# Perfluorinated Compounds in Washington Rivers and Lakes

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Cover photo: Upper Columbia River near Northport, Washington.

# Perfluorinated Compounds in Washington Rivers and Lakes

by

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Waterbody Numbers: See Appendix B.

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# Abstract

The Washington State Department of Ecology analyzed perfluorinated compounds (PFCs) in a variety of environmental matrices during 2008. The study was conducted to determine the occurrence of these emerging persistent, bioaccumulative, and toxic chemicals within the state. Results will be used to aid in the design of a PFC Chemical Action Plan describing the state's approach to these contaminants.

In total, 13 perfluoroalkyl acids were measured in 14 surface waters, 4 wastewater treatment plant (WWTP) effluents, 15 fish fillet composites, and 15 fish liver composites statewide. Surface water and WWTP effluent were collected during the spring and fall to examine concentrations during high and low flows. In addition, 11 osprey eggs from the Lower Columbia River were analyzed.

Surface water results indicate widespread occurrence of total PFCs at concentrations near or less than 10 ng/L. Concentrations greater than 10 ng/L were found in the South Fork Palouse River, West Medical Lake, and Lake Washington. Total PFC concentrations in WWTP effluent, ranging from 61 – 418 ng/L, were higher than in surface waters. At least 8 different PFCs were detected in each effluent sample analyzed.

Perfluorooctane sulfate was the dominant acid detected in fish tissues. A total of 40% of fillet samples and 67% of liver samples contained concentrations above 10 ng/g. Concentrations were highest in urban waterbodies and those with large WWTP contributions.

Total PFC concentrations ranged from 38 – 910 ng/g in osprey eggs collected from the Lower Columbia River. The majority of concentrations were less than 100 ng/g; however, 3 eggs contained levels greater than 250 ng/g.

Generally speaking, total PFC concentrations in all matrices recorded as part of the 2008 study were within or below the range of values recorded at other United States locations. The maximum osprey egg concentration (910 ng/g) was the second highest recorded value in the United States for that medium.

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# Introduction

Perfluorinated compounds (PFCs) are a generic term for a family of perfluoroalkyl acids (PFAAs) that contain a fluorinated carbon backbone and a charged functional group (typically carboxylate or sulfonate). The two most widely known PFCs, perfluorooctanoic acid (PFOA) and perfluorooctane sulfate (PFOS), are pictured in Figure 1. PFCs dramatically lower surface tension making them an ideal surfactant. The carbon-fluorine bonds in these compounds are among the strongest in organic chemistry and render the acids practically non-biodegradable (Lau et al., 2007).

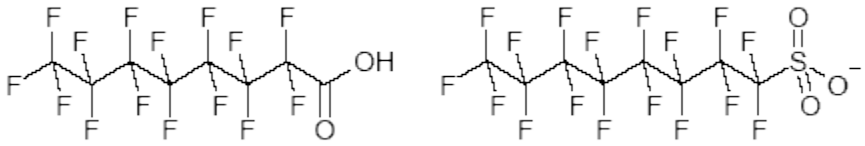


Figure 1. Chemical Structure of PFOA and PFOS.

The surfactant properties of PFCs impart unique physical characteristics controlled by a hydrophilic anionic head group and a hydrophobic perfluorinated tail, with overall lipophobic characteristics. The $K_{ow}$ value, measuring the equilibrium concentration of a compound between octanol and water, is a problematic parameter to measure due to the chemical's tendency to concentrate at the liquid-liquid interface. However, the acids are soluble in water, and the predictably low Henry's Law constant suggests the acids will preferentially accumulate in aquatic environments (Martin et al., 2003a). Subsequently, environmental monitoring of PFCs has largely surrounded aquatic environments (Gannon et al., 2006).

PFCs have been produced for over 50 years for use in a wide variety of industrial and consumer applications including stain-resistant coatings for clothing and carpet, fire-fighting foams, paints, adhesives, waxes, and polishes (Renner, 2001). Historically, PFOS was produced in much greater quantities than PFOA, but since the primary manufacturer of PFOS, 3M®, phased out production in 2002, PFOA is now the most common PFC in commerce. In 2006, the U.S. Environmental Protection Agency (EPA) began a PFOA stewardship program in which 8 major PFOA producers have committed to reducing the manufacture of PFOA by 95% no later than 2010 (EPA, 2006a). It is unknown if other PFAAs will be produced to fill the commercial void.

PFCs are widespread with quantifiable amounts found in virtually all media (e.g., human serum, surface water, groundwater, rain, air, soil, sediment, ice caps, animal tissue) around the globe (Giesy and Kannan, 2001; Kannan et al., 2004). Currently, 2 major sources have been suggested to account for the widespread distribution of PFCs in the environment: (1) leaching from consumer products and industrial processes and (2) degradation of fluorotelomer alcohols (FTAs) to PFCs in the environment (Kim and Kannan, 2007). FTAs are major raw materials

used in fluorosurfactant production and have a sufficiently high vapor pressure allowing for atmospheric transport (Ellis et al., 2003; 2004).

The toxicokinetics of PFCs are poorly understood (Kudo and Kawashima, 2003). Recently EPA has labeled PFOA and its salts "likely to be carcinogenic" (EPA, 2006b). Epidemiological studies conducted by 3M® have not shown PFOA to affect human health. However, PFOA animal tests have shown the chemical to be toxic at high concentrations (Kudo and Kawashima, 2003; Lau et al., 2007; EPA, 2006b).

Despite the widespread distribution of PFCs in the environment and the potential for adverse human health effects, little data exists describing the environmental occurrence of PFCs in the United States. No data exists for Washington State or any other state in the western United States. The Washington State Department of Ecology (Ecology) has identified PFOS as a persistent, bioaccumulative, toxic (PBT) chemical. Ecology and the Washington State Department of Health are planning on preparing a Chemical Action Plan identifying steps the state may take to reduce the threat of PFOS and other PFCs in the environment.

# Goals and Objectives

In view of the lack of PFC data for Washington State, Ecology conducted a one-time study seeking to determine concentrations in a variety of environmental media statewide. The goal of the study was to provide data to aid in the design of a Chemical Action Plan for addressing PFCs within the state.

Specific objectives of the study included:

- Measure PFC concentrations from 14 surface waters and 4 WWTP effluents.
- Measure fillet and liver concentrations in fish from 8 of the 14 surface water locations.
- Characterize PFC concentrations in Lower Columbia River osprey eggs.
- Evaluate spatial and seasonal concentration patterns in surface waters.

# Study Design

Samples of surface waters, WWTP effluents, fish tissues, and osprey eggs were collected in Washington State for analysis of PFCs. Sites included in the survey are displayed in Figure 2.

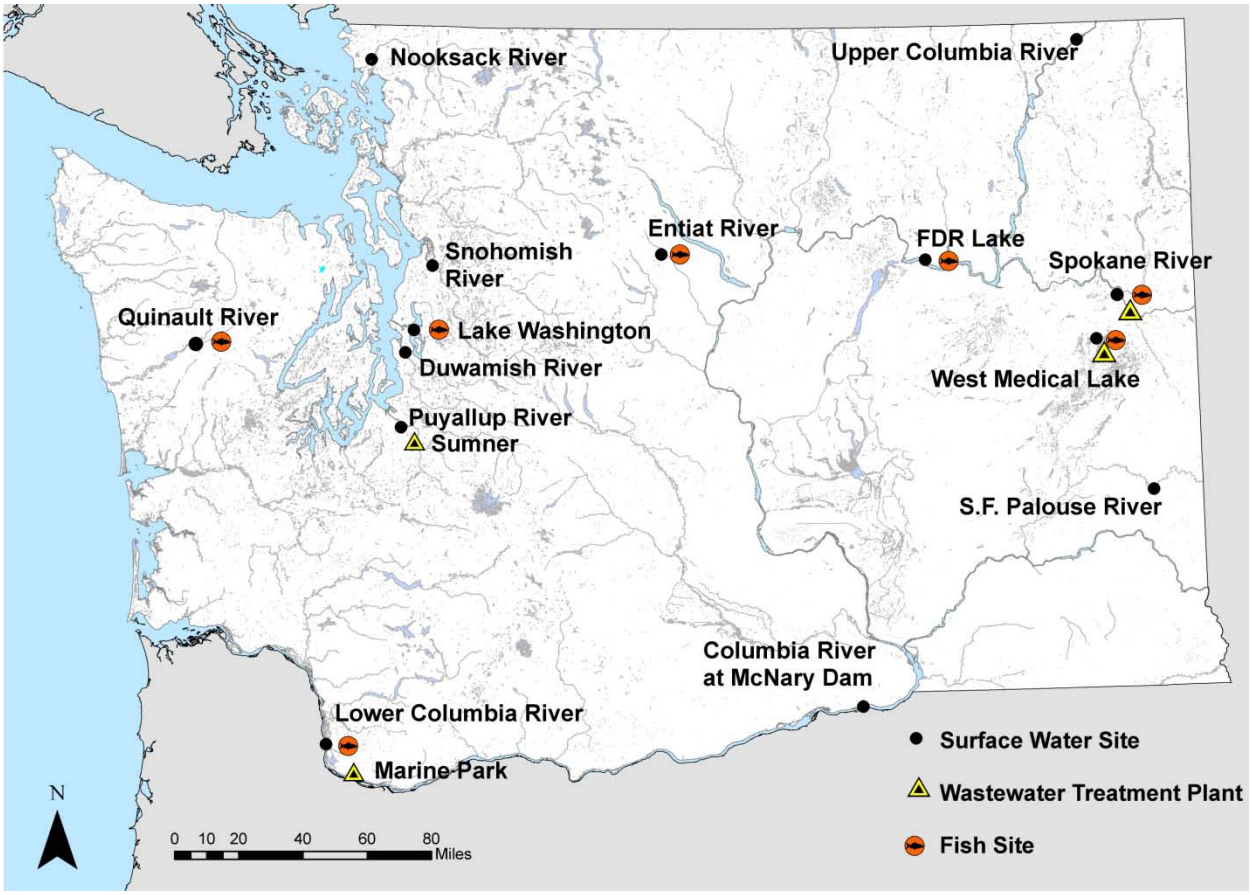


Figure 2. 2008 PFC Sampling Locations.

The surface water sampling locations focused primarily on rivers and impoundments. Sites were distributed equitably across eastern and western Washington and included urban, rural, and reference locations. Full considerations for site selection are included in the project plan (Furl and Meredith, 2008). Surface water samples were collected during the spring and fall of 2008 to assess seasonal differences in PFC concentrations during high-flow and low-flow conditions. Flow data for the sampling sites are presented in Appendix I.

Final effluent from 4 WWTPs was sampled seasonally concurrent with surface water sampling. Previous reports have shown WWTPs as a major source of aquatic PFC contamination (Sinclair and Kannan, 2006; Bossi et al., 2008; Becker et al., 2008). All 4 WWTPs discharge effluent upstream of surface water sampling stations. Table 1 includes information on all sample locations. Brief descriptions of the sampling sites are presented in Appendix B.

Eight of the surface water sites were targeted for fish tissue collections during the fall. Efforts at the Duwamish River were unsuccessful. In all, 15 liver and 15 fillet samples were analyzed from 7 locations (Table 1). Both fillet and liver tissues were analyzed to address human health concerns (fillet) and worst-case scenarios (liver). PFCs have been shown to preferentially accumulate in the liver (Martin et al., 2003a).

Table 1. Sample Location Descriptions for the 2008 PFC Survey.

| Name | Water Samples | Fish Samples | WRIA | County | Waterbody Type |
|---|---|---|---|---|---|
| **Surface Waters** | | | | | |
| Columbia River at McNary Dam | SP, F | --- | 31 | Benton | Impoundment |
| Duwamish River | SP, F | --- | 9 | King | River |
| Entiat River* | SP, F | F | 46 | Chelan | River |
| Franklin D. Roosevelt Lake | SP, F | F | 53 | Lincoln | Impoundment |
| Lake Washington | SP, F | F | 8 | King | Lake |
| Lower Columbia River | SP, F | F | 25 | Wahkiakum | River |
| Nooksack River | SP, F | --- | 1 | Whatcom | River |
| Puyallup River | SP, F | --- | 10 | Pierce | River |
| Quinault River* | SP, F | F | 21 | Jefferson | River |
| Snohomish River | SP, F | --- | 7 | Snohomish | River |
| South Fork Palouse River | SP, F | --- | 34 | Whitman | River |
| Spokane River | SP, F | F | 54 | Spokane | River |
| Upper Columbia River | SP, F | --- | 61 | Stevens | River |
| West Medical Lake | SP, F | F | 43 | Spokane | Lake |
| **Wastewater Treatment Plants** | | | | | |
| Marine Park | SP, F | ---- | 28 | Clark | --- |
| Puyallup Municipality | SP, F | ---- | 7 | Snohomish | --- |
| Spokane Municipality | SP, F | ---- | 54 | Spokane | --- |
| West Medical Lake Municipality | SP, F | ---- | 43 | Spokane | --- |
| **Osprey Collection Area** | | | | | |
| Columbia River from RM 71 through RM 113 | SP | ---- | 25 - 31 | Clark and Cowlitz | --- |

SP = Spring; F = Fall.
WRIA = Water Resources Inventory Area.
RM = River Mile.
* = Background Site.

