 272 kilograms (375 and 600 pounds). Increasing evidence of certain contaminants such as mercury in the wild food supply of these Alaskan Natives has been exhibited by methyl mercury levels that exceed those provisionally established as safe by the World Health Organization*.

[56] Presidential Executive Order 12898: Federal Actions To Address Environmental Justice In Minority Populations and Low-Income Populations. Signed by President William J. Clinton, February 11, 1994 web location: http://www.epa.gov/region2/ej/exec_order_12898.pdf

Tribal subsistence exposure scenario and fishers: "Subsistence" refers to the hunting, fishing, and gathering activities that are fundamental to the way of life of many indigenous peoples (Confederated Tribes of the Umatilla Indian Reservation, 2004, p. 4). Subsistence utilizes traditional, small-scale technologies for harvesting and preserving foods as well as for distributing the produce through communal networks of sharing and bartering. Because it often misinterpreted, an explanation of "subsistence" is taken from the National Park Service (Confederated Tribes of the Umatilla Indian Reservation, 2004):

> *While non-natives tend to define subsistence in terms of poverty or the minimum amount of food necessary to support life, native people equate subsistence with their culture. Among many tribes, maintaining a subsistence lifestyle has become the symbol of their survival in the face of mounting political and economic pressures. It defines who they are as a people. To Native Americans who continue to depend on natural resources, subsistence is more than eking out a living. While it is important to the economic well-being of their communities, the subsistence lifestyle is also the basis of cultural existence and survival. It is a communal activity. It unifies communities as cohesive functional units through collective production and distribution of the harvest. Some groups have formalized patterns of sharing, while others do so in more informal ways. Entire families participate, including elders, who assist with less physically demanding tasks. Parents teach the young to hunt, fish, and farm. Food and goods are also distributed through native cultural institutions. Most require young hunters to distribute their first catch throughout the community. Subsistence embodies cultural values that recognize both the social obligation to share as well as the special spiritual relationship to the land and resources. This relationship is portrayed in native art and in many ceremonies held throughout the year.*[57]

The average subsistence adult fish consumption rate is 620 g/day (500 pounds/year) for the Confederated Tribes of the Umatilla Indian Reservation.[58]

Usual and Accustomed Fishing Areas: also referred to as U & A areas or U & A fishing areas. The term refers to the 1854 and 1855 negotiated treaties with the Pacific Northwest Native Americans in Washington state: "The right of taking fish at usual and accustomed grounds and stations is further secured to said Indian in common with all citizens of the Territory…"

[57] National Park Service. Archeology Program. Preservation On the Reservation [And Beyond] Web location: http://www.nps.gov/archeology/cg/fa_1999/Subsist.htm

[58] Traditional Tribal Subsistence Exposure Scenario and Risk Assessment Guidance Manual. August 2007. Appendix 3: Fish Consumption Rate. Web location: http://www.hhs.oregonstate.edu/ph/tribal-grant-main-page2

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DEPARTMENT OF
ECOLOGY
State of Washington

Western Washington
NPDES Phase I Stormwater Permit

Final S8.D Data Characterization 2009-2013

February 2015

Publication No. 15-03-001

05592

Publication information

This report is available on the Department of Ecology's website at
https://fortress.wa.gov/ecy/publications/SummaryPages/1503001.html

Suggested Citation:
Hobbs, W., B. Lubliner, N. Kale, and E. Newell. 2015. Western Washington NPDES Phase 1 Stormwater Permit: Final Data Characterization 2009-2013. Washington State Department of Ecology, Olympia, WA. Publication No. 15-03-001.
https://fortress.wa.gov/ecy/publications/SummaryPages/1503001.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Search Study IDs:

- WAR044002_S8D
- WAR044003_S8D
- WAR044200_S8D
- WAR044501_S8D
- WAR044502_S8D
- WAR044503_S8D
- WAR044701_S8D
- WAR044001_S8D

The Activity Tracker Code for this study is 13-002.

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Western Washington
NPDES Phase I Stormwater Permit

Final S8.D Data Characterization 2009-2013

by

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Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area:

WRIAs
- 5, 7, 8, 9, 10, 12, and 28

HUC numbers
- 17080003, 17110010, 17110011, 17110012, 17110013, 17110014, 17110019

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Abstract

Stormwater and storm sediment discharge data were collected by NPDES Phase I Municipal Stormwater permittees, under Special Condition S8.D, between 2007 and 2013. This report is a summary of the data results. The Phase 1 permittees, all located in western Washington, collected highly representative storm-event data under a prescribed monitoring program that represented multiple land uses, storm characteristics, and seasons. The main goals of this study were to (1) compile and summarize the permittees' data using appropriate statistical techniques and (2) provide a western Washington regional baseline characterization of stormwater quality.

These findings are based on the analysis of 44,800 data records representing 597 storm events. Up to 85 parameters were analyzed in stormwater samples, and 67 parameters were analyzed in stormwater sediments. Metals, hydrocarbons, phthalates, total nitrogen and phosphorus, pentachlorophenol, and PCBs were detected more frequently and at higher concentrations from commercial and industrial areas than from residential areas. Residential areas exported stormwater with the highest dissolved nutrient concentrations.

For context, data were compared to previous stormwater studies and the Washington State water quality criteria. Stormwater pollutant concentrations were lower than those reported by EPA in the mid-1980s, but higher than stream and river concentrations draining to Puget Sound during storms. Across all land uses, copper, zinc, and lead were found more often than not to exceed (not meet) water quality criteria. Mercury and total PCBs exceeded criteria in 17% and 41% of the samples, respectively. For most parameters measured in both stormwater and stormwater sediments, concentrations in stormwater sediments paralleled the trends found in water samples across all four land uses.

The statistical analyses used in this study have produced reliable statistical summaries and allowed for robust comparisons of the impacts of land use and seasons on contaminant concentrations and mass loads. The statistical summaries form a baseline for contaminant concentrations in stormwater that will allow for future comparisons.

Acknowledgements

The authors thank the following for their contributions to this report.

Permittees who contributed data for analysis:

- Clark County
- King County
- Pierce County
- Snohomish County
- City of Seattle
- City of Tacoma
- Port of Seattle
- Port of Tacoma

Washington State Department of Ecology staff:

- Rachel McCrea, Ed O'Brien, Vince McGowan, Nancy Winters, Randall Marshall, Abbey Stockwell, and James Maroncelli for reviewing the draft report.
- Adam Oestreich for data quality control and EIM support.
- Dale Norton for project guidance.
- Jean Maust, Joan LeTourneau, and Cindy Cook for formatting and proofing the final report.

Dennis Helsel, Practical Stats, Inc., for statistical assistance.

Executive Summary

Introduction

In 1995, when the Washington State Department of Ecology (Ecology) issued its first National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater Permit, limited national stormwater data were available. The permit relied on data from the mid-1980s and a few local Superfund sites to provide a reasonable picture of pollutant types and ranges of concentrations in stormwater runoff. In developing the Phase I Municipal Stormwater Permit conditions, Ecology intended to help fill this data gap.

The 2007-2012 Phase I Municipal Stormwater Permit (permit) included stormwater discharge monitoring requirements in Section D of Special Condition 8 (S8.D) to gain local stormwater quality data. These monitoring requirements enabled uniform data collection and similar laboratory methods to represent runoff from local land uses. The Phase I permittees were four counties (Clark, King, Pierce, and Snohomish), two cities (Seattle and Tacoma), and two ports (Seattle and Tacoma). The monitored sample locations and land uses are detailed in Figure ES-1. Phase I permittees spent a tremendous amount of time and effort to collect the data compiled for this report. Some permittees continue to conduct outfall monitoring at some of the same sites under the current 2013-2018 permit, but this report only evaluates data collected under the 2007 permit.

The extensive multi-year effort to characterize sources and reduce toxics from riverine inputs to Puget Sound (*Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates*; herein called *PS Toxics Study*) took place concurrently with the permittees monitoring of outfalls. Results of the *PS Toxic Study* identified stormwater discharge data as a data gap (Herrera, 2011), while S8.D monitoring by permittees was underway. The *PS Toxics Study* reported that concentrations and loadings of toxic pollutants in monitored rivers and streams were higher during storm events than during baseflow, for all land uses.

Purpose

The primary purpose of this report is to summarize the S8.D stormwater discharge characterization monitoring data collected by the Phase I permittees under the 2007 permit.

What were the goals?

The primary goal for monitoring under the permit was to gather data directly from stormwater discharges and establish a regional (western Washington) baseline of data representing municipal stormwater quality. Such data were to be representative of stormwater discharge quality over the course of individual storm events.

The secondary goal in data analysis was to explore variability in stormwater concentrations across different land uses and seasons and to identify chemicals of interest in stormwater.

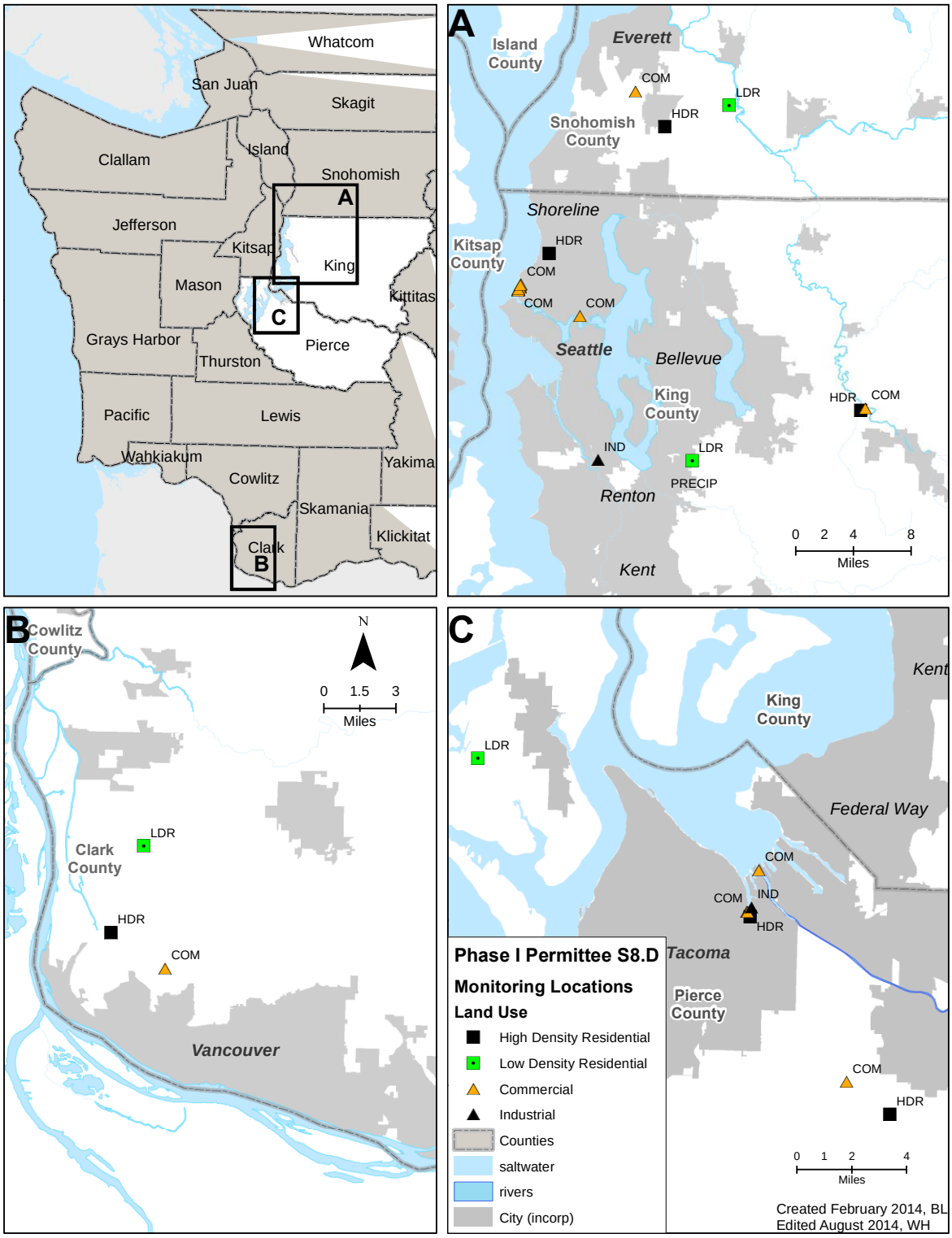

Figure ES-1. Site locations of monitored stormwater catchments and corresponding land use.

Land use types: LDR = low-density residential; HDR = high-density residential; COM = commercial; IND = industrial

What was achieved?

This report provides statistical summaries for municipal storm-event concentrations for 172 parameters across four land uses and wet and dry seasons in western Washington. Ecology recognizes the substantial contribution made by the permittees to our collective understanding of stormwater chemistry in western Washington.

Methods

For this final report, Ecology downloaded, compiled, and analyzed the complete permit monitoring data from Ecology's Environmental Information Management (EIM) database. Stormwater was monitored from 2009 through 2013, and samples were collected using flow-weighted automatic composite samplers for most parameters. Each location has at least three years of data.

Composite sample volumes were in compliance with the required collection approach of a storm's hydrograph under the permit. Samples generally spanned 75% or more of the first 24 hours of each storm. Permittees submitted rainfall amount, runoff volume, and concentration data for stormwater samples to Ecology's EIM database. Concentration data for stormwater-related sediments are also available in EIM; however, these data were collected less uniformly, using either grab samples or traps in the storm pipe system.

Results

The final data set encompassed 44,800 records submitted to Ecology by Phase 1 permittees, representing an estimated 597 storm events. Up to 85 chemicals were analyzed for any given stormwater sample, and 67 chemicals were analyzed in stormwater sediment samples. The composite stormwater samples were found to be representative of storm length, storm volumes, and frequency of storm events in western Washington. The database is suitable for characterizing stormwater quality in western Washington.

Detection Frequency

The rate of detection varied across land use and by parameter. Overall, metals, nutrients, and conventional parameters were detected in nearly all stormwater and stormwater sediment samples. The following parameters were frequently detected in stormwater:

- Conventional parameters (biochemical oxygen demand, pH, conductivity, chloride, turbidity, total suspended solids) had a 98% detection rate. Surfactants were detected in 60% of the samples.
- Metals except mercury were commonly detected; arsenic, copper, lead, magnesium, and zinc were found in 90% of the samples. Cadmium was detected in just over 60% of the samples.
- Nutrients (nitrogen and phosphorus) were detected in 90% of the samples.
- Polycyclic aromatic hydrocarbon (PAHs) were detected in 73% of the samples.
- Total petroleum hydrocarbons (diesel range fractions) were detected in 73% of the samples.
- bis(2-ethylhexyl)phthalate was found in 62% of the samples.

The detection rate of organic compounds (such as total petroleum hydrocarbons – diesel fractions, PAHs, and phthalates) and certain metals (copper, lead, and zinc) in stormwater sediments was more than 90%. Diesel, motor oil, copper, and zinc were found in all stormwater sediment samples collected.

Chemicals are considered *non-detect* if the concentration was not measured above the method detection limit. The following parameters were either infrequently detected or not detected at all:

- Benzene, toluene, ethylbenzene, and xylenes (BTEX) in stormwater were found in less than 3% of the samples.
- Malathion, prometon, chlorpyrifos, and diazinon in stormwater and stormwater sediments were found in less than 4% of the samples.
- Triclopyr and mecoprop was detected at a rate of 8% in stormwater sediments and approximately 11% in stormwater samples.
- Most phenolics in stormwater sediments were not detected at all, except for pentachlorophenol, o-cresol, and p-cresol (detection rates of 25, 19, and 77% respectively).

Land Use

Metals, hydrocarbons, phthalates, total nitrogen and phosphorus, pentachlorophenol, and PCBs were detected more frequently and at higher concentrations from commercial and industrial lands than from residential lands. Residential lands exported stormwater with the highest dissolved nutrient concentrations.

All parameters with high rates of detection exhibited statistically different concentrations across land uses. Individual parameters showed strong differences among land uses. However, when parameters were grouped or summed (e.g., sum of PAHs), greater overlap in stormwater chemistry among land uses was found.

Chemicals of Interest and Importance

To put the results of this compilation effort into context, Ecology compared these results using two primary sources of information. The first source was a suite of literature including the Nationwide Urban Runoff Program (NURP; EPA, 1983) and analysis of the National Stormwater Quality Database (Maestre et al., 2005). These are discussed in the next section. The second primary source was the Washington State Water Quality Criteria. The national studies and Washington's water quality criteria form the "bookends" for comparing the stormwater discharge results of this compilation. The intent of this report is to characterize data, not to evaluate compliance. The comparison to criteria presents an understanding of parameters and land uses where stormwater improvements and resources can be focused to improve water and sediment quality.

Across all four land uses, copper, zinc, and lead were−more often than not−found to exceed (not meet) water quality criteria (Table ES-1). Dissolved zinc and copper in stormwater samples exceeded acute aquatic life criteria in 36% and 50% of the samples, respectively, over the three years of data. Mercury and total PCBs exceeded chronic aquatic life criteria in 17% and 41% of

the samples, respectively. Commercial and industrial lands contributed higher concentrations of these compounds.

Table ES-1. Parameters ranked in order of percent of samples exceeding the aquatic life water quality criteria.

Acute aquatic life criteria				Chronic aquatic life criteria		
Parameter	Exceeds (%)	Samples (total)		Parameter	Exceeds (%)	Samples (total)
Dissolved Copper	50.30	600		Dissolved Copper	57.80	600
Dissolved Zinc	36.00	606		Total PCBs	40.70	27
Dissolved Lead	0.30	627		Dissolved Zinc	39.90	606
Dissolved Cadmium	0.30	635		Dissolved Lead	27.60	627
Diazinon	0.30	644		Total Mercury	17.40	455
Chloride	0.20	551		Chloride	0.70	551
Total PCBs	0.00	27		Dissolved Cadmium	0.50	635
Pentachlorophenol	0.00	473		Diazinon	0.30	644
Chlorpyrifos	0.00	644		Pentachlorophenol	0.00	473
Dissolved Arsenic	0.00	16		Chlorpyrifos	0.00	644
Dissolved Mercury	0.00	444		Dissolved Arsenic	0.00	16

PAHs, a significant component of the stormwater pollutants, do not have promulgated numeric criteria in water for the protection of aquatic life.

For most parameters measured in both stormwater and stormwater sediments, concentrations in the stormwater sediments reliably paralleled the trends found in water samples across land uses. Insoluble parameters had much higher frequencies of detection in stormwater sediments than in water. When concentrations in stormwater sediments were compared to the Washington State Sediment Cleanup Objectives (SCOs) for freshwater sediments under the Sediment Management Standards, the number of samples exceeding the SCOs was found highest for phthalates[1] (82% and 29% of samples) and PAHs (34% of samples). To a lesser extent, concentrations of phenolics (20%) and metals (1-18%) exceeded the SCOs.

[1] Bis(2-ethylhexyl) phthalate – 82% of samples; di-n-octyl phthalate – 29% of samples

Seasonality and Loads

Higher contaminant concentrations and mass loads were measured for nutrients and metals during the dry season (May through September). This provides strong evidence for an influence of seasonality (or antecedent dry periods) on stormwater concentrations, particularly in late summer through early fall; it also supports the idea that there is a degree of "buildup" in the dry periods between storms. Metals, diesel hydrocarbons, and total nutrient loads were higher in the dry season and highest from commercial and industrial areas.

PAHs, phthalates, and detected pesticides (dichlobenil and pentachlorophenol) did not exhibit this significant seasonal difference, suggesting a consistent source throughout the year and no buildup in the dry months.

Discussion

This study improves Ecology's understanding of the quality of stormwater discharges to receiving waters. The study provides:

- Local and land use-based stormwater quality data.
- Flow-weighted composite sample data which are superior in quality to grab samples and best represent storm-event concentrations.
- Direct baseline to measure the performance of stormwater management actions at a regional scale.
- Summary statistics from a very large data set that are not biased by substituting for *non-detect* results.

Generally in this stormwater discharge data set, individual storm-event concentrations were within the ranges reported in the National Stormwater Quality Database (NSQD) (Maestre et al., 2004 and 2005), but median values were consistently lower (Figure ES-2). These concentrations are also much lower in some cases (e.g., lead is 23 times lower) than those from the earliest national study on stormwater, NURP (EPA, 1983). This may be due to the age of the early studies, subsequent improvements in stormwater quality and management since the NURP sampling, or possibly our wetter climate that allows for more wash off between monitored storms. Nevertheless, the current study offers many of the same conclusions about land-use patterns as the *PS Toxics Study* (Herrera, 2011) and NURP/NSQD studies of the 1980s and 1990s. For example, concentrations of metals from commercial and industrial land uses have remained high.

For many of the parameters, concentrations were higher in stormwater discharges in the current study than levels found in the recent *PS Toxics Study* (Figure ES-2). This finding is not surprising given the *PS Toxics Study* sampled ambient receiving waters, while these current stormwater data are representative of discharges to receiving waters.

In the current study, metals (total and dissolved) were much lower (2 to 15 times) than in the NURP and NSQD data sets (Figure ES-2). Compared with the *PS Toxics Study*, metals were generally higher in stormwater, with the exception of dissolved arsenic. High background

arsenic from the regional geologic setting yields higher dissolved concentrations in receiving waters of rivers and streams. The largest difference in metals concentrations between this study and the *PS Toxics Study* was found in lead and zinc (12 and 8 times, respectively; Figure ES-2).

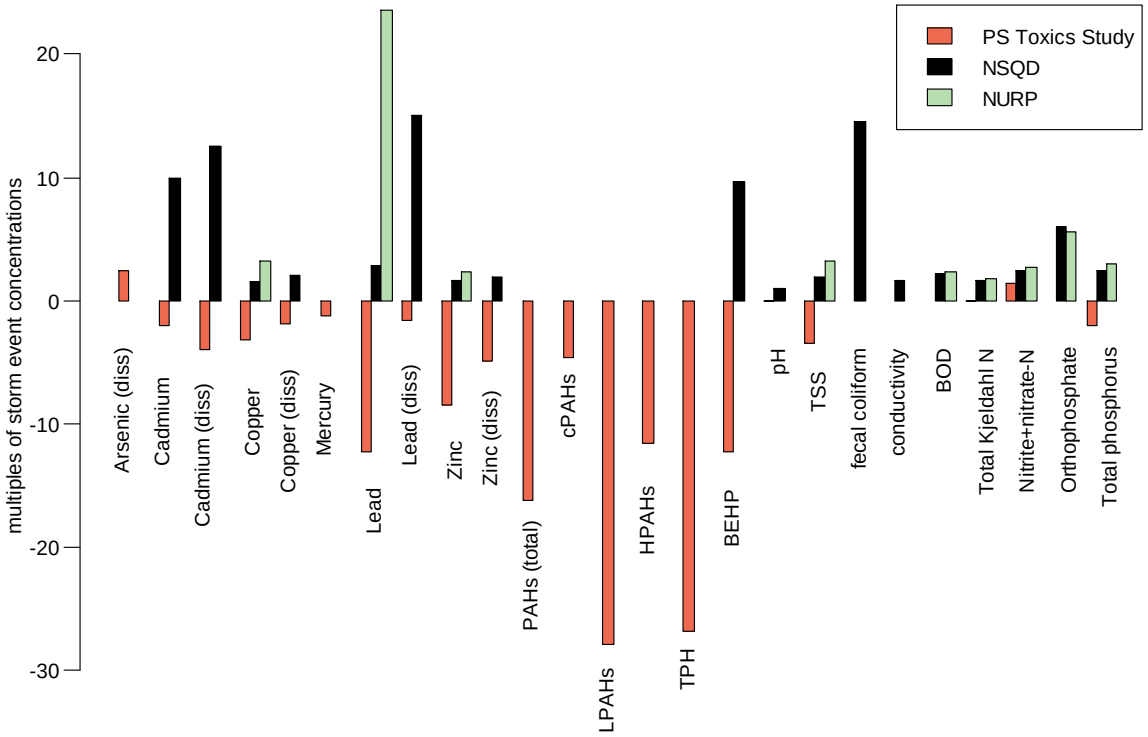

Figure ES-2: Summary of S8.D median stormwater concentrations relative to other studies.

The Y-axis units are the differences (multiples) of the S8.D stormwater median concentrations reported in the other two studies. Bars show the magnitude of difference as less than (negative) or more than (positive) the S8.D results. Many parameters were not measured in the previous studies.

Total nutrients and dissolved nutrients were found to have different land-use patterns. Like many of the metals and organic contaminants, total nutrients were found in higher concentrations and loads from areas of commercial and industrial land use. Total phosphorus concentrations in stormwater discharges were found to be double the receiving water concentrations under storm flows as reported in the *PS Toxics Study* for combined land uses.

Dissolved nutrient concentrations (nitrite+nitrate and orthophosphorus) were higher in stormwater from residential areas. Dissolved nutrients were lower in stormwater discharges than in receiving waters under storm events sampled in the *PS Toxics Study* (Figure ES-2). This suggests the major sources of dissolved nutrients are probably not in piped stormwater systems represented in this data set. This suggests that nonpoint sources for dissolved nutrients may be important delivery mechanisms for dissolved nutrients. Possible sources are shoreline sheet flow drainage, non-urbanized land runoff (such as agriculture and open space), other surface water bodies (such as wetlands), and groundwater.

The permittees analyzed far more parameters than the two older national studies did, particularly organic parameters such as PAHs that were frequently detected in western Washington stormwater. Hydrocarbon median concentrations (PAHs and TPH) were measured at 5 to 26 times higher in this study than those in the *PS Toxics Study* (Figure ES-2). This compilation of stormwater discharge data corroborates the *PS Toxics Study* findings about the dominant source of PAHs. High concentrations of PAHs are observed during storm events, with the greatest contribution of PAHs from areas with commercial and industrial land uses. No seasonal differences in PAH concentrations were found in this study.

Overall, the highest concentrations and the most frequent exceedances of water quality criteria for toxic compounds were found in stormwater and stormwater sediments discharged from basins with a higher percentage of commercial and industrial land uses. Residential lands contributed the highest concentrations of dissolved nutrients and the pesticides dichlobenil and triclopyr. Triclopyr, which had a high frequency of detection in the *PS Toxics Study,* was found in only 10% of the 575 stormwater samples analyzed under the permit in this current study.

Recommendations

Future Monitoring and Stormwater Management

- Continue collecting high quality data representing storm-event concentrations. This is realistic, since all eight permittees met sample frequency and representativeness of the qualifying storm event described in the permit.
- Reduce or eliminate from future stormwater monitoring those parameters which were rarely detected:
  - Benzene, toluene, ethylbenzene, and xylenes (BTEX) in water.
  - Malathion, prometon, chlorpyrifos, and diazinon in water and sediments.
  - Triclopyr and mecoprop in sediments.
- Limit testing of phenolics in sediments to pentachlorophenol, o- cresol, and p-cresol.
- Expand the spatial scale and number of sites for collection of annual stormwater sediment samples to enhance the survey of possible contaminant sources. Stormwater sediment samples effectively reflect the relative contaminant concentrations by land use.
- Apply the findings of this analysis to future stormwater management activities.
  - Stormwater management programs can sweep and conduct other housekeeping best management practices (BMPs) in industrial and commercial areas during the dry season to reduce high stormwater loads of metals, diesel hydrocarbons, and total nutrients during the first-season storms.

Future Puget Sound Monitoring and Modeling

- Use this study's measurements of storm-event concentrations to fill data gaps in Puget Sound models (identified by the *PS Toxics Study)* for areas draining directly to marine or fresh receiving waters. These areas were missed when monitoring the larger drainages in that study (Herrera, 2011).
- Use this stormwater data set in modeling studies for more accurate estimates of toxics loading from stormwater in the Puget Sound basin.
- Conduct future studies of BMP effectiveness in the sampled basins, using a similar suite of stormwater chemistry for comparison to these baseline data. For example, evaluate the best timing for sweeping high traffic areas, ports, and parking lots.

Further Study

- Consider providing the data online in a simple, user-friendly interface that stormwater managers could use to directly compare to future stormwater chemistry results.
- Link this data set with the NSQD to increase the temporal range of the data set.
- Further investigate statistical approaches to define "typical" stormwater chemistry for each land use or other basin characteristics (e.g., total impervious area, effective impervious area, vehicular uses, pollution-generating activities).
- Continue analysis of unusually high runoff coefficients (percent of a storm's rainfall that is directed through the stormwater system) that were calculated for some high-density residential sites. This could show whether the runoff coefficient influences the contaminant contributions from these sites.
- Explicitly test the influence of antecedent dry periods and seasonal first-flush events in stormwater discharges.
- Evaluate the data set for patterns that could help identify and reduce sources of pollution to stormwater. For example, analyze the relationship between the timing of the highest metals concentrations from commercial and industrial areas and whether BMPs can reduce the discharge of copper, zinc, and lead.
- Further investigate the data set for relationships between seasonality and land use (or other basin characteristics) for each parameter (e.g., total phosphorus exhibits strong statistical differences among land uses during the wet season, but no significant differences during the dry season).
- Evaluate more descriptive landscape variables (e.g., vehicle traffic or road density) with the concentration data.

Data Access

This data set is available from Ecology's Environmental Information Management (EIM) database. Inquiries can be made by contacting report authors B. Lubliner or N. Kale.

Introduction

Stormwater transport of pollutants to receiving waters is a local and national concern. The U.S. Environmental Protection Agency (EPA) states, "*Polluted stormwater is the leading cause of impairment to the nearly 40% of surveyed U.S. waterbodies which do not meet water quality standards.*" (EPA Stormwater website). The Washington State Department of Ecology (Ecology) is authorized to administer the Clean Water Act's National Pollutant Discharge Elimination System (NPDES) permits to implement controls designed to prevent stormwater pollutants from impairing local water bodies.

To understand the extent of pollutant loading by stormwater to streams, lakes, rivers, and Puget Sound, Ecology included monitoring requirements in the 2007-2012 Phase I Municipal Stormwater permit (permit)[2] (Ecology, 2006 and 2007). Ecology issued the permit to four counties, two cities, and two ports[3]. Special Condition 8 (S8) of the permit consisted of three main monitoring elements:

- Stormwater discharge characterization monitoring and assessment of seasonal first flush toxicity (S8.D).
- Stormwater treatment and hydrologic best management practices (BMP) evaluation monitoring (S8.E).
- Targeted stormwater management program effectiveness monitoring (S8.F).

This report summarizes the results of stormwater discharge characterization monitoring (S8.D) only. Appendix A provides a summary of the screening level toxicity of the first storms in the dry season. This report of the Phase I Permit's S8.D stormwater monitoring data represents the largest local data set characterizing municipal stormwater discharge quality. Compilation and analysis of stormwater discharges helps fill a data gap identified by a receiving water study: *Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates* by Herrera Environmental Consultants, Inc. (Herrera, 2011), herein called the *PS Toxics Study*. The *PS Toxics Study* stated the major data gap was in regional stormwater quality information from conveyance systems, and that discharge data were needed to improve loading estimates to Puget Sound.

Purpose

Characterization of stormwater pollutant discharges by land use on a regional scale is an Ecology priority. Stormwater management solutions and decisions are based on knowledge gathered from monitoring the types of pollutants in populated industrial, residential, and commercial land-use areas. The National Estuary Program (NEP) also identified stormwater discharge characterization as a priority. In 2012, NEP provided grant funding to Ecology to compile and

[2] The 2012-2013 Phase I Municipal Stormwater Permit continued the 2007 permit's monitoring requirements, clarifying endpoints for these monitoring programs and requirements for data submission.

[3] The Phase I Municipal Stormwater Permit also covers Secondary Permittees which were not required to conduct the monitoring discussed in this report.

review the S8.D monitoring data collected from 2007 through 2012. An interim report was published based on results available at the time (Lubliner and Newell, 2013). After the interim report was published, the remaining stormwater monitoring data were submitted to Ecology. This final compilation builds on the interim report and establishes a regional baseline of stormwater discharge quality based on monitoring results from the Phase I Permit.

The information presented herein provides natural resource managers and stormwater managers with actual stormwater discharge data in western Washington, which can decrease reliance on national studies that may not represent western Washington's climate or land uses. Improved confidence in local stormwater event concentrations is useful for stormwater managers, regulators, treatment technology development, and future contaminant studies (e.g., source identification and loading studies). This report provides recommendations for future analysis of this data set and recommendations for separate studies. This report also identifies parameters that provide little information about stormwater quality.

Permit-Defined Stormwater Monitoring

Stormwater Monitoring Design

Monitoring Permittees

The 2007 monitoring requirements applied to eight Phase I permittees:

- Cities of Tacoma and Seattle
- King, Snohomish, Pierce and Clark counties
- Ports of Tacoma and Seattle

To ensure consistency across jurisdictions, monitoring was conducted under Quality Assurance (QA) Project Plans written by the permittees and approved by Ecology. The monitoring program for each permittee is described in detail in each permittees' QA Project Plan (referenced in Appendix B and available from the permittees). A few aspects of the monitoring programs are important for understanding the monitoring results presented here.

Site Selection for Stormwater Characterization

The permit instructed permittees to monitor land uses where, ideally, the drainage area would constitute ≥80% of a particular land use. However, Ecology and the permittees found that stormwater sub-basins tended to contain more variety of land uses and meeting this 80% goal was not possible in all circumstances (Table 1). Permittees monitored one location for each different land-use type. The land-use types monitored by permittees were:

- Counties: commercial, high-density residential, and low-density residential.
- Cities: commercial, high-density residential, and industrial.
- Ports: commercial.

The permit required stormwater monitoring for a total of three years of data collection for each site and each permittee. Table 1 shows the land-use characterization of the drainage areas monitored by each permittee and lists the total impervious area (TIA) estimated in each of the stormwater subbasins monitored. Because estimates of effective impervious area

(e.g., impervious surfaces that are connected via sheet flow or discrete conveyance) were not available, the TIA information was intended to provide context for the amount of land area available for dispersion to the ground surface. Not all selected monitoring locations were outfalls to receiving waters; in many cases, the monitoring location was a catch basin or other node in the system that met the project needs. Both ports monitored locations primarily representative of parking lot runoff. The locations of the monitoring sites are shown in Figure 1.

Table 1. Phase I S8.D sites and land-use summary.

Permittee	Land Use			
	Low-Density Residential	High-Density Residential	Commercial	Industrial
Clark County	43 acres 100% residential 7% TIA	239 acres 99% residential 1% open space 52% TIA	27 acres 83% commercial 17% residential 76% TIA	NA
King County	43 acres 100% residential 17% TIA	5 acres 100% residential 50% TIA	5 acres 80% commercial 20% residential 80% TIA	NA
Pierce County	219 acres 43% residential 55% open space 2% other 5% TIA	125 acres 62% residential 16% commercial 14% roadway 8% open space 28% TIA	11 acres 96% commercial 4% open space 96% TIA	NA
Snohomish County	68 acres 85% residential 15% school 26% TIA	20 acres 100 residential 40% TIA	34 acres 100% commercial 77% TIA	NA
City of Seattle	NA	85 acres 95% residential 5% commercial 50% TIA	152 acres 61% commercial 37% residential 2% open space 61% TIA	137 acres 37% industrial 32% residential 18% open space 13% commercial 51% TIA
City of Tacoma	NA	1821 acres 80% residential 19% commercial 5% open space 0.8% industrial 42% TIA	181 acres 97% commercial 3% residential 65% TIA	36 acres 15% commercial 85% residential 90% TIA
Port of Seattle	NA	NA	1.3 acres 100% commercial 95% TIA	NA
Port of Tacoma	NA	NA	1.3 acres 100% commercial 82% TIA	NA

NA: Not applicable
TIA: Total impervious area

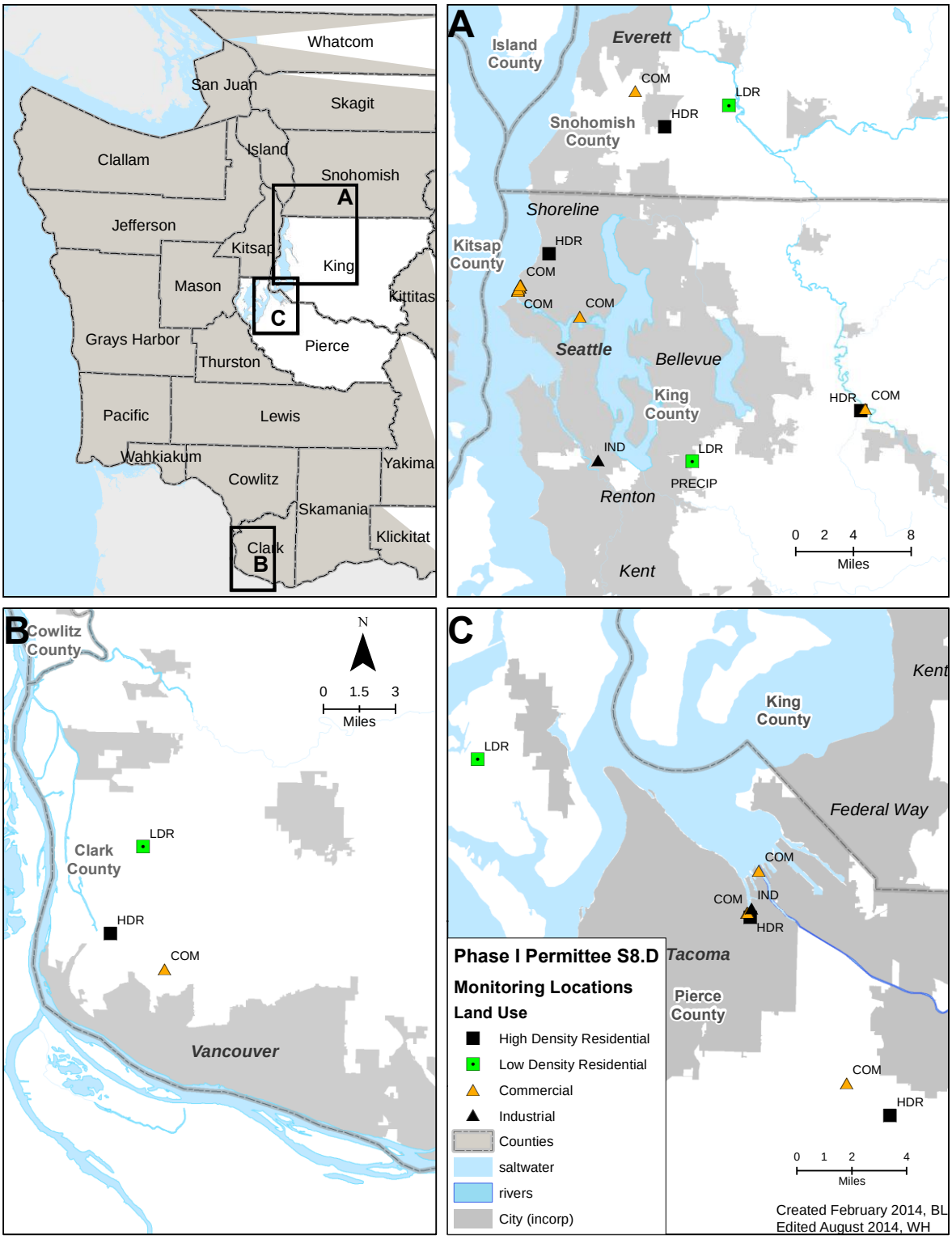

Figure 1. Site location map.

Land-use types: LDR = low-density residential; HDR = high-density residential; COM = commercial; IND = industrial

Storm-Event Criteria and Frequency

The permit specified the qualifying rainfall, antecedent dry period, and inter-event dry periods to define a storm event. The permit's criteria were highly specific and necessary to ensure consistent sampling for a regional program, particularly when considering the Pacific Northwest's winter climate with constant and sometimes overlapping wet weather patterns. Qualifying storm events were defined for the wet and dry season as follows:

All Storms

- Rainfall depth: 0.2 inch minimum, no maximum
- Rainfall duration: no fixed minimum or maximum
- Inter-event dry period: 6 hours

Wet Season (October 1 through April 30)

- Antecedent dry period: ≤ 0.02 inch rain in the previous 24 hours

Dry Season (May 1 through September 30)

- Antecedent dry period: ≤0.02 inch rain in the previous 72 hours

Permittees were required to monitor 67% of the forecasted qualifying storm events, up to a maximum of 11 storms per water year. The goal was to distribute sampling across the year with 60-80% of the storms representative of the wet season and 20-40% representative of the dry season. If, for a variety of reasons and despite good faith efforts, 11 "qualifying" storms were not sampled in a given year, a permittee could submit data from three storms that were "non-qualifying" for the 0.2 inch rainfall depth criterion.

Permittee information on timing of sampling or logistics in relation to storms is not evaluated in this report. Non-qualifying storm-event data were included in this project summary and were not differentially treated.

Parameters

Parameters were specified in both S8.D and Appendix 9 of the permit and were prioritized for each land use when the sample volume was limited. Table 2 lists the water quality parameters monitored in stormwater.

Stormwater Sample Collection

Stormwater samples were required to be collected using flow-weighted composite sampling techniques for all but two parameters. Flow-weighted composite samples best represent storm-event concentration. Flow-weighted stormwater samples were collected by automatic samplers (such as ISCO samplers), which were triggered to begin sampling once either the rainfall criteria of 0.02" of rainfall or a presence of flow in the conduit was detected. Permittees used telecommunications and automated equipment to ensure proper sample collection. A qualifying flow-weighted composite sample was required to be collected over 75% of the storm-event hydrograph. The permit defined a composite sample as at least ten aliquots, but as few as seven aliquots were accepted if all other criteria were met. Analytical results from this monitoring program are thus representative of storm-event concentrations, which provide the best indicator of the quality of the discharge over the length of a storm.

Two parameters, fecal coliform bacteria and total petroleum hydrocarbons, were required to be collected as grab samples.

Precipitation and flow volume data for each storm event were also monitored in real-time via electronic sensors.

Stormwater Sediment Monitoring Design

Entrained stormwater solids and sediments (stormwater sediments) were collected once annually. The list of parameters monitored in the stormwater sediment matrix included conventional parameters, PCBs (Aroclors), and phenols (Table 2).

The permit recommended that the sampling protocol use inline traps or other similar collection system, although a single specific sampling technique was not required. As a result, permittees used a variety of stormwater sediment sampling approaches from in-line traps to grab samples. Monitoring in-line stormwater solids using traps can be unpredictable and requires long periods of submersion and/or deployment to adequately trap sediments sufficient for analysis. Other permittees collected grab samples of stormwater sediments that had settled in catch basins. Permittees may also have treated samples differently following collection. Some may have decanted overlying water prior to laboratory analysis, whereas others may not have.

Uncertainty is higher for this stormwater sediment data in general due to the lack of defined protocols for collection and post-collection processing. This variety in collection and processing methods has an unknown impact on the variability of the stormwater sediment concentrations in the data set. For simplicity, Ecology overlooked the method of collection and combined all the stormwater sediment data for analysis, because there are far fewer numbers of samples in the data set due to the monitoring design. For the purposes of this data summary, the annual stormwater sediment samples were presumed to be comparable, and all results were compiled and evaluated. All stormwater sediment results are reported on the basis of dry weight.

Table 2. Permittee-monitored parameters.

Hydrology		
Storm-Event Precipitation		
Storm-Event Flow Volume		
Sampling-Event Flow Volume		
Water Quality		
Conventional Parameters	*Bacteria*	*Organics*
Total suspended solids	Fecal coliform	PAHs[(a)]
Turbidity		Phthalates[(b)]
Conductivity	*Metals (dissolved and total)*	Pesticides: Nitrogen (Prometon)
Chloride	Zinc	Pesticides: Organophosphates (Diazinon)
BOD_5	Lead	Herbicides: (2,4-D, MCPP, Triclopyr,
Particle Size Distribution	Copper	Dichlobenil, Pentachlorophenol)
Grain Size	Cadmium	
pH	Mercury	*Petroleum Hydrocarbons*
Hardness as $CaCO_3$		NWTPH-Dx
thylene Blue Activated		NWTPH-Gx
Substances (MBAS)		
Nutrients		
Total phosphorus		
Ortho-phosphate as phosphorus		
Total Kjeldahl nitrogen		
Nitrite+Nitrate as N		
Sediment Quality		
Conventional Parameters	*Metals*	*Organics*
Total Solids[(c)]	Zinc	PAHs[(a)]
Total Organic Carbon	Lead	Phthalates[(b)]
Grain Size	Copper	Phenolics[(d)]
Total Phosphorus	Cadmium	PCB Aroclors
Total Volatile Solids	Mercury	Pentachlorophenol
		Diazinon
		Chlorpyrifos and Malathion
		Petroleum Hydrocarbons
		NWTPH-Dx

(a) PAH compounds include at a minimum but are not limited to: 1-methylnaphthalene, 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo[b]fluoranthene, benzo(k)fluoranthene, benzo[ghi]perylene, benzo(a)pyrene, chrysene, dibenzo[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-cd]pyrene, naphthalene, phenanthrene, and pyrene.

(b) Phthalates include at a minimum but are not limited to: bis(2-ethylhexyl)phthalate, butyl benzyl phthalate, di-N-butyl phthalate, diethyl phthalate, dimethyl phthalate, and di-n-octyl phthalate.

(c) Appendix 9 of the permit mistakenly called for "Total Solids" when it should have said "Percent Solids" in the sediment parameter list. Despite the error in the text, this parameter was correctly analyzed by laboratories as the percent of the sediment sample that is the solid material (as opposed to water).

(d) Phenolics include but are not limited to: 2-methylphenol, 4-methylphenol, 2,4-dimethylphenol, and pentachlorophenol.

Laboratory Analytical Methods

The permit specified analytical methods and reporting limit targets for each parameter to ensure the stormwater data under this monitoring program were analyzed consistently and with comparable rigor among the various laboratories. In some cases, it allowed multiple methods (thought to be comparable) to be used for analysis of a parameter, provided the reporting limit target could be met. For example, conductivity could be analyzed using SM 2510 or EPA Method 120.1. Permittees used 15 laboratories for analysis; no permittee used only a single laboratory for all parameters. All data for a given parameter were pooled for analysis regardless of laboratory and regardless of analytical method.

Laboratory Quality Assurance

Each permittee's QA Project Plan was approved by Ecology and contains sections outlining the QA process and quality control (QC) procedures for its stormwater monitoring program. QA is a decision-making process, based on all available information that determines whether the data are usable for all intended purposes (Lombard and Kirchmer, 2004). QC refers to a set of standard operating procedures for the field and laboratory that are used to evaluate and control the accuracy of measurement data. Determination of laboratory QC and the overall stormwater monitoring program QA was performed by each permittee, per their QA Project Plans.

For this data analysis project, data entered into the EIM database are believed to be usable for the purpose of creating a baseline summary report as stated in the permittees' QA Project Plans.

Methods

Data Qualification

Quantitation and Reporting Limits

Reporting limits lower than those specified in the permit were allowed, provided that permittees' QC procedures were met and their instrumentation allowed resolution at a lower limit. Reporting limit and method detection limit terminology are illustrated in Figure 2. Appendix 9 of the permit listed reporting limit targets for each parameter and stated in the footnote:

> *"All results below reporting limits should be reported and identified as such. These results may be used in the statistical evaluations."*

It is Ecology's expectation that the detected concentrations below the target reporting limit were quantified and flagged as an estimate (e.g., typically a "J" flag).

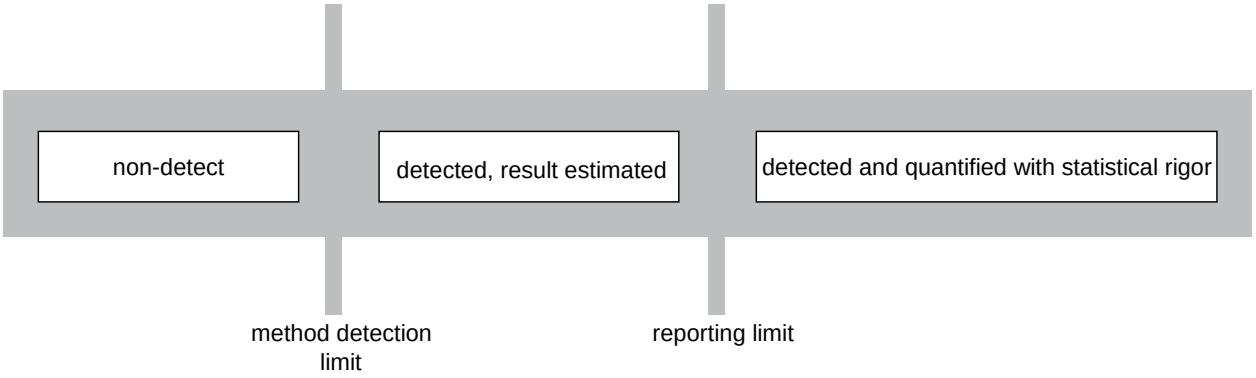

Figure 2. Simplified diagram of laboratory thresholds and data results.

Qualified Data

Data verification is the process of evaluating the completeness, correctness and conformance/ compliance of a specific data set against the laboratory method and study QA objectives. Data verification applies to activities in the field, at the laboratory, and the data user's (permittee's) review. Both the laboratory and the permittee's reviews determine whether the data record is usable as is or requires a corrective action, re-analysis, or flag to indicate qualification as estimate (J flag) or is rejected and is unusable (R or REJ flag). J flags may be given at the laboratory due to a slightly out of range QC sample or by the data QA managers (within the permittees' monitoring programs).

- *Method Detection Limit (MDL)* – The MDL is defined as the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte. The MDL is determined using the procedure at 40 CFR 136, Appendix C. The permit did not specify MDLs.

- *Reporting Limit (RL)* – The reporting limit has multiple definitions and values, because it is a user-defined value imposed upon the reporting laboratory. RL is the lowest concentration at which an analyte can be detected in a sample and its concentration can be reported with a reasonable degree of accuracy and precision. The reporting limit may vary based on the purpose and use of the data. Reporting limits should always be based on statistical rigor at each laboratory. Analyte detections between the MDL and the reporting limit are reported as having estimated concentrations. Reporting limits are typically three to five times the MDL.

Ultimately, a lack of a signal below the MDL or RL was flagged as "U" meaning the parameter was not detected. In this report Ecology refers to the non-detected data as "non-detect".

Variation in Reporting Limits

Permittees' results had highly variable reporting limits, both between samples and between laboratories. Some variability is common and expected. Generally, the laboratories met the reporting limits listed in Appendix 9 of the permit. In some cases, analyses and/or labs were changed during the three-year data collection period to ensure compliance with permit requirements.

Figure 3 shows an example of the variability in the reporting limits for one of the non-detected compounds. This type of plot was constructed for every parameter with non-detect data. The colored bars represent the non-detect value as extending from "zero" up to the threshold reported for each laboratory. This threshold may have been the MDL or the reporting limit (RL), and this was not determined for this project. Based on the data gathered for this report, there may be differences where laboratories reported the detection threshold. Below Figure 3 is a color key associated with each of the laboratories that contributed data. In this example, dichlobenil (an herbicide) had 611 storm-event concentration records, but 392 of those records were non-detects (64.2% of the records). The non-detects were reported at approximately 20 different reporting limits spanning two orders of magnitude. The Permit gave a target reporting limit of 0.01 – 1.0 ug/L for dichlobenil and other pesticides.

Non-detect data are shown in these plots as line segments extending from zero to the laboratory reporting level. The color of the line segment indicates which laboratory performed the analysis. Laboratory names were removed and represented by a number. The focus of this plot is not to identify permittees or their laboratories, but rather to illustrate the number of laboratories and RLs reported. The information about the non-detect RLs could be used to define a single, realistic RL for each parameter. However, this is outside the scope of this report.

Reporting limits vary for several reasons. Natural variability of concentrations in stormwater samples typically is greater than in surface water or wastewater samples. Natural variability is due to numerous factors such as rainfall intensity, season, air deposition, land use, and potential sampling bias towards seasonal or event-based first flush.

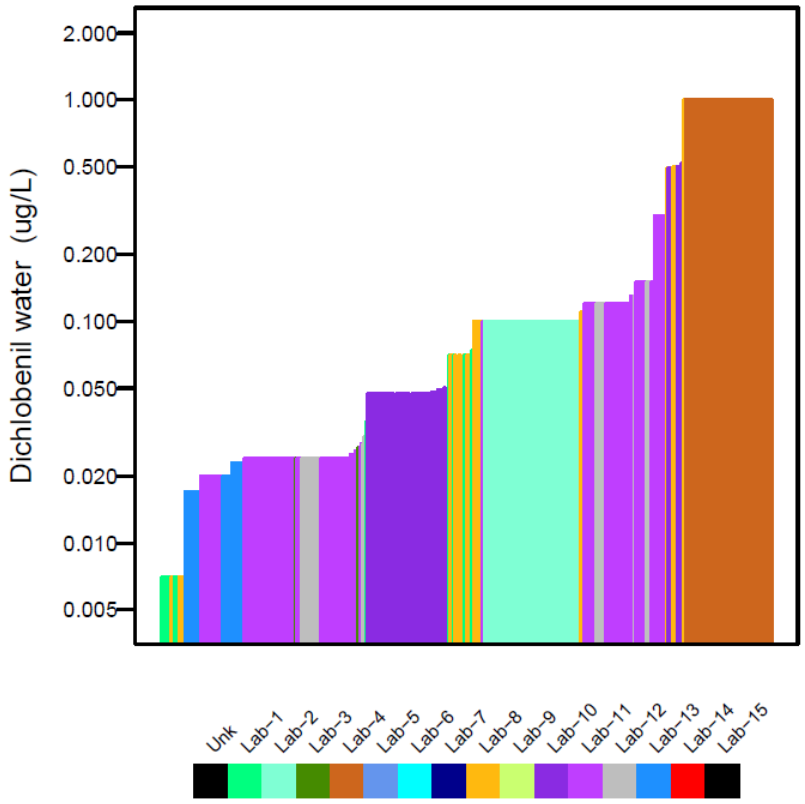

Figure 3. Non-detect reporting limits for dichlobenil by laboratory.

Other reasons for variability come from sampling design or sampling bias (e.g., sample volume collected). The sample volume typically required for an analysis has a predictable error rate associated with the analysis. When a smaller than normal volume is analyzed, the standard error increases, which increases the reporting limit. The anticipated stormwater volume was difficult to predict; it depended on the climatic event and was constrained by the capacity of the compositors. As a result, some samples were likely sent to the laboratory with less than ideal volumes.

Another major stormwater sampling source for variability is interference by compounds present in the stormwater sample (called *interfering matrix)*. Stormwater samples can contain debris, sediment, oil, and other compounds that can interfere with sensitive analytical equipment. Laboratories must clean up dirty samples prior to analyzing for the contaminant of interest. This often results in loss of resolution at low levels and, in turn, elevates the reporting limit.

Permittees were required to conduct QC and QA reviews on reported data. Because data verification was performed by the permittees, the data received by Ecology were thought to be usable. For this report, Ecology used the data as reported with few exceptions. Several obvious outliers were verified with permittees and errors resolved. Rejected records were not requested and, if supplied, were not used for summary statistics.

Data Compilation and Management

Data Collection and Accessibility

Permittees were responsible for submitting data collected under the S8.D stormwater monitoring permits, with the exception of the toxicity results, to Ecology for entry into the agency's Environmental Information Management (EIM) system (http://www.ecy.wa.gov/eim/). Toxicity results were submitted to Ecology for review. Ecology prepared a summary of stormwater seasonal first-flush toxicity on trout embryos. This summary is presented in Appendix A.

The S8.D data summarized and presented here are available in EIM. Data may be searched by various characteristics (e.g., parameter, study, geographic area). The study identification codes (IDs) for the S8.D data are detailed in Table 3.

Table 3. Summary of permittee data compiled for this report.

Permittee	EIM Study ID	Period of Record
Clark County	WAR044001_S8D	2009-2012
King County	WAR044501_S8D	2009-2013
Pierce County	WAR044002_S8D	2010-2013
Snohomish County	WAR044502_S8.D	2009-2012
City of Seattle	WAR044503_S8.D	2009-2012
City of Tacoma	WAR044003_S8D	2009-2012
Port of Seattle	WAR044701_S8.D	2009-2012
Port of Tacoma	WAR044200_S8.D	2009-2012

Data Compilation

Ecology downloaded all data associated with the project into a Microsoft Access Database File (.accdb) to query, reorganize, and manage the data into a uniform output file for analysis (Table 4). Reorganization of the data set included such items as renaming a parameter due to variability in nomenclature among the 15 labs. In addition, a number of macros for Microsoft Excel were written in Visual Basic to sum selected parameters. Once the data set was in the final form, it was exported into a comma-separated value (.csv) format, where it could be easily used in a variety of statistical packages.

Table 4. Summary of organizational considerations for stormwater data submitted to the EIM database.

Organizational Steps	Example Issues	Initial Form	Final Form
Removed extra parameters	Laboratory control samples, surrogates, or calculated sums.	Examples of removed parameters include: 1. Maximum conductivity 2. Total PAHs	NA
Parameter names	Different laboratories use slightly different naming conventions; these had to be resolved in the database.	Approximately 25 names were resolved. Example: Triclopyr Trichlopyr Triclopyr (Garlon)	Triclopyr was the chosen parameter name for the database. See Table 2 for list of parameters in the database.
Specific parameter issues (two examples)	NWTPH-Dx Multiple products can be reported.	No guidance was given for reporting.	Sums for several categories created. See description below.
	Percent Solids was erroneously named as Total Solids in permit. Total Solids refers to a water measurement, not solids.	Most of the data were labeled Total Solids	Left as Total Solids, but is thought to be Percent Solids because the sample matrix is sediment for all data points.
Units for parameters	Laboratories and permittees reported using equivalent but different units due to the methods.	Example: 1. Fecal coliform MPN/100 mL or cfu/100 mL 2. ug/L or ng/L or mg/L	Units were preserved as sent in one column, and a lookup table was used to create new columns with data in one unit per parameter for graphing and statistics analysis. Fecal coliform units were assumed to be equivalent.
Sample fraction	Dissolved, total, or total recoverable. Labs used total and total recoverable interchangeably.	There were many blanks in these fields that needed to be populated for the database.	Sample fraction for metals was understood to be totals if blank. The terms *Total* and *Total Recoverable* are interchangeable for NPDES program (EPA, 1998).

Petroleum Hydrocarbon Summations

Petroleum hydrocarbons in stormwater were monitored using an Ecology laboratory method called NWTPH (Northwest Total Petroleum Hydrocarbon; herein called *TPH*) developed in the late 1990s (Ecology, 1997).

TPH-Gx, also called gasoline range hydrocarbon method, is both a qualitative and quantitative method (extended) for assessing volatile ("gasoline") petroleum products in soil and water. Six chromatograms identified by this method include:

- Gasoline
- Weathered gasoline
- Naphtha
- Mineral spirits #1, #2, and #3

TPH-Dx, also called diesel range hydrocarbon method, is also a qualitative and quantitative method (extended) for determining semi-volatile (diesel) petroleum products in soil and water. 24 different chromatograms can be identified by this method, including:

- Jet fuels
- Kerosene
- Diesel fuel
- Diesel oils
- Hydraulic fluids
- Mineral oils
- Lubricating oils
- Fuel oils

According to the method guidance, these NWTPH chromatograms should be summed into a single TPH value. Many of the permittees' results were reported in partial-sum categories typically used at the laboratories. For example, TPH-Dx was reported not as a summed total but as sub-categories, such as "residual range organics" or "heavy fuel oil".

Ecology determined the best path forward for these results was to rename obvious and similar results, preserve the partial-sum designations, and develop a summation plan. The summed TPH-Gx fractions (gasoline, naphtha, and mineral spirits) are called Gasoline Range Hydrocarbons. For TPH-Dx, results are presented in five sub-categories: Diesel Range Hydrocarbons, Heavy Oil Range Hydrocarbons, Heavy Fuel Oil, Lube Oil, and Motor Oil.

PAH and PCB Summation

Polycyclic aromatic hydrocarbons (PAHs) were summed based on functional categories and as a total PAH concentration. Low molecular weight PAHs (LPAH) summed included:

- Acenaphthene
- Acenaphthylene
- Anthracene
- Fluorene
- Naphthalene
- Phenanthrene

High molecular weight PAHs (HPAH) summed included:

- Benzo(g,h,i)perylene
- Total benzofluoranthenes
- Fluoranthene
- Pyrene

Carcinogenic PAHs (cPAH) summed included:

- Benz(a)anthracene
- Benzo(a)pyrene
- Chrysene
- Dibenzo(a,h)anthracene
- Indeno(1,2,3-cd)pyrene

Polychlorinated biphenyls (PCBs) were summed based only on those Aroclors that were detected. All non-detect data were omitted from the sum.

Numerical Analysis

Non-Detect Data

Data sets with non-detect results, particularly with multiple reporting limits, presented complications for data analysis. A considerable amount of complexity accompanied data handling when non-detects made up a large fraction of the data set. However, data were not cast aside or uniformly substituted as a simple approach. Ecology used the approach detailed by Helsel (2012), who describes the nature, analysis, and interpretation of non-detect data.

For the analysis, no substitutions were made for non-detect data, and the data (ranks) were considered. In combining multiple data sets from the permittees, sample sizes increased and statistical power increased with more observations, which improved our confidence in using non-substitution techniques. The statistical approaches used to include the non-detect data are described in the following sections. All statistical analyses were carried out using R (R Core Development Team, 2012) and the NADA package (Helsel, 2012; Lee, 2013).

Data Distributions

Parameters with greater than a 90% detection rate were tested using the distribution hypothesis Shapiro-Wilk Test. The test excludes non-detect data and therefore is not reliable for parameters with a lot of censored data. The Shapiro-Wilk test statistic "W" tests the null hypothesis that the data represent a normally (or log-normally) distributed population. When the p-value is less than the alpha level of 0.05 (in this study), the null hypothesis is rejected.

Probability plots were prepared to assess the log-normal distribution of most parameters, including those with less than 90% detection rates. The plots provide a visual means to estimate the data distribution for any given parameter. Probability plots are described in Appendix C and shown in Appendix F.

In reality the distribution of the data was used largely for descriptive purposes only. Statistical analysis of the data was carried out using Kaplan-Meier (KM) methods which do not rely on transformed data. For those parameters summarized using tools that require data transformation (e.g., regression on statistics [ROS]), the empirical distribution function (EDF) distribution was consulted to define the necessary transformation.

Descriptive Statistics

Categorical Evaluations and Summary Statistics

For statistical analyses, Ecology defined categories within each parameter based on the rate of detection and number of observations. Categories of data are referred to as Case A, B, or C. These categories are based on Helsel's (2012) work and are delineated largely by the reliability of summarizing data using appropriate tools (Table 5). KM and ROS were employed to calculate summary statistics for the reported storm-event concentrations; (mean, median, standard error, and lower and upper confidence levels).

Table 5. Methods for estimating summary statistics.

Adapted from Table 6.11 in Helsel, 2012.

Case	Amount of Data by Parameter		
	Percent non-detect	**<50 Observations**	**> 50 Observations**
A	< 50% non-detects	Kaplan-Meier	Kaplan-Meier
B	50-80% non-detects	Kaplan-Meier Robust MLE, robust ROS	Kaplan-Meier MLE
C	> 80% non-detects	Report ranges or % above a meaningful threshold	Report ranges and high percentile concentrations

Case A

Parameters where non-detects make up less than 50% of the data set were summarized using KM statistics. Non-parametric statistics make no assumption about the data's distribution and can also be used on log-normal data to develop summary statistics. The data are ranked, including the non-detect data points, and the statistical analysis (KM) is carried out on the entire ranked data set. The method was not used if more than 50% of the data set was non-detect. For Case A data, the KM method yields robust measures of median, mean, and standard deviation.

Case B

Parameters with 50-80% of the data reported as non-detects were handled according to results from the distribution tests. For the parameters that follow parametric distributions, Helsel (2012) recommends that either substitution methods, robust Maximum Likelihood Estimations (MLE) or robust Regression on Order Statistics (ROS), be followed. However, the majority of the parameters that fell into the Case B situation were not normally distributed.

For these, Ecology calculated summary statistics on the portion of Case B parameters that had more than 50 observations. ROS was used to estimate the summary statistics for this portion of the Case B data.

However, for data sets with fewer than 50 observations, both ROS and MLE provide poor estimates of summary statistics. Thus these data were summarized as a Case C category because Ecology determined that the statistics would be unreliable.

Case C

Case C data were simply summarized as ranges. Calculating other summary statistics would have been unreliable (Helsel, 2012).

Land-Use Significance

To determine if there were significant differences between land uses for a given parameter, Ecology relied on the Peto-Prentice test. The Peto-Prentice score test has been shown to perform well with data sets that have unequal sample sizes and unequal censoring (i.e., detection limits) (Helsel, 2012). The Peto-Prentice is a modified generalized Wilcoxon test, where scores are weighted by the EDF. The Peto-Prentice test identifies when at least one land use among the four has significantly different concentrations. To visualize any significant differences among land uses for each parameter, a plot of the EDF can be produced.

Summary Plots

Ecology relied on six types of plots as visual tools to describe the concentration data (Appendix C). Each set of plots for each parameter consists of:

- Jitter Plot
- Probability Plot
- Non-Detects
- Empirical Distribution Function (EDF)
- Box Plot by Land Use
- Box Plot by Season

Appendix C contains a description of how to read each of these six plots (reproduced from Lubliner and Newell, 2013). Appendix F contains a page for each parameter with all six plots and matrix combination. Ecology also used box plots, cumulative density functions, and jitter plots to describe the contaminant loads (Appendix H).

Multivariate Statistics

In order to summarize multiple parameters for each stormwater catchment together with land use and observe any relevant similarities or associations among them, Ecology relied on principal components analysis (PCA). PCA is a statistical tool that describes the relative similarities among environmental variables (stormwater parameters) and study sites. Multiple axes or components are computed in decreasing order of strength or importance. Each axis represents a synthetic gradient across the sample sites, some more important than others. Visually, a plot of the two most dominant axes (an ordination diagram) can provide an effective means to describe large complex data sets. Points or sites on the plot that cluster together are more similar than

those that are more distant. Ecology selected those variables that appeared to be statistically relevant from the prior Peto-Prentice test. The PCA was run on the median concentration values as described above using the statistical techniques for non-detect data. Only parameters which were complete across all study sites were included in the analysis. Data were log transformed, centered, and standardized prior to the analysis. PCAs were run using the R framework and the Vegan package (Oksanen et al., 2013).

Additional tools used to detect similarities among the parameters across the land uses included a hierarchical cluster analysis and an analysis of similarities. The same data set used for the PCA analysis was used for the cluster analysis. Ecology calculated the Euclidean distance (measure of dissimilarity) between sample sites and computed the cluster analysis using Ward's minimum variance method (Hartigan, 1975). This technique is a way of identifying groups of data (sites) that are similar. Visually, a cluster diagram or dendrogram shows the groups of sites starting with the most dissimilar and then continues to separate the sites into groups until each site is on its own branch of the tree (dendrogram). We used the first two major separations of sites in the cluster dendrogram to describe similar 'groups' of sites based on their stormwater chemistry.

Analysis of similarities is a tool to statistically test whether there are significant differences between two or more groups of sampling units based on a dissimilarity matrix. We used the same dissimilarity matrix as the cluster analysis. Ecology employed this test to help determine whether there is a significant difference among land uses based on all sites and all relevant parameters. This differs from the previously described Peto-Prentice test for land-use significance, which tests a single parameter for significant differences.

Comparison to Stormwater Studies and Water Quality Criteria

To put the results of this compilation effort into context, Ecology used three primary sources of information for comparison of these results:

- A suite of literature including the Nationwide Urban Runoff Program (NURP) (EPA, 1983) and analysis of the National Stormwater Quality Database (Maestre et al., 2005).
- Washington State Water Quality Criteria. The national studies and the WA state water quality criteria form the "bookends" for comparison of the stormwater discharge results of this compilation effort.
- A local study to characterize stormwater concentrations and load to Puget Sound from the receiving water during storm events, *Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates* (Herrera, 2011) (called *PS Toxics Study* in this document).

Relevant Stormwater Studies Explored

The median concentrations from this study are compared to the median concentrations of a few other stormwater studies where data exist. Comparisons made to these other studies are informative for this database and are included to give context to the results of this study.

- The Nationwide Urban Runoff Program (NURP) (EPA, 1983).

- Nonparametric Statistical Tests Comparing First Flush and Composite Samples from the National Stormwater Quality Database (NSQD) (Maestre et al., 2004).
- The National Stormwater Quality Database, Version 1.1; A Compilation and Analysis of NPDES Stormwater Monitoring Information (Maestre et al., 2005) http://rpitt.eng.ua.edu/Publications/Stormwater%20Characteristics/NSQD%20EPA.pdf
- Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates (Herrera, 2011) (called *PS Toxics Study* in this document).

NURP and NSQD

The NURP study was a research project conducted by the U.S. Environmental Protection Agency (EPA) between 1979 and 1983. NURP was the first comprehensive study of urban stormwater pollution across the United States and established the national stormwater quality benchmark. NURP samples were also collected to represent the storm-event concentration, which allows us to compare results from the permittees directly. The study evaluated the stormwater data distributions and concluded that 90% of their study parameters followed a log-normal distribution.

The NSQD was created in the mid-1980s to store stormwater data collected by the NURP study and other Phase I MS4 data. Over time, the database gained some specialized U.S. Geological Survey stormwater studies and more recently selected outfall data from the International BMP Database. Several reports have been published by Alex Maestre and Robert Pitt, summarizing the stormwater monitoring data contained in versions of the database over the last 20 years (Version 1.0, 1.1 and 2). Version 3 of the NSQD is available online at: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml.

PS Toxics Study

The *PS Toxics Study*, the largest local study of receiving waters to date, was initiated to assess the relative loading and identify sources of toxic contaminants to Puget Sound. River and streams were sampled in 2009-2010 in multiple watersheds during baseflow and storm-event flows. Stormwater discharges were not directly sampled. Contaminant concentrations were measured and annual mass loads and annual loading rates were calculated.

In this report Ecology compares the stormwater discharge concentrations to the *PS Toxics Study* ambient data, and acknowledges this as an "apples to oranges" comparison. The permittees collected flow-weighted composites from stormwater discharges across 75% of the storm event's hydrograph. The *PS Toxics Study* samples were collected as grab samples from the receiving waters during storm events. The instream concentrations as captured by the *PS Toxics Study* were anticipated to be lower than stormwater discharge concentrations, particularly in urban areas. Nevertheless, it does give us a sense of the scale of differences and an understanding of where patterns in the results are similar.

Loads calculated for this stormwater discharge data compilation are event loads and not annual loads like those calculated in the *PS Toxics Study*. Thus, loading results are too dissimilar and are not comparable. Ecology can compare the trends across land uses for both concentrations and loads.

Water Quality Criteria

Promulgated water quality standards as well as non-promulgated criteria exist for a number of parameters measured in these stormwater discharges. The authors of this report used the Washington State acute and chronic freshwater standards (WAC[4] 173-201A), for comparison to provide context for the stormwater discharge results. For stormwater sediments, the authors made a comparison to freshwater sediment chemical criteria (Chapter 173-204 WAC). The comparisons do not include any consideration of the receiving water. These comparisons are not intended to, and are not appropriate for, determining compliance with regulatory requirements, such as water quality standards and permit conditions.

Water

The criteria for the protection of aquatic life in surface waters of the State of Washington are promulgated under Chapter 173-201A WAC. As defined by EPA (1994), the exposure periods assigned to the acute criteria are expressed as: (1) an instantaneous concentration not to be exceeded at any time or (2) a 1-hour average concentration not to be exceeded more than once every three years on the average. The exposure periods for the chronic criteria are either: (1) a 24-hour average not to be exceeded at any time or (2) a 4-day average concentration not to be exceeded more than once every three years on the average.

Each individual stormwater sample (recall that each sample is a composite across a storm event) was compared to the criteria value. For pH and hardness dependent criteria, Ecology wrote scripts in R to use each stormwater sample's pH and hardness result. If the concentration for a sample was non-detect, then it was excluded from the comparison. See Table ES-1 for results of the criteria comparisons.

Sediment

Sediment criteria are found in Washington State's Sediment Management Standards (SMS) (Chapter 173-204 WAC). The marine Sediment Quality Standards (SQS) found in Part III of the SMS are approved by EPA as water quality standards for the protection of the benthic community. Because these promulgated water quality standards values are for marine sediments only, the authors compared the stormwater sediment data to the freshwater sediment chemical criteria established as Sediment Cleanup Objectives (SCOs) in WAC 173-204-563. These SCO criteria are based on a "no adverse effects level" to the freshwater benthic community. At the time of this publication, EPA has neither approved nor disapproved the numeric freshwater sediment criteria as water quality standards.

Stormwater sediment concentrations are expressed as dry weight and not normalized to organic carbon content, which is suitable for the purposes of this contextual comparison (Michelson, 1992).

[4] Washington Administrative Code

Approaches to Non-Detected Data in the Stormwater Literature

In the NSQD Version 1.1 review, Maestre et al. (2005; Chapter 3) provide a review of how non-detects have been handled in stormwater studies. More recent environmental, and particularly stormwater, studies have used substitution techniques to substitute either one-half or full value of the method detection limit (MDL) for the value of the non-detect. This has been a common practice for data sets with relatively few non-detect data points. Antweiler and Taylor (2008) indicate that using substitutions for non-detects produces comparable summary statistics.

In the NURP study, non-detected data were summarized using substitution of the value of the reported detection limit. In the NSQD version 1.1 data summary, non-detected values were estimated using the Cohen's maximum likelihood method. This is a method that randomly generates the missing data based on the known probability distributions of the data (Maestre et al., 2005). The *PS Toxics Study* estimated the non-detect values by substituting one-half the value of the detection limit (Herrera, 2011). Comparisons of the permittee's data results to NURP, NSQD, and the *PS Toxics Study* are considered approximate because the methods for sample collection and data analysis differed among the studies.

Despite different methods for handling non-detects, comparisons of median values were retained in this report because the NURP and NSQD represent the earliest and largest national stormwater quality characterization efforts in the United States. Most of the parameters monitored in the NURP and NSQD were limited to the conventional parameters, nutrients, and metals where non-detections are infrequent and typically have less influence on summary statistics. The *PS Toxics Study* is the most recent regional publication with wet weather surface water concentrations for toxic pollutants.

Results and Discussion

Database Description

The final stormwater discharge characterization data set comprises 44,800 records across 172 parameters, where each record is a single value for a particular parameter. Table 6 summarizes this database by permittee, period of record, land use, and data type. Permittees achieved three years of data collection in different ways. In some cases, partial years were summed to achieve the permit requirements. In other cases, more than three years of data were collected in part to accommodate individual permittee objectives for evaluating loading on a water year basis.

Table 6. Number of records by permittee, land use, and year.

Permittee	Land-Use Type	Number of Records					
		2009	2010	2011	2012	2013	Totals
Clark County							
	Commercial	--	624	1034	324	--	1,982
	High-Density Residential	--	417	945	436	--	1,798
	Low-Density Residential	--	489	533	549	--	1,571
King County							
	Commercial	189	603	647	391	355	2,185
	High-Density Residential	191	498	433	298	73	1,493
	Low-Density Residential	145	815	664	130	212	1,966
Pierce County							
	Commercial	--	321	652	500	217	1,690
	High-Density Residential	--	76	393	171	97	737
	Low-Density Residential	--	139	548	346	183	1,216
Snohomish County							
	Commercial	407	1,012	816	544	--	2,779
	High-Density Residential	582	855	734	520	--	2,691
	Low-Density Residential	543	972	1,305	424	--	3,244
City of Seattle							
	Commercial	202	986	861	372	--	2,421
	High-Density Residential	372	913	654	509	--	2,448
	Industrial	203	941	879	376	--	2,399
City of Tacoma							
	Commercial	332	987	753	461	--	2,533
	High-Density Residential	352	723	1,223	870	--	3,168
	Industrial	289	655	624	456	--	2,024
Port of Seattle							
	Commercial	1,465	1,435	1,106	171	--	4,177
Port of Tacoma							
	Commercial	362	699	731	486	--	2,278
	Totals	5,634	14,160	15,535	8,334	1,137	44,800

Data Quality

Suitability for All of Western Washington

Concentrations monitored under the Permit reflect a range of results by land uses that can be applied to urban and suburban stormwater discharges in western Washington. The permittees monitored both large and small drainages. Ecology determined that both the range of concentrations and median values were useable and represented stormwater quality in western Washington. By summarizing multiple years of data, Ecology also accounted for inter-annual variability.

Pollutant concentrations overlapped between the land uses, and this variability increased confidence in the representativeness of the monitored basins. Table 1 illustrates the mix of land uses for each monitored basin.

Laboratory and Field Quality Control

The data entered into EIM has already undergone external quality control methods (e.g., field replicates, laboratory and field blanks) as defined by the permit. Laboratory assigned data qualifiers were relied upon to define detection rates and the degree to which a parameter is censored. No further quality assessment of the data quality was carried out during this analysis. The number of samples with data qualifiers (flags) for each parameter is presented by matrix in Appendix D, Table D-2, and by land use in Table D-3.

Data Distribution and Case Summary

The distribution defined by the Shapiro-Wilk test for each parameter is described in Table D-1. Parameters are divided into three categories: normal, log-normal, and distribution-free.

Water samples were found to have the following distributions:

- log-normal (18 parameters)
- distribution-free (59 parameters)

Sediment samples were distributed as follows:

- normally (3 parameters)
- log-normally (15 parameters)
- distribution-free (32 parameters).

Ecology restricted distribution testing to the parameters with the highest rates of detection and found that many of the parameter's probability plots (Appendix F) appeared nearly linear, indicating log-normal distribution.

Data Case Summary

The reliability of the data summaries depends on the level of detection for each parameter and is defined by the "case" category for each parameter as indicated in Table 5. Table D-4 describes, by land use, the case category for each parameter. Overall, 88 parameters were classified as Case A, 31 parameters as Case B and 53 parameters as Case C.

These results largely agree with the National Urban Runoff Program (NURP) results. NURP, a large national stormwater study, found that stormwater event mean concentrations (EMCs) for most parameters followed either log-normal distributions or were distribution-free (non-parametric) (EPA, 1983).

High Frequency Non-Detected Parameters

This monitoring program provided a suitable sample number and range of conditions to determine whether certain parameters could be reduced in sampling frequency or excluded from future stormwater monitoring studies. Note however that site-specific or study-specific circumstances may still necessitate the collection of these parameters.

With the exception of dissolved mercury (91.2% non-detect), the inorganic parameters were largely detected. Mercury was analyzed using a different method from other metals (SW7470). Reduction in frequency of dissolved mercury analysis using this method is justified; another method with a lower reporting limit may be more suitable in future studies.

The parameters detailed in Table 7 for stormwater and stormwater sediments were almost completely (>90%) undetected.

Insoluble Organics

The parameters in Table 7 were largely insoluble organic pollutants such as volatile and semi-volatiles; PCBs, phthalates, pesticides, or PAHs. Many organic compounds tend to adsorb to solids, making them easier to detect in the sediments. More volatile or more easily degraded (low molecular weight) chemicals may not have been found in stormwater samples, because they may have been older and weathered.

However, monitoring costs would not likely be reduced by removing a limited number of organics from the monitoring list, since the non-detected parameters from the EPA Method 8270D analytical list are often measured at no additional fee. However, for parameters that require a separate sample or a different extraction method, elimination of those parameters would reduce costs. For example, several pesticides were not found in stormwater or stormwater sediments. In particular, malathion, diazinon, prometon and chlorpyrifos were infrequently detected in both water and sediment. Furthermore, many of the phenols analyzed in sediment samples were detected in only 1 or 2 samples, although the sediment data set has fewer sample number. Pentachlorophenol and phenol degradation products (e.g., p-cresol) may be the most worthwhile parameters to monitor on a consistent basis.

Soluble Organics

The BTEX compounds were all listed in Table 7. This indicates that these four parameters are not found in stormwater, either because they are infrequent contaminants or because they volatilize prior to sampling.

Table 7. Stormwater and stormwater sediment parameters with >90% non-detect data.

Parameter in stormwater	% non-detect	Number of samples	Parameter in stormwater sediment	% non-detect	Number of samples
Insoluble organics			***Organics***		
Chlorpyrifos	99.8	644	2-Nitrophenol	100.0	23
Diazinon	99.1	644	2,4-Dichlorophenol	100.0	24
Malathion	98.9	643	2,4,5-Trichlorophenol	100.0	24
Prometon	96.4	607	2,4,6-Trichlorophenol	100.0	23
1-Methylnaphthalene	96.2	290	Prometon	100.0	15
Acenaphthylene	93.5	634	Chlorpyrifos	98.1	53
p-Cresol	92.3	26	Diazinon	98.1	52
Mercury	91.2	444	Malathion	98.1	53
Acenaphthene	90.2	634	4-Chloro-3-Methylphenol	95.2	21
			4-Nitrophenol	95.2	21
			Diethyl phthalate	94.6	56
			PCB-Aroclor 1248	93.9	33
			2,4-Dimethylphenol	92.9	42
			2,4-D	91.7	12
			Mecoprop	91.7	12
			Triclopyr	91.7	12
Soluble Organics					
Ethylbenzene	100.0	120			
Benzene	99.2	120			
BTEX	97.5	120			
Toluene	97.5	120			
Total Xylenes	99.2	120			

Hydrology

Storm Events

Storm events were described by the permittees as *sample volume* and *storm volume*. Sample volume represents the volume that flowed between the first and last automated sample. Storm volume represents the total volume that flowed during the storm. Permittees also measured the total precipitation amount during the storm.

Ecology assessed how the precipitation amounts of the sampled storms compared to the complete record of precipitation from SeaTac International Airport and Vancouver, Washington as a way of showing how representative the storms were (Figure 4). Ecology recognizes that comparing only to SeaTac precipitation records for the Puget Sound region does not acknowledge the regional variability. Data were accessed from the National Climatic Data Center (administered by NOAA) and are daily precipitation totals, while permittee data are median storm-event precipitation totals. From Figure 4 it is clear that the sampling by permittees did an excellent job of capturing the general timing of major storm events for the regions.

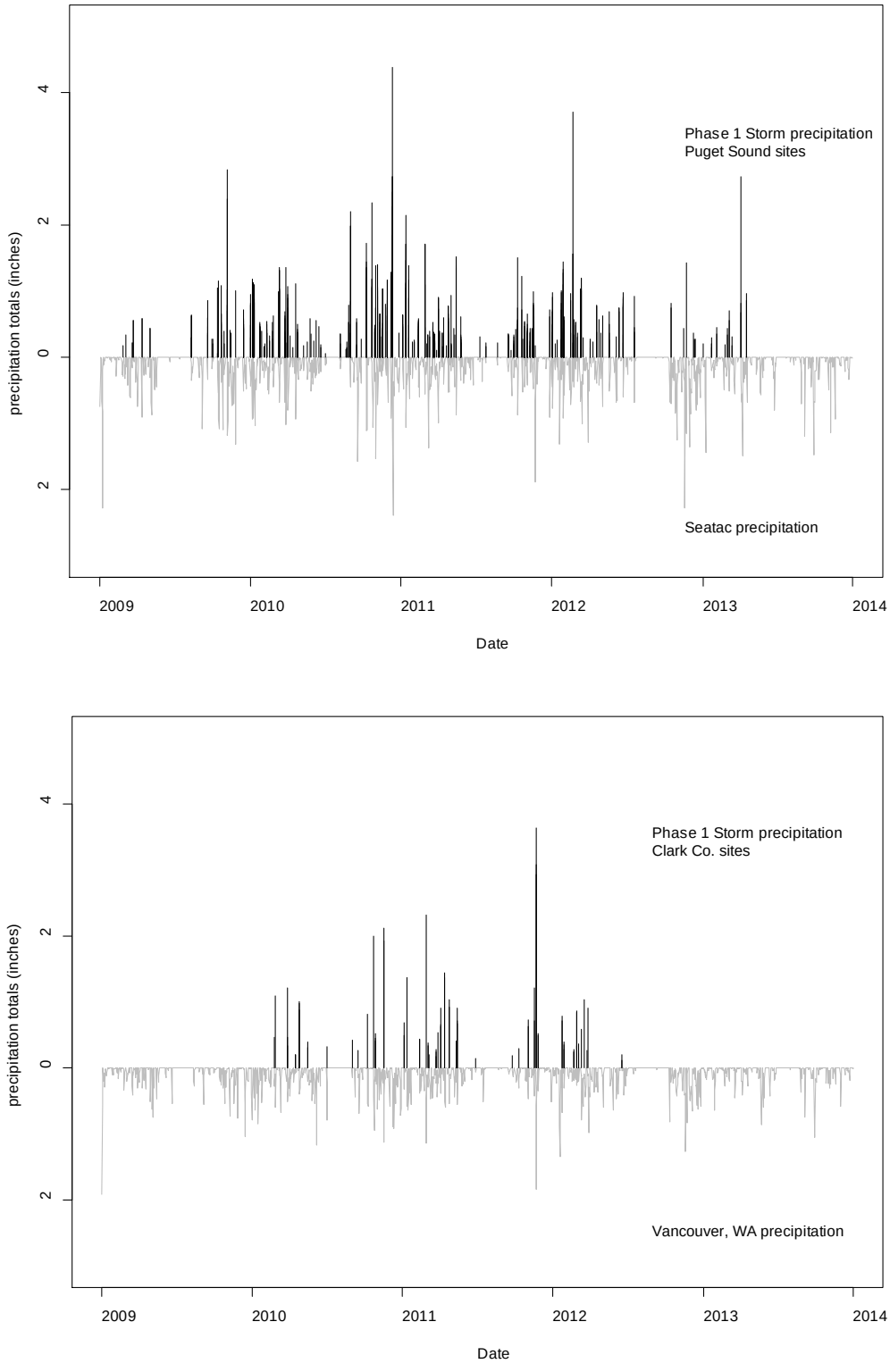

Figure 4. Median measured event precipitation totals for sample locations in the Puget Sound region and Clark County (upper sections of the graphs), combined with daily precipitation totals from SeaTac International Airport and Vancouver, Washington (lower sections of the graphs).

The total number of successfully sampled storm events is estimated in Table 8 by counting the unique start date at each location sampled. Some parameters were collected as discrete grab samples and could possibly be double-counted if two grab samples were collected over two storm-event days. However, given the small number of grab samples (< 1% of samples), it is unlikely this impacts the summary in Table 8. Each permittee was required to sample 67% of the forecasted qualifying storms, up to a maximum of 11 actual events per year. The Port of Seattle and Tacoma had low total numbers of samples, but this reflected a single sample point. In general, these two ports sampled storm events that were well distributed throughout the year. Pierce County collected the fewest number of samples distributed over each year, particularly for the high- and low-density residential land use. The lack of samples in Pierce County residential sites did not appear to bias the overall sample totals for these land-use types.

Table 8. Number of unique sampling dates for each permittee and land use.

Permittee	Count of Unique Sample Events	Land Use	Count of Unique Sample Events
City of Seattle	102	Commercial	262
City of Tacoma	110	High-density Residential	164
Clark County	79	Industrial	66
King County	80	Low-density Residential	105
Pierce County	44		
Port of Seattle	40		
Port of Tacoma	29		
Snohomish County	113		
Total	597	Total	597

Sample Representativeness

As detailed in the *Introduction* section, water samples were collected using flow-weighted automated samplers that allow for a sample that is representative of storm-event concentrations. The permit required the collection of at least 75% of the hydrograph for storms lasting less than 24 hours. For those storms greater than 24 hours, samples were collected for at least 75% of the storm during the first 24 hours. The remaining 25% of the event was typically sampled no more than 48 hours. Permittees reported both the volume of the sampled event and the whole storm event to Ecology. The representativeness of each storm by the respective sample was calculated from the data set by comparing these two reported volumes (Table E-1).

The vast majority of the sites showed that the collected and analyzed composite sample represented approximately 80-90% of the whole storm (Figure 5). The permit required the collection of at least 75% of the hydrograph, which appears to have been achieved. Visually comparing the percent of the storm sampled to the size of the storm, site location, wet or dry season, or the sample year, there appears to be no bias by these parameters on the percent of the storm sampled (Appendix E).

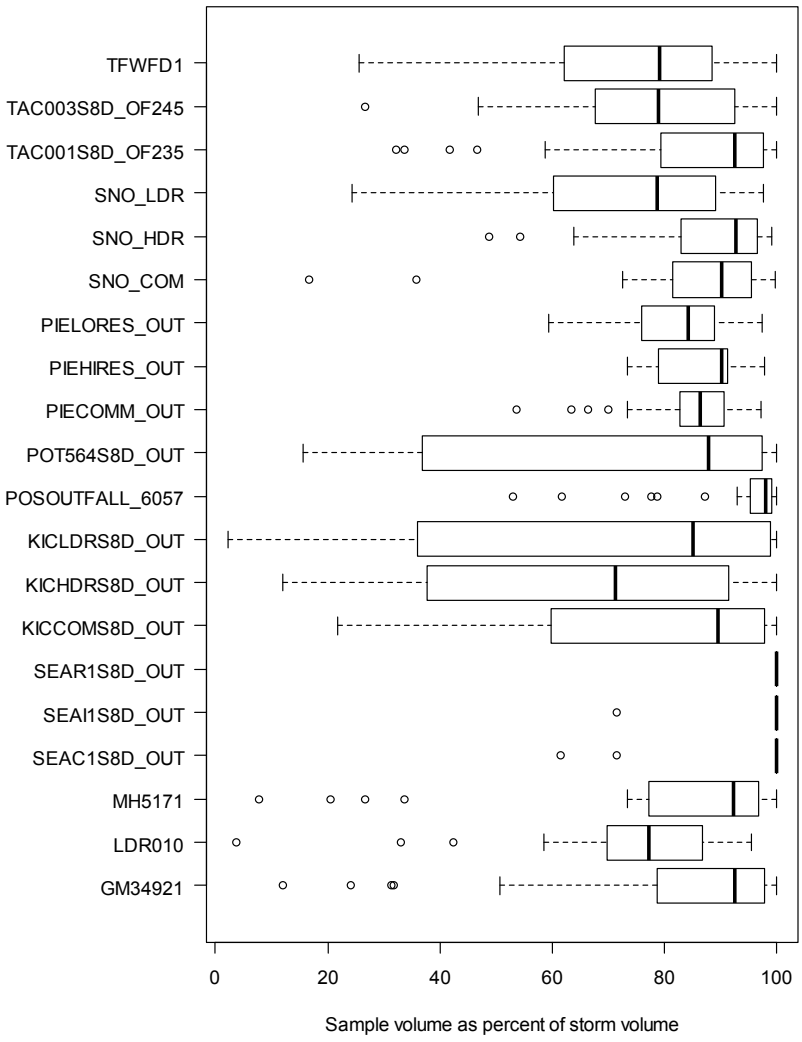

Figure 5. Percent of each storm captured by sampling for each sample site.

The permit required that the permittee collect grab samples for total petroleum hydrocarbons (TPH) and bacteria at the beginning of the storm. Permittees also sometimes collected grab samples for other parameters when the stormwater flow was insufficient for a composite or when attempting to sample the first flush. Overall, 535 records of samples collected using grab methods for parameters other than TPH and bacteria were found in the final data set. This represented only ~ 1% of the records, and these samples were not removed from the data set.

Runoff Coefficients

Ecology calculated the runoff coefficient for each stormwater catchment. The runoff coefficient is the ratio of total stormwater volume that flowed between the first and last automated sample (sample volume) to total rainfall volume across the catchment area. It therefore represents the amount of total rainfall that is captured by the stormwater drainage. Runoff coefficients ranged

from 0.05 to 1.00. Typically, Ecology would expect that as the amount of paved surface (percent total impervious surface) increased, more rainfall would have been directed into the storm catchment (yielding a higher ratio). This was true for sample sites with greater than 40% impervious surface (Figure 6). For sample sites with less than 40% impervious surface, the relationship was more variable. Two of the high-density residential catchments with low-percent impervious surface had very high runoff coefficients, suggesting that in these drainage basins the conveyance of precipitation to the stormwater system was greater than in drainage basins with more paved surface. It is unclear why this was the case, and it deserves further inquiry. Ecology can say that it did not appear to be related to catchment size or storm volume. We can speculate that the unusual runoff coefficients may be a result of: (1) incorrect basin delineation or (2) inaccurate flow data.

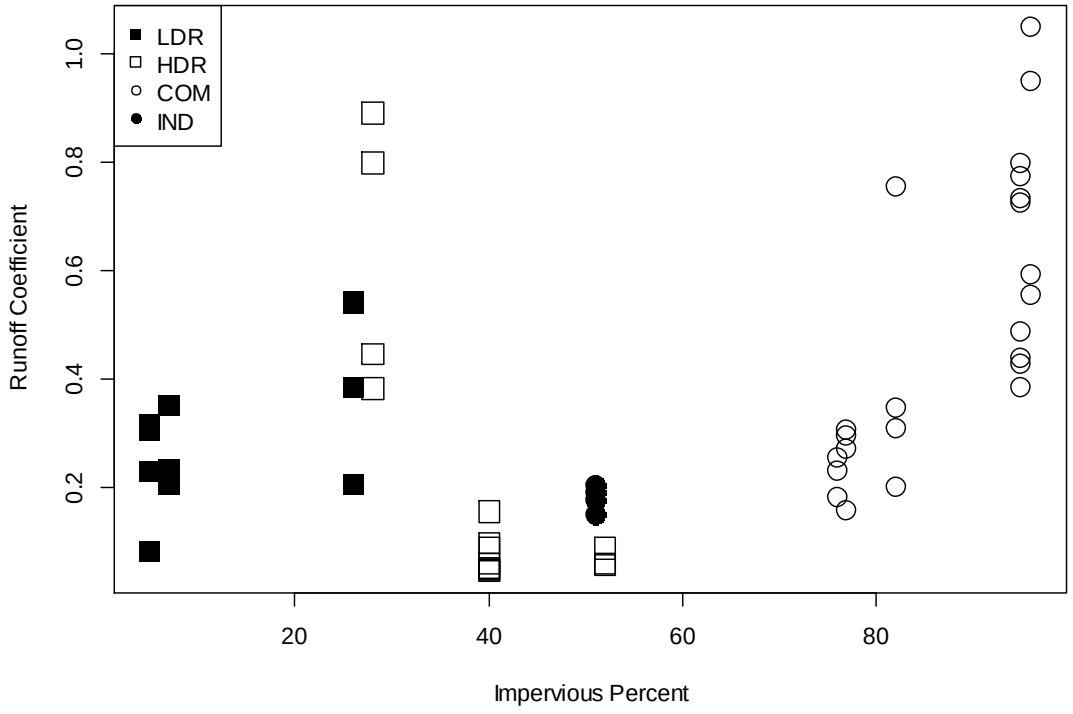

Figure 6. Runoff coefficient for each catchment basin, categorized by land use, relative to the percent impervious surface within each catchment.

Land-use types: LDR = low-density residential; HDR = high-density residential; COM = commercial; IND = industrial

Contaminant Concentrations

In this section, contaminant concentrations are discussed as *median values* (50th percentile) unless otherwise noted; therefore, Ecology is purposely not using the acronym EMC (event *mean* concentration). A summary table of each parameter appears below the parameter headings in each of the subsequent sections. Further detail on parameter summary statistics are calculated

and shown as combined land uses in Appendix G, Table G-1, separated by land uses in Table G-2, and by wet and dry seasons in Table G-3.

Where applicable, the contaminant concentrations were compared with water quality criteria as defined in the earlier section, *Water Quality Criteria*. The graphical description of each parameter's concentrations (in alphabetical order) is provided in Appendix F. Summary Figures G-1 through G-3 show graphics of stormwater concentrations ranges in comparison to various water quality criteria.

Conventional Parameters

The conventional parameters (except surfactants) were detected with high frequency (except surfactants) (Table G-1) and were considered as Case A for statistical summaries. All of the conventional water parameters, except pH, were found to have at least one land use for which concentrations were significantly different. Stormwater sediment conventional parameters (TOC and grain size) did not differ between land uses. Figure 7 summarizes the range, median, and 90th percentile for each conventional parameter in stormwater.

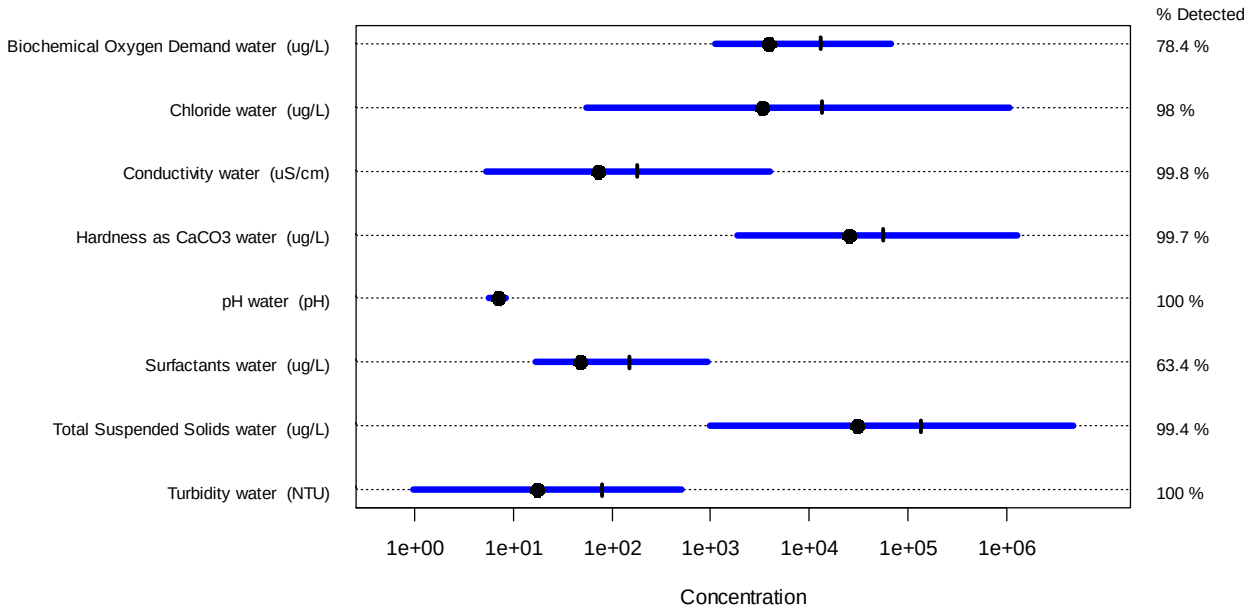

Figure 7. Summary of conventional parameters in water.

Blue horizontal segment is the contaminant range, black dot is the median concentration, vertical black segment is the 90th percentile concentration. The x-axis is logarithmic. The rate of detection for each parameter is listed on the secondary y-axis.

Fecal Coliform

Only 6.6% of the fecal coliform samples were below the detection limits, and the majority of these were in areas of low-density residential land use. Significantly lower fecal coliform counts were found in low-density residential land use (47 cfu 100 ml^{-1}), while none of the other land uses showed significant differences (Table 9). Fecal counts were also significantly higher during the dry season (1,220 cfu 100 ml^{-1}) compared with the wet season (300 cfu 100 ml^{-1}).

Table 9. Summary of fecal coliform bacteria data (cfu/100mL).

Land Use	Detected (%)	Count	Min	Max	Geometric mean	Arithmetic mean	SE	Median	90th percentile
Industrial	100	49	2	9.2×10^4	1,062	4,683	1,969	991	12,000
Commercial	96.8	251	1	1.1×10^6	442	7,198	4,392	515	6,900
High-density residential	94.3	157	2	1.6×10^5	260	3,631	1274	350	5,000
Low-density residential	80.6	103	1	1.6×10^4	40	675	209	47	1,600
Overall	93.4	560	1	1.1×10^6	264	4,778	2,009	350	5,400

SE = standard error of the arithmetic mean

The median values for fecal coliform were well below those observed from the NSQD; however, the ranges found in both studies overlapped. Seasonal data from NSQD (Pitt et al., 2004) also suggested that higher concentrations prevail during the summer and fall months. This is similar to the findings of the compiled permittee data set.

Surface water standards for fecal coliform apply to waters with a recreational intended use. For those waters in the secondary contact recreation category, fecal coliform counts cannot exceed a geometric mean of 200 cfu 100 ml^{-1}, with no more than 10% of the samples exceeding 400 cfu 100 ml^{-1}. Each land-use class, except low-density residential, exceeded the criteria (Table 9).

Conductance, Hardness, pH, and Chloride

Table 10. Summary of conductivity, hardness, pH, and chloride concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Conductance (uS cm^{-1})	99.8	5.3	72.3	4,020	yes	yes
Hardness (as ug L^{-1} $CaCO_3$)	99.7	1,900	25,200	1,300,000	yes	yes
pH	100	5.6	7.0	8.26	yes	no
Chloride (ug L^{-1})	98	55	3,300	1,080,000	yes	no

Conductance was significantly higher in discharges from industrial land-use areas (158 uS cm^{-1}; Appendix F). Interestingly, low-density residential land-use areas discharged runoff significantly higher in conductance (99 uS cm^{-1}) than commercial and high-density residential land-use areas. No real differences were found between dry and wet season samples.

Similar trends were found for both hardness (as CaCO3) and chloride concentrations. Chloride is regulated under the water quality standards. For chloride concentrations, 4 out of 551 samples exceeded (did not meet) the chronic water quality criteria for the protection of aquatic life. No samples exceeded the acute criteria.

The pH of the samples varied very little. The range of pH was 5.6 to 8.3 with a mean ± 95% confidence interval (CI) of 6.9 ± 0.03. Areas of high-density residential land use had slightly lower pH values. No significant differences between wet and dry seasons were found (Appendix F).

Surfactants and Biochemical Oxygen Demand (BOD)

Table 11. Summary surfactants and biochemical oxygen demand concentrations.

Parameter (ug L^{-1})	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Surfactants	63.4	17	47	920	yes	yes
BOD	78.4	1,100	3,900	68,000	yes	yes

Stormwater surfactant concentrations were strongly influenced by land use, where industrial and commercial land uses discharged comparable concentrations (63 ug L^{-1} and 64 ug L^{-1}, respectively) compared with significantly lower concentrations from high-density residential (36 ug L^{-1}) and low-density residential (14 ug L^{-1}) land-use areas. In low-density land-use areas, 70% of the samples were below the detection limit. Greater concentrations of surfactants were found during the dry season than the wet season (mean ± 95%CI; 114.5 ± 23.4 ug L^{-1} and 64.7 ± 7.0 ug L^{-1}, respectively).

BOD was detected in 78.4% of all samples. The vast majority of the non-detects occurred in discharges from the low-density residential land use (62.4% of the non-detects). Commercial land-use areas discharged the highest concentrations (5,600 ug L^{-1}). Higher BOD concentrations were found during the dry season (7,200 ug L^{-1}) compared with the wet season (3,600 ug L^{-1}).

BOD measurements in the NSQD were very similar in range to the data in this study, with commercial land uses discharging the highest concentrations. The median values for land-use categories were not as high as those in the NSQD. Surfactants were not quantified in other studies.

Turbidity and Total Suspended Solids (TSS)

Table 12. Summary of turbidity and total suspended solid concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Turbidity (NTU)	100	0.98	17.3	500	yes	no
TSS (mg L^{-1})	99.4	1	31	4,700	yes	no

Significantly higher turbidity was found in industrial areas compared with the other land uses (34.5 NTU). Significantly higher TSS concentrations were also found in industrial land-use discharges (48 mg L^{-1}) when compared with low-density residential land-use areas (14 mg L^{-1}). No significant differences in turbidity or TSS were found between wet (17.9 NTU and 29.8 mg L^{-1}, respectively) and dry (15 NTU and 34.6 mg L^{-1}, respectively) seasons (Appendix F).

In comparison to the *PS Toxics Study*, TSS concentrations in this data set were similar for residential land uses but significantly higher for industrial land uses. Overall, across all land uses, the median TSS values were much higher than that reported for the receiving waters sampled in the *PS Toxics Study*. However, median TSS concentrations reported here were much lower than results reported in the NSQD and NURP but within the ranges reported in these databases.

Total Organic Carbon (TOC) and Grain Size in Sediment

Table 13. Summary of total organic carbon concentration in sediments.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
TOC (%)	100	0.002	11	68	yes	no

The TOC of sediment samples ranged from <1% to 68%, and generally varied very little among samples (median was 11; mean of 12.7 ± 1.2% standard error). Slightly higher concentrations of TOC were noted in samples from commercial land-use areas. Overall, stormwater sediment composition was 29.4% fines and 77.3% sand, median values for combined land uses (Table G-1). The sediment composition did not vary among the land uses.

Nutrients

Figure 8 summarizes the range, median, and 90th percentile for each nutrient parameter in stormwater.

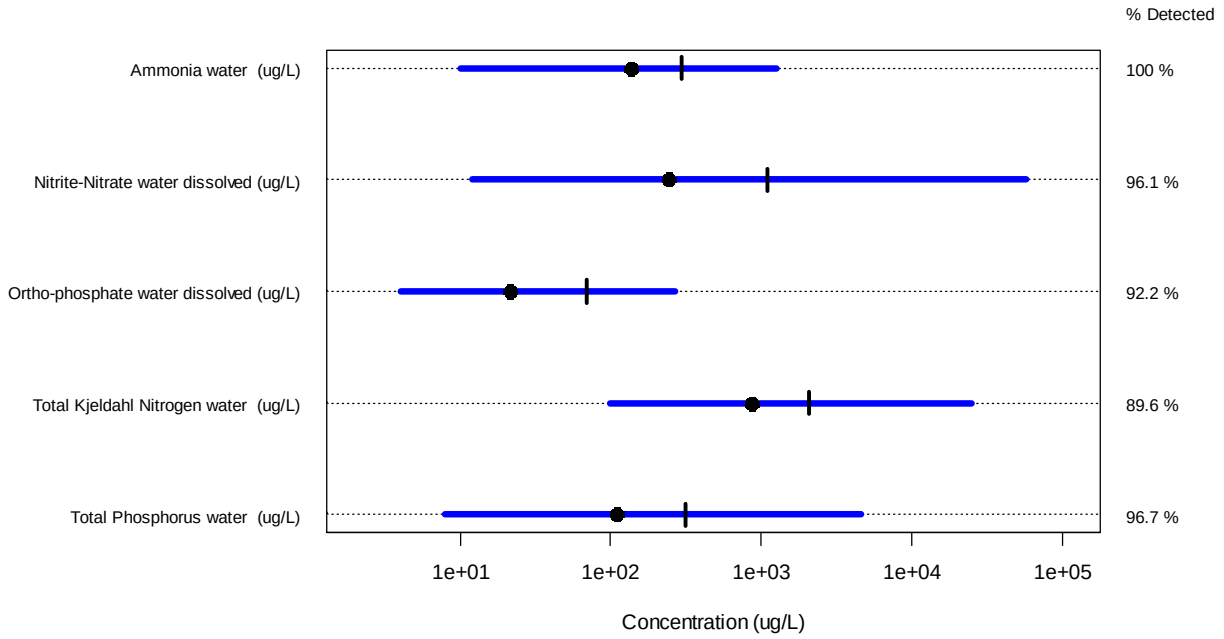

Figure 8. Summary of nutrient concentrations in water.

Blue horizontal segment is the contaminant range, black dot is the median concentration, vertical black segment is the 90th percentile concentration. The x-axis is logarithmic. The rate of detection for each parameter is listed on the secondary y-axis.

Phosphorus

Table 14. Summary of phosphorus concentrations.

Parameter (ug L^{-1})	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Orthophosphate	92.0	4	21.6	270	yes	yes
Total phosphorus	96.7	8	110.0	4,600	yes	yes

Phosphorus in water was measured as total phosphorus and orthophosphate, the dissolved, bioavailable fraction. Orthophosphate concentrations were significantly higher in stormwater from the low-density residential land-use areas (Appendix F). Significantly higher concentrations of orthophosphate were present during the dry season (26 ug L^{-1}) compared with the wet (20.7 ug L^{-1}).

Total phosphorus concentrations in the stormwater showed a different trend with the highest concentrations from industrial land-use areas (171 ug L^{-1}) and significantly lower concentrations from low-density residential land-use areas (90 ug L^{-1}). This trend could be related to a particulate form in the industrial discharge, as it follows the same trend as the concentrations for surfactants, turbidity, and TSS results. Total phosphorus had a median value of 110 ug L^{-1} for the combined land use (mean was 155 ug L^{-1}).

Ecology found total phosphorus concentrations in stormwater discharges were greater than the documented median for the *PS Toxics Study* but less than the concentrations in the NSQD and NURP databases. The land-use trends observed were also different from the *PS Toxics Study* where commercial and industrial areas had lower concentrations than residential and agricultural areas.

Nitrogen

Table 15. Summary of nitrogen concentrations.

Parameter (ug L^{-1})	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Total Kjeldahl N	89.6	100	863	25,000	yes	yes
Nitrite+nitrate N	96.1	12	245	58,000	yes	yes
Ammonia	100	10	136	1260	yes	yes

Nitrogen inputs were measured as total Kjeldahl nitrogen (TKN), nitrite+nitrate as nitrogen (NO_2+NO_3), and ammonia (NH_3). TKN is the sum of organic nitrogen, ammonia, and ammonium (NH_4). TKN was found at significantly lower concentrations in the low-density residential areas (600 ug L^{-1}) compared with other land-use areas (Appendix F). The dry season had higher TKN concentrations (1,300 ug L^{-1}) than the wet (800 ug L^{-1}).

Nitrite+nitrate concentrations were significantly greater in discharges from low-density residential land use, which was similar to the orthophosphate trends (Appendix F). Indeed, the nitrite+nitrate concentrations from both the high- (320 ug L^{-1}) and low-density residential land uses (510 ug L^{-1}) were higher than concentrations from the commercial (200 ug L^{-1}) and industrial (232 ug L^{-1}) land uses. Concentrations during the dry season were significantly higher (462 ug L^{-1}) than the wet season (213 ug L^{-1}) for nitrite+nitrate; however, a great deal of variability was found during the dry season (mean ± 95%CI was 493 ± 262 ug L^{-1}).

Ammonia was not a required parameter under the 2007 permit, but ammonia concentrations were reported by one permittee with 71 observations across three land uses. Significant lower concentrations were observed from industrial (190 ug L^{-1}) compared with commercial (123 ug L^{-1}) and high-density residential (85 ug L^{-1}) land uses. Samples displayed a strong difference between the dry season (163 ug L^{-1}) and the wet season (130 ug L^{-1}) (Appendix F).

Acute and chronic standards for the protection of aquatic life exist for ammonia, and these standards were not exceeded by any samples (Appendix G, Figures G1-G2).

TKN concentrations and ranges were very similar for all land uses to those reported in the NSQD (Pitt et al., 2004). Nitrite+nitrate concentration ranges were also similar to the NSQD, with the exception that residential land uses tended to have higher concentrations in this current study. In the NSQD, discharges from industrial land uses had higher nitrite+nitrate concentrations. Ecology found similar concentration ranges and trends across land uses to the NURP study (EPA, 1983). In comparison with the nitrite+nitrate concentrations observed in the *PS Toxics Study*, Ecology found much lower concentrations in waters discharged from residential land uses (~ 1000 ug L^{-1} in the *PS Toxics Study*). This finding suggests that dissolved nitrogen species were contributed from residential land uses via pathways other than stormwater drainage (e.g., groundwater). In commercial and industrial land-use areas, stormwater discharge and stormflow receiving water median concentrations in the *PS Toxics Study* were roughly similar.

Metals

Metals results in water are given in ug L^{-1}, also referred to as parts per billion (ppb). For stormwater sediments, the units are ug Kg^{-1}, which are also parts per billion (ppb). Figures 9 and 10 summarize the ranges and summary statistics (median and 90th percentile) for each metal parameter in stormwater and stormwater sediments, respectively. Metals concentrations in water and sediments across land uses showed similar trends, suggesting that the sediment serves as a representative sample of metals in the stormwater conveyance systems.

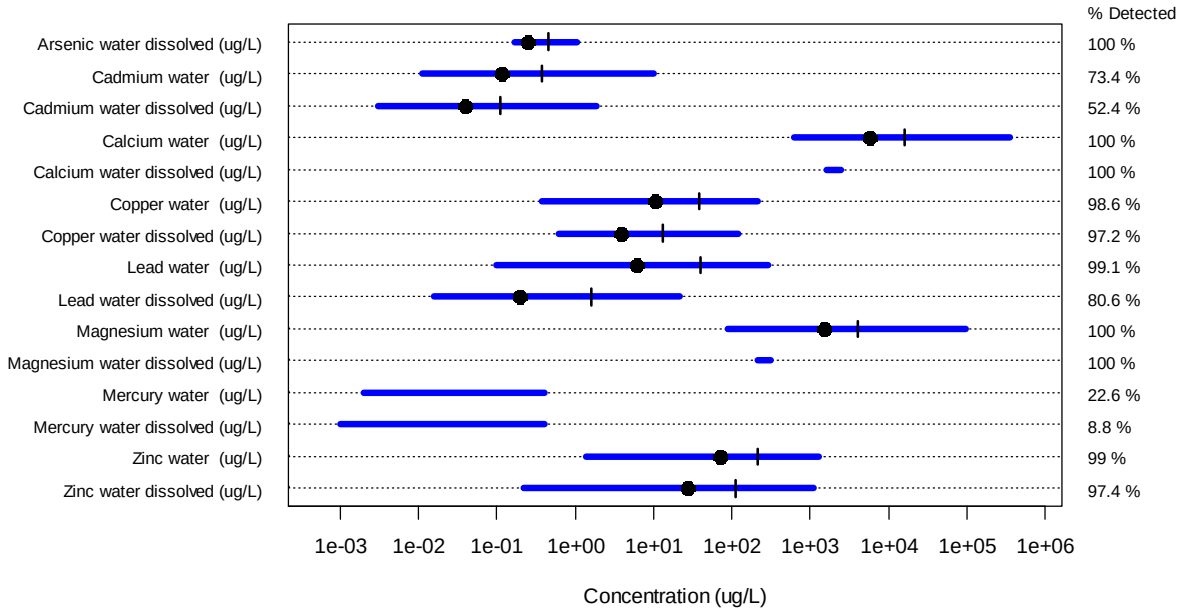

Figure 9. Summary of metals concentrations in water.

Blue horizontal segment is the contaminant range, black dot is the median concentration, vertical black segment is the 90th percentile concentration. The x-axis is logarithmic. The rate of detection for each parameter is listed on the secondary y-axis.

Arsenic

Table 16. Summary of dissolved arsenic concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Dissolved As (ug L^{-1})	100	0.17	0.25	1.04	NA	no

Dissolved arsenic was not a parameter required by the permit, but was reported by one permittee. Total arsenic was not measured in water or sediments. Dissolved arsenic (As) was detected in all of the 16 samples analyzed. All but one of these samples was collected from stormwater discharged from low-density residential land-use areas (Appendix F). Dissolved arsenic showed no differences between the wet and dry seasons. None of the measured concentrations exceeded the arsenic water quality criteria for the protection of aquatic life.

Dissolved arsenic concentrations in water from residential land uses sampled during the *PS Toxics Study* (0.60 ug L^{-1}) were twice the median concentrations found by the permittee. Concentrations of dissolved arsenic in the NSQD were considerably higher than observations in this current study (NSQD median = 1.5 ug L^{-1})

Cadmium

Table 17. Summary of cadmium concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Total Cd (ug L^{-1})	73.4	0.011	0.1	10.1	yes	yes
Dissolved Cd (ug L^{-1})	52.4	0.003	0.04	1.85	yes	yes
Cd in sediment (ug Kg^{-1})	90	0.78	819	4,900	yes	NA

Total cadmium showed clear differences among land uses (Appendix F). Areas of industrial land use discharged the highest median concentrations (0.22 ug L^{-1}) followed by commercial (0.17 ug L^{-1}), high-density residential (0.09 ug L^{-1}), and low-density residential (0.03 ug L^{-1}) land uses. Discharges from low-density residential land use had a 50% non-detect rate and fell into the Case B data classification for statistical analyses. No seasonal differences were found for total cadmium.

Dissolved cadmium showed a similar trend to total cadmium across land uses; however, a high rate of non-detect data made these interpretations more uncertain (Appendix F). Higher rates of non-detect also led to all but the commercial land use data being classified as Case B for statistical analyses. Sufficient sample numbers were attained for reliable summary statistics. No difference was noted between samples from the wet and dry seasons. Of the 635 samples analyzed for dissolved cadmium concentrations, two exceeded (did not meet) the acute water quality criteria and three exceeded the chronic criteria.

The median NSQD concentrations for both total and dissolved cadmium were much greater than concentrations observed in this study. Industrial land uses were also found to discharge the highest concentrations of cadmium in the NSQD. Concentrations found in the *PS Toxics Study* were much lower than those in this study. In fact, total cadmium measured during most storm events in the river systems had low rates of detection.

Cadmium concentrations in the sediment had a high rate of detection. Trends across the different land uses reflected those of the total cadmium in water, with significantly higher concentrations in the industrial and commercial catchments (Appendix F). Cadmium in stormwater sediments exceeded the SCO for 6% of the samples.

Copper

Table 18. Summary of copper concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Total Cu (ug L^{-1})	98.6	0.38	10.4	218	yes	yes
Dissolved Cu (ug L^{-1})	97.2	0.62	3.9	122	yes	yes
Cu in sediment (ug Kg^{-1})	100	156	81,000	1.26×10^6	yes	NA

Total copper median concentrations were statistically higher in discharges from industrial and commercial land uses (16.0 ug L^{-1} and 19.6 ug L^{-1}, respectively) compared with both high-density (7.7 ug L^{-1}) and low-density (2.8 ug L^{-1}) residential land uses (Table G-2 and Appendix F). Significantly higher concentrations were noted during the dry season (mean ± 95%CI; 25.7 ± 5.6 ug L^{-1}) compared to the wet season (14.7 ± 1.2 ug L^{-1}) (Table G-3).

Dissolved copper median concentrations were significantly different among all land uses; stormwater from commercial land use (6.25 ug L^{-1}) was statistically higher than the other land uses. Industrial (4.4 ug L^{-1}) and high-density residential (3.05 ug L^{-1}) land uses were quite similar, but stormwater discharged from low-density land use was significantly lower (1.84 ug L^{-1}) (Appendix F). Again, the dry season had statistically higher concentrations than the wet season across all land uses. 50% of the dissolved copper results exceeded the acute water quality target. 58% exceeded the chronic target.

Total and dissolved copper concentrations were similar to those reported in the NSQD. The *PS Toxics Study* found lower copper concentrations in waters from industrial and commercial land uses, but roughly similar concentrations in waters from residential land uses. Road systems are often implicated in contributions of copper to stormwater from brake pads and tires (McKenzie et al., 2009). This trend was evident in data from the NSQD. This stormwater data set may provide sufficient resolution to separate parking lots from the combined land uses; however, this was beyond the scope of this study and was not investigated.

Copper concentrations were detectable in all stormwater sediment samples. Similar to copper concentrations in water, significant differences were found in sediment samples between commercial and industrial land uses (157,000 ug Kg^{-1} and 114,000 ug Kg^{-1}, respectively) and between high-density (39,600 ug Kg^{-1}) and low-density residential land uses (15,000 ug Kg^{-1}). Copper in stormwater sediment exceeded the SCO for 9% of the samples (Figure G-3).

Lead

Table 19. Summary of lead concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Total Pb (ug L^{-1})	99.1	0.1	6.1	294	Yes	no
Dissolved Pb (ug L^{-1})	80.6	0.016	0.2	21.8	Yes	yes
Pb in sediment (ug Kg^{-1})	97.5	360	114,000	1.79 x 10^6	Yes	NA

Total lead concentrations were statistically different among the land uses: commercial (14.4 ug L^{-1}), industrial (7.94 ug L^{-1}), high-density residential (4.05 ug L^{-1}), and low-density residential 0.72 (ug L^{-1}). Commercial land use had statistically higher concentrations of total lead. Interestingly, the distribution of concentrations from high-density residential was similar to that of industrial land-use areas, above the 70^{th} percentile (approximately 7 ug L^{-1}), but overall the distributions were statistically different (p=0.003) (Appendix F). No significant difference in total lead concentrations was found between wet and dry seasons.

Dissolved lead in stormwater had a high non-detect rate, although this varied across land uses. Commercial land use had statistically higher dissolved lead concentrations. High-density residential and industrial land use did not have significantly different dissolved lead concentrations. Industrial, high-density residential, and low-density residential land use had between 25 to 33% non-detects (Appendix F).

Dissolved lead trends across land uses were similar to those observed for total lead. Commercial (0.32 ug L^{-1}) and industrial (0.25 ug L^{-1}) land uses discharged higher concentrations than high-residential (0.17 ug L^{-1}) and low-residential (0.065 ug L^{-1}) land uses. The higher frequency of non-detect data added uncertainty to the trends across land uses. Dissolved lead concentrations appeared to be higher during the dry season. Two samples for dissolved lead exceeded the acute water quality criteria (< 0.5%), but 173 exceeded the chronic criteria (28%).

Lead concentrations in this data set were generally lower than in the NSQD, but much higher than the in-stream concentrations found in the *PS Toxics Study*. Activities in commercial and industrial land uses have been highlighted as the major contributors of lead in all studies.

Lead concentrations in sediment samples followed similar trends as the water samples across land uses (Appendix F). Only two samples had non-detect lead concentrations. Detected concentrations ranged from 360 to 1.79 x 10^6 ug Kg^{-1} with a median of 114,000 ug Kg^{-1}

(Figure 10). Lead in stormwater samples exceeded the SCO for 18% of the samples (Figure G-3).

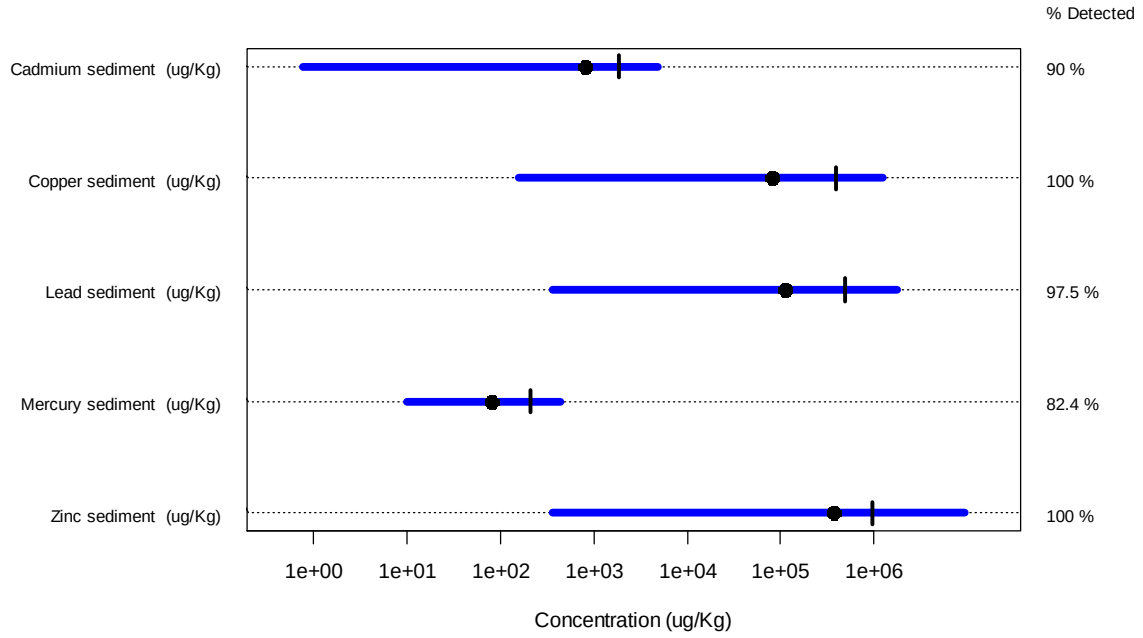

Figure 10. Summary of metals concentrations in stormwater sediment.

Blue horizontal segment is the contaminant range, black dot is the median concentration, vertical black segment is the 90th percentile concentration. The x-axis is logarithmic. The rate of detection for each parameter is listed on the secondary y-axis.

Mercury

Table 20. Summary of mercury concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Total Hg (ug L^{-1})	22.6	0.002	0.01	0.4	NA	no
Dissolved Hg (ug L^{-1})	8.8	0.001	NA	0.4	NA	NA
Hg in sediment (ug Kg^{-1})	82.4	10	80	442	yes	NA

Total and dissolved mercury concentrations in stormwater were not frequently detected. Overall, total mercury was classified as Case B for statistical analyses. When detected in stormwater, total mercury was primarily measured in samples from commercial land-use areas (median 0.01 ug L^{-1}) and, to a lesser extent, in samples from high-density residential land-use areas (0.028 to 0.30 ug L^{-1}). The chronic water criteria, 0.012 ug L^{-1}, was frequently less than the detection limit for total recoverable mercury achieved for these samples (ranging from

0.02 to 0.2 ug L^{-1} depending on the lab). As such, the total mercury results cannot be effectively evaluated against known criteria.

Dissolved mercury results were classified as Case C. No samples exceeded the acute water quality target.

Total mercury concentrations in water from the *PS Toxics Study* were an order of magnitude lower than in this study (median combined land use was 0.008 ug L^{-1}). Total mercury in the NSQD had a median concentration set near the detection limit, which is not an accurate description of environmental concentrations. Therefore, concentrations appeared similar across land uses.

Mercury was detected in sediments at a much higher frequency compared to water. Concentrations of mercury in sediments from commercial (130 ug Kg^{-1}) and industrial (71 ug Kg^{-1}) land uses were significantly higher than concentrations from high-density (31.1 ug Kg^{-1}) and low-density (27 ug Kg^{-1}) residential land uses. The comparisons are less certain due to the greater proportion of non-detects from residential land uses. None of the samples analyzed for mercury in sediments exceeded the SMS levels.

Mercury appears to be found in localized areas and does not appear to be a widespread contaminant in western Washington stormwater.

Zinc

Table 21. Summary of zinc concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Total Zn (ug L^{-1})	99.0	1.4	70.6	1,290	yes	yes
Dissolved Zn (ug L^{-1})	97.4	0.22	26.9	1,090	yes	yes
Zn in sediment (ug Kg^{-1})	100.0	366	373,000	9.25×10^6	yes	NA

Total zinc concentrations (median values) in stormwater collected from commercial (102 ug L^{-1}) and industrial (123 ug L^{-1}) land uses were not significantly different (p=0.08). Total zinc concentrations from high-density residential land-use areas (41.2 ug L^{-1}) were significantly lower, as were those from low-density residential land-use areas (13.7 ug L^{-1}) (Appendix F). This was similar to the trend found for copper concentrations. Significantly higher concentrations were detected during the dry season (mean ± 95%CI; 171.4 ± 41.6 ug L^{-1}) than the wet season (86.9 ± 8.0 ug L^{-1}).

Trends for dissolved zinc concentrations were similar across land uses to those found for total zinc (Table 21; Appendix F). Dissolved zinc concentrations were also significantly higher during the dry season than during the wet season. 36% of the samples exceeded the acute water quality criteria and 40% exceeded the chronic criteria.

Zinc concentrations from this study had considerably higher median concentration (5-10 times) than reported by the *PS Toxics Study*. Zinc concentrations were within similar ranges compared with the NSQD. In this study and both the *PS Toxics Study* and the NSQD, the highest concentrations were found in areas of industrial land use.

Zinc concentrations in sediment followed a trend similar to those in water. Zinc in stormwater sediments exceeded the SCO for 1% of the samples.

Hydrocarbons

TPH

Table 22. Summary of total petroleum hydrocarbon concentrations.

Parameter (ug L^{-1})	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
TPH-Dx	72.7	14	433	12,100	yes	yes
TPH-Gx	10.4	11	NA	395	NA	NA
Diesel range organics	57.5	13	130	4,900	yes	yes
Lube oil	41.6	194	207	1,550	NA	no
Motor oil	81.9	200	930	5,800	yes	no

Gasoline range total petroleum hydrocarbons (TPH-Gx) were detected at a low frequency. These data were classified as a Case C for statistical analyses. TPH-Gx is composed of volatile compounds. Insufficient numbers of detections were available to describe any differences among land uses or across seasons.

The diesel range hydrocarbon (TPH-Dx) analysis sums multiple hydrocarbon fractions (lube oil, motor oil, diesel fuel, and diesel range organics). Hydrocarbon fractions have variable rates of detection (Table 22). Significantly higher TPH-Dx concentrations were observed in stormwater from industrial and commercial land uses (890 ug L^{-1} and 870 ug L^{-1}, respectively) compared with high-density (320 ug L^{-1}) and low-density (113 ug L^{-1}) residential land uses. A greater proportion of non-detects were found in samples collected from residential land uses. TPH-Dx concentrations were significantly greater during the dry season (840 ug L^{-1}) than the wet season (390 ug L^{-1}).

Looking more closely at the components of TPH-Dx, the trends in land use were driven largely by the diesel range organics. Lube oil was not reported separately in industrial samples and was only detected in commercial samples (Appendix F). Motor oil was not reported in low-density residential samples but had a high rate of detection in other land uses. Discharges from industrial land uses were the major contributor of motor oil (1400 ug L^{-1}), followed by those from high-density residential land use (950 ug L^{-1}) and then commercial land uses (620 ug L^{-1}). Each of these differences was significant. Interestingly, the concentrations for each land use at the higher end of the ranges (> 80^{th} percentile) were very similar. No statistical difference was

found between contributions of motor oil during the dry season (980 ug L^{-1}) compared with the wet season (910 ug L^{-1}).

TPH-Dx was measured in the *PS Toxics Study,* and concentrations were considerably lower. With the exception of those from commercial and industrial land uses, median concentrations from other land uses were only estimates. Concentrations in commercial and industrial land uses in this study were an order of magnitude greater than those in the *PS Toxics Study*.

It is difficult to comment on any trends for TPH in sediments, as sample numbers were low. Appendix F and Table 22 provide the available data for the parameters. Concentrations of heavy fuel oil and diesel range organics suggested that greater concentrations were prevalent in sediments from commercial and industrial land uses.

BTEX

Table 23. Summary of BTEX concentrations.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
BTEX (ug L^{-1})	2.5	1.1	NA	6.4	NA	NA

Benzene, toluene, ethylbenzene, and xylenes (BTEX) were measured in 120 water samples and detected in only three samples. Benzene was detected once, ethylbenzene was not detected, toluene was detected three times, and total xylenes were sufficiently detected in one sample. The volatile nature of these compounds is the reason for the low detection rates. Continued monitoring for BTEX in stormwater samples does not appear to be cost-effective.

PAHs

Polycyclic Aromatic Hydrocarbons (PAHs) are cyclic compounds with various numbers of six-carbon rings. PAHs vary in volatility and rates of detection in stormwater samples. Half the individual PAHs were classified as Case B for statistical analysis, due to low detection rates but adequate numbers of samples to reliably summarize the data (Table 24). Only three PAH compounds had a high enough detection frequency to be classified as Case A: fluoranthene, phenanthrene, and pyrene. Fluoranthene concentrations were significantly higher in stormwater discharged from commercial land-use areas. No other significant differences were found among the remaining land-use types (Appendix F). Higher concentrations were discharged during the dry season (mean; 0.8 ug L^{-1}) than the wet season (0.4 ug L^{-1}). Phenanthrene and pyrene had very similar trends across the land uses; seasonal differences were weak to non-existent.

Low molecular weight PAH concentrations were summed and reported as LPAH. High molecular weight PAHs were summed and reported as HPAH. Likewise, the carcinogenic PAHs (cPAH) and total PAHs were summed and reported (Table 24; Figure 11). All PAH sums had similar trends across land uses, where commercial land-use discharges had statistically higher concentrations than the other land uses ($p<0.001$). In the case of cPAHs, there was no significant difference between high-density residential and industrial land use ($p=0.17$). No seasonal differences existed for the summed concentrations.

Table 24. Summary of individual PAHs in stormwater (ug L^{-1}).

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
1-Methylnaphthalene	3.8	0.100	-	1.6	NA	NA
2-Methylnaphthalene	17.2	0.003	-	2.5	NA	NA
Acenaphthene	9.8	0.003	-	1.5	NA	NA
Acenaphthylene	6.5	0.003	-	1.5	NA	NA
Anthracene	11.2	0.004	-	5.4	NA	NA
Benz(a)anthracene	34.4	0.004	0.006	11.0	NA	no
Benzo(a)pyrene	28.4	0.004	0.005	15.0	NA	no
Benzo(b)fluoranthene	30.4	0.020	0.014	13.0	NA	no
Benzo(b,k)fluoranthene	49.2	0.005	0.010	0.3	NA	no
Benzo(g,h,i)perylene	40.0	0.004	0.013	12.0	NA	no
Benzo(k)fluoranthene	24.0	0.014	0.007	13.0	NA	no
Benzofluoranthenes	45.6	0.067	0.091	5.7	NA	no
Chrysene	45.9	0.003	0.020	16.0	NA	no
Dibenzo(a,h)anthracene	13.9	0.005	-	5.3	NA	NA
Fluoranthene	59.1	0.007	0.039	33.0	yes	no
Fluorene	12.6	0.003	-	1.6	NA	NA
Indeno(1,2,3-cd)pyrene	28.7	0.004	0.005	10.0	NA	no
Naphthalene	31.1	0.004	0.017	2.2	NA	no
Phenanthrene	51.8	0.006	0.026	16.0	yes	no
Pyrene	63.3	0.007	0.048	26.0	yes	no
PAH Sums						
LPAH	61.4	0.021	0.162	172.5	yes	no
HPAH	67.3	0.012	0.110	154.3	yes	no
cPAH	51.6	0.004	0.044	83.3	yes	no
Total PAH	98.8	0.021	0.162	172.5	yes	no

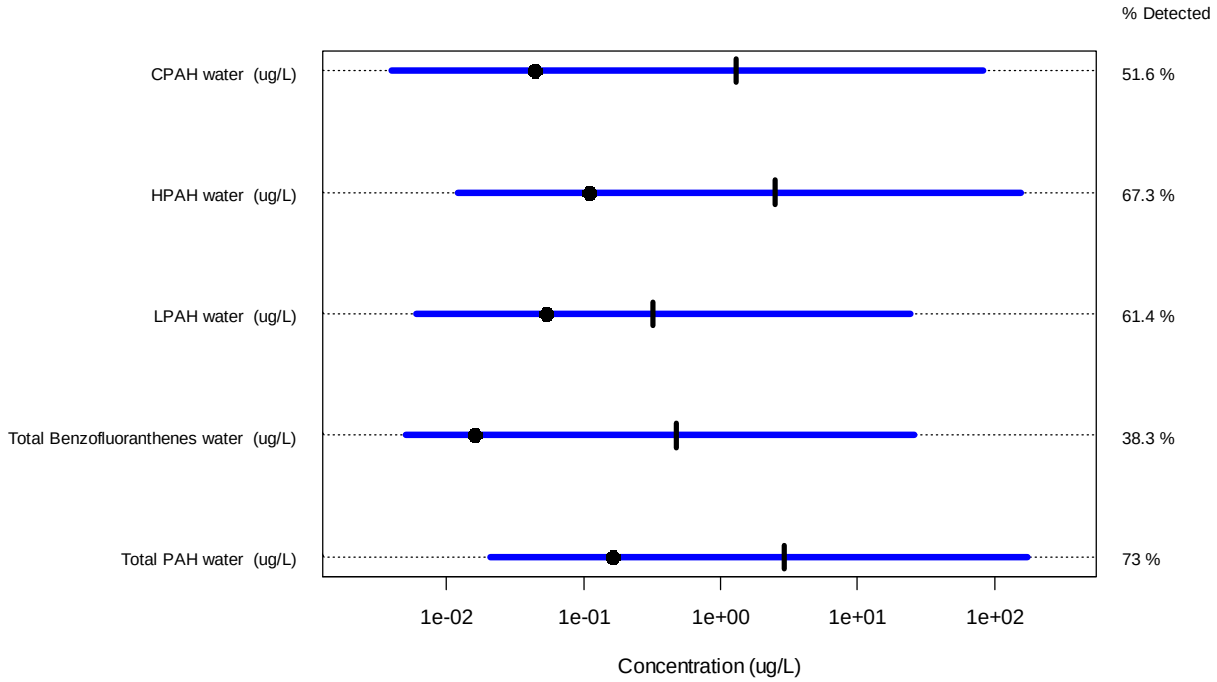

Figure 11. Summary of total PAH concentration sums in water.

Blue horizontal segment is the contaminant range, black dot is the median concentration, vertical black segment is the 90th percentile concentration. The x-axis is logarithmic. The rate of detection for each parameter is listed on the secondary y-axis.

Total PAHs all had sufficient levels of detection to be classified Case A data for statistical analyses. Median total PAH concentrations in stormwater discharges from commercial and industrial land uses were found to be 0.53 and 0.11 ug L^{-1}, respectively.

Median concentrations from areas of commercial land use were substantially higher (22 times) than concentrations reported in the *PS Toxics Study* (0.18 ug L^{-1}). Concentrations of individual PAH compounds had low rates of detection in NSQD, similar to this study. However, median concentrations of detected fluoranthene, phenanthrene, and pyrene were two orders of magnitude higher in the NSQD compared with this study.

PAHs were detected much more frequently in stormwater sediments than in stormwater discharges (Table 25; Figure 12). Most individual PAH compounds were classified as Case A data for statistical analyses. Overall, the trends across land-use types followed those observed in the water samples. Runoff from areas of commercial land use had significantly higher concentrations than runoff from the other land uses. Concentrations in discharges from industrial and high-density residential land uses did not differ greatly, while discharges from low-density residential land-use areas were significantly lower (Appendix F). 34% of the stormwater sediment samples exceeded the SCO criteria.

Table 25. Summary of individual PAHs in stormwater sediments (ug Kg^{-1}).

Parameter	% detected	Minimum	Median	Maximum	Land-use differences
1-Methylnaphthalene	40.4	1.07	6	870	yes
2-Methylnaphthalene	47.4	1.12	13	1,500	yes
Acenaphthene	54.4	8.70	34	8,900	yes
Acenaphthylene	32.9	15.80	28	3,600	yes
Anthracene	73.4	17.00	131	33,000	yes
Benz(a)anthracene	88.4	9.40	800	210,000	yes
Benzo(a)pyrene	82.3	16.20	720	260,000	yes
Benzo(b)fluoranthene	80.0	1.07	240	240,000	yes
Benzo(b,k)fluoranthene	100.0	110.00	1400	2,900	yes
Benzo(g,h,i)perylene	88.7	4.00	800	160,000	yes
Benzo(k)fluoranthene	71.1	10.20	131	230,000	yes
Benzofluoranthenes	100.0	177.00	57000	340,000	yes
Chrysene	92.4	1.07	1100	280,000	yes
Dibenzo(a,h)anthracene	73.4	6.54	190	73,000	yes
Fluoranthene	93.7	1.02	1900	590,000	yes
Fluorene	59.0	19.30	60	14,000	yes
Indeno(1,2,3-cd)pyrene	86.1	19.40	540	160,000	yes
Naphthalene	59.5	1.02	24	6,900	yes
Phenanthrene	93.6	2.16	950	250,000	yes
Pyrene	94.9	1.37	1800	490,000	yes
PAH Sums					
LPAH	94.2	1.94	1200	307,500	yes
HPAH	96.7	3.46	7840	2,683,000	yes
cPAH	93.9	1.07	3130	1,453,000	yes
Total PAH	98.8	4.10	6728	2,990,960	yes

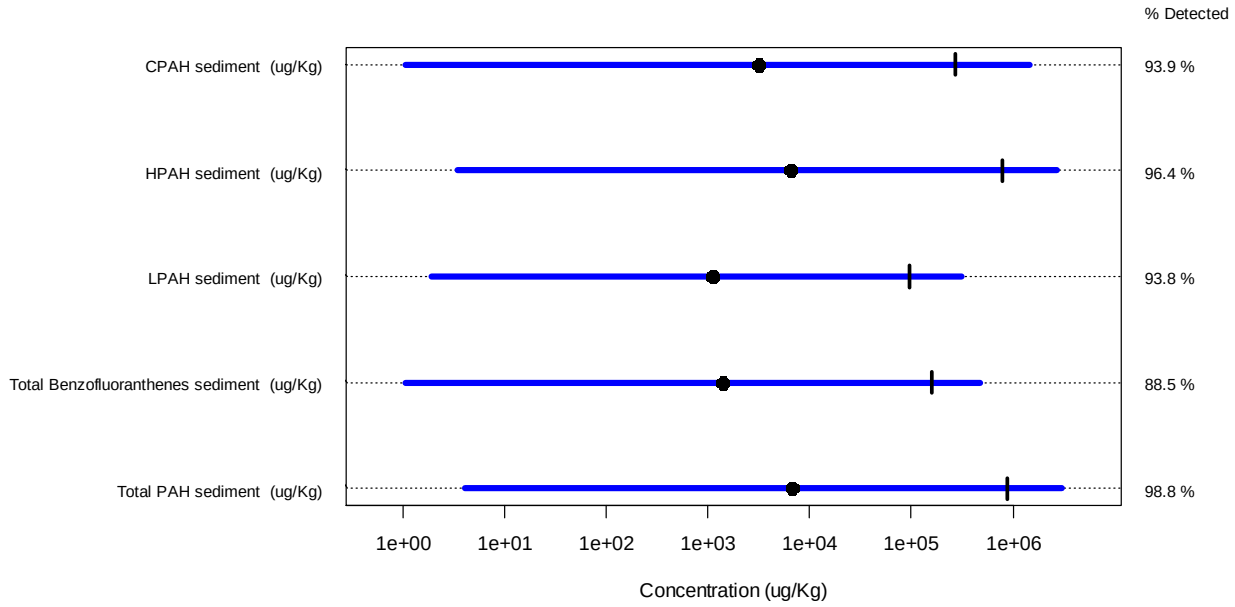

Figure 12. Summary of total PAH concentration sums in stormwater sediment.

Blue horizontal segment is the contaminant range, black dot is the median concentration, vertical black segment is the 90th percentile concentration. The x-axis is logarithmic. The rate of detection for each parameter is listed on the secondary y-axis.

Phthalates

Many of the analyzed phthalates had low rates of detection (Table 26), with one exception. Bis(2-ethylhexyl) phthalate had a detection frequency of 61.9%. Bis(2-ethylhexyl) phthalate showed a significant difference across land uses; commercial land-use areas discharged greater concentrations than other areas. Industrial and high-density residential land-use areas discharged similar concentrations, and low-density residential areas discharged significantly lower concentrations. Both residential areas had much lower rates of bis(2-ethylhexyl) phthalate compound detection.

A similar trend across land uses was observed for butyl benzyl phthalate and dibutyl phthalate. Diethyl phthalate did not show differences across land uses, but this was not assessed, given the high rates of non-detection (Appendix F). Diethyl phthalate was more frequently detected in residential samples and had higher concentrations during the wet season, though not significantly higher. No seasonal differences were observed for any of the other phthalates.

Table 26. Summary of phthalates in stormwater (ug L^{-1}).

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Bis(2-ethylhexyl) phthalate	61.9	0.150	0.977	41.4	yes	no
Butyl benzyl phthalate	22.6	0.022	0.0995	2.82	NA	no
Di-N-Octyl Phthalate	11.2	0.018	-	3.19	NA	NA
Dibutyl phthalate	31.8	0.024	0.1128	5.08	NA	no
Diethyl phthalate	30.6	0.026	0.1325	8.9	NA	no
Dimethyl phthalate	14.8	0.025	-	2.8	NA	NA
Sum						
Total phthalates	76.5	0.032	1.1600	41.4	yes	no

This study found much higher rates of detection but lower concentrations for bis(2-ethylhexyl) phthalate than did the NSQD. The *PS Toxics Study* reported rates of detection similar to those found in this study for commercial and industrial land uses. Bis(2-ethylhexyl) phthalate concentrations found in river systems (*PS Toxics Study)* were much lower than concentrations found in stormwater in this study.

The median sediment concentrations were calculated for four of the phthalates (Table 27). Bis(2-ethylhexyl) phthalate and benzyl butyl phthalate (Table 27) were found highest in discharges from industrial land-use areas, followed by commercial, high-density residential, and low-density residential land-use areas. The differences among land uses were significant (Appendix F). This finding is similar to results for water samples. Bis(2-ethylhexyl) phthalate and di-n-octyl phthalate exceeded the SCO in 82% and 29% of samples, respectively.

Table 27. Summary of individual phthalates in stormwater sediments (ug Kg^{-1}).

Parameter	% detected	Minimum	Median	Maximum	Land-use differences
Bis(2-ethylhexyl) phthalate	92.7	22	4,800	34,000	yes
Butyl benzyl phthalate	56.1	22	96	60,000	yes
Di-N-Octyl Phthalate	28.6	116	31	10,000	NA
Dibutyl phthalate	28.1	16	16	2,070	NA
Diethyl phthalate	5.4	81	-	123	NA
Dimethyl phthalate	19.6	28	-	628	NA
Sum					
Total phthalates	88.1	22	3,970	94,000	yes

Pesticides

The pesticides 2,4-D, chlorpyrifos, diazinon, malathion, mecoprop, phenol and p-cresol, prometon, and triclopyr were sampled but infrequently detected in stormwater. Summary statistics were not calculated for these. Only two of the 11 pesticides had rates of detection high enough to justify statistical analysis (Table 28; dichlobenil and pentachlorophenol).

Table 28. Summary of pesticides in stormwater.

Parameter (ug L^{-1})	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Dichlobenil	35.8	0.012	0.024	1.3	yes	no
Pentachlorophenol	25.4	0.02	0.06	5.1	yes	no
Diazinon	1.0	0.026	NA	0.53	NA	NA
2,4-D	16.9	0.02	NA	28.4	NA	NA
Triclopyr	11.0	0.02	NA	18.3	NA	NA

For an herbicide, dichlobenil, concentrations were highest in discharges from high-density residential land-use areas followed by concentrations in discharges from commercial and industrial land uses. Samples from low-density residential land uses had very low rates of detection (two of 113 samples). No differences in dichlobenil concentrations were found between wet and dry seasons, suggesting either a year-round application of the herbicide or a year-round runoff from soil residuals.

Pentachlorophenol is used as both an herbicide and insecticide. Most of the pentachlorophenol detections and highest concentrations were in discharges from areas of commercial land use. Similar concentrations of pentachlorophenol were measured throughout the year. None of the analyzed samples exceeded the acute and chronic criteria for the protection of aquatic life (Appendix G, Figures G-1 and G-2).

Concentration ranges are provided in Table G-1. Two sample results for diazinon exceeded the acute and chronic criteria for the protection of aquatic life.

Higher frequencies of detection were found for diazinon and 2,4-D in the NSQD study. Despite poor detection overall, triclopyr detection rate and concentrations were much higher in this study than in storm-event samples collected in the *PS Toxics Study*, which evaluated agricultural land uses.

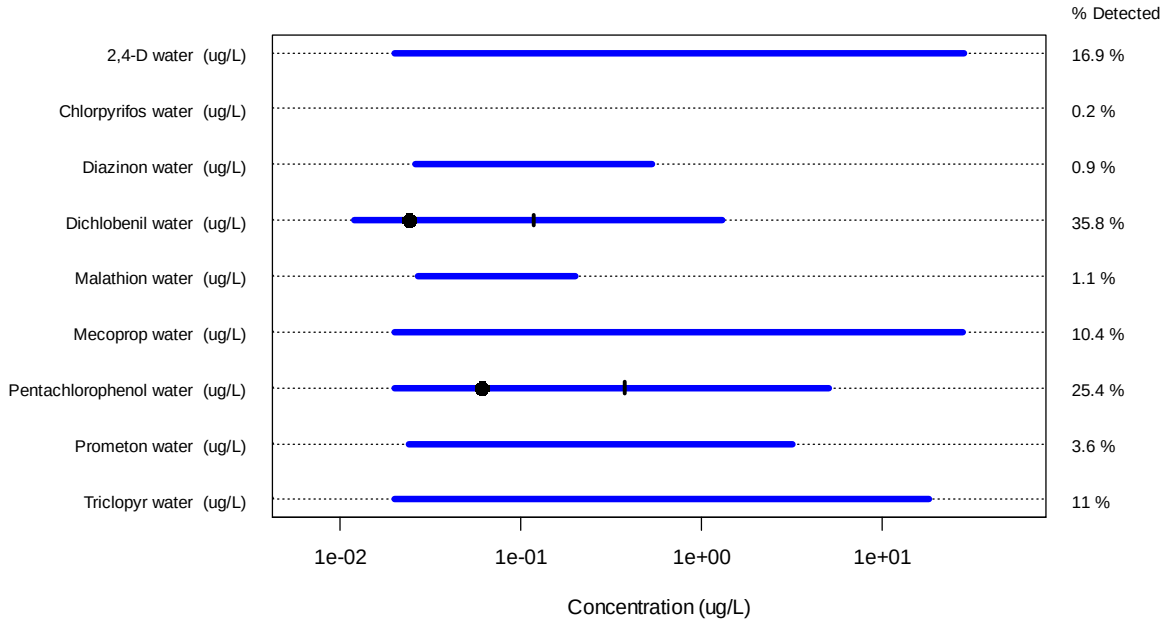

Figure 13. Summary of pesticide concentrations in stormwater.

Blue horizontal segment is the contaminant range, black dot is the median concentration, vertical black segment is the 90th percentile concentration. The x-axis is logarithmic. The rate of detection for each parameter is listed on the secondary y-axis. If no statistical summaries are presented the data are largely non-detect.

Pesticides in sediments also had very low rates of detection. Diazinon, chlorpyrifos, and malathion were detected in only 1 sample out of 53. Phenolics were the only chemical group with a sufficient amount of detected results to provide a summary. Pentachlorophenol and its degradation product, p-cresol, appeared to have higher concentrations in sediments sampled from commercial land-use areas. Concentrations of p-cresol were also high in discharges from high-density residential land-use areas. Other phenolics (2,4-dichlorophenol, 2,4-dimethylphenol, 2,4,5-trichlorophenol, 2,4,6-trichlorophenol, 4-chloro-3-methylphenol, 4-nitrophenol, phenol) and the remaining pesticides (2,4-D, dichlobenil, mecoprop, prometon, and triclopyr) were detected infrequently in most cases (5 - 10% of the samples). Pentachlorophenol in stormwater sediments exceeded the SCO for 1% of the samples. Phenol (Figure G-3) in stormwater sediments exceeded the SCO for 20% of the samples.

Table 29. Summary of pesticides concentrations in stormwater sediments.

Parameter (ug Kg^{-1})	% detected	Minimum	Median	Maximum	Land-use differences
Pentachlorophenol	24.7	7.8	11.2	17,800	NA
p-cresol	76.7	2.46	180	24,100	yes

PCBs

The permit only required monitoring polychlorinated biphenyls (PCBs) once annually in stormwater sediment samples; however, at least one permittee reported PCB monitoring results for stormwater samples across land uses as well. PCBs were measured as Aroclors in water and sediments. Only 27 stormwater samples were analyzed, and no samples were obtained from low-density residential land-use areas. Only 1 of 9 samples from high-density residential sites had a detected concentration, while all 8 samples from areas of commercial land use had detected Aroclor 1254 concentrations. Insufficient samples were collected for total PCBs to assess seasonal differences.

Table 30. Summary of total PCB concentrations in stormwater and stormwater sediments.

Parameter	% detected	Minimum	Median	Maximum	Land-use differences	Seasonal differences
Total PCBs[1] (ug L^{-1})	55.6	0.01	0.011	0.096	NA	NA
Total PCBs[1] (ug Kg^{-1})	51.5	8.5	9.6	770	NA	NA

[1] Sum of detected Aroclors (only 1248, 1254 and 1260)

PCBs in sediments were measured in 33 samples; however, detected concentrations were found only in samples from commercial and industrial land-use sites. One sample from a high-density residential site had detected concentrations. None of the measurements on individual Aroclors had a sufficient number of detected concentrations to summarize.

Contaminant Concentrations - Summary of Findings

Based on contaminant concentrations measured in stormwater discharges across multiple land uses, several major findings are worth highlighting as we move on to discuss land uses and seasonal differences more directly.

- The following parameters had high frequencies of detection and therefore were classified as Case A for statistical analyses:
  - Conventional parameters
  - Metals except mercury
  - Nutrients
  - PAH sums and TPH-Dx
  - PCB Aroclor 1254
  - Bis(2-ethylhexyl) phthalate

- All parameters with high frequencies of detection exhibited statistically different concentrations across land uses. Land use is discussed in detail in the next section of the report.

- Strong evidence exists for discharge of higher contaminant concentrations in stormwater during the dry season (May to September). This suggests the influence of a buildup/wash off relationship, particular to the first dry-season storm events for the following parameters:
  - Conventional parameters: conductivity, hardness, surfactants, BOD
  - Nutrients: all monitored
  - Total and dissolved cadmium, copper, and zinc
  - Dissolved lead
  - TPH-Dx
  - Organics: bis(2-ethylhexyl) phthalate and p-cresol

- For most parameters, stormwater sediment concentrations showed the same trends across land uses as those measured in water samples. Insoluble parameters in sediments had much better detection rates than those in water.

- Nutrients: Ortho-phosphate and nitrite+nitrate were found at higher concentrations in discharges from low-density residential land-use areas. Total nitrogen and phosphorus were highest in discharges from industrial and commercial land-use areas. Significantly higher nutrient concentrations were found during the dry season than the wet season.

- Metals: Commercial and industrial land uses discharged stormwater with comparable concentrations for zinc and copper. These frequently exceeded (did not meet) the water quality criteria. Areas of commercial land use discharged lead and mercury at statistically higher concentrations than other land uses. Areas of industrial land use discharged statistically higher cadmium concentrations. Statistically higher concentrations of zinc and copper were found during the dry season across all land uses.

- PAHs: No seasonal difference in PAH concentrations were found. Stormwater from commercial land-use areas routinely contained the highest concentration of PAHs.

- Total Petroleum Hydrocarbons: Diesel range (TPH-Dx) was discharged at significantly higher concentrations in stormwater from commercial and industrial land uses during the dry season. The motor oil component of TPH-Dx was generally observed at significantly higher concentrations in discharges from industrial land uses (median concentration). However, the higher concentrations (> 80^{th} percentile) did not differ among industrial, commercial, and high-density land use. No seasonal differences were observed. TPH-Gx had very low rates of detection, and BTEX compounds were almost always below detection limits.

- Pesticides: Few samples had detected concentrations of pesticides. Dichlobenil was found at the highest concentrations in stormwater from areas of high-density residential land use throughout the year. Areas of commercial land use contributed stormwater with the highest pentachlorophenol concentrations throughout the year.

Land Use Significance

Peto-Prentice Test

Significant differences among land uses for each of the parameters were tested using the Peto-Prentice test, described in the *Methods* section under *Descriptive Statistics*. We found statistically significant differences among land uses for all parameters detailed in Table 31. The Peto-Prentice test indicates that at least one of the land uses was significantly different from the others, but it does not list exactly which ones differ.

Land uses were separated into two categories for the Peto-Prentice test results: dominant and minor (Table 31). Dominant land use refers to the land use that has the highest concentrations and is the major contributor of the parameter. Minor land use has the lowest concentrations and contributes the least. The determination of major and minor land uses was based subjectively on the Peto-Prentice density functions, as detailed in Appendix F. The reason for defining the major and minor land use for each parameter is to aid in prioritizing the contributions by land use. Reference Table G-3 provides "typical" concentrations for a specific contaminant across land uses.

Table 31. Case A parameters with evidence of differences in water contaminant concentrations by land use.

Parameter	Dominant Land Use	Minor Land Use
Conventionals		
Turbidity	industrial	low-density residential
TSS	industrial	low-density residential
BOD	commercial	low-density residential
Surfactants	industrial and commercial	low-density residential
Fecal Coliform	industrial, commercial, and high-density residential	low-density residential
Conductivity	industrial	commercial/high-density residential
Hardness	industrial	commercial/high-density residential
Chloride	industrial	commercial/high-density residential
Nutrients		
Orthophosphate	low-density residential	commercial/high-density residential
Total Phosphorus	industrial	low-density residential
TKN	industrial, commercial, and high-density residential	low-density residential
Nitrite+nitrate	low-density residential	commercial and industrial
Ammonia	industrial	high-density residential

Table 31 (continued)

Parameter	Dominant Land Use	Minor Land Use
Metals		
Cadmium (total and dissolved)	industrial	low-density residential
Copper (total and dissolved)	industrial and commercial	low-density residential
Lead (total and dissolved)	commercial	low-density residential
Mercury	commercial	low-density residential
Zinc (total and dissolved)	commercial and industrial	low-density residential
Hydrocarbons		
TPH-Dx	commercial and industrial	low-density residential
Diesel range organics	commercial and industrial	low-density residential
Motor oil	industrial	commercial
Fluoranthene	commercial	low-density/ high-density residential
Phenanthrene	commercial	low-density/ high-density residential
Pyrene	commercial	low-density/ high-density residential
CPAH	commercial	low-density/ high-density residential
LPAH	commercial	low-density/ high-density residential
HPAH	commercial	low-density/ high-density residential
Total PAHs	commercial	low-density/ high-density residential
Additional Organics		
Bis(2-ethylhexyl) phthalate	commercial	low-density residential
Dichlobenil	high-density residential	low-density residential
Pentachlorophenol	commercial	low-density residential

The differences among land uses for each parameter have been detailed previously in the discussion of contaminant concentrations. For some parameters, e.g., zinc, the major land-use type is different at low concentrations compared with high concentrations. In other words, at a median zinc concentration, commercial land uses contributed higher concentrations. In contrast, at the 90th percentile of the distribution of concentrations, high-density residential land uses contributed higher concentrations. This finding shows that the relationship of a particular contaminant to land use is not linear. There may be a steady discharge of a contaminant from one land-use type across sites and large variability in discharge across sites for another land-use type.

Principal Components Analysis

The Peto-Prentice test showed significant differences among land uses for individual parameters. We used multivariate statistics to decipher trends among the sample sites and parameters, combined. Using the variables from Table 31 in a principal components analysis (PCA), the distribution of sample sites relative to contaminant parameters can be plotted (Figure 14). In Figure 14, the arrows represent concentration gradients of the parameters, and the points (circles and squares) represent sample sites. The arrow points to increasing concentration of that parameter, and parameters that had similar concentration trends across the sample sites are close together. Sample sites (points on Figure 14) that had similar stormwater chemistry are grouped together. Sample sites the arrows point to are sites that have high concentrations of these parameters.

The key observation from the PCA (Figure 14) is the general grouping of the sites (points) by land use, suggesting similar stormwater quality. For instance, all the low-density residential sites are grouped in the lower right quadrant of Figure 14. There is also considerable overlap for some sites. In particular, there is overlap between many commercial and high-density residential sites. This observation implies that stormwater chemistry from these land uses can be very similar. In addition, industrial sites do not group together and show more similarities to commercial and high-density residential sites.

The overlap of land uses is likely due to characteristics of the drainage area as described by the permittees (Table 1). For example, Pierce County high-residential site (PIEHIRES_OUT) appeared more similar to a low-density residential site (Figure 14). As shown in Table 1, PIEHIRES_OUT had a very low total impervious surface area, which could explain why the stormwater chemistry resembled the low-density residential sites.

By using multivariate statistics, we gained a greater understanding of how stormwater chemistry can be defined by land use; however, significant overlap or variability exists from site to site within the same land-use category.

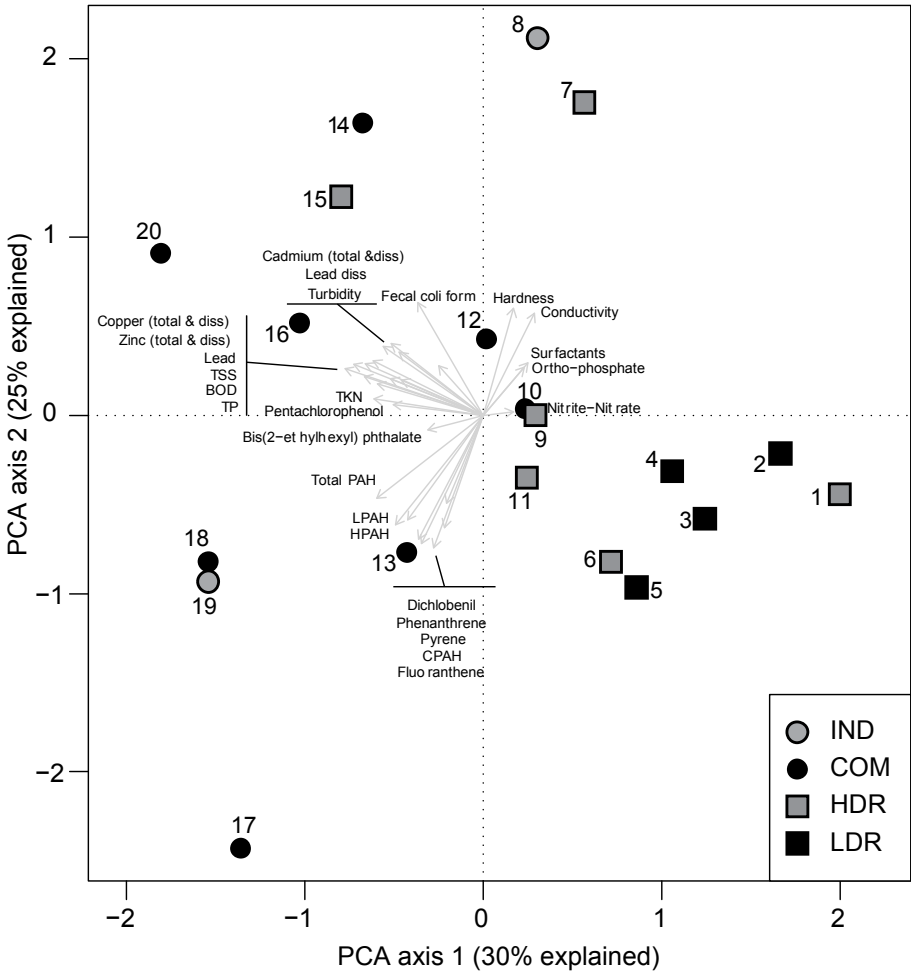

Figure 14. Principal components analysis of stormwater samples.

Biplot shows study sites (points) by land use and contaminant parameters (gray lines) that are statistically relevant across land uses. The amount of variation in the data explained by each axis is detailed in the axis titles.