One to 4 different species were retained from each waterbody. Where possible, both bottom feeders and predator species were retained to examine biomagnification. All samples were analyzed as composite samples. Composites consisted of 3-5 individual fish with one exception (Entiat River BKT = 2 fish).

One osprey egg was retained for analysis from 11 nests along the Lower Columbia River between river miles 71 and 113. Ospreys are obligate piscivores at the top of their food chain and a useful sentinel species for contaminant monitoring (Grove et al., 2009). Eggs were collected by the United States Geological Survey (USGS) during the spring.

Thirteen target PFCs were analyzed for each sample (Table 2).

Table 2. Perfluorinated Compounds Analyzed in this Study.

| Name | Acronym | Structure |
|---|---|---|
| Perfluorobutane sulfonate | PFBS | $C_4F_9SO_{3-}$ |
| Perfluorohexane sulfonate | PFHxS | $C_6F_{13}SO_{3-}$ |
| Perfluorooctane sulfonate | PFOS | $C_8F_{17}SO_{3-}$ |
| Perfluorodecane sulfonate | PFDS | $C_{10}F_{21}SO_{3-}$ |
| Perfluorobutanoic acid | PFBA | $C_3F_7COOH$ |
| Perfluoropentanoic acid | PFPeA | $C_4F_9COOH$ |
| Perfluorohexanoic acid | PFHxA | $C_5F_{11}COOH$ |
| Perfluoroheptanoic acid | PFHpA | $C_6F_{13}COOH$ |
| Perfluorooctanoic acid | PFOA | $C_7F_{15}COOH$ |
| Perfluorononanoic acid | PFNA | $C_8F_{17}COOH$ |
| Perfluorodecanoic acid | PFDA | $C_9F_{19}COOH$ |
| Perfluoroundecanoic acid | PFUnA | $C_{10}F_{21}COOH$ |
| Perfluorododecanoic acid | PFDoDA | $C_{11}F_{23}COOH$ |

In addition to analytical results, length, weight, and age data were collected for each fish used in composites. Temperature, specific conductivity, and pH were measured at all surface waters and WWTP effluents. Results for ancillary data on water and fish samples can be found in Appendices D and H, respectively.

This project was carried out in accordance with a Quality Assurance Project Plan (Furl and Meredith, 2008).

# Methods

## Sample Collection and Preparation

### Water and WWTP Effluent

Water and WWTP effluent sampling was conducted in accordance with the laboratory's standard operating procedure *Surface Water Collection Procedure for Perfluorinated Compounds* (Lindstrom, 2008). Pre-cleaned (methanol-rinsed), high density polypropylene (HDPE) bottles were provided by the laboratory for sample collection. Surface water grab samples were collected at 15-30 cm depth using a stainless steel Kemmerer, a pole dipper (sample bottle attached to a pole), or by hand dipping the bottle. Samples were retrieved as close to the thalweg as possible in rivers.

WWTP effluent samples were collected from final dechlorinated effluent using pole dippers. Morning and afternoon grabs were retrieved on the same day and composited into a new bottle. All surface water and effluent samples were spiked with 5 mL of 35% nitric acid ($HNO_3$) immediately after sample collection.

To avoid sample contamination, field crews wore nitrile gloves while sampling and did not use contaminating materials such as teflon® during the sample collection process. The stainless steel Kemmerer was decontaminated with a tap water rinse followed by a 100% methanol wash prior to sampling at each station. When sampling with the pole dipper, the middle of the bottle was clamped and the mouth of the bottle was directed upstream while submerged.

Samples were stored at Ecology headquarters in Lacey at room temperature until shipment. The latitude and longitude of each sampling location was determined by global positioning system (GPS) and recorded in field notes. Conductivity, pH, and temperature were measured at all locations using a multimeter. Collection, measurement, and equipment calibration procedures for pH samples were adapted from the Environmental Assessment Program's *Standard Operating Procedures for Collection and Analysis of pH Samples* (Ward, 2007).

### Fish

Fish were collected by boat electrofishing, gill netting, and hook and line following the Environmental Assessment Program's *Standard Operating Procedure for Field Collection, Processing, and Preservation of Finfish Samples at the Time of Collection in the Field* (Sandvik, 2006a).

Selected fish were euthanized by a blow to the head with a dull object and rinsed in ambient water to remove foreign material from their exterior. Individual fish were then weighed to the nearest gram, their total lengths measured to the nearest millimeter, and double-wrapped in foil. Wrapped fish were placed in zip-lock bags, along with a sample identification tag, and placed on ice for transport to Ecology headquarters. Fish were held frozen at -20° C until processing in the lab.

For sample preparation, fish were partially thawed and scales along with other debris were removed from the exterior followed by a deionized water rinse. The fish were then opened to remove livers. After collection of the livers, the fish were filleted skin-off. Sample preparation followed adapted guidelines from the Environmental Assessment Program's *Standard Operating Procedures for Resecting Finfish Whole Body, Body Parts, or Tissue Samples* (Sandvik, 2006b).

Composites of muscle and liver tissues generally consisted of 3-5 individual fish. Composite samples were prepared using equal weights from each fish. Muscle and liver tissues were ground using a stainless steel homogenizer. Subsamples of the ground homogenate were placed into pre-cleaned polypropylene tubes, frozen, and shipped to the laboratory for analyses. Excess homogenate was labeled and archived frozen at -20° C.

The sex of the fish was determined after tissue removal. Aging structures were collected and sent to Washington Department of Fish and Wildlife biologists.

All utensils used in fish tissue processing were cleaned to prevent contamination of the sample. Utensils include stainless steel bowls, knives, spoons, and sonicator homogenizing device parts. Utensils were cleaned with the following procedure: hand washed with soap (Liquinox) and hot water, hot tap water rinse, and 100% methanol rinse. Utensils were air-dried and wrapped in aluminum foil until used for processing. Fish were filleted and tissues processed on the dull side of heavy-duty aluminum foil covering a nylon cutting board, using new/clean sheets of aluminum foil with clean utensils for each sample. All personnel wore nitrile gloves while processing fish.

### Osprey Eggs

Partially incubated osprey eggs were collected by USGS staff during the spring of 2008 in conjunction with long-term monitoring. Egg samples were homogenized to a consistent color and texture following the same procedure as fish tissues. Egg content weights were measured along with age estimation at the time of processing.

## Laboratory Procedures

Water, fish tissue, and osprey egg tissue samples were prepared and analyzed for PFCs by the EPA Office of Research and Development (ORD) laboratory using a modification of the method described by Taniyasu et al. (2003). A detailed description of the EPA ORD laboratory measurement procedures can be found in Nakayama et al. (2007), Delinsky et al. (2010), and EPA's standard operating procedure (SOP) for extraction and analysis of PFCs in surface waters (Lindstrom, 2009).

Water and WWTP effluent samples were divided into aliquots, spiked with 5 internal standards ($^{13}$C-PFHxA, $^{13}$C-PFOA, $^{13}$C-PFUnA, $^{18}$O-PFHxS, and $^{18}$O-PSOS) and solid phase extracted using pre-conditioned WAX Plus cartridges. PFCs were analyzed using a Waters Aquity ultra high-performance liquid chromatograph coupled with a Quatro Premier XE triple quadrupole mass spectrometer (UPLC/MS/MS) operated in the electro-spray ionization (ESI) mode using multiple reaction monitoring (MRM). Five to 6 point calibration curves were produced for

quantitation by spiking blank deionized water with known amounts of target PFCs and the internal standards.

Fish tissue samples were digested with a sodium hydroxide/methanol solution, centrifuged, and then loaded onto pre-conditioned Oasis WAX SPE cartridges. PFCs were eluted from the cartridge, concentrated, and prepared for analysis. PFC analysis of fish tissue was conducted by high-performance liquid chromatography (HPLC) coupled with LC/MS/MS.

Osprey egg samples were digested with sodium hydroxide in methanol, spiked with internal standards ($^{18}O_2$-PFOS and $^{13}C_2$-PFOA), and then solid-phase extracted using pre-conditioned Oasis WAX cartridges. The eluted samples were analyzed using a UPLC coupled with a Quattro Premier XE triple quadrupole mass spectrometer (UPLC/MS/MS).

PFC results were reported down to the LOQ which typically ranged from 0.2 – 1 ng/L for water analyses. LOQs for osprey egg analyses ranged from 0.5 – 5.0 ng/g. Fish tissue LOQs ranged from 5.0 – 25.0 ng/g.

# Data Processing

## PFC Summing

Total PFC values are reported as the sum of detected values for each individual acid. Values qualified as estimates (J) by the laboratory are treated as detected values. Non-detect values (U and UJ) are assigned a value of zero when other congeners making up the sum are detected. If qualified congeners (J) comprise greater than 10% of the total summed concentration, the total concentration is qualified. When all individual congeners are reported as non-detects (U and/or UJ), the highest reporting limit, appropriately qualified, represents the sum.

## Flow Estimates

Estimated mean daily flows were calculated for sites where nearby USGS gages were available. Thomas et al. (1994) developed an equation for computing discharges for ungaged sites on streams with nearby discharge gages. This equation can be used if the drainage area of the ungaged site is between 50 to 150% of the gaged site drainage area. This criterion was satisfied at Duwamish, Entiat, Nooksack, Puyallup, Snohomish, South Fork Palouse, and Spokane sampling sites. Flows at these sampling sites were estimated using the equation from Thomas et al. (1994):

$$Q_u = Q_g\left(\frac{Au}{Ag}\right)^x$$

where

$Q_u$ = discharge (cfs) at ungaged sampling site for specified interval.
$Q_g$ = discharge (cfs) at nearby USGS gaged site for specified interval.
$A_u$ = contributing drainage area ($mi^2$) at ungaged sampling site.
$A_g$ = contributing drainage area ($mi^2$) at USGS gaged site.
x = exponent for region in which both sites are located (Knowles and Sumioka, 2001).

Drainage areas of sampling points were delineated using the USGS web-based application StreamStats (USGS, 2007).

Columbia River flows (Upper and Lower Columbia River, FDR Lake, and McNary Dam) were taken from the nearest USGS gage or DART data (USGS, 2009; UW, 2009). No flow data were available for the Quinault River due to absence of a flow gage on the river upstream from Lake Quinault.

## Effluent Dilution Modeling

A simple dilution model was employed to estimate surface water concentrations downstream of the WWTPs attributed to effluent discharges (Baumgartner et al., 1994). Estimated downstream concentrations were then compared to measured surface water concentrations.
The model estimates surface water concentrations assuming complete mixing and ignoring any removal processes (e.g., volatilization, absorption and settling, biotic sequestration).
Downstream surface water concentrations were calculated as:

$$C_r = \frac{Ce * Qe}{Qu + Qe}$$

where

$C_r$ = estimated concentration (ng/L) attributed to WWTP effluent.
$C_e$ = measured concentration (ng/L) in effluent.
$Q_e$ = WWTP effluent flow rate (cfs).
$Q_u$ = river flow rate (cfs) at downstream surface water sampling location.

## Osprey Egg Fresh Weight Adjustment

Osprey egg PFC residues were adjusted to a fresh weight to make concentrations comparable between eggs. The adjustment accounts for moisture loss in the eggs during incubation and is calculated by dividing egg content mass at the time of processing by the egg volume estimated at collection (Stickel et al., 1973).

# Data Quality

Ecology's Manchester Environmental Laboratory provided written case narratives assessing the quality of data provided by the EPA ORD laboratory (Appendix E). The reviews include a summary of the analysis performed and an assessment of holding times, instrument tuning, calibration, ongoing precision, laboratory control samples, matrix spikes, and duplicates.