Sediment concentrations observed in annual sediment samples from the basins strongly paralleled trends in water concentrations across the land uses. For example, those sites with high concentrations of metals in stormwater had high concentrations of metals in catch basin sediments. Similar to water samples, there is an overlap among land uses and variability from site to site within a land use (Figure 15). A significant amount of variation among sites can be explained by the first axis of the PCA (84%; axis 2 explains a further 8% of the variation). Overall, there was a significant difference among the land uses when analyzing all sites and all sediment contaminants (analysis of similarities p=0.004). Note that overall there were fewer parameters available for the sediment PCA compared with the water samples, but similar contaminant groups were represented (metals, phenols, and PAHs).

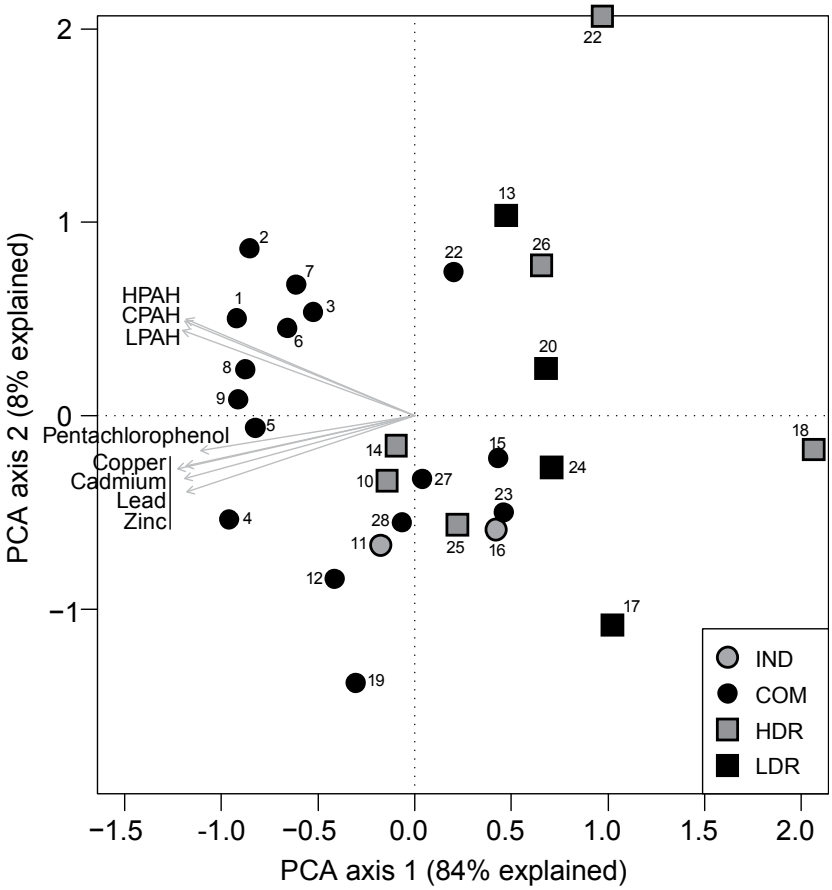

Figure 15. Principal components analysis of stormwater sediment samples

Biplot shows study sites (points) by land use and contaminant parameters (gray lines) that are statistically relevant across land uses. The amount of variation in the data explained by each axis is detailed in the axis titles.

The major difference among the sediment samples was that sediments from the Port of Seattle commercial sites (samples 1 through 9 on Figure 15) were very distinct from the others. Using a cluster analysis (described in the *Methods* section on *Multivariate Statistics*), we were able to define three main groupings of the sites, a "group" of sites having statistically similar sediment chemistry (Figure G-5). Each of these groups was a mixture of land uses, which is the same observation made from the PCA, where many land uses overlap. An example of this overlap is Group 2A in Figure G-5, which had a mixture of industrial (City of Seattle), commercial (City of Seattle, Pierce Co., Clark Co. and the City of Tacoma), and high-density residential sites (King Co. and City of Seattle). Therefore, similar conclusions to those made for the water concentration data can be drawn for sediments: there was considerable overlap in contaminant concentrations among land uses and high variability among sites within a land use.

Overall, the multivariate analysis for water and sediment samples suggests that defining a 'typical' sediment or water contaminant composition for a particular land use is unrealistic. However, this analysis was successful in showing that statistically significant differences exist among land uses over multiple sample sites and parameters.

Parameter Similarities

The grouping of parameters used in the PCA of water concentrations indicated that some parameters were closely related across the sites (Figure 14). This was determined visually by noting which arrows on the PCA plot (Figure 14) were closer together. Parameters that appeared to be positively correlated include:

- PAHs and dichlobenil
- copper, zinc, total lead, TSS, BOD, and total phosphorus
- cadmium, dissolved lead, and turbidity
- TKN and pentachlorophenol
- hardness, conductivity, surfactants, and ortho-phosphate

Nitrite+nitrate and bis(2-ethylhexyl) phthalate are inversely related. Fecal coliform is not strongly related to other parameters.

The apparent similarities among some parameters were related to land-use practices and reflected a common source. For instance, the main group of metals (defined as the second group listed above) was most strongly associated with two commercial sites (KICCOMS8D_OUT and SEAC1S8D_OUT). Also, this group was most weakly associated with residential sites.

The apparent similarities among some parameters could inform stormwater managers whether additional parameters need to be included in a monitoring program. For example, a program that monitors for PAHs may want to consider analyzing for dichlobenil. An additional example is the significant positive relationship between surfactants and ortho-phosphate ($p=0.01$). Further analysis of this relationship suggests that samples from commercial ($p<0.001$) and high-density residential land use ($p<0.001$) are the land uses with strong statistical significance. Surfactants also appear to have a strong relationship with dissolved copper and dissolved zinc in samples from commercial areas ($p<0.001$ in both cases), but not in residential areas. Surfactants do not appear to have any relationship with total suspended solids ($p=0.21$) or turbidity ($p=0.74$). This analysis highlights some of the potential this data set has for exploring relationships between key parameters.

Seasonality

The seasonality and "first flush" storm events are important characteristics for stormwater management. To truly capture first flush events, an instantaneous sample must be taken early in the storm (within approximately 30 minutes). It can then be compared with a composite sample from the same storm event. Few first flush samples from particular storm events were collected by the permittees. Thus, no conclusions can be drawn about the relative load of contaminants discharged during the initial hour of storm events. The dry season in the Pacific Northwest has long antecedent dry periods prior to storms; therefore, Ecology expected the dry-season storm events to exhibit higher contaminant concentrations.

To compare the seasonality of contaminant discharge during storm events, Ecology compared a wet and dry season. In reality, there was considerable overlap between the wet and dry seasons in western Washington (Figure 16). However a statistically significant difference existed between the volume of runoff generated in the two seasons (p = 0.009).

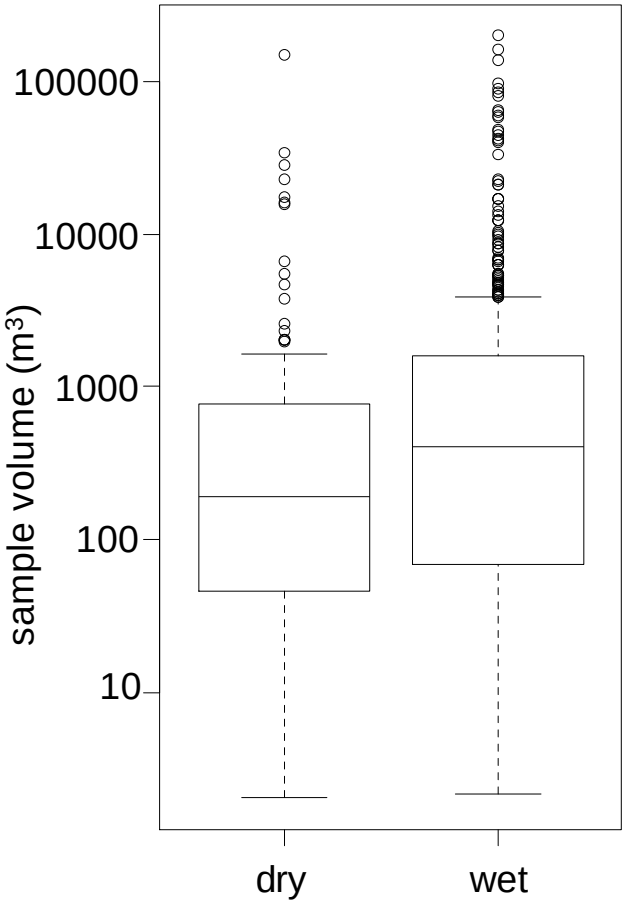

Figure 16. Box plot of measured storm volume (m^3) during the wet and dry season.

Median values is the solid black line within each box. Box extremities from bottom to top are the 10^{th}, 25^{th}, $75^{th,}$ and 90^{th} percentile.

For some parameters, significantly higher concentrations were measured in the dry season (Table 32). Metals concentration data show particularly strong differences between the seasons, with the exception of total lead (Appendix F). The possible mechanisms for seasonal differences are: (1) a reduction in water volume with a similar contaminant mass throughout the year or (2) greater contaminant contributions during the dry season. Figure 16 suggests that the difference in concentrations between seasons was due to a smaller dry-season storm volume. Yet, when Ecology assessed mass loads of the contaminants per storm event (kg per storm event), which normalized the data, the same group of parameters exhibited seasonal differences. In reality, both of these mechanisms likely contributed to greater contaminant concentrations during the dry season.

A further analysis of concentrations and loads compared to the antecedent dry-period length is a natural next step. Unfortunately, Ecology did not require antecedent dry period data to be submitted to EIM; therefore, the analysis could not be conducted.

Table 32. Seasonality of stormwater concentrations.

Conventional Parameters	Nutrients	Metals	Hydrocarbons	Pesticides	Phthalates	PCBs
Significant seasonal difference						
BOD Surfactants Fecal coliform Conductivity Hardness as CaCO3 Turbidity	Total phosphorus Ortho-phosphate TKN Nitrite+nitrate Ammonia	Cadmium (total and dissolved) Copper (total and dissolved) Lead (dissolved) Zinc (total and dissolved) Mercury	TPH-Dx Diesel Range Organics Fluoranthene Heavy Fuel Oil Pyrene	none	none	none
No seasonal difference						
pH Total suspended solids	none	Lead (total)	Benz(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(k)fluoranthene Benzo(b,k)fluoranthene Benzo(g,h,i)perylene Indeno(1,2,3-cd)pyrene CPAH HPAH LPAH Lube Oil Motor Oil Phenanthrene Total PAH Total TPH-Dx	Dichlobenil Pentachlorophenol Phenol	Bis(2-ethylhexyl) phthalate Dibutyl phthalate Diethyl phthalate Total Phthalate	PCB-Aroclor 1254 PCB-Aroclor 1260 Total PCB

Findings in this study that the dry-season contaminant concentrations were significantly higher for *some* of the parameters was consistent with findings from the NSQD which show that first flush events were detectable for some parameters predominantly in areas of commercial and residential land uses (Maestre et al., 2004). The *PS Toxics Study* also observed greater concentrations during fall storm events when longer antecedent dry periods prevailed.

Contaminant Loads

Data summaries for storm-event contaminant loads were calculated for the Case A parameters. For those contaminants that were classified as Case B and had more than 50 observations (summarized used Robust ROS techniques), contaminant loads should be considered estimates. For all other parameters, a range of contaminant loads was given. Often the ranges were limited by the analytical detection limit, thus ranges were not an accurate assessment of environmental contaminant loads. Event loads were summarized using the same statistical approach as used for the concentration data (i.e., data qualifiers associated with the each concentration were used for the corresponding load). Loads were not calculated for parameters collected by grab samples, as these do not represent the load throughout a storm event.

Ecology calculated both weight-based (mass) loads (kg per storm event) and loads per unit area (kg ha^{-1}) based on the catchment area given in Table 1 for each stormwater basin.

Loads calculated here are reliable, as no bias towards large volume storms was evident across the sample sites, and sample representation of the storms was excellent. Loads are summarized by land use in Table I-2 (mass) and I-5 (per unit area). All data summaries are detailed in Table I-1 through I-6. Graphical summaries for each parameter load are detailed in Appendix H. Peto-Prentice and Kaplan-Meier cumulative density functions were also run on the load by area to describe any significant differences among land uses.

Unfortunately, Ecology could not directly compare to load estimates presented in the *PS Toxics Study*, which were true annual loads; those presented in this study were event loads. However, trends across land uses were compared. In general, mass loads exhibited the same seasonal trends as contaminant concentrations. Contaminant loads per unit area in general followed seasonal trends, but with more exceptions. Contaminant loads per unit area for each parameter are discussed in greater detail below.

Summary of Loads per Unit Area

In this section, contaminant loads (kg per hectare) are discussed as *median values* (50th percentile) unless otherwise noted. Tables I-3 through I-6 detail the data summaries for contaminant loads per unit area (hectares).

Conventional Parameters

Surfactants

Contributions of surfactants were 0.0002 kg per hectare per storm event. Significant differences existed among land uses, but not between wet and dry seasons. Loading data followed trends similar to concentration data across land uses. Commercial and industrial land uses contributed greater loads.

Total Suspended Solids (TSS)

TSS load varied significantly across land uses and showed a significant difference between wet and dry seasons (Table I-3). Loads from industrial and commercial land uses were significantly greater (0.71 kg ha^{-1} and 0.28 kg ha^{-1}, respectively) than loads from high-density residential land

use (0.06 kg ha^{-1}) and low-density residential land use (0.04 kg ha^{-1}). TSS load exhibited a clearer difference among land uses than concentration, consistent with findings from the *PS Toxics Study*.

Nutrients

Phosphorus

Total phosphorus loads per unit area had a median value of 0.00045 kg ha^{-1} with 8.46 x 10-5 kg ha^{-1} contributed as ortho-phosphate. Land uses contributed significantly different loads on a per unit area basis. Seasonal loads were not different, in contrast to concentration data where concentrations were significantly higher during the dry season.

As with concentration, total phosphorus loads were significantly greater in stormwater from the commercial and industrial land uses. The residential land uses were significantly lower and quite similar to each other (in kg ha^{-1}; Table I-5).

Dissolved phosphorus load (as ortho-phosphate) from low-density residential land use (1.1×10^{-4} kg ha^{-1}) was similar to the load from industrial (1.5×10^{-4} kg ha^{-1}) and commercial (1.1×10^{-4} kg ha^{-1}) land use. These results are an order magnitude higher than high-density residential land use (3.5×10^{-5} kg ha^{-1}).

Findings from this study agreed with the *PS Toxics Study* which found that commercial and industrial land uses contributed a higher load of total phosphorus than residential land uses. Dissolved phosphorus was not measured in the *PS Toxics Study*.

Nitrogen

The observed nitrogen loads suggested that 0.0043 kg ha^{-1} of nitrogen was discharged per storm event (sum of total Kjeldahl N and nitrite+nitrate, as nitrogen), with a 90^{th} percentile of 0.026 kg ha^{-1} N. The TKN loads (as kg ha^{-1}) across land uses differed from that observed for concentrations. TKN loads were dominated by contributions from commercial and industrial land-use areas, with residential land-use contributions significantly lower. Nitrite+nitrate loads were also highest in discharges from commercial and industrial land uses. Above the 75^{th} percentile of the distribution, the highest loads observed in the data set were discharged from residential land-use areas. This finding highlights the complexity and variability among land uses and among sites.

There was no difference in nitrogen loads between wet and dry seasons.

The *PS Toxics Study* found that residential land uses contributed the majority of nitrite+nitrate, which was similar to observations of this study. Commercial and industrial land uses were found to contribute the lowest nitrite+nitrate load in the *PS Toxics Study*, which was contrary to the findings of this study in which commercial and industrial land uses contributed the greatest median loads.

Metals

Metals loading (as kg ha^{-1}) generally followed trends similar to concentration data. Commercial and industrial land-use areas discharged the greatest load, followed by discharges from residential land uses. Some deviations from this trend were noted for lead. Similar loading trends during storm events among land uses were noted in the *PS Toxics Study*. All metals showed greater loading during the dry season.

Cadmium

The 90^{th} percentile of the total cadmium load from all land uses was 3.37×10^{-6} kg ha^{-1} per storm event with a median of 4.83×10^{-7} kg ha^{-1}. Approximately 20% of the total cadmium was in dissolved form. The differences among land uses were similar to the cadmium concentration data, where commercial and industrial land uses discharged significantly higher loads than residential land uses. No significant differences were found between the wet and dry seasons for loads per unit area.

Copper

The 90^{th} percentile of copper load discharged during each storm was 3.6×10^{-4} kg ha^{-1} and the median was 5.1×10^{-5} kg ha^{-1}. Approximately 25% of the copper was in dissolved form. Trends across land uses and between seasons were similar to those found for cadmium.

Lead

The 90^{th} percentile of the distribution of total lead load was 3.0×10^{-4} kg ha^{-1} per storm event, and the median was 2.7×10^{-5} kg ha^{-1} per storm event. Land-use trends for loads were similar to those found for concentrations. Commercial land-use areas discharged significantly higher loads; industrial and high-density residential land uses discharged roughly similar loads. Low-density residential land-use areas discharged significantly lower lead loads. No significant differences were found between the wet and dry seasons for loads per unit area.

Mercury

Mercury loads were heavily influenced by the number of non-detect concentrations. Only for areas of commercial land use could the loads be quantified (Appendix I). No seasonal differences were apparent in the loads of mercury from commercial land-use areas.

Zinc

The median zinc load was 3.1×10^{-4} kg ha^{-1} per storm event, while the 90^{th} percentile of the load distribution was 1.5×10^{-3} kg ha^{-1} of zinc per storm event. Land-use trends for loads were very similar to those measured for concentrations, where commercial and industrial land uses showed nearly identical loads. Commercial and industrial lands had significantly higher loads of zinc, than did residential lands. No significant differences were found between the wet and dry seasons for loads per unit area.

Hydrocarbons

TPH

TPH-Dx had significantly higher loads in stormwater (as kg ha^{-1}) from commercial and industrial land uses compared with residential land uses, similar to the concentration trends. The 90^{th} percentile of the distribution of TPH-Dx load was 0.02 kg ha^{-1} per storm event, and the median across all land uses was 2.0 x 10^{-3} kg ha^{-1}. The motor oil component of TPH-Dx was discharged at a load of 0.02 kg ha^{-1}(90^{th} percentile), with a median of 3.0 x 10^{-3} kg ha^{-1} per storm event. The TPH-Dx load from high-density residential land use was significantly lower than the load from commercial and industrial land use. No significant differences were found between the wet and dry seasons for loads per unit area.

Polycyclic Aromatic Hydrocarbons (PAHs)

Individual PAH compound concentrations were well-quantified for fluoranthene, phenanthrene, and pyrene. These three compounds displayed trends similar to concentration trends for land uses, where significant differences were present between loads from commercial, industrial, high-density residential, and low-density residential. The 90^{th} percentile of the total PAH mass loads was 2.0 x 10-5 kg $ha^{-1,}$ and the median was 6.7 x 10^{-7} kg ha^{-1} contributed per storm event. Trends across land uses for loading of total PAHs, CPAHs, LPAHs, and HPAHs were the same as described for the individual PAH compounds.

Significant differences in PAH loads were found between wet and dry seasons, contrary to concentration data. Greater PAH loads were found during the wet season.

Phthalates

Bis(2-ethylhexyl)phthalate was the only well-quantified phthalate in stormwater from all land uses. Ecology estimated the 90^{th} percentile of the load was 3.5 x 10 -5 kg ha^{-1}, and the median was 3.9 x 10^{-6} kg ha^{-1} discharged per storm. Significant differences in load trended downward from commercial to industrial to high-density residential to low-density residential land uses. A similar pattern was observed for total phthalates across land uses. A significant difference was found between wet and dry seasons.

Pesticides

The load of dichlobenil did not vary across the three land uses (commercial, industrial, and high-density residential) where concentrations were detected. The estimated load per unit area was a median of 4.82 x 10^{-8} kg ha^{-1} of dichlobenil per storm event. No difference in dichlobenil load was found between wet and dry seasons.

Pentachlorophenol load in stormwater was calculated only for commercial land-use areas, where the estimated median was 6.31 x 10^{-8} kg ha^{-1} per storm event. No difference in pentachlorophenol load was found between wet and dry seasons.

Contaminant Load Summary

Storm-event mass (kg) and load per unit area (kg ha^{-1}) were calculated for contaminants that were quantified above detection limits in stormwater. Contaminant loads showed trends similar to the contaminant concentrations, with the exception of nutrients. While contaminant mass loads (kg) were not discussed in detail in this report, we observed similar seasonal trends to the contaminant concentration data. On the other hand, loads per unit area were generally constant throughout the year. Contaminant loads per unit area are summarized below:

- *Nutrients*: Total nitrogen and phosphorus loads were highest from commercial and industrial land uses. Low-density residential land uses contributed as much ortho-phosphate load as the commercial and industrial land uses, while ortho-phosphate load from high-density residential land use was significantly lower. Dissolved nitrogen (as nitrite+nitrate) load from high-density residential land use was greater than the 75^{th} percentile of the load from commercial and industrial land uses. Nutrient loads calculated per area were constant throughout the year, although nutrient concentrations were higher in the dry season.

- *Metals*: Commercial and industrial land uses discharged the greatest metal loads, and lower loads were discharged from residential land uses. All metals showed no significant difference in loading between the wet and dry season, contrary to the concentration data and mass loads (kg). A high mass loading observed during the dry season seemed more highly influenced by elevated concentrations rather than by volume.

- *Hydrocarbons:* Commercial and industrial land uses contributed the greatest loads of diesel range total petroleum hydrocarbons (TPH-Dx) and PAHs. Overall, loads per unit area (kg ha^{-1}) showed significant differences between seasons, with greater loads during the wet season.

- *Pesticides*: Commercial, industrial, and high-density residential land uses had comparable dichlobenil loads. No seasonal differences in contaminant loads were noted.

Summary

Stormwater and storm sediment discharge data were collected by NPDES Phase I Municipal Stormwater permittees, under Special Condition S8.D, between 2007 and 2012. This report is a summary of data results contained in Ecology's Environmental Information Management (EIM) System. The eight Phase 1 permittees, all located in western Washington, collected highly representative storm-event data under a prescribed monitoring program that represented multiple land uses, storm characteristics, and seasons. The main goals of this study were to (1) compile and summarize the permittees' data using appropriate statistical techniques and (2) provide a western Washington regional baseline characterization of stormwater quality.

Ecology's analysis provides a comprehensive review of the pollutants in western Washington stormwater from 2007 - 2012. These findings are based on the analysis of 44,800 data records representing 597 different storm events. Up to 85 chemicals were analyzed in stormwater samples, and 67 chemicals were analyzed in stormwater sediment samples. Compiling data from multiple sources was challenging due to differences in parameter names, sample fractions, units, reporting limits, and basin characteristics.

The representativeness of the collected samples across storm events appeared to be of high quality, generally representing above 90% of storm hydrographs. Samples showed no bias of storm volume. The distribution of sampling events over the year was also of high quality with few exceptions.

The statistical analyses used in this study have produced reliable statistical summaries and allowed for robust comparisons of the impacts of land use and seasons on contaminant concentrations and mass loads. The statistical summaries form a baseline for contaminant concentrations in stormwater that will allow for future comparisons. Results can be used to track improvement in stormwater quality as local programs continue to be implemented.

Key Findings

The following key findings are highlighted from this report.

Stormwater Monitoring Program

- Ecology finds the permittees' stormwater monitoring data to be representative of storm events in western Washington. The stormwater discharge data set is large, captured a wide variety of storm events, and does not appear to have biases toward storm size, limb of hydrograph, land use, or season. Results are suitable for creating a baseline understanding of stormwater discharges in western Washington.
- Stormwater monitoring as required in the 2007 permit was met (qualifying storm, sample frequency, and representativeness). The continued collection of high quality data representing storm-event pollutant concentrations seems realistic.
- "Typical" stormwater chemistry for a particular land use was difficult to define.
- This database is a suitable baseline to compare stormwater contaminant concentrations against management actions in future studies.
- Permittees' initial efforts to assess toxicity of stormwater on trout embryos per permit requirements in S8.F were met with considerable logistical and bioassay complexity. Twelve of the 17 samples analyzed using bioassays had no adverse effects. Only samples from larger commercial areas showed toxicity to trout embryos, with the likely toxicants being zinc and copper. Appendix A provides a summary of the bioassay effort and lessons learned.

Stormwater Discharge Quality

- Commercial and industrial areas discharged stormwater with the highest concentrations of metals, hydrocarbons, phthalates, total nutrients, and a few pesticides.
- Residential areas discharged stormwater with the highest dissolved nutrient concentrations.
- Copper, zinc, and lead most frequently exceeded (did not meet) the water quality criteria for protection of aquatic life. Cadmium and mercury also exceeded criteria for protection of aquatic life. Mercury was not a widespread contaminant in western Washington stormwater, although localized areas of concern existed. Comparisons to water quality criteria were made for context in this report.
- Metals concentrations monitored during the dry season (May through September) were statistically higher than concentrations monitored during the wet season. Dissolved zinc, copper, and lead exceeded acute and chronic water quality criteria regularly. Comparisons to water quality criteria were made for context in this report.
- Higher contaminant concentrations and mass loads (kg per storm event) were measured for nutrients and metals during the dry season. This supports the idea that there is a "buildup" during the dry season, when the antecedent dry periods are longer.

- PAHs, phthalates, PCBs, and the few detected pesticides did not exhibit a significant seasonal difference, suggesting these parameters were being discharged from a consistent source throughout the year.
- Bis(2-ethylhexyl) phthalate was frequently found in stormwater and stormwater sediment.
- NWTPH-Dx compounds were persistent stormwater contaminants. Commercial and industrial areas discharged much higher concentrations and loads than did residential areas. When the motor oil fraction was considered separately, the highest load was from residential areas.
- NWTPH-Gx was poorly detected and, if present, was likely volatized before monitoring.
- Individual parameter concentrations showed strong differences between land uses.
- The most volatile organics (some pesticides, lighter weight PCBs, and PAHs) were poorly detected (less than 10% of the samples).
- The most volatile parameters (BTEX) provided less useful information when gathered from composite samples.

Stormwater Sediment Quality

- While the data set for stormwater sediment samples is smaller the data set for stormwater samples, contaminants in stormwater sediments showed trends similar to contaminants in stormwater across land uses.
- The stormwater sediment monitoring design precluded an understanding of sediment pollutants across seasons. A more refined sediment design for both spatial and temporal monitoring would improve our understanding of stormwater sediments.
- Bis(2-ethylhexyl) phthalates in stormwater sediments exceeded the freshwater aquatic life criteria (Sediment Cleanup Objectives) 82% of the time. Di-n-octyl phthalate exceeded the criteria 29% of the time.
- Total PAHs in stormwater sediments exceeded the freshwater aquatic life criteria (SCO) 34% of the time.
- Copper (9%) and lead (18%) were the main metals in stormwater sediments exceeding the SCO. Zinc and mercury were not of concern in stormwater sediments.
- Phenol in stormwater sediment exceeded the SCO 20% of the time.

Comparisons with Relevant National and Local Stormwater Studies

Generally, contaminant concentrations reported in this study were within the ranges reported in the National Stormwater Quality Database (NSQD), but median values were often lower. This is primarily due to the age of the NSQD (early 1980s) and improvements in stormwater quality and management since the National Urban Runoff Program (NURP) sampling. Many of the contaminant concentrations in this study were higher than those found in the *PS Toxics Study*.

This finding is not surprising given that the *PS Toxics Study* sampled receiving waters, not stormwater discharges, during storm events.

- The *PS Toxics Study* found high concentrations of PAHs in receiving waters during storm events. The majority of PAHs were contributed from commercial and industrial areas, which was corroborated by this current study. PAHs in stormwater discharges showed no seasonal differences in concentrations.
- The pesticides, dichlobenil and pentachlorophenol, were reliably detected in this study. Triclopyr, which was detected in the *PS Toxics Study*, was found in only 10% of the 575 samples analyzed in this study.
- The few samples with detected concentrations of PCBs in water showed much lower concentrations in this study than in the *PS Toxics Study*.
- Dissolved nutrients (orthophosphate and nitrite+nitrate-nitrogen) were much lower in stormwater discharges as compared to receiving waters sampled in the PS Toxic Study. This suggests that dissolved nutrient contributions are larger to receiving waters from pathways other than stormwater drainages (e.g., tributary streams and groundwater).
- Higher concentrations and storm-event loads of metals were contributed to receiving waters from commercial and industrial areas than from other land-use areas. The *PS Toxics Study* also found the highest metals concentrations in waters from commercial and industrial areas.

Recommendations

Based on the findings of this study, further actions and data analysis are recommended.

- Implement best management practices (BMPs) and adjust stormwater management programs based on these findings. Use findings to help prioritize activities within stormwater programs.
- Present the data online in a simple, user-friendly interface that stormwater managers could use to directly compare with future stormwater chemistry results.
- Link this database with the National Stormwater Quality Database (NSQD) to increase the temporal range of the data set.
- Further investigate the relationships between seasonality and land use for each parameter. For example, total phosphorus exhibits strong statistical differences between land uses during the wet season but no significant differences during the dry season.
- Conduct further analysis to identify the land use associated with each sample that exceeded (did not meet) water quality criteria.
- Expand the number of sites for annual sediment sample collection to enhance the spatial survey of possible contaminant sources.
- Use results from this study to fill gaps found in the *Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates* (Herrera, 2011; *PS Toxics study*): for example, areas draining directly to marine waters or fresh receiving waters that were missed when monitoring the larger drainages in that study.
- Reduce the sampling frequency of, or eliminate, the following parameters from further stormwater discharge sampling:
  - BTEX in water and sediments.
  - Malathion, prometon, chlorpyrifos, and diazinon in water and sediments.
  - Triclopyr and mecoprop in sediments.
  - Limit phenolics in sediments to pentachlorophenol, o- cresol, and p-cresol.
- Evaluate the data set for patterns among parameters that could help identify sources of pollution to stormwater.
  - Explicitly test the influence of seasonal first flush, or antecedent dry period lengths, on stormwater discharge concentrations.
  - Explore whether the correlations between some parameters and land uses are causative or coincident. For example, surfactants and copper; does the application of surfactants increase the mobilization of copper from the catchment?
  - Investigate dissolved nutrient concentrations in stormwater from low-density residential areas and investigate pollution reduction approaches.

- Track and evaluate any BMPs within each basin using a similar suite of stormwater chemistry (e.g., timing of sweeping or cleaning of Ports or parking lots).
- Explore the high-runoff coefficient calculated for specific high-density residential sites to determine whether the high-runoff coefficients influence the contaminant contributions from these sites.

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Appendices

Appendix A. Municipal Stormwater Trout Embryo Toxicity Testing: Results from First Flush, 2010-2011

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Monitoring Strategy

The permittees under the Phase I Municipal Stormwater Permit made attempts to sample seasonal first flush stormwater for toxicity testing in August through October of 2010 and 2011. Each permittee sampled only in one of those years but targeted three of the following four landuse types:

- Commercial.
- Industrial.
- Low density residential.
- High density residential.

Half of the permittees could only sample the discharge from two landuse types because of inadequate discharge volumes during the seasonal first flush timeframe defined in the permit. This monitoring did not provide for results from multiple years or multiple seasons and must be considered no more than a snapshot of any of the discharge locations. In addition, only nine of the seventeen samples were collected in August and represented well a seasonal first flush. Five of the seventeen samples were collected in October.

Metals in water with higher hardness are less toxic and water quality criteria for metals are calculated based upon hardness. The hardness of receiving water is often significantly higher than stormwater. The permit allowed the hardness of stormwater samples to be adjusted to match receiving water hardness to provide some environmental realism.

However, other relevant features of the receiving water environment were not incorporated into test conditions. Features left out include:

- Upstream sources of metals and other pollutants.
- Pulsed pollutant exposures.
- Dilution
- Dissolved organic carbon.
- Suspended solids.
- Variability of stream chemistry during storms.

The monitoring results have limited environmental relevance.

The trout embryo viability test is good for assessing conditions for the first 7 days of a trout or salmon's life. The test measures survival and development during this time. It misses other sensitive lifestage transitions such as hatch or swim-up. Since the toxicity testing did not include other organisms, lifestages, and biological endpoints, the results need to be considered solely within the context of the 7-day trout embryo test.

Test Method and Results

Labs conducted the Environment Canada 7-day trout embryo viability test[5] on the stormwater samples. Tests began with freshly fertilized rainbow trout eggs and continued for a week. At the end of 7 days the labs counted the number of live embryos and the number of normally developed embryos. All tests provided valid results based upon control response. Twelve of the seventeen tests showed no adverse effects to either survival or development.

Only the Port of Tacoma and Port of Seattle samples had EC50s equal to or less than 100% sample[6] and triggered the follow-up actions in the permit. Follow-up actions compare chemical analysis results on split samples to published toxic thresholds. The comparison revealed zinc to be the likely toxicant for the Port of Tacoma sample and copper to be the likely toxicant for the Port of Seattle sample. Ports are especially large and intensive commercial operations.

The dissolved copper and zinc concentrations in the samples from the commercial landuse types were 2 to 10 times higher than the concentrations of the same metals in samples from residential landuse. The Pierce County and Snohomish County commercial samples had higher concentrations of zinc than the one industrial landuse area sampled. The Snohomish County commercial sample also had higher copper than the industrial sample. Parking lots are significant sources of copper and zinc. Galvanized metal roofs can produce runoff with toxic concentrations of zinc. Commercial areas have abundant parking lots and galvanized steel. Table A-1 shows the average concentration of copper and zinc in the same samples from the various landuse types that were tested for toxicity.

Table A-1 – Average Copper and Zinc Concentrations in Samples from Different Land Uses.

	Copper	Zinc
Commercial (n = 6)	17.9	100.8
Residential (n = 8)	5.4	18.4
Industrial (n = 1)	19.2	125.0
Port of Seattle	101.0	171.0
Port of Tacoma	13.7	767.0

Copper and zinc concentrations along with toxicity test results for all samples are listed in Table A-2.

The samples from the commercial landuse types for the City of Seattle, Pierce County, and Snohomish County were moderately toxic. The toxicity test result for the Snohomish County

[5] EPS 1/RM/28

[6] This toxicity test used a series of dilutions of the sample (starting at 100% concentration). Therefore if the half maximal effective concentration (EC50) was equivalent to or less than the raw sample, the sample had regulatory significant toxicity.

commercial sample nearly triggered the follow-up actions in the permit, but the results from the other commercial samples were not as close. None of the residential landuse samples showed any toxicity. The one industrial sample did not either. Toxicity test results are given in Table A-2.

Lessons Learned

- Rainbow trout do not naturally spawn in late summer through early fall. The hatchery had to make a special effort at that time to bring fish into spawning condition. Permittees and labs had to predict a qualifying seasonal first flush storm event enough in advance to arrange for the hatchery to have trout gametes available for setting up tests. Scheduling was not always successful and most tests needed variances from sample holding times. Ten out of seventeen samples were past the recommended sample holding time of 36 hours at test startup. Two samples were slightly older at test setup than the EPA maximum allowed holding time of 72 hours.
- Uneven quality of trout gametes due to the time of year may have produced variability in response that led to poor statistical sensitivity. Five out of the seventeen trout embryo tests did not meet the chronic statistical power standard[7] of being able to determine that a reduction in survival or development of 40% or more is statistically significant. The percent minimum significant differences (PMSDs) highlighted in Table A-2 show which tests failed to meet the power standard. These municipal stormwater tests had 50% of the PMSDs ≥ 40% from all ninety-seven trout embryo tests in the toxicity test database even though they are only 18% of the total.
- The seasonal first flush was over by early fall in 2010 and probably most years. It was also more pronounced for commercial (metals 3.5 to 4 times higher than average) rather than residential (metals 1.5 to 2.5 times higher) sites. See Table A-3 for an example.
- The most experienced lab closed at the beginning of the 2011 monitoring season. The replacement labs failed to take advantage of the opportunity to adjust sample hardness to match the receiving water.
  - The Port of Seattle's sample may not have been toxic if its hardness had been adjusted.
  - The Port of Tacoma's sample would likely have still been toxic even if hardness was adjusted.
  - The King County samples were also not adjusted.
- Available information is more than adequate to guide stormwater management for many years. These toxicity test results confirm what Ecology already knows about urban sources of copper and zinc. Commerce depends upon transportation and supporting infrastructure. Transportation and infrastructure are major sources of copper and zinc.
- Toxicity testing of stormwater or urban streams should be reintroduced when stormwater controls are well-implemented in order to see if they are missing pollutants or sources.

[7] See WAC 173-205-020

Table A-2 – Trout Embryo Toxicity Test Results with Sample Handling and Copper (Cu) and Zinc (Zn) Concentrations.

Phase I Permittee	Land Use	Collected	Start Date	Sample Holding Time	Hardness Adjusted?	Test Hardness (ppm)	diss. Cu (µg/L)	diss. Zn (µg/L)	Endpoint	NOEC	LOEC	PMSD	EC50	EC25	% Response
City of Tacoma	Commercial	10/10/2010	10/11/2010	38.7	Yes	100	18.2	51.7	Survival	100	> 100	11.4%	> 100	> 100	87%
									Development	100	> 100	15.2%	> 100	> 100	89%
	Residential	10/10/2010	10/11/2010	38.1	Yes	100	3	19.4	Survival	100	> 100	17.1%	> 100	> 100	83%
									Development	100	> 100	18.6%	> 100	> 100	93%
Clark County	Commercial	8/31/2010	9/2/2010	41.3	Yes	84	22.2	106	Survival	100	> 100	17.4%	> 100	> 100	87%
									Development	100	> 100	52.0%	> 100	> 100	78%
	Low Density Residential	10/24/2010	10/25/2010	36.7	No	44	5.5	9.6	Survival	100	> 100	42.8%	> 100	> 100	89%
									Development	100	> 100	29.0%	> 100	> 100	94%
King County	Commercial	10/11/2011	10/13/2011	59.5	No	29	6.6	14.9	Survival	100	> 100	21.8%	> 100	> 100	76%
									Development	100	> 100	2.1%	> 100	> 100	100%
	High Density Residential	10/11/2011	10/13/2011	59.1	No	12	1.9	2.4	Survival	100	> 100	24.9%	> 100	> 100	92%
									Development	100	> 100	2.8%	> 100	> 100	100%
	Low Density Residential	10/11/2011	10/13/2011	55.5	No	9.4	3.1	4.0	Survival	100	> 100	49.1%	> 100	> 100	75%
									Development	100	> 100	1.8%	> 100	> 100	100%
Pierce County	Low Density Residential	8/23/2011	8/24/2011	26.7	No	56	0.7	< 0.5	Survival	100	> 100	2.7%	> 100	> 100	98%
									Development	100	> 100	13.0%	> 100	> 100	94%
	Commercial	8/23/2011	8/24/2011	25.1	No	44	15.4	134	Survival	100	> 100	2.7%	> 100	> 100	99%
									Development	50	100	9.1%	> 100	> 100	84%
Port of Seattle	Parking Lots & Buildings	9/18/2011	9/21/2011	81.0	No	27	101	171	Survival	25	50	23.0%	47.1	37.8	44%
									Development	100	> 100	11.5%	> 100	> 100	87%
Port of Tacoma	Parking Lots & Buildings	9/18/2011	9/21/2011	80.3	No	15	13.7	767	Survival	12.5	25	32.2%	12.5	9.5	0%
									Development	25	> 25	28.0%	58.0	30.2	NC
City of Seattle	Commercial	8/22/2010	8/23/2010	27.9	No	68	22.6	54	Survival	100	> 100	28.2%	> 100	104.5	75%
									Development	100	> 100	62.6%	> 100	87.1	58%
	Industrial	8/31/2010	9/1/2010	29.4	Yes	96	19.2	125	Survival	100	> 100	6.0%	> 100	> 100	98%
									Development	100	> 100	23.9%	> 100	> 100	89%
	Residential	8/31/2010	9/1/2010	23.6	Yes	76	16	26	Survival	100	> 100	2.4%	> 100	> 100	98%
									Development	100	> 100	13.6%	> 100	> 100	89%
Snohomish County	Commercial	8/8/2010	8/9/2010	40.3	Yes	128	22.4	244	Survival	50	100	12.4%	101.3	84.5	52%
									Development	100	> 100	71.3%	> 100	> 100	57%
	Low Density Residential	8/8/2010	8/9/2010	36.4	Yes	76	6.2	63.5	Survival	100	> 100	2.6%	> 100	> 100	99%
									Development	100	> 100	25.8%	> 100	> 100	84%
	High Density Residential	8/8/2010	8/9/2010	29.3	Yes	92	6.8	22	Survival	100	> 100	5.7%	> 100	> 100	98%
									Development	100	> 100	25.6%	> 100	> 100	84%

Sample had some toxicity based upon EC50 ≤ 100%, EC25 ≤ 100%, LOEC ≤ 100%, or % response ≤ 65%.

PMSD did not meet the power standard of < 40%.

Recommended sample holding time of 36 hours exceeded.

Maximum sample holding time of 72 hours exceeded.

Table A-3 – Dissolved Copper, Zinc, and Lead Stormwater Concentrations over a Year from Tacoma Commercial and Residential Areas.

Tacoma Phase I monitoring as example for seasonal and storm event variability

commercial outfall 235	10/9/2010	10/31/2010	11/9/2010	11/30/2010	12/12/2010	1/21/2011	1/29/2011	2/13/2011	3/5/2011	4/4/2011	4/13/2011	5/2/2011	5/25/2011	8/22/2011	mean	SD	CV
dissolved copper (µg/L)	18.2	8.24	9.84	2.7	5.23	7.64	9.56	5.59	6.35	9.02	18	28.5	20.9	63.3	15.22	15.62	1.03
dissolved zinc (µg/L)	51.7	28.8	37.8	40.4	22.6	28.1	30.8	24.3	27.2	23.6	41	60.3	42.7	153	43.74	33.36	0.76
dissolved lead (µg/L)	16.8	5.32	6.9	0.178	2.66	2.99	2.32	1.03	2.12	3.44	3.72	9.55	6.32	21.3	6.05	6.10	1.01
	normalized to mean (value/mean) to produce a multiplier indicating the degree to which value is less than or exceeds the mean for all samples														min	max	
dissolved copper (µg/L)	1.2	0.5	0.6	0.2	0.3	0.5	0.6	0.4	0.4	0.6	1.2	1.9	1.4	4.2	0.18	4.16	
dissolved zinc (µg/L)	1.2	0.7	0.9	0.9	0.5	0.6	0.7	0.6	0.6	0.5	0.9	1.4	1.0	3.5	0.52	3.50	
dissolved lead (µg/L)	2.8	0.9	1.1	0.03	0.4	0.5	0.4	0.2	0.4	0.6	0.6	1.6	1.0	3.5	0.03	3.52	
mean	1.7	0.7	0.9	0.4	0.4	0.5	0.6	0.4	0.5	0.6	0.9	1.6	1.1	3.7			

residential outfall 237B	10/10/2010	10/31/2010	11/18/2010	12/12/2010	1/21/2011	2/12/2011	3/4/2011	4/4/2011	4/13/2011	4/26/2011	5/15/2011	5/25/2011	8/22/2011	mean	SD	CV
dissolved copper (µg/L)	3	1.76	2.26	3.41	1.81	2.12	2.07	2.1	2.83	3.66	2.39	4.35	8.06	3.06	1.69	0.55
dissolved zinc (µg/L)	19.4	15.1	66.6	12.7	21.2	21.4	13.9	11.3	21.8	12.8	11.9	16.6	36.4	21.62	15.09	0.70
dissolved lead (µg/L)	0.185	0.315	0.287	0.167	0.219	0.297	0.241	0.235	0.324	0.229	0.194	0.308	0.358	0.26	0.06	0.23
	normalized to mean (value/mean) to produce a multiplier indicating the degree to which value is less than or exceeds the mean for all samples													min	max	
dissolved copper (µg/L)	1.0	0.6	0.7	1.1	0.6	0.7	0.7	0.7	0.9	1.2	0.8	1.4	2.6	0.57	2.63	
dissolved zinc (µg/L)	0.9	0.7	3.1	0.6	1.0	1.0	0.6	0.5	1.0	0.6	0.6	0.8	1.7	0.52	3.08	
dissolved lead (µg/L)	0.7	1.2	1.1	0.6	0.8	1.1	0.9	0.9	1.3	0.9	0.8	1.2	1.4	0.65	1.39	
mean	0.9	0.8	1.6	0.8	0.8	0.9	0.8	0.7	1.1	0.9	0.7	1.1	1.9			

Appendix B. Permittees' Quality Assurance Project Plans

Website link to QA Project Plans on file with Ecology
www.ecy.wa.gov/programs/wq/stormwater/municipal/s8dswmonitoring.html

Clark County

Quality Assurance Project Plan for Stormwater Characterization Monitoring. Conducted Under Section S8.D of the Phase I Municipal Stormwater Permit by Clark County. Prepared by U.S. Geological Survey, Oregon Water Science Center. Revised March 2011 by Clark County Department of Environmental Services, Clean Water Program, Vancouver, WA.

King County

Quality Assurance Project Plan for King County Stormwater Monitoring Under the NPDES Phase 1 Municipal Permit WAR04-4501 (Issued February 2007). Updated November 2010. King County Department of Natural Resources and Parks, Water and Land Resources Division, Science Section. King Street Center, KSC-NR-0600, 201 South Jackson Street, Suite 600, Seattle, WA 98104.

Pierce County

Quality Assurance Project Plan for Pierce County Phase I Municipal Stormwater NPDES Permit Section S8.D – Stormwater Characterization. November 5, 2009. Prepared for Pierce County Surface Water Management, 2702 South 42nd Street, Suite 201, Tacoma, WA 98409-7322. Prepared by Herrera Environmental Consultants.

Snohomish County

Quality Assurance Project Plan (QAPP) Stormwater Characterization Monitoring S8.D Final. December 2008. Prepared by Snohomish County Public Works, Surface Water Management Division, 3000 Rockefeller Ave, Everett, WA 98201.

City of Seattle

Section S8.D - Stormwater Characterization Quality Management System Planning Document, Quality Assurance Project Plan. NPDES Phase I Municipal Stormwater Permit, Permit No.: WAR04-4503. Revision: R2D0 (Final). Draft revised: 03/31/2011.

City of Tacoma

Section S8.D - Stormwater Characterization Quality Assurance Project Plan, Phase I Municipal Stormwater NPDES Permit, Permit No.: WAR04-4003. Revision: S8.D-003 (Final). Revision Date: 08/16/2009. City of Tacoma, Tacoma, WA.

Port of Seattle

Quality Assurance Project Plan for Stormwater Monitoring Conducted Under Section S8.D of the Phase I Municipal Stormwater Permit. Addendum #1. November 2011. Port of Seattle Marine Division. Prepared by TEC Inc. and Otak, Inc. for Port of Seattle.

Quality Assurance Project Plan for Stormwater Monitoring Conducted Under Section S8.D of the Phase I Municipal Stormwater Permit. February 20, 2009. Port of Seattle Marine Division. Prepared by TEC Inc. and Otak, Inc. for Port of Seattle.

Port of Tacoma

Quality Assurance Project Plan for Stormwater Monitoring Conducted Under the Phase I Municipal Stormwater Permit by Port of Tacoma. Final August 2009.

Appendix C. Description of the Statistical Plots

This appendix describes each of the six plots created for data analysis. Four parameters are displayed and described for each of the six plot types. The four parameters are fecal coliform bacteria, total phosphorus, total copper, and Dichlobenil (an herbicide). These parameters were selected because they display a variety of discussion elements, considerations for data summaries, and peculiarities encountered in this report. For both the jitter and box plots, the x-axis is categorical and uses the abbreviations defined below:

Land Uses
- Ind = Industrial
- Com = Commercial
- HRes = High-Density Residential
- LRes = Low-Density Residential

Sample Result
- Det = Count of detected records
- ND = Count of non-detected records and the percent non-detected records of the total

Season Type
- Winter = Winter Quarter (January, February, March)
- Spring = Spring Quarter (April, May, June)
- Summer = Summer Quarter (July, August, September)
- Fall = Fall Quarter (October, November, December)
- DrySeas = Dry Season (May 1 through September 30)
- WetSeas = Wet Season (October 1 through April 30)

1. Jitter Plot

Jitter plots offer an excellent visual of the data. The jitter plot (Figure C-1) shows both the detected data as points and the non-detected data as bars extending from zero to provided reporting limit. The bar is useful in conveying the idea that the true value of the non-detect is unknown; only the range for which its true value may occur. The two-toned purple dots are the detected data points, divided into dry and wet seasons.

The jitter plots are divided into four vertical panels. Each panel represents a different land-use type. Within each panel, the x-values are randomized (jittered) to spread the data out and make them easier to view. Land-use types are indicated by abbreviations below the x-axis, along with the number of detects, the number of non-detects, and the percentage of non-detect data.

As seen in the jitter plots, most of the data for fecal coliform, total phosphorus, and dissolved copper were detected values, whereas the majority of the data for Dichlobenil were non-detects as indicated by the gray lines.

The fecal coliform jitter plot shows that the data spans 5 orders of magnitude and includes non-detects.

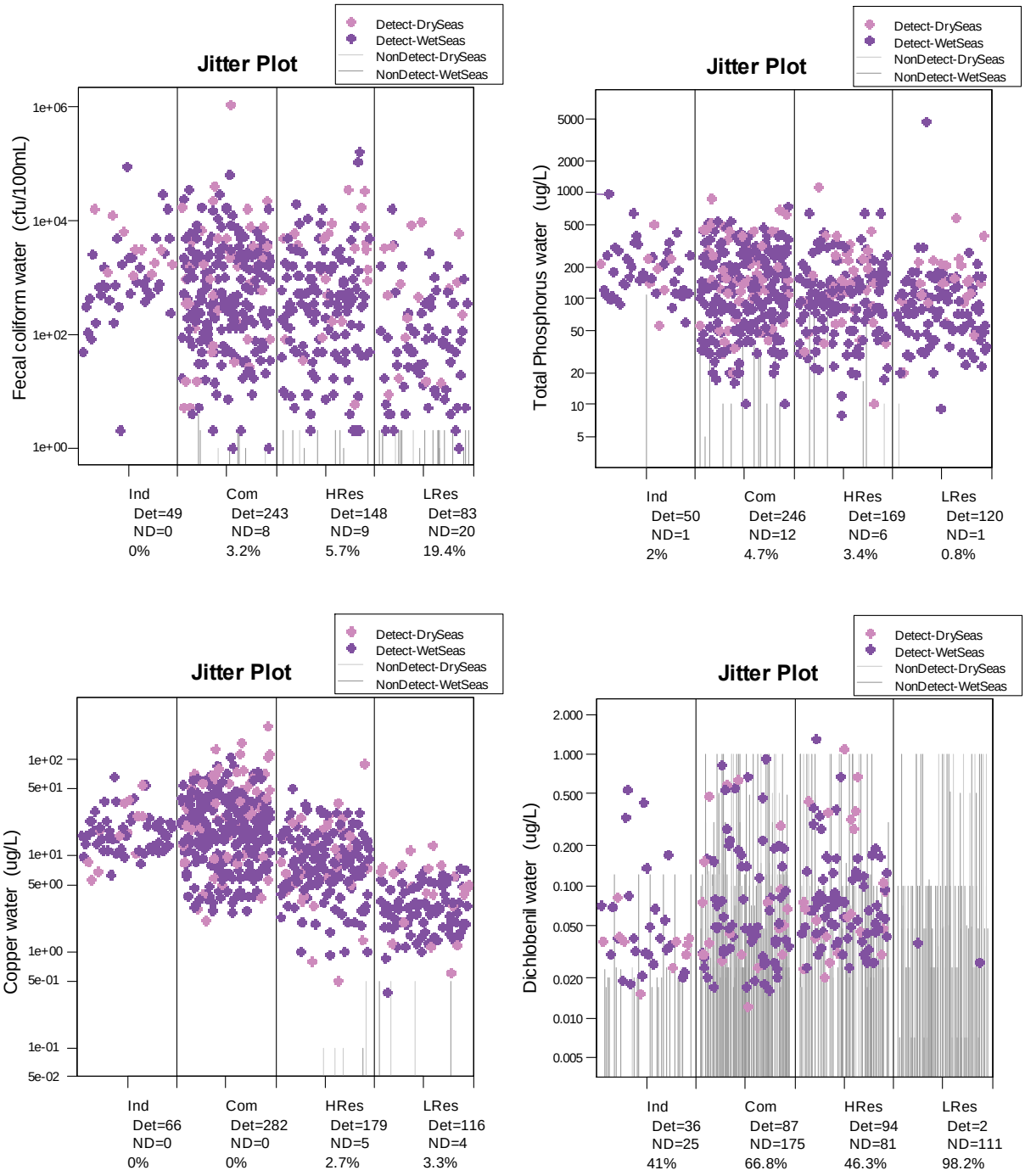


Figure C-1. Jitter plots for four example parameters.

The total phosphorus data range from 0.008 to 4.6 mg/L. There are a number of non-detects at elevated reporting limits. The reason for these elevated non-detects is unknown. This could be due to matrix interference, or this could illustrate a gap in the data QA process (QA) at the laboratory or the data review level. Ecology did not investigate peculiarities such as these for two reasons: (1) The data had already been QA reviewed by the laboratory and the permittees

and therefore were useable for summarization into the regional data set, and (2) time was limited under the grant process to investigate a small number of oddities.

The jitter plot for Dichlobenil shows that the bulk of the data were non-detect. Organic contaminants in stormwater were more likely to contain greater percentages of non-detects than conventional parameters, nutrients, or metals. Additionally, non-detects for organics were more likely, as shown for 2,4-D, to have multiple reporting limits for non-detects. The variable reporting limits may be due to the interfering matrices, low sample volumes, or different laboratory QA processes. An inter-laboratory comparison for the analytical methods used under the S8.D monitoring programs in the Puget Sound region has not been investigated, to Ecology's knowledge.

The jitter plot was also used in summarizing the contaminant load data over a gradient of % impervious cover (Figure C-2). Here, Ecology has binned or grouped the results into ranges of % impervious area by 20%. The gray dots are results that are qualified as non-detect, while the blue dots are detected concentrations. The goal of this plot is to show the distribution of contaminant loads across the range of % impervious ground cover. The plot for total copper typifies what one might expect: as the % impervious surface increases, the load of copper increases.

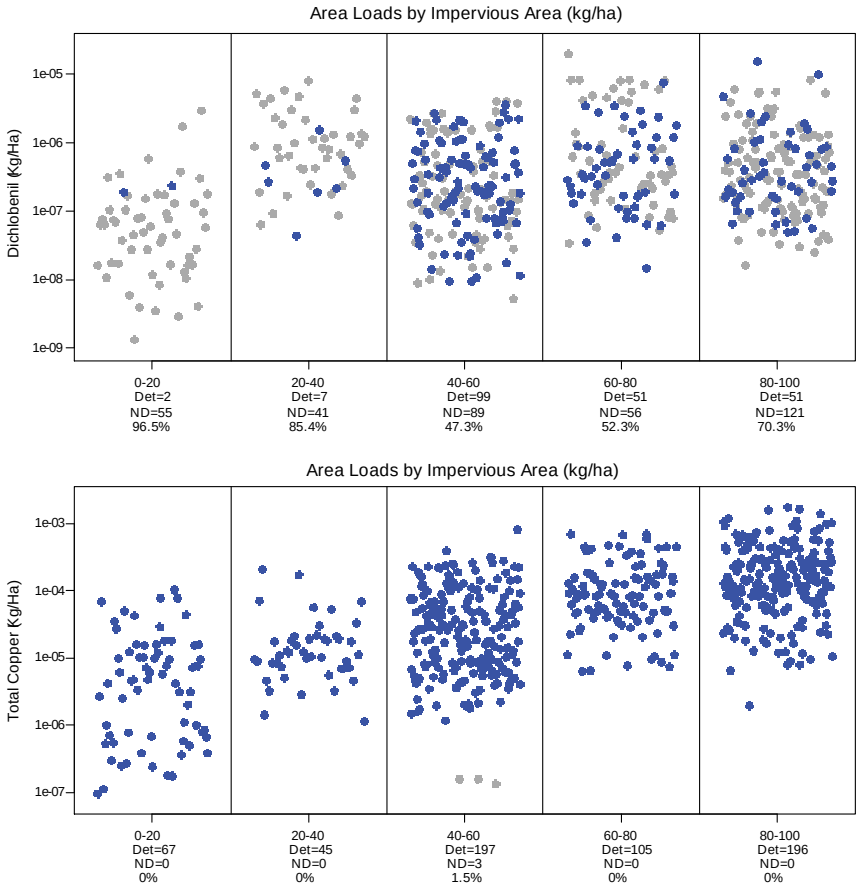


Figure C-2. Jitter plots of contaminant loads for total copper and Dichlobenil.

2. Probability Plots

Some statistical calculations assume that data follow a specific distribution. In these cases, a method is needed to check whether this assumption is valid. For example, stormwater professionals have consistently found that the concentrations of many stormwater parameters follow a log-normal distribution (EPA, 1983; Burton and Pitt, 2002; Maestre et al., 2004, 2005). A log-normal distribution results in a positive bias, meaning the average values are larger than the median values (Pitt, 2011).

Probability plots are used to visually compare a data set to a specified distribution (Helsel, 2012), in this case a log-normal distribution. The distribution is represented on the plot as a straight line, and observed data are plotted as individual points. If the data points fall near the line then they are described as reasonably fitting the log-normal distribution. If the data points show curvature or have a number of points that plot far from the line, then the data are said to differ significantly from the log-normal distribution. Parameters with few or no non-detects were tested for a normal or log-normal distribution using the Shapiro-Wilk test. This was discussed further in the *Methods* section of the report.

For all other parameters, the presence of non-detects must be properly accounted for when creating a probability plot. Although non-detects are not shown on the plot, they affect the placement of the observed data points on a probability plot. A probability plot that ignores non-detected data is invalid according to Helsel (2012). Ecology used the regression on statistic (ROS) approach to generate probability plots for this report. This approach accounts for the proportion of the data below each reporting limit and adjusts the placement of the detected data accordingly.

On these plots, the lower x-axis shows the quantile while the upper x-axis represents the percentiles of the data distribution (Figure C-3). The y-axis shows the concentrations (typically in log scale). The detected data are shown as black dots. The non-detect values are ranked, and the positional range and count of data points associated with the non-detects is taken into consideration, but are not shown on the plot.

These plots use the entire data set and do not divide the data by land use. This is particularly useful in describing stormwater baseline characterization conditions.

In the examples shown in Figure C-3, only total copper appears to "fit" the straight line well over the entire distribution of the data. This is a visual indication that total copper is the only log-normally distributed parameter in this example. The Shapiro-Wilks test indicates the fecal coliform, total phosphorus, and dichlobenil data are distribution-free.

Probability plots accurately present the median, as well as other percentiles presented on the upper x-axis of the entire data set. For example, the median values for fecal coliform, total phosphorus, and total copper appear to fall at the middle point of the detected data. This makes sense, since Figure C-1 showed that the majority of their data were made up of detected records.

On the other hand, the median for Dichlobenil is near the lower limit of much of the detected data. This also is logical, because in Figure C-1 76% of the 2,4-D data points were non-detect. Therefore, in Figure C-3 the median value falls in the area of the plot where there are few to no data points showing.

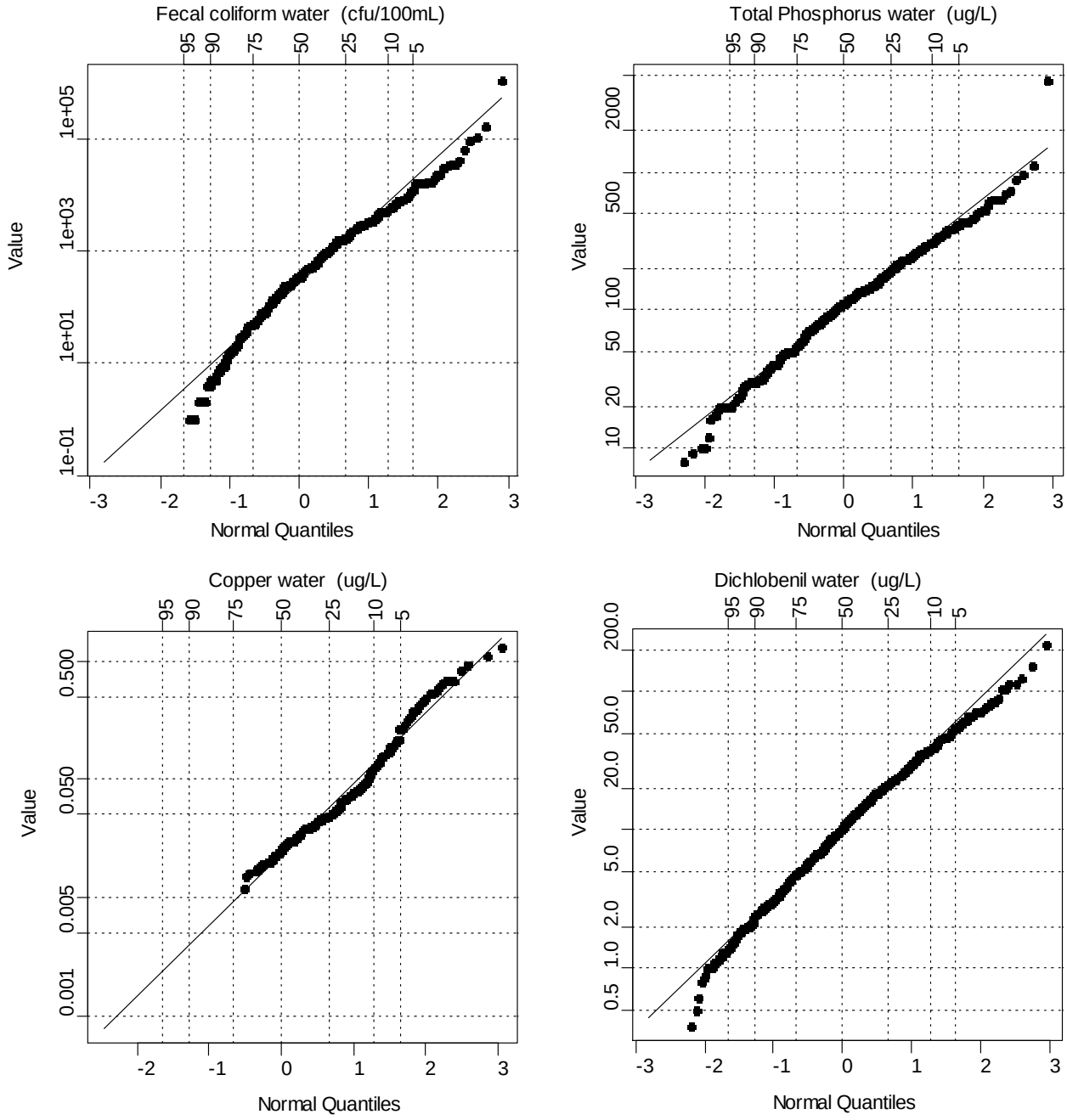


Figure C-3. Probability plots for four example parameters.

3. Plots of Non-Detects

To understand differences in laboratory reporting levels, Ecology plotted non-detect thresholds reported by the permittees. Non-detect data are shown in these plots as line segments extending from zero to the laboratory reporting level. The color of the line segment indicates which laboratory performed the analysis. Laboratory names were removed and represented by a number. The focus of this plot is not to identify permittees or their laboratories, but rather to illustrate the number of laboratories and the numerous reporting limits reported.

Within each plot, the non-detect data are spaced evenly and sorted from lowest to highest reporting level. Plots with few points show the lines distinctly, whereas plots with a large number of data points show no spaces between the lines. Examples are shown in Figure C-4.

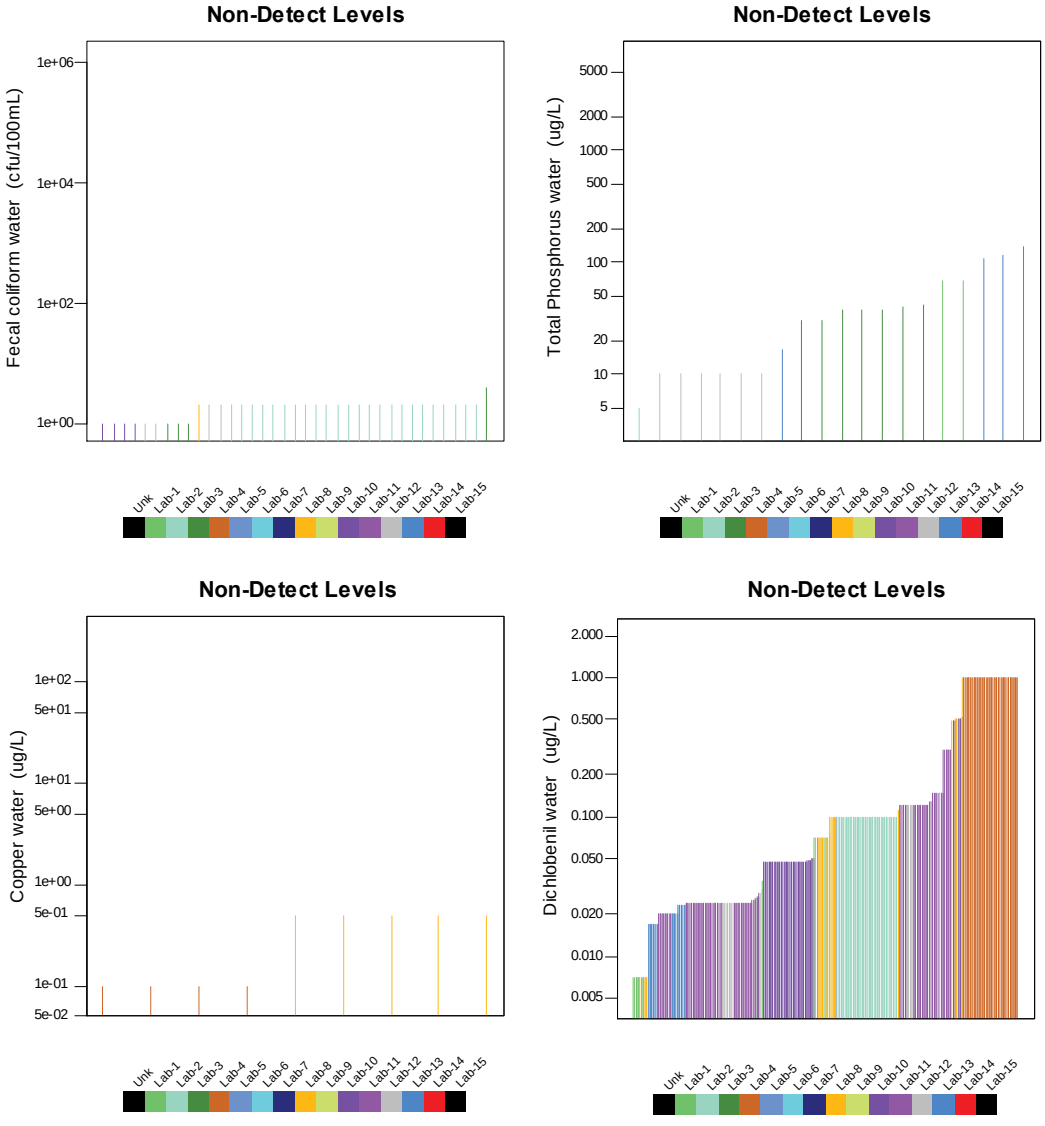


Figure C-4. Non-detect plots for four example parameters.

These examples illustrate both the frequency a parameter was not detected and the variability in the reporting limit threshold for the non-detect data. Recall that variability comes from different samples' matrices, sampling dates, handling techniques, and laboratories. The parameter data in Appendix F did not contain this plot if there were no non-detect data.

4. Empirical Distribution Function (EDF)

These plots (Figure C-5) help identify differences in concentrations among the four land-use types. EDF plots of the observed data are constructed by ranking the data from smallest to largest (Helsel, 2012). EDF plots are also known as the Kaplan-Meier (KM) Curves. The graph shows the likelihood of any given sample concentration to occur in the population of the data set by percentiles. Line type and color indicates land use, as shown in the plot legend.

On these plots, Ecology swapped axes from the usual convention in order to allow comparison with the jitter plots and box plots. Only the detect values are actually plotted, but their positions are influenced by both detections and non-detections. This is a preferred method to display data sets that contain non-detects, as opposed to the traditional box and whisker plots that use only detected values. EDF plots were not shown if there were less than five detected values for any given parameter, and in this case, the data plots (Appendix F) will show the message: "Not Plotted (Less than 5 detections)".

These four example parameters begin to illustrate the impact of the surrounding land use on the water quality of stormwater.

In the case of fecal coliform, the EDF curve for industrial is similar to commercial but quite different from low-density residential. A vertical dashed line was placed on the fecal coliform plot to illustrate where the median value (50%) occurs by land use. A horizontal dashed line was placed to show that fecal concentrations of 100 cfu/100 mL or higher occur approximately >95% of the time for the industrial land use, > 75% for commercial, > 65% for high-density residential, and > 40% of the time for low-density land use.

For total phosphorus, there is less difference observed among the four land-use types.

For Dichlobenil, the EDF for high-density residential shows both a higher proportion of detections and consistently higher concentrations. The data for low-density residential land use reflects the large number of non-detects (98%) and low concentrations in the detected samples. When many non-detects occur at the same reporting level, this shows up in the EDF plot as a long horizontal line segment.

EDF plots were also created for each parameter load as kg ha^{-1}. These are part of the plot summaries for the loading per unit area in Appendix H. Data qualifiers associated with the parameter concentrations were incorporated into the Kaplan-Meier analysis with the load value.

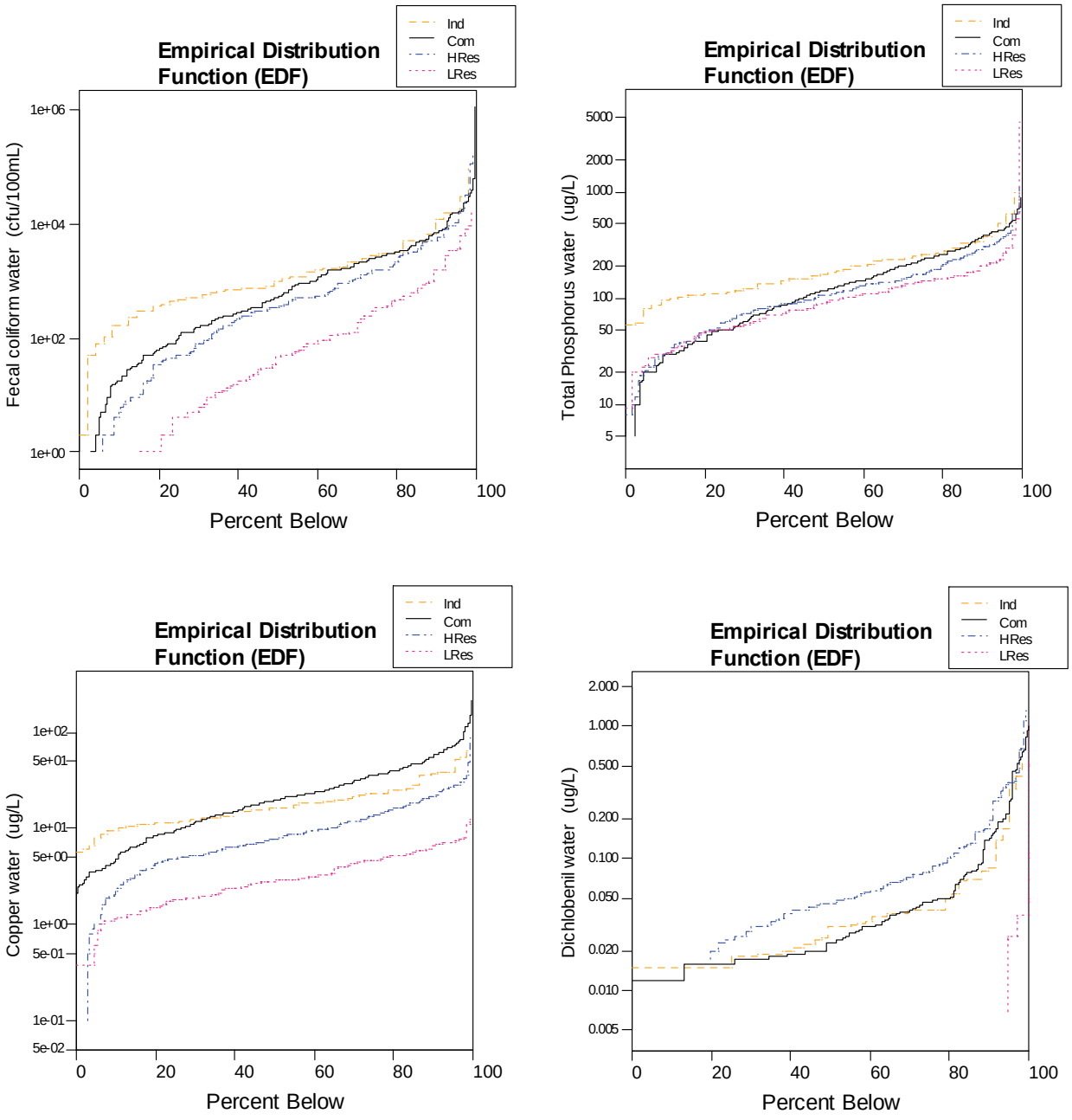


Figure C-5. EDF plots based on KM for four example parameters.

5. Box Plot by Land Use

Standard box and whisker plots were created to compare concentrations between land-use types (Figure C-6). This type of box plot is described in Helsel and Hirsch (2002). The box extends from the 25th to the 75th percentile and is split with a heavy line at the 50th percentile. Whiskers extend to the last observation within 1.5 times of the box height (prior to log transformation). Observations beyond this are shown as individual hollow circles. Thus, half of the data should fall within the box, a quarter of the data should lie above the box, and a quarter of the data should lie below the box. The box plots were created using the entire data set and make no distinction between detected and non-detected values. That is, all data values were included as if they were detections.

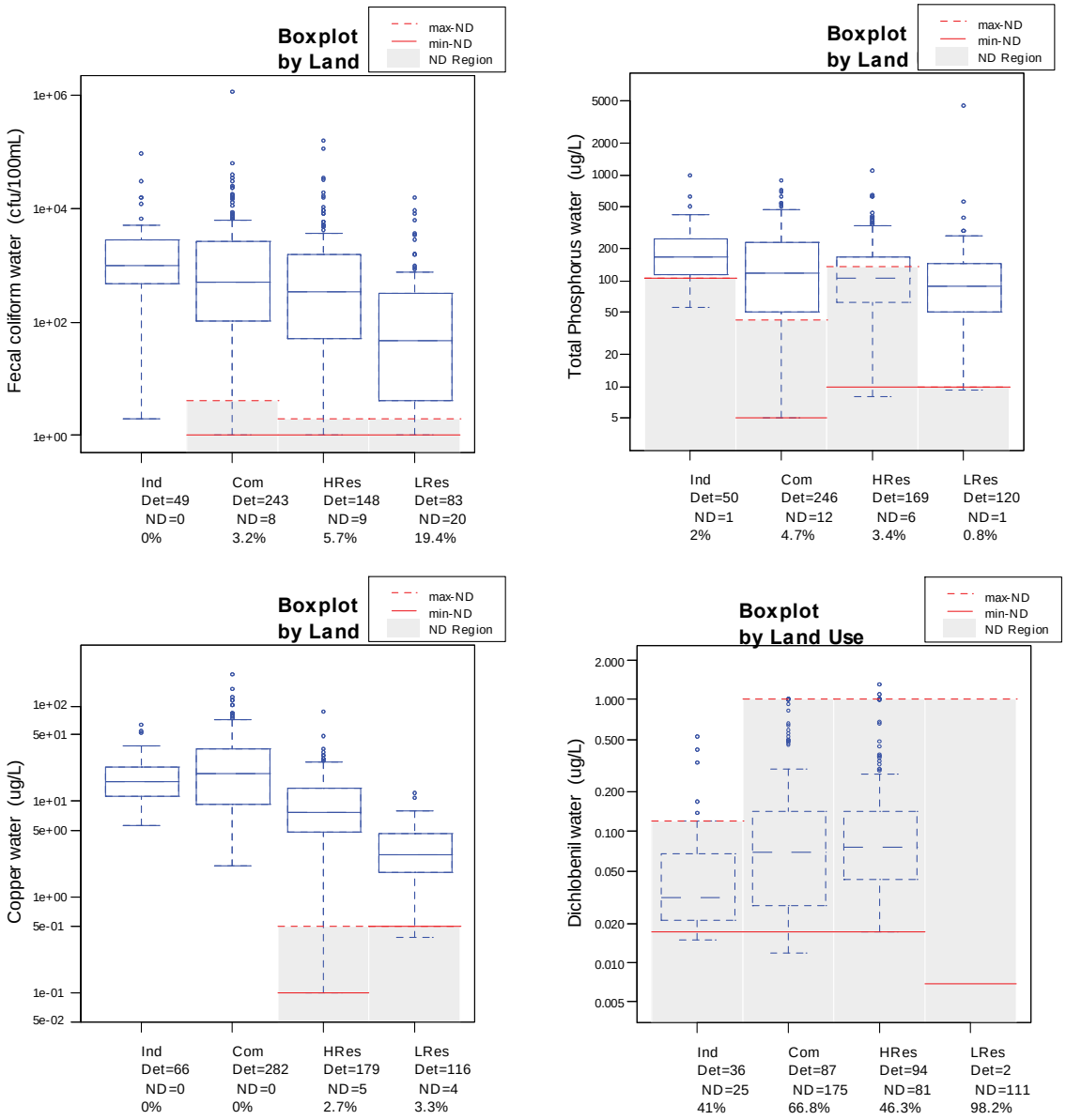


Figure C-6. Box and whisker plots of the detected data by land use for four example parameters.

As discussed in Helsel (2012), only the portions of the box plot which lie above the maximum non-detect limit are known exactly. To illustrate the region where the non-detected thresholds would influence the box plots, the visual of a gray "curtain" is used to represent the range of non-detects, as if it were pulled up over the box plot to illustrate where uncertainty still remains in the data set. The box outline is dashed under the gray curtain to reflect this uncertainty. Red horizontal lines also indicate the maximum and minimum non-detect thresholds.

Helsel (2012) recommends calculating the portion of the box plot using either KM or ROS statistics to estimate the 25^{th}-50^{th}-75^{th} percentiles. This was not done for this report, so very little weight should be given to portions of the box plot in the shaded region. In some cases, the shaded region may be caused by only one or two non-detects. In these cases, the box plot may be only slightly affected. Each case must be assessed individually.

Similar to EDF plots (Figure C-5), box plots (C-6) illustrate how the surrounding land uses impact water quality of stormwater. In the case of fecal coliform, the box (25^{th} and 75^{th}) and median values (line) for industrial is quite different than the box for low-density residential. Visually the reader can see that the open circles range up to almost the same values, despite the land use categories. Box plots by land use were not calculated if there were less than 5 detected values for any given parameter. Data plots (Appendix E) will show the message: "Not Plotted (No land use has 5 or more detections)".

The box plot graphs and the EDF plots show similar patterns for fecal coliform and total phosphorus, with industrial and commercial areas showing higher concentrations than the residential land uses. If a parameter was detected in all samples or had relatively few non-detects, then the EDF and box plots will show the same information. For parameters where non-detects account for a larger percentages of the data set, the box plot is not presenting the same information as the EDFs. This means that the box plots are misleading for data sets that comprise medium to large percentages of non-detect data, as is the case for Dichlobenil and many of the organic parameters monitored.

Box plots were also used to summarize the contaminant loads by mass (kg) and area (kg ha^{-1}) over the land-use categories. The same approach and tools were used to construct the box plots for the load data, including the non-detect "curtain" which was calculated using the data qualifiers from the concentration data.

6. Box Plot by Season

These box and whisker plots (Figure C-7) are identical to the box plots by land use (Figure C-6), except that they are broken up by season. Seasons are as follows: Winter was Jan-Mar, spring was Apr-Jun, summer was July-Sept, and fall was Oct-Dec.

Box plots by season were not calculated if there were less than 5 detected values for any given parameter. Data plots (Appendix D) will show the message: "Not Plotted (No season has 5 or more detections)".