Measurement quality objectives (MQOs) as outlined in the project plan are included in Table 3. An overview of MQO exceedances and other special considerations are described below by matrix. Results for all data quality tests are found in Appendix F.

Table 3. Measurement Quality Objectives for PFC Analyses.

| Analysis | Lab Control Samples (% recov.) | Laboratory Duplicates (RPD) | Method Blanks | Matrix Spike (% recov.) | Field Replicates (RPD %) | Trip Spike (% recov.) |
|---|---|---|---|---|---|---|
| PFCs | 80-120% | ± 50% | < LOQ | 80-120% | ± 50% | 50-150% |

RPD = Relative Percent Difference.
LOQ = Limit of Quantitation.
recov. = recovery.

## Water and Effluent Samples

Surface water and WWTP effluent samples were received by the EPA ORD laboratory in good condition and analyzed within the 4-week holding time. Several problems were encountered during instrument tuning and calibration. Analysis of standard solutions resulted in a poor coefficient of determination for some analytes resulting in the linearity of the curve to be compromised. Detections falling between standards that were not within ±30% of their expected values were qualified as estimates. Refer to case narratives in Appendix E for more information on instrument calibration.

Data quality measures for water and effluent samples included a trip spike, a low and high concentration laboratory control sample, a method blank, and field replicates for each of the 2 seasonal sampling events (Appendix F).

Trip spikes and control samples were prepared by spiking known amounts of PFCs in deionized water. All data for PFDoDA and PFUnDA were rejected for use due to poor recoveries in the spring trip spike (< 50%). Both compounds were not detected above the LOQ in the fall samples.

Low levels of PFHpA and PFOS were detected in the laboratory blanks analyzed with the fall samples. Results less than 10 times the blank contamination were qualified UJ for both compounds.

All LCS recoveries were acceptable with the exception of PFDoDA in the fall low concentration (5.0 ng/L) spike.

The majority of field replicates were within established MQOs (+-50%). Poor precision occurred in several instances where values were near the limit of quantification.

## Fish Tissue Samples

Tissue samples were received by the laboratory frozen and in good condition. Analysis of standard solutions for all compounds detected above LOQ in the samples were within laboratory specified limits.

Data quality measures for fillet and liver samples included method blanks, matrix blanks, a low and high laboratory control sample, two matrix spikes, and two duplicates (Appendix F). Matrix blanks and control samples were prepared in locally purchased tilapia tissues.

Several recoveries were outside of their expected values for fillet and liver control samples. Among the compounds detected outside of established quality control limits, only PFDA and PFDoDA were detected above the LOQ in samples. PFDA was recovered high (143.7%) in the high concentration fillet spike, and results were qualified as estimates. For livers, PFDoDA was recovered high in the low liver spike, and results were qualified as estimates.

Several matrix spike recoveries were outside of their expected values for both fillet and livers. Results for PFDA and PFDoDA were qualified as estimates.

## Osprey Egg Tissue Samples

Egg samples were received by the laboratory frozen and in good condition. Analyses of standard solutions were within laboratory specified limits.

Data quality measures for egg samples included a method blank, matrix blank, matrix spikes, and duplicates (Appendix F). The matrix blank was prepared using chicken egg whites.

PFDoDA and PFDS were qualified as estimates in their source samples due to poor matrix spike recoveries. PFDA and PFNA were qualified as estimates in source samples due to poor duplicate precision.

# Results and Discussion

## Surface Waters

Fourteen waterbodies were sampled in the spring and fall of 2008 as part of the statewide PFC survey. Spring and fall results for the 11 individual acids along with their summed values are included in Appendix C. A bar chart of individual waterbody summed totals is shown in Figure 3.

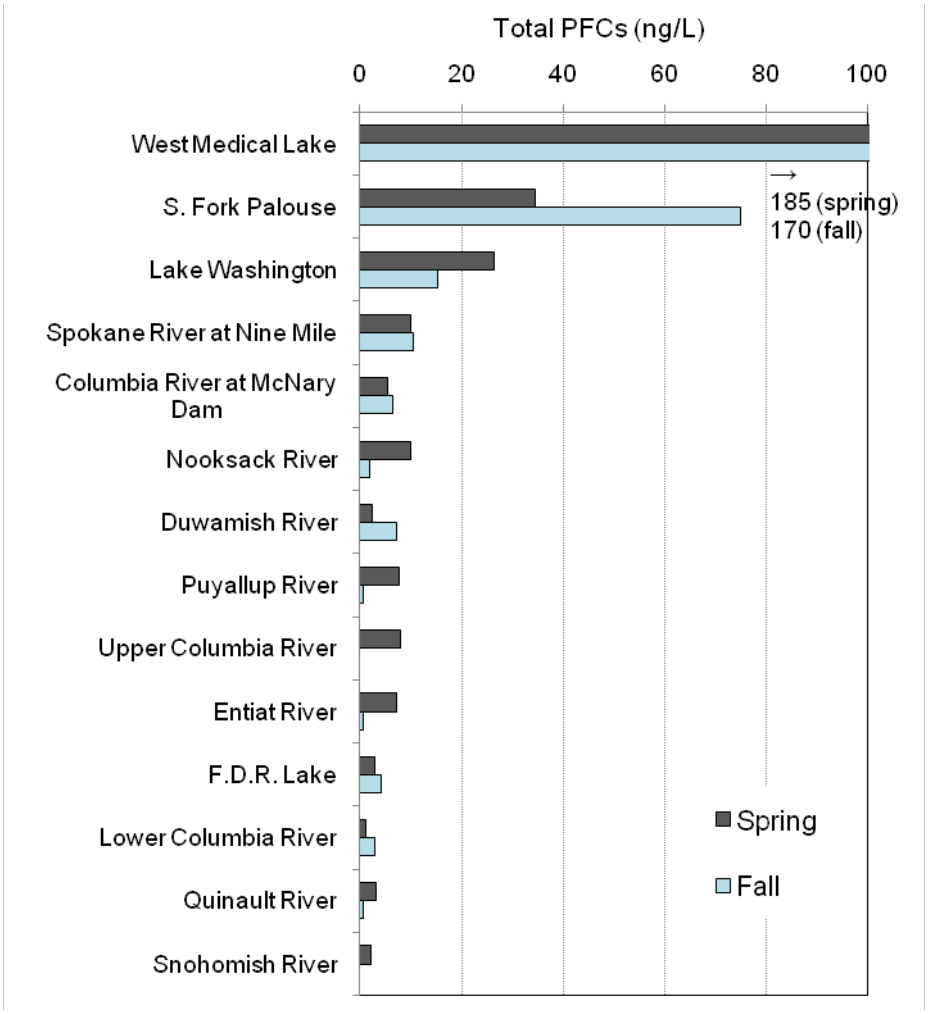


Figure 3. Spring and Fall PFC Totals at Surface Water Sampling Sites.

Total PFC concentrations ranged from 1.11 – 185 ng/L in the spring and < 0.9 – 170 ng/L during the fall. Reporting limits ranged from 0.2 – 1.0 ng/L for each of the analytes. The majority of total concentrations (78%) recorded during both seasons were less than 10.5 ng/L. A statistical summary of the results is provided in Table 4. For calculation purposes, values < LOQ were set to zero.

Table 4. Statistical Summary of Surface Water PFC Data (ng/L).
*Values preceded by "<" indicate calculated value was less than the LOQ indicated.*

| Analyte | Spring Samples | | | | | Fall Samples | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Detection Frequency | Min | Max | Median | Mean | Detection Frequency | Min | Max | Median | Mean |
| PFDA | 93% | < 1.0 | 4.92 | 1.08 | 1.34 | 50% | < 0.5 | 3.79 | 0.27 | 0.74 |
| PFNA | 21% | < 1.0 | 16.7 | < 1.0 | 1.36 | 21% | < 0.5 | 6.97 | < 0.5 | 0.75 |
| PFOA | 64% | < 1.0 | 95.6 | 1.28 | 8.5 | 50% | < 0.5 | 48.3 | 0.38 | 5.7 |
| PFHpA | 93% | < 1.0 | 28.1 | 3.30 | 4.45 | 21% | < 0.5 | 22.4 | < 0.5 | 2.45 |
| PFHxA | 64% | < 1.0 | 10.5 | 1.19 | 1.9 | 64% | < 0.5 | 36.9 | 1.24 | 4.22 |
| PFPeA | 21% | < 1.0 | 26.5 | < 1.0 | 2.21 | 43% | < 0.5 | 31.6 | < 0.5 | 3.47 |
| PFBA | 21% | < 0.2 | 3.62 | < 0.2 | 0.55 | 21% | < 0.5 | 5.51 | < 0.5 | 0.65 |
| PFDS | 0% | < 1.0 | < 1.0 | < 1.0 | < 1.0 | 7% | < 0.5 | 1.29 | < 0.5 | < 0.5 |
| PFOS | 43% | < 0.2 | 6.54 | < 0.2 | 1.07 | 29% | < 0.5 | 7.60 | < 0.5 | 1.66 |
| PFHS | 21% | < 1.0 | 3.33 | < 1.0 | < 1.0 | 36% | < 0.5 | 4.48 | < 0.5 | 0.74 |
| PFBS | 21% | < 0.2 | 0.64 | < 0.2 | < 0.2 | 64% | < 0.5 | 1.98 | 0.59 | 0.60 |
| Total PFCs | 100% | 1.11 | 185.3 | 7.47 | 21.9 | 86% | < 0.9 | 170.4 | 3.60 | 21.10 |

Out of 308 measurements (28 water samples x 11 PFCs), 123 (40%) were above the LOQ. PFDA and PFHpA were the most frequently detected compounds (93%) in spring water samples, and PFHxA and PFBS were the most common acids detected (64%) in fall samples. At least one PFC was detected in each of the spring water samples and all but 2 (Upper Columbia River and Snohomish) of the fall samples.

The highest concentrations in the study were recorded at West Medical Lake, South Fork Palouse River (SFPR), and Lake Washington. Average seasonal concentrations at West Medical Lake were highly elevated over the entire data set, approximately 3 and 9 times higher than the SFPR and Lake Washington, respectively.

The elevated concentrations at West Medical Lake and the SFPR are likely caused by WWTP effluent discharges. West Medical Lake is one of the few lentic waterbodies in the state receiving effluent from a WWTP (Coots, 2008). The lake serves as the receiving waterbody for the City of Medical Lake WWTP. PFC data on effluent from the Medical Lake WWTP are provided in the following section. Point source discharges coupled with a 30-year water residence time make West Medical Lake a "worst case" scenario regarding PFCs.

The SFPR also receives significant discharge from WWTP effluent. WWTP discharges from Moscow, Idaho, and Pullman have the potential to account for most of the total river flow during low-flow periods (Pelletier, 1993). PFC concentrations were highest at the SFPR during the fall sampling period. SFPR flow was 4 cfs in the fall and 50 cfs during spring sampling.

With the exception of the 3 elevated locations, concentrations were broadly similar among the rest of the waterbodies (< LOQ – 10.4). Total concentrations recorded at the background sites (Entiat and Quinault) differed little from the Columbia River system (Upper Columbia, FDR Lake, McNary Dam, and Lower Columbia) and other, more urbanized, areas along Puget Sound (Nooksack, Puyallup, Duwamish, and Snohomish) (Figure 3).

## Seasonal Differences

Figure 4 presents average contributions of individual acids to the total PFC value for both seasons. On average, PFHpA was the dominant compound in the spring, with a mean contribution of 37% to the total. PFDA, PFOA, and PFHxA followed with average contributions to the total of 23%, 16%, and 15%, respectively. Congener profiles in fall samples were less consistent with the dominant compound varying among sites. Overall, PFHxA had the highest mean percent contribution in the fall, at 29%. Other mean compound contributions ranged from 0 – 16% of the sum.