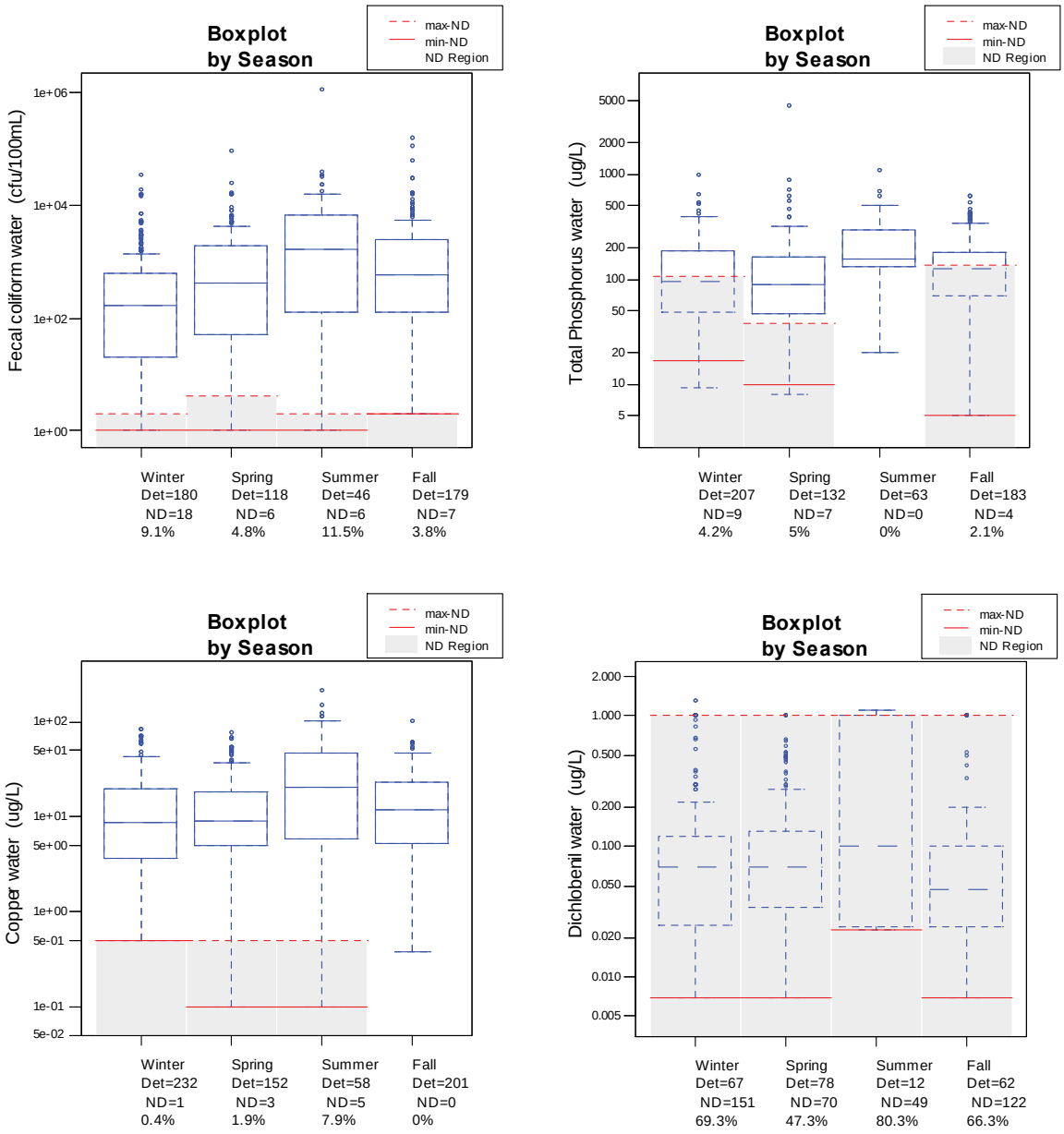


Figure C-7. Box and whisker plots of the detected data by season for four example parameters.

Statistical tests were carried out for the contaminant data on whether there was a significant difference between dry and wet seasons. The *dry* season is the months of May and June and the summer season in the box plot, and the *wet* season is the rest of the year. There is therefore more detailed information on seasonal differences shown in the box plot than described by the simple Wilcoxon test for significant differences. The observation that many of the parameters have higher concentrations during the dry season can be seen by the position of the summer median values for each of the example parameters (Figure C-7). However, this observation becomes more uncertain for the Dichlobenil data. Indeed, the Wilcoxon test describes the wet and dry season as being not significantly different.

Seasonal differences in storm-event contaminant loads (kg ha^{-1}) are also summarized using the box plots (Appendix H).

Case C Parameter – Data Sheet

In the data plots, many of the graphs are not shown, and the message "Not Plotted (Case C)" is given. Figure C-8 gives an example data sheet for a Case C parameter, triclopyr.

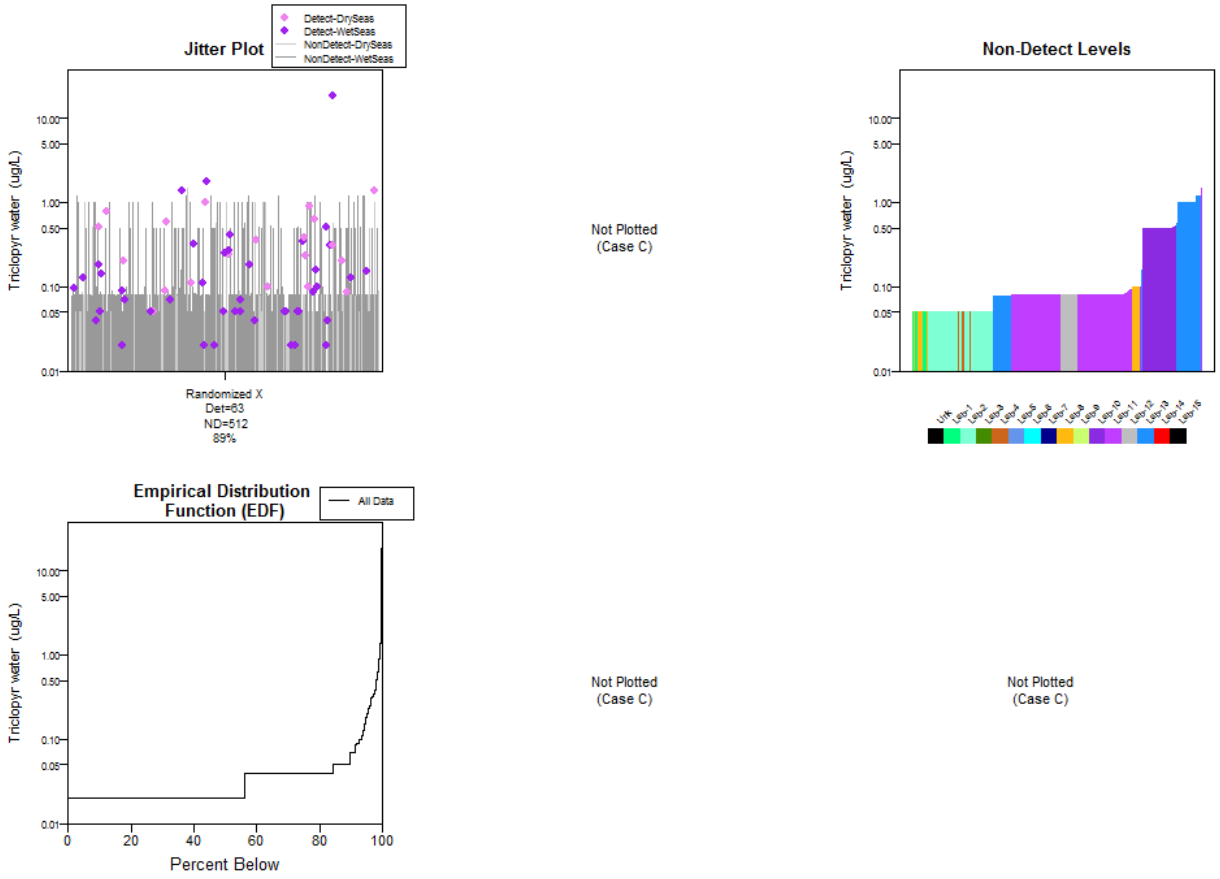


Figure C-8. Six plots for the parameter, triclopyr, in stormwater.

Triclopyr is an herbicide typically used in weed control. The previous *PS Toxics Study* found detectable concentrations in ~ 50% of the samples from commercial, industrial, and residential land uses, which was not the case in this stormwater study. It is soluble in water and breaks down fairly rapidly. Data sets that contain a large frequency of non-detects, such as for triclopyr, do not have enough detected values to warrant further analysis. The three plots that give the most information about the non-detections are retained. The jitter plot shows that there were 63 detected concentrations and that there were 512 non-detects. The plot of non-detect thresholds shows that many reporting limits were reported. The EDF plot shows that >90% of data was non-detect, and when detections were made, they varied from 0.1 to 18.3 ug/L.

Appendix D. Tables for Database Description

Table D-1. Distribution results for parameters with detection rates >95%.

Water	Sediment
Log-normal	***Normal***
1-Methylnaphthalene water (ug/L)	Dimethyl phthalate solid/sediment (ug/Kg)
Ammonia water (ug/L)	Heavy Fuel Oil solid/sediment (ug/Kg)
Butyl benzyl phthalate water (ug/L)	Total Benzofluoranthenes solid/sediment (ug/Kg)
Copper water (ug/L)	
Di-N-Octyl Phthalate water (ug/L)	***Log-normal***
Diesel Fuel water (ug/L)	1-Methylnaphthalene solid/sediment (ug/Kg)
Heavy Fuel Oil water (ug/L)	2-Methylnaphthalene solid/sediment (ug/Kg)
Lube Oil water (ug/L)	Acenaphthylene solid/sediment (ug/Kg)
Motor Oil water (ug/L)	Butyl benzyl phthalate solid/sediment (ug/Kg)
PCB-aroclor 1254 water (ug/L)	Di-N-Octyl Phthalate solid/sediment (ug/Kg)
Pentachlorophenol water (ug/L)	Dibutyl phthalate solid/sediment (ug/Kg)
Precipitation water (in)	Diesel Fuel solid/sediment (ug/Kg)
Prometon water (ug/L)	Fines solid/sediment (%)
Total PCB water (ug/L)	p-Cresol solid/sediment (ug/Kg)
Total Phthalate water (ug/L)	PCB-aroclor 1254 solid/sediment (ug/Kg)
Total TPHDx water (ug/L)	Pentachlorophenol solid/sediment (ug/Kg)
Turbidity water (NTU)	Phenol solid/sediment (ug/Kg)
Zinc water (ug/L)	Total PCB solid/sediment (ug/Kg)
	Total Phthalate solid/sediment (ug/Kg)
Non-parametric	Total TPHDx solid/sediment (ug/Kg)
2-Methylnaphthalene water (ug/L)	
2,4-D water (ug/L)	***Non-parametric***
Acenaphthene water (ug/L)	Acenaphthene solid/sediment (ug/Kg)
Acenaphthylene water (ug/L)	Anthracene solid/sediment (ug/Kg)
Anthracene water (ug/L)	Benz(a)anthracene solid/sediment (ug/Kg)
Arsenic water dissolved (ug/L)	Benzo(a)pyrene solid/sediment (ug/Kg)
Benz(a)anthracene water (ug/L)	Benzo(b)fluoranthene solid/sediment (ug/Kg)
Benzo(a)pyrene water (ug/L)	Benzo(g,h,i)perylene solid/sediment (ug/Kg)
Benzo(b)fluoranthene water (ug/L)	Benzo(k)fluoranthene solid/sediment (ug/Kg)
Benzo(b,k)fluoranthene water (ug/L)	Benzofluoranthenes, Total solid/sediment (ug/Kg)
Benzo(g,h,i)perylene water (ug/L)	Bis(2-ethylhexyl) phthalate solid/sediment (ug/Kg)
Benzo(k)fluoranthene water (ug/L)	Cadmium solid/sediment (ug/Kg)
Benzofluoranthenes, Total water (ug/L)	Chrysene solid/sediment (ug/Kg)
Biochemical Oxygen Demand water (ug/L)	Copper solid/sediment (ug/Kg)
Bis(2-ethylhexyl) phthalate water (ug/L)	CPAH solid/sediment (ug/Kg)
Cadmium water (ug/L)	Dibenzo(a,h)anthracene solid/sediment (ug/Kg)

Water	Sediment
Cadmium water dissolved (ug/L)	Fluoranthene solid/sediment (ug/Kg)
Calcium water (ug/L)	Fluorene solid/sediment (ug/Kg)
Chloride water (ug/L)	HPAH solid/sediment (ug/Kg)
Chrysene water (ug/L)	Gravel solid/sediment (%)
Conductivity water (uS/cm)	HPAH solid/sediment (ug/Kg)
Copper water dissolved (ug/L)	Indeno(1,2,3-cd)pyrene solid/sediment (ug/Kg)
CPAH water (ug/L)	Lead solid/sediment (ug/Kg)
Dibenzo(a,h)anthracene water (ug/L)	LPAH solid/sediment (ug/Kg)
Dibutyl phthalate water (ug/L)	Mercury solid/sediment (ug/Kg)
Dichlobenil water (ug/L)	Motor Oil solid/sediment (ug/Kg)
Diesel Range Organics water (ug/L)	Naphthalene solid/sediment (ug/Kg)
Diethyl phthalate water (ug/L)	Phenanthrene solid/sediment (ug/Kg)
Dimethyl phthalate water (ug/L)	Pyrene solid/sediment (ug/Kg)
Fecal coliform water (cfu/100mL)	Sand solid/sediment (%)
Fluoranthene water (ug/L)	Solids solid/sediment (%)
Fluorene water (ug/L)	Total Organic Carbon solid/sediment (%)
Gasoline Range Organics water (ug/L)	Total PAH solid/sediment (ug/Kg)
Hardness as CaCO3 water (ug/L)	Zinc solid/sediment (ug/Kg)
HPAH water (ug/L)	
Indeno(1,2,3-cd)pyrene water (ug/L)	
Lead water (ug/L)	
Lead water dissolved (ug/L)	
LPAH water (ug/L)	
Magnesium water (ug/L)	
Mecoprop water (ug/L)	
Mercury water (ug/L)	
Mercury water dissolved (ug/L)	
Naphthalene water (ug/L)	
Nitrite-Nitrate water dissolved (ug/L)	
Ortho-phosphate water dissolved (ug/L)	
pH water (pH)	
Phenanthrene water (ug/L)	
Pyrene water (ug/L)	
Sampled-Event Flow Volume water (m3)	
Storm Event Flow Volume water (m3)	
Surfactants water (ug/L)	
Total Benzofluoranthenes water (ug/L)	
Total Kjeldahl Nitrogen water (ug/L)	
Total PAH water (ug/L)	
Total Phosphorus water (ug/L)	
Total Suspended Solids water (ug/L)	
Triclopyr water (ug/L)	
Zinc water dissolved (ug/L)	

Table D-2. Summary of data qualifiers by parameter and matrix.
Those parameters with < 5% detection are highlighted with a gray-shaded box.

Parameter	Matrix	% detection	No qualifier	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
1-Methylnaphthalene	Sediment	40.4%	20	0	0	0	0	1	0	0	0	0	0	29	2	0
1-Methylnaphthalene	Water	**3.8%**	10	0	0	0	0	1	0	0	0	0	0	272	7	0
2-Methylnaphthalene	Sediment	47.4%	28	0	0	0	0	8	0	0	1	0	0	37	4	0
2-Methylnaphthalene	Water	17.2%	62	0	0	0	0	44	2	0	1	0	0	444	78	3
2-Nitrophenol	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	17	6	0
2,4-D	Sediment	8.3%	1	0	0	0	0	0	0	0	0	0	0	8	3	0
2,4-D	Water	16.9%	74	13	0	0	0	15	0	0	0	0	0	458	44	0
2,4-Dichlorophenol	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	18	6	0
2,4-Dimethylphenol	Sediment	7.1%	3	0	0	0	0	0	0	0	0	0	0	35	4	0
2,4,5-Trichlorophenol	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	18	6	0
2,4,6-Trichlorophenol	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	17	6	0
4-Chloro-3-Methylphenol	Sediment	**4.8%**	1	0	0	0	0	0	0	0	0	0	0	17	3	0
4-Nitrophenol	Sediment	**4.8%**	1	0	0	0	0	0	0	0	0	0	0	13	7	0
Acenaphthene	Sediment	54.4%	34	0	0	0	0	9	0	0	0	0	0	34	2	0
Acenaphthene	Water	9.8%	25	0	0	0	0	37	0	0	0	0	0	480	92	0
Acenaphthylene	Sediment	32.9%	24	0	0	0	0	2	0	0	0	0	0	47	6	0
Acenaphthylene	Water	6.5%	11	1	0	0	0	28	0	0	1	0	0	513	80	0
Ammonia	Water	100.0%	71	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthracene	Sediment	73.4%	43	0	0	0	0	12	0	0	3	0	0	20	1	0
Anthracene	Water	11.2%	38	1	0	0	0	26	0	0	6	0	0	484	79	0
Arsenic	Water	100.0%	0	0	0	0	0	1	0	0	15	0	0	0	0	0
Benz(a)anthracene	Sediment	88.4%	53	0	0	0	0	8	0	0	0	0	0	8	0	0
Benz(a)anthracene	Water	34.4%	113	2	0	0	0	58	0	0	3	0	0	288	47	0
Benzene	Water	**0.8%**	1	0	0	0	0	0	0	0	0	0	0	115	4	0
Benzo(a)pyrene	Sediment	82.3%	51	0	0	0	0	14	0	0	0	0	0	13	1	0
Benzo(a)pyrene	Water	28.4%	133	1	0	0	0	41	0	0	4	0	0	379	73	0
Benzo(b)fluoranthene	Sediment	80.0%	25	0	0	0	0	11	0	0	0	0	0	9	0	0
Benzo(b)fluoranthene	Water	30.4%	87	1	0	0	0	21	0	0	0	0	0	198	52	0

Parameter	Matrix	% detection	No qualifier	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Benzo(b,k)fluoranthene	Sediment	100.0%	4	0	0	0	0	5	0	0	0	0	0	0	0	0
Benzo(b,k)fluoranthene	Water	49.2%	35	0	0	0	0	27	0	0	0	0	0	63	1	0
Benzo(g,h,i)perylene	Sediment	88.7%	51	0	0	0	0	12	0	0	0	0	0	8	0	0
Benzo(g,h,i)perylene	Water	40.0%	188	2	0	0	0	60	1	0	2	0	0	313	67	0
Benzo(k)fluoranthene	Sediment	71.1%	23	0	0	0	0	8	0	0	1	0	0	13	0	0
Benzo(k)fluoranthene	Water	24.0%	68	1	0	0	0	14	0	0	3	0	0	210	63	0
Benzofluoranthenes, Total	Sediment	100.0%	34	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzofluoranthenes, Total	Water	45.6%	59	0	0	0	0	4	0	0	5	0	0	79	2	0
Biochemical Oxygen Demand	Water	78.4%	368	14	0	0	0	40	0	0	0	0	0	98	18	0
Bis(2-ethylhexyl) phthalate	Sediment	92.7%	42	0	0	0	0	9	0	0	0	0	0	3	1	0
Bis(2-ethylhexyl) phthalate	Water	61.9%	202	7	0	0	0	175	0	1	0	0	0	154	83	0
BTEX	Water	**2.5%**	3	0	0	0	0	0	0	0	0	0	0	113	4	0
Butyl benzyl phthalate	Sediment	56.1%	24	0	0	0	0	8	0	0	0	0	0	22	3	0
Butyl benzyl phthalate	Water	22.6%	45	3	0	0	0	87	0	0	8	0	0	467	23	0
Cadmium	Sediment	90.0%	56	0	0	0	0	7	0	0	9	0	0	8	0	0
Cadmium	Water	63.0%	431	34	0	0	0	292	0	0	45	0	0	393	79	0
Calcium	Water	100.0%	352	0	0	0	0	3	0	0	0	0	0	0	0	0
Chloride	Water	98.0%	502	21	0	0	0	16	0	0	1	0	0	11	0	0
Chlorpyrifos	Sediment	**1.9%**	0	0	0	0	0	1	0	0	0	0	0	45	7	0
Chlorpyrifos	Water	**0.2%**	1	0	0	0	0	0	0	0	0	0	0	577	65	1
Chrysene	Sediment	92.4%	56	0	0	0	0	17	0	0	0	0	0	6	0	0
Chrysene	Water	45.9%	230	2	0	0	0	57	0	0	2	0	0	288	55	0
Conductivity	Water	99.8%	585	21	0	0	1	29	0	0	0	0	0	1	0	0
Copper	Sediment	100.0%	72	0	0	0	0	6	0	0	0	0	0	0	0	0
Copper	Water	97.9%	871	30	0	0	1	285	0	0	41	0	0	15	11	0
CPAH	Sediment	93.9%	46	0	0	0	0	31	0	0	0	0	0	5	0	0
CPAH	Water	51.3%	187	0	0	0	0	143	0	0	0	0	0	272	41	0
Di-N-Octyl Phthalate	Sediment	28.6%	12	0	0	0	0	4	0	0	0	0	0	35	5	0
Di-N-Octyl Phthalate	Water	11.2%	41	3	0	0	0	25	0	1	1	0	0	502	59	0
Diazinon	Sediment	**1.9%**	0	0	0	0	0	1	0	0	0	0	0	46	5	0
Diazinon	Water	**0.9%**	3	0	0	0	0	3	0	0	0	0	0	573	64	1

Parameter	Matrix	% detection	No qualifier	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Dibenzo(a,h)anthracene	Sediment	73.4%	45	0	0	0	0	10	0	0	2	1	0	18	3	0
Dibenzo(a,h)anthracene	Water	13.9%	63	0	0	0	0	19	0	0	6	0	0	457	89	0
Dibutyl phthalate	Sediment	28.1%	9	0	0	0	0	6	0	0	1	0	0	35	6	0
Dibutyl phthalate	Water	31.8%	39	3	0	0	0	149	0	0	10	0	0	393	39	0
Dichlobenil	Sediment	40.0%	5	0	0	0	0	1	0	0	0	0	0	7	2	0
Dichlobenil	Water	35.8%	110	2	0	0	0	107	0	0	0	0	0	343	48	1
Diesel Fuel	Sediment	100.0%	22	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel Fuel	Water	46.8%	35	0	0	0	0	1	0	0	0	0	0	41	0	0
Diesel Range Organics	Sediment	75.0%	9	0	0	0	0	0	0	0	0	0	0	3	0	0
Diesel Range Organics	Water	57.5%	186	1	0	0	0	92	0	0	0	0	1	205	2	0
Diethyl phthalate	Sediment	5.4%	1	0	0	0	0	2	0	0	0	0	0	47	6	0
Diethyl phthalate	Water	30.6%	85	1	0	0	0	104	0	1	3	0	0	409	31	0
Dimethyl phthalate	Sediment	19.6%	4	0	0	0	0	7	0	0	0	0	0	39	6	0
Dimethyl phthalate	Water	14.8%	22	3	0	0	0	60	0	0	9	0	0	511	29	0
Ethylbenzene	Water	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	116	4	0
Fecal coliform	Water	93.4%	470	3	1	2	0	47	0	0	0	0	0	34	3	0
Fines	Sediment	100.0%	72	0	0	0	0	1	0	0	0	0	0	0	0	0
Fluoranthene	Sediment	93.7%	66	0	0	0	0	8	0	0	0	0	0	5	0	0
Fluoranthene	Water	59.1%	314	3	0	0	0	55	0	0	2	0	0	216	43	0
Fluorene	Sediment	59.0%	38	0	0	0	0	7	0	0	1	0	0	31	1	0
Fluorene	Water	12.6%	34	0	0	0	0	43	0	0	3	0	0	475	79	0
Gasoline Range Organics	Water	10.4%	4	0	0	0	0	47	0	0	0	0	0	374	66	0
Gravel	Sediment	93.2%	66	0	0	0	0	2	0	0	0	0	0	5	0	0
Hardness as CaCO3	Water	99.7%	611	21	0	0	1	7	0	0	0	0	0	2	0	0
Heavy Fuel Oil	Sediment	100.0%	12	0	0	0	0	0	0	0	0	0	0	0	0	0
Heavy Fuel Oil	Water	78.5%	136	1	0	0	0	95	0	0	0	0	2	60	4	0
HPAH	Sediment	96.7%	66	0	0	0	0	21	0	0	0	0	0	3	0	0
HPAH	Water	67.3%	259	0	0	0	0	173	0	0	0	0	0	188	22	0
Indeno(1,2,3-cd)pyrene	Sediment	86.1%	55	0	0	0	0	12	0	0	1	0	0	10	1	0
Indeno(1,2,3-cd)pyrene	Water	28.7%	132	1	0	0	0	43	0	0	6	0	0	374	78	0
Lead	Sediment	97.5%	62	0	0	0	0	16	0	0	0	0	0	2	0	0

Parameter	Matrix	% detection	No qualifier	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Lead	Water	89.9%	936	41	0	0	0	104	0	0	57	0	0	101	27	0
LPAH	Sediment	94.2%	58	0	0	0	0	23	0	0	0	0	0	5	0	0
LPAH	Water	61.0%	220	0	0	0	0	172	0	0	0	0	0	219	32	0
Lube Oil	Water	41.6%	37	0	0	0	0	0	0	0	0	0	0	52	0	0
Magnesium	Water	100.0%	353	0	0	0	0	2	0	0	0	0	0	0	0	0
Malathion	Sediment	**1.9%**	0	0	0	0	0	1	0	0	0	0	0	44	8	0
Malathion	Water	**1.1%**	4	0	0	0	0	3	0	0	0	0	0	569	66	1
Mecoprop	Sediment	8.3%	0	0	0	0	0	1	0	0	0	0	0	9	2	0
Mecoprop	Water	10.4%	41	7	0	0	0	16	0	0	0	0	0	498	54	0
Mercury	Sediment	82.4%	42	0	0	0	0	10	0	0	4	0	0	12	0	0
Mercury	Water	15.8%	121	0	0	0	0	19	0	0	2	0	0	672	85	0
Motor Oil	Sediment	100.0%	22	0	0	0	0	0	0	0	0	0	0	0	0	0
Motor Oil	Water	81.9%	84	0	0	0	0	2	0	0	0	0	0	19	0	0
Naphthalene	Sediment	59.5%	36	0	0	0	0	9	0	0	2	0	0	29	3	0
Naphthalene	Water	37.1%	126	0	0	0	0	91	0	0	16	0	0	339	54	2
Nitrite-Nitrate	Water	96.1%	455	13	0	0	0	87	0	0	6	0	0	23	0	0
o-Cresol	Sediment	18.6%	7	0	0	0	0	1	0	0	0	0	0	32	3	0
Oil and grease	Water	5.7%	2	0	0	0	0	0	0	0	0	0	0	33	0	0
Ortho-phosphate	Water	92.2%	400	14	0	0	0	130	0	0	0	0	0	44	2	0
p-Cresol	Sediment	76.7%	27	0	0	0	0	5	0	0	1	0	0	9	1	0
p-Cresol	Water	7.7%	2	0	0	0	0	0	0	0	0	0	0	24	0	0
PCB-aroclor 1016	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	32	1	0
PCB-aroclor 1016	Water	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	27	0	0
PCB-aroclor 1221	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	32	1	0
PCB-aroclor 1221	Water	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	27	0	0
PCB-aroclor 1232	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	32	1	0
PCB-aroclor 1232	Water	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	27	0	0
PCB-aroclor 1242	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	32	1	0
PCB-aroclor 1242	Water	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	27	0	0
PCB-aroclor 1248	Sediment	6.1%	2	0	0	0	0	0	0	0	0	0	0	30	1	0
PCB-aroclor 1248	Water	**3.7%**	1	0	0	0	0	0	0	0	0	0	0	26	0	0

Parameter	Matrix	% detection	No qualifier	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
PCB-aroclor 1254	Sediment	45.5%	12	0	0	0	0	2	0	0	1	0	0	17	1	0
PCB-aroclor 1254	Water	51.9%	14	0	0	0	0	0	0	0	0	0	0	12	1	0
PCB-aroclor 1260	Sediment	27.3%	5	0	0	0	0	4	0	0	0	0	0	23	1	0
PCB-aroclor 1260	Water	25.9%	6	0	0	0	0	1	0	0	0	0	0	20	0	0
Pentachlorophenol	Sediment	24.7%	15	0	0	0	0	4	0	0	0	0	0	55	3	0
Pentachlorophenol	Water	25.4%	109	8	0	0	0	31	0	0	2	0	0	408	33	0
pH	Water	100.0%	221	0	0	0	0	3	0	0	0	0	0	0	0	0
Phenanthrene	Sediment	93.6%	63	0	0	0	0	10	0	0	0	0	0	5	0	0
Phenanthrene	Water	51.8%	276	1	0	0	0	48	0	0	3	0	0	258	47	0
Phenol	Sediment	42.9%	17	0	0	0	0	4	0	0	0	0	0	27	1	0
Phenol	Water	30.8%	7	0	0	0	0	0	0	0	1	0	0	18	0	0
Precipitation	Water	100.0%	592	3	0	0	0	0	0	0	0	0	0	0	0	0
Prometon	Sediment	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	12	3	0
Prometon	Water	**3.6%**	10	1	0	0	0	10	0	0	1	0	0	505	78	2
Pyrene	Sediment	94.9%	64	0	0	0	0	11	0	0	0	0	0	4	0	0
Pyrene	Water	63.3%	335	2	0	0	0	61	0	0	3	0	0	199	33	0
Sampled-Event Flow Volume	Water	100.0%	574	26	0	0	0	0	0	0	0	0	0	0	0	0
Sand	Sediment	100.0%	72	0	0	0	0	1	0	0	0	0	0	0	0	0
Solids	Sediment	100.0%	79	0	0	0	0	3	0	0	0	0	0	0	0	0
Storm Event Flow Volume	Water	100.0%	626	1	0	0	0	0	0	0	0	0	0	0	0	0
Surfactants	Water	63.4%	335	10	0	0	0	40	0	0	0	0	0	173	49	0
Toluene	Water	**2.5%**	3	0	0	0	0	0	0	0	0	0	0	113	4	0
Total Benzofluoranthenes	Sediment	88.5%	51	0	0	0	0	18	0	0	0	0	0	9	0	0
Total Benzofluoranthenes	Water	37.8%	180	0	0	0	0	63	0	0	0	0	0	341	59	0
Total Kjeldahl Nitrogen	Water	89.6%	353	21	0	0	0	149	0	0	1	0	0	58	3	0
Total Organic Carbon	Sediment	100.0%	78	0	0	0	0	2	0	0	0	0	0	0	0	0
Total PAH	Sediment	98.8%	61	0	0	0	0	24	0	0	0	0	0	1	0	0
Total PAH	Water	72.9%	264	0	0	0	0	205	0	0	0	0	0	158	16	0
Total PCB	Sediment	51.5%	11	0	0	0	0	6	0	0	0	0	0	15	1	0
Total PCB	Water	55.6%	14	0	0	0	0	1	0	0	0	0	0	12	0	0
Total Phosphorus	Sediment	100.0%	3	0	0	0	0	0	0	0	0	0	0	0	0	0

Parameter	Matrix	% detection	No qualifier	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Total Phosphorus	Water	96.7%	495	15	0	0	0	73	0	0	2	0	0	16	4	0
Total Phthalate	Sediment	88.1%	46	0	0	0	0	13	0	0	0	0	0	6	2	0
Total Phthalate	Water	76.8%	220	0	0	0	0	274	0	0	0	0	0	143	6	0
Total Suspended Solids	Water	99.4%	578	21	0	0	1	21	0	0	0	0	0	3	1	0
Total TPHDx	Sediment	100.0%	38	0	0	0	0	0	0	0	0	0	0	0	0	0
Total TPHDx	Water	72.7%	309	0	0	0	0	112	0	0	0	0	0	158	0	0
Total Xylenes	Water	**0.8%**	1	0	0	0	0	0	0	0	0	0	0	115	4	0
TPHGx	Water	**2.9%**	1	0	0	0	0	0	0	0	0	0	0	34	0	0
Triclopyr	Sediment	8.3%	1	0	0	0	0	0	0	0	0	0	0	8	3	0
Triclopyr	Water	11.0%	32	6	0	0	0	25	0	0	0	0	0	461	50	1
Turbidity	Water	100.0%	462	21	0	0	0	65	0	0	0	0	0	0	0	0
Zinc	Sediment	100.0%	61	0	0	0	0	19	0	0	0	0	0	0	0	0
Zinc	Water	98.2%	901	42	0	0	1	264	0	0	8	0	0	15	7	0

C = This flag applies to pesticide and PCB Aroclor results when the identification has been confirmed by GC/MS.

E = Reported result is an estimate because it exceeds the calibration range.

G = Expected/scheduled analyses could not be performed.

j or J = Analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.

L = Off-scale high. Actual value is known to be greater than value given. To be used when the concentration of the analyte is above the acceptable level for quantitation (exceeds the linear range or highest calibration standard) and the calibration curve is known to exhibit a negative deflection.

T = Value reported is less than the laboratory method detection limit. The value is reported for informational purposes only and shall not be used in statistical analysis.

U = Analyte was not detected at or above the reported sample quantitation limit.

UJ = Analyte was not detected at or above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately measure the analyte in the sample.

Multiple qualifiers may apply (e.g. JT).

Table D-3. Summary of data qualifiers by parameter and land use.
Those parameters with < 5% detection are highlighted with a gray-shaded box.

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
1-Methylnaphthalene	COM	**3.2%**	5	0	0	0	0	0	0	0	0	0	0	146	4	0
1-Methylnaphthalene	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	60	1	0
1-Methylnaphthalene	IND	18.8%	5	0	0	0	0	1	0	0	0	0	0	24	2	0
1-Methylnaphthalene	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	42	0	0
2-Methylnaphthalene	COM	20.9%	31	0	0	0	0	25	1	0	1	0	0	197	23	0
2-Methylnaphthalene	HDR	15.0%	17	0	0	0	0	9	1	0	0	0	0	123	28	2
2-Methylnaphthalene	IND	37.5%	14	0	0	0	0	10	0	0	0	0	0	35	5	0
2-Methylnaphthalene	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	89	22	1
2,4-D	COM	12.3%	24	4	0	0	0	4	0	0	0	0	0	208	20	0
2,4-D	HDR	33.7%	40	8	0	0	0	9	0	0	0	0	0	108	4	0
2,4-D	IND	**3.6%**	2	0	0	0	0	0	0	0	0	0	0	50	3	0
2,4-D	LDR	9.2%	8	1	0	0	0	2	0	0	0	0	0	92	17	0
Acenaphthene	COM	11.9%	16	0	0	0	0	17	0	0	0	0	0	215	30	0
Acenaphthene	HDR	**4.4%**	1	0	0	0	0	7	0	0	0	0	0	137	35	0
Acenaphthene	IND	31.3%	8	0	0	0	0	12	0	0	0	0	0	39	5	0
Acenaphthene	LDR	**0.9%**	0	0	0	0	0	1	0	0	0	0	0	89	22	0
Acenaphthylene	COM	7.2%	4	1	0	0	0	14	0	0	1	0	0	233	25	0
Acenaphthylene	HDR	6.1%	4	0	0	0	0	7	0	0	0	0	0	143	26	0
Acenaphthylene	IND	15.6%	3	0	0	0	0	7	0	0	0	0	0	47	7	0
Acenaphthylene	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	90	22	0
Ammonia	COM	100.0%	24	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	HDR	100.0%	23	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	IND	100.0%	24	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthracene	COM	18.0%	32	1	0	0	0	17	0	0	0	0	0	204	24	0
Anthracene	HDR	5.0%	4	0	0	0	0	3	0	0	2	0	0	145	26	0
Anthracene	IND	10.9%	1	0	0	0	0	6	0	0	0	0	0	52	5	0
Anthracene	LDR	**4.5%**	1	0	0	0	0	0	0	0	4	0	0	83	24	0
Arsenic	COM	100.0%	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Arsenic	LDR	100.0%	0	0	0	0	0	1	0	0	14	0	0	0	0	0
Benz(a)anthracene	COM	38.5%	66	2	0	0	0	23	0	0	1	0	0	135	12	0
Benz(a)anthracene	HDR	29.6%	21	0	0	0	0	21	0	0	0	0	0	83	17	0
Benz(a)anthracene	IND	20.3%	4	0	0	0	0	9	0	0	0	0	0	49	2	0
Benz(a)anthracene	LDR	43.9%	22	0	0	0	0	5	0	0	2	0	0	21	16	0
Benzene	COM	**2.8%**	1	0	0	0	0	0	0	0	0	0	0	34	1	0
Benzene	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	36	2	0
Benzene	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	45	1	0
Benzo(a)pyrene	COM	39.4%	77	1	0	0	0	30	0	0	1	0	0	149	19	0
Benzo(a)pyrene	HDR	16.8%	24	0	0	0	0	5	0	0	1	0	0	122	27	0
Benzo(a)pyrene	IND	17.2%	6	0	0	0	0	5	0	0	0	0	0	48	5	0
Benzo(a)pyrene	LDR	26.1%	26	0	0	0	0	1	0	0	2	0	0	60	22	0
Benzo(b)fluoranthene	COM	46.3%	61	1	0	0	0	14	0	0	0	0	0	78	10	0
Benzo(b)fluoranthene	HDR	18.3%	10	0	0	0	0	7	0	0	0	0	0	56	20	0
Benzo(b)fluoranthene	IND	50.0%	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Benzo(b)fluoranthene	LDR	15.0%	15	0	0	0	0	0	0	0	0	0	0	63	22	0
Benzo(b,k)fluoranthene	COM	64.3%	18	0	0	0	0	9	0	0	0	0	0	15	0	0
Benzo(b,k)fluoranthene	HDR	46.2%	13	0	0	0	0	11	0	0	0	0	0	28	0	0
Benzo(b,k)fluoranthene	IND	34.4%	4	0	0	0	0	7	0	0	0	0	0	20	1	0
Benzo(g,h,i)perylene	COM	53.4%	114	2	0	0	0	29	1	0	2	0	0	115	14	0
Benzo(g,h,i)perylene	HDR	30.6%	35	0	0	0	0	20	0	0	0	0	0	99	26	0
Benzo(g,h,i)perylene	IND	37.5%	14	0	0	0	0	10	0	0	0	0	0	35	5	0
Benzo(g,h,i)perylene	LDR	23.2%	25	0	0	0	0	1	0	0	0	0	0	64	22	0
Benzo(k)fluoranthene	COM	35.4%	44	1	0	0	0	12	0	0	1	0	0	91	15	0
Benzo(k)fluoranthene	HDR	11.8%	8	0	0	0	0	2	0	0	1	0	0	56	26	0
Benzo(k)fluoranthene	IND	50.0%	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Benzo(k)fluoranthene	LDR	16.0%	15	0	0	0	0	0	0	0	1	0	0	62	22	0
Benzofluoranthenes, Total	COM	58.3%	36	0	0	0	0	4	0	0	2	0	0	29	1	0
Benzofluoranthenes, Total	HDR	22.9%	7	0	0	0	0	0	0	0	1	0	0	27	0	0
Benzofluoranthenes, Total	IND	23.3%	7	0	0	0	0	0	0	0	0	0	0	22	1	0
Benzofluoranthenes, Total	LDR	91.7%	9	0	0	0	0	0	0	0	2	0	0	1	0	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Biochemical Oxygen Demand	COM	90.5%	204	5	0	0	0	10	0	0	0	0	0	21	2	0
Biochemical Oxygen Demand	HDR	82.0%	101	7	0	0	0	15	0	0	0	0	0	21	6	0
Biochemical Oxygen Demand	IND	93.3%	36	0	0	0	0	6	0	0	0	0	0	3	0	0
Biochemical Oxygen Demand	LDR	37.6%	27	2	0	0	0	9	0	0	0	0	0	53	10	0
Bis(2-ethylhexyl) phthalate	COM	77.2%	127	4	0	0	0	74	0	1	0	0	0	43	18	0
Bis(2-ethylhexyl) phthalate	HDR	58.9%	47	3	0	0	0	56	0	0	0	0	0	49	25	0
Bis(2-ethylhexyl) phthalate	IND	63.5%	25	0	0	0	0	15	0	0	0	0	0	20	3	0
Bis(2-ethylhexyl) phthalate	LDR	29.5%	3	0	0	0	0	30	0	0	0	0	0	42	37	0
BTEX	COM	**2.8%**	1	0	0	0	0	0	0	0	0	0	0	34	1	0
BTEX	HDR	5.3%	2	0	0	0	0	0	0	0	0	0	0	34	2	0
BTEX	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	45	1	0
Butyl benzyl phthalate	COM	25.6%	35	1	0	0	0	31	0	0	4	0	0	199	7	0
Butyl benzyl phthalate	HDR	23.3%	5	2	0	0	0	32	0	0	3	0	0	131	7	0
Butyl benzyl phthalate	IND	15.6%	0	0	0	0	0	10	0	0	0	0	0	53	1	0
Butyl benzyl phthalate	LDR	17.9%	5	0	0	0	0	14	0	0	1	0	0	84	8	0
Cadmium	COM	72.2%	255	14	0	0	0	100	0	0	30	0	0	129	25	0
Cadmium	HDR	59.1%	84	17	0	0	0	104	0	0	7	0	0	125	22	0
Cadmium	IND	64.4%	52	0	0	0	0	33	0	0	0	0	0	47	0	0
Cadmium	LDR	46.1%	40	3	0	0	0	55	0	0	8	0	0	92	32	0
Calcium	COM	100.0%	153	0	0	0	0	1	0	0	0	0	0	0	0	0
Calcium	HDR	100.0%	93	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcium	IND	100.0%	31	0	0	0	0	1	0	0	0	0	0	0	0	0
Calcium	LDR	100.0%	75	0	0	0	0	1	0	0	0	0	0	0	0	0
Chloride	COM	99.1%	210	8	0	0	0	7	0	0	0	0	0	2	0	0
Chloride	HDR	95.1%	139	10	0	0	0	4	0	0	1	0	0	8	0	0
Chloride	IND	100.0%	49	0	0	0	0	1	0	0	0	0	0	0	0	0
Chloride	LDR	99.1%	104	3	0	0	0	4	0	0	0	0	0	1	0	0
Chlorpyrifos	COM	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	250	22	1
Chlorpyrifos	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	165	22	0
Chlorpyrifos	IND	**1.6%**	1	0	0	0	0	0	0	0	0	0	0	60	3	0
Chlorpyrifos	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	102	18	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Chrysene	COM	63.3%	147	2	0	0	0	27	0	0	0	0	0	93	9	0
Chrysene	HDR	33.3%	36	0	0	0	0	22	0	0	2	0	0	97	23	0
Chrysene	IND	40.6%	19	0	0	0	0	7	0	0	0	0	0	37	1	0
Chrysene	LDR	25.9%	28	0	0	0	0	1	0	0	0	0	0	61	22	0
Conductivity	COM	99.6%	251	8	0	0	0	16	0	0	0	0	0	1	0	0
Conductivity	HDR	100.0%	162	10	0	0	1	7	0	0	0	0	0	0	0	0
Conductivity	IND	100.0%	62	0	0	0	0	4	0	0	0	0	0	0	0	0
Conductivity	LDR	100.0%	110	3	0	0	0	2	0	0	0	0	0	0	0	0
Copper	COM	99.1%	433	12	0	0	0	102	0	0	0	0	0	1	4	0
Copper	HDR	96.3%	243	12	0	0	1	66	0	0	14	0	0	9	4	0
Copper	IND	99.2%	127	0	0	0	0	3	0	0	0	0	0	0	1	0
Copper	LDR	96.8%	68	6	0	0	0	114	0	0	27	0	0	5	2	0
CPAH	COM	65.8%	117	0	0	0	0	68	0	0	0	0	0	92	4	0
CPAH	HDR	42.2%	32	0	0	0	0	44	0	0	0	0	0	88	16	0
CPAH	IND	43.8%	11	0	0	0	0	17	0	0	0	0	0	35	1	0
CPAH	LDR	34.7%	27	0	0	0	0	14	0	0	0	0	0	57	20	0
Di-N-Octyl Phthalate	COM	14.1%	27	2	0	0	0	9	0	1	0	0	0	222	16	0
Di-N-Octyl Phthalate	HDR	13.4%	7	1	0	0	0	15	0	0	1	0	0	138	17	0
Di-N-Octyl Phthalate	IND	9.4%	6	0	0	0	0	0	0	0	0	0	0	49	9	0
Di-N-Octyl Phthalate	LDR	**1.8%**	1	0	0	0	0	1	0	0	0	0	0	93	17	0
Diazinon	COM	**0.7%**	2	0	0	0	0	0	0	0	0	0	0	248	22	1
Diazinon	HDR	**1.6%**	1	0	0	0	0	2	0	0	0	0	0	162	22	0
Diazinon	IND	**1.6%**	0	0	0	0	0	1	0	0	0	0	0	61	2	0
Diazinon	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	102	18	0
Dibenzo(a,h)anthracene	COM	21.6%	43	0	0	0	0	16	0	0	1	0	0	192	26	0
Dibenzo(a,h)anthracene	HDR	6.1%	7	0	0	0	0	2	0	0	2	0	0	133	36	0
Dibenzo(a,h)anthracene	IND	**1.6%**	1	0	0	0	0	0	0	0	0	0	0	58	5	0
Dibenzo(a,h)anthracene	LDR	14.3%	12	0	0	0	0	1	0	0	3	0	0	74	22	0
Dibutyl phthalate	COM	27.4%	28	3	0	0	0	44	0	0	1	0	0	186	15	0
Dibutyl phthalate	HDR	37.8%	6	0	0	0	0	58	0	0	4	0	0	105	7	0
Dibutyl phthalate	IND	35.9%	0	0	0	0	0	23	0	0	0	0	0	39	2	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Dibutyl phthalate	LDR	30.4%	5	0	0	0	0	24	0	0	5	0	0	63	15	0
Dichlobenil	COM	33.2%	53	0	0	0	0	34	0	0	0	0	0	153	21	1
Dichlobenil	HDR	53.7%	43	2	0	0	0	49	0	0	0	0	0	75	6	0
Dichlobenil	IND	59.0%	12	0	0	0	0	24	0	0	0	0	0	22	3	0
Dichlobenil	LDR	**1.8%**	2	0	0	0	0	0	0	0	0	0	0	93	18	0
Diesel Fuel	COM	46.8%	35	0	0	0	0	1	0	0	0	0	0	41	0	0
Diesel Range Organics	COM	62.9%	80	1	0	0	0	24	0	0	0	0	0	61	1	0
Diesel Range Organics	HDR	55.2%	58	0	0	0	0	32	0	0	0	0	1	73	1	0
Diesel Range Organics	IND	64.0%	30	0	0	0	0	2	0	0	0	0	0	18	0	0
Diesel Range Organics	LDR	49.5%	18	0	0	0	0	34	0	0	0	0	0	53	0	0
Diethyl phthalate	COM	26.3%	36	0	0	0	0	36	0	1	0	0	0	191	14	0
Diethyl phthalate	HDR	33.9%	20	1	0	0	0	37	0	0	3	0	0	111	8	0
Diethyl phthalate	IND	20.3%	2	0	0	0	0	11	0	0	0	0	0	49	2	0
Diethyl phthalate	LDR	42.0%	27	0	0	0	0	20	0	0	0	0	0	58	7	0
Dimethyl phthalate	COM	12.9%	17	3	0	0	0	14	0	0	2	0	0	229	13	0
Dimethyl phthalate	HDR	15.0%	0	0	0	0	0	25	0	0	2	0	0	145	8	0
Dimethyl phthalate	IND	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	58	6	0
Dimethyl phthalate	LDR	27.7%	5	0	0	0	0	21	0	0	5	0	0	79	2	0
Ethylbenzene	COM	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	35	1	0
Ethylbenzene	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	36	2	0
Ethylbenzene	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	45	1	0
Fecal coliform	COM	96.8%	222	1	1	1	0	18	0	0	0	0	0	8	0	0
Fecal coliform	HDR	94.3%	133	0	0	0	0	15	0	0	0	0	0	7	2	0
Fecal coliform	IND	100.0%	46	0	0	1	0	2	0	0	0	0	0	0	0	0
Fecal coliform	LDR	80.6%	69	2	0	0	0	12	0	0	0	0	0	19	1	0
Fluoranthene	COM	72.6%	178	3	0	0	0	20	0	0	0	0	0	72	4	0
Fluoranthene	HDR	53.9%	74	0	0	0	0	22	0	0	1	0	0	65	18	0
Fluoranthene	IND	73.4%	36	0	0	0	0	11	0	0	0	0	0	17	0	0
Fluoranthene	LDR	25.9%	26	0	0	0	0	2	0	0	1	0	0	62	21	0
Fluorene	COM	15.5%	23	0	0	0	0	19	0	0	1	0	0	210	25	0
Fluorene	HDR	8.3%	3	0	0	0	0	11	0	0	1	0	0	137	28	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Fluorene	IND	32.8%	8	0	0	0	0	13	0	0	0	0	0	40	3	0
Fluorene	LDR	**0.9%**	0	0	0	0	0	0	0	0	1	0	0	88	23	0
Gasoline Range Organics	COM	9.6%	0	0	0	0	0	18	0	0	0	0	0	149	20	0
Gasoline Range Organics	HDR	12.3%	2	0	0	0	0	17	0	0	0	0	0	108	28	0
Gasoline Range Organics	IND	31.8%	2	0	0	0	0	12	0	0	0	0	0	25	5	0
Gasoline Range Organics	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	92	13	0
Hardness as CaCO3	COM	99.3%	267	8	0	0	0	4	0	0	0	0	0	2	0	0
Hardness as CaCO3	HDR	100.0%	170	10	0	0	1	0	0	0	0	0	0	0	0	0
Hardness as CaCO3	IND	100.0%	64	0	0	0	0	1	0	0	0	0	0	0	0	0
Hardness as CaCO3	LDR	100.0%	110	3	0	0	0	2	0	0	0	0	0	0	0	0
Heavy Fuel Oil	COM	93.9%	72	1	0	0	0	20	0	0	0	0	0	6	0	0
Heavy Fuel Oil	HDR	78.8%	40	0	0	0	0	37	0	0	0	0	1	19	2	0
Heavy Fuel Oil	IND	73.7%	9	0	0	0	0	5	0	0	0	0	0	4	1	0
Heavy Fuel Oil	LDR	60.5%	15	0	0	0	0	33	0	0	0	0	1	31	1	0
HPAH	COM	77.5%	151	0	0	0	0	66	0	0	0	0	0	63	0	0
HPAH	HDR	62.2%	53	0	0	0	0	59	0	0	0	0	0	59	9	0
HPAH	IND	82.8%	27	0	0	0	0	26	0	0	0	0	0	11	0	0
HPAH	LDR	42.4%	28	0	0	0	0	22	0	0	0	0	0	55	13	0
eno(1,2,3-cd)pyrene	COM	39.2%	79	1	0	0	0	28	0	0	1	0	0	148	21	0
eno(1,2,3-cd)pyrene	HDR	19.4%	25	0	0	0	0	8	0	0	2	0	0	114	31	0
eno(1,2,3-cd)pyrene	IND	17.2%	5	0	0	0	0	6	0	0	0	0	0	49	4	0
eno(1,2,3-cd)pyrene	LDR	24.1%	23	0	0	0	0	1	0	0	3	0	0	63	22	0
Lead	COM	96.4%	451	16	0	0	0	39	0	0	27	0	0	19	1	0
Lead	HDR	86.3%	254	20	0	0	0	22	0	0	13	0	0	41	8	0
Lead	IND	83.3%	100	0	0	0	0	10	0	0	0	0	0	21	1	0
Lead	LDR	83.4%	131	5	0	0	0	33	0	0	17	0	0	20	17	0
LPAH	COM	70.8%	142	0	0	0	0	57	0	0	0	0	0	75	7	0
LPAH	HDR	53.3%	36	0	0	0	0	60	0	0	0	0	0	73	11	0
LPAH	IND	70.3%	22	0	0	0	0	23	0	0	0	0	0	18	1	0
LPAH	LDR	44.1%	20	0	0	0	0	32	0	0	0	0	0	53	13	0
Lube Oil	COM	94.4%	34	0	0	0	0	0	0	0	0	0	0	2	0	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Lube Oil	HDR	10.0%	3	0	0	0	0	0	0	0	0	0	0	27	0	0
Lube Oil	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	23	0	0
Magnesium	COM	100.0%	153	0	0	0	0	1	0	0	0	0	0	0	0	0
Magnesium	HDR	100.0%	93	0	0	0	0	0	0	0	0	0	0	0	0	0
Magnesium	IND	100.0%	32	0	0	0	0	0	0	0	0	0	0	0	0	0
Magnesium	LDR	100.0%	75	0	0	0	0	1	0	0	0	0	0	0	0	0
Malathion	COM	**1.8%**	3	0	0	0	0	2	0	0	0	0	0	244	22	1
Malathion	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	164	23	0
Malathion	IND	**1.6%**	0	0	0	0	0	1	0	0	0	0	0	60	3	0
Malathion	LDR	**0.8%**	1	0	0	0	0	0	0	0	0	0	0	101	18	0
Mecoprop	COM	5.5%	10	2	0	0	0	3	0	0	0	0	0	231	25	0
Mecoprop	HDR	24.7%	25	5	0	0	0	12	0	0	0	0	0	120	8	0
Mecoprop	IND	**1.8%**	1	0	0	0	0	0	0	0	0	0	0	51	3	0
Mecoprop	LDR	5.0%	5	0	0	0	0	1	0	0	0	0	0	96	18	0
Mercury	COM	22.3%	103	0	0	0	0	17	0	0	1	0	0	362	60	0
Mercury	HDR	7.3%	9	0	0	0	0	1	0	0	1	0	0	130	9	0
Mercury	IND	6.1%	7	0	0	0	0	1	0	0	0	0	0	124	0	0
Mercury	LDR	**2.7%**	2	0	0	0	0	0	0	0	0	0	0	56	16	0
Motor Oil	COM	75.0%	47	0	0	0	0	1	0	0	0	0	0	16	0	0
Motor Oil	HDR	84.2%	15	0	0	0	0	1	0	0	0	0	0	3	0	0
Motor Oil	IND	100.0%	22	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	COM	36.2%	66	0	0	0	0	33	0	0	1	0	0	157	19	0
Naphthalene	HDR	37.6%	26	0	0	0	0	36	0	0	5	0	0	90	20	1
Naphthalene	IND	46.0%	22	0	0	0	0	7	0	0	0	0	0	30	4	0
Naphthalene	LDR	33.3%	12	0	0	0	0	15	0	0	10	0	0	62	11	1
Nitrite-Nitrate	COM	90.8%	186	6	0	0	0	35	0	0	0	0	0	23	0	0
Nitrite-Nitrate	HDR	100.0%	133	6	0	0	0	23	0	0	6	0	0	0	0	0
Nitrite-Nitrate	IND	100.0%	43	0	0	0	0	9	0	0	0	0	0	0	0	0
Nitrite-Nitrate	LDR	100.0%	93	1	0	0	0	20	0	0	0	0	0	0	0	0
Oil and grease	COM	5.7%	2	0	0	0	0	0	0	0	0	0	0	33	0	0
Ortho-phosphate	COM	90.4%	169	4	0	0	0	53	0	0	0	0	0	22	2	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Ortho-phosphate	HDR	90.1%	115	7	0	0	0	33	0	0	0	0	0	17	0	0
Ortho-phosphate	IND	94.4%	44	0	0	0	0	7	0	0	0	0	0	3	0	0
Ortho-phosphate	LDR	98.2%	72	3	0	0	0	37	0	0	0	0	0	2	0	0
p-Cresol	COM	25.0%	2	0	0	0	0	0	0	0	0	0	0	6	0	0
p-Cresol	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	7	0	0
p-Cresol	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	11	0	0
PCB-aroclor 1016	COM	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	8	0	0
PCB-aroclor 1016	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	10	0	0
PCB-aroclor 1016	IND	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	9	0	0
PCB-aroclor 1221	COM	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	8	0	0
PCB-aroclor 1221	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	10	0	0
PCB-aroclor 1221	IND	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	9	0	0
PCB-aroclor 1232	COM	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	8	0	0
PCB-aroclor 1232	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	10	0	0
PCB-aroclor 1232	IND	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	9	0	0
PCB-aroclor 1242	COM	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	8	0	0
PCB-aroclor 1242	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	10	0	0
PCB-aroclor 1242	IND	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	9	0	0
PCB-aroclor 1248	COM	12.5%	1	0	0	0	0	0	0	0	0	0	0	7	0	0
PCB-aroclor 1248	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	10	0	0
PCB-aroclor 1248	IND	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	9	0	0
PCB-aroclor 1254	COM	100.0%	8	0	0	0	0	0	0	0	0	0	0	0	0	0
PCB-aroclor 1254	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	10	0	0
PCB-aroclor 1254	IND	66.7%	6	0	0	0	0	0	0	0	0	0	0	2	1	0
PCB-aroclor 1260	COM	50.0%	3	0	0	0	0	1	0	0	0	0	0	4	0	0
PCB-aroclor 1260	HDR	10.0%	1	0	0	0	0	0	0	0	0	0	0	9	0	0
PCB-aroclor 1260	IND	22.2%	2	0	0	0	0	0	0	0	0	0	0	7	0	0
Pentachlorophenol	COM	40.5%	93	8	0	0	0	3	0	0	2	0	0	151	5	0
Pentachlorophenol	HDR	12.9%	8	0	0	0	0	13	0	0	0	0	0	122	20	0
Pentachlorophenol	IND	9.1%	0	0	0	0	0	5	0	0	0	0	0	50	0	0
Pentachlorophenol	LDR	16.2%	8	0	0	0	0	10	0	0	0	0	0	85	8	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
pH	COM	100.0%	72	0	0	0	0	1	0	0	0	0	0	0	0	0
pH	HDR	100.0%	85	0	0	0	0	1	0	0	0	0	0	0	0	0
pH	IND	100.0%	64	0	0	0	0	1	0	0	0	0	0	0	0	0
Phenanthrene	COM	62.8%	155	1	0	0	0	18	0	0	0	0	0	92	11	0
Phenanthrene	HDR	46.7%	59	0	0	0	0	23	0	0	2	0	0	81	15	0
Phenanthrene	IND	68.8%	39	0	0	0	0	5	0	0	0	0	0	20	0	0
Phenanthrene	LDR	23.2%	23	0	0	0	0	2	0	0	1	0	0	65	21	0
Phenol	COM	37.5%	3	0	0	0	0	0	0	0	0	0	0	5	0	0
Phenol	HDR	42.9%	3	0	0	0	0	0	0	0	0	0	0	4	0	0
Phenol	LDR	18.2%	1	0	0	0	0	0	0	0	1	0	0	9	0	0
Precipitation	COM	100.0%	219	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	HDR	100.0%	125	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	IND	100.0%	33	0	0	0	0	0	0	0	0	0	0	0	0	0
Precipitation	LDR	100.0%	91	3	0	0	0	0	0	0	0	0	0	0	0	0
Prometon	COM	**0.8%**	0	0	0	0	0	2	0	0	0	0	0	230	27	1
Prometon	HDR	6.9%	6	1	0	0	0	5	0	0	0	0	0	135	26	1
Prometon	IND	10.0%	4	0	0	0	0	2	0	0	0	0	0	51	3	0
Prometon	LDR	**1.8%**	0	0	0	0	0	1	0	0	1	0	0	89	22	0
Pyrene	COM	75.1%	182	2	0	0	0	24	0	0	0	0	0	64	5	0
Pyrene	HDR	58.9%	80	0	0	0	0	24	0	0	2	0	0	62	12	0
Pyrene	IND	81.3%	46	0	0	0	0	6	0	0	0	0	0	12	0	0
Pyrene	LDR	31.3%	27	0	0	0	0	7	0	0	1	0	0	61	16	0
Sampled-Event Flow Volume	COM	100.0%	257	8	0	0	0	0	0	0	0	0	0	0	0	0
Sampled-Event Flow Volume	HDR	100.0%	154	10	0	0	0	0	0	0	0	0	0	0	0	0
Sampled-Event Flow Volume	IND	100.0%	66	0	0	0	0	0	0	0	0	0	0	0	0	0
Sampled-Event Flow Volume	LDR	100.0%	97	8	0	0	0	0	0	0	0	0	0	0	0	0
Storm Event Flow Volume	COM	100.0%	272	0	0	0	0	0	0	0	0	0	0	0	0	0
Storm Event Flow Volume	HDR	100.0%	173	0	0	0	0	0	0	0	0	0	0	0	0	0
Storm Event Flow Volume	IND	100.0%	66	0	0	0	0	0	0	0	0	0	0	0	0	0
Storm Event Flow Volume	LDR	100.0%	115	1	0	0	0	0	0	0	0	0	0	0	0	0
Surfactants	COM	78.6%	181	7	0	0	0	21	0	0	0	0	0	48	9	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Surfactants	HDR	58.4%	86	3	0	0	0	12	0	0	0	0	0	53	19	0
Surfactants	IND	75.0%	39	0	0	0	0	3	0	0	0	0	0	14	0	0
Surfactants	LDR	29.5%	29	0	0	0	0	4	0	0	0	0	0	58	21	0
Toluene	COM	**2.8%**	1	0	0	0	0	0	0	0	0	0	0	34	1	0
Toluene	HDR	5.3%	2	0	0	0	0	0	0	0	0	0	0	34	2	0
Toluene	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	45	1	0
Total Benzofluoranthenes	COM	52.3%	115	0	0	0	0	32	0	0	0	0	0	125	9	0
Total Benzofluoranthenes	HDR	27.8%	29	0	0	0	0	21	0	0	0	0	0	110	20	0
Total Benzofluoranthenes	IND	29.7%	12	0	0	0	0	7	0	0	0	0	0	43	2	0
Total Benzofluoranthenes	LDR	22.9%	24	0	0	0	0	3	0	0	0	0	0	63	28	0
Total Kjeldahl Nitrogen	COM	86.5%	159	8	0	0	0	51	0	0	0	0	0	34	0	0
Total Kjeldahl Nitrogen	HDR	91.6%	102	10	0	0	0	40	0	0	1	0	0	12	2	0
Total Kjeldahl Nitrogen	IND	98.1%	37	0	0	0	0	15	0	0	0	0	0	1	0	0
Total Kjeldahl Nitrogen	LDR	89.4%	55	3	0	0	0	43	0	0	0	0	0	11	1	0
Total PAH	COM	82.9%	159	0	0	0	0	74	0	0	0	0	0	47	1	0
Total PAH	HDR	65.6%	48	0	0	0	0	70	0	0	0	0	0	55	7	0
Total PAH	IND	84.4%	26	0	0	0	0	28	0	0	0	0	0	9	1	0
Total PAH	LDR	54.2%	31	0	0	0	0	33	0	0	0	0	0	47	7	0
Total PCB	COM	100.0%	7	0	0	0	0	1	0	0	0	0	0	0	0	0
Total PCB	HDR	10.0%	1	0	0	0	0	0	0	0	0	0	0	9	0	0
Total PCB	IND	66.7%	6	0	0	0	0	0	0	0	0	0	0	3	0	0
Total Phosphorus	COM	95.3%	216	6	0	0	0	23	0	0	1	0	0	12	0	0
Total Phosphorus	HDR	96.6%	138	6	0	0	0	25	0	0	0	0	0	2	4	0
Total Phosphorus	IND	98.0%	40	0	0	0	0	10	0	0	0	0	0	1	0	0
Total Phosphorus	LDR	99.2%	101	3	0	0	0	15	0	0	1	0	0	1	0	0
Total Phthalate	COM	82.2%	123	0	0	0	0	108	0	0	0	0	0	50	0	0
Total Phthalate	HDR	74.4%	49	0	0	0	0	85	0	0	0	0	0	41	5	0
Total Phthalate	IND	81.3%	21	0	0	0	0	31	0	0	0	0	0	11	1	0
Total Phthalate	LDR	65.3%	27	0	0	0	0	50	0	0	0	0	0	41	0	0
Total Suspended Solids	COM	99.6%	252	8	0	0	0	10	0	0	0	0	0	0	1	0
Total Suspended Solids	HDR	99.4%	157	10	0	0	1	8	0	0	0	0	0	1	0	0

Parameter	Land use	% detection	No qualifiers	C	E	G	j	J	JG	JL	JT	JTL	L	U	UJ	UJG
Total Suspended Solids	IND	100.0%	62	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Suspended Solids	LDR	98.3%	107	3	0	0	0	3	0	0	0	0	0	2	0	0
Total TPHDx	COM	80.2%	173	0	0	0	0	29	0	0	0	0	0	50	0	0
Total TPHDx	HDR	70.7%	77	0	0	0	0	41	0	0	0	0	0	49	0	0
Total TPHDx	IND	88.9%	42	0	0	0	0	6	0	0	0	0	0	6	0	0
Total TPHDx	LDR	50.0%	17	0	0	0	0	36	0	0	0	0	0	53	0	0
Total Xylenes	COM	**2.8%**	1	0	0	0	0	0	0	0	0	0	0	34	1	0
Total Xylenes	HDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	36	2	0
Total Xylenes	LDR	**0.0%**	0	0	0	0	0	0	0	0	0	0	0	45	1	0
TPHGx	COM	**2.9%**	1	0	0	0	0	0	0	0	0	0	0	34	0	0
Triclopyr	COM	6.4%	13	0	0	0	0	3	0	0	0	0	0	208	26	0
Triclopyr	HDR	17.0%	10	5	0	0	0	12	0	0	0	0	0	121	10	1
Triclopyr	IND	5.7%	3	0	0	0	0	0	0	0	0	0	0	42	8	0
Triclopyr	LDR	15.0%	6	1	0	0	0	10	0	0	0	0	0	90	6	0
Turbidity	COM	100.0%	215	8	0	0	0	22	0	0	0	0	0	0	0	0
Turbidity	HDR	100.0%	122	10	0	0	0	17	0	0	0	0	0	0	0	0
Turbidity	IND	100.0%	41	0	0	0	0	1	0	0	0	0	0	0	0	0
Turbidity	LDR	100.0%	84	3	0	0	0	25	0	0	0	0	0	0	0	0
Zinc	COM	100.0%	443	16	0	0	0	87	0	0	0	0	0	0	0	0
Zinc	HDR	97.4%	253	20	0	0	1	54	0	0	8	0	0	8	1	0
Zinc	IND	99.2%	128	0	0	0	0	1	0	0	0	0	0	0	1	0
Zinc	LDR	94.5%	77	6	0	0	0	122	0	0	0	0	0	7	5	0

Table D-4. Summary of data cases for each parameter by matrix and land use.
The % non-detect is shown in parentheses beside the Case letter.

Parameter	Commercial	High-density residential	Industrial	Low-density residential
1-Methylnaphthalene sediment (ug/Kg)	A (48.6)	C (100)	C (100)	B (60)
1-Methylnaphthalene water (ug/L)	C (96.8)	C (100)	C (81.2)	C (100)
2-Methylnaphthalene sediment (ug/Kg)	A (37.8)	B (62.5)	C (83.3)	C (81.8)
2-Methylnaphthalene water (ug/L)	B (79.1)	C (85)	B (62.5)	C (100)
2-Nitrophenol sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
2,4-D sediment (ug/Kg)	C (100)	C (100)	C (96.4)	B (80)
2,4-D water (ug/L)	C (87.7)	B (66.3)	C (100)	C (90.8)
2,4-Dichlorophenol sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
2,4-Dimethylphenol sediment (ug/Kg)	C (84.2)	C (100)	C (100)	C (100)
2,4,5-Trichlorophenol sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
2,4,6-Trichlorophenol sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
4-Chloro-3-Methylphenol sediment (ug/Kg)	C (91.7)	C (100)	C (100)	C (100)
4-Nitrophenol sediment (ug/Kg)	C (100)	C (100)		B (66.7)
Acenaphthene sediment (ug/Kg)	A (23.9)	B (68.8)	C (83.3)	C (81.8)
Acenaphthene water (ug/L)	C (88.1)	C (95.6)	B (68.8)	C (99.1)
Acenaphthylene sediment (ug/Kg)	A (43.5)	C (100)	C (100)	C (100)
Acenaphthylene water (ug/L)	C (92.8)	C (93.9)	C (84.4)	C (100)
Ammonia water (ug/L)	A (0)	A (0)	A (0)	
Anthracene sediment (ug/Kg)	A (10.9)	A (37.5)	A (16.7)	C (81.8)
Anthracene water (ug/L)	C (82)	C (95)	C (89.1)	C (95.5)
Arsenic water dissolved (ug/L)	A (0)			A (0)
Benz(a)anthracene sediment (ug/Kg)	A (0)	A (23.1)	A (16.7)	A (50)
Benz(a)anthracene water (ug/L)	B (61.5)	B (70.4)	B (79.7)	B (56.1)
Benzene water (ug/L)	C (97.2)	C (100)		C (100)
Benzo(a)pyrene sediment (ug/Kg)	A (2.2)	A (31.2)	A (16.7)	B (63.6)
Benzo(a)pyrene water (ug/L)	B (60.6)	C (83.2)	C (82.8)	B (73.9)
Benzo(b)fluoranthene sediment (ug/Kg)	A (3.8)	A (22.2)	A (0)	B (66.7)
Benzo(b)fluoranthene water (ug/L)	B (53.7)	C (81.7)	A (50)	C (85)
Benzo(b,k)fluoranthene sediment (ug/Kg)	A (0)	A (0)	A (0)	
Benzo(b,k)fluoranthene water (ug/L)	A (35.7)	B (53.8)	B (65.6)	
Benzo(g,h,i)perylene sediment (ug/Kg)	A (0)	A (23.1)	A (0)	B (62.5)
Benzo(g,h,i)perylene water (ug/L)	A (46.6)	B (69.4)	B (62.5)	B (76.8)
Benzo(k)fluoranthene sediment (ug/Kg)	A (7.7)	A (44.4)	A (0)	B (77.8)
Benzo(k)fluoranthene water (ug/L)	B (64.6)	C (88.2)	A (50)	C (84)
Benzofluoranthenes, Total sediment (ug/Kg)	A (0)	A (0)	A (0)	A (0)
Benzofluoranthenes, Total water (ug/L)	A (41.7)	B (77.1)	B (76.7)	A (8.3)
Biochemical Oxygen Demand water (ug/L)	A (9.5)	A (18)	A (6.7)	B (62.4)
Bis(2-ethylhexyl) phthalate sediment (ug/Kg)	A (0)	A (6.2)	A (0)	A (27.3)
Bis(2-ethylhexyl) phthalate water (ug/L)	A (22.8)	A (41.1)	A (36.5)	B (70.5)

Parameter	Commercial	High-density residential	Industrial	Low-density residential
BTEX water (ug/L)	C (97.2)	C (94.7)		C (100)
Butyl benzyl phthalate sediment (ug/Kg)	A (37.5)	A (50)	A (33.3)	B (54.5)
Butyl benzyl phthalate water (ug/L)	B (74.4)	B (76.7)	C (84.4)	C (82.1)
Cadmium sediment (ug/Kg)	A (4.3)	A (29.4)	A (0)	A (9.1)
Cadmium water (ug/L)	A (16.5)	A (30.6)	A (16.7)	B (50.4)
Cadmium water dissolved (ug/L)	A (39.3)	B (51.4)	B (54.5)	B (57.4)
Calcium water (ug/L)	A (0)	A (0)	A (0)	A (0)
Calcium water dissolved (ug/L)	A (0)			
Chloride water (ug/L)	A (0.9)	A (4.9)	A (0)	A (0.9)
Chlorpyrifos sediment (ug/Kg)	C (95.2)	C (100)	C (100)	C (100)
Chlorpyrifos water (ug/L)	C (100)	C (100)	C (98.4)	C (100)
Chrysene sediment (ug/Kg)	A (0)	A (6.2)	A (0)	A (45.5)
Chrysene water (ug/L)	A (36.7)	B (66.7)	B (59.4)	B (74.1)
Conductivity water (uS/cm)	A (0.4)	A (0)	A (0)	A (0)
Copper sediment (ug/Kg)	A (0)	A (0)	A (0)	A (0)
Copper water (ug/L)	A (0)	A (2.7)	A (0)	A (3.3)
Copper water dissolved (ug/L)	A (1.9)	A (4.8)	A (1.5)	A (2.9)
CPAH sediment (ug/Kg)	A (0)	A (6.2)	A (0)	A (36.4)
CPAH water (ug/L)	A (33.5)	B (57.8)	B (56.2)	B (66.1)
Di-N-Octyl Phthalate sediment (ug/Kg)	B (60.9)	C (81.2)	A (33.3)	C (100)
Di-N-Octyl Phthalate water (ug/L)	C (85.9)	C (86.6)	C (90.6)	C (98.2)
Diazinon sediment (ug/Kg)	C (95)	C (100)	C (100)	C (100)
Diazinon water (ug/L)	C (99.3)	C (98.4)	C (98.4)	C (100)
Dibenzo(a,h)anthracene sediment (ug/Kg)	A (13)	A (37.5)	A (33.3)	B (63.6)
Dibenzo(a,h)anthracene water (ug/L)	B (78.4)	C (93.9)	C (98.4)	C (85.7)
Dibutyl phthalate sediment (ug/Kg)	B (58.3)	C (93.8)	A (50)	C (81.8)
Dibutyl phthalate water (ug/L)	B (72.6)	B (62.2)	B (64.1)	B (69.6)
Dichlobenil sediment (ug/Kg)	A (20)	B (75)		C (83.3)
Dichlobenil water (ug/L)	B (66.8)	A (46.3)	A (41)	C (98.2)
Diesel Fuel sediment (ug/Kg)	A (0)			
Diesel Fuel water (ug/L)	B (53.2)			
Diesel Range Organics sediment (ug/Kg)	A (50)	A (0)	A (0)	
Diesel Range Organics water (ug/L)	A (37.1)	A (44.8)	A (36)	B (50.5)
Diethyl phthalate sediment (ug/Kg)	C (91.3)	C (100)	C (83.3)	C (100)
Diethyl phthalate water (ug/L)	B (73.7)	B (66.1)	B (79.7)	B (58)
Dimethyl phthalate sediment (ug/Kg)	B (65.2)	C (93.8)	C (83.3)	C (90.9)
Dimethyl phthalate water (ug/L)	C (87.1)	C (85)	C (100)	B (72.3)
Ethylbenzene water (ug/L)	C (100)	C (100)		C (100)
Fecal coliform water (cfu/100mL)	A (3.2)	A (5.7)	A (0)	A (19.4)
Fines sediment (%)	A (0)	A (0)	A (0)	A (0)
Fluoranthene sediment (ug/Kg)	A (0)	A (12.5)	A (0)	A (27.3)

Parameter	Commercial	High-density residential	Industrial	Low-density residential
Fluoranthene water (ug/L)	A (27.4)	A (46.1)	A (26.6)	B (74.1)
Fluorene sediment (ug/Kg)	A (17.4)	B (66.7)	C (83.3)	C (81.8)
Fluorene water (ug/L)	C (84.5)	C (91.7)	B (67.2)	C (99.1)
Gasoline Range Organics water (ug/L)	C (90.4)	C (87.7)	B (68.2)	C (100)
Gravel sediment (%)	A (4.7)	A (13.3)	A (0)	A (10)
Hardness as CaCO3 water (ug/L)	A (0.7)	A (0)	A (0)	A (0)
Heavy Fuel Oil sediment (ug/Kg)	A (0)	A (0)	A (0)	A (39.5)
Heavy Fuel Oil water (ug/L)	A (6.1)	A (21.2)	A (26.3)	
HPAH sediment (ug/Kg)	A (0)	A (5.3)	A (0)	A (15.4)
HPAH water (ug/L)	A (21.7)	A (37.8)	A (17.2)	B (60.7)
Indeno(1,2,3-cd)pyrene sediment (ug/Kg)	A (2.2)	A (18.8)	A (16.7)	B (54.5)
Indeno(1,2,3-cd)pyrene water (ug/L)	B (60.8)	C (80.6)	C (82.8)	B (75.9)
Lead sediment (ug/Kg)	A (0)	A (5.9)	A (0)	A (9.1)
Lead water (ug/L)	A (0)	A (2.2)	A (0)	A (1.8)
Lead water dissolved (ug/L)	A (7.3)	A (25.1)	A (33.3)	A (32.1)
LPAH sediment (ug/Kg)	A (2.1)	A (5.6)	A (14.3)	A (15.4)
LPAH water (ug/L)	A (28.4)	A (46.7)	A (29.7)	B (56.2)
Lube Oil water (ug/L)	A (5.6)	C (90)		C (100)
Magnesium water (ug/L)	A (0)	A (0)	A (0)	A (0)
Magnesium water dissolved (ug/L)	A (0)			
Malathion sediment (ug/Kg)	C (95.2)	C (100)	C (100)	C (100)
Malathion water (ug/L)	C (98.2)	C (100)	C (98.4)	C (99.2)
Mecoprop sediment (ug/Kg)	C (100)	C (100)		B (80)
Mecoprop water (ug/L)	C (94.5)	B (75.3)	C (98.2)	C (95)
Mercury sediment (ug/Kg)	A (13)	A (33.3)	A (0)	A (42.9)
Mercury water (ug/L)	B (69)	C (89.3)	C (87.9)	C (97.3)
Mercury water dissolved (ug/L)	C (86.8)	C (96)	C (100)	C (97.3)
Motor Oil sediment (ug/Kg)	A (0)			
Motor Oil water (ug/L)	A (25)	A (15.8)	A (0)	
Naphthalene sediment (ug/Kg)	A (17.4)	B (75)	B (66.7)	B (72.7)
Naphthalene water (ug/L)	B (63.8)	B (62.4)	B (54)	B (66.7)
Nitrite-Nitrate water dissolved (ug/L)	A (9.2)	A (0)	A (0)	A (0)
o-Cresol sediment (ug/Kg)	B (70)	C (81.8)	C (100)	C (100)
Oil and grease water (ug/L)	C (94.3)			
Ortho-phosphate water dissolved (ug/L)	A (9.6)	A (9.9)	A (5.6)	A (1.8)
p-Cresol sediment (ug/Kg)	A (10)	A (18.2)	A (50)	A (50)
p-Cresol water (ug/L)	B (75)	C (100)		C (100)
PCB-aroclor 1016 sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
PCB-aroclor 1016 water (ug/L)	C (100)	C (100)	C (100)	
PCB-aroclor 1221 sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
PCB-aroclor 1221 water (ug/L)	C (100)	C (100)	C (100)	

Parameter	Commercial	High-density residential	Industrial	Low-density residential
PCB-aroclor 1232 sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
PCB-aroclor 1232 water (ug/L)	C (100)	C (100)	C (100)	
PCB-aroclor 1242 sediment (ug/Kg)	C (100)	C (100)	C (100)	C (100)
PCB-aroclor 1242 water (ug/L)	C (100)	C (100)	C (100)	
PCB-aroclor 1248 sediment (ug/Kg)	C (94.7)	C (83.3)	C (100)	C (100)
PCB-aroclor 1248 water (ug/L)	C (87.5)	C (100)	C (100)	
PCB-aroclor 1254 sediment (ug/Kg)	A (36.8)	C (100)	A (50)	C (100)
PCB-aroclor 1254 water (ug/L)	A (0)	C (100)	A (33.3)	
PCB-aroclor 1260 sediment (ug/Kg)	B (63.2)	C (100)	B (66.7)	C (100)
PCB-aroclor 1260 water (ug/L)	A (50)	C (90)	B (77.8)	
Pentachlorophenol sediment (ug/Kg)	B (69.6)	B (80)	B (80)	C (90.9)
Pentachlorophenol water (ug/L)	B (59.5)	C (87.1)	C (90.9)	C (83.8)
pH water (pH)	A (0)	A (0)	A (0)	
Phenanthrene sediment (ug/Kg)	A (2.2)	A (6.7)	A (16.7)	A (18.2)
Phenanthrene water (ug/L)	A (37.2)	B (53.3)	A (31.2)	B (76.8)
Phenol sediment (ug/Kg)	A (40.9)	B (69.2)	B (80)	B (66.7)
Phenol water (ug/L)	B (62.5)	B (57.1)		C (81.8)
Precipitation water (in)	A (0)	A (0)	A (0)	A (0)
Prometon sediment (ug/Kg)	C (100)	C (100)		C (100)
Prometon water (ug/L)	C (99.2)	C (93.1)	C (90)	C (98.2)
Pyrene sediment (ug/Kg)	A (0)	A (12.5)	A (0)	A (18.2)
Pyrene water (ug/L)	A (24.9)	A (41.1)	A (18.8)	B (68.8)
Sampled-Event Flow Volume water (m3)	A (0)	A (0)	A (0)	A (0)
Sand sediment (%)	A (0)	A (0)	A (0)	A (0)
Solids sediment (%)	A (0)	A (0)	A (0)	A (0)
Storm Event Flow Volume water (m3)	A (0)	A (0)	A (0)	A (0)
Surfactants water (ug/L)	A (21.4)	A (41.6)	A (25)	B (70.5)
Toluene water (ug/L)	C (97.2)	C (94.7)		C (100)
Total Benzofluoranthenes sediment (ug/Kg)	A (2.2)	A (12.5)	A (0)	B (54.5)
Total Benzofluoranthenes water (ug/L)	A (47.1)	B (72.2)	B (70.3)	B (75.9)
Total Kjeldahl Nitrogen water (ug/L)	A (13.5)	A (8.4)	A (1.9)	A (10.6)
Total Organic Carbon sediment (%)	A (0)	A (0)	A (0)	A (0)
Total PAH sediment (ug/Kg)	A (0)	A (0)	A (0)	A (9.1)
Total PAH water (ug/L)	A (16.2)	A (34.4)	A (15.6)	A (48.2)
Total PCB sediment (ug/Kg)	A (31.6)	C (83.3)	A (50)	C (100)
Total PCB water (ug/L)	A (0)	C (90)	A (33.3)	
Total Phosphorus sediment (ug/Kg)	A (0)			
Total Phosphorus water (ug/L)	A (4.7)	A (3.4)	A (2)	A (0.8)
Total Phthalate sediment (ug/Kg)	A (7.1)	A (11.8)	A (18.2)	A (18.2)
Total Phthalate water (ug/L)	A (18)	A (25.6)	A (18.8)	A (36.6)
Total Suspended Solids water (ug/L)	A (0.4)	A (0.6)	A (0)	A (1.7)

Parameter	Commercial	High-density residential	Industrial	Low-density residential
Total TPHDx sediment (ug/Kg)	A (0)	A (0)	A (0)	
Total TPHDx water (ug/L)	A (19.8)	A (29.3)	A (11.1)	A (50)
Total Xylenes water (ug/L)	C (97.2)	C (100)		C (100)
TPHGx water (ug/L)	C (97.1)			
Triclopyr sediment (ug/Kg)	C (100)	C (100)		B (80)
Triclopyr water (ug/L)	C (93.6)	C (83)	C (94.3)	C (85)
Turbidity water (NTU)	A (0)	A (0)	A (0)	A (0)
Zinc sediment (ug/Kg)	A (0)	A (0)	A (0)	A (0)
Zinc water (ug/L)	A (0)	A (2.2)	A (0)	A (1.8)
Zinc water dissolved (ug/L)	A (0)	A (3)	A (1.5)	A (9.5)

Appendix E. Hydrology

Table E-1. Percentage of the storms sampled per year for each catchment.
Minimum and maximum percent and number of storms.