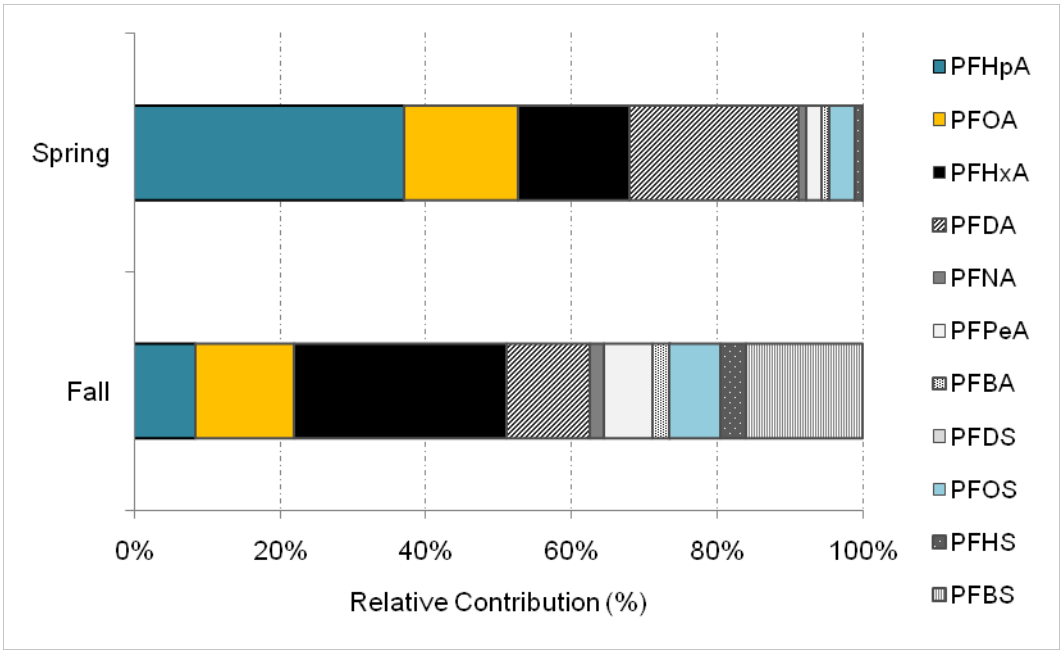


Figure 4. Average PFC Congener Profiles for Spring and Fall Surface Water Samples.

There was no clear seasonal trend in total concentrations across all waterbodies. Total concentrations were higher in the spring at 8 of the 14 locations. Large seasonal changes were apparent in percent contributions from individual acids at the sampling sites. The profiles for most waterbodies differed substantially between spring and fall, suggesting unique seasonal

sources. Figure 5 displays the percent contribution profiles of the individual acids for each waterbody.

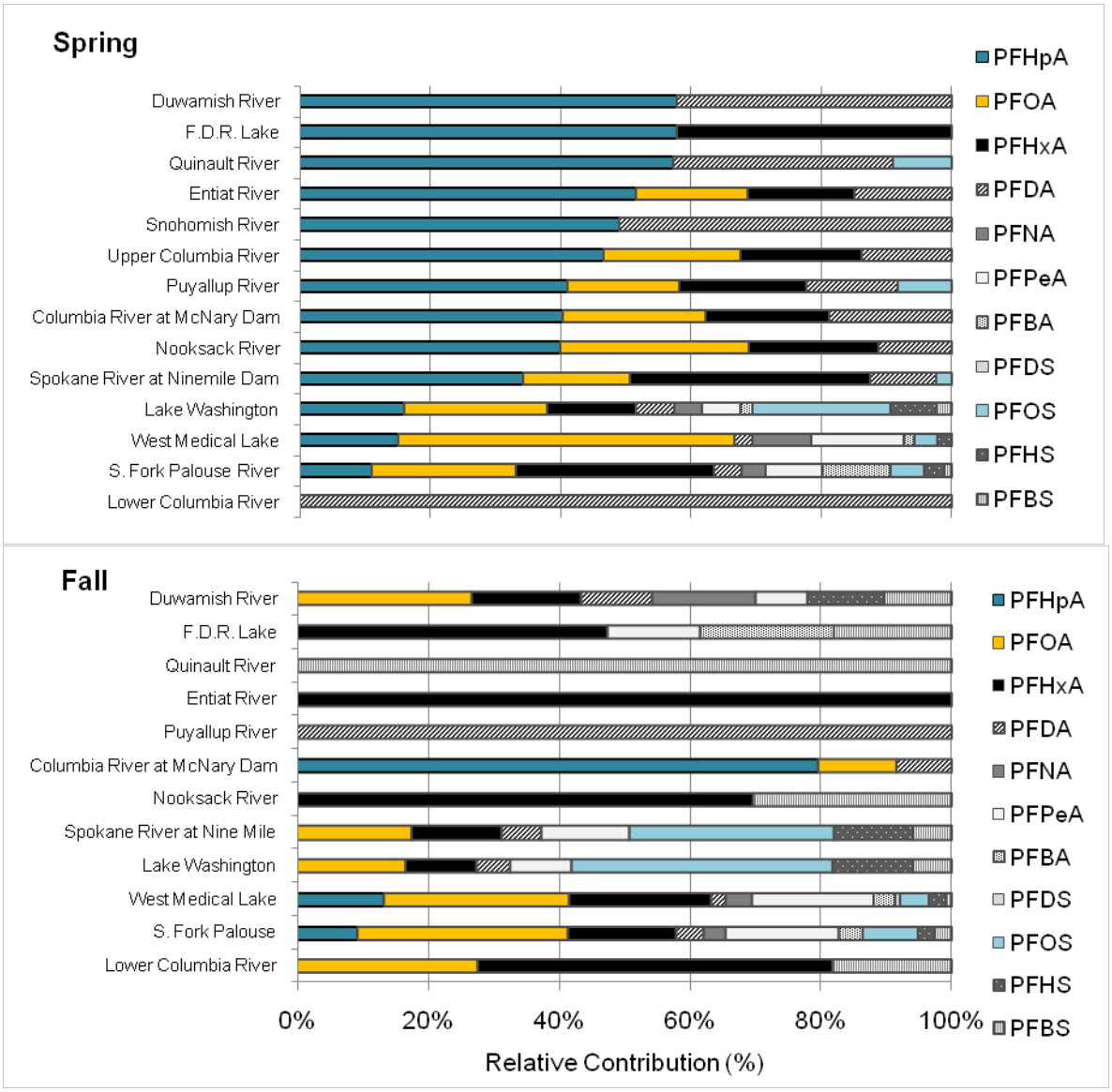


Figure 5. Contribution of Individual PFCs to Total PFC Concentrations in Spring and Fall Water Samples, 2008.
*Snohomish River and Upper Columbia River were excluded from the fall graph since no PFCs were above the LOQ for those samples.*

PFHpA and PFBS exhibited the largest seasonal changes. PFHpA was both the largest contributor (37%) to the total and the most frequently detected (93%) acid during the spring. In the fall, PFHpA was only detected at 3 (21%) locations. Reporting limits for PFHpA were elevated during the fall sampling period due to blank contamination; however, spring concentrations were generally greater than fall qualified (UJ) values. The opposite occurred with PFBS where the analyte was frequently detected in the fall (64%) but not the spring (21%).

PFHpA has been proposed as a tracer of atmospheric sources of PFCs to surface waters (Simcik and Dorwiler, 2005). Simick and Dorweiler (2005) found the ratio of PFHpA:PFOA > 1 (i.e., larger amounts of PFHpA) was indicative of atmospherically deposited PFCs. During the spring, PFHpA was found in greater quantities than PFOA with the exception of the elevated sites (Lake Washington, South Fork Palouse River, and West Medical Lake). The large contribution of PFHpA, particularly in the spring, suggests atmospheric sources deposited to the waterbodies via runoff are important.

## Comparison to Other PFOA and PFOS Findings

The combination of different PFCs that can be analyzed make comparing total values across studies problematic. PFOA and PFOS are the most common analytes in literature and allow a simpler means for comparison. Table 5 presents PFOA and PFOS concentrations recorded in other surface waters in the United States.

Table 5. PFOA and PFOS Concentrations in Surfaces Waters from Selected U.S. Locations. *Additional summary statistics are included for Washington State data.*

| Location | n | PFOA† (ng/L) | PFOS† (ng/L) | Study |
|---|---|---|---|---|
| Minnesota - urban | 4 | 0.45 - 19 (na) | 2.4 - 47 (na) | Simcik and Dorweiler, 2005 |
| Minnesota - remote | 4 | 0.14 - 0.66 (na) | ND - 1.2 (na) | Simcik and Dorweiler, 2005 |
| Minnesota statewide | 105 | < 0.947 - 59 (1.19) | < 2.18 - 151 (< 5.07) | MPCA, 2008 |
| Lake Michigan | 4 | 0.28 - 3.4 (na) | 0.93 - 3.1 (na) | Simcik and Dorweiler, 2005 |
| Lake Erie | 8 | 21 - 47 (34.5) | 11 - 39 (32) | Boulanger et al., 2004 |
| Lake Ontario | 8 | 15 - 70 (50) | 15 - 121 (56) | Boulanger et al., 2004 |
| Great Lakes | 4 | 4 - 14.7 (na) | 1.9 - 3.5 (na) | Kannan et al., 2005 |
| New York | 51 | 14 - 49 (na) | 0.8 - 1090 (na) | Sinclair et al., 2006 |
| | 11 | 3.27 - 15.8 (7.20) | ND - 9.3 (2.88) | Kim and Kannan, 2007 |
| Alabama | 40 | < LOQ - 598 (< 25) | 16.8 - 144 (52.3) | Hansen et al., 2002 |
| North Carolina | 100 | < LOQ - 287 (12.6) | < LOQ - 132 (28.9) | Nakayama et al., 2007 |
| Washington** | 28 | < LOQ - 95.6 (1.0) | ND - 7.6 (< LOQ) | Present Study |
| | % above LOQ: | 57 | 42 | |
| | 90th percentile: | 12.6 | 6.2 | |

† Range of values and median: min - max (median).
na = not available.
** Spring and fall data combined.
LOQ = less than limit of quantitation.
ND = not detected.

Results from the present study are similar to values reported in remote and urban waterbodies of Minnesota (Simcik and Dorwiler, 2005), Lake Michigan (Simcik and Dorweiler, 2005), and the Great Lakes (Kannan et al., 2005). Washington concentrations are lower than values recorded in North Carolina (Nakayama et al., 2007), Alabama near a fluorochemical manufacturer (Hansen et al., 2002), and New York (Kim and Kannan, 2007; Sinclair, 2006). Generally, concentrations in Washington are similar to or lower than concentrations reported in other United States surface waters.

# Wastewater Treatment Plant Effluent

## Effluent Concentrations

Four WWTP effluent samples were retrieved concurrent with surface water sampling. Samples consisted of composites of morning and afternoon grabs. Full results from the spring and fall are presented in Appendix C. Total PFC concentrations recorded at each plant during spring and fall are displayed in Figure 6.

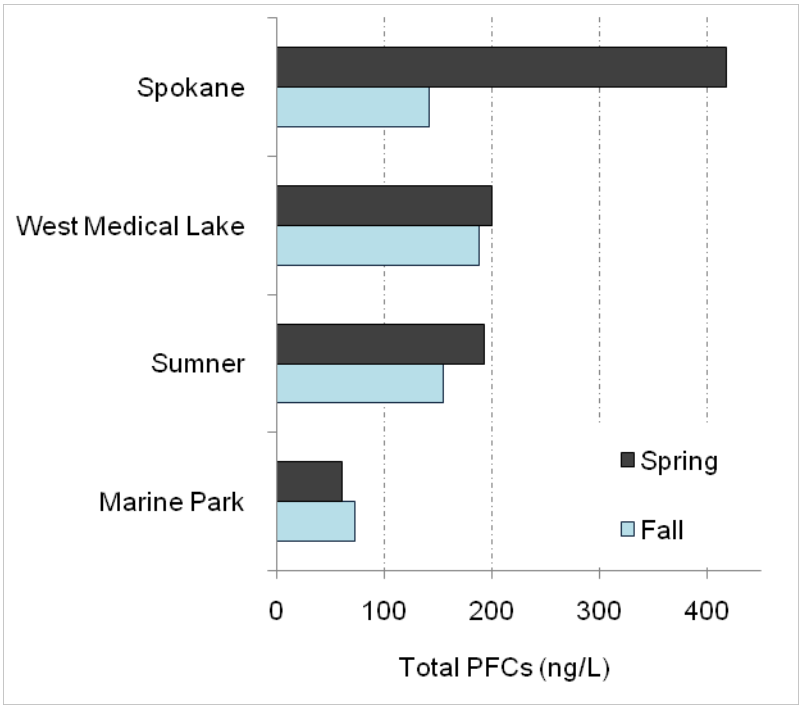


Figure 6. Total PFC Concentrations in WWTP Effluent Measured during the Spring and Fall of 2008.

Concentrations of total PFCs in WWTP effluent ranged from 61 – 418 ng/L in the spring and from 73 – 188 ng/L in the fall. The highest concentration (418 ng/L) was recorded at the Spokane WWTP during the spring sampling event. Concentrations at the West Medical Lake and Sumner plants were similar, ranging from 150 – 200 ng/L. The lowest values were recorded at Marine Park where values were less than 100 ng/L. A statistical summary of the results is provided in Table 6. For calculation purposes, values < LOQ were set to zero.

Table 6. Statistical Summary of 2008 WWTP Effluent PFC Data (ng/L).
*Values preceded by "<" indicate calculated value was less than the LOQ indicated.*

| Analyte | Spring Samples | | | | | Fall Samples | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Detection Frequency | Min | Max | Median | Mean | Detection Frequency | Min | Max | Median | Mean |
| PFDA | 100% | 3.63 | 13.3 | 9.28 | 8.86 | 100% | 3.67 | 13.2 | 5.25 | 6.85 |
| PFNA | 100% | 3.56 | 17.9 | 8.75 | 9.75 | 100% | 5.66 | 13.8 | 6.81 | 8.28 |
| PFOA | 100% | 16.5 | 128 | 83.20 | 77.83 | 100% | 22.1 | 63.1 | 48.25 | 45.41 |
| PFHpA | 100% | 4.13 | 35.3 | 10.48 | 15.09 | 75% | < 3.5 | 12.9 | 11.29 | 8.86 |
| PFHxA | 100% | 14.5 | 141 | 52.45 | 65.08 | 100% | 10.9 | 29.8 | 23.26 | 21.82 |
| PFPeA | 100% | 3.78 | 31.4 | 25.05 | 21.34 | 100% | 12.6 | 46.7 | 18.86 | 24.26 |
| PFBA | 100% | 0.72 | 3.27 | 2.27 | 2.13 | 100% | 1.91 | 5.43 | 3.53 | 3.60 |
| PFDS | 0% | < 1.0 | < 1.0 | < 1.0 | < 1.0 | 0% | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| PFOS | 100% | 3.86 | 31.2 | 6.48 | 12.01 | 100% | 9.36 | 18.1 | 10.95 | 12.34 |
| PFHS | 100% | 1.33 | 16.4 | 2.76 | 5.80 | 100% | 2.19 | 11.9 | 3.35 | 5.19 |
| PFBS | 25% | < 0.2 | 1.51 | 1.51 | 0.38 | 75% | < 0.5 | 6.58 | 2.78 | 3.03 |
| Total PFCs | 100% | 61.0 | 418.0 | 218.3 | 97 | 100% | 73.3 | 188.4 | 139.6 | 148.4 |

Reporting limits were the same as surface water samples (0.2 – 1.0 ng/L) for each of the analytes. Detections in effluent occurred at a much higher frequency than in surface water. Out of 88 measurements (8 samples x 11 acids), 75 (85%) were greater than the LOQ. At least 8 different PFCs were detected in all effluent samples. PFDS was the only analyte not detected.

Average congener profiles for the 4 WWTPs are presented in Figure 7. There were no significant differences between PFC compositions at each of the plants. PFOA accounted for the majority of total PFC concentrations in all but one sample. Percent contributions of PFOA ranged from 26 – 39%, with an average of 34%. During the spring, PFHxA was the second most prevalent acid, contributing approximately 28% to the total. The trend was slightly different in the fall where PFPeA (17%) and PFHxA (16%) followed PFOA. PFHpa:PFOA ratios were low ranging from < 0.16 - .35 in effluent samples and did not vary greatly between seasons. The low ratios found in effluent support the conclusion that atmospheric sources are important contributors to surface waters.

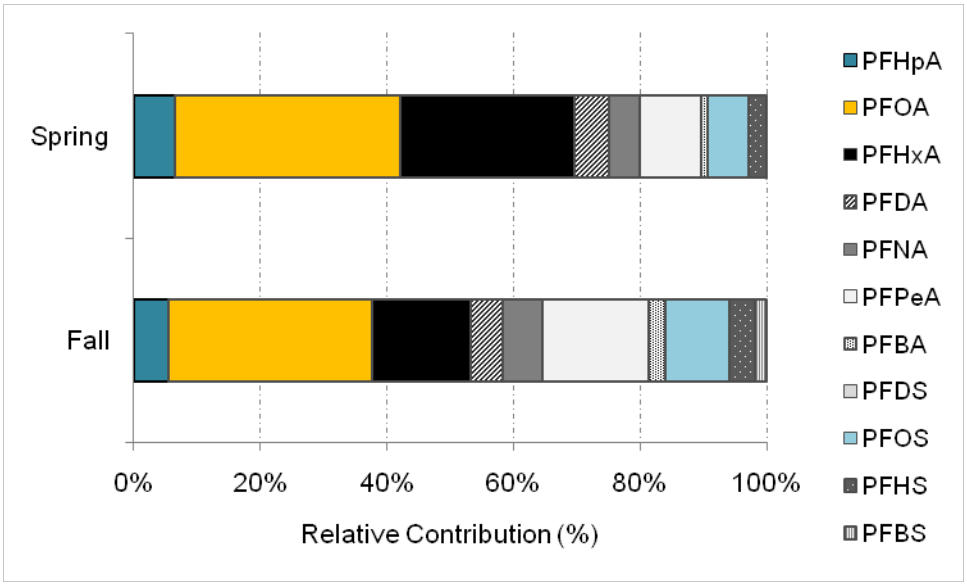


Figure 7. Average PFC Contribution to Total PFC Concentrations in Fall and Spring WWTP Effluent Samples.

## Loads and Dilution Modeling

The WWTPs vary greatly in their daily effluent flow rates and PFC loads delivered to their receiving waters. Table 7 presents PFC loads from the WWTPs during spring and fall. Effluent discharge represents a 24-hour average from the day the samples were collected.

Table 7. Effluent Discharge Rates and PFC Loads in WWTP Effluent during Spring and Fall Sampling Events.

| Wastewater Treatment Plant | Maximum Loading Capacity (mgd) | Spring | | Fall | |
|---|---|---|---|---|---|
| | | Effluent Discharge rate (mgd) | Total PFC Load (g day$^{-1}$) | Effluent Discharge Rate (mgd) | Total PFC Load (g day$^{-1}$) |
| Marine Park | 16.1 | 10.7 | 2.40 | 10.09 | 2.88 |
| West Medical Lake | 1.9 | 0.38 | 0.24 | 0.28 | 0.24 |
| Spokane | 44 (dry); 100 (wet) | 37.5 | 59.3 | 34.4 | 18.5 |
| Sumner | 4.6 | 1.86 | 1.44 | 1.68 | 0.96 |

Table 8 displays results from WWTP effluent dilution modeling. During the spring sampling period, the percent of effluent contributions to measured concentrations was low (≤ 10%). In the fall, the estimated contribution of effluent discharge to measured concentrations was much higher at the Spokane River and Puyallup River (≈ 38%). Modeled estimates at the Lower Columbia River could not be conducted during the fall since river discharge was not available for that time period. The large difference between effluent contributions and measured values during the spring and fall at the Spokane River and Puyallup River suggests differing sources throughout the year with additional sources during the spring.

Table 8. WWTP Effluent Dilution Model Results.

| Wastewater Treatment Plant | Receiving Waterbody | Season | Estimated concentration attributed to WWTP (ng/L) | Measured concentration (ng/L) | Percent of measured concentration attributed to WWTP |
|---|---|---|---|---|---|
| Marine Park | Lower Columbia R. | Spring | 0.004 | 1.11 | 0.36% |
| | | Fall | na | --- | --- |
| Spokane | Spokane R. | Spring | 1.08 | 9.97 | 10.8% |
| | | Fall | 3.94 | 10.4 | 37.9% |
| Sumner | Puyallup R. | Spring | 0.13 | 7.73 | 1.68% |
| | | Fall | 0.24 | 0.62 | 38.7% |

na = not available.

## Comparison to Other PFOA and PFOS Findings

Selected PFOA and PFOS concentrations in final effluent from other WWTPs in the U.S. are shown in Table 9. Results from 10 Washington State WWTPs within the Puget Sound basin collected as part of a separate project are also included in the table.

Table 9. PFOA and PFOS Concentrations in WWTP Effluent from Selected Studies around the U.S.

| Location | No. of Wastewater Treatment Plants | No. | PFOA† (ng/L) | PFOS† (ng/L) | Study |
|---|---|---|---|---|---|
| Southeastern U.S. | 2 | 7 | 6.7 - 183 (122) | 1.8 - 28 (13) | Loganathan et al., 2007 |
| | 1 | 1 | 97 | 24 | Schultz et al., 2006a |
| Northeastern U.S. | 1 | 1 | 65 | 1.1 | Schultz et al., 2006a |
| Iowa | 1 | 1 | 22 | 26 | Boulanger et al., 2005 |
| New York | 6 | 45 | 58 - 1050 (na) | 3 - 68 (na) | Sinclair and Kannan, 2006 |
| Minnesota | 41 | 71 | < 4.45 - 148 (21) | < 4.91 - 1510 (5.24) | MPCA, 2008 |
| Western U.S. | 5 | 5 | 7.7 - 58 (12) | 5.3 - 25 (11) | Schultz et al., 2006a |
| Pacific Northwest | 3 | 3 | 2.5 - 28 (6.6) | 6.2 - 130 (11) | Schultz et al., 2006a |
| | 1 | 10 | 8.2 - 15 (na) | 15 - 34 (na) | Schultz et al., 2006b |
| Puget Sound | 10 | 20 | 10.9 - 69.8 (23.5) | < 1.98 - 55 (5.96) | Ecology and Environment Inc. et al., in prep. |
| Washington* | 4 | 8 | 16.5 - 128 (61.5) | 3.86 - 31.2 (9.80) | Present Study |
| | % above LOQ: | | 75% | 62.5% | |
| | 90th percentile: | | 99.2 | 22 | |

† Statistics include range of values and median: minimum - maximum (median).
na = not available.
*spring and fall data combined.

PFOA and PFOS concentrations measured as part of the current study were within a very wide range of values reported in other regions of the U.S. Median values for PFOA were greater than most studies where a median could be calculated. However, PFOS median values were lower in most instances using the same comparison. Both PFOA and PFOS medians from the present study were greater than median concentrations calculated from the larger set of Washington WWTPs (n = 10) within the Puget Sound basin.

## Fish Tissue

Fifteen composite samples of skin-off fillets and livers were each measured for PFCs. In total, 11 species from 7 waterbodies statewide were assessed (Figure 8). Results from the fillet and liver tissue samples are included in Appendix C. Ancillary data (length, weight, and age) for each fish included in the composites are located in Appendix H.