Location_ID	2009 min	2009 max	2009 count	2010 min	2010 max	2010 count	2011 min	2011 max	2011 count	2012 min	2012 max	2012 count	2013 min	2013 max	2013 count
GM34921	-	-	-	24.2	100	9	12	99.8	15	96.5	99	5	-	-	-
KICCOMS8D_OUT	36.2	74	3	21.8	97.5	8	30.1	97.2	9	76.8	99.7	5	97.8	100	6
KICHDRS8D_OUT	16.3	91.3	3	12	100	7	20.4	97.1	6	50.2	96.1	4	71.4	71.4	1
KICLDRS8D_OUT	83.4	100	3	7.5	94.5	12	2.3	100	9	99.5	99.5	1	90.1	100	3
LDR010	-	-	-	33	95.5	7	3.7	93.3	8	42.4	94.5	8	-	-	-
MH5171	-	-	-	85	100	6	7.9	99.7	15	26.8	99.2	6	-	-	-
PIECOMM_OUT	-	-	-	53.6	95.3	4	63.5	97.2	9	85.6	94.3	5	66.4	89.5	3
PIEHIRES_OUT	-	-	-	76.3	76.3	1	73.5	98	5	89.8	89.8	1	81.8	81.8	1
PIELORES_OUT	-	-	-	90.1	90.1	1	59.5	96	7	64.3	85.5	4	86.8	97.4	3
POSOUTFALL_6057	77.8	100	9	61.7	100	16	53	99.7	12	73.1	97.8	3	-	-	-
POT564S8D_OUT	91	99.7	3	73.9	98.4	7	25.9	100	11	15.6	56.8	8	-	-	-
SEAC1S8D_OUT	71.5	100	3	100	100	14	100	100	12	61.5	100	5	-	-	-
SEAI1S8D_OUT	100	100	3	71.6	100	13	100	100	12	100	100	5	-	-	-
SEAR1S8D_OUT	100	100	5	100	100	13	100	100	10	100	100	7	-	-	-
SNO_COM	95	99.8	5	16.7	99.7	12	76.8	99.4	11	72.6	98.1	8	-	-	-
SNO_HDR	83.1	99.3	7	48.8	97.1	13	82.1	98.2	10	70.8	98	8	-	-	-
SNO_LDR	24.3	94	5	35.6	91.7	13	29.5	97.8	15	32.7	95.9	6	-	-	-
TAC001S8D_OF235	95.5	100	5	33.6	100	16	79.4	100	12	32.2	98.1	8	-	-	-
TAC003S8D_OF245	46.9	100	4	56.1	89.8	10	61.4	100	11	26.6	95.3	8	-	-	-
TFWFD1	83.5	100	5	25.7	100	11	30.3	93.9	11	55.7	89	8	-	-	-

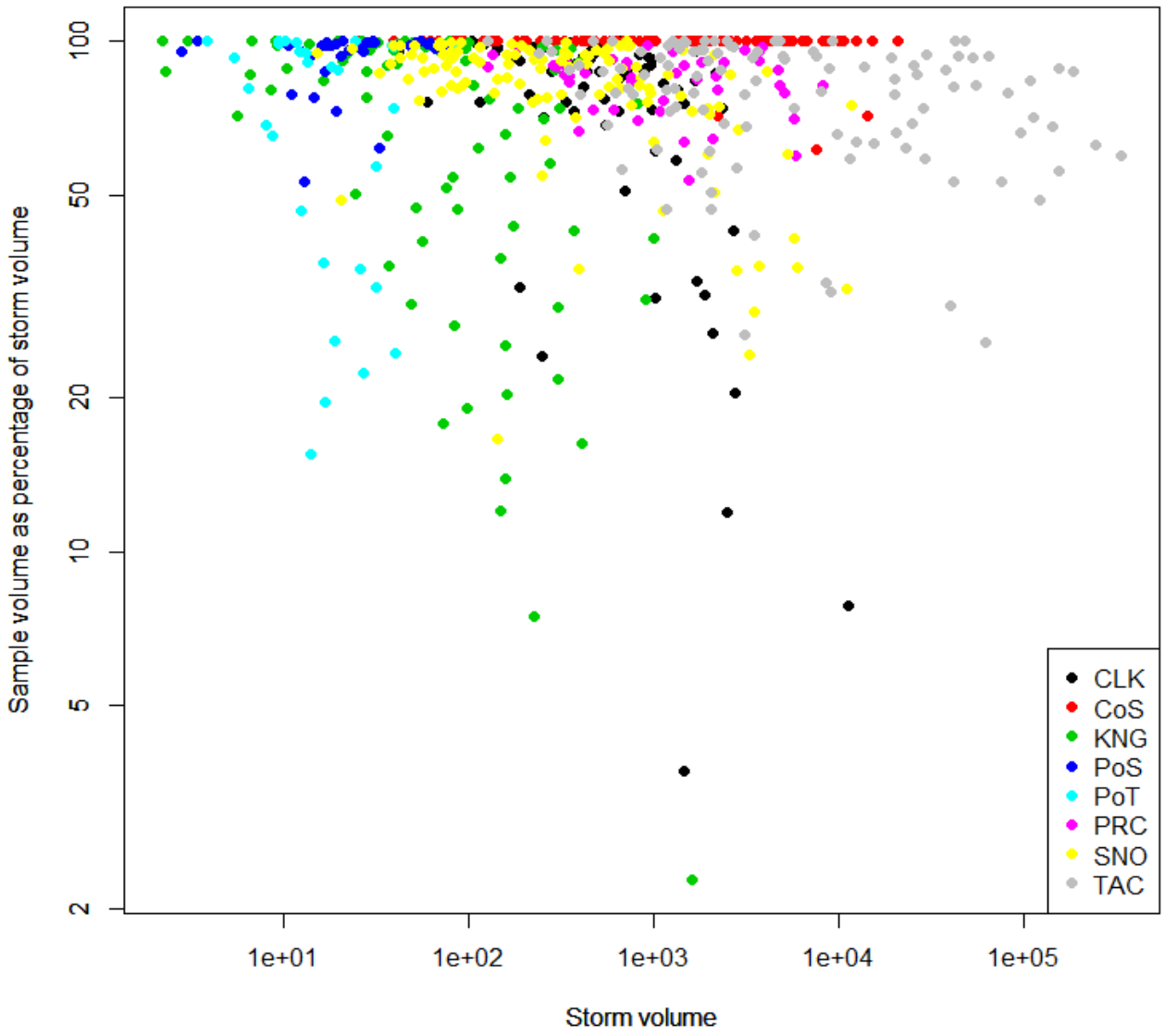


Figure E-1. Log-log scatterplot of sample volume against storm volume.
Permittees are identified as unique colors.

CLK = Clark County
CoS = City of Seattle
KNG = King County
PoS = Port of Seattle
PoT = Port of Tacoma
PRC = Pierce County
SNO = Snohomish County
TAC = City of Tacoma

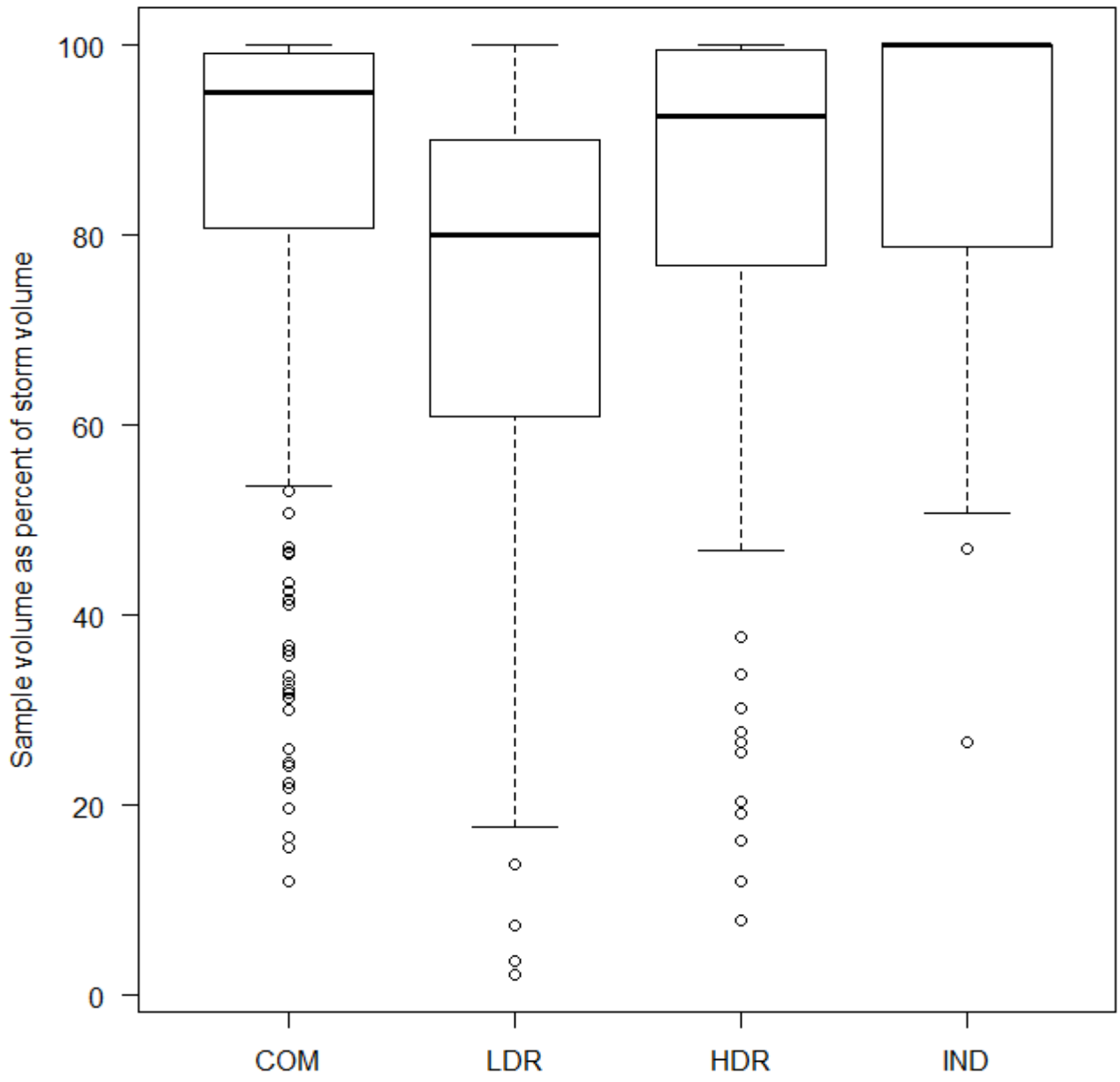


Figure E-2. Box plot of the percent of the storm volume captured by the sample, categorized by land use.

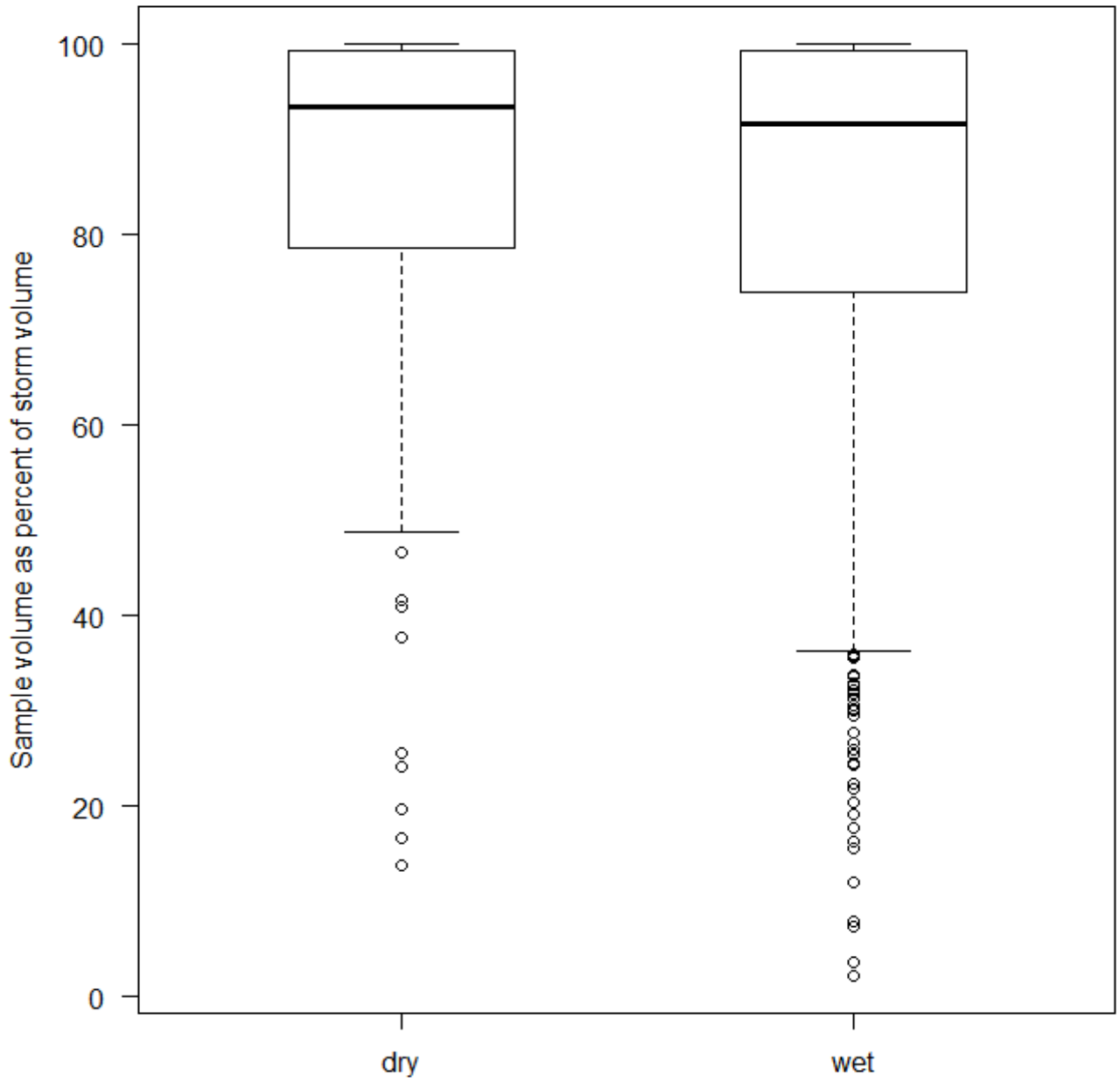


Figure E-3. Box plot of the percent of the storm volume captured by the sample, categorized by wet and dry season.

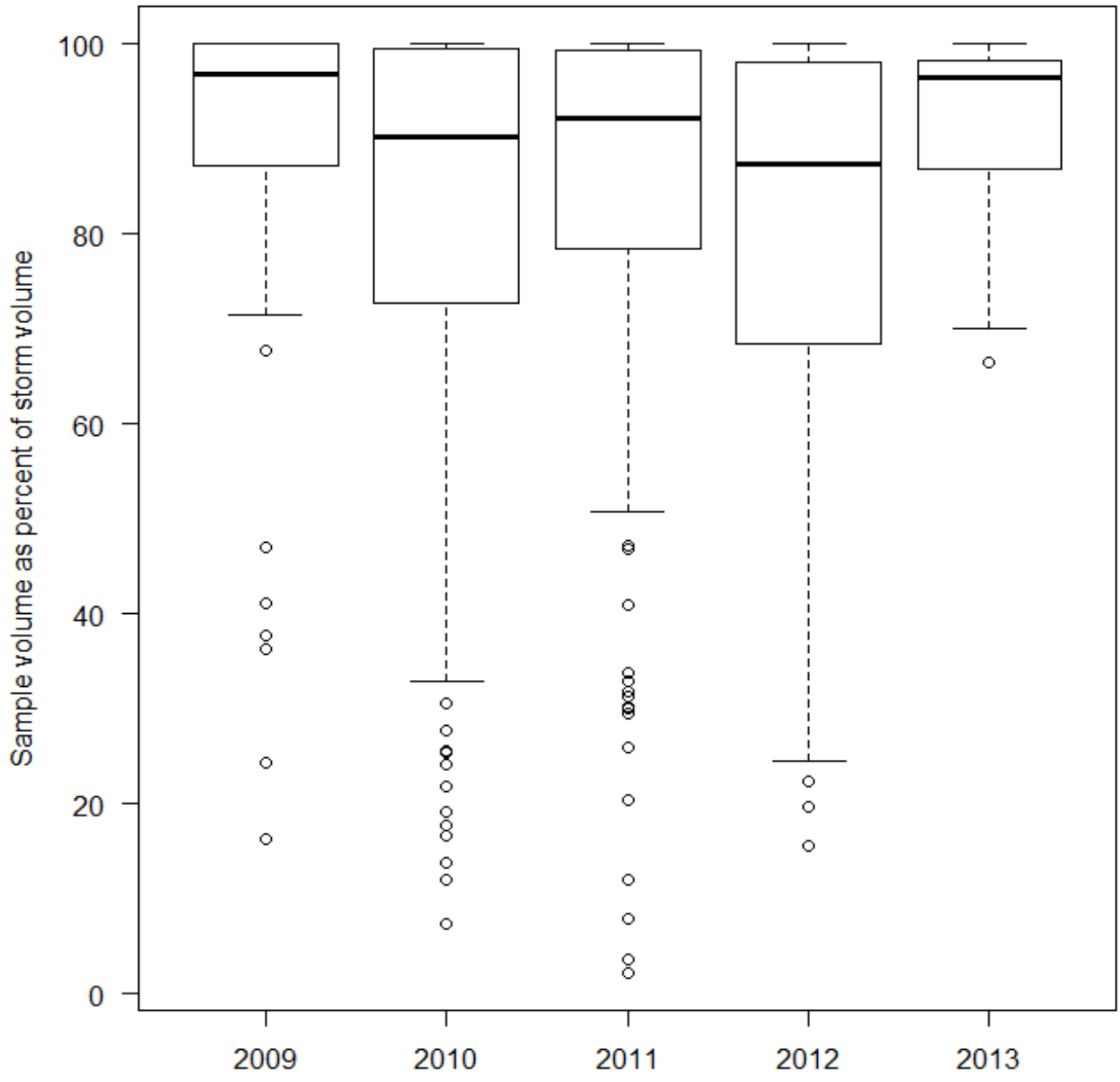


Figure E-4. Box plot of the percent of the storm volume captured by the sample, categorized by sample year.

Appendix F. Data Plots for Contaminant Concentrations

Appendix F (172 pages) is available only online.

It is linked to this report at https://fortress.wa.gov/ecy/publications/SummaryPages/1503001.html

Appendix G. Contaminant Concentrations

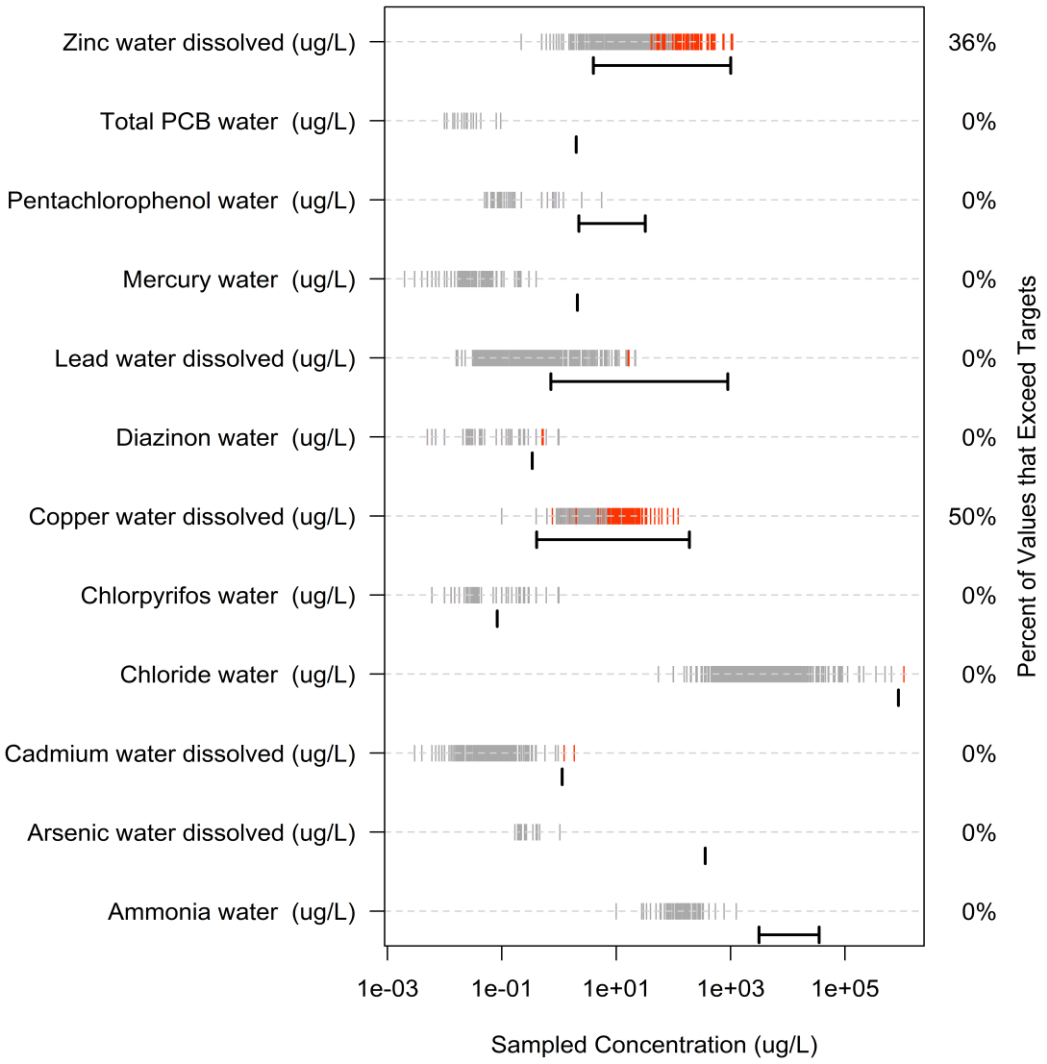


Figure G-1. Range of concentrations compared with water quality standards for the protection of aquatic life (acute criteria).

Vertical gray bars are concentrations that do not exceed criteria, and vertical red bars exceed the target. The range of criteria calculated for parameters with pH or hardness dependent criteria is highlighted by the black bar. The percent of samples which exceed the criteria is documented on the secondary y-axis.

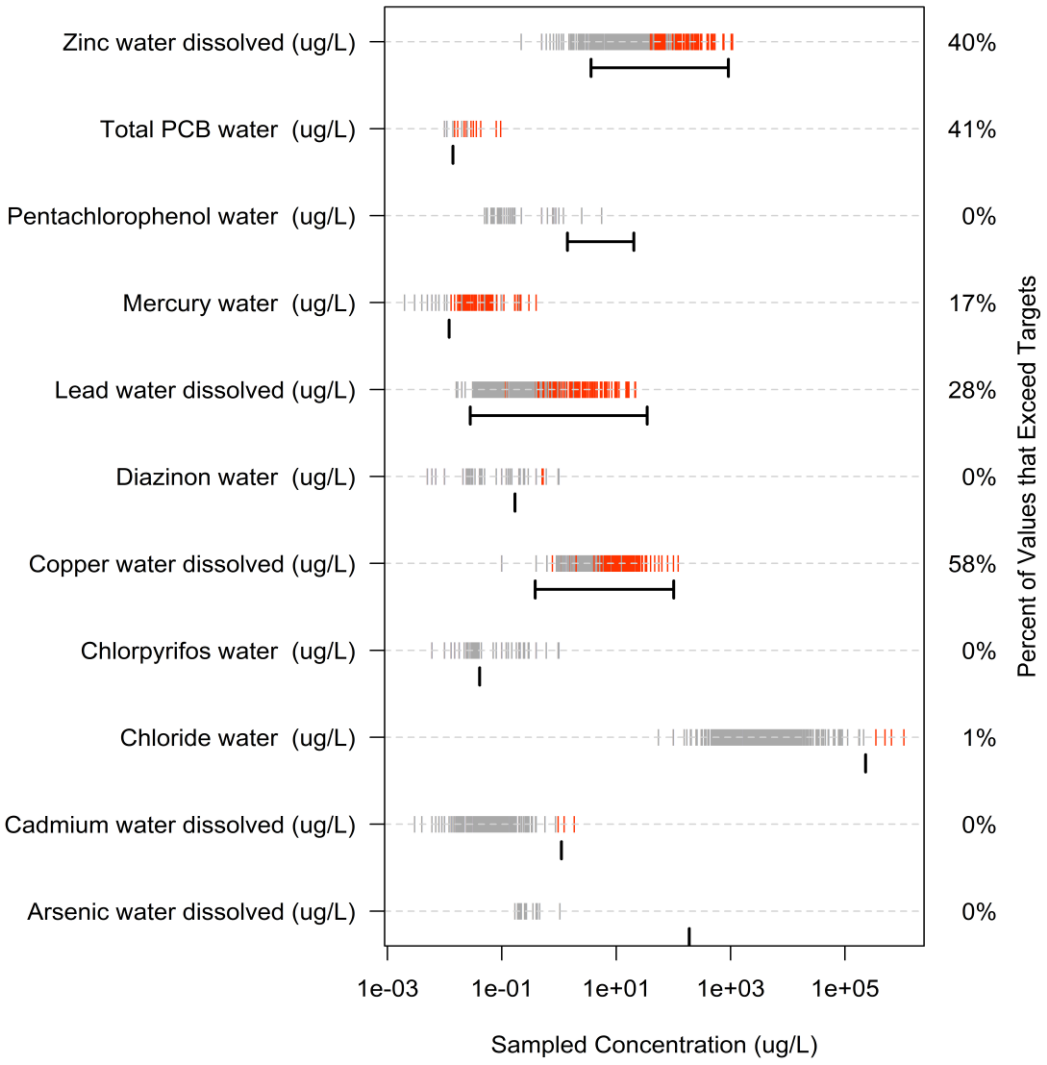


Figure G-2. Range of concentrations compared with water quality criteria for the protection of aquatic life (chronic criteria).

Vertical gray bars are concentrations that do not exceed criteria, and vertical red bars exceed the target. The range of criteria calculated for parameters with pH or hardness dependent criteria is highlighted by the black bar. The percent of samples which exceed the criteria is documented on the secondary y-axis.

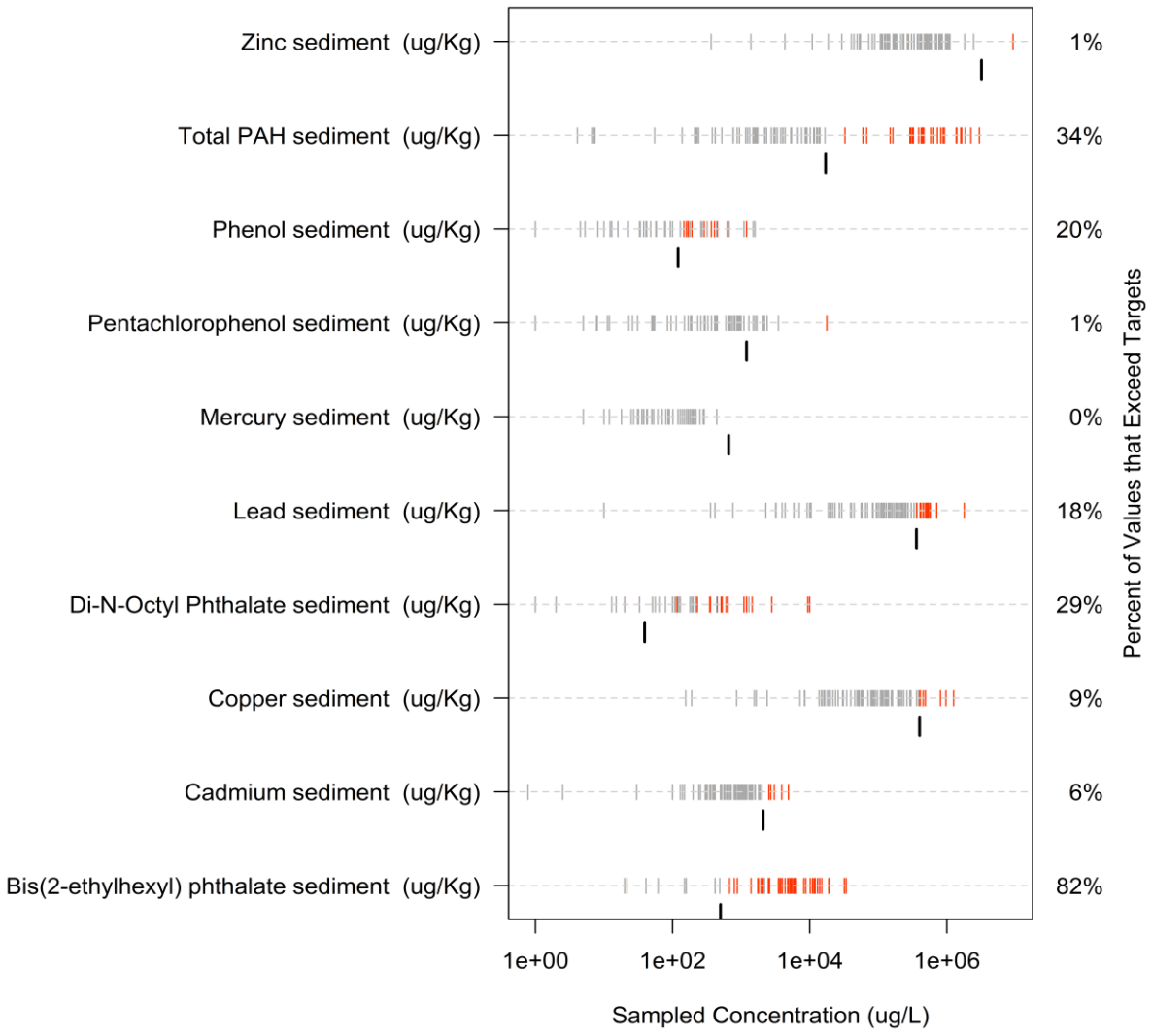


Figure G-3. Range of concentrations compared with sediment cleanup objectives.

Vertical gray bars are concentrations that do not exceed criteria, and vertical red bars exceed the target. The target is highlighted by the black bar. The percent of samples which exceed the criteria is documented on the secondary y-axis.

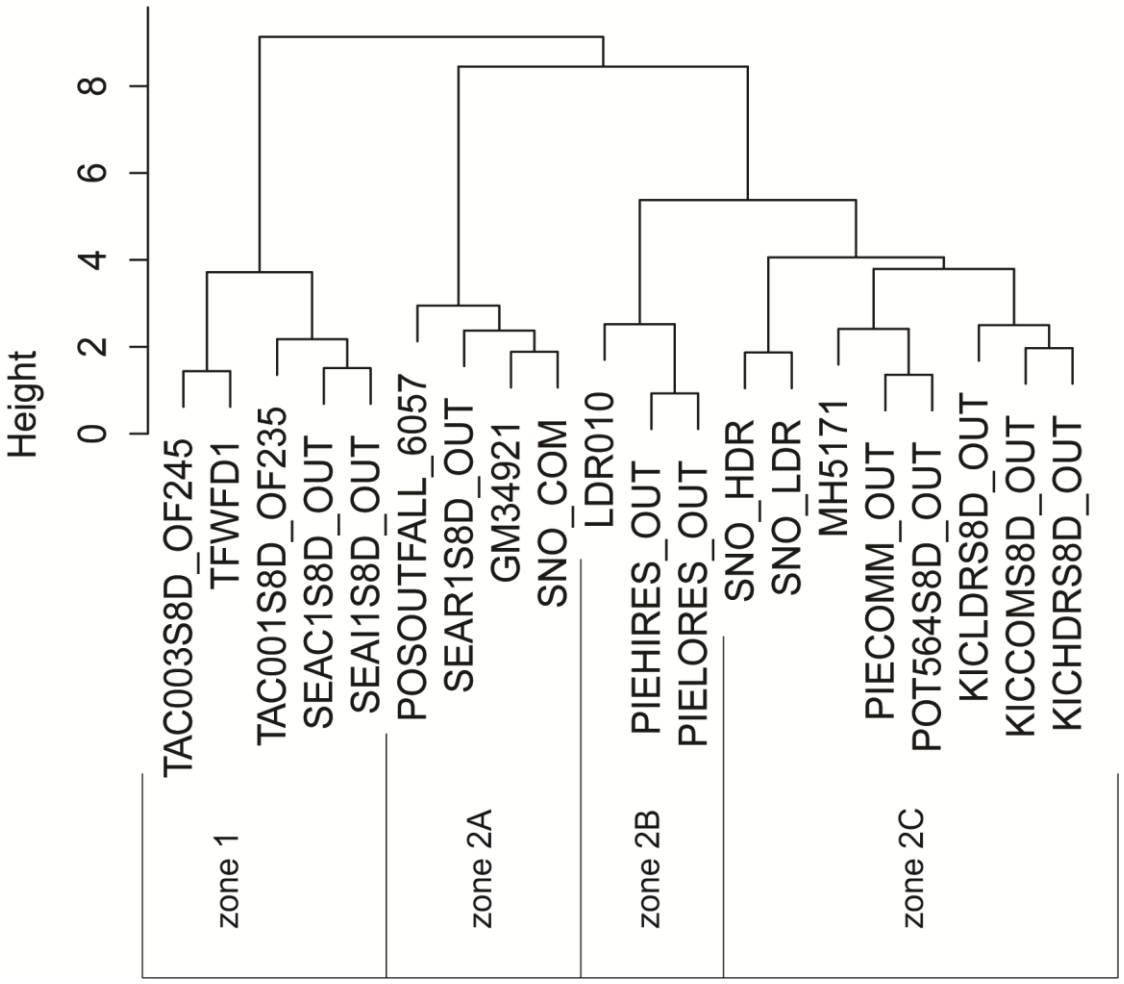


Figure G-4. Dendrogram of the cluster analysis of stormwater concentrations using Ward's method.

Sample sites are grouped based on water concentrations of the parameters used in the PCA. Zones are groups of similar sites.

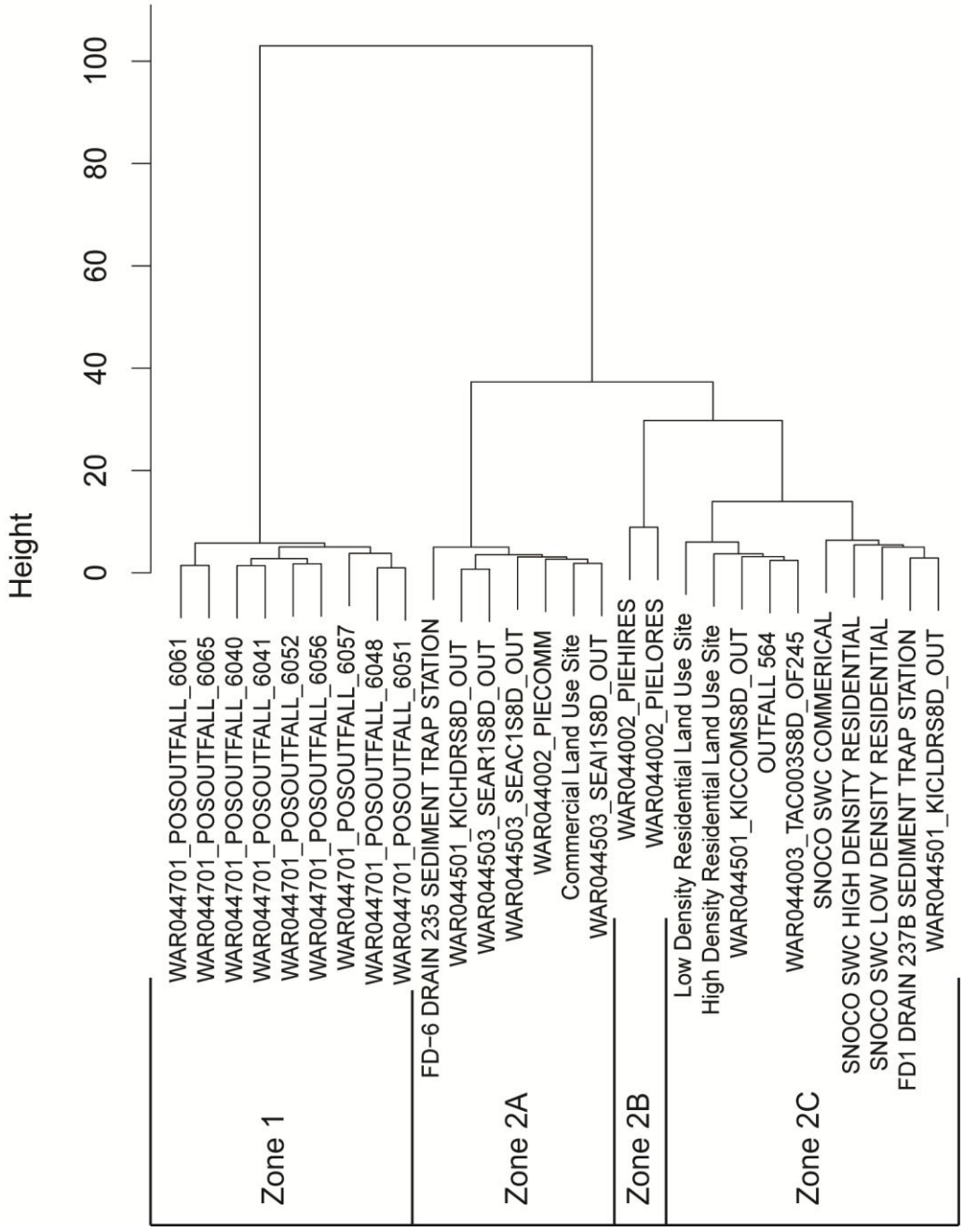


Figure G-5. Dendrogram of the cluster analysis of stormwater sediment concentrations using Ward's method.

Sample sites are grouped based on water concentrations of the parameters used in the PCA. Zones are groups of similar sites.

The following Appendix G tables are available only online as zip files.

They are linked to this report at
https://fortress.wa.gov/ecy/publications/SummaryPages/1503001.html

Table G-1. Statistical summary of contaminant concentrations by parameter and media.

Table G-2. Statistical summary of contaminant concentrations by parameter, media, and land use.

Table G-3. Statistical summary of contaminant concentrations by parameter, media, and season.

Appendix H. Data Plots for Contaminant Loads

Appendix H (89 pages) is available only online.

It is linked to this report at https://fortress.wa.gov/ecy/publications/SummaryPages/1503001.html

Appendix I. Contaminant Loads

The following Appendix I tables are available only online as zip files.

They are linked to this report at
https://fortress.wa.gov/ecy/publications/SummaryPages/1503001.html

Table I-1. Statistical summary of contaminant mass loads (kg) by parameter.

Table I-2. Statistical summary of contaminant mass loads (kg) by parameter and land use.

Table I-3. Statistical summary of contaminant mass loads (kg) by parameter and season.

Table I-4. Statistical summary of contaminant load per area (kg ha^{-1}).

Table I-5. Statistical summary of contaminant load per area (kg ha^{-1}) by parameter and land use.

Table I-6. Statistical summary of contaminant load per area (kg ha^{-1}) by parameter and season.

Appendix J. Glossary, Acronyms, and Abbreviations

Glossary

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the total maximum daily load (TMDL) program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Exceed criterion or standard: Did not meet (or violated) the criterion or standard.

Fecal coliform: That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

Parameter: A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Percentile: A statistical number obtained from a distribution of a data set.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural,

recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

PS Toxics Study: Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates (Herrera, 2011).

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Total suspended solids (TSS): Portion of solids retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

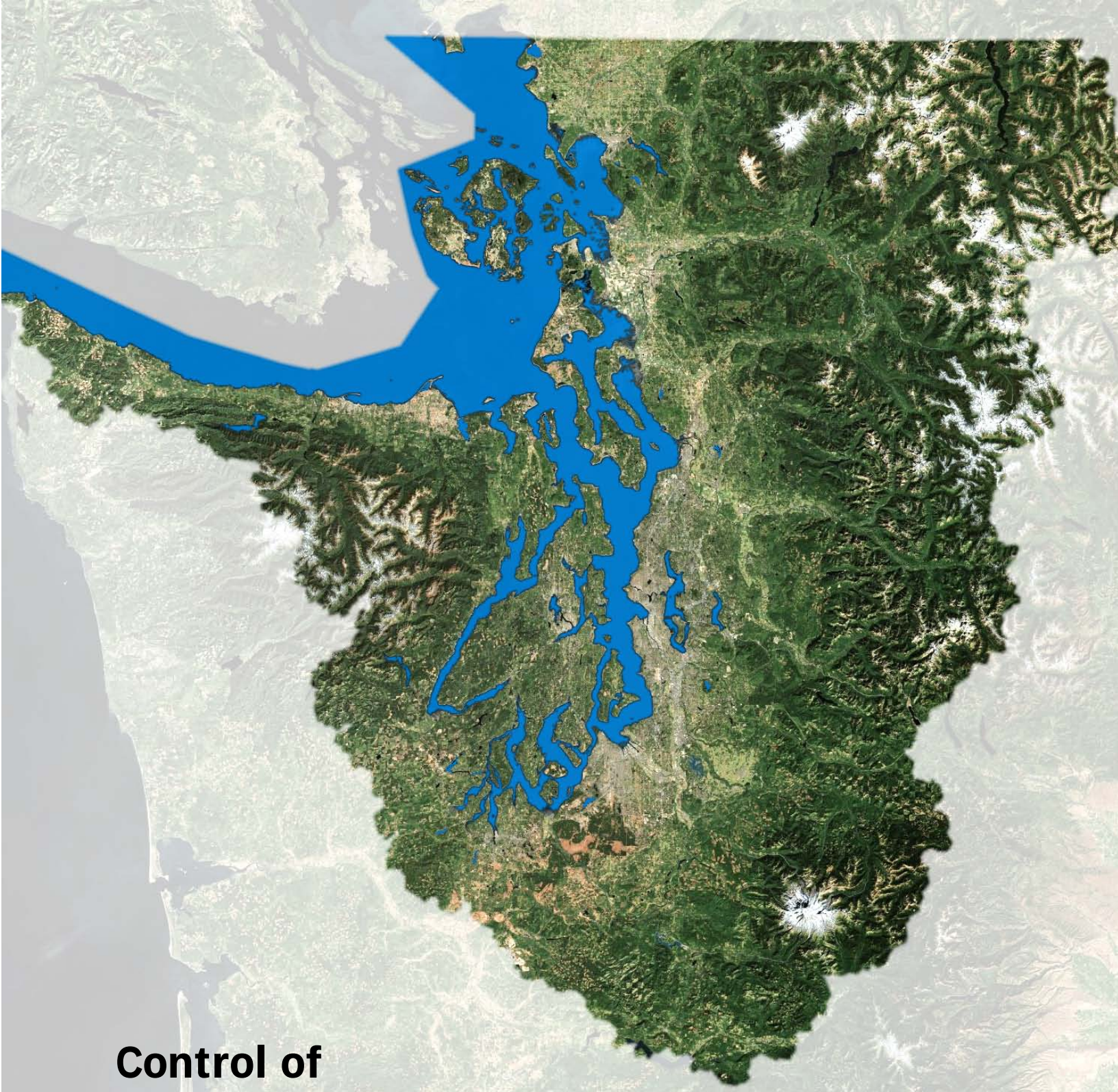
Acronyms and Abbreviations

BEHP	bis(2-Ethylhexyl) phthalate
BMP	Best management practice
BOD	Biological oxygen demand
BTEX	Benzene, toluene, ethylbenzene, and xylene
Ecology	Washington State Department of Ecology
EDF	Empirical Distribution Function
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
HPAH	High molecular weight PAH
KM	Kaplan-Meier
LPAH	Low molecular weight PAH
MDL	Method detection limit
MLE	Maximum Likelihood Estimation
MQO	Measurement quality objective
NOAA	National Oceanic and Atmospheric Administration
NPDES	(See Glossary above)
NSQD	National Stormwater Quality Database
NURP	National Urban Runoff Program
NWTPH	Northwest Total Petroleum Hydrocarbon
PAH	Polycyclic aromatic hydrocarbon
PCA	Principal components analysis
PCB	Polychlorinated biphenyl
QA	Quality assurance
QC	Quality control
RL	Reporting limit
ROS	Regression on Order Statistics

SCO	Sediment Cleanup Objective
SMS	Sediment Management Standard
SVOC	Semi-volatile organic compound
TIA	Total impervious area
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
TPH	Total petroleum hydrocarbon
TSS	(See Glossary above)
WAC	Washington Administrative Code
WQP	Water Quality Program

Units of Measurement

°C	degrees centigrade
cfu	colony forming units
dw	dry weight
ha	hectare
kg	kilograms, a unit of mass equal to 1,000 grams
mg	milligram
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
ng/L	nanograms per liter (parts per trillion)
NTU	nephelometric turbidity units
s.u.	standard units
ug/Kg	micrograms per kilogram (parts per billion)
ug/L	micrograms per liter (parts per billion)
umhos/cm	micromhos per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity



Control of Toxic Chemicals in Puget Sound

Summary Technical Report for Phase 3: Loadings from POTW Discharge of Treated Wastewater

DEPARTMENT OF ECOLOGY
State of Washington

HERRERA ENVIRONMENTAL CONSULTANTS

05746

Publication and Contact Information

This report is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/1010057.html.

Data for this project will be available on Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search User Study ID: ToxLPh3F.

Recommended Citation:

> Washington Department of Ecology and Herrera Environmental Consultants, Inc. Phase 3: Loadings of Toxic Chemicals to Puget Sound from POTW Discharge of Treated Wastewater. Ecology Publication Number 10-10-057. December 2010. Olympia, Washington.

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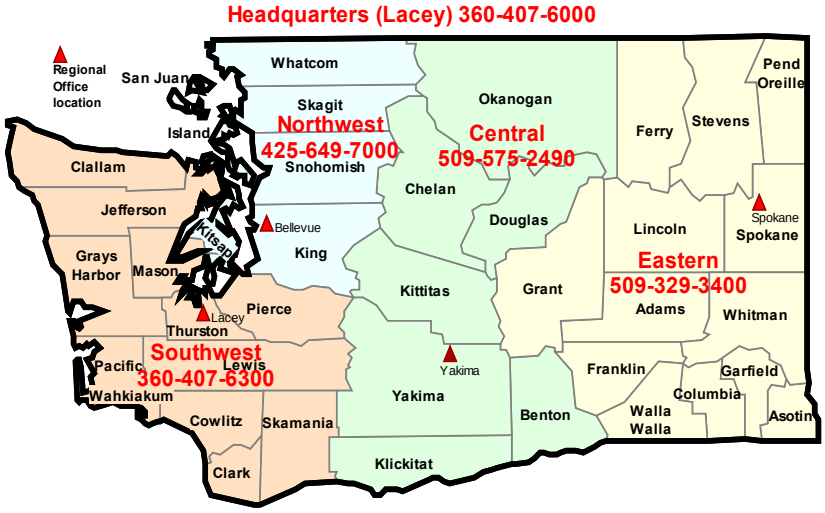
Work Assignment Information:

1. Firm: Ecology and Environment, Inc.
2. Contract No.: C0700036
3. Project Name: Phase 3: Priority Pollutant Scans of Ten POTWs
4. Work Assignment Number: 025



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Summary Technical Report

Control of Toxic Chemicals in Puget Sound Phase 3: Loadings from POTW Discharge of Treated Wastewater

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December 2010
Publication Number 10-10-057

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Acknowledgements

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List of Abbreviations and Acronyms

ARI	Analytical Resources, Inc.
BNAs	base/neutral/acid extractable compounds
DDT	dichlorodiphenyltrichloroethane
DMR	discharge monitoring report
E & E	Ecology and Environment, Inc.
ECD	electron capture detector
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
GC	gas chromatograph
GC/ECD	gas chromatography/electron capture detector
GC/HRMS	gas chromatography/high-resolution mass spectrometry
GC/MS	gas chromatography/mass spectrometry
Herrera	Herrera Environmental Consultants, Inc.
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
kg/yr	kilograms per year
L	liter
LC/MS/MS	liquid chromatography-tandem mass spectrometry
MBR	membrane bioreactor
MDL	method detection limit
MEL	Manchester Environmental Laboratory
mgd	million gallons per day
mgy	million gallons per year
ml	milliliter
MS	mass spectrometer
ng/L	nanogram/liter (parts per trillion)
NPDES	National Pollutant Discharge Elimination System
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl

List of Abbreviations and Acronyms
(continued)

PFC	perfluorinated compound
PFOA	perfluoroorganic acid
PFOS	perfluorosulfonate
pg/L	picograms per liter (parts per quadrillion)
POTW	publicly owned treatment works
PPCPs	pharmaceuticals and personal care products
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
ROS	regression on order statistics
SIM	selected ion monitoring
STP	Sewage Treatment Plant
µg/L	micrograms per liter (parts per billion)
U.S. EPA	United States Environmental Protection Agency
UV	ultraviolet
WWTP	wastewater treatment plant

Executive Summary

The project team's purpose was to improve the estimates of toxic chemical loadings to Puget Sound by targeted assessment of National Pollutant Discharge Elimination System (NPDES) permitted publicly owned treatment works (POTWs). Our goals were (1) to screen treated wastewater discharges for toxic chemicals that POTW operators do not routinely monitor, and (2) to improve the loading estimates for certain toxic chemicals by employing more sensitive analytical methods.

The project team identified and collected treated wastewater samples from ten POTWs of varying types of treatment process, size, and source of wastewater, distributed around the Puget Sound Basin. Two of the POTWs discharged to freshwater rivers, and the rest to Puget Sound marine waters. Together, the ten sampled POTWs discharged an average of about 48 percent of the total treated municipal wastewater discharged by all Ecology-permitted POTWs in the Puget Sound Basin. Although we collected samples only twice from each POTW (in February and July 2009), these 20 samples represented the aggregate of all treated wastewater discharged by the 106 permitted POTWs of the Puget Sound Basin.

The project team analyzed the wastewater samples for the following classes of toxic chemicals, using methods that yielded significantly lower than typical reporting limits:

- Polycyclic aromatic hydrocarbons (PAHs)
- Phthalates
- Other base/neutral/acid (BNA) extractable compounds
- Pesticides
- Herbicides
- Polybrominated diphenyl ethers (PBDEs)
- Perfluorinated compounds (PFCs)
- Polychlorinated biphenyls (PCBs)
- Metals (copper, lead, and zinc)

Following data review and validation, this project generated a total of 4,579 valid analytical results that characterized treated wastewater discharged from POTWs into the Puget Sound Basin. Toxic chemicals from each chemical class were detected in at least one sample from each of the ten sampled POTWs. We detected a total of 230 chemicals, not counting PBDE and PCB homologs. In order to evaluate the reasonableness of the results from this study, we compared the total concentrations of phthalates, PFCs, and PCBs discharged from the ten subject POTWs with those reportedly discharged to or from other POTWs in the state. The results of this study were similar to the results of those several other previous studies.

The project team determined individual annual loading rates of each of the chemicals from each of the ten sampled POTWs. Although the small number of samples precluded drawing any conclusions regarding specific POTWs, a few general findings were apparent.

- The majority of the PAHs discharged from most of the POTWs consisted primarily of five chemicals (fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene).

- The majority of the phthalates discharged from each of the ten POTWs consisted of bis(2-ethylhexyl) phthalate.

- The POTWs discharged only relatively small amounts of about a dozen pesticides and herbicides.

- Although the POTWs discharged many PBDEs, only three of them (BDE-047, BDE-099, and BDE-209) comprised almost all of the total loadings from each.

- Similarly, the POTWs discharged most of the PFCs that were analyzed, but only four of the PFCs (perfluorohexanoate, perfluorononanoate, perfluorooctane sulfonate, and perfluorooctanoate) comprised most of the total loadings from each POTW.

- Generally, as the total loadings of PCBs increased from any given POTW, so did the number of different PCB congeners that were discharged. Most of the PCB congeners were distributed among the tri-, tetra-, and penta-chlorobiphenyl homolog groups.

The project team also estimated the total loadings from POTWs to the surface waters of the Puget Sound Basin of 68 chemicals, plus two homolog groups and seven chemical classes. Chemical classifications are useful because they often indicate which chemicals might share a single source, affect environmental receptors in a similar manner, or all be amenable to particular treatments or other control actions. These estimated loadings were divided to represent the input from each of the 14 geographically distinct study areas of the basin. Due to the limited number of sampling events and atypical weather during the sampling period, we did not discern seasonal variations in loadings.

The results from this study greatly extended our understanding of chemical loadings from POTWs and were consistent with the results from Phase 2 and other recent studies conducted by Ecology and others. Future determination of the most effective and efficient actions for controlling or managing toxic threats should include evaluation of the effects of the chemicals, the new loading estimates of those chemicals, and the many other interdependent variables that characterize the pathways that facilitate chemical movement through the environment to Puget Sound.

1. Background and Purpose

1.1 Context of This Project

The Washington State Department of Ecology (Ecology) and several other groups have been working with the U.S. Environmental Protection Agency (EPA) and the Puget Sound Partnership (PSP) to restore the environmental health of Puget Sound by 2020 (PSP, 2010). This multi-year effort has required development of strategies, actions, and performance measures for restoring the Puget Sound ecosystem. Ecology has teamed with several partner organizations to study toxic chemical loadings to Puget Sound to understand the relative contributions from sources of contaminants in the Puget Sound ecosystem (Ecology, 2010). The main objectives of the "Control of Toxic Chemicals in Puget Sound" projects have included:

- Identify toxic chemicals that have harmed or threaten to harm the Puget Sound ecosystem or the beneficial uses which humans obtain from the Sound.

- Estimate the loading rates of key contaminants from their sources through their major pathways to Puget Sound.

- Provide information that will support development of a strategy to identify the actions, practices, and policies necessary to protect and restore the overall health of the Puget Sound ecosystem.

Accomplishing these objectives requires an understanding of the complex inter-relationships among the following three distinct elements of the Puget Sound ecosystem:

- The sources of pollutants.
- The pathways those pollutants take through the environment.
- The effects of those pollutants on the ecosystem.

It is important to clarify the difference between sources and pathways.

The term *source* may apply in a variety of ways with regard to chemicals in the environment. For the purpose of this project, the term source is defined as the location, object, or activity from which a pollutant is released to environmental media or released in a form that can be mobilized and transported through an environmental *pathway*. The term *primary source* identifies the initial release of a pollutant, as distinct from a *secondary source*, such as an old toxic chemical spill site, atmospheric deposition, or a publicly owned wastewater treatment plant (POTW). However, these secondary sources are more accurately described as pathways because they transport and mobilize chemicals from one location to another, or (in the case of POTWs) act as a focal point for chemical collection. Often, as also is the case for POTWs, pollutants moving along a pathway are degraded, destroyed, or permanently rendered harmless through designed or natural treatment processes.

The following examples illustrate the distinction between primary sources and secondary sources:

- Examples of *Primary Sources*:
  - Polycyclic aromatic hydrocarbons released to air from wood or petroleum burning.
  - Copper released to air, stormwater, and roadside ditches from brake pad wear.
  - Unmetabolized pharmaceuticals discharged from homes into sanitary wastewaters.
  - PCBs released to soil from transformer leakage.
  - Triclopyr applied to roadside ditches to control weeds.

- Examples of *Secondary Sources*, which are typically also pathways:
  - Atmospheric deposition of pollutants onto the surface of land or waterbodies.
  - Stormwater discharged from a municipal outfall into a stream.
  - Treated wastewater discharged from a POTW.
  - Contaminated soil leachate entering either groundwater or surface water.
  - Forest fire releasing back into the air the mercury that the growing vegetation had previously absorbed.

The toxic effects of a chemical depend on the dose (or exposure concentration), the duration of exposure, the timing of the exposure (e.g., at what stage of the lifecycle exposure occurs), the synergism and antagonism among multiple toxicants, and the harmful result of the exposure (e.g., temporary functional impairment, reduced reproductive capacity, shortened lifespan, and death). Given the goal of protecting the entire Puget Sound ecosystem, when evaluating relative toxic effects, Ecology must also consider the impacts of chemicals on the dependencies and interactions among species, such as through food chain relationships and altered predator avoidance behaviors.

Thus, while estimates of total loadings are important data, they are not particularly meaningful when considered in isolation. Loadings do not directly translate into threats, such that reducing the loading by half would reduce the threat by half. Determining the most effective and efficient actions for controlling or managing toxic threats must include evaluation of many interdependent variables and options. Management actions may occur at several different points along the pathways that facilitate chemical movement through the environment. For example, a control action may be to eliminate the initial release of the chemical by banning the primary source. Alternately, a more efficient method to reduce the threat from a chemical may be to treat a contaminated medium at a location where the pathways of several chemicals converge. Another approach for managing a toxic threat may be to establish a management zone for a small area, for example by prohibiting shellfish harvest within the vicinity of a POTW outfall. In some cases, targeting some of the available resources on limited goals may be preferable so that the remaining resources will be sufficient to ensure that other critical areas always remain healthy and usable. Final policy decisions for how to control and manage the chemicals that enter the Puget Sound ecosystem must include consideration of all these factors along with the various estimates of chemical loading.

These toxic chemical loading projects have been conducted in three phases, which are described in the following subsections. The Phase 1 study provided initial estimates of toxic chemical loadings to Puget Sound. Phase 2 projects improved those loading estimates. Phase 3 activities, of which this project is one component, target priority sources to collect and analyze environmental samples and improve the numerical model of the Sound (the Puget Sound box model) with the new data. The results of Phase 3 will help to enable Ecology and the PSP to assign the threats from toxic chemicals to specific sources and to select and implement actions to clean up and prevent contamination from those sources posing the greatest risks to Puget Sound.

Phase 1 – Initial Estimate of Toxic Chemical Loadings to Puget Sound

The purpose of this project was to assemble preliminary estimates of loadings of the most important toxic chemicals to Puget Sound via the presumed nine major pathways. These pathways were: surface runoff, aerial deposition onto Puget Sound, wastewater discharge, combined sewer overflows, direct spills to aquatic systems, groundwater discharges to marine surface waters, exchanges with the Pacific Ocean, leaching or biologically-induced movement from contaminated sediments, and migration of contaminated biota into Puget Sound. Based on data already available for the first five of these, the authors estimated the loadings of 17 chemicals (or classes of chemicals) from 14 hydrologically-based study areas that comprised the Puget Sound Basin. Depending on the contaminant, the main pathways were surface runoff and direct deposition from the air to the Sound (Hart Crowser, Inc., et al., 2007).

Phase 2 – Improve Loading Estimates

Two critical informational needs were to better understand and quantify the sources of toxic contaminants that enter Puget Sound and to improve the understanding of how toxics move within the ecosystem once they are there. The seven different projects in Phase 2 built upon the initial Phase 1 study to address these needs, and their results are available (Ecology, 2010a).

One of the Phase 2 projects focused on improving the loading estimates from permitted point source dischargers of wastewater within the Puget Sound Basin (EnviroVision Corporation, et al., 2008). While the available data were limited, the authors found that the contributions of toxic chemicals from wastewater dischargers (both publicly and privately owned) were small relative to the total loadings from all the major loading sources to Puget Sound, ranging from 1.4 to 7.0 percent of the total. The data also suggested that publicly owned treatment works (POTWs) discharged significantly more of some toxic chemicals than did the privately owned industrial point source dischargers.

Phase 3 – Targeting Priority Toxic Sources

In Phase 3, six of the 11 projects included the collection and analysis of environmental samples from within the Puget Sound Basin so that Ecology and its partners could further improve estimates of loadings from specific sources. The other projects focused on improving the Puget Sound box model with the new data and the synthesis and reporting of the results from all three phases to date. Results of the studies completed to date are available (Ecology, 2010a).

Two of the Phase 3 projects focused on POTWs regulated by Ecology through the National Pollution Elimination System (NPDES) permit program. One of these projects consisted of collecting and analyzing samples of wastewater for pharmaceuticals and personal care products

(PPCPs) (Lubliner, et al., 2010). The authors found differences in the removal efficiency of PPCPs among wastewater treatment plant processes, and that advanced nutrient reduction and tertiary filtration may provide additional PPCP removal. The other Phase 3 project that focused on POTWs is the project addressed by this report.

1.2 Purpose of This Project

One of the recommendations from one of the Phase 2 projects was:

> "If better estimates of toxic chemical loadings are necessary, Ecology should collect targeted samples and analyze them using methods that produce smaller MDLs. Also, as Ecology identifies emerging potential threats from other toxic chemicals (for example, polybrominated diphenyl ethers, fluorinated organic compounds, bisphenol A, and pharmaceuticals and personal care products), Ecology should (or should require permittees to) collect and analyze wastewater samples for those newly identified pollutants." (EnviroVision, et al., 2008)

The purpose of this project was to improve the estimates of toxic chemical loadings to Puget Sound by targeting POTWs and collecting and analyzing representative samples of the treated wastewater that they discharge. The goals of this project were (1) to screen treated wastewater discharges for toxic chemicals that POTW operators do not routinely monitor, and (2) to improve loading estimates for certain toxic chemicals by employing more sensitive analytical methods.

2. Methods

The project team consisted of the following organizations:

- Washington State Department of Ecology (Ecology)
- Herrera Environmental Consultants, Inc. (Herrera)
- Ecology and Environment, Inc. (E & E)
- Analytical Resources, Inc. (ARI)
- Axys Analytical Services, Ltd. (Axys)
- Pacific Rim Laboratories, Inc. (Pacific Rim)

Ecology was the project lead. E & E worked under contract to Ecology and was responsible for coordination of field and laboratory activities and quality assurance review of the analytical data. Herrera worked under subcontract to E & E and was responsible for sample collection and loading calculations. ARI worked under subcontract to Herrera and provided clean sample containers. Axys and Pacific Rim worked under subcontract to the Ecology Manchester Environmental Laboratory (MEL) and conducted the analyses of polybrominated diphenyl ethers, perfluorinated compounds, and polychlorinated biphenyls. MEL conducted the analyses of all the other parameters.

2.1 General Approach

The project team expected that variations in the following factors might drive differences in the loading rates of the various toxic chemicals discharged from POTWs:

- Types of treatment processes employed by the POTW.
- Rate of flow through the POTW.
- Activities of the sources in the POTW service area (e.g., residential or industrial).
- Time of day.
- Season of year.

Assessing these factors would have involved collecting samples from several POTWs that represented each type of treatment, at several different flow rates, for a variety of upstream sources located in different areas of the Puget Sound Basin, and collecting many samples from each POTW to establish how the loading rates of toxic chemicals varied at different times of the day and during the seasons of the year. However, due to a limited budget, the project team needed to produce a limited scope of work that balanced all of these factors, while maximizing the amount of usable data that this project would produce.

2.1.1 Selection of Pollutants

Ecology requires NPDES-permitted POTWs to periodically analyze their treated effluents for Priority Pollutant chemicals using standard analytical methodology and to report that data to Ecology. Review of that data in Phase 2 (EnviroVision, et al., 2008) found that most organic

analytes were not detected in the effluents discharged from the POTWs using then standard analytical methods. These organic compounds included:

- Polycyclic aromatic hydrocarbons (PAHs)
- Phthalates
- Other base/neutral/acid (BNA) extractable compounds
- Pesticides
- Herbicides
- Polychlorinated biphenyls (PCBs)

In addition, Ecology was aware that several new classes of toxic chemicals were emerging as potentially harmful components of POTW effluent. These chemicals included:

- Polybrominated diphenyl ethers (PBDEs)
- Perfluorinated compounds (PFCs)
- Pharmaceuticals and personal care products (PPCPs)

The project team chose to analyze the wastewater discharges for 390 of the compounds contained within these chemical classes, excluding PPCPs. We did not focus on PPCPs in this study because another toxics loading project was evaluating these chemicals (Lubliner, et al., 2010). The project team also analyzed the treated wastewaters for total copper, lead, and zinc to enable a better comparison of the results from this study with the previous loading estimates derived in Phase 2 (EnviroVision, et al., 2008). We employed analytical methods that were more sensitive than those which POTW operators have been required to use so that we might detect smaller concentrations of the target pollutants (i.e., to decrease the "minimum detection limits" – MDLs). We analyzed for PCBs in only the samples collected in February, and only for six of the POTWs (Bremerton STP, City of Tacoma (Central No. 1), Everett STP (Outfall 100), King County West Point, Pierce County Chambers Creek STP, and Shelton STP).

2.1.2 Selection of POTWs

General POTW Characteristics

POTWs receive the following types of wastewater for treatment:

- Raw sewage from residential toilets, showers, and sinks, including wastes from laundry, dishwashing, and food preparation activities.

- A wide variety of wastes from industrial, commercial, and institutional facilities which may or may not undergo pretreatment prior to discharge to the POTW.

- Unless collected and conveyed separately, stormwater runoff from streets, rooftops, and other impervious surfaces.

Once wastewater reaches a POTW, it undergoes treatment before it is discharged to the environment, typically a surface water body. The treatment process can involve three stages: primary, secondary, and tertiary treatment. Occasionally where stormwater and sanitary lines are combined, large storm events can produce an influx of stormwater in excess of plant capacity

that overwhelms the treatment system, resulting in the combined stormwater and sewage bypassing the treatment plant and discharging directly to surface waters untreated. This is a "combined sewer overflow" event and, except for the potentially severely impacted local areas, does not constitute a large part of the total loading of toxic chemicals to Puget Sound (Hart Crowser, et al., 2007).

For treating wastewater, the primary treatment stage employs a mechanical or physical process designed to remove solids and immiscible fats and oils. This may be accomplished in large settling tanks (usually referred to as sedimentation tanks or primary clarifiers) where solids and immiscible materials either float to the top or sink to the bottom. POTWs may also use preliminary screens to separate large objects before wastewater enters the settling tanks. The top product is skimmed off with a raking mechanism and is processed for disposal. The bottom product (or sludge) is scraped into a hopper where it is further dewatered before disposal to a landfill, biosludge composter, or waste fuel incinerator. Sludge can also be processed along with other compostable waste (grass clippings, leaves, food waste, and some cardboard products) and be sold as a biosolid fertilizer.

The purpose of secondary treatment is to meet federal and state secondary effluent standards by substantially degrading the biological or organic content of the liquid sewage effluent. These standards target biological oxygen demand and total suspended solids, typically using aerobic biological processes. The essential elements that drive the secondary treatment process are oxygen and biota, consisting of bacteria and protozoa that are capable of consuming the soluble organic contaminants (e.g., sugars, fats, and other hydrocarbons). The biota require a substrate in which they can thrive and bind much of the less soluble fractions into flocculent. Flocculation is a process of contact and adhesion whereby the particles of dispersion form larger-size clusters. Secondary clarifiers separate the flocculated solids from the wastewater stream, producing an additional sludge product that is processed in similar ways as the primary sludge product.

Some POTWs use treatment processes with the intent to address specific pollutants (e.g., organic nitrogen and phosphorus) beyond those specified in secondary water quality standards (biological oxygen demand, total suspended solids, and fecal coliform). They may employ multiple treatment processes for removing specific target pollutants. Sometimes this is called "tertiary treatment."

Prior to discharge to the environment, treated wastewater requires disinfection to inactivate pathogens that were not destroyed earlier in the treatment process. Disinfection is the additional step used to decrease the number of microorganisms. While the traditional and most common disinfection method is chlorination, ultraviolet (UV) and ozone are alternate methods.

Representative POTWs of the Puget Sound Basin

Under the NPDES permit program, Ecology has permitted approximately 106 POTWs to discharge treated wastewater in the Puget Sound Basin. Ecology had discharge flow information available in its NPDES permit management database (Ecology, 2010b) for the years 2007 through 2009 for all 106 POTWs except for the ten relatively smaller facilities operated by the U.S. Navy, U.S. Army, or Tribes. Appendix A identifies the total population of 96 candidate POTWs that the project team considered for this study. Of these 96 POTWs, 83 had flow data

for all 36 months, seven had flow data for at least 24 months but less than 36, five had flow data for at least 12 months but less than 24, and one had flow data for less than 12 months. The data were sufficient for determining average flows, and were comparable to the flows used for the prior Phase 2 loading estimation by EnviroVision, et al. (2008). The total discharge volume to the Puget Sound Basin employed for the Phase 2 estimation was 130,061 mgy, while the total volume employed in this study was 124,142 mgy.

Although the project team hoped to select a sufficient number of POTWs to represent the entire range of operating variables in Puget Sound Basin, due to the limited budget the number of POTWs that we could sample was limited to ten. Although all the variations of size, age, type of treatment process, and type of source cannot be adequately compared through evaluation of only ten facilities, by providing some representation of each we expected to cover a relatively wide range of conditions. Access to the facilities and their current operating status (e.g., no plant upgrades ongoing or planned between the two sampling events) also contributed to the final selection. Table 1 identifies the POTWs that we selected as the subjects of this study.

The project team selected POTWs to represent a flow-weighted cross-section of the 96 candidate POTWs. The percentages of the total flows to Puget Sound from the selected POTWs were roughly comparable to those of all 96 POTWs. These percentages were for small POTWs (<1 mgd) 0.5% for the ten selected POTWs versus 3.8% for all 96 Puget Sound POTWs, for medium POTWs (1 to 10 mgd) 6.0% versus 23.2%, and for large POTWs (>10 mgd) 93.5% versus 73.0%, respectively. Since the five largest sampled POTWs discharged about 46% of the total treated effluent discharged by the POTWs in the Puget Sound Basin, the project team determined that this distribution of facilities adequately represented the actual flows to the Sound. Table 2 shows the similarity between the distributions of the total flows among all 96 small, medium, and large POTWs and the distributions among the ten POTWs sampled in this project.

Nine of the ten selected POTWs used an activated sludge secondary treatment process. The remaining facility (Everett STP (Outfall 100)) was a trickling filter/solids contact system. Since at least 66 percent of the POTWs in the Puget Sound Basin used activated sludge for secondary treatment, weighting the selection toward this treatment process was appropriate.

Four POTWs in the Puget Sound Basin employed treatment processes to address pollutants beyond those specified in the secondary effluent standards. We sampled one of these, the Sumner STP, for this study. Since only four Ecology-permitted POTWs that discharged to surface waters in the Puget Sound Basin employed a membrane bioreactor (MBR) (Carnation WWTP, Duvall STP, Port Orchard WWTP, and Seashore Villa STP), and their discharges have been relatively small, with a combined total flow of 2.34 mgd, we sampled none of the MBR-equipped facilities for this study.

For disinfection, seven of the selected facilities used chlorine, and the remaining operations used UV. This distribution adequately represented the types of disinfection employed in the Puget Sound Basin because most of the older facilities there still use chlorine, while newer facilities often rely on UV.

In terms of source activities in the POTW service areas, five of the selected POTWs received a significant amount of industrial influent, two received minor amounts, and three treated practically only sanitary waste from their primarily residential service areas. The selected POTWs were distributed among seven of the 14 study areas in the Puget Sound Basin to ensure representative geographic coverage (Figure 1).

2.1.3 Seasonal and Temporal Sampling

The project team sampled each POTW twice. To maximize the potential seasonal variation in loading rates, we scheduled collection of those two samples to represent significantly different weather conditions: winter (wet season) and summer (dry season), in February and July 2009, respectively. As mentioned previously, we analyzed PCBs only once for six selected POTWs, in February 2009.

The limited budget prevented the project team from tracking the variation in loading rates that may occur during the course of a given day because doing so would have required analyses of many more samples. However, we did account for potential variations during a typical weekday by analyzing 24-hour composited samples collected Mondays through Fridays.

2.2 Field Methods

This section summarizes how the project team collected representative samples of treated wastewater from the ten POTWs. Additional details may be found in the Quality Assurance Project Plan (QAPP) (E & E and Herrera, 2009).

The project team conducted a site visit to each facility to assess site access, select the most appropriate locations for collecting samples, and evaluate equipment installation needs. The following bullet items describe the general sampling site location at each POTW.

- Bellingham STP – Automated and grab samples were collected from the outfall flume downstream of the chlorination and dechlorination facility.

- Bremerton STP – Automated and grab samples were collected from contact tanks downstream of the chlorination and dechlorination facility, just upstream of the outfall.

- Burlington WWTP – Automated and grab samples were collected from the inlet to the outfall pipe downstream of the UV radiation treatment.

- City of Tacoma (Central No. 1) – Automated and grab samples were collected from the contact tank near the outfall.

- Everett STP (Outfall 100) – The automated sample was collected by way of an access stand pipe located downstream of the first chlorination facility. This represented the permit compliance point for the Everett POTW for all parameters except residual chlorine and fecal coliform. This location was upstream of the comingling with the Marysville STP effluent and upstream of a pump station where additional chlorination may occur.

The grab sample was collected from a sampling spigot located downstream of this pump station at the compliance point for residual chlorine and fecal coliform. Grab samples could not be collected from the same location as the automated samples due to physical constraints.

- Gig Harbor STP – Automated and grab samples were collected from a mixed effluent contact tank downstream of the chlorination and dechlorination facility. The grab samples were collected slightly downstream of the automated sampler location.

- King County West Point – Automated and grab samples were collected from the effluent wet well downstream of the chlorination and dechlorination facility.

- Pierce County Chambers Creek STP – Automated and grab samples were collected from the contact tank mixing area downstream of the chlorination and dechlorination facility, just upstream of the outfall.

- Shelton STP – Automated and grab samples were collected from contact tanks downstream of the chlorination and dechlorination facility.

- Sumner STP – Automated and grab samples were collected near the outfall.

The project team collected all 20 treated wastewater samples as specified in the QAPP (E & E and Herrera, 2009). The 24-hour composite samples represented the treated effluent discharged during one full weekday. Tables 3 and 4 provide the specific sampling schedules for each of the ten POTWs, winter and summer, respectively. We used automated samplers to collect time-weighted composite samples for all analytes except PFCs and metals. Since parts of the automated sampling equipment were composed of Teflon and glass, we collected the aliquots for PFCs and metals analyses as discrete grab samples in appropriate containers. We collected these grab samples at two times to represent both the high and low daily flow at each POTW. We sampled all ten POTWs within a narrow time frame so that the samples represented similar weather conditions.

The project team cleaned the sample bottles (including the 9-liter [L] glass jar, the 1-L polypropylene bottle, and the 500-milliliter [ml] Teflon bottle for metals) as described in the QAPP (E & E and Herrera, 2009). Sample bottles and tubing were kept tightly sealed, and the ends of the tubing were covered with aluminum foil and placed into a pre-marked sealable plastic bag until installation at the facility.

The project team programmed the automated, refrigerated sampling devices (ISCO Avalanche®) to collect a 175-ml aliquot every 30 minutes, for a total of 48 sample aliquots collected from each POTW over the 24-hour sampling period. On the scheduled sampling day, we installed each sampling device at the site and verified the program. We then operated the sampling device manually, collecting and discharging effluent, to rinse the intake hosing and verify that the device collected 175 ml of effluent. To verify that the program had started and the automatic sampling device was working correctly, before moving to the next POTW, we waited while the ISCO-Avalanche collected at least two sample aliquots.

Upon completion of the automated collection of the 24-hour composite sample, project personnel checked the equipment to verify that no sampling errors had occurred. We capped the sample jar, removed it from the sampling device, and placed it on ice. At this time, we manually operated the sampling device to collect an aliquot of effluent to verify that 175 ml of effluent was still being collected.

The project team transported bottles for the grab portions of each sample in single resealable plastic bags. We collected grab samples from all the POTWs using the modified one-person clean hands/dirty hands procedure. In most cases it was necessary to use an extension pole and attach the sample bottle with zip ties to reach the effluent stream. We then rinsed the extension pole with deionized water before using it at the next POTW.

Once project personnel had collected both the grab and composite aliquots, we immediately capped, labeled, and put them on ice in a cooler. We then transported the samples to the Ecology Field Operations Center in Lacey and refrigerated them until delivering them the following morning to MEL for analysis.

Winter sampling occurred during the week of February 9, 2009. However, the project team resampled two of the POTWs (Tacoma Central and Chambers Creek) the following week due to the partial failure of two of the automated samplers and damage to the field duplicate sample. Thus the grab samples for these two POTWs were not collected on the same day as the composites. We successfully collected the entire set of 48 aliquots at nine of the ten facilities. However, the Burlington POTW shut down in the final hour of the sampling effort and resulted in collection of only 47 aliquots from this facility.

Summer sampling occurred during the week of July 13, 2009. All 48 aliquot were collected at all ten POTWs, and there were no irregularities associated with this event.

The project team obtained daily flow rate information from the operators of each of the POTWs for the days when samples were collected. We also reviewed the flow data that the POTWs had submitted to Ecology via their discharge monitoring reports for the 3 years from January 2007 through December 2009.

2.3 Laboratory Methods

The Ecology MEL analyzed the wastewater samples for all of the targeted toxic chemicals except PBDEs, PFCs, and PCBs. Pacific Rim analyzed its portion of the samples for PBDEs and PCBs. Axys analyzed its portion of the samples for PFCs. The analytical methods identified in the following subsection are described in detail in U.S. EPA 1999a, 2004, and 2007.

2.3.1 Analytical Methods

PAHs were analyzed using U.S. EPA SW-846 Method 8270 SIM. Method 8270 SIM is a modification of Method 8270. Selected ion monitoring (SIM) enhances sensitivity by setting the mass spectrometer (MS) to detect specific ions rather than a range of ions. Sensitivity is

generally increased by a factor of 10 over standard MS measurements. The primary disadvantage of SIM is a loss of qualitative information (unable to compare spectra).

BNAs and herbicides were analyzed using U.S. EPA SW-846 Method 8270. BNA extractable compounds included the phthalates chemical class. Samples were analyzed by gas chromatography/mass spectrometry (GC/MS) following extraction and, if necessary, appropriate sample cleanup and derivatization procedures. Sample extracts were injected into a gas chromatograph (GC) equipped with a capillary column that utilized a temperature program to separate analytes that were then detected with an MS. Analytes were identified by comparing electron impact spectra to the spectra of known standards. Analytes were quantified by comparing the response of a major ion relative to an internal standard using a calibration curve developed for each analyte.

Pesticides were analyzed using U.S. EPA SW-846 Method 8081. Samples were analyzed by gas chromatography/electron capture detector (GC/ECD) following extraction and, if necessary, appropriate sample cleanup procedures. Sample extracts were injected into a GC equipped with a capillary column, which utilized a temperature program to separate analytes that were then detected with an electron capture detector (ECD). Analytes were identified by comparing the retention time of target compounds with retention times of known standards on two dissimilar columns. Analytes were quantified by comparing the sample peak response using a calibration curve developed for each target compound.

PBDEs were analyzed using U.S. EPA method GC/HRMS 1614. Samples were analyzed using gas chromatography/high-resolution mass spectrometry (GC/HRMS) following extraction and, if necessary, appropriate sample cleanup procedures. Sample extracts were injected into a GC equipped with a capillary column, which utilized a temperature program to separate analytes that were then detected with an HRMS. Individual compounds (i.e., congeners) were identified by comparing the retention time and ion-abundance ratio of target compounds and associated labeled analog compounds with retention times and ion-abundance ratios of known standards. Congeners were quantified using the isotopic dilution quantitation technique, comparing the area of the quantification ion to that of the 13C-labeled standard and correcting for response factors.

PFCs were analyzed using Axys Method MLA-060 (Axys Analytical Services, Ltd., 2008). Samples were analyzed by liquid chromatography-tandem mass spectrometry (LC/MS/MS) following solid-phase extraction and selective elution procedures. Sample extracts were analyzed on a high-performance liquid chromatograph coupled to a triple quadrupole mass spectrometer. Target compounds were quantified using the internal standard method, comparing the area of the quantification ion to that of the 13C-labeled standard and correcting for response factors.