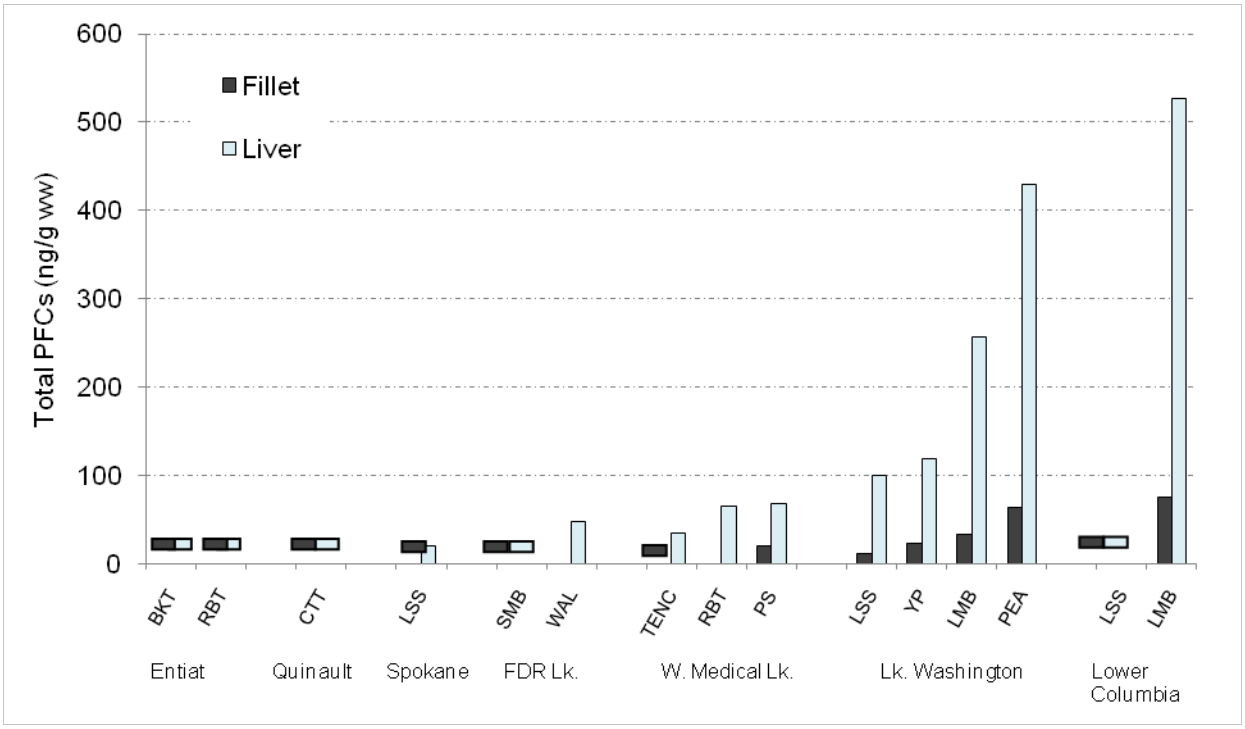


Figure 8. Total PFCs Measured in Fish Fillet and Liver Tissue during the 2008 PFC Survey. *Blocks suspended above the x-axis indicate values < LOQ. See Appendix G for species codes.*

PFOS, PFDA, PFUnA, and PFDoDA were the only PFCs quantified in fillet and liver samples. PFOS reporting limits were 10 ng/g for both fillet and liver analyses, and ranged from 5 – 25 ng/g for all other acids. Figures 9 and 10 display congener profiles for fillet and liver samples with concentrations > LOQ.

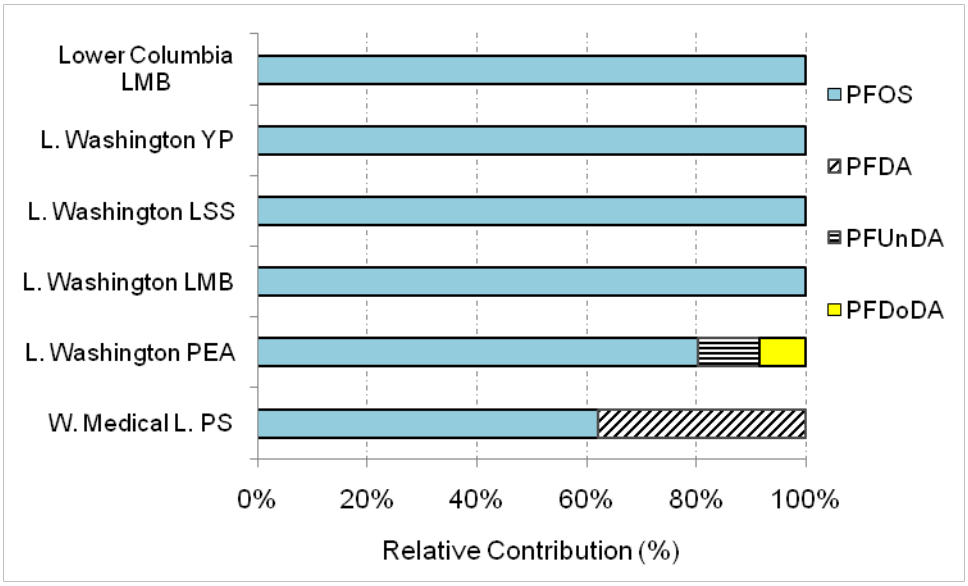


Figure 9. Contribution of Individual PFCs to Total PFC Concentrations in Fish Fillet Tissue. *See Appendix G for species codes.*

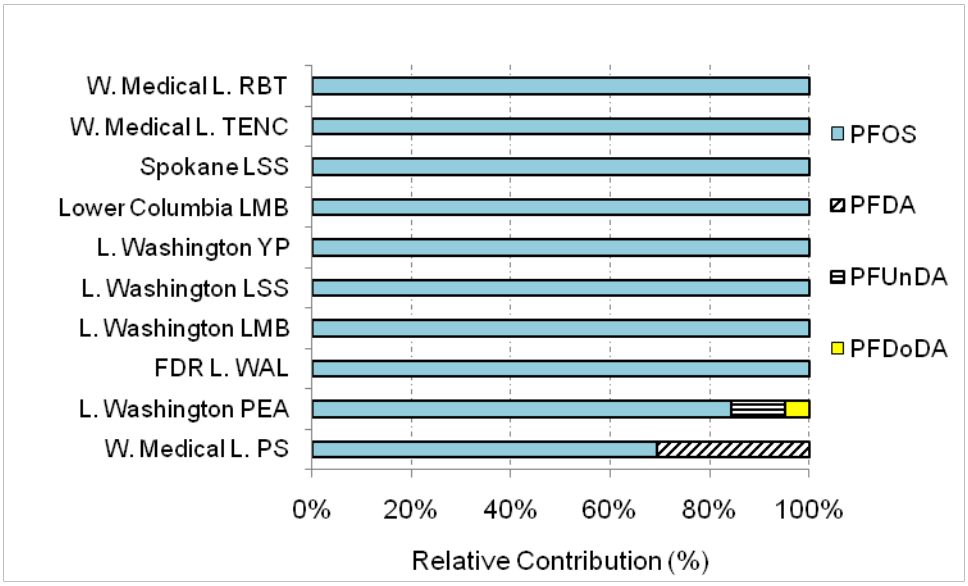


Figure 10. Contribution of Individual PFCs to Total PFC Concentrations in Fish Liver Tissue. *See Appendix G for species codes.*

Despite numerous acids being quantified in surface waters, PFOS was clearly the most prevalent acid in tissues. Forty percent of fillet samples and 67% of liver samples contained concentrations above the LOQ. Summary statistics describing PFOS concentrations can be found in Table 10. PFDA, PFUnDA, and PFDoDA were each detected once in both fillet and livers at lower levels than PFOS. Much higher accumulation of PFOS relative to other acids has been observed in other fish tissue studies (Ye et al., 2008; Delinsky et al., 2009; 2010).

Table 10. Summary Statistics for PFOS (ng/g) in Fish Tissues.
*Values preceded by "<" indicate calculated value was less than the LOQ indicated.*

| Analyte | Liver | | | | | Fillet | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Detection Frequency | Min | Max | Median | Mean | Detection Frequency | Min | Max | Median | Mean |
| PFOS | 67% | < 10 | 527.0 | 47.5 | 105.5 | 40% | < 10 | 75.5 | < 10 | 13.8 |

The highest concentrations were found in Lower Columbia River largemouth bass (fillet = 75.5 ng/g; liver = 527.3 ng/g) and Lake Washington peamouth (fillet = 51.2 ng/g; liver = 363.2 ng/g). Detectable amounts of PFOS in both fillets and livers were confined to the Lower Columbia River, Lake Washington, and West Medical Lake. Quantifiable amounts were found only in liver samples from FDR Lake and Spokane River. The background sites (Entiat and Quinault Rivers) were the only locations where PFCs were not detected in either fillets or livers.

PFOS concentrations in bottom feeders were lower than predator species within the same waterbody (Lower Columbia River, Lake Washington, and West Medical Lake), suggesting PFOS bioaccumulates through the food web. Food web studies have reported varying degrees of PFC bioaccumulation; however, the general consensus is PFOS and longer chain perfluoroalkyl carboxylates have high bioconcentration factors (> 1000) with little potential (if any) to bioaccumulate in aquatic systems (Kannan et al., 2005; Conder et al., 2008; Martin et al., 2004; 2003a; 2003b). High levels of bioaccumulation in terrestrial food webs and marine mammals have been noted (Kelly et al., 2009; Sinclair et al., 2006). Our findings underscore the need for additional research to understand the movement of PFOS through aquatic food chains.

## Liver and Tissue Comparison

Unlike other halogenated contaminants such as organochlorine pesticides, polychlorinated biphenyls, and polybrominated diphenyl ethers, which are associated with an organism's lipids, PFCs are proteinophilic and tend to accumulate in blood and livers (Kelly et al., 2009). In the present study, liver concentrations were 4 – 9 fold higher in livers than fillets. Studies examining body distribution of PFCs between blood, liver, fillet, and whole-body homogenate are lacking. Figure 11 plots fillet and liver concentrations in samples where PFOS was detected in both tissues.

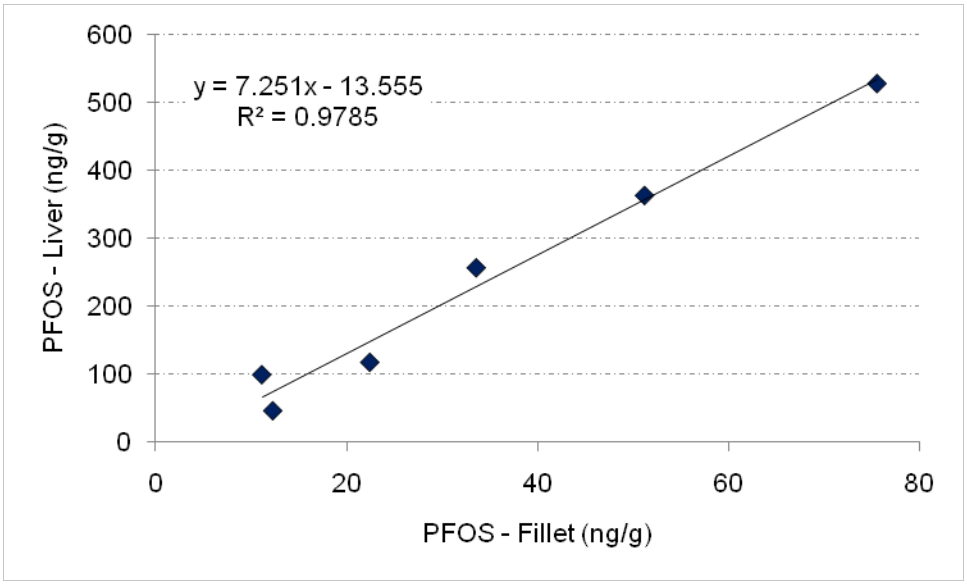

Figure 11. Fillet and Liver Concentrations in Samples where PFOS was Detected in Both Tissues.

The small data set (n = 6) displayed an excellent relationship between the two variables. Liver and fillet concentrations were obtained from 5 species at 3 locations, suggesting body disposition between fillet and liver is not dependent on species or location.

## Human Health Considerations

National criteria to protect human health have not been established for PFCs. Drinking water guidelines have been established for PFOA in 3 states and 1 for PFOS in 1 state (Donohue, 2009). Currently only the Minnesota Department of Health (MDH) has issued fish consumption advisories for PFOS. The MDH recommends consuming no more than one meal a week if concentrations exceed 40 ng/g (Delinsky et al., 2009). If concentrations exceed 200 ng/g, the MDH recommends no more than one meal per month. The advisories were designed to keep exposure below 80 ng/Kg/day.

Largemouth bass from the Lower Columbia River and peamouth from Lake Washington exceeded the MDH 40 ng/g advisory in fillets. Additional species collected from both waterbodies did not exceed the 40 ng/g threshold. No values over 200 ng/g were recorded in fillet samples.

## Comparison to Other PFOS Findings

Table 11 presents PFOS fillet and liver concentrations recorded at various U.S. locations.

Table 11. PFOS Fillet and Liver Concentrations Recorded at Various U.S. Locations.
*Additional summary statistics are included for Washington State data.*

| Location | Matrix | No. | PFOS[†] (ng/g) | Study |
|---|---|---|---|---|
| Minnesota | Fillet | 30 | 1.22 - 428 | Delinsky et al., 2009 |
| | | 70 | < 1 - 144 | Delinsky et al., 2010 |
| Minnesota – Upper Mississippi River | | 30 | 4.3 - 90 | Ye et al., 2008 |
| North Carolina | | 61 | 15.9 - 136 | Delinsky et al., 2009 |
| Michigan | | 31 | < 6 - 300 | Giesy and Kannan, 2001 |
| | | 10 | 59 - 297 | Kannan et al., 2005 |
| Washington | | 15 | < 10 - 75.5 | Present Study |
| % above LOQ | | | 40 | |
| Median | | | < 10 | |
| 90 percentile | | | 44.2 | |
| Michigan | Liver | 21 | < 17 - 170 | Giesy and Kannan, 2001 |
| | | 8 | 32 - 173 | Kannan et al., 2005 |
| New York | | 42 | 9 - 431 | Sinclair et al., 2006 |
| New York - remote | | 24 | 14 - 120 | Sinclair et al., 2006 |
| Washington | | 15 | < 10 - 527 | Present Study |
| % above LOQ | | | 67 | |
| Median | | | 47.5 | |
| 90th percentile | | | 320.7 | |

[†] Statistics include range of values: minimum – maximum.

Similar to surface water concentrations, Washington State fillet values were within or lower than the expected range based on previous studies. Median and 90$^{th}$ percentile values for liver analyses were also within the expected range. The maximum liver value (527 ng/g) was slightly elevated over the other studies reviewed.

## Osprey Eggs

PFCs were measured in 11 osprey eggs collected along the Lower Columbia River from river mile 71 through 113. Five eggs were collected upstream of the Willamette River confluence and the remaining six eggs were collected downstream. Results for moisture loss corrected values and uncorrected values are located in Appendix C.

Total PFC concentrations ranged from 38 – 910 ng/g. A statistical summary of the results is provided in Table 12. For calculation purposes, values < LOQ were set to zero.

Table 12. Statistical Summary of PFCs (ng/g) in Osprey Eggs.
*Values preceded by "<" indicate calculated value was less than the LOQ indicated.*

| Analyte | No. of Samples | Detection Frequency | Minimum | Maximum | Median | Mean |
|---|---|---|---|---|---|---|
| PFDoA | 11 | 27% | < 5.0 | 10.67 | < 5.0 | < 5.0 |
| PFUnA | 11 | 100% | 3.46 | 12.63 | 7.8 | 8.2 |
| PFDA | 11 | 100% | 2.0 | 10.21 | 5.62 | 5.61 |
| PFNA | 11 | 36% | < 0.5 | 6.4 | < 0.5 | 1.0 |
| PFOA | 11 | 0% | < 1.0 | < 1.0 | < 1.0 | < 1.0 |
| PFHpA | 11 | 9% | < 0.5 | 0.8 | < 0.5 | < 0.5 |
| PFHxA | 11 | 9% | < 0.5 | 0.8 | < 0.5 | < 0.5 |
| PFPeA | 11 | 0% | < 5.0 | < 5.0 | < 5.0 | < 5.0 |
| PFBA | 11 | 0% | < 5.0 | < 5.0 | < 5.0 | < 5.0 |
| PFDS | 11 | 73% | < 1.0 | 5.8 | 1.96 | 2.32 |
| PFOS | 11 | 100% | 24 | 884 | 69 | 174 |
| PFHS | 11 | 27% | < 0.5 | 1.8 | < 0.5 | < 0.5 |
| PFBS | 11 | 0% | < 0.5 | < 0.5 | < 0.5 | < 0.5 |
| Total PFCs | 11 | 100% | 37.5 | 910.3 | 90.7 | 193.9 |

Reporting limits ranged from 0.5 – 1.0 ng/g with the exception of PFDoA, PFPeA, and PFBA which had a reporting limit of 5.0 ng/g. PFOS, PFDA, and PFUnA were detected in every egg collected. Figure 12 displays percent contribution of the individual acids to the sum.

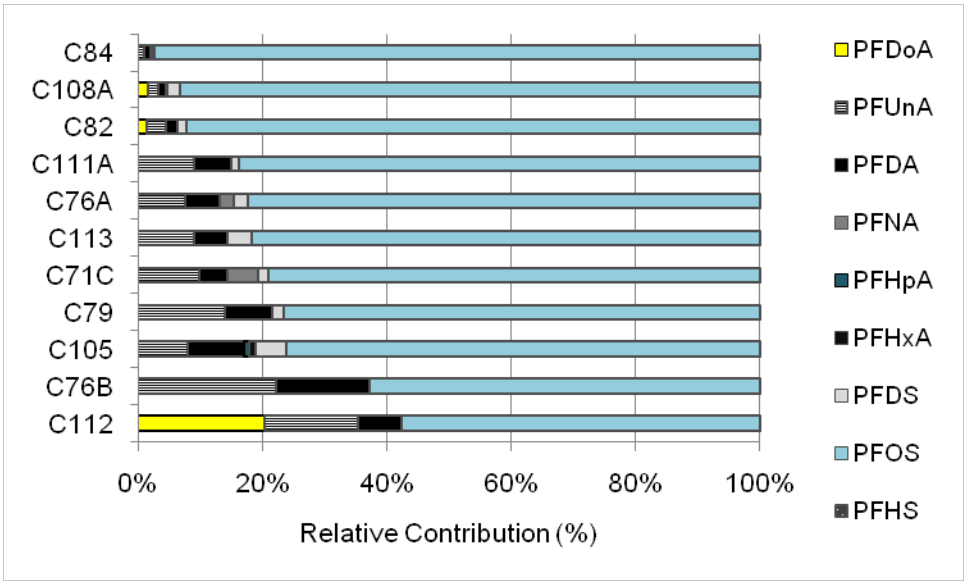


Figure 12. Contribution of Individual PFCs to Total PFC Concentrations in Egg Samples. *Additional summary statistics are included for Washington State data.*

As with fish tissue, PFOS was the most prevalent acid (detected in all eggs) and contained the highest concentrations (58 – 97% of the total) of any single acid. In total, 9 acids were detected in egg samples. Ospreys are obligate piscivores and typically drink little or no water. The variety of acids found in their eggs indicates the acids are present at low levels in fish tissues.

Figure 13 displays total egg concentrations alongside a map of the Lower Columbia River.

Total PFC concentrations had significant spread among the nests over 42 river miles (range = 38 – 910 ng/g; standard deviation = 257). The majority of concentrations were less than 100 ng/g; however, 3 eggs contained levels greater than 250 ng/g. Osprey feed relatively close to their nests, and the spread in concentrations may reflect dietary variations, local pollution, or physical factors (Grove et al., 2009). PFC elimination rates in osprey are unknown but they are suggested to be very slow in air-breathing animals (Kelly et al., 2009). The possibility of a significant portion of the PFC burden accumulated from their overwintering grounds in tropical regions cannot be ruled out.

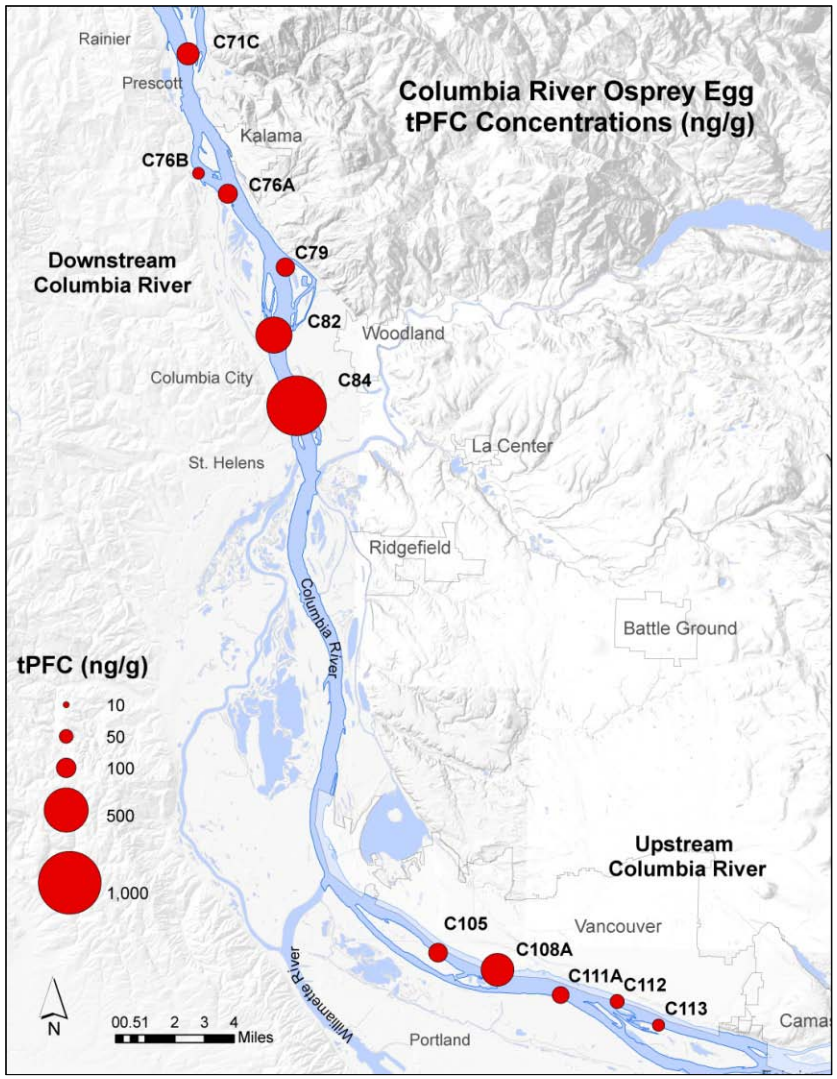


Figure 13. Total PFC Concentrations in Osprey Eggs Collected from the Lower Columbia River, 2008.

## Comparison to Other PFOS Findings

To date, little information is available describing PFC concentrations in osprey eggs. Table 13 provides data describing PFOS concentrations in other osprey egg monitoring efforts.

Table 13. PFOS Osprey Egg Concentrations Recorded at Various U.S. Locations.

| Location | No. | PFOS† (ng/g) | Study |
|---|---|---|---|
| Chesapeake Bay A | 3 | 106 - 130 (115) | Rattner et al., 2004 |
| Chesapeake Bay B | 3 | 193 - 428 (291) | |
| Chesapeake Bay C | 3 | 255 - 317 (275) | |
| Chesapeake Bay D | 3 | 133 - 195 (154) | |
| Chesapeake Bay E | 3 | 110 - 227 (149) | |
| Delaware Bay A | 2 | 33.8 - 42.3 (38) | Toschik et al., 2005 |
| Delaware Bay B | 6 | 37.4 - 370 (97) | |
| Delaware Bay C | 6 | 127 - 799 (293) | |
| Delaware River | 1 | 122 | |
| Maine (2007) | 6 | 60 - 441 (183) | Goodale, 2008 |
| Maine (2009) | 10 | 67 - 2,545 (211) | Goodale, 2010 |
| Washington | 11 | 24 - 884 (91) | Present Study |
| % above LOQ: | | 100 | |
| 90th percentile: | | 313 | |

†Statistics include range of values and median: minimum - maximum (geometric mean).

Our geometric means are similar to values recorded at Delaware Bay and lower than geometric means from Chesapeake Bay and Maine. The highest PFOS concentration recorded in eggs from the Lower Columbia River is the second highest value of recorded osprey egg concentrations in the United States.

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# Conclusions

Results from the 2008 statewide PFC survey indicate widespread occurrence of the contaminants in surface waters at concentrations near or less than 10 ng/L. Concentrations greater than 10 ng/L were found at the South Fork Palouse River, West Medical Lake, and Lake Washington. Elevated concentrations from South Fork Palouse River and West Medical Lake are likely due to wastewater treatment plant (WWTP) effluent discharges into the waterbodies.

Little difference was seen among the low concentration (< 10 ng/L) sites. The two reference waterbodies (Quinault and Entiat Rivers) displayed similar concentrations to the Columbia River system (Upper Columbia River, FDR Lake, McNary Dam, and Lower Columbia River) and other, more urbanized, sites in the Puget Sound basin (Nooksack, Snohomish, Duwamish, and Puyallup Rivers).

No strong seasonal pattern was observed in terms of total PFC concentrations; however, the congener makeup was markedly different during spring and fall. PFHpA was both the largest contributor (37%) to the total and the most frequently detected (93%) acid during the spring. In the fall, PFHpA was infrequently detected (21%) at the surface water sites. Greater levels of PFHpA than PFOA, particularly in the spring, suggest atmospheric sources of PFCs are important.

PFCs were detected in all WWTP effluent samples. Concentrations ranged from 61 – 418 ng/L. On average, PFOA, PFHxA, and PFHpA were the dominant contaminants comprising the majority of the total concentration. At least 8 different PFCs were detected in each wastewater sample. Total PFC concentrations varied little between seasons, with the exception of the Spokane WWTP where concentrations were 142 ng/L during the fall and 418 ng/L in the spring.