PCBs were analyzed using U.S. EPA method GC/HRMS 1668A. Samples were analyzed using gas chromatography/high-resolution mass spectrometry (GC/HRMS) following extraction and, if necessary, appropriate sample cleanup procedures. Sample extracts were injected into a GC equipped with a capillary column, which utilized a temperature program to separate analytes that were then detected with an HRMS. Individual compounds (i.e., congeners) were identified by comparing the retention time and ion-abundance ratio of target compounds and associated

labeled analog compounds with retention times and ion-abundance ratios of known standards. Congeners were quantified using the isotopic dilution quantitation technique, comparing the area of the quantification ion to that of the 13C-labeled standard and correcting for response factors.

Metals were analyzed using U.S. EPA Method 200.8. Samples were analyzed by inductively coupled plasma-mass spectrometry (ICP-MS) following acid extraction. Sample extracts injected into the ICP-MS were quantified by comparing instrument response to a calibration curve developed for each analyte. Results were reported for total (unfiltered) copper, lead, and zinc.

2.3.2 Data Review and Validation

The project team conducted data review and validation in general accordance with the detailed quality control (QC) procedures documented in the MEL Quality Assurance Manual (Manchester Environmental Laboratory, 2007) and Lab Users Manual (Manchester Environmental Laboratory, 2008), and in each subcontracted laboratory's quality assurance (QA) manual. One QC target for this project was for each laboratory to extract and analyze all the samples collected during each event in a single batch. By doing this, a single set of QC parameters would be applicable to all samples collected during each sampling event.

2.4 Data Analysis

2.4.1 Quality Assurance Review

The project team validated analytical data to verify they met project data quality objectives and to identify any limitations of the data, following the process outlined in Ecology QA1 review guidelines (PTI Environmental Services, 1989). Validation consisted of comparing calibration, accuracy, and precision results to the QC criteria listed in the method, the laboratory standard operating procedure, and the QAPP. If no QA guidelines existed for specific analytes, then the project team used applicable U.S. EPA national and regional data review guidelines (U.S. EPA, 1999b).

Since the Ecology MEL employs standardized analyte lists that partially overlap, they analyzed the following six chemicals with more than one method.

- 2,3,4,6-Tetrachlorophenol
- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol
- Dacthal
- Hexachlorobenzene
- Pentachlorophenol

For example, the laboratory used U.S. EPA Method SW-846 8270 (for semivolatile [BNA extractable] organic compounds by GC/MS) and 8270 (chlorinated herbicides by solid-phase extraction and GC/MS) to quantify the amount of pentachlorophenol in the samples. Thus, the laboratory reported more than one result for these six chemicals (i.e., two results for each sample). For each chemical, the project team selected only one of the results for use in estimating loadings – the one obtained with the more sensitive method which provided the smaller reporting limit.

The generally accepted practice is that concentrations between the method detection limit (MDL) and the reporting limit are reported as detected but not quantified, due to the potential for misuse of low-level data with relatively high quantitative uncertainty. However, for this investigation concentrations of all analytes reported between the MDL and reporting limit have been quantified and annotated with a "J" qualifier (estimated concentration), indicating a higher level of uncertainty in the quantitative value. Statistical evaluations of data whose uncertainties are "high" can lead to erroneous conclusions, especially if the sample populations are limited in size or are highly censored (high percentages of non-detect data – results where analytes are not present at detectable concentrations).

For this study, only wastewater sample results quantified at concentrations at least three times greater than the corresponding results in the method blank and in the field blank samples were considered "detected." Wastewater sample results that were not at least three times greater than the corresponding results in the method blank were qualified with a "U" to indicate "not detected." Wastewater sample results that were not at least three times greater than the corresponding results in the field or rinseate blank samples were qualified with a "UFB" to indicate "not detected due to contamination of the field or rinseate blank" for the purposes of this project only. The qualifier "U" subsequently replaced "UFB" in the data uploaded to the Ecology Environmental Information Management (EIM) system database.

2.4.2 Estimated Discharge from POTWs

The project team reviewed the wastewater discharge rates reported for January 2007 through December 2009 by the 96 POTWs listed in Appendix A (raw data in Ecology, 2010b), and determined the average annual discharge rate for each POTW. For estimating chemical loadings, we employed the average flows self-reported by the POTWs via their discharge monitoring reports.

2.4.3 Estimated Loadings of Toxic Chemicals from Each of the Ten POTWs

Using the toxic chemical concentration data obtained through this study, the project team developed annual loading rates for each of the ten sampled POTWs. We calculated annual loading rates by multiplying the average annual discharge rate from each facility by the average concentration for each toxic chemical. The average concentration depended on the number of detect and non-detect values from the two sampling events. We used the following procedures to compute annual loading rates for each POTW:

- If a chemical were detected during both sampling events, an average concentration was computed using the two detect values. We then used this average in the subsequent loading calculation.

- If a chemical were analyzed during only one sampling event and were detected, we used the reported concentration in the subsequent loading calculation.

- If a chemical were analyzed during both sampling events and were detected during only one of them, we computed an average concentration using the detect value and one-half the reporting limit for the non-detect value. We then used this average in the subsequent loading calculation.

- If a chemical were analyzed during both sampling events and were not detected during either of them, we did not generate a loading estimate.

2.4.4 Estimated Total Loadings to Puget Sound

The project team computed annual loading rates of each toxic chemical or chemical class for each of the 14 study areas in Puget Sound by multiplying the average annual volume of treated wastewater discharged from all the POTWs located in each study area by a representative concentration for each toxic chemical or chemical class. The average annual discharge volume for each study area was the sum of the discharge volumes from the POTWs located within the area. Table 6 identifies the average annual total discharge of wastewater from POTWs for each study area and compares the values used in this Phase 3 study with those that were used and that should have been used in the Phase 2 study (EnviroVision, et al., 2008). The discharge volumes were quite similar after correction for the mis-location of several POTWs in the Phase 2 study.

In determining some of the representative concentrations, the project team employed Regression on Order Statistics (ROS) to account for non-detect results, as described in the calculation steps provided later in this section. ROS is a commonly used procedure for estimating summary statistics from data sets that contain below-detection-limit (censored) observations (Helsel, 2005). The procedure first computes the Weibull-type plotting positions of the combined uncensored and censored observations. A linear regression model is then generated from the plotting positions of the uncensored observations and their normal quantiles. This linear regression model is the basis for estimating the concentration of the censored observations as a function of their normal quantiles. Finally, the observed uncensored values are combined with the modeled censored values to estimate summary statistics for the entire population. In this application, the project team used ROS to estimate summary statistics (i.e., 5th, 25th, 50th, 75th, and 95th percentiles) for individual and classes of toxic chemicals.

The project team compared the summary statistics derived from the treatment of non-detect results using the ROS method with those derived from three simpler substitution methods. They employed substitutions of non-detect data with zero, half the reporting limit, and the full reporting limit.

Individual Chemicals

To obtain representative concentrations for each toxic chemical, the project team pooled the data from samples collected at all ten POTWs during both the winter and summer sampling events. After pooling the data, we used different procedures to obtain a representative concentration for each chemical. The selected procedure for each chemical depended on the total number of results and the number of detect and non-detect values. We used the following steps to calculate representative concentrations if ten or more results were available for a given chemical:

1. Compute the detection frequency for each chemical by dividing the number of detect values by the total number of valid values, after excluding from both counts any rejected results. The number of valid values varied for each chemical because some values were rejected for quality assurance reasons, and some chemicals were analyzed a different number of times. Appendix D summarizes these detection frequencies.

2. Screen the frequencies from Step 1 to identify only those chemicals that had a detection frequency of 50 percent or greater. Given that the maximum number of results possible for any chemical was 20, this 50 percent detection frequency was the minimum likely to provide meaningful loading rate estimates.

3. Calculate the 5th, 25th, 50th, 75th, and 95th percentiles from the subset of chemicals identified in Step 2 using ROS, a statistical method for calculating summary statistics on censored datasets. Appendix E summarizes these percentiles.

4. Use the 25th, 50th, and 75th percentiles from Step 3 as the representative concentrations in the loading calculations to provide a measure of the central tendency and overall variability of the loading rates.

If fewer than ten results were available for a given chemical, the project team used the following steps to compute representative concentrations:

1. Compute the detection frequency for each chemical by dividing the number of detect values by the total number of valid values, after excluding from both counts any rejected results. The number of valid values varied for each chemical because some values were rejected for quality assurance reasons, and some chemicals were analyzed a different number of times. Appendix D summarizes these detection frequencies.

2. Screen the frequencies from Step 1 to identify only those chemicals that had a detection frequency of 65 percent or greater. For chemicals with fewer than ten results, this 65 percent detection frequency was the minimum likely to provide meaningful loading rate estimates.

3. Calculate the 5th, 25th, 50th, 75th, and 95th percentiles for each of the chemicals identified in Step 2, substituting one-half the reporting limit for all non-detect values in the data. Appendix E summarizes these percentiles.

4. Use the 25th, 50th, and 75th percentiles from Step 3 as the representative concentrations in the loading calculations to provide a measure of the central tendency and overall variability of the loading rates.

Further statistical and loading calculations employed only those chemicals selected by one of the two options described above.

Classes of Toxic Chemicals

Chemical classifications reflect the general internal structure of a group of chemicals or the reactive groups attached to that general structure. Aggregating chemicals into groups or classes with similar structures or reactive groups is sometimes useful because chemical classifications often indicate that the chemicals within such a group might share a single source, behave or affect environmental receptors in a similar manner, or all be amenable to particular treatments or other control actions that remove them from the waste stream.

The specific analytical method by which a chemical may be measured need not correspond with how that chemical may be "classified." For this study, the project team grouped the toxic chemicals of concern into classifications that did not necessarily reflect the analytical method that the laboratories used. Thus, for example, although pentachlorophenol is one of the BNA extractable analytes and is also detectable using the chlorinated herbicides method, we reported it, only once, as a member of the class of other BNA extractables and used the herbicide result because it was derived from the more sensitive analytical method.

The project team grouped the toxic chemicals into the 11 different classes listed below. Where we had sufficient data, we calculated the summary statistics and loading rates for individual chemicals. Where we had sufficient data, we also calculated the summary statistics and loading rates for certain chemical classes, comprised of specific individual compounds, as shown below. A "congener" is an example of a specific compound. For this project, a "homolog" is the group of compounds that contains a specific number of chlorine or bromine atoms. For example, the dibrominated diphenyl ether homolog group consists of the three individual congeners BDE-007, BDE-010, and BDE-015. Carcinogenic PAHs (cPAHs) constituted a subset of the heavy PAHs (HPAHs). A complete list of the chemicals and classes is provided in Appendix C.

Chemical Class	Number of Chemicals	Loading for Chemicals	Loading for Class
PAHs (light, heavy, and carcinogenic)	16 (6, 10, 7)	Yes	Yes
Phthalates	6	Yes	Yes
Other Base/Neutral/Acid Extractables	55	Yes	No
Pesticides	34	Yes	No
Herbicides	18	Yes	No
PBDEs (congeners)	38	Yes	Yes
PBDEs (homologs)	9	Yes	No
PFCs	13	Yes	Yes
PCBs (congeners)	209	Yes	Yes
PCBs (homologs)	10	Yes	No
Metals (copper, lead, and zinc)	3	Yes	No

To determine a representative concentration for each toxic chemical class, the project team pooled the data from all the samples collected from all ten POTWs during both the winter and summer sampling events. We summed the reported concentrations of each chemical within each class of chemicals for each sampling event at each POTW. We used the following steps to derive representative concentrations for each class of toxic chemicals:

1. For these summations, substitute zero for all non-detect values of individual chemicals unless all the reported values of the individual chemicals of a given chemical class/event/POTW combination were non-detects. In that case, use the highest reporting limit of all the individual chemicals within that chemical class/event/POTW combination to represent the non-detect concentration for that chemical class/event/POTW combination.

2. If none of the summed concentrations for a chemical class were non-detect, calculate the 5th, 25th, 50th, 75th, and 95th percentiles from those summed concentrations. If any of the

summed concentrations were non-detect, calculate the 5th, 25th, 50th, 75th, and 95th percentiles using ROS. Appendix E summarizes these percentiles.

3. Use the 25th, 50th, and 75th percentiles from Step 2 as the representative concentrations in the loading calculations to provide a measure of the central tendency and overall variability of the loading rates.

3. Results

3.1 Field Work

Table 5 shows the average daily flows for 2007 through 2009 compared with the average of measured discharge flow rates that each POTW operator provided for the two sampling events, and presents the annual flows that we used in calculating toxic chemical loadings. The flow values that the project team selected for loading calculations were based on the more representative monthly monitoring results reported by the POTWs to Ecology to comply with their NPDES permits.

3.2 Laboratory Work

3.2.1 Review of Data Quality

Appendix B contains copies of the Data Usability Summary Reports that document the results of the Level 1 data quality review. Brief descriptions of the data quality are provided below for each analytical method.

Polycyclic Aromatic Hydrocarbons

The Ecology MEL analyzed samples from February and July for PAHs using U.S. EPA Method SW-846 Method 8270D SIM (Polycyclic Aromatic Hydrocarbons by GC/MS) in accordance with the QAPP. The 320 PAH results generally met the project data quality objectives for reporting and QC limits. The project team qualified 35 percent of the results with a "J" qualifier to indicate uncertainty in the quantitative measurements. Of the results that indicated a detectable amount of pollutant ("detect results"), 52 percent were qualified with a "J."

Base/Neutral/Acid Extractable Compounds

The Ecology MEL analyzed samples from February and July for BNAs using U.S. EPA Method SW-846 Method 8270 (Semivolatile Organic Compounds by GC/MS) in accordance with the QAPP. BNA extractable compounds included the phthalates chemical class. The 1,160 BNA results generally met the project data quality objectives for reporting and QC limits. The project team qualified 30 percent of the results with a "J" qualifier to indicate uncertainty in the quantitative measurements. Of the detect results, 60 percent were qualified with a "J." Four of the detect results were also qualified as tentatively identified when qualitative QC criteria were not met. We rejected 70 results for failing to meet QC criteria (6.0 percent of the total possible BNA results). The following ten compounds had rejected results:

- 2,4-Dimethylphenol..... 2 Rejects
- 2-Nitroaniline ..... 5 Rejects
- 3,3'-Dichlorobenzidine.....11 Rejects
- 3-Nitroaniline ..... 5 Rejects
- 4-Chloroaniline.....20 Rejects
- 4-Nitroaniline .....10 Rejects
- 4-Nonylphenol..... 4 Rejects
- bis(2-Chloroethoxy) methane... 5 Rejects
- Bisphenol A..... 5 Rejects
- Caffeine ..... 3 Rejects

The Ecology MEL analyzed all of the required BNAs with the exception of benzidine (in both events) and N-nitrosodimethylamine (in July). In both February and July, the laboratory also provided data for the following five chemicals, not specified in the QAPP.

- 2-Methylphenol
- 4-Methylphenol
- Caffeine
- Triclosan
- Triethyl citrate

In July only, the laboratory provided data for the following five chemicals, also not specified in the QAPP.

- 3B-Coprostanol
- Benzoic acid
- Benzyl alcohol
- Cholesterol
- 2-Chloroethanol phosphate (3:1)

The BNA data met the project data quality objectives, although the reporting limits for several of the analytes were slightly greater than the values identified in the QAPP.

Pesticides

The Ecology MEL analyzed samples from February and July for pesticides using U.S. EPA Method SW-846 Method 8081 (Chlorinated Pesticide Compounds by GC/ECD) in accordance with the QAPP. The 650 pesticide results generally met the project data quality objectives for reporting and QC limits. The project team qualified 43 percent of the results with a "J" qualifier to indicate uncertainty in the quantitative measurements. Of the detect results, 62 percent were qualified with a "J."

In July only, the Ecology MEL provided data for the following seven chemicals that were not specified in the QAPP.

- 2,4'-DDD
- 2,4'-DDE
- 2,4'-DDT
- Chlordane, technical
- DDMU
- Mirex
- Pentachloroanisole

Herbicides

The Ecology MEL analyzed samples from February and July for herbicides using U.S. EPA Method SW-846 Method 535/8270 (Chlorinated Herbicides by Solid-Phase Extraction and GC/MS) in accordance with the QAPP. The 360 herbicide results generally met the project data quality objectives for reporting and QC limits. The project team qualified 12 percent of the results with a "J" qualifier to indicate uncertainty in the quantitative measurements. Of the detect results, 79 percent were qualified with a "J." Eleven of the detect results were also qualified as tentatively identified when qualitative QC criteria were not met. We rejected five results for failing to meet QC criteria (1.4 percent of the total possible herbicide results). The following four compounds had rejected results:

- 2,4-DB.....1 Reject
- Acifluorfen.....1 Reject
- Dinoseb .....1 Reject
- Picloram ..... 2 Rejects

Polybrominated Diphenyl Ethers
Pacific Rim analyzed samples from February and July for PBDE congeners using U.S. EPA SW-846 Method 1614 (Brominated Diphenyl Ethers in Water, Soil, Sediment, and Tissue by HRGC/HRMS) rather than U.S. EPA Method 1668 as specified in the QAPP. This variation was acceptable because it provided equivalent or better data than required to meet project data quality objectives.

The 710 PBDE results generally met the project data quality objectives for reporting and QC limits. The project team qualified 37 percent of the results with a "J" qualifier to indicate uncertainty in the quantitative measurements. Of the detect results, 23 percent were qualified with a "J." Ten of the detect results were also qualified as tentatively identified when qualitative QC criteria were not met.

Pacific Rim analyzed all the required congeners, except that in both February and July the results for BDE-197 and BDE-204 were reported as a total value rather than separately, and in February the results for BDE-049 and BDE-071 were reported as a total value rather than separately. The inability of the laboratory to separate these very similar congeners did not negatively impact the data usability. In addition, Pacific Rim provided data for the following three congeners that were not specified in the QAPP.

- BDE-007
- BDE-010
- BDE-015

Perfluorinated Organic Compounds
Axys analyzed samples from February and July for PFCs using Method MLA-060 (Analytical Procedure for Perfluorinated Organic Compounds in Aqueous Samples by LC-MS/MS) in accordance with the QAPP. In addition, the laboratory provided data for perfluorooctane sulfonamide (PFOSA).

Although the 260 PFC results complied with all other project data quality objectives, Axys employed reporting limits that were approximately an order of magnitude greater than the reporting limits identified in the QAPP. While this made no difference for detected congeners, and the quality of the non-detect results was acceptable, a possibility exists that the actual total concentrations of PFCs, and thus their loadings to Puget Sound, was greater than the estimate provided by this study.

Polychlorinated Biphenyls
Pacific Rim analyzed samples from February for PCB congeners using U.S. EPA Method 1668 (Chlorinated Biphenyl Congeners by HRGC/HRMS) in accordance with the QAPP. The 1,134 PCB results generally met the project data quality objectives for reporting and QC limits. The project team qualified less than 0.1 percent of the results with a "J" qualifier to indicate uncertainty in the quantitative measurements. None of the detect results were qualified with a "J." Seventeen of the detect results were also qualified as tentatively identified when qualitative QC criteria were not met.

Metals
The Ecology MEL analyzed samples for total metals (copper, lead, and zinc) using U.S. EPA Method 200.8 (Inductively Coupled Plasma – Mass Spectrometry) in accordance with the QAPP. The 60 metals results met the project data quality objectives for reporting and QC limits, and none of them were qualified.

3.2.2 Summary of Analytical Results

Excluding duplicate and field blank/rinseate samples, this project generated a total of 4,579 valid analytical results that characterized 20 samples of treated wastewater from ten subject POTWs (two samples from each POTW). Through data review and validation, the project team qualified 95 results as non-detects (with the "UFB" qualifier) due to potential contamination during handling based on the results of field/rinseate samples. A detectable amount of target analyte was present from every class of toxic chemicals that the project team assessed in one or more of the treated wastewater discharges. We detected a total of 230 chemicals, not counting PBDE and PCB homologs (212 chemicals if PCB co-elutants are considered individual analytes). Except for the PFC class, the range (i.e., variability) of the total concentrations of each chemical class among the POTWs was greater in summer than in winter. Appendix C summarizes all of the results from the chemical analyses. Appendix D summarizes for each analyzed chemical the number of valid results and the percentage of those results that indicated the detectable presence of that chemical. Table 7 shows the number of chemicals detected within each of the chemical classes. Note that all data provided in the text, tables, and appendices are precise to only two significant figures.

Polycyclic Aromatic Hydrocarbons
The project team analyzed for 16 PAHs, consisting of six low molecular weight compounds (LPAHs) and ten high molecular weight compounds (HPAHs). The greatest number of PAHs detected in any of the 20 samples was eight, and the largest single PAH concentration was 0.37 micrograms per liter (μg/L) of naphthalene. The most frequently detected PAHs were fluorene, fluoranthene, phenanthrene, and pyrene.

Each one of the six LPAHs was detected in effluent samples from at least one POTW. LPAHs were detected in all but four samples and in all but one POTW, and the largest concentration of total LPAHs in any sample was 0.79 μg/L. For the ten samples collected in February, the number of detected LPAHs ranged from zero to five, and the largest sum of the LPAHs was 0.14 μg/L. For the ten samples collected in July, the number of detected LPAHs ranged from zero to six, and the largest sum of the LPAHs was 0.79 μg/L.

Seven of the ten HPAHs were detected in effluent samples from at least one POTW. HPAHs were detected in all but two samples, those from a single POTW. The number of detected HPAHs ranged from zero to five, and the largest sum of the HPAHs was 0.076 μg/L. For the ten samples collected in February, the number of detected HPAHs ranged from zero to four, and the largest sum of the HPAHs ranged was 0.047 μg/L. For the ten samples collected in July, the number of detected HPAHs ranged from zero to five, and the largest sum of the HPAHs was 0.076 μg/L.

The effluent samples from only two POTWs contained detectable carcinogenic PAHs (cPAHs).

Phthalates
The project team analyzed for six phthalates. For the ten samples collected in February, the number of detected phthalates ranged from one to three, and the sum of phthalates ranged from 0.31 to 3.4 µg/L. For the ten samples collected in July, only bis(2-ethylhexyl) phthalate phthalate was detected, at concentrations ranging from 0.19 to 5.3 µg/L.

Other Base/Neutral/Acid Extractables
The project team analyzed 55 semi-volatile compounds (BNA extractables) that were not grouped within another chemical class. Thirty of these compounds were detected in the wastewater samples, and each of the 20 samples contained detectable concentrations of from four to 15 of them. The three chemicals that typically showed the greatest concentrations were 3B-coprostanol, caffeine, and cholesterol. When these three compounds were excluded (due to absent analyses or rejected results for the February samples), the results for the remaining 27 compounds did not indicate the existence of a seasonal pattern.

Pesticides
The project team analyzed 20 samples for 34 pesticides and detected six. Endosulfan I and alpha-BHC were detected only in winter, at three and two POTWs, respectively. Chlorpyriphos, pentachloroanisole, and toxaphene were detected only in summer, at one, three, and two POTWs, respectively. Hexachlorobenzene was detected in the wastewater from one POTW in the summer, and from another POTW in the winter.

Herbicides
The project team analyzed 20 samples for 18 herbicides and detected only five, generally more frequently in the summer than in the winter. Detectable concentrations of MCPP and triclopyr were present in only five of the wastewater samples. Detectable concentrations of 2,4-D; Dicamba I; and MCPA were present in three samples.

Polybrominated Diphenyl Ethers
Congeners
The project team analyzed for 38 PBDE congeners, with six of them co-eluting with another congener, producing three combinations. Considering the co-eluting congener combinations to be individual analytes, for the ten samples collected in February, the number of detected PBDEs ranged from 11 to 25, and the sum of PBDEs ranged from 9,100 to 125,000 picograms per liter (pg/L). For the ten samples collected in July, the number of detected PBDEs ranged from 11 to 31, and the sum of PBDEs ranged from 8,600 to 135,000 pg/L.

Homologs
The project team calculated concentrations for the nine PBDE homologs based upon the congener data. PBDEs from each homolog group were detected, and four of the homolog groups were detected in every sample (the hexa-, penta-, tetra-, and tri-BDEs).

Perfluorinated Compounds
The project team analyzed for 13 PFCs and detected from six to ten of these toxic chemicals in each of the wastewater samples. The four compounds that were typically present in the greatest concentrations were perfluorohexanoate (maximum of 52 nanograms per liter (ng/L)), perfluorononanoate (maximum of 134 ng/L), perfluorooctane sulfonate (maximum of 55 ng/L), and perfluorooctanoate (maximum of 70 ng/L). All 20 samples contained detectable concentrations of these four chemicals.

Polychlorinated Biphenyls
Congeners
The project team analyzed the six wastewater samples collected in February for 209 PCB congeners, with 37 of them co-eluting in one or another of 17 combinations. Considering the 17 co-eluting congener combinations to be individual analytes, the number of detected PCB congeners ranged from five to 105, and the sum of PCB congeners ranged from 69 to 15,400 pg/L. Every effluent sample contained PCBs.

Homologs
The MEL calculated concentrations for the ten PCB homologs based upon the congener data. PCBs in each homolog group were detected, and eight of the homologs were detected in at least half of the samples.

Metals
The project team detected copper, lead, and zinc in all 20 samples of wastewater. The smallest reported concentrations were 2.6 μg/L for copper, 0.15 μg/L for lead, and 13 μg/L for zinc. The two greatest concentrations of copper were in the wastewaters from the King County West Point and Sumner POTWs (14 and 17 μg/L, respectively). The two greatest concentrations of lead were in the wastewaters from the Everett STP and City of Tacoma (Central No. 1) POTWs (1.2 and 0.72 μg/L, respectively). The two greatest concentrations of zinc were in the wastewaters from the Gig Harbor STP (95 and 76 μg/L, for summer and winter, respectively).

Summary Statistics
Using the calculation methods described in Section 2.4.4, the project team quantified the variability of the results of each chemical and class of chemicals for which Puget Sound-wide loadings were later calculated. Appendix E summarizes these summary statistics, listing the expected concentration of each chemical and class of chemicals at the 5th, 25th, 50th, 75th, and 95th percentiles.

When comparing the methods for handling non-detect data, the project team found that the median concentrations obtained by substituting half the reporting limit were the most similar to those derived by the ROS method. Of the 63 chemicals and chemical classes where ROS was used, the corresponding median concentrations for 60 of them were the same or within a 10% relative difference, and for two others were within a 15% relative difference. Substituting half the reporting limit gave median values slightly larger than the ROS method for 4-methylphenol (58% relative difference). These results were consistent with those of Antweiler and Taylor, 2008. Appendix F contains additional details of this comparison.

3.3 Estimated Loadings of Toxic Chemicals from Each of the POTWs

The project team multiplied the average flows of wastewater discharge shown in Table 5 by the chemical concentrations selected as described in Section 2.4.3 to estimate rough annual loading rates from each of the ten subject POTWs. Appendix G summarizes the annual loadings from each POTW to the Puget Sound Basin.

Polycyclic Aromatic Hydrocarbons
Of the 16 PAHs analyzed among the ten POTWs, the number of PAHs detected in the discharge from any given POTW ranged from two to eight. Only five chemicals (fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene) comprised almost all of the total PAH loadings (61 to 100 percent) from nine of the POTWs. The effluent from one of the POTWs (Everett (outfall 100)) contained five PAHs not usually found in the other discharges, among which were four cPAHs.

Phthalates
Of the six phthalates analyzed among the ten POTWs, the number of phthalates detected at any given POTW ranged from one to three. All ten POTWs discharged bis(2-ethylhexyl) phthalate, which constituted 52 to 100 percent of their total loadings of phthalates via treated effluent.

Other Base/Neutral/Acid Extractables
Of the 55 miscellaneous BNA extractable chemicals discharged by the ten subject POTWs, the project team detected seven of them in all 20 samples of wastewater. These were 1,4-dichlorobenzene; 2,4,6-trichlorophenol; 2-chloroethanol phosphate; cholesterol; dibenzofuran; triclosan; and triethyl citrate. The three chemicals discharged in the greatest amounts were 3B-coprostanol (ranging from not detectable to 1,100 kilograms per year (kg/year)), caffeine (ranging from not detectable to 54 kg/year), and cholesterol (ranging from 14 to 1,500 kg/year).

Pesticides
Of the ten POTWs, the treated wastewater discharges of three of them contained no detectable amount of the 34 analyzed pesticides. Only five chemicals (chlorpyriphos, endosulfan I, hexachlorobenzene, pentachloroanisole, and toxaphene) comprised 96 to 100 percent of the total pesticide loadings from each of the other seven POTWs.

Herbicides
Of the ten POTWs, the treated wastewater discharges of three of them contained no detectable amount of the 18 analyzed herbicides. Only four chemicals (2,4-D; MCPA; MCPP; and triclopyr) comprised 84 to 100 percent of the total herbicide loadings from each of the other seven POTWs.

Polybrominated Diphenyl Ethers
Congeners
Of the 38 PBDEs analyzed among the ten POTWs, the number of PBDEs detected at any given POTW ranged from 18 to 32 (when considering the three co-eluting congener combinations as

individual analytes). Only three congeners (BDE-047, BDE-099, and BDE-209) comprised 69 to 82 percent of the total PBDE loadings from each of the ten POTWs.

Homologs

The two homologs that constituted the greatest portion of the PBDE loadings (from 45 to 81 percent) were the penta- and tetra-bromodiphenyl ethers. Decabromodiphenyl ether represented 43 percent of the total loading discharged by the Gig Harbor STP. The Everett STP (Outfall 100), King County West Point, and City of Tacoma (Central No. 1) facilities discharged the largest amounts of PBDEs annually, from 2.6 to 64 times as much as any of the other POTWs.

Perfluorinated Compounds

Of the 13 PFCs analyzed among the ten POTWs, the number detected at any given POTW ranged from eight to ten. Five of these compounds were detected in every one of the 20 sample analyzed. Only four chemicals (perfluorohexanoate, perfluorononanoate, perfluorooctane sulfonate, and perfluorooctanoate) comprised 56 to 87 percent of the total PFCs discharged from each of the POTWs.

Polychlorinated Biphenyls

Congeners

Of the 209 PCB congeners analyzed among the six sampled POTWs, the number detected at any given POTW ranged from five to 105 (when considering the 17 co-eluting congener combinations as individual analytes). The variety of congeners detected at a given POTW generally corresponded with their total loadings. The five congeners that the six POTWs discharged in the greatest amounts were PCBs-004, 052/064, 118, and 138. The total loading of these five congeners constituted about 19 percent of the total loading of PCB congeners.

Homologs

Of the ten homolog groups, the number detected at the six sampled POTWs ranged from one to nine. For three of the POTWs, the tetra-, penta-, and hexa-chlorobiphenyl homologs constituted 63 to 70 percent of their discharges. For the Shelton STP, the tri-, tetra-, and hepta-chlorobiphenyl homologs constituted 94 percent of its discharge. For the Pierce County Chambers Creek STP, the di-, tri, and tetra-chlorobiphenyl homologs constituted 93 percent of its discharge.

Metals

The ranges of the loadings of the three analyzed metals from the ten sampled POTWs varied considerably. The median annual loading of copper was 59 kg/year, within an 180-fold high-to-low range. The median annual loading of lead was 4.3 kg/year, within a 90-fold high-to-low range. The median annual loading of zinc was 240 kg/year, within a 48-fold high-to-low range.

3.4 Estimated Total Loadings to Puget Sound

Based on the total number of valid analyses and the frequencies of detection, the project team identified 68 individual chemicals, discounting PBDE and PCB homologs, for which we could reliably estimate total loadings to Puget Sound (using the method described in Section 2.4.4).

The data also allowed calculation of estimates for the total loadings of 13 PBDE and PCB homologs and seven chemical classes. Appendix E identifies the summary statistics (the 5th, 25th, 50th, 75th, and 95th percentiles) for these individual chemicals and chemical classes. Appendix H summarizes the estimated loadings of these chemicals and chemical classes in the 14 study areas of Puget Sound (25th, 50th, and 75th percentiles only).

Since the available data required the grouping of chemical results from all ten of the subject POTWs, the areal distribution of loadings to the Puget Sound Basin directly corresponded to the total discharge rates from the POTWs within each study area. Since no POTWs were located within the Elliott Bay study area, the loadings from that study area were zero. The following bullets identify the estimated ranges of total loadings for toxic chemical classes and the three metals to the Puget Sound Basin from all the POTWs in the 14 study areas, shown as from the 25th to the 75th percentiles. Appendix H presents additional details along with the loading estimates for the other chemicals.

- Total PAHs: 7.6 to 46 kg/year.
  LPAHs comprised from 43 to 76 percent of the total PAHs annually discharged to Puget Sound. The amount of LPAHs ranged from 3.3 to 35 kg/year.

- Total phthalates: 220 to 910 kg/year.
  Bis(2-ethylhexyl) phthalate comprised 80 to 100 percent of the total phthalates annually discharged to Puget Sound. The amount of bis(2-ethylhexyl) phthalate ranged from 220 to 900 kg/year.

- Total PBDEs: 7.0 to 21 kg/year.
  From 71 to 79 percent of the PBDE congeners annually discharged to Puget Sound were BDE-047, BDE-099, and BDE-209, constituents within the tetra-, penta-, and deca-bromodiphenyl ether homolog groups, respectively.

- Total PFCs: 31 to 59 kg/year.
  From 39 to 49 percent of the PFCs annually discharged to Puget Sound consisted of perfluorohexanoate and perfluorooctanoate.

- Total PCBs: 0.13 to 1.8 kg/year.
  Approximately 55 percent of the PCB congeners annually discharged to Puget Sound were distributed among the tri-, tetra-, and penta-chlorobiphenyl homolog groups.

- Copper: 2,500 to 5,500 kg/year.

- Lead: 140 to 250 kg/year.

- Zinc: 16,000 to 24,000 kg/year.

4. Discussion

4.1 Comparison with Results from Phase 2

Most of the difference in estimated loadings between the Phase 2 study in 2008 and this Phase 3 study appeared to be due to variations in the concentrations rather than total discharge volume of treated wastewater. Table 6 shows the similarity between the Phase 2 and Phase 3 studies of the average total flows from POTWs to the 14 Puget Sound study areas.

Based on the limited suite of NPDES self-monitoring analytes and the use of standard analytical reporting limits (i.e., larger than those used for this study), the Phase 2 study provided estimates of total loadings for seven chemicals: copper, lead, mercury, zinc, chloroform, bis(2-ethylhexyl) phthalate, and phenolics. The total estimated loadings of copper and zinc to Puget Sound from this study were about 70 and 97 percent, respectively, of the Phase 2 study estimates. The estimated loadings of lead and bis(2-ethylhexyl)phthalate from this study were 18 and 17 percent, respectively, of the Phase 2 study estimates. For each of the 14 Puget Sound study areas, Table 8 compares the loading rate estimates of the four chemicals that we assessed in Phase 2 with the results from this study.

In general, the current study has improved and extended the results from Phase 2, and has clearly demonstrated that POTWs discharge toxic chemicals in their treated wastewater effluents.

4.2 Comparison with Results from Other Studies

The project team evaluated whether the results from this study for these particular ten POTWs were similar to or differed from the discharges of treated effluents from other POTWs in Washington State. We focused primarily on PCBs, which are legacy pollutants, and PFCs, which are pollutants of emerging concern.

Polychlorinated Biphenyls
PCBs are the class of toxic organic chemicals for which Ecology had the greatest amount of historical data. The following studies addressed historical discharges of PCBs from POTWs:

- Albion, Colfax, Pullman — Lubliner, 2009.
- College Place, Walla Walla — Lubliner, 2007.
- Liberty Lake, Spokane — Golding, 2002.
- Okanogan, Omak, Oroville — Serdar, 2003.
- 18 POTWs in the Yakima River watershed — Johnson, et al., 2009.

For all of these studies, the analytical laboratories employed methods that reduced the final detection limits to values lower than normal, similar to this study. Figure 2 illustrates the total concentrations of PCBs discharged from these facilities and shows that the results found in this study were similar to results from elsewhere. This study found that the concentrations of total PCBs from the Everett STP (Outfall 100) and City of Tacoma (Central No. 1) facilities were

greater than the other POTWs shown in Figure 2. However, these results were based upon only a single composite sample from each facility. Further analyses are required to support any conclusions.

Ten of the PCB congeners (and their three co-elutants) detected most frequently and at the greatest concentrations in this study were the same PCB congeners that Ross, et al. (2000) found at the greatest concentrations in blubber tissue samples from the northern and southern resident populations of Orca whales. These ten congeners were PCBs-052, 099, 101, 105, 118, 138, 149, 153, 180, and 187. They and their co-elutants were among the top 12 percent of all PCB congeners ranked according to the greatest average concentration discharged from the six POTWs and among the top 25 percent frequency of detection, and contributed 31 percent of the total average concentration of all the PCB congeners. Four of the 21 congeners for which Ecology estimated loadings were among the ten that Ross, et al. identified as the greatest in the Orca whales. These congeners and their two co-elutants comprised from 9.7 to 23 percent of the total loading of PCBs from POTWs to Puget Sound.

Since the manufacture of PCBs ceased several decades ago, the frequent detection of PCBs in POTW wastewaters indicated that legacy contamination remains a significant source of PCBs. The presence of PCBs in a variety of building materials (e.g., caulking, paint, insulation, roofing, siding, and asphalt) is an ongoing source that slowly and continually releases small amounts of PCBs into the environment and the regional wastewater infrastructure. The U.S. EPA (1997) summarized data that indicated that 32 to 65 metric tons of PCBs had been incorporated into caulking materials alone in the Puget Sound region (Ecology, 2011 in preparation). Since PCBs degrade very slowly and adhere to organic matter, the majority of residual PCBs appear to have bound to particles, and some have become trapped in wastewater systems (i.e., in the sediments in the piping). Therefore, uncontrolled construction or cleaning activities may mobilize these residuals and release additional pulses of PCBs into the environment for many more years.

Perfluorinated Compounds

Ecology has only recently begun to acquire monitoring data concerning PFCs in wastewater discharges. A recent study (Furl and Meredith, 2010) assessed the PFCs discharged in 2008 from four Washington state POTWs. Figure 3 illustrates the concentrations of total PFCs discharged from those four facilities and compares them with the results from the ten POTWs sampled in this study. The results from the two studies were similar. Almost all the total PFC concentrations in the treated wastewaters were between 50 and 200 ng/L.

Phthalates

Information about discharges of phthalates from POTWs in Washington state is limited. One study estimated the loading of bis(2-ethylhexyl) phthalate to POTWs in the Puget Sound region (Washington Toxics Coalitions and People for Puget Sound, 2009). Based upon analyses of residential dust and laundry wastewaters, the authors determined that approximately 959 kg of bis(2-ethylhexyl) phthalate flows annually from residences to POTWs in the Puget Sound region. This loading is consistent with our estimate in this study that POTWs discharge from 220 to 900 kg of bis(2-ethylhexyl) phthalate. The smaller amount discharged <u>from</u> POTWs than discharged <u>to</u> POTWs likely indicates that POTWs successfully treat or remove some of the phthalates in their wastewaters.

4.3 Seasonal Comparisons

The original intent for collecting treated effluent samples in February and July was to characterize possible differences in the concentrations and loadings of toxic chemicals during the wet and dry seasons. The project team suspected that a greater amount of precipitation and a higher groundwater table in the winter might increase the flow to POTWs and possibly affect the contaminant loads entering the POTWs and the degree of treatment they experienced prior to discharge. Also seasonal differences in the activities of wastewater producers may have caused the loadings of certain toxic chemicals to vary from one part of the year to another.

Unfortunately, the weather did not cooperate, and January to early February 2009 was an unusually dry period. Although some precipitation did occur in mid-February when samples were collected, the flow volumes from several of the POTWs were less in February than in July (Table 5).

Given that the measured effluent concentrations and flows varied substantially among the POTWs and that one day of sampling could not represent an entire season, this study could not distinguish a seasonal pattern. However, the winter samples from the three largest facilities (based on flow) contained from two to seven times as many detected PAHs and total concentrations from four to 19 times as great as the other POTWs. Whether this variation was due to a seasonal difference is not clear. Additional study may be warranted in the future.

4.4 Limitations

1. Based on 4,579 valid concentration results for toxic chemicals in 20 samples of wastewater, the results represented only a small portion of the total amount of wastewater treated and discharged by the POTWs in the Puget Sound Basin. Some comparisons are:

   - The Puget Sound Basin contained 106 permitted POTWs, and flow information was available for 96 of them.
     However, the project team collected samples from only ten POTWs and based loading estimates for the entire Sound on only 20 samples (six samples for PCBs).

   - The total flow from the 96 Puget Sound POTWs was approximately 124,140 mgy.
     However, the project team collected samples from POTWs whose discharges totaled 59,900 mgy (Table 5) – only 48 percent of the total POTW discharge to the Sound.

   - The rates of toxic chemical loadings from POTW discharges vary day-to-day throughout the year.
     However, the project team collected samples that represented only two days of the year (one day for PCBs).

2. Almost 73 percent of the analytical results were "non-detects." As a consequence, the project team did not estimate loadings from all 96 Puget Sound POTWs for 303 of the total 371 individual chemicals that we analyzed, not counting the PBDE and PCB homologs and

PCB co-elutants. However, a non-detect result did not mean that the amount of a particular chemical in a given wastewater sample was zero. Thus, this study could not support conclusions about whether any of these 303 chemicals were or were not threats to the health of the Puget Sound ecosystem.

3. The project team used the ROS method to "fill in" values for 48 individual chemicals, eight homolog groups, and seven chemical classes for which only some of the results were non-detect (less than 35 percent for individual chemicals with fewer than ten results, and less than 50 percent for the other individual chemicals). Therefore, the concentration summary statistics in Appendix E and the loading estimates in Appendix H were accurate only to the extent that the assumptions behind the ROS method were true for these data.

5. Conclusions

The goals of this project were (1) to screen treated wastewater discharges for toxic chemicals that POTW operators do not routinely monitor, and (2) to improve the loading estimates for certain toxic chemicals by employing more sensitive analytical methods.

This study developed improved estimates for the loadings of toxic chemicals discharged from permitted POTWs into the surface waters of the Puget Sound Basin. These new loading estimates are improved and more accurate than the Phase 2 estimates because the project team:

(a) Sampled from facilities that employed a wide variety of treatment techniques.

(b) Applied uniform and approved methods for sampling and analyses.

(c) Used more recent data than in prior studies.

(d) Covered a much broader list of chemicals than normally monitored.

(e) Employed more sensitive analytical methods than normally used.

POTWs are a significant secondary source of toxic chemicals. The results from this study will support development and prioritization of future control actions to improve and protect the Puget Sound ecosystem.

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Tables

Table 1. Characteristics of the Ten Subject POTWs

POTW Name	Permit Number	Study Area	Treatment Process	Industrial Influent	Max Month Avg Design Flow (MGD)	Representative Flow (MGD)
Bellingham STP	WA0023744	Strait of Georgia	Secondary oxygen-activated sludge with chlorine.	Yes	37	12.3
Bremerton STP	WA0029289	Sinclair-Dyes Inlet	Secondary activated sludge with chlorine.	Yes	10.1	4.30
Burlington WWTP	WA0020150	Whidbey Basin	Secondary activated sludge with UV disinfection.	Negligible	3.79	1.64
City of Tacoma (Central No.1)	WA0037087	Commencement Bay	Secondary activated sludge with chlorine.	Yes	60	19.9
Everett STP (Outfall 100)	WA0024490	Port Gardner	Trickling filter and solids contact with chlorine.	Yes	21.0	10.6
Gig Harbor STP	WA0023957	South Sound East	Secondary activated sludge with chlorine.	Negligible	1.6	0.809
King County West Point	WA0029181	Main Basin	Secondary activated sludge with chlorine.	Yes	215	92.5
Pierce County Chambers Creek STP	WA0039624	South Sound East	Secondary activated sludge (aerobic and anoxic) with UV.	Minimal	28.7	17.9
Shelton STP	WA0023345	South Sound East	Secondary activated sludge in oxidation ditch with chlorine.	Negligible	4.02	1.99
Sumner STP	WA0023353	Commencement Bay	Activated sludge with UV disinfection and anaerobic sludge digestion.	Minimal	4.59	2.01

Key:

MGD = Million gallons per day.
POTW = Publicly Owned Treatment Works.
STP = Sewage Treatment Plant.
UV = Ultraviolet.
WWTP = Wastewater Treatment Plant.

Table 2. Comparison of Sampled POTWs with All POTWs in the Puget Sound Basin

Size of the Average Flow	POTWs in the Puget Sound Basin (a)			POTWs Sampled in This Project		
	Number	Total Flow from POTWs Considered (MGY)	Percentage of Total Flow	Number	Total Flow from POTWs Sampled (MGY)	Percentage of Total Flow
Small (<1 MGD)	60	4,710	3.8%	1	295	0.5%
Medium (1 to 10 MGD)	29	28,770	23.2%	4	3,630	6.0%
Large (>10 MGD)	7	90,660	73.0%	5	56,900 (b)	93.5%
Total =	96	124,140	100.0%	10	60,800 (c)	100.0%

Key:

The precision of the data in this table is only two significant figures.

The flows may not add up due to rounding.

The flows are based upon the average monthly flows self-reported by each POTW from January 2007 through December 2009 (Ecology, 2010b).

MGD = Million gallons per day.

MGY = Million gallons per year.

POTW = Publicly Owned Treatment Works.

(a) = Excluding the ten small facilities operated by the U.S. Army and Navy and the Tribes.

(b) = Includes only the sampled Outfall 100 at the Everett STP.

(c) = This value differs from the corresponding total in Table 5 due to rounding.

Table 3. Summary of Winter Samples

POTW Name	Composite Samples					Grab Samples	
	Volume Submitted to Laboratory (Liter)	Number of Aliquots	Start (date/time)	End (date/time)	Collected (date/time)	Grab 1 (date/time)	Grab 2 (date/time)
Bellingham STP	8.4	48	2/11/09 09:35	2/12/09 09:06	2/12/09 09:30	2/11/09 07:15	2/12/09 10:40
Bremerton STP	8.3	48	02/09/09 09:30	2/10/09 09:01	2/10/09 10:00	02/09/09 08:45	2/10/09 10:45
Burlington WWTP	9	47	2/09/09 10:40	2/10/09 10:10	2/10/09 10:40	2/10/09 0735	2/10/09 10:10
City of Tacoma (Central No. 1)	8.4	48	2/18/09 10:44	2/19/09 10:15	2/19/09 10:30	2/11/09 05:45	2/12/09 14:15
Field Duplicate	8.4	48	2/18/09 11:08	2/19/09 10:39	2/19/09 10:45	NA	NA
Lab Duplicate	8.4	48	2/18/09 11:30	2/19/09 11:03	2/19/09 11:15	NA	NA
Everett STP (Outfall 100)	8.5	48	2/11/2009 12:06	2/12/09 11:37	2/12/2009 12:40	2/11/09 12:20	2/12/09 13:00
Gig Harbor STP	8.3	48	2/09/09 07:05	2/10/09 06:35	2/12/09 12:15	2/09/09 05:55	2/10/09 12:25
King County West Point	8.8	48	2/09/2009 07:20	2/10/2009 06:50	2/10/2009 12:30	2/09/09 05:30	02/09/09 13:35
Field Duplicate	NA	NA	NA	NA	NA	2/09/09 05:30	02/09/09 13:35
Lab Duplicate	NA	NA	NA	NA	NA	2/09/09 05:30	02/09/09 13:35
Pierce County Chambers Creek STP	8.4	48	2/18/09 14:34	2/19/09 14:05	2/19/09 14:30	2/11/09 07:30	2/12/09 16:30
Shelton STP	8.4	48	2/09/09 12:37	2/10/09 12:08	2/10/09 16:00	2/09/09 12:10	2/10/09 06:00
Sumner STP	8.4	48	2/11/09 10:00	2/12/09 09:30	2/12/2009 12:00	2/11/09 10:40	2/12/09 06:15

Key:
NA = Not applicable.
POTW = Publicly Owned Treatment Works.
STP = Sewage Treatment Plant.
WWTP = Wastewater Treatment Plant.

Table 4. Summary of Summer Samples

POTW Name	Composite Samples					Grab Samples	
	Volume Submitted to Laboratory (Liter)	Number of Aliquots	Start (date/time)	End (date/time)	Collected (date/time)	Grab 1 (date/time)	Grab 2 (date/time)
Bellingham STP	9	48	7/15/2009 07:10	7/16/2009 07:20	7/16/2009 09:20	7/15/2009 07:20	7/16/2009 09:24
Bremerton STP	9	48	7/13/2009 10:00	7/14/2009 09:30	7/14/2009 09:30	7/13/2009 08:35	7/14/2009 10:30
Burlington WWTP	9	48	7/13/2009 11:25	7/14/2009 10:54	7/14/2009 08:15	7/13/2009 10:00	7/14/2009 08:20
City of Tacoma (Central No. 1)	9	48	7/15/2009 06:50	7/16/2009 06:10	7/16/2009 07:30	7/15/2009 06:00	7/16/2009 14:40
Everett STP (Outfall 100)	9	48	7/15/2009 10:59	7/16/2009 10:29	7/16/2009 12:28	7/15/2009 10:30	7/16/2009 12:37
Gig Harbor STP	9	48	7/13/2009 06:28	7/14/2009 06:00	7/14/2009 11:30	7/13/2009 06:00	7/14/2009 12:15
King County West Point	9	48	7/13/2009 07:44	7/14/2009 07:12	7/14/2009 13:25	7/13/2009 05:55	7/14/2009 13:30
Field Duplicate	9	48	7/13/2009 07:50	7/14/2009 07:17	7/14/2009 13:25	7/13/2009 05:40	NA
Pierce County Chambers Creek STP	9	48	7/15/2009 15:30	7/16/2009 15:00	7/16/2009 16:00	7/16/2009 07:25	7/16/2009 16:14
Shelton STP	9	48	7/14/2009 07:50	7/15/2009 07:20	7/15/2009 12:45	7/13/2009 12:45	7/14/2009 07:30
Sumner STP	9	48	7/16/2009 06:30	7/17/2009 06:00	7/17/2009 06:00	7/15/2009 10:35	7/16/2009 06:15

Key:

NA = Not applicable.
POTW = Publicly Owned Treatment Works.
STP = Sewage Treatment Plant.
WWTP = Wastewater Treatment Plant.

Table 5. Average Flow Volumes for the Ten POTWs

	Phase 2 (a) (MGD / MGY)	Self-Reported via DMRs (b) (MGD)	Phase 3 (this study)			
			February Event (MGD)	July Event (MGD)	Average (MGD / MGY)	Value Used for Loading Estimates (MGD / MGY)
Bellingham STP	12.1 / 4,430	12.3 (c)	10.94	9.98 (d)	10.5 / 3,820	12.3 / 4,490
Bremerton STP	5.04 / 1,840	4.30 (e)	3.71	4.91	4.31 / 1,570	4.30 / 1,570
Burlington WWTP	1.56 / 569	1.64 (e)	no data	no data	no data	1.64 / 599
City of Tacoma (Central No. 1)	19.7 / 7,190	19.9 (e)	17.28	16.25	16.8 / 6,120	19.9 / 7,260
Everett STP (Outfall 100)	12.6 / 4,620	10.6 (e)	11.98	14.58	13.3 / 4,470 (f)	10.6 / 3,870
Gig Harbor STP	0.800 / 292	0.809 (e)	0.7133	0.6725	0.693 / 253	0.809 / 295
King County West Point	102 / 37,400	92.5 (g)	110.9	66.24	88.6 / 32,300	92.5 / 33,800
Pierce County Chambers Creek STP	17.8 / 6,480	17.9 (e)	8.52	15.72	12.1 / 4,420	17.9 / 6,530
Shelton STP	2.13 / 776	1.99 (e)	2.13	no data	2.13 / 777 (h)	1.99 / 726
Sumner STP	1.89 / 690	2.01 (e)	1.95	1.96	1.96 / 714	2.01 / 734

Key:

DMR = Discharge Monitoring Report required by NPDES permit.
MGD = Million gallons per day.
MGY = Million gallons per year.
POTW = Publicly Owned Treatment Works.
STP = Sewage Treatment Plant.
WWTP = Wastewater Treatment Plant.
(a) = From EnviroVision, et al., 2008.
(b) = From Ecology PARIS database of permittee-reported monitoring results (Ecology, 2010b).
(c) = December 2007 through December 2009.
(d) = Average of daily flows for July 15 and 16, 2009 (Wendling, 2010).
(e) = January 2007 through December 2009.
(f) = Annual flow was adjusted to account for an average of 29 days per year out of service.
(g) = July 2009 through December 2009.
(h) = Only one data point.

Table 6. Average Total POTW Flow Volumes for the 14 Puget Sound Study Areas

Study Area	Average Total POTW Flows (MGY)			Comparison Phase 3 versus Phase 2 (corrected) (percent)
	Phase 2	Phase 2 (corrected)	Phase 3 (this study)	
Admiralty Inlet	338	338	332	- 1.8
Commencement Bay	12,126	12,162	12,169	+ 0.058
Elliott Bay	0	0	0	0
Hood Canal (North)	4	270	73.4	- 73.
Hood Canal (South)	0	5.9	5.9	0
Main Basin	77,329	77,161	72,543	- 6.0
Port Gardner	12,634	12,935	11,736	- 9.3
San Juan Islands	1,529	858	828	- 3.5
Sinclair-Dyes Inlet	3,798	3,796	3,624	- 4.5
South Sound (East)	7,832	7,062	7,097	- 0.50
South Sound (West)	4,243	4,904	4,731	- 3.5
Strait of Georgia	5,943	5,943	6,068	- 2.1
Strait of Juan de Fuca	1,160	1,160	1,110	- 4.3
Whidbey Basin	3,126	3,701	3,825	- 3.4
Total =	**130,061**	**130,296**	**124,142**	**- 4.7**

Key:

The precision of the data in this table is only two significant figures.
Values may not appear to sum correctly due to rounding.

MGY = Million gallons per year.

POTW = Publicly Owned Treatment Works.

The POTWs reassigned to their correct Study Areas were:

Alderbrook Resort and Spa
Carnation WWTP
Granite Falls STP STP
Messenger House Care Center
North Bend STP
Oak Harbor STP
Olympic Water and Sewer, Inc.
Penn Cove WWTP
Pope Resources
Rainier State School
Shelton STP
Taylor Bay STP

Table 7. Number of Chemicals Detected within Each Chemical Class

Chemical Class	Number of Chemicals			
	Analyzed	Detected (a)	Detected >= 50% (b)	Detected >= 65% (b)
Polycyclic Aromatic Hydrocarbons (PAHs)	16	13	4	nc
Phthalates	6	4	1	nc
Other Base/Neutral/Acid Extractables	55	30	(c)	nc
Pesticides	34	6	0	nc
Herbicides	18	5	0	nc
Polybrominated Diphenyl Ethers (PBDE Congeners)	38	33	18	nc
Polybrominated Diphenyl Ethers (PBDE Homologs)	9	9	8	nc
Perfluorinated Compound (PFCs)	13	12	9	nc
Polychlorinated Biphenyls (Congeners) (PCB Congeners)	209	124	nc	21
Polychlorinated Biphenyls (Homologs) (PCB Homologs)	10	10	nc	5
Metals (Copper, Lead, and Zinc)	3	3	nc	nc

Key:

nc = Not calculated.
(a) = Derived from data in Appendix C; used for determining loadings by chemical class.
(b) = Derived from Percent Detection column in Appendix D; used for determining loadings for individual chemicals.
(c) = Total loading rates were not determined for these groups of chemicals.

Table 8. Comparison of Estimated Loadings from Phase 1 and Phase 2

Study Area	Copper				Lead				Zinc				bis(2-Ethylhexyl) Phthalate			
	Phase 2 (a) Best Estimate (kg/year)	Phase 3 (this study)			Phase 2 (a) Best Estimate (kg/year)	Phase 3 (this study)			Phase 2 (a) Best Estimate (kg/year)	Phase 3 (this study)			Phase 2 (a) Best Estimate (kg/year)	Phase 3 (this study)		
		25th Percentile (kg/year)	50th Percentile (kg/year)	75th Percentile (kg/year)		25th Percentile (kg/year)	50th Percentile (kg/year)	75th Percentile (kg/year)		25th Percentile (kg/year)	50th Percentile (kg/year)	75th Percentile (kg/year)		25th Percentile (kg/year)	50th Percentile (kg/year)	75th Percentile (kg/year)
Admiralty Inlet	1.32E+01	6.69E+00	1.16E+01	1.47E+01	1.41E+00	3.74E-01	4.96E-01	6.79E-01	5.88E+01	4.29E+01	5.08E+01	6.37E+01	4.16E+00	5.78E-01	1.18E+00	2.42E+00
Elliott Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Commencement Bay	5.25E+02	2.45E+02	4.25E+02	5.40E+02	1.07E+02	1.37E+01	1.82E+01	2.49E+01	2.03E+03	1.57E+03	1.86E+03	2.33E+03	1.85E+02	2.12E+01	4.31E+01	8.87E+01
Hood Canal (North)	1.60E-01	1.48E+00	2.56E+00	3.26E+00	1.70E-02	8.27E-02	1.10E-01	1.50E-01	7.00E-01	9.48E+00	1.12E+01	1.41E+01	5.00E-02	1.28E-01	2.60E-01	5.35E-01
Hood Canal (South)	0	1.18E-01	2.05E-01	2.61E-01	0	6.61E-03	8.78E-03	1.20E-02	0	7.58E-01	8.98E-01	1.13E+00	0	1.02E-02	2.08E-02	4.28E-02
Main Basin	3.81E+03	1.46E+03	2.53E+03	3.22E+03	3.19E+02	8.17E+01	1.08E+02	1.48E+02	9.29E+03	9.37E+03	1.11E+04	1.39E+04	5.58E+02	1.26E+02	2.57E+02	5.29E+02
Port Gardner	2.75E+02	2.36E+02	4.10E+02	5.21E+02	1.53E+02	1.32E+01	1.75E+01	2.40E+01	1.07E+03	1.52E+03	1.79E+03	2.25E+03	3.41E+02	2.04E+01	4.15E+01	8.55E+01
San Juan Islands	6.74E+01	1.67E+01	2.89E+01	3.67E+01	3.04E+00	9.32E-01	1.24E+00	1.69E+00	1.71E+02	1.07E+02	1.27E+02	1.59E+02	6.73E+00	1.44E+00	2.93E+00	6.03E+00
Sinclair-Dyes Inlet	6.08E+01	7.30E+01	1.26E+02	1.61E+02	2.01E+02	4.08E+00	5.42E+00	7.41E+00	1.12E+03	4.68E+02	5.54E+02	6.95E+02	1.01E+02	6.31E+00	1.28E+01	2.64E+01
South Sound (East)	5.64E+02	1.43E+02	2.48E+02	3.15E+02	1.57E+02	7.99E+00	1.06E+01	1.45E+01	2.19E+03	9.17E+02	1.09E+03	1.36E+03	3.76E+02	1.24E+01	2.51E+01	5.17E+01
South Sound (West)	2.87E+02	9.53E+01	1.65E+02	2.10E+02	1.00E+01	5.33E+00	7.07E+00	9.67E+00	1.43E+03	6.11E+02	7.24E+02	9.07E+02	6.57E+02	8.24E+00	1.67E+01	3.45E+01
Strait of Georgia	4.93E+02	1.22E+02	2.12E+02	2.69E+02	9.62E+01	6.83E+00	9.07E+00	1.24E+01	1.38E+03	7.84E+02	9.28E+02	1.16E+03	3.04E+02	1.06E+01	2.15E+01	4.42E+01
Strait of Juan de Fuca	4.54E+01	2.24E+01	3.87E+01	4.93E+01	4.83E+00	1.25E+00	1.66E+00	2.27E+00	2.02E+02	1.43E+02	1.70E+02	2.13E+02	9.98E+00	1.93E+00	3.93E+00	8.09E+00
Whidbey Basin	9.55E+01	7.71E+01	1.33E+02	1.70E+02	1.07E+01	4.31E+00	5.72E+00	7.82E+00	6.49E+02	4.94E+02	5.85E+02	7.33E+02	2.78E+01	6.66E+00	1.35E+01	2.79E+01
Puget Sound Total	**6.23E+03**	**2.50E+03**	**4.33E+03**	**5.51E+03**	**1.06E+03**	**1.40E+02**	**1.86E+02**	**2.54E+02**	**1.96E+04**	**1.60E+04**	**1.90E+04**	**2.38E+04**	**2.57E+03**	**2.16E+02**	**4.39E+02**	**9.05E+02**

Key:

The precision of the data in this table is only two significant figures.

The loadings from POTWs to the Elliott Bay Study Area was zero because this area of Puget Sound had no POTWs discharging to it.

kg/year = Kilograms per year.

(a) = From EnviroVision, et al., 2008; and Maroncelli, James, 2009.
The estimated loadings were based on: (1) Replacement of non-detect results with one-half the method detection limit or method reporting limit; and (2) Extrapolations for those POTWs without analytical results by using the median concentration of all POTWs.

Figures

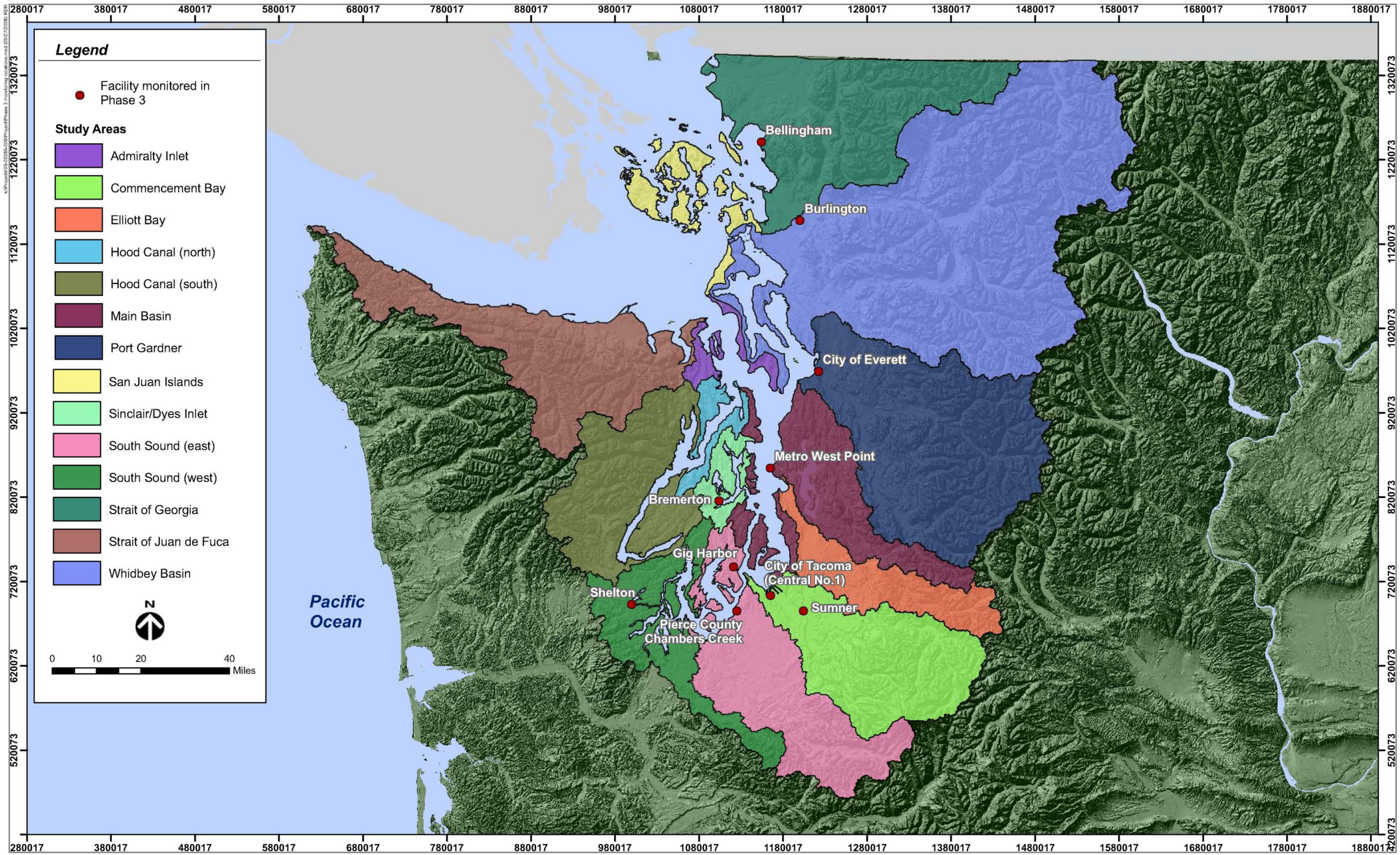

Figure 1. Location Map of the Ten Publicly Owned Treatment Works.

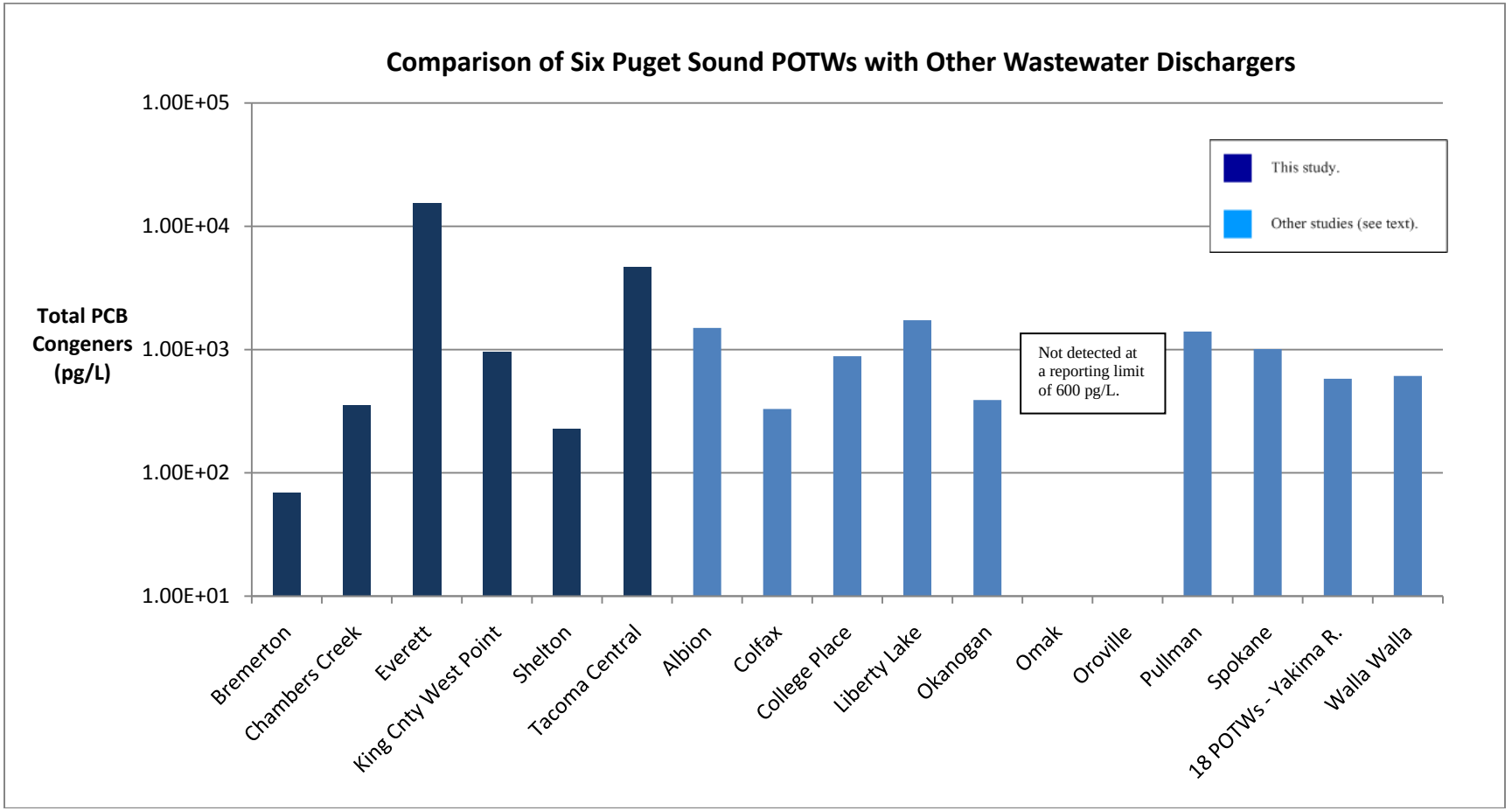

Figure 2. Comparison of Average Total PCB Results among Several POTWs

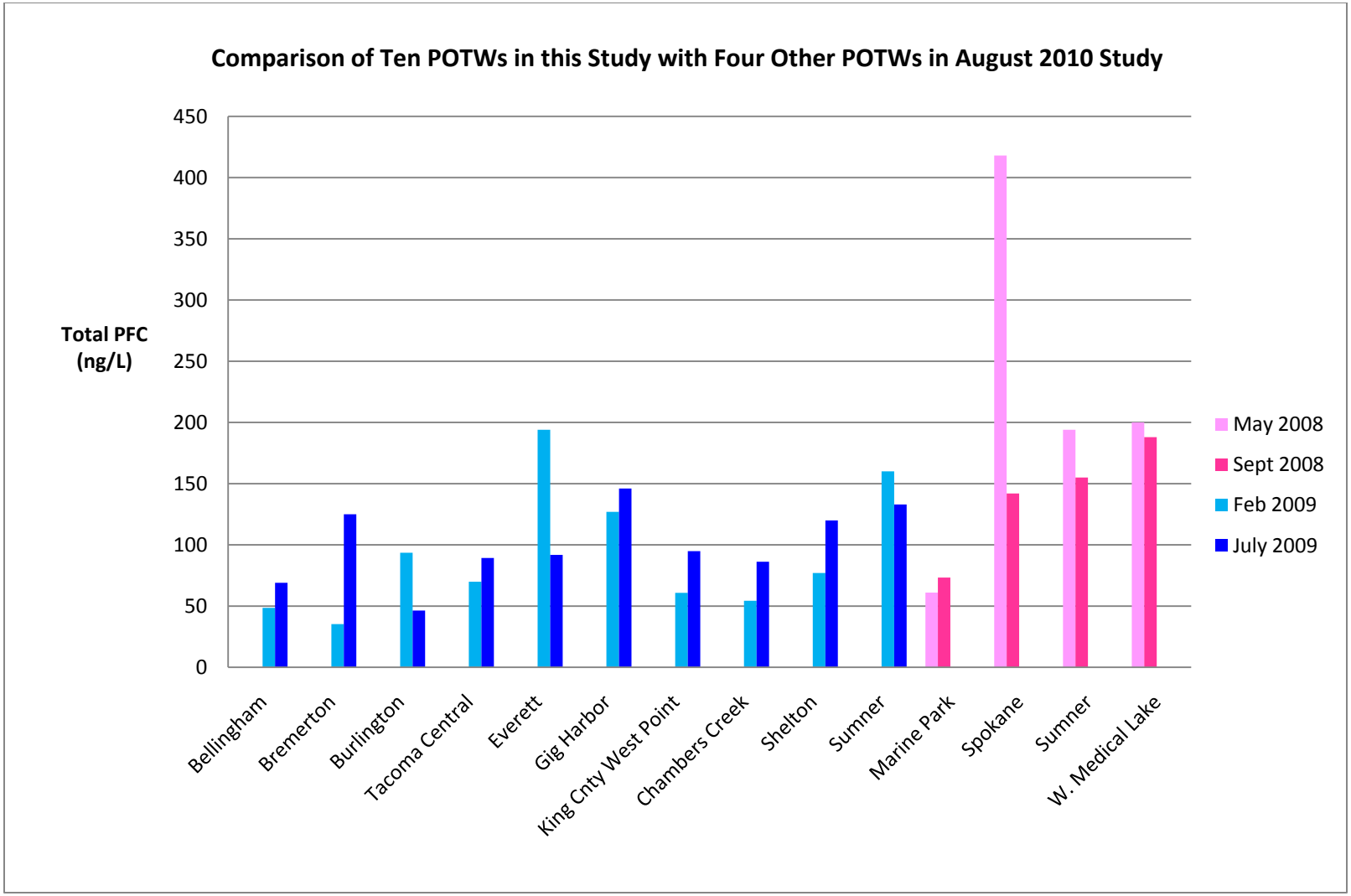

Figure 3. Comparison of Average Total PFC Results among Several POTWs

Appendix A.

List of the POTWs in the Puget Sound Basin

Appendix A. List of POTWs in the Puget Sound Basin

Study Area	POTW Name	Permit Number	Average Flow: Reported 2007 - 2009 (MGD)
Admiralty Inlet	Port Townsend STP (Biosolids Facility)	WA0037052	0.9089
Commencement Bay	Buckley STP	WA0023361	0.5633
	Carbonado STP	WA0020834	0.02422
	Cherrywood Mobile Home Manor	WA0037079	0.01175
	City of Tacoma Central No. 1	WA0037087	19.87
	City of Tacoma North No. 3	WA0037214	4.475
	Enumclaw STP	WA0020575	1.572
	Orting STP	WA0020303	0.5762
	Puyallup STP	WA0037168	4.039
	Rainier State School	WA0037923	0.112
	South Prairie STP	WA0040479	0.02736
	Sumner STP	WA0023353	2.006
	Wilkeson STP	WA0023281	0.04119
Elliott Bay	none		
Hood Canal (north)	Olympic Water and Sewer, Inc.	WA0021202	0.1893
	Pope Resources (a)	WA0022292	0.0118
Hood Canal (south)	Alderbrook Resort and Spa	WA0037753	0.01607
Main Basin	Alderwood WTP	WA0020826	2.085
	Bainbridge Island City WWTP	WA0020907	0.5251
	Edmonds STP	WA0024058	5.488
	Kitsap County Kingston WWTP	WA0032077	0.1042
	Kitsap County Manchester	WA0023701	0.2066
	Lakehaven Utility District (Lakota STP)	WA0022624	5.2
	Lynnwood STP	WA0024031	4.065
	King County Renton (South Treatment Plant)	WA0029581	74.9
	King County West Point	WA0029181	92.46
	Messenger House Care Center	WA0023469	0.005892
	Midway Sewer District	WA0020958	4.136
	Miller Creek WWTP	WA0022764	2.797
	Mukilteo Water District (Olympus Terrace STP)	WA0023396	1.609
	Redondo WWTP	WA0023451	2.694
	Salmon Creek WWTP (Burien)	WA0022772	2.25
	Vashon STP	WA0022527	0.09314

Appendix A. List of POTWs in the Puget Sound Basin

Study Area	POTW Name	Permit Number	Average Flow: Reported 2007 - 2009 (MGD)
Port Gardner	Carnation WWTP	WA0032182	0.0907
	Duvall STP	WA0029513	0.5366
	Everett STP (all outfalls)	WA0024490	20.02
	Granite Falls STP	WA0021130	0.2921
	Lake Stevens Sewer District	WA0020893	2.12
	Marysville STP	WA0022497	4.538
	Monroe WWTP	WA0020486	1.526
	North Bend STP	WA0029351	0.4658
	Snohomish STP	WA0029548	1.192
	Snoqualmie WWTP	WA0022403	0.9815
	Sultan WWTP	WA0023302	0.3696
San Juan Islands	Anacortes WWTP	WA0020257	1.821
	Eastsound Orcas Village	WA0030911	0.003354
	Eastsound Water District	WA0030571	0.09869
	Fisherman Bay STP	WA0030589	0.01658
	Friday Harbor STP	WA0023582	0.2696
	Roche Harbor Resort	WA0021822	0.03388
	Rosario WWTP	WA0029891	0.0241
Sinclair/Dyes Inlet	Bremerton STP	WA0029289	4.304
	Kitsap County Central Kitsap	WA0030520	3.83
	Kitsap County Sewer District 7	WA0030317	0.08297
	Port Orchard WWTP	WA0020346	1.704
South Sound (east)	Eatonville STP	WA0037231	0.2073
	Gig Harbor STP	WA0023957	0.8088
	Pierce County Chambers Creek STP	WA0039624	17.89
	WA DOC McNeil Island STP	WA0040002	0.2264
	Yelm STP	WA0040762	0.2986
South Sound (west)	Boston Harbor STP	WA0040291	0.03061
	Carlyon Beach STP	WA0037915	0.02169
	Hartstene Pointe STP	WA0038377	0.06468
	LOTT WWTP	WA0037061	10.77
	Rustlewood STP	WA0038075	0.02942
	Seashore Villa STP	WA0037273	0.01229
	Shelton STP	WA0023345	1.988
	Tamoshan STP	WA0037290	0.02594
	Taylor Bay STP	WA0037656	0.01095

Appendix A. List of POTWs in the Puget Sound Basin

Study Area	POTW Name	Permit Number	Average Flow: Reported 2007 - 2009 (MGD)
Strait of Georgia	Bellingham STP	WA0023744	12.3
	Birch Bay STP	WA0029556	0.849
	Blaine STP	WA0022641	0.539
	Everson STP	WA0020435	0.2556
	Ferndale STP	WA0022454	1.533
	Lynden STP	WA0022578	1.131
	WA Parks Larrabee State Park	WA0023787	0.006589
Strait of Juan de Fuca	Clallam Bay STP	WA0024431	0.02675
	Port Angeles STP	WA0023973	2.324
	Sekiu STP	WA0024449	0.06453
	Sequim STP	WA0022349	0.4912
	WA DOC Clallam Bay Corrections Center	WA0039845	0.1314
Whidbey Basin	Arlington STP	WA0022560	1.203
	Burlington WWTP	WA0020150	1.637
	Concrete STP	WA0020851	0.08774
	Coupeville STP	WA0029378	0.1628
	Indian Ridge Youth Camp	WA0029424	0.00005325
	La Conner STP	WA0022446	0.2365
	Langley STP	WA0020702	0.07734
	Mt Vernon WWTP	WA0024074	3.674
	Oak Harbor STP	WA0020567	1.839
	Penn Cove WWTP	WA0029386	0.02442
	Seattle City Light Diablo	WA0029858	0.006129
	Seattle City Light Newhalem	WA0029670	0.005357
	Sedro Woolley STP	WA0023752	0.8123
	Skagit County Sewer District 2 (Big Lake)	WA0030597	0.1318
	Stanwood STP	WA0020290	0.5494
	Warm Beach Campground & Conference Center	WA0029904	0.02604
Puget Sound Total =		**MGY =**	**124,143**

Key:

The precision of the data in this table is only two significant figures.

MGD = Million gallons per day.

MGY = Million gallons per year.

POTW = Publicly Owned Treatment Works.

(a) = Although the Pope Resources facility treats Port Gardner's sanitary wastewater, it is privately owned.

Appendix B.

Data Usability Summary Reports

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: March 31, 2008	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance level 1 review (QA1) (PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Matrix	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0902008	Water	Sumner	0902008-01	02/12/2009		None
0902008	Water	Gig Harbor	0902008-02	02/10/2009		None
0902008	Water	Shelton	0902008-03	02/10/2009		None
0902008	Water	Everett	0902008-04	02/12/2009		None
0902008	Water	Burlington	0902008-05	02/10/2009		None
0902008	Water	Bremerton	0902008-06	02/10/2009		None
0902008	Water	Tacoma	0902008-07	02/19/2009	MS/MSD	None
0902008	Water	Chambers Creek	0902008-08	02/19/2009		None
0902008	Water	Metro West Point	0902008-09	02/10/2009		None
0902008	Water	Bellingham	0902008-10	02/12/2009		None
0902008	Water	Field Blank	0902008-11	02/12/2009		None

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Orders	Matrix	Test Method	Method Name	Number of Samples
0902008	Water	SW846 8270 SIM	Polycyclic Aromatic Hydrocarbons by Gas Chromatography/Mass Spectrometry-SIM	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes
Did coolers arrive at lab between 0 °C and 6°C and in good condition as indicated on COC and Cooler Receipt Form?	Yes
Frequency of Field QC Samples Correct? Field Duplicate – Not required. Field Blank – 1/20 samples. MS/MSD samples – 1/20 samples.	Yes
Case narrative present and complete?	Yes
Any holding time violations?	No - All samples were prepared and analyzed within holding times.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);

- Surrogates Outside Limits (Table 4);
- MS/MSD Outside Limits (Table 5);
- LCS Outside Limits (Table 6); and
- Re-analysis Results (Table 7).

The PAH data was originally reviewed Dickey Huntamer, Manchester Environmental Laboratory (MEL) on March 10, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided by the laboratory.

Polycyclic Aromatic Hydrocarbons (PAHs) by GC/MS SIM	
Description	**Notes and Qualifiers**
Any compounds present in method and field blanks?	Yes, refer to Table 3.
For samples, if associated results are <5 times the method blank or <3 times the field blank then "U" flag data.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one blank and LCS with each batch and one set of MS/MSD per 20 samples?	Yes.
Surrogate standard recovery values for samples, MS/MSD, method blanks, and LCS/LCSD samples within laboratory QC limits?	No, please refer to Table 4. No action was taken for one surrogate outlier.
Internal standard recovery values for samples, MS/MSD, method blanks, and LCS/LCSD samples within laboratory QC limits?	Yes.
MS/MSD percent recovery values within laboratory QC criteria?	Yes.
MS/MSD relative percent difference values within QC criteria (see Table 4) of <35%?	Yes.
LCS percent recovery values within laboratory QC criteria (see Table 5)? If the value is high with no positive values in the associated data; then no data qualification is required.	Yes.
Is initial calibration for target compounds <20 % RSD or curve fit?	Yes
Is initial calibration verification standard for target compounds <30 %?	Yes.
Is continuing calibration for target compounds < 20%?	Yes
Were any samples re-analyzed or diluted (see Table 6)? For any sample re-analysis and dilutions is only one reportable result by flagged?	No

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Samples results below the PQL are reported at the PQL and flagged not detected (U) due to method blank contamination. Matrix spike (B09B138-MS1, parent sample Tacoma) percent recovery values were outside QC limits, the sample results were qualified (refer to Table 4). Laboratory control sample percent recovery values were outside QC limits, associated samples were qualified (refer to Table 5).

Table 3 - List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL	MDL
SW846 8270SIM	B09B099-BLK1	MBLK	1-Methylnaphthalene	0.0048	J	µg/L	0.010	0.0016
SW846 8270SIM	B09B099-BLK1	MBLK	2-Methylnaphthalene	0.0048	J	µg/L	0.010	0.0015

Method	SampleID	SampType	Analyte	Result	Qual	Units	PQL	MDL
SW846 8270SIM	B09B099-BLK1	MBLK	Naphthalene	0.0051	J	µg/L	0.010	0.0011
SW846 8270SIM	B09B115-BLK1	MBLK	1-Methylnaphthalene	0.0048	J	µg/L	0.010	0.0016
SW846 8270SIM	B09B115-BLK1	MBLK	2-Methylnaphthalene	0.0048	J	µg/L	0.010	0.0015
SW846 8270SIM	B09B115-BLK1	MBLK	Fluorene	0.0015	J	µg/L	0.010	0.0014
SW846 8270SIM	B09B115-BLK1	MBLK	Naphthalene	0.0051	J	µg/L	0.010	0.0011
SW846 8270SIM	B09B139-BLK1	MBLK	1-Methylnaphthalene	0.0052	J	µg/L	0.010	0.0016
SW846 8270SIM	B09B139-BLK1	MBLK	2-Methylnaphthalene	0.0049	J	µg/L	0.010	0.0015
SW846 8270SIM	B09B139-BLK1	MBLK	Fluorene	0.0027	J	µg/L	0.010	0.0014
SW846 8270SIM	B09B139-BLK1	MBLK	Naphthalene	0.0053	J	µg/L	0.010	0.0011
SW846 8270SIM	B09B139-BLK1	MBLK	Phenanthrene	0.0022	J	µg/L	0.010	

Table 3A - List of Samples Qualified for Method Blank Contamination

Method	Sample ID	Analyte	Result	Qual
SW846 8270SIM	Gig Harbor	1-Methylnaphthalene	0.012	U
SW846 8270SIM	Gig Harbor	2-Methylnaphthalene	0.0094	U
SW846 8270SIM	Shelton	1-Methylnaphthalene	0.0084	U
SW846 8270SIM	Shelton	2-Methylnaphthalene	0.0090	U
SW846 8270SIM	Shelton	Naphthalene	0.025	U
SW846 8270SIM	Burlington	1-Methylnaphthalene	0.012	U
SW846 8270SIM	Burlington	2-Methylnaphthalene	0.0082	U
SW846 8270SIM	Bremerton	1-Methylnaphthalene	0.012	U
SW846 8270SIM	Bremerton	2-Methylnaphthalene	0.011	U
SW846 8270SIM	Metro Point West	1-Methylnaphthalene	0.020	U
SW846 8270SIM	Metro Point West	2-Methylnaphthalene	0.022	U
SW846 8270SIM	Sumner	1-Methylnaphthalene	0.012	U
SW846 8270SIM	Sumner	2-Methylnaphthalene	0.0090	U
SW846 8270SIM	Everett	Naphthalene	0.018	U
SW846 8270SIM	Bellingham	1-Methylnaphthalene	0.0099	U
SW846 8270SIM	Bellingham	2-Methylnaphthalene	0.010	U
SW846 8270SIM	Field Blank	Naphthalene	0.017	U
SW846 8270SIM	Tacoma	1-Methylnaphthalene	0.015	U
SW846 8270SIM	Tacoma	2-Methylnaphthalene	0.018	U
SW846 8270SIM	Tacoma	Phenanthrene	0.0080	U
SW846 8270SIM	Chambers Creek	2-Methylnaphthalene	0.014	U

Table 4 - List of Samples with Surrogates outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	QC Limit	Sample Qualification
SW846 8270SIM	Everett	Benzo(a)pyrene- d12	43	50 - 150	None
SW846 8270SIM	Tacoma	Benzo(a)pyrene- d12	42	50 - 150	None
SW846 8270SIM	Tacoma MS	Benzo(a)pyrene- d12	28	50 - 150	None
SW846 8270SIM	Tacoma MSD	Benzo(a)pyrene- d12	34	50 - 150	None
SW846 8270SIM	Chambers Creek	Benzo(a)pyrene- d12	34	50 - 150	None

Table 5 - List MS/MSD Percent Recovery Values and RPDs outside Control Limits
None

Table 6 - List LCS Percent Recovery Values outside Control Limits
None

Table 7 –Samples that were Reanalyzed
None

Key:
A = Analyte
NC = Not Calculated
ND = Not Detected
PQL = Practical Quantitation Limit
RPD = Relative Percent Difference

Data Validation Qualifiers:

Code	Description
B	Analyte detected in sample and method blank. Reported result is sample concentration without blank correction or associated quantitation limit.
JG	Analyte was positively identified. Value may be greater than the reported estimate.
JK	Analyte was positively identified. Reported result is an estimate with unknown bias.
JL	Analyte was positively identified. Value may be less than the reported estimate.
JT	Analyte was positively identified. Reported result is an estimate below the associated quantitation limit but above the MDL.
JTG	Analyte was positively identified. Value may be greater than the reported result, which is an estimate below the associated quantitation limit but above the MDL.
JTK	Analyte was positively identified. Reported result is an estimate with unknown bias, below the associated quantitation limit but above the MDL.
JTL	Analyte was positively identified. Value may be less than the reported result which is an estimate below associated quantitation limit but above MDL.
NJ	There is evidence that the analyte is present in the sample. Reported result for the tentatively identified analyte is an estimate.
NJT	There is evidence the analyte is present in the sample. Reported result for the tentatively identified analyte is an estimate below the associated quantitation limit but above the MDL.
NU	There is evidence the analyte is present in the sample. Tentatively identified analyte was not detected at or above the reported result.
NUJ	There is evidence the analyte is present in the sample. Tentatively identified analyte was not detected at or above the reported estimate.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
U	Analyte was not detected at or above the reported result.
UJ	Analyte was not detected at or above the reported estimate
UJG	Analyte was not detected at or above the reported estimate with likely low bias.
UJK	Analyte was not detected at or above the reported estimate with unknown bias.
UJL	Analyte was not detected at or above the reported estimate with likely high bias.

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Gig Harbor

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1500 mL
Final Vol: 1 mL

Lab ID #: 0902008-02
Collected: 2/10/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B099
Prepared: 2/12/2009
Analyzed: 2/18/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	1-Methylnaphthalene	0.012	~~UT~~ U	0.0067	0.0010
91-58-7	2-Chloronaphthalene	0.0067	U	0.0067	0.0008
91-57-6	2-Methylnaphthalene	0.0094	~~UT~~ U	0.0067	0.0010
83-32-9	Acenaphthene	0.0067	U	0.0067	0.0016
208-96-8	Acenaphthylene	0.0067	U	0.0067	0.0009
120-12-7	Anthracene	0.0067	U	0.0067	
56-55-3	Benzo(a)anthracene	0.0067	U	0.0067	0.0007
50-32-8	Benzo(a)pyrene	0.0067	U	0.0067	0.0007
205-99-2	Benzo(b)fluoranthene	0.0067	U	0.0067	0.0012
191-24-2	Benzo(ghi)perylene	0.0067	U	0.0067	0.0007
207-08-9	Benzo(k)fluoranthene	0.0067	U	0.0067	0.0014
86-74-8	Carbazole	0.0067	U	0.0067	0.0010
218-01-9	Chrysene	0.0067	U	0.0067	0.0008
53-70-3	Dibenzo(a,h)anthracene	0.0067	U	0.0067	0.0010
132-64-9	Dibenzofuran	0.0067	U	0.0067	0.0008
206-44-0	Fluoranthene	0.0067	U	0.0067	0.0010
86-73-7	Fluorene	0.0067	U	0.0067	0.0009
193-39-5	Indeno(1,2,3-cd)pyrene	0.0067	U	0.0067	0.0021
91-20-3	**Naphthalene**	**0.13**		0.0067	0.0007
85-01-8	**Phenanthrene**	**0.0061**	JT	0.0067	
129-00-0	**Pyrene**	**0.0043**	JT	0.0067	0.0011
483-65-8	Retene	0.0067	U	0.0067	

Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.254		0.267	95	30-115
93951-97-4	Acenaphthylene-D8	0.209		0.267	78	50-150
1719-06-8	Anthracene-D10	0.224		0.267	84	50-150
63466-71-7	Benzo(a)pyrene-D12	0.141		0.267	53	50-150
81103-79-9	Fluorene-D10	0.214		0.267	80	50-150
1718-52-1	Pyrene-D10	0.254		0.267	95	50-150
1718-51-0	Terphenyl-D14	0.181		0.267	68	18-137

Authorized by: _____ Release Date: 3/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Shelton

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1580 mL
Final Vol: 1 mL

Lab ID #: 0902008-03
Collected: 2/10/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B099
Prepared: 2/12/2009
Analyzed: 2/18/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	1-Methylnaphthalene	0.0084	~~U~~ U	0.0063	0.0010
91-58-7	**2-Chloronaphthalene**	**0.0047**	JT	0.0063	0.0008
91-57-6	2-Methylnaphthalene	0.0090	~~U~~ U	0.0063	0.0009
83-32-9	Acenaphthene	0.0063	U	0.0063	0.0015
208-96-8	Acenaphthylene	0.0063	U	0.0063	0.0009
120-12-7	Anthracene	0.0063	U	0.0063	
56-55-3	Benzo(a)anthracene	0.0063	U	0.0063	0.0007
50-32-8	Benzo(a)pyrene	0.0063	U	0.0063	0.0007
205-99-2	Benzo(b)fluoranthene	0.0063	U	0.0063	0.0011
191-24-2	Benzo(ghi)perylene	0.0063	U	0.0063	0.0006
207-08-9	Benzo(k)fluoranthene	0.0063	U	0.0063	0.0014
86-74-8	Carbazole	0.0063	U	0.0063	0.0009
218-01-9	Chrysene	0.0063	U	0.0063	0.0008
53-70-3	Dibenzo(a,h)anthracene	0.0063	U	0.0063	0.0010
132-64-9	**Dibenzofuran**	**0.0056**	JT	0.0063	0.0007
206-44-0	Fluoranthene	0.0063	U	0.0063	0.0009
86-73-7	**Fluorene**	**0.0057**	JT	0.0063	0.0009
193-39-5	Indeno(1,2,3-cd)pyrene	0.0063	U	0.0063	0.0019
91-20-3	**Naphthalene**	**0.025**	U	0.0063	0.0007
85-01-8	**Phenanthrene**	**0.0051**	JT	0.0063	
129-00-0	Pyrene	0.0063	U	0.0063	0.0011
483-65-8	Retene	0.0063	U	0.0063	

(1) no peak at RT

Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.223		0.253	88	30-115
93951-97-4	Acenaphthylene-D8	0.196		0.253	77	50-150
1719-06-8	Anthracene-D10	0.213		0.253	84	50-150
63466-71-7	Benzo(a)pyrene-D12	0.181		0.253	72	50-150
81103-79-9	Fluorene-D10	0.195		0.253	77	50-150
1718-52-1	Pyrene-D10	0.231		0.253	91	50-150
1718-51-0	Terphenyl-D14	0.198		0.253	78	18-137

Authorized by: _____ Release Date: 5/20/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs **Field ID: Burlington**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1660 mL
Final Vol: 1 mL

Lab ID #: 0902008-05
Collected: 2/10/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B099
Prepared: 2/12/2009
Analyzed: 2/19/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	1-Methylnaphthalene	0.0097	~~U~~	0.0060	0.0009
91-58-7	2-Chloronaphthalene	0.0060	U	0.0060	0.0007
91-57-6	2-Methylnaphthalene	0.0082	~~U~~	0.0060	0.0009
83-32-9	Acenaphthene	0.0060	U	0.0060	0.0015
208-96-8	Acenaphthylene	0.0060	U	0.0060	0.0008
120-12-7	Anthracene	0.0060	U	0.0060	
56-55-3	Benzo(a)anthracene	0.0060	U	0.0060	0.0007
50-32-8	Benzo(a)pyrene	0.0060	U	0.0060	0.0006
205-99-2	Benzo(b)fluoranthene	0.0060	U	0.0060	0.0011
191-24-2	Benzo(ghi)perylene	0.0060	U	0.0060	0.0006
207-08-9	Benzo(k)fluoranthene	0.0060	U	0.0060	0.0013
86-74-8	Carbazole	0.0060	U	0.0060	0.0009
218-01-9	Chrysene	0.0060	U	0.0060	0.0007
53-70-3	Dibenzo(a,h)anthracene	0.0060	U	0.0060	0.0009
132-64-9	**Dibenzofuran**	**0.0061**		0.0060	0.0007
206-44-0	**Fluoranthene**	**0.0037**	J	0.0060	0.0009
86-73-7	**Fluorene**	**0.011**		0.0060	0.0008
193-39-5	Indeno(1,2,3-cd)pyrene	0.0060	U	0.0060	0.0019
91-20-3	**Naphthalene**	**0.027**		0.0060	0.0007
85-01-8	Phenanthrene	0.0060	U	0.0060	
129-00-0	**Pyrene**	**0.0045**	J	0.0060	0.0010
483-65-8	Retene	0.0060	U	0.0060	

PRIMARY

Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.219		0.241	91	30-115
93951-97-4	Acenaphthylene-D8	0.185		0.241	77	50-150
1719-06-8	Anthracene-D10	0.209		0.241	87	50-150
63466-71-7	Benzo(a)pyrene-D12	0.164		0.241	68	50-150
81103-79-9	Fluorene-D10	0.183		0.241	76	50-150
1718-52-1	Pyrene-D10	0.220		0.241	91	50-150
1718-51-0	Terphenyl-D14	0.184		0.241	76	18-137

Authorized by: _____ Release Date: 3/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Bremerton

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1540 mL
Final Vol: 1 mL

Lab ID #: 0902008-06
Collected: 2/10/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B099
Prepared: 2/12/2009
Analyzed: 2/19/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	**1-Methylnaphthalene**	**0.012**	U	0.0065	0.0010
91-58-7	2-Chloronaphthalene	0.0065	U	0.0065	0.0008
91-57-6	**2-Methylnaphthalene**	**0.011**	U	0.0065	0.0010
83-32-9	Acenaphthene	0.0065	U	0.0065	0.0016
208-96-8	Acenaphthylene	0.0065	U	0.0065	0.0009
120-12-7	Anthracene	0.0065	U	0.0065	
56-55-3	Benzo(a)anthracene	0.0065	U	0.0065	0.0007
50-32-8	Benzo(a)pyrene	0.0065	U	0.0065	0.0007
205-99-2	Benzo(b)fluoranthene	0.0065	U	0.0065	0.0012
191-24-2	Benzo(ghi)perylene	0.0065	U	0.0065	0.0006
207-08-9	Benzo(k)fluoranthene	0.0065	U	0.0065	0.0014
86-74-8	Carbazole	0.0065	U	0.0065	0.0009
218-01-9	Chrysene	0.0065	U	0.0065	0.0008
53-70-3	Dibenzo(a,h)anthracene	0.0065	U	0.0065	0.0010
132-64-9	**Dibenzofuran**	**0.0062**	J T	0.0065	0.0008
206-44-0	**Fluoranthene**	**0.0037**	J T	0.0065	0.0009
86-73-7	**Fluorene**	**0.0069**		0.0065	0.0009
193-39-5	Indeno(1,2,3-cd)pyrene	0.0065	U	0.0065	0.0020
91-20-3	**Naphthalene**	**0.040**		0.0065	0.0007
85-01-8	**Phenanthrene**	**0.0054**	J T	0.0065	
129-00-0	**Pyrene**	**0.0060**	J T	0.0065	0.0011
483-65-8	Retene	0.0065	U	0.0065	

(1) 10 April 2009

Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.233		0.26	90	30-115
93951-97-4	Acenaphthylene-D8	0.192		0.26	74	50-150
1719-06-8	Anthracene-D10	0.227		0.26	87	50-150
63466-71-7	Benzo(a)pyrene-D12	0.156		0.26	60	50-150
81103-79-9	Fluorene-D10	0.194		0.26	75	50-150
1718-52-1	Pyrene-D10	0.243		0.26	94	50-150
1718-51-0	Terphenyl-D14	0.191		0.26	74	18-137

Authorized by: _____ Release Date: 3/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs **Field ID: Metro West Point**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1700 mL
Final Vol: 1 mL

Lab ID #: 0902008-09
Collected: 2/10/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B099
Prepared: 2/12/2009
Analyzed: 2/19/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	**1-Methylnaphthalene**	**0.020**	J	0.0059	0.0009
91-58-7	2-Chloronaphthalene	0.0059	U	0.0059	0.0007
91-57-6	**2-Methylnaphthalene**	**0.022**	J	0.0059	0.0009
83-32-9	**Acenaphthene**	**0.012**		0.0059	0.0014
208-96-8	**Acenaphthylene**	**0.0051**	JT	0.0059	0.0008
120-12-7	**Anthracene**	**0.0039**	JT	0.0059	
56-55-3	Benzo(a)anthracene	0.0059	U	0.0059	0.0006
50-32-8	Benzo(a)pyrene	0.0059	U	0.0059	0.0006
205-99-2	Benzo(b)fluoranthene	0.0059	U	0.0059	0.0011
191-24-2	Benzo(ghi)perylene	0.0059	U	0.0059	0.0006
207-08-9	Benzo(k)fluoranthene	0.0059	U	0.0059	0.0013
86-74-8	Carbazole	0.0059	U	0.0059	0.0008
218-01-9	Chrysene	0.0059	U	0.0059	0.0007
53-70-3	Dibenzo(a,h)anthracene	0.0059	U	0.0059	0.0009
132-64-9	**Dibenzofuran**	**0.021**		0.0059	0.0007
206-44-0	**Fluoranthene**	**0.0075**		0.0059	0.0009
86-73-7	**Fluorene**	**0.025**		0.0059	0.0008
193-39-5	**Indeno(1,2,3-cd)pyrene**	**0.0047**	JT	0.0059	0.0018
91-20-3	**Naphthalene**	**0.044**		0.0059	0.0007
85-01-8	**Phenanthrene**	**0.016**		0.0059	
129-00-0	**Pyrene**	**0.014**		0.0059	0.0010
483-65-8	Retene	0.0059	U	0.0059	

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Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.224		0.235	95	30-115
93951-97-4	Acenaphthylene-D8	0.193		0.235	82	50-150
1719-06-8	Anthracene-D10	0.199		0.235	84	50-150
63466-71-7	Benzo(a)pyrene-D12	0.118		0.235	50	50-150
81103-79-9	Fluorene-D10	0.195		0.235	83	50-150
1718-52-1	Pyrene-D10	0.207		0.235	88	50-150
1718-51-0	Terphenyl-D14	0.145		0.235	62	18-137

Authorized by: _____ Release Date: 5/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Sumner

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1615 mL
Final Vol: 1 mL

Lab ID #: 0902008-01
Collected: 2/12/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B115
Prepared: 2/17/2009
Analyzed: 2/18/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	1-Methylnaphthalene	0.012	~~U~~ J	0.0062	0.0010
91-58-7	2-Chloronaphthalene	0.0062	U	0.0062	0.0008
91-57-6	2-Methylnaphthalene	0.0090	~~U~~ J	0.0062	0.0009
83-32-9	**Acenaphthene**	**0.0055**	J	0.0062	0.0015
208-96-8	**Acenaphthylene**	**0.0032**	J	0.0062	0.0009
120-12-7	Anthracene	0.0062	U	0.0062	
56-55-3	Benzo(a)anthracene	0.0062	U	0.0062	0.0007
50-32-8	Benzo(a)pyrene	0.0062	U	0.0062	0.0007
205-99-2	Benzo(b)fluoranthene	0.0062	U	0.0062	0.0011
191-24-2	Benzo(ghi)perylene	0.0062	U	0.0062	0.0006
207-08-9	Benzo(k)fluoranthene	0.0062	U	0.0062	0.0013
86-74-8	Carbazole	0.0062	U	0.0062	0.0009
218-01-9	Chrysene	0.0062	U	0.0062	0.0007
53-70-3	Dibenzo(a,h)anthracene	0.0062	U	0.0062	0.0009
132-64-9	**Dibenzofuran**	**0.0081**		0.0062	0.0007
206-44-0	**Fluoranthene**	**0.0049**	J	0.0062	0.0009
86-73-7	**Fluorene**	**0.0090**		0.0062	0.0008
193-39-5	Indeno(1,2,3-cd)pyrene	0.0062	U	0.0062	0.0019
91-20-3	**Naphthalene**	**0.030**		0.0062	0.0007
85-01-8	**Phenanthrene**	**0.0060**	J	0.0062	
129-00-0	**Pyrene**	**0.0043**	J	0.0062	0.0010
483-65-8	Retene	0.0062	U	0.0062	

Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.216		0.248	87	30-115
93951-97-4	Acenaphthylene-D8	0.180		0.248	73	50-150
1719-06-8	Anthracene-D10	0.207		0.248	83	50-150
63466-71-7	Benzo(a)pyrene-D12	0.179		0.248	72	50-150
81103-79-9	Fluorene-D10	0.178		0.248	72	50-150
1718-52-1	Pyrene-D10	0.226		0.248	91	50-150
1718-51-0	Terphenyl-D14	0.204		0.248	82	18-137

Authorized by: _____ Release Date: 3/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Everett

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1520 mL
Final Vol: 1 mL

Lab ID #: 0902008-04
Collected: 2/12/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B115
Prepared: 2/17/2009
Analyzed: 2/18/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	1-Methylnaphthalene	0.0066	U	0.0066	0.0010
91-58-7	2-Chloronaphthalene	0.0066	U	0.0066	0.0008
91-57-6	2-Methylnaphthalene	0.0066	U	0.0066	0.0010
83-32-9	Acenaphthene	0.0066	U	0.0066	0.0016
208-96-8	Acenaphthylene	0.0066	U	0.0066	0.0009
120-12-7	Anthracene	0.0066	U	0.0066	
56-55-3	Benzo(a)anthracene	0.0066	U	0.0066	0.0007
50-32-8	Benzo(a)pyrene	0.0066	U	0.0066	0.0007
205-99-2	Benzo(b)fluoranthene	0.0066	U	0.0066	0.0012
191-24-2	**Benzo(ghi)perylene**	**0.0059**	J+	0.0066	0.0007
207-08-9	Benzo(k)fluoranthene	0.0066	U	0.0066	0.0014
86-74-8	Carbazole	0.0066	U	0.0066	0.0009
218-01-9	Chrysene	0.0066	U	0.0066	0.0008
53-70-3	Dibenzo(a,h)anthracene	0.0066	U	0.0066	0.0010
132-64-9	Dibenzofuran	0.0066	U	0.0066	0.0008
206-44-0	**Fluoranthene**	**0.0087**		0.0066	0.0010
86-73-7	Fluorene	0.0066	U	0.0066	0.0009
193-39-5	**Indeno(1,2,3-cd)pyrene**	**0.016**		0.0066	0.0020
91-20-3	**Naphthalene**	**0.018**	U	0.0066	0.0007
85-01-8	Phenanthrene	0.0066	U	0.0066	
129-00-0	**Pyrene**	**0.016**		0.0066	0.0011
483-65-8	Retene	0.0066	U	0.0066	

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Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.252		0.263	96	30-115
93951-97-4	Acenaphthylene-D8	0.194		0.263	74	50-150
1719-06-8	Anthracene-D10	0.206		0.263	78	50-150
63466-71-7	Benzo(a)pyrene-D12	0.113		0.263	43	50-150
81103-79-9	Fluorene-D10	0.201		0.263	76	50-150
1718-52-1	Pyrene-D10	0.198		0.263	75	50-150
1718-51-0	Terphenyl-D14	0.139		0.263	53	18-137

Authorized by: _____ Release Date: 3/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Bellingham

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1650 mL
Final Vol: 1 mL

Lab ID #: 0902008-10
Collected: 2/12/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B115
Prepared: 2/17/2009
Analyzed: 2/18/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	1-Methylnaphthalene	0.0099	U	0.0061	0.0010
91-58-7	2-Chloronaphthalene	0.0086		0.0061	0.0007
91-57-6	2-Methylnaphthalene	0.010	U	0.0061	0.0009
83-32-9	Acenaphthene	0.0061	U	0.0061	0.0015
208-96-8	Acenaphthylene	0.0061	U	0.0061	0.0008
120-12-7	Anthracene	0.0061	U	0.0061	
56-55-3	Benzo(a)anthracene	0.0061	U	0.0061	0.0007
50-32-8	Benzo(a)pyrene	0.0061	U	0.0061	0.0006
205-99-2	Benzo(b)fluoranthene	0.0061	U	0.0061	0.0011
191-24-2	Benzo(ghi)perylene	0.0061	U	0.0061	0.0006
207-08-9	Benzo(k)fluoranthene	0.0061	U	0.0061	0.0013
86-74-8	Carbazole	0.0061	U	0.0061	0.0009
218-01-9	Chrysene	0.0061	U	0.0061	0.0007
53-70-3	Dibenzo(a,h)anthracene	0.0061	U	0.0061	0.0009
132-64-9	Dibenzofuran	0.011		0.0061	0.0007
206-44-0	Fluoranthene	0.0084		0.0061	0.0009
86-73-7	Fluorene	0.011		0.0061	0.0008
193-39-5	Indeno(1,2,3-cd)pyrene	0.0061	U	0.0061	0.0019
91-20-3	Naphthalene	0.037		0.0061	0.0007
85-01-8	Phenanthrene	0.011		0.0061	
129-00-0	Pyrene	0.0078		0.0061	0.0010
483-65-8	Retene	0.0061	U	0.0061	

Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.211		0.242	87	30-115
93951-97-4	Acenaphthylene-D8	0.176		0.242	73	50-150
1719-06-8	Anthracene-D10	0.208		0.242	86	50-150
63466-71-7	Benzo(a)pyrene-D12	0.134		0.242	55	50-150
81103-79-9	Fluorene-D10	0.182		0.242	75	50-150
1718-52-1	Pyrene-D10	0.217		0.242	90	50-150
1718-51-0	Terphenyl-D14	0.159		0.242	66	18-137

Authorized by: _____ Release Date: 3/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Field Blank

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1505 mL
Final Vol: 1 mL

Lab ID #: 0902008-11
Collected: 2/12/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B115
Prepared: 2/17/2009
Analyzed: 2/18/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	1-Methylnaphthalene	0.0066	U	0.0066	0.0010
91-58-7	2-Chloronaphthalene	0.0066	U	0.0066	0.0008
91-57-6	2-Methylnaphthalene	0.0066	U	0.0066	0.0010
83-32-9	Acenaphthene	0.0066	U	0.0066	0.0016
208-96-8	Acenaphthylene	0.0066	U	0.0066	0.0009
120-12-7	Anthracene	0.0066	U	0.0066	
56-55-3	Benzo(a)anthracene	0.0066	U	0.0066	0.0007
50-32-8	Benzo(a)pyrene	0.0066	U	0.0066	0.0007
205-99-2	Benzo(b)fluoranthene	0.0066	U	0.0066	0.0012
191-24-2	Benzo(ghi)perylene	0.0066	U	0.0066	0.0007
207-08-9	Benzo(k)fluoranthene	0.0066	U	0.0066	0.0014
86-74-8	Carbazole	0.0066	U	0.0066	0.0010
218-01-9	Chrysene	0.0066	U	0.0066	0.0008
53-70-3	Dibenzo(a,h)anthracene	0.0066	U	0.0066	0.0010
132-64-9	Dibenzofuran	0.0066	U	0.0066	0.0008
206-44-0	Fluoranthene	0.0066	U	0.0066	0.0010
86-73-7	Fluorene	0.0066	U	0.0066	0.0009
193-39-5	Indeno(1,2,3-cd)pyrene	0.0066	U	0.0066	0.0020
91-20-3	**Naphthalene**	**0.017**	**u**	0.0066	0.0007
85-01-8	Phenanthrene	0.0066	U	0.0066	
129-00-0	Pyrene	0.0066	U	0.0066	0.0011
483-65-8	Retene	0.0066	U	0.0066	

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Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.227		0.266	86	30-115
93951-97-4	Acenaphthylene-D8	0.221		0.266	83	50-150
1719-06-8	Anthracene-D10	0.215		0.266	81	50-150
63466-71-7	Benzo(a)pyrene-D12	0.226		0.266	85	50-150
81103-79-9	Fluorene-D10	0.207		0.266	78	50-150
1718-52-1	Pyrene-D10	0.230		0.266	87	50-150
1718-51-0	Terphenyl-D14	0.221		0.266	83	18-137

Authorized by: _____ Release Date: 2/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs — Field ID: Tacoma

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1360 mL
Final Vol: 1 mL

Lab ID #: 0902008-07
Collected: 2/19/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B139
Prepared: 2/24/2009
Analyzed: 2/24/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	**1-Methylnaphthalene**	**0.015**	U	0.0074	0.0012
91-58-7	2-Chloronaphthalene	0.0074	U	0.0074	0.0009
91-57-6	2-Methylnaphthalene	0.0082	~~J~~ U	0.0074	0.0011
83-32-9	**Acenaphthene**	**0.011**		0.0074	0.0018
208-96-8	**Acenaphthylene**	**0.0058**	J	0.0074	0.0010
120-12-7	Anthracene	0.0074	U	0.0074	
56-55-3	Benzo(a)anthracene	0.0074	U	0.0074	0.0008
50-32-8	Benzo(a)pyrene	0.0074	U	0.0074	0.0008
205-99-2	Benzo(b)fluoranthene	0.0074	U	0.0074	0.0013
191-24-2	Benzo(ghi)perylene	0.0074	U	0.0074	0.0007
207-08-9	Benzo(k)fluoranthene	0.0074	U	0.0074	0.0016
86-74-8	Carbazole	0.0074	U	0.0074	0.0011
218-01-9	Chrysene	0.0074	U	0.0074	0.0009
53-70-3	Dibenzo(a,h)anthracene	0.0074	U	0.0074	0.0011
132-64-9	**Dibenzofuran**	**0.019**		0.0074	0.0009
206-44-0	**Fluoranthene**	**0.015**		0.0074	0.0011
86-73-7	**Fluorene**	**0.022**		0.0074	0.0010
193-39-5	Indeno(1,2,3-cd)pyrene	0.0074	U	0.0074	0.0023
91-20-3	**Naphthalene**	**0.036**		0.0074	0.0008
85-01-8	**Phenanthrene**	**0.0080**	U	0.0074	
129-00-0	**Pyrene**	**0.018**		0.0074	0.0012
483-65-8	Retene	0.0074	U	0.0074	

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Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.287		0.294	97	30-115
93951-97-4	Acenaphthylene-D8	0.246		0.294	84	50-150
1719-06-8	Anthracene-D10	0.245		0.294	83	50-150
63466-71-7	Benzo(a)pyrene-D12	0.123		0.294	42	50-150
81103-79-9	Fluorene-D10	0.251		0.294	85	50-150
1718-52-1	Pyrene-D10	0.249		0.294	85	50-150
1718-51-0	Terphenyl-D14	0.162		0.294	55	18-137

Authorized by: _____ Release Date: 3/26/09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
PAHs SIM list

Project: Phase 3: Priority Pollutant Scans of Ten POTWs **Field ID: Chambers Creek**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1540 mL
Final Vol: 1 mL

Lab ID #: 0902008-08
Collected: 2/19/2009
Prep Method: SW3510A
Analysis Method: SW8270

Batch ID: B09B139
Prepared: 2/24/2009
Analyzed: 2/24/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
90-12-0	**1-Methylnaphthalene**	**0.025**		0.0065	0.0010
91-58-7	2-Chloronaphthalene	0.0065	U	0.0065	0.0008
91-57-6	**2-Methylnaphthalene**	**0.014**	J	0.0065	0.0010
83-32-9	**Acenaphthene**	**0.014**		0.0065	0.0016
208-96-8	Acenaphthylene	0.0065	U	0.0065	0.0009
120-12-7	Anthracene	0.0065	U	0.0065	
56-55-3	Benzo(a)anthracene	0.0065	U	0.0065	0.0007
50-32-8	Benzo(a)pyrene	0.0065	U	0.0065	0.0007
205-99-2	Benzo(b)fluoranthene	0.0065	U	0.0065	0.0012
191-24-2	Benzo(ghi)perylene	0.0065	U	0.0065	0.0006
207-08-9	Benzo(k)fluoranthene	0.0065	U	0.0065	0.0014
86-74-8	Carbazole	0.0065	U	0.0065	0.0009
218-01-9	Chrysene	0.0065	U	0.0065	0.0008
53-70-3	Dibenzo(a,h)anthracene	0.0065	U	0.0065	0.0010
132-64-9	**Dibenzofuran**	**0.016**		0.0065	0.0008
206-44-0	**Fluoranthene**	**0.0085**		0.0065	0.0009
86-73-7	**Fluorene**	**0.018**		0.0065	0.0009
193-39-5	Indeno(1,2,3-cd)pyrene	0.0065	U	0.0065	0.0020
91-20-3	**Naphthalene**	**0.063**		0.0065	0.0007
85-01-8	**Phenanthrene**	**0.016**		0.0065	
129-00-0	**Pyrene**	**0.0068**		0.0065	0.0011
483-65-8	Retene	0.0065	U	0.0065	

Surrogate Recovery:

CAS#	Analyte	Result	Qualifier	Spike Level	% Recovery	%Rec.Limits
321-60-8	2-Fluorobiphenyl	0.232		0.26	89	30-115
93951-97-4	Acenaphthylene-D8	0.194		0.26	75	50-150
1719-06-8	Anthracene-D10	0.226		0.26	87	50-150
63466-71-7	Benzo(a)pyrene-D12	0.124		0.26	48	50-150
81103-79-9	Fluorene-D10	0.194		0.26	75	50-150
1718-52-1	Pyrene-D10	0.231		0.26	89	50-150
1718-51-0	Terphenyl-D14	0.163		0.26	63	18-137

Authorized by: _____ Release Date: 3/26/09

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 14, 2009	Completed by: Mark Woodke

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0907021	Gig Harbor	0907021-01	07/14/2009	Batch	
0907021	Bremerton	0907021-02	07/14/2009		
0907021	West Point	0907021-04	07/14/2009		
0907021	Burlington	0907021-05	07/14/2009		
0907021	Tacoma	0907021-06	07/16/2009		
0907021	Chambers Creek	0907021-07	07/16/2009		
0907021	Sumner	0907021-08	07/17/2009		
0907021	Bellingham	0907021-09	07/16/2009		
0907021	Everett	0907021-10	07/16/2009		
0907021	Shelton	0907021-13	07/15/2009		
0907021	Rinsate	0907021-12	07/10/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
0907021	Water	EPA 8270D SIM	Polycyclic Aromatic Hydrocarbons by GC/MS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes.
Did coolers arrive at lab less than 6^{0}C and in good condition as indicated on COC and Cooler Receipt Form?	Assumed based on the data review memoranda by Dickey Huntamer.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	Yes according to the data review memorandum by Dickey Huntamer. Sample extracts for Gig Harbor and Burlington were re-analyzed after the extraction holding time. Associated sample results were qualified estimated biased low (JG or UJG).

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- Surrogates Outside Limits (Table 4);
- MS/MSD Outside Limits (Table 5);
- LCS Outside Limits (Table 6); and
- Re-analysis Results (Table 7)

The semivolatile organic analyses (BNAs) data was originally reviewed by Dickey Huntamer, Manchester Environmental Laboratory (MEL) on October 22, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Polycyclic Aromatic Hydrocarbons by GC/MS-SIM	
Description	**Notes and Qualifiers**
Any compounds present in method, trip, and field blanks (see Table 3)?	Yes.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data. Qualification also applies to TICs.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one method blank and LCS with each batch and one set of MS/MSD per 20 samples?	Yes
Surrogate recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	No
Surrogate recovery values for samples and MS/MSD within laboratory QC limits? All samples should be re-analyzed for VOCs? Samples should be re-analyzed if >1 BN and/or AP for SVOCs is out.	No
MS/MSD percent recovery values within laboratory QC criteria (see Table 5)?	No – Several compounds were outside QC limits. The analytes were qualified in the parent sample "JG" and "UJG" for low MS/MSD recovery. If both MS/MSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ".
MS/MSD relative percent difference values within QC criteria (see Table 5) of <35%?	No – Several compounds were outside QC limits. The analytes were qualified in the parent sample "JK" and "UJK" for relative percent difference outliers.
LCS percent recovery values within Laboratory QC criteria (see Table 6)?	No – Several compounds were outside QC limits. All analytes were qualified in associated samples "JG" and "UJG" for low LCS/LCSD recovery. If LCS/LCSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ".
Do internal standards areas and retention time meet criteria? If not was sample re-analyzed to establish matrix?	No, several IS were outside QC limits in all samples except Burlington; associated sample results were flagged as estimated by Dickey Huntamer.
Is initial calibration for target compounds <20 % RSD or curve fit?	No – several compounds were above the QC limit, all associated samples results were qualified "JK or UJK".
Is continuing calibration for target compounds < 20%?	No – several compounds were above the QC limit, all associated samples results were qualified "JK or UJK".

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 14, 2009	Completed by: Mark Woodke

Polycyclic Aromatic Hydrocarbons by GC/MS-SIM	
Description	**Notes and Qualifiers**
Were any samples re-analyzed or diluted (see Table 7)? For any sample re-analysis and dilutions is only one reportable result by flagged?	Yes.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Analytes were detected in the method and field blanks. The associated sample results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U. Several MS/MSD compound percent recovery values were outside QC limits. The analytes were qualified in the parent sample "JG" and "UJG" for low MS/MSD recovery. If both MS/MSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ". Several LCS/LCSD compound percent recovery values were outside QC limits. All analytes were qualified in associated samples "JG" and "UJG" for low LCS/LCSD recovery. If both LCS/LCSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ". Several compounds were above the initial and continuing calibrations QC limit, all associated samples results were qualified estimated quantities (UJK, JH, JTK, or JK). Sample results greater than MDL and less than PQL are flagged estimated (JT). Sample results associated with internal standard outliers were qualified as estimated quantities with an unknown bias (JK or UJK). Sample results associated with holding time exceedances were qualified as estimated quantities with a low bias (JG or UJG).

Table 3 – List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL
SW846 8270	B09G136-BLK1	MBLK	Carbazole	0.012	J	µg/L	0.010
SW846 8270	B09G203-BLK1	MBLK	Carbazole	0.013		µg/L	0.010

Table 3A - List of Samples Qualified for Method Blank Contamination
None

Table 4 - List of Samples with Surrogates outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	QC Limit	Sample Qualification
SW846 8270	Chambers Creek	2-Fluorobiphenyl	12	30 - 115	None
SW846 8270	Bellingham	2-Fluorobiphenyl	9	30 – 115	None
SW846 8270	Shelton	2-Fluorobiphenyl	17	30 – 115	None
SW846 8270	B09G136-MS1	2-Fluorobiphenyl	17	30 – 115	None
SW846 8270	B09G203-BLK1	2-Fluorobiphenyl	25	30 – 115	None
SW846 8270	B09G203-BS1	2-Fluorobiphenyl	17	30 – 115	None
SW846 8270	Rinsate	2-Fluorobiphenyl	124	30 – 115	None
SW846 8270	Chambers Creek	Acenaphthylene-d8	29	50 - 150	None
SW846 8270	Bellingham	Acenaphthylene-d8	28	50 - 150	None
SW846 8270	Everett	Acenaphthylene-d8	39	50 - 150	None
SW846 8270	Shelton	Acenaphthylene-d8	30	50 - 150	None

Method	Sample ID	Analyte	Percent Recovery	QC Limit	Sample Qualification
SW846 8270	B09G136-MS1	Acenaphthylene-d8	27	50 - 150	None
SW846 8270	B09G203-BLK1	Acenaphthylene-d8	32	50 - 150	None
SW846 8270	B09G203-BS1	Acenaphthylene-d8	35	50 - 150	None
SW846 8270	B09G136-MS1	Anthracene-d10	49	50 - 150	None
SW846 8270	Gig Harbor	Benzo(a)pyrene-d12	37	50 - 150	None
SW846 8270	Bremerton	Benzo(a)pyrene-d12	44	50 - 150	None
SW846 8270	West Point	Benzo(a)pyrene-d12	49	50 - 150	None
SW846 8270	Burlington	Benzo(a)pyrene-d12	37	50 - 150	None
SW846 8270	Tacoma	Benzo(a)pyrene-d12	47	50 - 150	None
SW846 8270	B09G136-MS1	Benzo(a)pyrene-d12	49	50 - 150	None
SW846 8270	B09G136-MSD1	Benzo(a)pyrene-d12	48	50 - 150	None

Table 5 - List MS/MSD Percent Recovery Values and RPDs outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	West Point MS/MSD	Naphthalene	0/18	NA	50 – 150	JG/UJG
SW846 8270	West Point MS/MSD	2-Methylnaphthalene	4/18	NA	50 – 150	JG/UJG
SW846 8270	West Point MS/MSD	1-Methylnaphthalene	4/18	NA	50 – 150	JG/UJG
SW846 8270	West Point MS/MSD	2-Chloronaphthalene	3/9	NA	50 – 150	JG/UJG
SW846 8270	West Point MS/MSD	Acenaphthene	5/23	NA	50 – 150	JG/UJG
SW846 8270	West Point MS/MSD	Indeno(1,2,3-cd)pyrene	48/44	NA	50 – 150	JG/UJG
SW846 8270	West Point MS/MSD	Dibenzo(a,h)anthracene	44/41	NA	50 – 150	JG/UJG
SW846 8270	West Point MS/MSD	Benzo(g,h,i)perylene	45/42	NA	50 – 150	JG/UJG
SW846 8270	West Point MS	Acenaphthylene	17	NA	50 – 150	None
SW846 8270	West Point MS	Dibenzofuran	17	NA	50 – 150	None
SW846 8270	West Point MS	Fluorene	35	NA	50 – 150	None
SW846 8270	West Point MS	Phenanthrene	42	NA	50 – 150	None
SW846 8270	West Point MS	Anthracene	37	NA	50 – 150	None
SW846 8270	West Point MS/MSD	Naphthalene	Not Calculated	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	2-Methylnaphthalene	127	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	1-Methylnaphthalene	130	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	2-Chloronaphthalene	89	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	Acenaphthylene	111	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	Acenaphthene	125	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	Dibenzofuran	111	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	Fluorene	70	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	Phenanthrene	53	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	Anthracene	72	40	NA	JK/UJK
SW846 8270	West Point MS/MSD	Retene	64	40	NA	JK/UJK

Table 6 - List LCS Percent Recovery Values outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	B09G136-BS1/BSD1	Naphthalene	10/16	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	2-Methylnaphthalene	11/16	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	1-Methylnaphthalene	11/17	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	2-Chloronaphthalene	9/11	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	Acenaphthylene	28/45	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	Acenapthene	12/18	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	Dibenzofuran	27/43	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	Indeno(1,2,3-cd)pyrene	44/42	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	Dibenzo(a,h)anthracene	43/41	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1/BSD1	Benzo(g,h,i)perylene	45/43	NA	50 – 150	JG/UJG
SW846 8270	B09G136-BS1	Fluorene	43	NA	50 – 150	None
SW846 8270	B09G136-BS1	Phenanthrene	48	NA	50 – 150	None
SW846 8270	B09G136-BS1	Anthracene	44	NA	50 – 150	None
SW846 8270	B09G136-BS1/BSD1	Naphthalene	NA	43	<40	JK/UJK
SW846 8270	B09G136-BS1/BSD1	2-Methylnaphthalene	NA	40	<40	JK/UJK
SW846 8270	B09G136-BS1/BSD1	1-Methylnaphthalene	NA	41	<40	JK/UJK
SW846 8270	B09G136-BS1/BSD1	Acenaphthylene	NA	45	<40	JK/UJK
SW846 8270	B09G136-BS1/BSD1	Acenaphthene	NA	42	<40	JK/UJK
SW846 8270	B09G136-BS1/BSD1	Dibenzofuran	NA	43	<40	JK/UJK

Table 7 –Samples that were Reanalyzed

Sample ID	Reason for Reanalysis
Gig Harbor	Sample was reanalyzed due to initial poor analysis.

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
K	Bias could not be determined.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
T	The associated positive result is less than the quantitation limit.
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: June 12, 2009	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0902008	Sumner	0902008-01	02/12/2009		
0902008	Gig Harbor	0902008-02	02/10/2009		
0902008	Shelton	0902008-03	02/10/2009		
0902008	Everett	0902008-04	02/12/2009		
0902008	Burlington	0902008-05	02/10/2009		
0902008	Bremerton	0902008-06	02/10/2009		
0902008	Tacoma	0902008-07	02/19/2009	MS/MSD	
0902008	Chambers Creek	0902008-08	02/19/2009		
0902008	Metro West Point	0902008-09	02/10/2009		
0902008	Bellingham	0902008-10	02/12/2009		
0902008	Field Blank	0902008-11	02/12/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
0902008	Water	EPA 8270	Semivolatile Organic Compounds by GC/MS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes.
Did coolers arrive at lab less than 6^{o}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, according to the data review memoranda by Dickey Huntamer.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	Yes, according to the data review memoranda by Dickey Huntamer. Sample extracts for Sumner, Everett, and Field blank were analyzed after the extraction holding time. Associated sample results were qualified estimated biased low (JG or UJG).

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- Surrogates Outside Limits (Table 4);
- MS/MSD Outside Limits (Table 5);
- LCS Outside Limits (Table 6); and
- Re-analysis Results (Table 7)

The semivolatile organic analyses (BNAs) data was originally reviewed by Dickey Huntamer, Manchester Environmental Laboratory (MEL) on May 22, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Semivolatile Organics (including organotins) by GCMS	
Description	**Notes and Qualifiers**
Any compounds present in method, trip, and field blanks (see Table 2)?	Yes.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data. Qualification also applies to TICs.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one method blank and LCS with each batch and one set of MS/MSD per 20 samples?	Yes
Surrogate recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	Yes
Surrogate recovery values for samples and MS/MSD within laboratory QC limits? All samples should be re-analyzed for VOCs? Samples should be re-analyzed if >1 BN and/or AP for SVOCs is out.	Yes
MS/MSD percent recovery values within laboratory QC criteria (see Table 4)?	No – Several compounds were outside QC limits. The analytes were qualified in the parent sample "JG" and "UJG" for low MS/MSD recovery. If MS/MSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ".
MS/MSD relative percent difference values within QC criteria (see Table 4) of <35%?	No – Several compounds were outside QC limits. No action was taken.
LCS percent recovery values within Laboratory QC criteria (see Table 5)?	No – Several compounds were outside QC limits. All analytes were qualified in associated samples "JG" and "UJG" for low LCS/LCSD recovery. If LCS/LCSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ".
Do internal standards areas and retention time meet criteria? If not was sample re-analyzed to establish matrix (see Table 6)?	No, several IS were low in samples Sumner, Everett, Bellingham, and Field blank; associated sample results were flagged as estimated, biased high (UJ or J) by Dickey Huntamer.
Is initial calibration for target compounds <20 % RSD or curve fit?	No – several compounds were above the QC limit, all associated samples results were qualified "JK or UJK".
Is continuing calibration for target compounds < 20%?	No – several compounds were above the QC limit, all associated samples results were qualified "JK or UJK".

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: June 12, 2009	Completed by: David Ikeda

Semivolatile Organics (including organotins) by GCMS	
Description	**Notes and Qualifiers**
Were any samples re-analyzed or diluted (see Table 6)? For any sample re-analysis and dilutions is only one reportable result by flagged?	Yes.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Analytes were detected in the method and field blanks. The associated amples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U. Several MS/MSD compound percent recovery valuess were outside QC limits. The analytes were qualified in the parent sample "JG" and "UJG" for low MS/MSD recovery. If MS/MSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ". Several LCS/LCSD compound percent recovery values were outside QC limits. All analytes were qualified in associated samples "JG" and "UJG" for low LCS/LCSD recovery. If LCS/LCSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ". Several IS recovery were low in samples Sumner, Everett, Bellingham, and Field blank; associated sample results were flagged as estimated, biased high (UJ or J) y Dickey Huntamer. Several compounds were above the initial and continuing calibrations QC limit, all associated samples results were qualified estimated, bias unknown (UJK, JTK, or JK). Sample results greater than MDL and less than PQL are flagged estimated (JT).

Table 3 – List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL
SW846 8270	B09B100-BLK1	MBLK	Di-n-butylphthalate	0.25	J	µg/L	0.25
SW846 8270	B09B100-BLK1	MBLK	Bis(2-hexylethyl)phthalate	0.007	J	µg/L	0.50
SW846 8270	B09B116-BLK1	MBLK	Butylbenzylphthalate	0.62	J	µg/L	0.50
SW846 8270	B09B116-BLK1	MBLK	Bis(2-hexylethyl)phthalate	0.78	J	µg/L	0.50
SW846 8270	Field Blank	FBLK	1,2-Dichlorobenzene	0.02	J	µg/L	0.16
SW846 8270	Field Blank	FBLK	1,3-Dichlorobenzene	0.01	J	µg/L	0.16
SW846 8270	Field Blank	FBLK	4-Nonylphenol	0.28	J	µg/L	0.64
SW846 8270	Field Blank	FBLK	Bis(2-hexylethyl)phthalate	0.47	J	µg/L	0.32
SW846 8270	Field Blank	FBLK	Dimethylphthalate	0.58	J	µg/L	0.32
SW846 8270	Field Blank	FBLK	Phenol	0.19	J	µg/L	0.64

Table 3A - List of Samples Qualified for Method Blank Contamination

Method	Sample ID	Analyte	Result	Qual
SW846 8270	Sumner	1,2-Dichlorobenzene	0.15	U
SW846 8270	Sumner	Butylbenzylphthalate	0.62	U
SW846 8270	Sumner	Bis(2-hexylethyl)phthalate	1.1	U
SW846 8270	Sumner	Phenol	0.62	U
SW846 8270	Gig Harbor	1,2-Dichlorobenzene	0.16	U
SW846 8270	Gig Harbor	1,3-Dichlorobenzene	0.16	U
SW846 8270	Gig Harbor	Di-n-butylphthalate	0.22	U
SW846 8270	Gig Harbor	Bis(2-hexylethyl)phthalate	1.4	U

Method	Sample ID	Analyte	Result	Qual
SW846 8270	Shelton	1,2-Dichlorobenzene	0.16	U
SW846 8270	Shelton	1,3-Dichlorobenzene	0.16	U
SW846 8270	Shelton	Di-n-butylphthalate	0.43	U
SW846 8270	Shelton	Bis(2-hexylethyl)phthalate	1.0	U
SW846 8270	Shelton	Phenol	0.63	U
SW846 8270	Everett	4-Nonylphenol	0.65	U
SW846 8270	Everett	Bis(2-hexylethyl)phthalate	3.4	U
SW846 8270	Everett	Phenol	0.78	U
SW846 8270	Burlington	Di-n-butylphthalate	0.24	U
SW846 8270	Burlington	Bis(2-hexylethyl)phthalate	0.53	U
SW846 8270	Burlington	Phenol	0.56	U
SW846 8270	Bremerton	Di-n-butylphthalate	0.36	U
SW846 8270	Bremerton	Bis(2-hexylethyl)phthalate	2.4	U
SW846 8270	Bremerton	Phenol	0.86	U
SW846 8270	Tacoma	4-Nonylphenol	1.0	U
SW846 8270	Tacoma	Di-n-butylphthalate	0.28	U
SW846 8270	Tacoma	Bis(2-hexylethyl)phthalate	2.8	U
SW846 8270	Tacoma	Phenol	0.72	U
SW846 8270	Chambers Creek	4-Nonylphenol	0.68	U
SW846 8270	Chambers Creek	Bis(2-hexylethyl)phthalate	1.2	U
SW846 8270	Chambers Creek	Phenol	0.68	U
SW846 8270	Metro West Point	Di-n-butylphthalate	0.38	U
SW846 8270	Metro West Point	Bis(2-hexylethyl)phthalate	1.4	U
SW846 8270	Metro West Point	Phenol	0.94	U

Table 4 - List of Samples with Surrogates outside Control Limits
None

Table 5 - List MS/MSD Percent Recovery Values and RPDs outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	Tacoma MS	Phenol	39	NA	50 – 150	None
SW846 8270	Tacoma MSD	Phenol	36	NA	50 – 150	None
SW846 8270	Tacoma MS	4-Methylphenol	41	NA	50 – 150	JG
SW846 8270	Tacoma MSD	4-Methylphenol	45	NA	50 – 150	JG
SW846 8270	Tacoma MS	4-Nitrophenol	0	NA	50 – 150	REJ
SW846 8270	Tacoma MSD	4-Nitrophenol	0	NA	50 – 150	REJ
SW846 8270	Tacoma MS	Hexachloroethane	43	NA	50 – 150	UJG
SW846 8270	Tacoma MSD	Hexachloroethane	31	NA	50 – 150	UJG
SW846 8270	Tacoma MS	Hexachlorobutadiene	49	NA	50 – 150	UJG
SW846 8270	Tacoma MSD	Hexachlorobutadiene	37	NA	50 – 150	UJG
SW846 8270	Tacoma MS	2-Nitroaniline	22	NA	50 – 150	UJG
SW846 8270	Tacoma MSD	2-Nitroaniline	37	NA	50 – 150	UJG
SW846 8270	Tacoma MSD	2-Nitroaniline	NA	43	<40	None

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	Tacoma MS	3-Nitroaniline	23	NA	50 – 150	UJG
SW846 8270	Tacoma MSD	3-Nitroaniline	39	NA	50 – 150	UJG
SW846 8270	Tacoma MSD	3-Nitroaniline	NA	46	<40	None
SW846 8270	Tacoma MS	4-Nitroaniline	0	NA	50 – 150	REJ
SW846 8270	Tacoma MSD	4-Nitroaniline	0	NA	50 – 150	REJ
SW846 8270	Tacoma MS	n-Nitrosodiphenylamine	41	NA	50 – 150	JG
SW846 8270	Tacoma MSD	n-Nitrosodiphenylamine	62	NA	50 – 150	None
SW846 8270	Tacoma MS	4-Nonylphenol	30	NA	50 – 150	None
SW846 8270	Tacoma MSD	4-Nonylphenol	39	NA	50 – 150	None
SW846 8270	Tacoma MS	Bisphenol A	3	NA	50 – 150	REJ
SW846 8270	Tacoma MSD	Bisphenol A	0	NA	50 – 150	REJ

Table 6 - List LCS Percent Recovery Values outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	B09B100-BS1	Hexachlorocyclopentadiene	46	NA	50 – 150	UJG
SW846 8270	B09B100-BSD1	Hexachlorocyclopentadiene	51	NA	50 – 150	None
SW846 8270	B09B100-BS1	4-Chloroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B100-BSD1	4-Chloroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B100-BS1	4-Nonylphenol	0	NA	50 – 150	REJ
SW846 8270	B09B100-BSD1	4-Nonylphenol	0	NA	50 – 150	REJ
SW846 8270	B09B116-BS1	Benzyl alcohol	NA	44	<40	None
SW846 8270	B09B116-BS1	Benzoic acid	NA	64	<40	None
SW846 8270	B09B116-BS1	4-Chloroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B116-BSD1	4-Chloroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B116-BS1	3,3'-Dichlorobenzidine	0	NA	50 – 150	REJ
SW846 8270	B09B116-BSD1	3,3'-Dichlorobenzidine	0	NA	50 – 150	REJ
SW846 8270	B09B116-BS1	2-Nitroaniline	7.7	NA	50 – 150	REJ
SW846 8270	B09B116-BSD1	2-Nitroaniline	29	NA	50 – 150	None
SW846 8270	B09B116-BS1	2-Nitroaniline	NA	118	<40	None
SW846 8270	B09B116-BSD1	3-Nitroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B116-BS1	3-Nitroaniline	29	NA	50 – 150	None
SW846 8270	B09B116-BSD1	3-Nitroaniline	NA	114	<40	None
SW846 8270	B09B116-BS1	4-Nitroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B116-BSD1	4-Nitroaniline	22	NA	50 – 150	None
SW846 8270	B09B116-BS1	n-Nitrosodiphenylamine	41	NA	50 – 150	UJG or JTG
SW846 8270	B09B116-BSD1	n-Nitrosodiphenylamine	62	NA	50 – 150	UJG or JTG
SW846 8270	B09B116-BS1	n-Nitrosodiphenylamine	NA	190	<40	None
SW846 8270	B09B116-BS1	Triethyl citrate	20	NA	50 – 150	None
SW846 8270	B09B116-BSD1	Triethyl citrate	11	NA	50 – 150	None
SW846 8270	B09B116-BSD1	Triethyl citrate	NA	61	<40	None
SW846 8270	B09B116-BSD1	4-Nonylphenol	24	NA	50 – 150	UJG or JTG

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	B09B116-BS1	4-Nonylphenol	71	NA	50 – 150	UJG or JTG
SW846 8270	B09B116-BSD1	4-Nonylphenol	NA	99	<40	None
SW846 8270	B09B116-BS1	Bisphenol A	0	NA	50 – 150	REJ
SW846 8270	B09B116-BSD1	Bisphenol A	9	NA	50 – 150	REJ
SW846 8270	B09B116-BSD1	Bisphenol A	NA	100	<40	None
SW846 8270	B09B116-BS1	di-n-Ocytlphthalate	358	NA	50 – 150	JL
SW846 8270	B09B116-BSD1	di-n-Ocytlphthalate	2980	NA	50 – 150	JL
SW846 8270	B09B116-BSD1	di-n-Ocytlphthalate	NA	157	<40	None
SW846 8270	B09B146-BS1	Benzyl alcohol	0	NA	50 – 150	None
SW846 8270	B09B146-BS1	Bis(2-chloroethoxy)methane	0	NA	50 – 150	REJ
SW846 8270	B09B146-BS1	4-Chloroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B146-BS1	4-Nitrophenol	0	NA	50 – 150	None
SW846 8270	B09B146-BS1	4-Nitroaniline	0	NA	50 – 150	REJ
SW846 8270	B09B146-BS1	Bisphenol A	0	NA	50 – 150	REJ
SW846 8270	B09B146-BS1	4-Methylphenol	39	NA	50 – 150	JG
SW846 8270	B09B146-BS1	Benzoic acid	39	NA	50 – 150	None
SW846 8270	B09B146-BS1	2-Nitroaniline	8	NA	50 – 150	REJ
SW846 8270	B09B146-BS1	3-Nitroaniline	8	NA	50 – 150	REJ
SW846 8270	B09B146-BS1	Caffeine	5	NA	50 – 150	JTG
SW846 8270	B09B146-BS1	Triclosan	33	NA	50 – 150	None

Table 7 –Samples that were Reanalyzed

Sample ID	Reason for Reanalysis
Sumner	Sample was reanalyzed due to IS outliers.
Everett	Sample was reanalyzed due to IS outliers.
Bellingham	Sample was reanalyzed due to QC outliers.
Field blank	Sample was reanalyzed due to QC outliers.

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
K	Bias could not be determined.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 14, 2009	Completed by: Mark Woodke

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0907021	Gig Harbor	0907021-01	07/14/2009		
0907021	Bremerton	0907021-02	07/14/2009		
0907021	West Point	0907021-04	07/14/2009	MS/MSD	
0907021	Burlington	0907021-05	07/14/2009		
0907021	Tacoma	0907021-06	07/16/2009		
0907021	Chambers Creek	0907021-07	07/16/2009		
0907021	Sumner	0907021-08	07/17/2009		
0907021	Bellingham	0907021-09	07/16/2009		
0907021	Everett	0907021-10	07/16/2009		
0907021	Shelton	0907021-13	07/15/2009		
0907021	Rinsate	0907021-12	07/10/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
0907021	Water	EPA 8270	Semivolatile Organic Compounds by GC/MS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes.
Did coolers arrive at lab less than 6^{0}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, assumed based on the data review memorandum by Dickey Huntamer.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	No.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blank Results (Table 3);
- Surrogates Outside Limits (Table 4);
- MS/MSD Outside Limits (Table 5);
- LCS Outside Limits (Table 6); and
- Re-analysis Results (Table 7)

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 14, 2009	Completed by: Mark Woodke

The semivolatile organic analyses (BNAs) data was originally reviewed by Dickey Huntamer, Manchester Environmental Laboratory (MEL) on September 22, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Semivolatile Organics (including organotins) by GCMS	
Description	**Notes and Qualifiers**
Any compounds present in method, trip, and field blanks (see Table 2)?	Yes.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data. Qualification also applies to TICs.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one method blank and LCS with each batch and one set of MS/MSD per 20 samples?	Yes
Surrogate recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	No
Surrogate recovery values for samples and MS/MSD within laboratory QC limits? All samples should be re-analyzed for VOCs? Samples should be re-analyzed if >1 BN and/or AP for SVOCs is out.	No
MS/MSD percent recovery values within laboratory QC criteria (see Table 4)?	No – Several compounds were outside QC limits. The analytes were qualified in the parent sample "JG" and "UJG" for low MS/MSD recovery. If MS/MSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ".
MS/MSD relative percent difference values within QC criteria (see Table 4) of <35%?	Yes.
LCS percent recovery values within Laboratory QC criteria (see Table 5)?	No – Several compounds were outside QC limits. All analytes were qualified in associated samples "JG" and "UJG" for low LCS/LCSD recovery. If LCS/LCSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ".
Do internal standards areas and retention time meet criteria? If not was sample re-analyzed to establish matrix (see Table 6)?	Yes.
Is initial calibration for target compounds <20 % RSD or curve fit?	No – several compounds were above the QC limit, all associated samples results were qualified "JK or UJK".
Is continuing calibration for target compounds < 20%?	No – several compounds were above the QC limit, all associated samples results were qualified "JK or UJK".
Were any samples re-analyzed or diluted (see Table 6)? For any sample re-analysis and dilutions is only one reportable result by flagged?	Yes.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 14, 2009	Completed by: Mark Woodke

Analytes were detected in the method blanks. The associated samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged UJ. Several MS/MSD compound percent recovery values were outside QC limits. The analytes were qualified in the parent sample "JG" and "UJG" for low MS/MSD recovery. If both MS/MSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ". Several LCS/LCSD compound percent recovery values were outside QC limits. All analytes were qualified in associated samples "JG" and "UJG" for low LCS/LCSD recovery. If both LCS/LCSD percent recovery values were below 10%, then non-detect results were flagged as rejected "REJ". Several compounds were above the initial and continuing calibrations QC limit, all associated samples results were qualified estimated, bias unknown (UJK, JTK, or JK). Sample results greater than MDL and less than PQL are flagged estimated (JT).

Table 3 – List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL
SW846 8270	B09G117-BLK1	MBLK	Di-n-butylphthalate	0.18	J	µg/L	0.25
SW846 8270	B09G161-BLK1	MBLK	Di-n-butylphthalate	0.78	J	µg/L	0.25

Table 3A - List of Samples Qualified for Method Blank Contamination

Method	Sample ID	Analyte	Result	Qualifier
SW846 8270	Gig Harbor	Di-n-butylphthalate	0.32	UJ
SW846 8270	Bremerton	Di-n-butylphthalate	0.19	UJ
SW846 8270	West Point	Di-n-butylphthalate	0.21	UJ
SW846 8270	Burlington	Di-n-butylphthalate	0.39	UJ
SW846 8270	Tacoma	Di-n-butylphthalate	0.24	UJ
SW846 8270	Chambers Creek	Di-n-butylphthalate	0.33	UJ
SW846 8270	Sumner	Di-n-butylphthalate	0.24	UJ
SW846 8270	Bellingham	Di-n-butylphthalate	0.26	UJ
SW846 8270	Everett	Di-n-butylphthalate	0.25	UJ
SW846 8270	Shelton	Di-n-butylphthalate	0.22	UJ

Table 4 - List of Samples with Surrogates outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	QC Limit	Sample Qualification
SW846 8270	Sumner	2-Fluorobiphenyl	42	43 – 116	None
SW846 8270	B09G161-BSD1	2-Fluorophenol	139	43 – 116	None
SW846 8270	B09G161-BLK1	2-Fluorophenol	128	43 – 116	None
SW846 8270	B09G117-BLK1	2-Fluorophenol	135	43 – 116	None

Table 5 - List MS/MSD Percent Recovery Values and RPDs outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	West Point MS	Phenol	44	NA	50 – 150	JG/UJG
SW846 8270	West Point MSD	Phenol	46	NA	50 – 150	JG/UJG

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	West Point MS	Benzyl Alcohol	41	NA	50 – 150	JG/UJG
SW846 8270	West Point MSD	Benzyl Alcohol	41	NA	50 – 150	JG/UJG
SW846 8270	West Point MS	Hexachloroethane	48	NA	50 – 150	JG/UJG
SW846 8270	West Point MSD	Hexachloroethane	40	NA	50 – 150	JG/UJG
SW846 8270	West Point MS	4-Nitroaniline	12	NA	50 – 150	JG/UJG
SW846 8270	West Point MSD	4-Nitroaniline	12	NA	50 – 150	JG/UJG
SW846 8270	West Point MS	Hexachlorocyclopentadiene	39	NA	50 – 150	JG/UJG
SW846 8270	West Point MSD	Hexachlorocyclopentadiene	32	NA	50 – 150	JG/UJG
SW846 8270	West Point MS	Hexachlorobutadiene	44	NA	50 – 150	None
SW846 8270	West Point MS	N-Nitrosodiphenylamine	161	NA	50 – 150	J
SW846 8270	West Point MSD	N-Nitrosodiphenylamine	162	NA	50 – 150	J
SW846 8270	West Point MS	Cholesterol	204	NA	50 – 150	J
SW846 8270	West Point MSD	Cholesterol	217	NA	50 – 150	J
SW846 8270	West Point MS	Bisphenol A	156	NA	50 – 150	J
SW846 8270	West Point MSD	Bisphenol A	154	NA	50 – 150	J
SW846 8270	West Point MS	Coprostanol	151	NA	50 – 150	None
SW846 8270	West Point MS	4-Chloroaniline	0	NA	50 – 150	Rej
SW846 8270	West Point MSD	4-Chloroaniline	0	NA	50 – 150	Rej
SW846 8270	West Point MS	3,3'-Dichlorobenzidine	0	NA	50 – 150	Rej
SW846 8270	West Point MSD	3,3'-Dichlorobenzidine	0	NA	50 – 150	Rej

Table 6 - List LCS Percent Recovery Values outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	B09G117-BS1	Benzyl Alcohol	47	NA	50 – 150	JG/UJG
SW846 8270	B09G117-BS1	Benzoic Acid	35	NA	50 – 150	JG/UJG

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	B09G117-BS1	Hexachlorocyclopentadiene	20	NA	50 – 150	JG/UJG
SW846 8270	B09G117-BS1	4-Chloroaniline	0	NA	50 – 150	Rej
SW846 8270	B09G117-BS1	N-Nitrosodiphenylamine	199	NA	50 – 150	J
SW846 8270	B09G117-BS1	4-Nitroaniline	191	NA	50 – 150	J
SW846 8270	B09G117-BS1	N-Nonylphenol	152	NA	50 – 150	J
SW846 8270	B09G161-BS1/-BSD1	Hexachlorocyclopentadiene	20/44	NA	50 – 150	JG/UJG
SW846 8270	B09G161-BS1/-BSD1	Benzyl alcohol	42/48	NA	50 – 150	JG/UJG
SW846 8270	B09G161-BS1/-BSD1	Benzoic acid	25/33	NA	50 – 150	JG/UJG
SW846 8270	B09G161-BS1/-BSD1	Bisphenol A	140/41	NA	50 – 150	None
SW846 8270	B09G161-BS1/-BSD1	Hexachloroethane	49/68	NA	50 – 150	None
SW846 8270	B09G161-BS1/-BSD1	4-Chloroaniline	6/0	NA	50 – 150	Rej
SW846 8270	B09G161-BS1/-BSD1	N-Nitrosodiphenylamine	189/197	NA	50 – 150	J
SW846 8270	B09G161-BS1/-BSD1	4-Nitroaniline	183/150	NA	50 – 150	J
SW846 8270	B09G161-BS1/-BSD1	N-Nonylphenol	140/145	NA	50 – 150	J
SW846 8270	B09G161-BS1	Bisphenol A	NA	108	<40	J
SW846 8270	B09G161-BS1	Hexachlorocyclopentadiene	NA	75	<40	J

Table 7 –Samples that were Reanalyzed

Sample ID	Reason for Reanalysis
B09G117-BS1	Sample was reanalyzed due to overwriting file.
B09G161-BS1	Sample was reanalyzed due to overwriting file.

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
K	Bias could not be determined.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
T	The associated positive result is less than the quantitation limit.
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: March 31, 2008	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance level 1 review (QA1) (PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Matrix	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0902008	Water	Sumner	0902008-01	02/12/2009		None
0902008	Water	Gig Harbor	0902008-02	02/10/2009		None
0902008	Water	Shelton	0902008-03	02/10/2009		None
0902008	Water	Everett	0902008-04	02/12/2009		None
0902008	Water	Burlington	0902008-05	02/10/2009		None
0902008	Water	Bremerton	0902008-06	02/10/2009		None
0902008	Water	Tacoma	0902008-07	02/19/2009	MS/MSD	None
0902008	Water	Chambers Creek	0902008-08	02/19/2009		None
0902008	Water	Metro West Point	0902008-09	02/10/2009		None
0902008	Water	Bellingham	0902008-10	02/12/2009		None
0902008	Water	Field Blank	0902008-11	02/12/2009		None

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Orders	Matrix	Test Method	Method Name	Number of Samples
0902008	Water	SW846 8270	Acid Herbicides by Gas Chromatography/Mass Spectrometry	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes
Did coolers arrive at lab between 0 °C and 6°C and in good condition as indicated on COC and Cooler Receipt Form?	Yes
Frequency of Field QC Samples Correct? Field Duplicate – Not required. Field Blank – 1/20 samples. MS/MSD samples – 1/20 samples.	Yes
Case narrative present and complete?	Yes
Any holding time violations?	No - All samples were prepared and analyzed within holding times.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- Surrogates Outside Limits (Table 4);

- MS/MSD Outside Limits (Table 5);
- LCS Outside Limits (Table 6); and
- Re-analysis Results (Table 7).

The acid herbicides data was reviewed by Bob Carrell, Manchester Environmental Laboratory (MEL) on March 11, 2009. The laboratory provided the analytical summaries for samples, including QC samples. No raw data was provided by the laboratory.

Acid Herbicides by GC/MS	
Description	**Notes and Qualifiers**
Any compounds present in method and field blanks?	No.
For samples, if results are <5 times the blank then "U" flag data.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one blank and LCS with each batch and one set of MS/MSD per 20 samples?	Yes.
Surrogate standard recovery values for samples, MS/MSD, method blanks, and LCS/LCSD samples within laboratory QC limits?	No, please refer to Table 4. No action was taken for LCS surrogate outliers.
Internal standard recovery values for samples, MS/MSD, method blanks, and LCS/LCSD samples within laboratory QC limits?	Yes.
MS/MSD percent recovery values within laboratory QC criteria?	No, please refer to Table 5.
MS/MSD relative percent difference values within QC criteria (see Table 4) of <40%?	No, please refer to Table 5. No action was taken, since results were qualified due to MS/MSD recovery.
LCS percent recovery values within laboratory QC criteria (see Table 5)? If the value is high with no positive values in the associated data; then no data qualification is required.	No, please refer to Table 6.
Is initial calibration for target compounds <20 % RSD or curve fit?	Yes
Is initial calibration verification standard for target compounds <30 %?	No, 4-nitrophenol and dinoseb were outside QC limits. No action was taken since the anayltes were not detected in the associated samples.
Is continuing calibration for target compounds < 20%?	Yes
Were any samples re-analyzed or diluted (see Table 6)? For any sample re-analysis and dilutions is only one reportable result by flagged?	No

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Matrix spike (B09B138-MS1 and –MSD, parent sample Tacoma) percent recovery values were outside QC limits, the sample results were qualified (refer to Table 4). Laboratory control sample percent recovery values were outside QC limits, associated samples were qualified (refer to Table 5).

Table 3 - List of Positive Results for Blank Samples
None

Table 3A - List of Samples Qualified for Method Blank Contamination
None

Table 4 - List of Samples with Surrogates outside Control Limits

Method	Sample ID	Analyte	Recovery	QC Limit	Sample Qualification
SW846 8270	B09B102-BS1	2,4-Dichlorophenylacetic Acid	24	40 - 130	None

Table 5 - List MS/MSD Percent Recovery Values and RPDs outside Control Limits

Method	Sample ID	Analyte	Recovery	QC Limit	Sample Qualification
SW846 8270	B09B138-MS1	2,4-DB	0	40 - 130	R
SW846 8270	B09B138-MS1	4-Nitrophenol	23	40 - 130	UJL or JL
SW846 8270	B09B138-MS1	Acifluorfen (Blazer)	0	40 - 130	R
SW846 8270	B09B138-MS1	Clopyralid	38	40 - 130	UJL or JL
SW846 8270	B09B138-MS1	Dinoseb	0	40 - 130	R
SW846 8270	B09B138-MS1	Picloram	15	40 - 130	None
SW846 8270	B09B138-MSD1	2,4-DB	0	40 - 130	R
SW846 8270	B09B138-MSD1	4-Nitrophenol	19	40 - 130	UJL or JL
SW846 8270	B09B138-MS1	Clopyralid	34	40 - 130	UJL or JL
SW846 8270	B09B138-MS1	Dinoseb	34	40 - 130	R
SW846 8270	B09B138-MS1	Picloram	0	40 - 130	R
SW846 8270	B09B138-MS1	2,4-DB	RPD = NC	40	None
SW846 8270	B09B138-MS1	Acifluorfen (Blazer)	RPD = NC	40	None
SW846 8270	B09B138-MS1	Dinoseb	RPD = NC	40	None
SW846 8270	B09B138-MS1	Picloram	RPD = NC	40	None

Table 6 - List LCS Percent Recovery Values outside Control Limits

Method	Sample ID	Analyte	Recovery	QC Limit	Sample Qualification
SW846 8270	B09B102-BS1	2,3,4,5-Tetrachlorophenol	24	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	2,3,4,6-Tetrachlorophenol	39	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	2,4,5-T	36	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	2,4,5-Trichlorophenol	21	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	2,4,6-Trichlorophenol	26	40 - 130	UJL, JTL or JL
SW846 8270	B09B102-BS1	2,4-D	35	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	2,4-DB	23	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	4-Nitrophenol	22	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	Acifluorfen (Blazer)	34	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	Clopyralid	30	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	Dicamba l	39	40 - 130	UJL, NJTL, or JL
SW846 8270	B09B102-BS1	Diclofop-Methyl	38	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	Dinoseb	24	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	MCPA	38	40 - 130	UJL, NJTL, or JL
SW846 8270	B09B102-BS1	MCPP (Mecoprop)	38	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	Picloram	26	40 - 130	UJL or JL
SW846 8270	B09B102-BS1	Trichlopry	38	40 - 130	UJL, NJTL, or JL
SW846 8270	B09B138-BS1	Dinoseb	35	40 - 130	UJL or JL
SW846 8270	B09B148-BS1	Picloram	36	40 - 130	UJL or JL
SW846 8270	B09B148-BSD	Clopyralid	28	40 - 130	UJL or JL

Method	Sample ID	Analyte	Recovery	QC Limit	Sample Qualification
SW846 8270	B09B148-BSD	Picloram	36	40 - 130	UJL or JL

Table 7 –Samples that were Reanalyzed
None

Key:
A = Analyte
NC = Not Calculated
ND = Not Detected
PQL = Practical Quantitation Limit
RPD = Relative Percent Difference

Data Validation Qualifiers:

Code	Description
B	Analyte detected in sample and method blank. Reported result is sample concentration without blank correction or associated quantitation limit.
JG	Analyte was positively identified. Value may be greater than the reported estimate.
JK	Analyte was positively identified. Reported result is an estimate with unknown bias.
JL	Analyte was positively identified. Value may be less than the reported estimate.
JT	Analyte was positively identified. Reported result is an estimate below the associated quantitation limit but above the MDL.
JTG	Analyte was positively identified. Value may be greater than the reported result, which is an estimate below the associated quantitation limit but above the MDL.
JTK	Analyte was positively identified. Reported result is an estimate with unknown bias, below the associated quantitation limit but above the MDL.
JTL	Analyte was positively identified. Value may be less than the reported result which is an estimate below associated quantitation limit but above MDL.
NJ	There is evidence that the analyte is present in the sample. Reported result for the tentatively identified analyte is an estimate.
NJT	There is evidence the analyte is present in the sample. Reported result for the tentatively identified analyte is an estimate below the associated quantitation limit but above the MDL.
NU	There is evidence the analyte is present in the sample. Tentatively identified analyte was not detected at or above the reported result.
NUJ	There is evidence the analyte is present in the sample. Tentatively identified analyte was not detected at or above the reported estimate.
NAF	Not analyzed for.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
U	Analyte was not detected at or above the reported result.
UJ	Analyte was not detected at or above the reported estimate
UJG	Analyte was not detected at or above the reported estimate with likely low bias.
UJK	Analyte was not detected at or above the reported estimate with unknown bias.
UJL	Analyte was not detected at or above the reported estimate with likely high bias.

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Gig Harbor**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 995 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-02
Collected: 2/10/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B102
Prepared: 2/11/2009
Analyzed: 3/2/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.063	U J L	0.063	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.063	U J L	0.063	0.007
93-76-5	2,4,5-T	0.063	U J L	0.063	0.009
93-72-1	2,4,5-TP (Silvex)	0.063	U	0.063	0.010
95-95-4	2,4,5-Trichlorophenol	0.063	U J L	0.063	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.16**	J L	0.063	0.011
94-75-7	2,4-D	0.063	U J L	0.063	0.012
94-82-6	2,4-DB	0.063	U J L	0.063	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.063	U	0.063	0.007
100-02-7	4-Nitrophenol	0.063	U J L	0.063	0.022
62476-59-9	Acifluorfen (Blazer)	0.063	U J L	0.063	0.054
25057-89-0	Bentazon	0.063	U	0.063	0.007
1689-84-5	Bromoxynil	0.063	U J L	0.063	0.006
1702-17-6	Clopyralid	0.063	U	0.063	0.008
1861-32-1	Dacthal (DCPA)	0.063	U	0.063	0.005
1918-00-9	Dicamba I	0.063	U J L	0.063	0.007
120-36-5	Dichlorprop	0.063	U	0.063	0.009
51338-27-3	Diclofop-Methyl	0.063	U J L	0.063	0.017
88-85-7	Dinoseb	0.063	U J L	0.063	0.041
1689-83-4	Ioxynil	0.063	U	0.063	0.016
94-74-6	MCPA	0.063	U J L	0.063	0.008
93-65-2	MCPP (Mecoprop)	0.063	U J L	0.063	0.008
87-86-5	Pentachlorophenol	0.063	U	0.063	0.007
1918-02-1	Picloram	0.063	UJ L	0.063	0.018
55335-06-3	Trichlopyr	0.063	U J L	0.063	0.007

1 10 April 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	1.01	1.01	100	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.668	1.01	67	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Shelton**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 985 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-03
Collected: 2/10/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B102
Prepared: 2/11/2009
Analyzed: 3/2/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.063	U JL	0.063	0.004
58-90-2	**2,3,4,6-Tetrachlorophenol**	**0.15**	JL	0.063	0.007
93-76-5	2,4,5-T	0.063	U JL	0.063	0.009
93-72-1	2,4,5-TP (Silvex)	0.063	U	0.063	0.010
95-95-4	2,4,5-Trichlorophenol	0.063	U JL	0.063	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.30**	JL	0.063	0.011
94-75-7	2,4-D	0.063	U JL	0.063	0.012
94-82-6	2,4-DB	0.063	U JL	0.063	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.063	U	0.063	0.007
100-02-7	4-Nitrophenol	0.063	U JL	0.063	0.022
62476-59-9	Acifluorfen (Blazer)	0.063	U JL	0.063	0.054
25057-89-0	Bentazon	0.063	U	0.063	0.007
1689-84-5	Bromoxynil	0.063	U	0.063	0.006
1702-17-6	Clopyralid	0.063	U JL	0.063	0.009
1861-32-1	Dacthal (DCPA)	0.063	U	0.063	0.005
1918-00-9	Dicamba I	0.063	U JL	0.063	0.007
120-36-5	Dichlorprop	0.063	U	0.063	0.009
51338-27-3	Diclofop-Methyl	0.063	U JL	0.063	0.017
88-85-7	Dinoseb	0.063	U JL	0.063	0.041
1689-83-4	Ioxynil	0.063	U	0.063	0.016
94-74-6	MCPA	0.063	U JL	0.063	0.008
93-65-2	MCPP (Mecoprop)	0.063	U JL	0.063	0.008
87-86-5	Pentachlorophenol	0.063	U	0.063	0.007
1918-02-1	Picloram	0.063	UJ JL	0.063	0.018
55335-06-3	**Trichlopyr**	**0.054**	~~NJ JL~~ NJ JL	0.063	0.007

1 APRIL 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	0.904	1.02	89	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.670	1.02	66	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Burlington**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1020 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-05
Collected: 2/10/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B102
Prepared: 2/11/2009
Analyzed: 3/2/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.061	U JL	0.061	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.061	U JL	0.061	0.007
93-76-5	2,4,5-T	0.061	U JL	0.061	0.009
93-72-1	2,4,5-TP (Silvex)	0.061	U	0.061	0.010
95-95-4	2,4,5-Trichlorophenol	0.061	U JL	0.061	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.029**	JTL	0.061	0.011
94-75-7	2,4-D	0.061	U JL	0.061	0.012
94-82-6	2,4-DB	0.061	U JL	0.061	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.061	U	0.061	0.007
100-02-7	4-Nitrophenol	0.061	U JL	0.061	0.021
62476-59-9	Acifluorfen (Blazer)	0.061	U JL	0.061	0.053
25057-89-0	Bentazon	0.061	U	0.061	0.006
1689-84-5	Bromoxynil	0.061	U	0.061	0.006
1702-17-6	Clopyralid	0.061	U JL	0.061	0.008
1861-32-1	Dacthal (DCPA)	0.061	U	0.061	0.005
1918-00-9	Dicamba I	0.061	U JL	0.061	0.007
120-36-5	Dichlorprop	0.061	U	0.061	0.008
51338-27-3	Diclofop-Methyl	0.061	U JL	0.061	0.016
88-85-7	Dinoseb	0.061	U JL	0.061	0.040
1689-83-4	Ioxynil	0.061	U	0.061	0.016
94-74-6	MCPA	0.061	U JL	0.061	0.008
93-65-2	MCPP (Mecoprop)	0.061	U JL	0.061	0.008
87-86-5	**Pentachlorophenol**	**0.037**	NJT	0.061	0.007
1918-02-1	Picloram	0.061	UJ L	0.061	0.017
55335-06-3	Trichlopyr	0.061	U JL	0.061	0.007

1 10 April 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	0.917	0.98	94	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.745	0.98	76	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Bremerton**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 995 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-06
Collected: 2/10/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B102
Prepared: 2/11/2009
Analyzed: 3/2/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.063	U J L	0.063	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.063	U J L	0.063	0.007
93-76-5	2,4,5-T	0.063	U J L	0.063	0.009
93-72-1	2,4,5-TP (Silvex)	0.063	U	0.063	0.010
95-95-4	2,4,5-Trichlorophenol	0.063	U J L	0.063	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.033**	J T L	0.063	0.011
94-75-7	2,4-D	0.063	U J L	0.063	0.012
94-82-6	2,4-DB	0.063	U J L	0.063	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.063	U	0.063	0.007
100-02-7	4-Nitrophenol	0.063	U J L	0.063	0.022
62476-59-9	Acifluorfen (Blazer)	0.063	U J L	0.063	0.054
25057-89-0	Bentazon	0.063	U	0.063	0.007
1689-84-5	Bromoxynil	0.063	U	0.063	0.006
1702-17-6	Clopyralid	0.063	U J L	0.063	0.008
1861-32-1	Dacthal (DCPA)	0.063	U	0.063	0.005
1918-00-9	Dicamba I	0.063	U J L	0.063	0.007
120-36-5	Dichlorprop	0.063	U	0.063	0.009
51338-27-3	Diclofop-Methyl	0.063	U J L	0.063	0.017
88-85-7	Dinoseb	0.063	U J L	0.063	0.041
1689-83-4	Ioxynil	0.063	U	0.063	0.016
94-74-6	MCPA	0.063	U J L	0.063	0.008
93-65-2	MCPP (Mecoprop)	0.063	U J L	0.063	0.008
87-86-5	**Pentachlorophenol**	**0.044**	NJ T	0.063	0.007
1918-02-1	Picloram	0.063	UJ L	0.063	0.018
55335-06-3	Trichlopyr	0.063	U J L	0.063	0.007

10 April 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	0.894	1.01	89	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.724	1.01	72	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Metro West Point**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1015 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-09
Collected: 2/10/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B102
Prepared: 2/11/2009
Analyzed: 3/3/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.062	U JL	0.062	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.062	U JL	0.062	0.007
93-76-5	2,4,5-T	0.062	U JL	0.062	0.009
93-72-1	2,4,5-TP (Silvex)	0.062	U	0.062	0.010
95-95-4	2,4,5-Trichlorophenol	0.062	U JL	0.062	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.046**	JTL	0.062	0.011
94-75-7	2,4-D	0.062	U JL	0.062	0.012
94-82-6	2,4-DB	0.062	U JL	0.062	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.062	U	0.062	0.007
100-02-7	4-Nitrophenol	0.062	U JL	0.062	0.021
62476-59-9	Acifluorfen (Blazer)	0.062	U JL	0.062	0.053
25057-89-0	Bentazon	0.062	U	0.062	0.006
1689-84-5	Bromoxynil	0.062	U	0.062	0.006
1702-17-6	Clopyralid	0.062	U JL	0.062	0.008
1861-32-1	Dacthal (DCPA)	0.062	U	0.062	0.005
1918-00-9	**Dicamba I**	**0.031**	NJTL	0.062	0.007
120-36-5	Dichlorprop	0.062	U	0.062	0.008
51338-27-3	Diclofop-Methyl	0.062	U JL	0.062	0.017
88-85-7	Dinoseb	0.062	U JL	0.062	0.040
1689-83-4	Ioxynil	0.062	U	0.062	0.016
94-74-6	**MCPA**	**0.16**	NJTL	0.062	0.008
93-65-2	MCPP (Mecoprop)	0.062	U JL	0.062	0.008
87-86-5	Pentachlorophenol	0.062	U	0.062	0.007
1918-02-1	Picloram	0.062	UJL	0.062	0.017
55335-06-3	**Trichlopyr**	**0.051**	NJTL	0.062	0.007

10 APRIL 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	0.901	0.985	92	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.724	0.985	74	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Tacoma**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1010 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-07
Collected: 2/19/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B138
Prepared: 2/20/2009
Analyzed: 3/3/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.062	U	0.062	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.062	U	0.062	0.007
93-76-5	2,4,5-T	0.062	U	0.062	0.009
93-72-1	2,4,5-TP (Silvex)	0.062	U	0.062	0.010
95-95-4	2,4,5-Trichlorophenol	0.062	U	0.062	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.12**		0.062	0.011
94-75-7	2,4-D	0.062	U	0.062	0.012
94-82-6	2,4-DB		~~REJ~~ R	0.062	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.062	U	0.062	0.007
100-02-7	4-Nitrophenol	0.062	UJ L	0.062	0.021
62476-59-9	Acifluorfen (Blazer)	0.062	~~UJ~~ R	0.062	0.053
25057-89-0	Bentazon	0.062	U	0.062	0.006
1689-84-5	Bromoxynil	0.062	U	0.062	0.006
1702-17-6	Clopyralid	0.062	UJ L	0.062	0.008
1861-32-1	Dacthal (DCPA)	0.062	U	0.062	0.005
1918-00-9	Dicamba I	0.062	U	0.062	0.007
120-36-5	Dichlorprop	0.062	U	0.062	0.008
51338-27-3	Diclofop-Methyl	0.062	U	0.062	0.017
88-85-7	Dinoseb	0.062	~~UJ~~ R	0.062	0.040
1689-83-4	Ioxynil	0.062	U	0.062	0.016
94-74-6	MCPA	0.062	U	0.062	0.008
93-65-2	MCPP (Mecoprop)	0.062	U	0.062	0.008
87-86-5	Pentachlorophenol	0.062	U	0.062	0.007
1918-02-1	Picloram	0.062	~~U~~ R	0.062	0.018
55335-06-3	Trichlopyr	0.062	U	0.062	0.007

10 April 20

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	1.04	0.99	106	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.688	0.99	70	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Result_Re ported_Va lue | Result_Va lue_UOM | Result_Re porting_Li mit | Result_Re porting_Li mit_Type | Result_De tection_Li mit | Result_De tection_Li mit_Type | Result_Da ta_Qualifie r | Result_La b_Name

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Chambers Creek**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 980 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-08
Collected: 2/19/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B138
Prepared: 2/20/2009
Analyzed: 3/3/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.064	U	0.064	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.064	U	0.064	0.007
93-76-5	2,4,5-T	0.064	U	0.064	0.009
93-72-1	2,4,5-TP (Silvex)	0.064	U	0.064	0.010
95-95-4	2,4,5-Trichlorophenol	0.064	U	0.064	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.092**		0.064	0.011
94-75-7	2,4-D	0.064	U	0.064	0.013
94-82-6	2,4-DB	0.064	U	0.064	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.064	U	0.064	0.007
100-02-7	4-Nitrophenol	0.064	U	0.064	0.022
62476-59-9	Acifluorfen (Blazer)	0.064	U	0.064	0.055
25057-89-0	Bentazon	0.064	U	0.064	0.007
1689-84-5	Bromoxynil	0.064	U	0.064	0.006
1702-17-6	Clopyralid	0.064	U	0.064	0.009
1861-32-1	Dacthal (DCPA)	0.064	U	0.064	0.005
1918-00-9	Dicamba I	0.064	U	0.064	0.007
120-36-5	Dichlorprop	0.064	U	0.064	0.009
51338-27-3	Diclofop-Methyl	0.064	U	0.064	0.017
88-85-7	Dinoseb	0.064	U JL	0.064	0.042
1689-83-4	Ioxynil	0.064	U	0.064	0.016
94-74-6	MCPA	0.064	U	0.064	0.008
93-65-2	**MCPP (Mecoprop)**	**0.23**		0.064	0.008
87-86-5	Pentachlorophenol	0.064	U	0.064	0.007
1918-02-1	Picloram	0.064	UJ U	0.064	0.018
55335-06-3	Trichlopyr	0.064	U	0.064	0.007

10 APRIL 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	1.06	1.02	104	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.776	1.02	76	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Sumner**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1010 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-01
Collected: 2/12/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B148
Prepared: 2/17/2009
Analyzed: 3/3/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.062	U	0.062	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.062	U	0.062	0.007
93-76-5	2,4,5-T	0.062	U	0.062	0.009
93-72-1	2,4,5-TP (Silvex)	0.062	U	0.062	0.010
95-95-4	2,4,5-Trichlorophenol	0.062	U	0.062	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.057**	**J T**	0.062	0.011
94-75-7	2,4-D	0.062	U	0.062	0.012
94-82-6	2,4-DB	0.062	U	0.062	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.062	U	0.062	0.007
100-02-7	4-Nitrophenol	0.062	U	0.062	0.021
62476-59-9	Acifluorfen (Blazer)	0.062	U	0.062	0.053
25057-89-0	Bentazon	0.062	U	0.062	0.006
1689-84-5	Bromoxynil	0.062	U	0.062	0.006
1702-17-6	Clopyralid	0.062	UJ L	0.062	0.008
1861-32-1	Dacthal (DCPA)	0.062	U	0.062	0.005
1918-00-9	Dicamba l	0.062	U	0.062	0.007
120-36-5	Dichlorprop	0.062	U	0.062	0.008
51338-27-3	Diclofop-Methyl	0.062	U	0.062	0.017
88-85-7	Dinoseb	0.062	U	0.062	0.040
1689-83-4	Ioxynil	0.062	U	0.062	0.016
94-74-6	**MCPA**	**0.11**	**NJ T**	0.062	0.008
93-65-2	MCPP (Mecoprop)	0.062	U	0.062	0.008
87-86-5	Pentachlorophenol	0.062	U	0.062	0.007
1918-02-1	Picloram	0.062	UJ L	0.062	0.018
55335-06-3	Trichlopyr	0.062	U	0.062	0.007

10 April 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	0.965	0.99	98	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.827	0.99	84	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Everett**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1015 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-04
Collected: 2/12/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B148
Prepared: 2/17/2009
Analyzed: 3/3/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.062	U	0.062	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.062	U	0.062	0.007
93-76-5	2,4,5-T	0.062	U	0.062	0.009
93-72-1	2,4,5-TP (Silvex)	0.062	U	0.062	0.010
95-95-4	2,4,5-Trichlorophenol	0.062	U	0.062	0.008
88-06-2	2,4,6-Trichlorophenol	0.062	U	0.062	0.011
94-75-7	2,4-D	0.062	U	0.062	0.012
94-82-6	2,4-DB	0.062	U	0.062	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.062	U	0.062	0.007
100-02-7	4-Nitrophenol	0.062	U	0.062	0.021
62476-59-9	Acifluorfen (Blazer)	0.062	U	0.062	0.053
25057-89-0	Bentazon	0.062	U	0.062	0.006
1689-84-5	Bromoxynil	0.062	U	0.062	0.006
1702-17-6	Clopyralid	0.062	UJ	0.062	0.008
1861-32-1	Dacthal (DCPA)	0.062	U	0.062	0.005
1918-00-9	Dicamba I	0.062	U	0.062	0.007
120-36-5	Dichlorprop	0.062	U	0.062	0.008
51338-27-3	Diclofop-Methyl	0.062	U	0.062	0.017
88-85-7	Dinoseb	0.062	U	0.062	0.040
1689-83-4	Ioxynil	0.062	U	0.062	0.016
94-74-6	MCPA	0.062	U	0.062	0.008
93-65-2	MCPP (Mecoprop)	0.062	U	0.062	0.008
87-86-5	Pentachlorophenol	0.062	U	0.062	0.007
1918-02-1	Picloram	0.062	UJ	0.062	0.017
55335-06-3	Trichlopyr	0.062	U	0.062	0.007

ID APR 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	1.08	0.985	110	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.788	0.985	80	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Bellingham**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 1010 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-10
Collected: 2/12/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B148
Prepared: 2/17/2009
Analyzed: 3/3/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.062	U	0.062	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.062	U	0.062	0.007
93-76-5	2,4,5-T	0.062	U	0.062	0.009
93-72-1	2,4,5-TP (Silvex)	0.062	U	0.062	0.010
95-95-4	2,4,5-Trichlorophenol	0.062	U	0.062	0.008
88-06-2	**2,4,6-Trichlorophenol**	**0.049**	JT	0.062	0.011
94-75-7	2,4-D	0.062	U	0.062	0.012
94-82-6	2,4-DB	0.062	U	0.062	0.008
51-36-5	3,5-Dichlorobenzoic Acid	0.062	U	0.062	0.007
100-02-7	4-Nitrophenol	0.062	U	0.062	0.021
62476-59-9	Acifluorfen (Blazer)	0.062	U	0.062	0.053
25057-89-0	Bentazon	0.062	U	0.062	0.006
1689-84-5	Bromoxynil	0.062	U	0.062	0.006
1702-17-6	Clopyralid	0.062	UJL	0.062	0.008
1861-32-1	Dacthal (DCPA)	0.062	U	0.062	0.005
1918-00-9	Dicamba I	0.062	U	0.062	0.007
120-36-5	Dichlorprop	0.062	U	0.062	0.008
51338-27-3	Diclofop-Methyl	0.062	U	0.062	0.017
88-85-7	Dinoseb	0.062	U	0.062	0.040
1689-83-4	Ioxynil	0.062	U	0.062	0.016
94-74-6	MCPA	0.062	U	0.062	0.008
93-65-2	MCPP (Mecoprop)	0.062	U	0.062	0.008
87-86-5	**Pentachlorophenol**	**0.076**	NJT	0.062	0.007
1918-02-1	Picloram	0.062	UJL	0.062	0.018
55335-06-3	Trichlopyr	0.062	U	0.062	0.007

10 APRIL 2009

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	0.985	0.99	100	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.718	0.99	72	40-130

Authorized by: _____ Release Date: 3-16-09

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Chlorophenoxy Herbicides

Project: Phase 3: Priority Pollutant Scans of Ten **Field ID: Field Blank**

Work Order: 0902008
Project Officer: Maroncelli, Jim
Initial Vol: 970 mL
Final Vol: 0.5 mL

Lab ID #: 0902008-11
Collected: 2/12/2009
Prep Method: SW3535
Analysis Method: SW 8270

Batch ID: B09B148
Prepared: 2/17/2009
Analyzed: 3/3/2009
Matrix: Water
Units: ug/L

CAS#	Analyte	Result	Qualifier	RL	MDL
4901-51-3	2,3,4,5-Tetrachlorophenol	0.064	U	0.064	0.004
58-90-2	2,3,4,6-Tetrachlorophenol	0.064	U	0.064	0.007
93-76-5	2,4,5-T	0.064	U	0.064	0.009
93-72-1	2,4,5-TP (Silvex)	0.064	U	0.064	0.010
95-95-4	2,4,5-Trichlorophenol	0.064	U	0.064	0.009
88-06-2	2,4,6-Trichlorophenol	0.064	U	0.064	0.011
94-75-7	2,4-D	0.064	U	0.064	0.013
94-82-6	2,4-DB	0.064	U	0.064	0.009
51-36-5	3,5-Dichlorobenzoic Acid	0.064	U	0.064	0.007
100-02-7	4-Nitrophenol	0.064	U	0.064	0.022
62476-59-9	Acifluorfen (Blazer)	0.064	U	0.064	0.055
25057-89-0	Bentazon	0.064	U	0.064	0.007
1689-84-5	Bromoxynil	0.064	U	0.064	0.006
1702-17-6	Clopyralid	0.064	UJ	0.064	0.009
1861-32-1	Dacthal (DCPA)	0.064	U	0.064	0.006
1918-00-9	Dicamba I	0.064	U	0.064	0.007
120-36-5	Dichlorprop	0.064	U	0.064	0.009
51338-27-3	Diclofop-Methyl	0.064	U	0.064	0.017
88-85-7	Dinoseb	0.064	U	0.064	0.042
1689-83-4	Ioxynil	0.064	U	0.064	0.016
94-74-6	MCPA	0.064	U	0.064	0.008
93-65-2	MCPP (Mecoprop)	0.064	U	0.064	0.008
87-86-5	Pentachlorophenol	0.064	U	0.064	0.007
1918-02-1	Picloram	0.064	UJ	0.064	0.018
55335-06-3	Trichlopyr	0.064	U	0.064	0.007

Surrogate Recovery:

CAS#	Analyte	Result	Spike Level	% Recovery	%Rec.Limits
118-79-6	2,4,6-Tribromophenol	0.938	1.03	91	40-130
19719-28-9	2,4-Dichlorophenylacetic acid	0.732	1.03	71	40-130

Authorized by: _____ Release Date: 3-16-09

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: August 26, 2009	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0907021	Gig Harbor	0907021-01	07/14/2009		
0907021	Bremerton	0907021-02	07/14/2009		
0907021	West Point	0907021-04	07/14/2009	MS/MSD	
0907021	Burlington	0907021-05	07/14/2009		
0907021	Tacoma	0907021-06	07/16/2009		
0907021	Chambers Creek	0907021-07	07/16/2009		
0907021	Sumner	0907021-08	07/17/2009		
0907021	Bellingham	0907021-09	07/16/2009		
0907021	Everett	0907021-10	07/20/2009		
0907021	Rinsate	0907021-12	07/10/2009		
0907021	Shelton	0907021-13	07/20/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
0907021	Water	EPA 535/8270	Chlorinated Herbicides by solid phase extraction and GC/MS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes, implied in the data review memoranda by Bob Carrell.
Did coolers arrive at lab less than 6^{o}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, implied in the data review memoranda by Bob Carrell.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	No.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- Internal Standards Outside Limits (Table 4);
- Surrogates Outside Limits (Table 5);
- LCS Outside Limits (Table 6);
- MS/MSD Outside Limits (Table 7); and
- Re-analysis Results (Table 8).

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: August 26, 2009	Completed by: David Ikeda

The chlorinated herbicides analyses data was originally reviewed by Bob Carrell, Manchester Environmental Laboratory (MEL) on July 29, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Chlorinated Pesticides by GC/ECD	
Description	**Notes and Qualifiers**
Any compounds present in method, trip, and field blanks (see Table 3)?	No.
For samples, if results are <10 times the blank then "UJ" flag data.	Not applicable.
Laboratory QC frequency of one method blank and LCS with each batch per 20 samples?	Yes
Internal standards and clean-up standards percent recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	Yes.
Internal standards and clean-up standards recovery values for samples and MS/MSD within laboratory QC limits (see Table 4)?	Yes.
Surrogate recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	Yes.
Surrogate recovery values for samples and MS/MSD within laboratory QC limits (see Table 5)?	Yes.
LCS percent recovery values within Laboratory QC criteria (see Table 6)?	No, picloram was outside QC limits, associated sample results were qualified as estimated (UJG).
MS/MSD percent recovery values within laboratory QC criteria (see Table 7)?	No, several compounds were outside Laboratory QC limits, West Point results were qualified as estimated (UJG or JG), except for picloram. The Picloram quantitation limit was qualified as rejected (REJ).
MS/MSD relative percent difference values within laboratory QC criteria (see Table 7)?	Yes.
Is initial calibration for target compounds <20 % RSD or curve fit?	Yes.
Is continuing calibration for target compounds < 20%?	No, 2,4,6-trichlorophenol and 3,5-dichlorobenzoic acid were outside calibration QC limits. Associated sample results were qualified as estimated (UJK, JTK, or JK).
Were any samples re-analyzed or diluted (see Table 6)? For any sample re-analysis and dilutions is only one reportable result by flagged?	Yes.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: August 26, 2009	Completed by: David Ikeda

The picloram was outside LCS QC limits, associated sample results were qualified as estimated (UJG). Several compounds were outside Laboratory MS/MSD QC limits, West Point results were qualified as estimated (UJG or JG), except for picloram. The Picloram quantitation limit was qualified as rejected (REJ). 2,4,6-Trichlorophenol and 3,5-dichlorobenzoic acid were outside calibration QC limits. Associated sample results were qualified as estimated (UJK, JTK, or JK). Sample results greater than MDL and less than PQL are flagged estimated (JT). Sample results that are outside laboratory QC criteria, the results are flagged tentative identification (NK or NJK).

Table 3 – List of Positive Results for Blank Samples
None.

Table 3A - List of Samples Qualified for Method Blank Contamination
None.

Table 4 - List Internal Standard Recovery Values outside Control Limits
None.

Table 5 – Surrogate Precent Recovery Values outside Control Limits
None.

Table 6 – LCS Precent Recovery Values outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
EPA 8270	B09G181-BS1	Picloram	38	NA	40 – 130	None
EPA 8270	B09G181-BSD1	Picloram	NA	50	40	None

Table 7 – MS/MSD Precent Recovery Values outside Control Limits

Method	Sample ID	Analyte	MS Recovery	MSD Recovery	QC Limit	Sample Qualification
EPA 8270	West Point	2,4,5-T	33	39	40 – 130	UJG
EPA 8270	West Point	2,4-D	28	34	40 – 130	JG
EPA 8270	West Point	4-Nitrophenol	15	19	40 – 130	UJG
EPA 8270	West Point	Bentazon	30	38	40 – 130	UJG
EPA 8270	West Point	Clopyralid	30	34	40 – 130	UJG
EPA 8270	West Point	Picloram	6	7	40 – 130	REJ

Table 8 - Samples that were Reanalyzed
None.

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
K	Bias could not be determined.
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a “tentative identification”.
NJ	The analysis indicates the presence of an analyte that has been “tentatively identified” and the associated numerical value represents its approximate concentration.

REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
T	Sample results are greater than MDL and less than PQL
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: June 19, 2009	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0902008	Sumner	0902008-01	02/12/2009		
0902008	Gig Harbor	0902008-02	02/10/2009		
0902008	Shelton	0902008-03	02/10/2009		
0902008	Everett	0902008-04	02/12/2009		
0902008	Burlington	0902008-05	02/10/2009		
0902008	Bremerton	0902008-06	02/10/2009		
0902008	Tacoma	0902008-07	02/19/2009	MS/MSD	
0902008	Chambers Creek	0902008-08	02/19/2009		
0902008	Metro West Point	0902008-09	02/10/2009		
0902008	Bellingham	0902008-10	02/12/2009		
0902008	Field Blank	0902008-11	02/12/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
0902008	Water	EPA 8081	Chlorinated Pesticide Compounds by GC/ECD	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes.
Did coolers arrive at lab less than 6^{o}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, according to the data review memoranda by M. Mandjikov.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	No.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- Surrogates Outside Limits (Table 4);
- MS/MSD Outside Limits (Table 5);
- LCS Outside Limits (Table 6); and
- Re-analysis Results (Table 7)

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: June 19, 2009	Completed by: David Ikeda

The Chlorinated pesticides analyses (BNAs) data was originally reviewed by M. Mandjikov, Manchester Environmental Laboratory (MEL) on May 21, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Chlorinated Pesticides by GC/ECD	
Description	**Notes and Qualifiers**
Any compounds present in method, trip, and field blanks (see Table 2)?	Yes.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data. Qualification also applies to TICs.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one method blank and LCS with each batch and one set of MS/MSD per 20 samples?	Yes
Surrogate recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	No. No action was taken for the outliers.
Surrogate recovery values for samples and MS/MSD within laboratory QC limits (see Table 4)?	No.
MS/MSD percent recovery values within laboratory QC criteria (see Table 4)?	No – Several compounds were outside QC limits. The analytes were not qualified in the parent sample.
MS/MSD relative percent difference values within QC criteria (see Table 5) of <35%?	No – Several compounds were outside QC limits. No action was taken.
LCS percent recovery values within Laboratory QC criteria (see Table 6)?	No – Several compounds were outside QC limits in B09B101-BSD1, according to the memoranda by M. Madjikov, the laboratory lost part of the sample extract. No action was taken for this LCSD, since the associated LCS was within QC limits.
Confirmation column quantitation results are with QC limits of less than 40 percent?	Several compounds were quantitatively confirmed on the confirmation sample. Sample results that exceeded a relative percent difference of 40% were qualified as estimated bias unknown (JK or JTK).
Is initial calibration for target compounds <20 % RSD or curve fit?	Yes.
Is continuing calibration for target compounds < 20%?	Yes
Were any samples re-analyzed or diluted (see Table 6)? For any sample re-analysis and dilutions is only one reportable result by flagged?	No

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Analytes were detected in the method blanks. The associated samples results were not changed and flagged U. Several MS/MSD compound percent recovery values were outside QC limits. Sample results greater than MDL and less than PQL are flagged estimated (JT).

Table 3 – List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL
SW846 8081	B09B101-BLK1	MBLK	Lindane	0.004	J	µg/L	0.25
SW846 8081	B09B117-BLK1	MBLK	Lindane	0.003	J	µg/L	0.25
SW846 8081	B09B135-BLK1	MBLK	Lindane	0.004	J	µg/L	0.25

Table 3A - List of Samples Qualified for Method Blank Contamination

Method	Sample ID	Analyte	Result	Qual
SW846 8081	Sumner	Lindane	0.0045	U
SW846 8081	Gig Harbor	Lindane	0.0049	U
SW846 8081	Shelton	Lindane	0.0043	U
SW846 8081	Everett	Lindane	0.0025	U
SW846 8081	Burlington	Lindane	0.0049	U
SW846 8081	Bremerton	Lindane	0.0037	U
SW846 8081	Tacoma	Lindane	0.0039	U
SW846 8081	Chambers Creek	Lindane	0.0048	U
SW846 8081	Metro West Point	Lindane	0.0029	U
SW846 8081	Bellingham	Lindane	0.0040	U

Table 4 - List of Samples with Surrogates outside Control Limits

Method	Sample ID	TMX Recovery	DBOB Recovery	DBC Recovery	DCB Recovery	QC Limit	Sample Qualification
SW846 8081	Sumner	52	63	55	74	50 – 150	None
SW846 8081	Gig Harbor	54	56	29	50	50 – 150	UJG or JG
SW846 8081	Shelton	62	73	53	76	50 – 150	None
SW846 8081	Everett	47	56	28	55	50 – 150	UJG
SW846 8081	Burlington	60	72	51	81	50 – 150	None
SW846 8081	Bremerton	60	71	51	73	50 – 150	None
SW846 8081	Tacoma	58	65	39	68	50 – 150	UJG
SW846 8081	Chambers Creek	54	65	38	71	50 – 150	UJG
SW846 8081	Metro West Point	49	56	33	48	50 – 150	UJG
SW846 8081	Bellingham	40	56	38	56	50 – 150	UJG

TMX = Tetrachloro-m-xylene.
DBOB = Dibromooctafluorobiphenyl.
DBC = Dibutylchlrendate.
DCB = Decachlorobiphenyl.

Table 5 - List MS/MSD Percent Recovery Values and RPDs outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	Tacoma MS	Aldrin	49	NA	50 – 150	None
SW846 8270	Tacoma MSD	Aldrin	48	NA	50 – 150	None
SW846 8270	Tacoma MS	4,4'-DDE	41	NA	50 – 150	None
SW846 8270	Tacoma MSD	4,4'-DDE	39	NA	50 – 150	None
SW846 8270	Tacoma MS	4,4'-DDT	46	NA	50 – 150	None
SW846 8270	Tacoma MSD	4,4'-DDT	42	NA	50 – 150	None
SW846 8270	Tacoma MSD	cis-Nonachlor	49	NA	50 – 150	None

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8270	Tacoma MSD	trans-Nonachlor	49	NA	50 – 150	None

Table 6 - List LCS Percent Recovery Values outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8081	B09B117-BS1	Endrin aldehyde	49	NA	50 – 150	None

Table 7 –Samples that were Reanalyzed
None

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: September 9, 2009	Completed by: Mark Woodke

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0907021	Gig Harbor	0907021-01	07/14/2009		
0907021	Bremerton	0907021-02	07/14/2009		
0907021	West Point	0907021-04	07/14/2009	MS/MSD	
0907021	Burlington	0907021-05	07/14/2009		
0907021	Tacoma	0907021-06	07/16/2009		
0907021	Chambers Creek	0907021-07	07/16/2009		
0907021	Sumner	0907021-08	07/17/2009		
0907021	Bellingham	0907021-09	07/16/2009		
0907021	Everett	0907021-10	07/16/2009		
0907021	Rinsate	0907021-12	07/10/2009		
0907021	Shelton	0907021-13	07/15/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
0907021	Water	EPA 8081	Chlorinated Pesticides Compounds by GC/ECD	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes, implied in the data review memorandum by M. Mandjikov.
Did coolers arrive at lab less than 6^{o}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, implied in the data review memorandum by M. Mandjikov.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes.
Case narrative present and complete?	Yes.
Any holding time violations?	No.

The following tables are presented at the end of this QA1 Review Memorandum and provide summaries of results outside QC criteria.

- Method Blank Results (Table 3);
- Surrogates Outside Limits (Table 4);
- MS/MSD Outside Limits (Table 5);
- LCS Outside Limits (Table 6); and
- Re-analysis Results (Table 7).

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: September 9, 2009	Completed by: Mark Woodke

The chlorinated pesticides analyses data was originally reviewed by M. Mandjikov, Manchester Environmental Laboratory (MEL) on August 19, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Chlorinated Pesticides by GC/ECD	
Description	**Notes and Qualifiers**
Any compounds present in method, trip, and field blanks (see Table 3)?	Yes.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data. Qualification also applies to TICs.	Sample results below the PQL are reported at the PQL and flagged U. Sample results greater than the PQL are not changed and flagged U.
Laboratory QC frequency of one method blank and LCS with each batch and one set of MS/MSD per 20 samples?	Yes.
Surrogate recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	No. No action was taken for the outliers.
Surrogate recovery values for samples and MS/MSD within laboratory QC limits (see Table 4)?	No.
LCS percent recovery values within Laboratory QC criteria (see Table 6)?	Yes.
MS/MSD percent recovery values within laboratory QC criteria (see Table 5)?	No, several compounds were outside Laboratory QC limits. The analytes were not qualified in the parent sample.
MS/MSD relative percent difference values within laboratory QC criteria of < 35% (see Table 5)?	Yes.
Confirmation column quantitation results are within QC limits of less than 40 percent?	Several compounds were quantitatively confirmed on the confirmation sample. Sample results that exceeded a relative percent difference of 40 % were qualified as estimated with an unknown bias (JK or JTK).
Is initial calibration for target compounds <20 % RSD or curve fit?	Yes.
Is continuing calibration for target compounds < 20%?	Yes.
Were any samples re-analyzed or diluted (see Table 7)? For any sample re-analysis and dilutions is only one reportable result by flagged?	No.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Analytes were detected in the method blanks. The associated sample results were not changed and were flagged U. Several MS/MSD compound percent recovery values were outside QC limits. Sample results greater than the MDL and less than the PQL are flagged as estimated quantities (JT).

Table 3 – List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL
SW846 8081	B09G116-BLK1	MBLK	Lindane	0.005	J	µg/L	0.0025
SW846 8081	B09G178-BLK1	MBLK	Lindane	0.002	J	µg/L	0.0025

Table 3A - List of Samples Qualified for Method Blank Contamination

Method	Sample ID	Analyte	Result	Qual
SW846 8081	Sumner	Lindane	0.0027	UJ
SW846 8081	Gig Harbor	Lindane	0.010	UJ
SW846 8081	Shelton	Lindane	0.0027	UJ
SW846 8081	Everett	Lindane	0.0051	UJ
SW846 8081	Burlington	Lindane	0.0066	UJ
SW846 8081	Bremerton	Lindane	0.0036	UJ
SW846 8081	Tacoma	Lindane	0.0032	UJ
SW846 8081	Metro West Point	Lindane	0.0047	UJ
SW846 8081	Bellingham	Lindane	0.0053	UJ

Table 4 - List of Samples with Surrogates Outside Control Limits

Method	Sample ID	TMX Recovery	DBOB Recovery	DBC Recovery	DCB Recovery	QC Limit	Sample Qualification
SW846 8081	Gig Harbor	64	57	49	59	50 - 150	JG or UJG
SW846 8081	Everett	33	37	40	69	50 - 150	JG or UJG
SW846 8081	Metro West Point	56	57	48	64	50 - 150	JG or UJG

TMX = Tetrachloro-m-xylene.
DBOB = Dibromooctafluorobiphenyl.
DBC = Dibutylchlorendate.
DCB = Decachlorobiphenyl.

Table 5 – List of MS/MSD Percent Recovery Values and RPDs outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
SW846 8081	Metro West Point MS	2,4'-DDT	39	NA	50 – 150	None
SW846 8081	Metro West Point MS	4,4'-DDE	37	NA	50 – 150	None
SW846 8081	Metro West Point MS	4,4'-DDT	42	NA	50 – 150	None
SW846 8081	Metro West Point MS	Aldrin	45	NA	50 – 150	None
SW846 8081	Metro West Point MS	Cis-Nonachlor	39	NA	50 – 150	None
SW846 8081	Metro West Point MS	Mirex	29	NA	50 – 150	None
SW846 8081	Metro West Point MS	Trans-Nonachlor	46	NA	50 – 150	None
SW846 8081	Metro West Point MSD	2,4'-DDT	38	NA	50 – 150	None
SW846 8081	Metro West Point MSD	4,4'-DDE	38	NA	50 – 150	None
SW846 8081	Metro West Point MSD	4,4'-DDT	42	NA	50 – 150	None
SW846 8081	Metro West Point MSD	Aldrin	47	NA	50 – 150	None
SW846 8081	Metro West Point MSD	Cis-Nonachlor	42	NA	50 – 150	None
SW846 8081	Metro West Point MSD	Mirex	28	NA	50 – 150	None

Table 6 – List of LCS Percent Recovery Values Outside Control Limits
None.

Table 7 - Samples that were Reanalyzed

None.

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
K	Bias could not be determined.
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a “tentative identification”.
NJ	The analysis indicates the presence of an analyte that has been “tentatively identified” and the associated numerical value represents its approximate concentration.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
T	Sample results are greater than MDL and less than PQL
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: May 29, 2009	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
PR90268	Summer	PR90276	02/12/2009		Sumner
PR90268	Gig Harbor	PR90277	02/10/2009		
PR90268	Shelton	PR90278	02/10/2009		
PR90268	Everett	PR90269	02/12/2009		
PR90268	Burlington	PR90280	02/10/2009		
PR90268	Bremerton	PR90270	02/10/2009		
PR90268	Tacoma	PR90271	02/19/2009		
PR90268	Chambers Creek	PR90273	02/19/2009		
PR90268	Metro West Point	PR90274	02/10/2009	Dup	
PR90268	Bellingham	PR90286	02/12/2009		
PR90268	Herrera	PR90287	02/12/2009		Field Blank

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
PR90268	Water	EPA 1614	Brominated Diphenyl Ethers in Water, Soil, Sediment, and Tissue by HRGC/HRMS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes, according to the data review memoranda by Karin Feddersen.
Did coolers arrive at lab less than 6^{o}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, according to the data review memoranda by Karin Feddersen.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	No, according to the data review memoranda by Karin Feddersen.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- OPR outside QC limits (Table 4);
- Sample Reanalysis (Table 5).

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: May 29, 2009	Completed by: David Ikeda

The Polybrominated Diphenyl Ethers (PBDEs) data were originally reviewed by Karin Feddersen, Manchester Environmental Laboratory (MEL) on May 11, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

PFOAs by LCMS-MS	
Description	**Notes and Qualifiers**
Any compounds present in method and field blanks?	Yes, according to the data review memoranda by Karin Feddersen.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one method blank and ongoing precision and recovery (OPR) with each batch?	Yes, according to the data review memoranda by Feddersen.
Initial precision and recovery (IPR) values are within QC limits?	Yes, according to the data review memoranda by Karin Feddersen.
OPR recovery values are within laboratory QC limits?	Yes, according to the data review memoranda by Karin Feddersen.
C-13 labeled isotope dilution internal standard recovery values for samples within QC limits?	Yes, according to the data review memoranda by Karin Feddersen.
Is initial calibration within Method QC limits?	Yes, according to the data review memoranda by Karin Feddersen.
Is continuing calibration within Method QC limits?	Yes, according to the data review memoranda by Karin Feddersen.
Were any samples re-analyzed or diluted? For any sample re-analysis and dilutions is only one reportable result by flagged?	No.
Did compound ion abundances meet method QC requirements for compound identification?	No, according to the data review memoranda by Karin Feddersen. Data was qualified as estimated tentatively identified, bias unknown (NJK or NK).
Laboratory Duplicate Sample analyzed?	Yes, all relative percent difference values were within QC limits.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Several compound ion abundances did not meet method QC requirements for compound identification. Data was qualified as estimated tentatively identified (NJK or NK). No Form Is were received by the secondary reviewer. Several qualifiers were changed by the secondary reviewer, and the spreadsheet that accompanied the data review was updated.

Table 3 – List of Positive Results for Blank Samples
None

Table 4 - OPR outside QC limits
None

Table 5 - List of Reanalyzed Samples
None

Data Validation Qualifiers:

Code	Description
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
K	Bias could not be determined.
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a "tentative identification".
NJ	The analysis indicates the presence of an analyte that has been "tentatively identified" and the associated numerical value represents its approximate concentration.
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 14, 2009	Completed by: Mark Woodke

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
PR90775	Gig Harbor	PR90775	07/16/2009		
PR90775	Bremerton	PR90776	07/16/2009		
PR90775	West Point	PR90777	07/16/2009		
PR90775	Burlington	PR90778	07/16/2009		
PR90775	Tacoma	PR90802	07/24/2009		
PR90775	Chambers Creek	PR90803	07/24/2009		
PR90775	Sumner	PR90804	07/24/2009		
PR90775	Bellingham	PR90805	07/24/2009		
PR90775	Everett	PR90806	07/24/2009	Dup	
PR90775	Shelton	PR90808	07/24/2009		
PR90775	X	PR90779	07/16/2009		Rinsate Blank

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
PR90775	Water	EPA 1614	Brominated Diphenyl Ethers in Water, Soil, Sediment, and Tissue by HRGC/HRMS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes, implied in the data review memoranda by Karin Feddersen.
Did coolers arrive at lab less than 6^{o}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, according to the data review memoranda by Karin Feddersen.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes.
Case narrative present and complete?	Yes.
Any holding time violations?	No, according to the data review memoranda by Karin Feddersen.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blank Results (Table 3);
- OPR outside QC limits (Table 4);
- Sample Reanalysis (Table 5).

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 14, 2009	Completed by: Mark Woodke

The Polybrominated Diphenyl Ethers (PBDEs) data were originally reviewed by Karin Feddersen, Manchester Environmental Laboratory (MEL) on October 9, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

PBDEs by HRGC/HRMS	
Description	**Notes and Qualifiers**
Any compounds present in method and field blanks?	Yes, according to the data review memoranda by Karin Feddersen.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged UJ.
Laboratory QC frequency of one method blank and ongoing precision and recovery (OPR) with each batch?	Yes, according to the data review memoranda by Karin Feddersen.
Initial precision and recovery (IPR) values are within QC limits?	Not discussed in the data review memorandum.
OPR recovery values are within laboratory QC limits?	Yes, according to the data review memoranda by Karin Feddersen.
C-13 labeled isotope dilution internal standard recovery values for samples within QC limits?	No, associated results were qualified UJ.
Is initial calibration within Method QC limits?	No, associated results were qualified JH.
Is continuing calibration within Method QC limits?	No, no qualifiers were applied based on these outliers.
Were any samples re-analyzed or diluted? For any sample re-analysis and dilutions is only one reportable result by flagged?	Yes.
Did compound ion abundances meet method QC requirements for compound identification?	No, according to the data review memoranda by Karin Feddersen. Data was qualified as estimated tentatively identified, bias unknown (NJK or NK).
Laboratory Duplicate Sample analyzed?	Yes, but was not discussed in the data review memorandum.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Several compound ion abundances did not meet method QC requirements for compound identification. Data was qualified as estimated tentatively identified (NJK). Sample results less than 10 times the associated method blank results were qualified UJ. Positive calibration outliers were qualified as estimated quantities (JH). Internal standard quantitation limit outliers were qualified as estimated (UJG). No Form Is were received by the secondary reviewer. Several qualifiers were changed by the secondary reviewer, and the spreadsheet that accompanied the data review was updated.

Table 3 – List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL
1614	BDE09323B	MBLK	BDE-047	26		pg/L	25
1614	BDE09323B	MBLK	BDE-099	15	J	pg/L	25

Table 3A - List of Samples Qualified for Method Blank Contamination

Method	Sample ID	Analyte	Result	Qualifier
1614	Rinsate	BDE-047	151	UJ

Table 4 - OPR outside QC limits
None

Table 5 - List of Reanalyzed Samples

Sample ID	Reason for Reanalysis
BDE09323B	Sample was reanalyzed to get appropriate detection limits.

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
K	Bias could not be determined.
L	The result is low biased.
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a “tentative identification”.
NJ	The analysis indicates the presence of an analyte that has been “tentatively identified” and the associated numerical value represents its approximate concentration.
T	The associated positive result is less than the quantitation limit.
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: August 10, 2009	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0902008	Shelton	0902008-03	02/10/2009		
0902008	Everett	0902008-04	02/12/2009		
0902008	Bremerton	0902008-06	02/10/2009		
0902008	Tacoma	0902008-07	02/19/2009	MS/MSD	
0902008	Chambers Creek	0902008-08	02/19/2009		
0902008	Metro West Point	0902008-09	02/10/2009		
0902008	Field Blank	0902008-11	02/12/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
0902008	Water	EPA 1668	Chlorinated Biphenyl Congeners by HRGC/HRMS	7

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes.
Did coolers arrive at lab less than 6^{o}C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, according to the data review memoranda by Karin Feddersen.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	No.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- Internal and Clean-up Standards Outside Limits (Table 4);
- LCS Outside Limits (Table 5); and
- Re-analysis Results (Table 6)

The chlorinated biphenyl congeners analyses data was originally reviewed by Karin Feddersen, Manchester Environmental Laboratory (MEL) on August 9, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Chlorinated Pesticides by GC/ECD	
Description	**Notes and Qualifiers**

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: August 10, 2009	Completed by: David Ikeda

Chlorinated Pesticides by GC/ECD	
Description	**Notes and Qualifiers**
Any compounds present in method, trip, and field blanks (see Table 2)?	Yes.
For samples, if results are <10 times the blank then "UJ" flag data. Qualification also applies to Total Homolog data.	Samples results are flagged UJ. Associated Total Homolog results are not changed and flagged J.
Laboratory QC frequency of one method blank and LCS (OPR) with each batch per 20 samples?	Yes
Internal standards and clean-up standards percent recovery values for method blanks and LCS/LCSD samples within laboratory QC limits?	Yes.
Internal standards and clean-up standards recovery values for samples and MS/MSD within laboratory QC limits (see Table 4)?	No. No action was taken.
MS/MSD percent recovery values within laboratory QC criteria?	Not required.
MS/MSD relative percent difference values within QC criteria of <35%?	Not required.
LCS percent recovery values within Laboratory QC criteria (see Table 5)?	Yes
Is initial calibration for target compounds <20 % RSD or curve fit?	Yes.
Is continuing calibration for target compounds < 20%?	Yes
Were any samples re-analyzed or diluted (see Table 6)? For any sample re-analysis and dilutions is only one reportable result by flagged?	Yes.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
Analytes were detected in the method blanks. The associated samples results were not changed and flagged UJ. Associated total homolog results were not corrected and were qualified as estimated (J). For sample results with peak ratios outside of acceptable criteria, the results are flagged tentative identification (N or NJ).

Table 3 – List of Positive Results for Blank Samples

Method	Sample ID	Samp Type	Analyte	Result	Qual	Units	PQL
EPA 1668	PC09100B	MBLK	PCB-005/008	10.5		pg/L	10
EPA 1668	PC09100B	MBLK	PCB-011	43.3		pg/L	10
EPA 1668	PC09100B	MBLK	PCB-052/069	11.6		pg/L	10
EPA 1668	PC09100B	MBLK	PCB-101	11		pg/L	10
EPA 1668	PC09100B	MBLK	Dichlorobiphenyls	53.8		pg/L	10
EPA 1668	PC09100B	MBLK	Tetrachlorobiphenyls	11.6		pg/L	10
EPA 1668	PC09100B	MBLK	Pentachlorobiphenyls	11		pg/L	10
EPA 1668	PC09100B	MBLK	Total PCB	76.4		pg/L	10

Table 3A - List of Samples Qualified for Method Blank Contamination

Method	Sample ID	Analyte	Result	Qual

Method	Sample ID	Analyte	Result	Qual
EPA 1668	Everett	PCB-005/008	77	UJ
EPA 1668	Everett	PCB-011	283	UJ
EPA 1668	Bremerton	PCB-005/008	12.1	UJ
EPA 1668	Bremerton	PCB-011	42.9	UJ
EPA 1668	Bremerton	PCB-052/069	19.8	UJ
EPA 1668	Chambers Creek	PCB-005/008	37.5	UJ
EPA 1668	Chambers Creek	PCB-011	94	UJ
EPA 1668	Chambers Creek	PCB-052/069	43.6	UJ
EPA 1668	Metro West Point	PCB-005/008	64.9	UJ
EPA 1668	Metro West Point	PCB-011	68.5	UJ
EPA 1668	Metro West Point	PCB-052/069	89.9	UJ
EPA 1668	Shelton	PCB-011	28.5	UJ
EPA 1668	Shelton	PCB-052/069	27.7	UJ
EPA 1668	Tacoma	PCB-011	95.1	UJ
EPA 1668	Herrera	PCB-011	42.1	UJ
EPA 1668	Herrera	PCB-052/069	32	UJ

Table 4 - List Internal Standard Percent Recovery Values outside Control Limits

Method	Sample ID	Analyte	Percent Recovery	RPD	QC Limit	Sample Qualification
EPA 1668	Shelton	PCB-178L	173	NA	60 – 130	None
EPA 1668	Everett	PCB-178L	160	NA	60 – 130	None
EPA 1668	Bremerton	PCB-178L	190	NA	60 – 130	None

Table 5 – LCS Precent Recovery Values outside Control Limits
None.

Table 6 - Samples that were Reanalyzed

Method	Sample	Reason
EPA 1668	Bremerton	Retention time shifting and peak area suppression. Report original sample.

Data Validation Qualifiers:

Code	Description
G	Value is likely greater than the reported result. Reported result may be biased low.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a “tentative identification”.
NJ	The analysis indicates the presence of an analyte that has been “tentatively identified” and the associated numerical value represents its approximate concentration.
REJ	Data are unusable for all purposes. Sample results rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
U	Analyte was not detected at or above the reported result.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: May 12, 2009	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
L12354	Field Blank	L12354-01	02/12/2009		
L12354	Summer	L12354-02	02/12/2009		Sumner
L12354	Gig Harbor	L12354-03	02/10/2009		
L12354	Shelton	L12354-04	02/10/2009		
L12354	Everett	L12354-05	02/12/2009		
L12354	Burlington	L12354-06	02/10/2009		
L12354	Bremerton	L12354-07	02/10/2009		
L12354	Tacoma	L12354-08	02/19/2009		
L12354	Chambers Creek	L12354-09	02/19/2009		
L12354	Metro West Point	L12354-10	02/10/2009	Dup	
L12354	Bellingham	L12354-12	02/12/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
L12354	Water	MLA-060	Analytical Procedure for the Analysis of Perfluorinated Organic Compounds in Aquaeous Samples by LC-MS/MS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes, according to the data review memoranda by Jim Maroncelli.
Did coolers arrive at lab less than 6°C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, according to the data review memoranda by Jim Maroncelli.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes
Case narrative present and complete?	Yes.
Any holding time violations?	No, according to the data review memoranda by Jim Maroncelli.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);
- OPR outside QC limits (Table 4);
- Sample Reanalysis (Table 5).

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: May 12, 2009	Completed by: David Ikeda

The perfluorinated organic analyses (PFOAs) data was originally reviewed by Jim Maroncelli, Manchester Environmental Laboratory (MEL) on May 5, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

PFOAs by LCMS-MS	
Description	**Notes and Qualifiers**
Any compounds present in method and field blanks?	No.
For samples, if results are <5 times the blank or < 10 times blank for common laboratory contaminants then "U" flag data.	Samples results below the PQL are reported at the PQL and flagged U. Sample results greater than PQL are not changed and flagged U.
Laboratory QC frequency of one method blank and ongoing precision and recovery (OPR) with each batch?	Yes.
Initial precision and recovery (IPR) values are within QC limits?	Yes.
OPR recovery values are within laboratory QC limits?	Yes.
C-13 labeled isotope dilution internal standard recovery values for samples within QC limits?	Yes.
Is initial calibration within Method QC limits?	Yes, according to the data review memoranda by Jim Maroncelli.
Is continuing calibration within Method QC limits?	Yes, according to the data review memoranda by Jim Maroncelli.
Were any samples re-analyzed or diluted? For any sample re-analysis and dilutions is only one reportable result by flagged?	No.
Laboratory Duplicate Sample analyzed?	Yes, all relative percent difference values were within QC limits.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
None

Table 3 – List of Positive Results for Blank Samples
None

Table 4 - OPR outside QC limits
None

Table 5 - List of Reanalyzed Samples
None

Data Validation Qualifiers:

Code	Description
U	Analyte was not detected at or above the reported result.

AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
Field Blank
Sample Collection:
N/A

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-1
Matrix:	AQUEOUS	**Sample Size:**	0.504 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 01:12:50	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 13**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		0.993	
PFPeA	U		0.993	
PFHxA	U		0.993	
PFHpA	U		0.993	
PFOA	U		0.993	
PFNA	U		0.993	
PFDA	U		0.993	
PFUnA	U		0.993	
PFDoA	U		0.993	
PFBS	U		1.99	
PFHxS	U		1.99	
PFOS	U		1.99	
PFOSA	U		0.993	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Matthew Ou_____ QA/QC Chemist

For Axys Internal Use Only [XSL Template: FC-Form1A.xsl; Created: 23-Mar-2009 08:37:20; Application: XMLTransformer-1.9.22;
Report Filename: PFC_FC_LC_PFOA_L12354-1_Form1A_FC9G_069S13_SJ990254.html; Workgroup: WG28032; Design ID: 1058]

12 Mar 2009

Contact: analytical@axys.com

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
~~Summer~~ Sumner
Sample Collection:
N/A

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

		Project No.	PRIORITY POLLUTANTS IN 10 POTWS
Contract No.:	4499	**Lab Sample I.D.:**	L12354-2
Matrix:	AQUEOUS	**Sample Size:**	0.510 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 01:31:33	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 14**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		2.95	0.981	5:23
PFPeA		13.3	0.981	6:05
PFHxA		52.1	0.981	6:28
PFHpA		4.29	0.981	6:51
PFOA		69.8	0.981	7:17
PFNA		6.27	0.981	7:41
PFDA		7.85	0.981	8:11
PFUnA	U		0.981	
PFDoA	U		0.981	
PFBS	U		1.96	
PFHxS	U		1.96	
PFOS		2.57	1.96	8:31
PFOSA		1.08	0.981	10:08

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: Matthew Ou QA/QC Chemist

For Axys Internal Use Only [XSL Template: FC-Form1A.xsl; Created: 23-Mar-2009 08:37:20; Application: XMLTransformer-1.9.22; Report Filename: PFC_FC_LC_PFOA_L12354-2_Form1A_FC9G_069S14_SJ990255.html; Workgroup: WG28032; Design ID: 1058]

AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
Gig Harbor
Sample Collection:
N/A

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-3
Matrix:	AQUEOUS	**Sample Size:**	0.505 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 01:50:14	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 15**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		0.991	
PFPeA		15.9	1.05	6:05
PFHxA		34.1	0.991	6:29
PFHpA		4.65	0.991	6:51
PFOA		48.6	0.991	7:17
PFNA		12.3	0.991	7:41
PFDA		5.66	0.991	8:15
PFUnA	U		0.991	
PFDoA	U		0.991	
PFBS	U		1.98	
PFHxS	U		1.98	
PFOS		5.60	1.98	8:31
PFOSA	U		0.991	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Matthew Ou_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L12354-3_Form1A_FC9G_069S15_SJ990256.html; Workgroup: WG28032; Design ID: 1058]

12 MAY 2009

Contact: analytical@axys.com

AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
Shelton
Sample Collection:
N/A

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-4
Matrix:	AQUEOUS	**Sample Size:**	0.504 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 02:08:05	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 16**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		0.991	
PFPeA		8.47	1.65	6:05
PFHxA		25.5	1.03	6:28
PFHpA		2.80	1.10	6:51
PFOA		33.1	1.05	7:14
PFNA		1.39	0.991	7:41
PFDA		5.78	0.991	8:11
PFUnA	U		0.991	
PFDoA	U		0.991	
PFBS	U		1.98	
PFHxS	U		1.98	
PFOS	U		1.98	
PFOSA	U		0.991	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Matthew Ou_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L12354-4_Form1A_FC9G_069S16_SJ990257.html; Workgroup: WG28032; Design ID: 1058]

12 MAY 2009

Contact: analytical@axys.com

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
Everett
Sample Collection:
N/A

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Contract No.:	4499	**Project No.**	PRIORITY POLLUTANTS IN 10 POTWS
Matrix:	AQUEOUS	**Lab Sample I.D.:**	L12354-5
Sample Receipt Date:	24-Feb-2009	**Sample Size:**	0.480 L
Extraction Date:	26-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Analysis Date:	27-Feb-2009 **Time:** 02:26:47	**Instrument ID:**	LC MS/MS
Extract Volume (uL):	4000	**Column ID:**	C18
Injection Volume (uL):	15	**Sample Data Filename:**	**FC9G_069 S: 17**
Dilution Factor:	N/A	**Blank Data Filename:**	FC9G_069 S: 11
Concentration Units:	ng/L	**Cal. Ver. Data Filename:**	FC9G_069 S: 4

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		1.04	
PFPeA	U		1.50	
PFHxA		11.9	1.04	6:28
PFHpA		10.3	1.04	6:51
PFOA		24.3	1.04	7:14
PFNA		134	1.04	7:41
PFDA		1.91	1.04	8:11
PFUnA		1.18	1.04	8:49
PFDoA	U		1.04	
PFBS	U		2.08	
PFHxS		2.57	2.08	7:26
PFOS		7.57	2.08	8:15
PFOSA	U		1.04	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Matthew Ou_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L12354-5_Form1A_FC9G_069S17_SJ990258.html; Workgroup: WG28032; Design ID: 1058]

12 May 2009

AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
Burlington
Sample Collection:
N/A

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-6
Matrix:	AQUEOUS	**Sample Size:**	0.505 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 02:45:31	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 18**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		0.991	
PFPeA		5.80	1.58	6:05
PFHxA		24.9	1.24	6:29
PFHpA		4.06	1.31	6:51
PFOA		30.5	0.991	7:17
PFNA		13.1	0.991	7:41
PFDA		4.27	0.991	8:11
PFUnA	U		0.991	
PFDoA	U		0.991	
PFBS	U		1.98	
PFHxS		3.17	1.98	7:26
PFOS		5.89	1.98	8:31
PFOSA		1.95	0.991	10:07

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: Matthew Ou QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L12354-6_Form1A_FC9G_069S18_SJ990259.html; Workgroup: WG28032; Design ID: 1058]

12 MAY 2009

Contact: analytical@axys.com

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
Bremerton
Sample Collection:
N/A

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Contract No.:	4499	**Project No.**	PRIORITY POLLUTANTS IN 10 POTWS
Matrix:	AQUEOUS	**Lab Sample I.D.:**	L12354-7
Sample Receipt Date:	24-Feb-2009	**Sample Size:**	0.516 L
Extraction Date:	26-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Analysis Date:	27-Feb-2009 **Time:** 03:04:13	**Instrument ID:**	LC MS/MS
Extract Volume (uL):	4000	**Column ID:**	C18
Injection Volume (uL):	15	**Sample Data Filename:**	**FC9G_069 S: 19**
Dilution Factor:	N/A	**Blank Data Filename:**	FC9G_069 S: 11
Concentration Units:	ng/L	**Cal. Ver. Data Filename:**	FC9G_069 S: 4

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		1.40	1.36	5:23
PFPeA		1.16	0.968	6:05
PFHxA		10.8	0.968	6:28
PFHpA		2.08	0.968	6:51
PFOA		11.3	0.968	7:14
PFNA		2.36	0.968	7:41
PFDA		1.74	0.968	8:02
PFUnA	U		0.968	
PFDoA	U		0.968	
PFBS	U		1.94	
PFHxS	U		1.94	
PFOS		4.50	1.94	8:31
PFOSA	U		0.968	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Matthew Ou_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L12354-7_Form1A_FC9G_069S19_SJ990260.html; Workgroup: WG28032; Design ID: 1058]

12 May 2009

Contact: analytical@axys.com

AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
Tacoma
Sample Collection:
N/A

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-8
Matrix:	AQUEOUS	**Sample Size:**	0.509 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 03:22:55	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 20**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		1.38	0.982	5:22
PFPeA		3.77	2.25	6:05
PFHxA		10.9	1.83	6:27
PFHpA		5.64	0.982	6:51
PFOA		27.0	0.982	7:14
PFNA		4.47	0.982	7:41
PFDA		2.62	0.982	8:11
PFUnA	U		0.982	
PFDoA	U		0.982	
PFBS	U		1.96	
PFHxS		4.42	2.75	7:26
PFOS		9.71	1.96	8:27
PFOSA	U		0.982	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Matthew Ou_____ QA/QC Chemist

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12 May 2009

AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
Chambers Creek
Sample Collection:
N/A

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-9
Matrix:	AQUEOUS	**Sample Size:**	0.509 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 03:41:37	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 21**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		3.60	0.983	5:23
PFPeA		2.02	1.11	6:02
PFHxA		12.1	1.17	6:28
PFHpA		3.98	1.09	6:51
PFOA		10.9	0.983	7:14
PFNA		2.76	0.983	7:41
PFDA		5.54	0.983	7:59
PFUnA	U		0.983	
PFDoA	U		0.983	
PFBS	U		1.97	
PFHxS		6.87	1.97	7:26
PFOS		6.56	1.97	8:27
PFOSA	U		0.983	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: Matthew Ou QA/QC Chemist

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AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
Metro West Point (GP)
Sample Collection:
N/A

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-10
Matrix:	AQUEOUS	**Sample Size:**	0.501 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 04:00:19	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 22**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		1.31	0.997	5:20
PFPeA		1.84	1.46	6:03
PFHxA		13.2	0.997	6:28
PFHpA		2.75	0.997	6:51
PFOA		12.5	0.997	7:14
PFNA		3.73	0.997	7:41
PFDA		2.82	0.997	8:11
PFUnA	U		0.997	
PFDoA	U		0.997	
PFBS	U		1.99	
PFHxS		3.12	1.99	7:26
PFOS		19.5	1.99	8:31
PFOSA	U		0.997	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: Matthew Ou QA/QC Chemist

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12 March 2009

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
Bellingham
Sample Collection:
N/A

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L12354-12
Matrix:	AQUEOUS	**Sample Size:**	0.499 L
Sample Receipt Date:	24-Feb-2009	**Initial Calibration Date:**	25-Feb-2009
Extraction Date:	26-Feb-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	27-Feb-2009 **Time:** 04:37:43	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_069 S: 24**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_069 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_069 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		1.86	1.00	5:22
PFPeA		1.90	1.00	6:05
PFHxA		15.4	1.00	6:28
PFHpA		3.53	1.00	6:51
PFOA		11.6	1.00	7:17
PFNA		3.52	1.00	7:41
PFDA		1.37	1.00	8:11
PFUnA	U		1.00	
PFDoA	U		1.00	
PFBS	U		2.00	
PFHxS		3.31	2.00	7:26
PFOS		6.02	2.28	8:27
PFOSA	U		1.00	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: Matthew Ou QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L12354-12_Form1A_FC9G_069S24_SJ990265.html; Workgroup: WG28032; Design ID: 1058]

12 MAY 2009

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 7, 2009	Completed by: Mark Woodke

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance review level 1 review (QA1, PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
L13114	Field Blank	L12114-1	07/14/2009		
L13114	0907021-01	L12114-2	07/14/2009		
L13114	0907021-02	L12114-3	07/14/2009		
L13114	0907021-03	L12114-4	07/14/2009		
L13114	0907021-04	L12114-5(A)	07/14/2009	DUP	
L13114	0907021-05	L12114-7	07/14/2009		
L13114	0907021-06	L12114-8	07/16/2009		
L13114	0907021-07	L12114-9	07/16/2009		
L13114	0907021-08	L12114-10	07/16/2009		
L13114	0907021-09	L12114-11	07/16/2009		
L13114	0907021-10	L12114-12	07/16/2009		

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Order	Matrix	Test Method	Method Name	Number of Samples
L13114	Water	MLA-060	Analytical Procedure for the Analysis of Perfluorinated Organic Compounds in Aqueous Samples by LC-MS/MS	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes, implied in the data review memorandum by Karin Feddersen.
Did coolers arrive at lab at less than 6°C and in good condition as indicated on COC and Cooler Receipt Form?	Yes, implied in the data review memorandum by Karin Feddersen.
Frequency of Field QC Samples Correct? Field Duplicate – Not required.	Yes.
Case narrative present and complete?	Yes.
Any holding time violations?	No, according to the data review memorandum by Karin Feddersen.

The following tables are presented at the end of this QA1 Review Memorandum and provide summaries of results outside QC criteria.

- Method Blank Results (Table 3);
- OPR Outside Limits (Table 4); and
- Sample Reanalysis (Table 5).

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: October 7, 2009	Completed by: Mark Woodke

The Perfluorinated organic analyses (PFOAs) data was originally reviewed by Karin Feddersen, Manchester Environmental Laboratory, on October 5, 2009. The laboratory provided analytical summaries for samples, including QC samples. No raw data was provided with the deliverable.

Metals by GC/ECD	
Description	**Notes and Qualifiers**
Any compounds present in method and field blanks?	No.
For samples, if results are <5 times the blank or <10 times the blank for common laboratory contaminants then "U" flag data.	Not applicable.
Laboratory QC frequency of one method blank and ongoing precision and recovery (OPR) with each batch?	Yes.
Initial precision and recovery (IPR) values are within QC limits?	Not provided.
OPR recovery values are within laboratory QC limits?	Yes.
C-13 labeled isotope dilution internal standard recovery values for samples within QC limits?	Yes.
Is initial calibration within method QC limits?	Yes according to the data review memorandum by Karin Feddersen.
Is continuing calibration within method QC limits?	Yes according to the data review memorandum by Karin Feddersen.
Were any samples re-analyzed or diluted? For any sample re-analysis and dilutions, is only one reportable result flagged?	No.
Laboratory duplicate sample analyzed?	Yes, all relative percent difference values were within QC limits.

Summary of Potential Impacts on Data Usability
Major Concerns
None
Minor Concerns
None.

Table 3 – List of Positive Results for Blank Samples
None

Table 4 – OPR outside QC Limits
None

Table 5 – List of Reanalyzed Samples
None.

Data Validation Qualifiers:

Code	Description
U	Analyte was not detected at or above the reported result.

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
Field Blank
Sample Collection:
N/A

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Contract No.:	4499	**Project No.**	PRIORITY POLLUTANTS IN 10 POTWS
Matrix:	AQUEOUS	**Lab Sample I.D.:**	L13114-1
Sample Receipt Date:	22-Jul-2009	**Sample Size:**	0.496 L
Extraction Date:	23-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Analysis Date:	08-Aug-2009 **Time:** 14:55:09	**Instrument ID:**	LC MS/MS
Extract Volume (uL):	4000	**Column ID:**	C18
Injection Volume (uL):	15	**Sample Data Filename:**	FC9G_347 S: 13
Dilution Factor:	N/A	**Blank Data Filename:**	FC9G_347 S: 11
Concentration Units:	ng/L	**Cal. Ver. Data Filename:**	FC9G_347 S: 4

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		1.01	
PFPeA	U		1.01	
PFHxA	U		1.01	
PFHpA	U		1.01	
PFOA	U		1.01	
PFNA	U		1.01	
PFDA	U		1.01	
PFUnA	U		1.01	
PFDoA	U		1.01	
PFBS	U		2.01	
PFHxS	U		2.01	
PFOS	U		2.01	
PFOSA	U		2.52	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Bryan Alonzo_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L13114-1_Form1A_FC9G_347S13_SJ1043102.html; Workgroup: WG29556; Design ID: 1058]

These pages are part of a larger report that may contain information necessary for full data evaluation.
Results reported relate only to the sample tested.
Results are compliant with NELAP where specific accreditation is held.

MW
10-7-09

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
0907021-01
Sample Collection:
14-Jul-2009 12:15

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Contract No.:	4499	**Project No.**	PRIORITY POLLUTANTS IN 10 POTWS
Matrix:	AQUEOUS	**Lab Sample I.D.:**	L13114-2
Sample Receipt Date:	22-Jul-2009	**Sample Size:**	0.492 L
Extraction Date:	23-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Analysis Date:	08-Aug-2009 **Time:** 15:14:36	**Instrument ID:**	LC MS/MS
Extract Volume (uL):	4000	**Column ID:**	C18
Injection Volume (uL):	15	**Sample Data Filename:**	**FC9G_347 S: 14**
Dilution Factor:	N/A	**Blank Data Filename:**	FC9G_347 S: 11
Concentration Units:	ng/L	**Cal. Ver. Data Filename:**	FC9G_347 S: 4

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		1.38	1.02	5:23
PFPeA		12.6	1.02	6:06
PFHxA		41.3	1.02	6:28
PFHpA		5.27	1.02	6:51
PFOA		52.5	1.02	7:17
PFNA		23.2	1.02	7:41
PFDA		7.31	1.02	8:15
PFUnA	U		1.02	
PFDoA	U		1.02	
PFBS	U		2.03	
PFHxS	U		2.03	
PFOS		2.24	2.03	8:21
PFOSA	U		2.54	

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Approved by: _____Bryan Alonzo_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L13114-2_Form1A_FC9G_347S14_SJ1043103.html; Workgroup: WG29556; Design ID: 1058]

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MW 10-7-09

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
0907021-02
Sample Collection:
14-Jul-2009 09:45

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Contract No.:	4499	**Project No.**	PRIORITY POLLUTANTS IN 10 POTWS
Matrix:	AQUEOUS	**Lab Sample I.D.:**	L13114-3
Sample Receipt Date:	22-Jul-2009	**Sample Size:**	0.499 L
Extraction Date:	23-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Analysis Date:	08-Aug-2009 **Time:** 15:34:03	**Instrument ID:**	LC MS/MS
Extract Volume (uL):	4000	**Column ID:**	C18
Injection Volume (uL):	15	**Sample Data Filename:**	**FC9G_347 S: 15**
Dilution Factor:	N/A	**Blank Data Filename:**	FC9G_347 S: 11
Concentration Units:	ng/L	**Cal. Ver. Data Filename:**	FC9G_347 S: 4

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		1.83	1.00	5:20
PFPeA	U		1.00	
PFHxA		14.3	1.00	6:29
PFHpA		3.44	1.00	6:51
PFOA		11.1	1.00	7:17
PFNA		10.8	1.00	7:41
PFDA		2.77	1.00	8:15
PFUnA	U		1.00	
PFDoA	U		1.00	
PFBS		17.7	2.01	6:26
PFHxS		7.79	2.01	7:30
PFOS		55.0	2.01	8:31
PFOSA	U		2.51	

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Report Filename: PFC_FC_LC_PFOA_L13114-3_Form1A_FC9G_347S15_SJ1043104.html; Workgroup: WG29556; Design ID: 1058]

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AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
0907021-03
Sample Collection:
14-Jul-2009 07:30

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L13114-4
Matrix:	AQUEOUS	**Sample Size:**	0.489 L
Sample Receipt Date:	22-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Extraction Date:	23-Jul-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	08-Aug-2009 **Time:** 15:52:42	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_347 S: 16**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_347 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_347 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		2.99	1.02	5:20
PFPeA		16.5	1.02	6:05
PFHxA		44.3	1.02	6:28
PFHpA		3.74	1.02	6:47
PFOA		38.9	1.02	7:14
PFNA		3.29	1.02	7:41
PFDA		6.30	1.02	8:15
PFUnA	U		1.02	
PFDoA	U		1.02	
PFBS	U		2.04	
PFHxS	U		2.04	
PFOS		4.37	2.04	8:31
PFOSA	U		2.56	

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Report Filename: PFC_FC_LC_PFOA_L13114-4_Form1A_FC9G_347S16_SJ1043105.html; Workgroup: WG29556; Design ID: 1058]

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AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
0907021-04
Sample Collection:
14-Jul-2009 07:17

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L13114-5 (A)
Matrix:	AQUEOUS	**Sample Size:**	0.506 L
Sample Receipt Date:	22-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Extraction Date:	23-Jul-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	08-Aug-2009 **Time:** 16:11:20	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_347 S: 17**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_347 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_347 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		2.47	1.52	5:20
PFPeA	U		1.38	
PFHxA		16.1	0.987	6:27
PFHpA		6.00	1.04	6:51
PFOA		22.6	0.987	7:14
PFNA		5.83	0.987	7:38
PFDA		4.28	0.987	8:11
PFUnA	U		0.987	
PFDoA	U		0.987	
PFBS		13.8	1.97	6:28
PFHxS		2.65	1.97	7:26
PFOS		21.2	1.97	8:27
PFOSA	U		2.47	

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Approved by: _____Bryan Alonzo_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L13114-5_Form1A_FC9G_347S17_SJ1043106.html; Workgroup: WG29556; Design ID: 1058]

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Contact: analytical@axys.com

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
0907021-05
Sample Collection:
14-Jul-2009 17:00

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L13114-7
Matrix:	AQUEOUS	**Sample Size:**	0.508 L
Sample Receipt Date:	22-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Extraction Date:	23-Jul-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	08-Aug-2009 **Time:** 16:48:37	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_347 S: 19**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_347 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_347 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		1.27	
PFPeA		1.94	0.984	6:03
PFHxA		9.62	0.984	6:28
PFHpA		4.73	0.984	6:51
PFOA		16.5	0.984	7:14
PFNA		4.11	0.984	7:41
PFDA		3.57	0.984	8:11
PFUnA	U		0.984	
PFDoA	U		0.984	
PFBS	U		1.97	
PFHxS		2.34	1.97	7:26
PFOS		3.51	1.97	8:31
PFOSA	U		2.46	

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Approved by: Bryan Alonzo QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L13114-7_Form1A_FC9G_347S19_SJ1043108.html; Workgroup: WG29556; Design ID: 1058]

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AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
0907021-06
Sample Collection:
16-Jul-2009 14:40

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L13114-8
Matrix:	AQUEOUS	**Sample Size:**	0.506 L
Sample Receipt Date:	22-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Extraction Date:	23-Jul-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	08-Aug-2009 **Time:** 17:08:12	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_347 S: 20**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_347 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_347 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		1.53	
PFPeA		6.79	0.988	6:05
PFHxA		22.8	0.988	6:28
PFHpA		9.69	0.988	6:51
PFOA		30.2	0.988	7:14
PFNA		7.02	0.988	7:41
PFDA		1.54	0.988	8:08
PFUnA	U		0.988	
PFDoA	U		0.988	
PFBS	U		1.98	
PFHxS		7.01	1.98	7:26
PFOS		4.23	1.98	8:21
PFOSA	U		2.47	

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Report Filename: PFC_FC_LC_PFOA_L13114-8_Form1A_FC9G_347S20_SJ1043109.html; Workgroup: WG29556; Design ID: 1058]

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AXYS METHOD MLA-060 Rev 07

CLIENT SAMPLE NO.
0907021-07
Sample Collection:
16-Jul-2009 16:14

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L13114-9
Matrix:	AQUEOUS	**Sample Size:**	0.504 L
Sample Receipt Date:	22-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Extraction Date:	23-Jul-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	08-Aug-2009 **Time:** 17:27:39	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_347 S: 21**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_347 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_347 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		4.87	1.46	5:22
PFPeA		1.98	0.993	6:03
PFHxA		18.5	0.993	6:28
PFHpA		6.49	0.993	6:51
PFOA		13.2	0.993	7:14
PFNA		5.76	1.02	7:41
PFDA		3.66	0.993	8:05
PFUnA	U		0.993	
PFDoA	U		0.993	
PFBS		14.7	1.99	6:32
PFHxS		8.27	1.99	7:26
PFOS		8.78	1.99	8:27
PFOSA	U		2.48	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Bryan Alonzo_____ QA/QC Chemist

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MW 10709

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
0907021-08
Sample Collection:
16-Jul-2009 11:05

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L13114-10
Matrix:	AQUEOUS	**Sample Size:**	0.508 L
Sample Receipt Date:	22-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Extraction Date:	23-Jul-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	08-Aug-2009 **Time:** 17:47:06	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	**FC9G_347 S: 22**
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_347 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_347 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		0.985	
PFPeA		18.2	0.985	6:06
PFHxA		30.9	0.985	6:29
PFHpA		6.96	0.985	6:51
PFOA		46.5	0.985	7:17
PFNA		9.16	0.985	7:41
PFDA		10.4	0.985	8:15
PFUnA	U		0.985	
PFDoA	U		0.985	
PFBS	U		1.97	
PFHxS	U		1.97	
PFOS		10.7	1.97	8:31
PFOSA	U		2.46	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Bryan Alonzo_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L13114-10_Form1A_FC9G_347S22_SJ1043111.html; Workgroup: WG29556; Design ID: 1058]

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10-7-09

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
0907021-09
Sample Collection:
16-Jul-2009 09:24

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Project No.	PRIORITY POLLUTANTS IN 10 POTWS		
Contract No.:	4499	**Lab Sample I.D.:**	L13114-11
Matrix:	AQUEOUS	**Sample Size:**	0.505 L
Sample Receipt Date:	22-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Extraction Date:	23-Jul-2009	**Instrument ID:**	LC MS/MS
Analysis Date:	08-Aug-2009 **Time:** 18:05:44	**Column ID:**	C18
Extract Volume (uL):	4000	**Sample Data Filename:**	FC9G_347 S: 23
Injection Volume (uL):	15	**Blank Data Filename:**	FC9G_347 S: 11
Dilution Factor:	N/A	**Cal. Ver. Data Filename:**	FC9G_347 S: 4
Concentration Units:	ng/L		

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA	U		1.46	
PFPeA		2.05	0.991	6:03
PFHxA		17.2	0.991	6:28
PFHpA		5.10	0.991	6:51
PFOA		17.4	0.991	7:14
PFNA		22.0	0.991	7:38
PFDA		2.82	0.991	8:08
PFUnA	U		0.991	
PFDoA	U		0.991	
PFBS	U		1.98	
PFHxS		2.41	1.98	7:26
PFOS	U		1.98	
PFOSA	U		2.48	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Bryan Alonzo_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L13114-11_Form1A_FC9G_347S23_SJ1043112.html; Workgroup: WG29556; Design ID: 1058]

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MW 10-7-09

05911

AXYS METHOD MLA-060 Rev 07

Form 1A

PERFLUORINATED ORGANICS ANALYSIS REPORT

CLIENT SAMPLE NO.
0907021-10
Sample Collection:
16-Jul-2009 12:37

AXYS ANALYTICAL SERVICES
2045 MILLS RD., SIDNEY, B.C., CANADA
V8L 5X2 TEL (250) 655-5800 FAX (250) 655-5811

Contract No.:	4499	**Project No.**	PRIORITY POLLUTANTS IN 10 POTWS
Matrix:	AQUEOUS	**Lab Sample I.D.:**	L13114-12
Sample Receipt Date:	22-Jul-2009	**Sample Size:**	0.500 L
Extraction Date:	23-Jul-2009	**Initial Calibration Date:**	06-Aug-2009
Analysis Date:	08-Aug-2009 **Time:** 18:24:23	**Instrument ID:**	LC MS/MS
Extract Volume (uL):	4000	**Column ID:**	C18
Injection Volume (uL):	15	**Sample Data Filename:**	**FC9G_347 S: 24**
Dilution Factor:	N/A	**Blank Data Filename:**	FC9G_347 S: 11
Concentration Units:	ng/L	**Cal. Ver. Data Filename:**	FC9G_347 S: 4

COMPOUND	LAB FLAG [1]	CONC. FOUND	DETECTION LIMIT	RETENTION TIME
PFBA		3.24	1.00	5:24
PFPeA		3.18	1.41	6:03
PFHxA		16.1	1.04	6:27
PFHpA		7.83	1.33	6:51
PFOA		16.8	1.00	7:14
PFNA		28.7	1.47	7:41
PFDA		2.55	1.00	8:11
PFUnA	U		1.00	
PFDoA	U		1.00	
PFBS	U		2.00	
PFHxS		3.36	2.00	7:23
PFOS		10.0	2.00	8:31
PFOSA	U		2.50	

(1) Where applicable, custom lab flags have been used on this report; U = not detected.

Approved by: _____Bryan Alonzo_____ QA/QC Chemist

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Report Filename: PFC_FC_LC_PFOA_L13114-12_Form1A_FC9G_347S24_SJ1043113.html; Workgroup: WG29556; Design ID: 1058]

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MW 10-7-09

Quality Assurance Review Level 1 Report	Project: Ecology – POTW Pollution Scans
Date Completed: March 31, 2008	Completed by: David Ikeda

The analytical data provided by the laboratory were reviewed for precision, accuracy, and completeness per Washington Department of Ecology (Ecology) Quality Assurance Review Guidance for the quality assurance level 1 review (QA1) (PTI, 1989). Specific criteria for QC limits were obtained from the project QAPP. Compliance with the project QA program is indicated on the in the checklist and tables. Any major or minor concern affecting data usability is summarized below. The checklist and tables also indicate whether data qualification is required and/or the type of qualifier assigned.

Reference:

Table 1 Sample Summary Tables from Electronic Data Deliverable

Work Order	Matrix	Sample ID	Lab ID	Sample Date	Lab QC	ID Corrections
0902008	Water	Sumner	0902008-01	02/12/2009		None
0902008	Water	Gig Harbor	0902008-02	02/10/2009	MS/MSD	None
0902008	Water	Shelton	0902008-03	02/10/2009		None
0902008	Water	Everett	0902008-04	02/12/2009		None
0902008	Water	Burlington	0902008-05	02/10/2009		None
0902008	Water	Bremerton	0902008-06	02/10/2009		None
0902008	Water	Tacoma	0902008-07	02/19/2009		None
0902008	Water	Chambers Creek	0902008-08	02/19/2009		None
0902008	Water	Metro West Point	0902008-09	02/10/2009	Duplicate	None
0902008	Water	Bellingham	0902008-10	02/12/2009		None
0902008	Water	Field Blank	0902008-11	02/12/2009		None

Table 2 Work Orders, Tests and Number of Samples included in this DUSR

Work Orders	Matrix	Test Method	Method Name	Number of Samples
0902008	Water	EPA 200.8	Inductively Coupled Plasma - Mass Spectrometry	11

General Sample Information	
Do Samples and Analyses on COC check against Lab Sample Tracking Form?	Yes
Did coolers arrive at lab between 0 °C and 6°C and in good condition as indicated on COC and Cooler Receipt Form?	Yes
Frequency of Field QC Samples Correct? Field Duplicate – Not required. Field Blank – 1/20 samples. MS/MSD samples – 1/20 samples.	Yes
Case narrative present and complete?	Yes
Any holding time violations?	No - All samples were prepared and analyzed within holding times.

The following tables are presented at the end of this QA1 Review Memorandum and provided summaries of results outside QC criteria.

- Method Blanks Results (Table 3);