PFOS was the primary contaminant detected in fish tissues. Concentrations ranged from < 10 – 75 ng/g in fillet tissues and < 10 - 527 ng/g in liver samples. Forty percent of fillet samples and 67% of liver samples contained concentrations above 10 ng/g. PFDA, PFUnA, and PFDoDA were each detected once in both fillet and liver samples at concentrations lower than PFOS. Largemouth bass from the Lower Columbia River and peamouth from Lake Washington were the only fillet samples that failed to meet human consumption criteria set forth by the Minnesota Department of Health (40 ng/g). PFCs were not detected at the 2 background locations.

Total PFC concentrations ranged from 38 – 910 ng/g in osprey eggs collected from the Lower Columbia River. A wide range of PFC concentrations were measured in osprey eggs collected from 11 nests spread across 42 miles. The majority of concentrations were less than 100 ng/g; however, 3 eggs contained levels greater than 250 ng/g.

Generally speaking, PFC concentrations in all matrices recorded as part of this study were within or below the range of values recorded at other United States locations. The maximum osprey egg concentration (910 ng/g) was the second highest recorded value in that medium in the United States.

# Recommendations

The findings of this 2008 study support the following recommendations:

- Conduct a food web study to accurately estimate PFOS biomagnification. The highest PFOS concentrations from the study were found in an apex predator living in an area with relatively low surface water concentrations.

- Develop analytical capabilities at Manchester Environmental Laboratory to analyze PFCs.

- Conduct a larger fish tissue study to more accurately characterize fillet concentrations around the state. Only 5 non-background sites were examined as part of the current study. PFC screening could be incorporated into routine fish toxics monitoring.

- Develop PFC criteria addressing human health, wildlife, and aquatic life concerns.

# References


Baumgartner, D., W. Frick, and P. Roberts. 1994. Dilution Models for Effluent Discharges. U.S. Environmental Protection Agency EPA/600/R-94/086. www.epa.gov/waterscience/standards/mixingzone/files/RSB_UM_PLUMES.pdf.

Becker, A., S. Gerstmann, and H. Frank. 2008. Perfluorooctane Surfactants in Waste Waters, the Major Source of River Pollution. Chemosphere, Vol. 72: 115-121.

Bossi, R., J. Strand, O. Sortkjaer, and M.M. Larsen. 2008. Perfluoroalkyl Compounds in Danish Wastewater Treatment Plants and Aquatic Environments. Environment International, Vol. 34: 443-450.

Boulanger, B., J. Vargo, J.L. Schnoor, and K.C. Hornbuckle. 2004. Detection of Perfluorooctane Surfactants in Great Lakes Water. Environmental Science and Technology, Vol. 38: 4064-4070.

Boulanger, B., J. Vargo, J.L. Schnoor, and K.C. Hornbuckle. 2004. Detection of Perfluorooctane Surfactants in Great Lakes Water. Environmental Science and Technology, Vol. 38: 4064-4070.

Conder, J.M., R.A. Hoke, W. De Wolf, M.H. Russell, and R.C. Buck. 2008. Are PFCAs Bioaccumulative? A Critical Review and Comparison with Regulatory Criteria and Persistent Lipophilic Compounds. Environmental Science and Technology, Vol. 42: 995-1003.

Coots, R. 2008. West Medical Lake Total PCBs and Dioxin (2,3,7,8- TCDD) Total Maximum Daily Load: Water Quality Study Design (Quality Assurance Project Plan). Washington State Department of Ecology, Olympia WA. Publication No. 08-03-104. www.ecy.wa.gov/biblio/0803104.html.

Delinsky, A.D., M.J. Strynar, S.F. Nakayama, J.L. Varns, X. Ye, P.J. McCann, and A.B. Lindstrom. 2009. Determination of Ten Perfluorinated Compounds in Bluegill Sunfish (Lepomis macrochirus) Fillets. Environmental Research, Vol. 109: 975-984.

Delinsky, A.D., M.J. Strynar, P.J. McCann, J.L. Varns, L. McMillan, S. Nakayama, and A.B. Lindstrom. 2010. Geographical Distribution of Perfluorinated Compounds in Fish from Minnesota Lakes and Rivers. Environmental Science and Technology, Vol. 44: 2549-2554.

Donohue, J. 2009. Provisional Health Advisories for PFOA and PFOS. Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency. Given at the National Forum on Contaminants in Fish, November, 2009. Portland, OR

Ellis, D.A., J.W. Martin, and S.A. Mabury. 2003. Atmospheric Lifetime of Fluorotelomer Alcohols. Environmental Science and Technology, Vol. 37: 3816-3820.

Ellis, D.A., J.W. Martin, A.O. De Silva, S.A. Mabury, M.D. Hurley, M.P. Sulbaek Andersen, and T.J. Wallington. 2004. Degradation of Fluorotelomer Alcohols: A Likely Atmospheric Source of Perfluorinated Carboxylic Acids. Environmental Science and Technology, Vol. 38 (12): 3316-3321.

EPA. 2006a. Announcement of Stewardship Program by Administrator Stephen L. Johnson. U.S. Environmental Protection Agency. Available at: www.epa.gov/oppt/pfoa/pubs/pfoastewardship.htm.

EPA. 2006b. SAB Review of EPA's Draft Risk Assessment of Potential Human Health Effects Associated with PFOA and Its Salts. U.S. Environmental Protection Agency. Publication No. EPA-SAB-06-006.

Furl, C. and C. Meredith. 2008. Quality Assurance Project Plan: PBT Monitoring: Measuring Perfluorinated Compounds in Washington Rivers and Lakes. Washington State Department of Ecology, Olympia, WA. Publication No. 08-03-107. www.ecy.wa.gov/biblio/0803107.html.

Gannon, J.T., R.A., Hoke, M.A., Kaiser, and T. Mueller. 2006. Review II: Perfluorooctanoic acid (PFOA) in the environment. White paper by DuPont. Wilmington, DE. DuPont-19567.

Giesy, J.P. and K. Kannan. 2001. Global Distribution of Perfluorooctane Sulfonate in Wildlife. Environmental Science and Technology, Vol. 35: 1339-1342.

Goodale, W. 2008. Preliminary Findings of Contaminant Screening of Maine Bird Eggs: 2007 Field Season. BioDiversity Research Institute, Gorham, Maine.

Goodale, W. 2010. Contaminant Screening of Osprey Eggs in Casco Bay, Maine: 2009 Field Season. BioDiversity Research Institute, Gorham, Maine. BRI report number 2010-09.

Grove, R.A., C.J. Henny, J.L. Kaiser. 2009. Osprey: Worldwide Sentinel Species for Assessing and Monitoring Environmental Contamination in Rivers, Lakes, Reservoirs, and Estuaries. Journal of Toxicology and Environmental Health, Part B, Vol. 12: 25-44.

Hansen, K.J., H.O. Johnson, J.S. Eldridge, J.L. Butenhoff, and L.A. Dick. 2002. Quantitative Characterization of Trace Levels of PFOS and PFOA in the Tennessee River. Environmental Science and Technology, Vol. 36: 1681-1685.

Kannan, K., S. Corsolini, J. Falandysz, G. Fillmann, K.S. Kumar, B.G. Loganathan, M.A. Mohd, J. Olivero, N.V. Wouwe, J.H. Yang, and K.M. Aldous. 2004. Perfluorooctanesulfonate and Related Fluorochemicals in Human Blood from Several Countries. Environmental Science and Technology, Vol. 38: 4489-4495.

Kannan, K., L. Tao, E. Sinclair, S.D. Pastva, D.J. Jude, J.P. Giesy. 2005. Perfluorinated Compounds in Aquatic Organisms at Various Trophic Levels in a Great Lakes Food Chain. Archives of Environmental Contamination and Toxicology, Vol. 48: 559-566.

Kelly, B.C., M.G. Ikonomou, J.D. Blair, B. Surridge, D. Hoover, R. Grace, and F. Gobas. 2009. Perfluoroalkyl Contaminants in an Arctic Marine Food Web: Trophic Magnification and Wildlife Exposure. Environmental Science and Technology, Vol. 43: 4037-4043.

Kim, S. and K. Kannan. 2007. Perfluorinated Acids in Air, Rain, Snow, Surface Runoff, and Lakes: Relative Importance of Pathways to Contamination of Urban Lakes. Environmental Science and Technology, Vol. 41: 8328-8334.

Knowles, S.M. and S.S. Sumioka. 2001. The National Flood-Frequency Program – Methods for Estimating Flood Magnitude and Frequency in Washington, 2001. U.S. Geological Survey Open Report, 016-01.

Kudo, N. and Y. Kawashima, 2003. Toxicity and Toxicokinetics of Perfluorooctanoic Acid in Humans and Animals. The Journal of Toxicological Sciences, Vol. 28: 49-57.

Lau, C., K. Anitole, C. Hodes, D. Lai, A. Pfahles-Hutchens, and J. Seed. 2007. Perfluoroalkyl Acids: A Review of Monitoring and Toxicological Findings. Toxicological Sciences, Vol. 99: 366-394.

Lindstrom, A.B. 2008. SOP: Surface Water Collection Procedure for Perfluorinated Compounds (PFCs). U.S. Environmental Protection Agency, National Exposure Research Laboratory, NC.

Lindstrom, A.B. 2009. SOP: Improved Method for Extraction and Analysis of Perfluorinated Compounds (PFCs) from Surface Waters and Well Water by Ultra-High Performance Liquid Chromatography (UPLC)-Tandem Mass Spectrometry (MS/MS). U.S. Environmental Protection Agency, National Exposure Research Laboratory, NC. EPA SOP # EMAB 114.0.

Loganathan, B.G., K.S. Sajwan, E. Sinclair, K.S. Kumar, and K. Kannan. 2007. Perfluoroalkyl Sulfonates and Perfluorocarboxylates in Two Wastewater Treatment Facilities in Kentucky and Georgia. Water Research, Vol. 41: 4611-4620.

Martin, J.W., S.A. Macbury, K.R. Solomon, and D Muir. 2003a. Dietary Accumulation of Perfluorinated Acids in Juvenile Rainbow Trout (Oncorhynchus mykiss). Environmental Toxicology and Chemistry, Vol. 22: 189-195.

Martin, J.W., S.A. Mabury, K.R. Solomon, and D.C.G. Muir. 2003b. Bioconcentration and Tissue Distribution of Perfluorinated Acids in Rainbow Trout (Oncorhynchus mykiss). Environmental Toxicology and Chemistry, Vol. 22: 196-204.

Martin, J.W., D.M. Whittle, D.C.G. Muir, and S.A. Mabury. 2004. Perfluoroalkyl Contaminants in a Food Web from Lake Ontario. Environmental Science and Technology, Vol. 38: 5379-5385.

Minnesota Pollution Control Agency. 2008. PFCs in Minnesota's Ambient Environment: 2008 Progress Report.

Nakayama, S., M. Strynar, L. Helfant, P. Egeghy, X. Ye, and A. Lindstrom. 2007. Perfluorinated Compounds in the Cape Fear Drainage Basin in North Carolina. Environmental Science and Technology, Vol. 41: 5271-5276.

Nakayama, S., M. Strynar, J. Reiner, A. Delinsky, and A. Lindstrom. 2010. Determination of Perfluorinated Compounds in the Upper Mississippi River Basin. Environmental Science and Technology, DOI: 10.1021/es100382z.

Pelletier, G. 1993. South Fork Palouse River Total Maximum Daily Load of Ammonia. Washington State Department of Ecology, Olympia, WA. Publication No. 93-e48. www.ecy.wa.gov/biblio/93e48.html.

Rattner, B.A., P.C. McGowan, N.H. Golden, J.S. Hatfield, P.C. Toschik, R.F. Lukei Jr., R.C. Hale, I. Schmitz-Afonso, and C.P. Rice. 2004. Contaminant Exposure and Reproductive Success of Ospreys (Pandion haliaetus) Nesting in Chesapeake Bay Regions of Concern. Archives of Environmental Contamination and Toxicology, Vol. 47: 126-140.

Renner, R. 2001. Growing Concern over Perfluorinated Chemicals. Environmental Science and Technology. Vol. 35: 154A-160A.

Sandvik, P. 2006a. Standard Operating Procedure for Field Collection, Processing, and Preservation of Finfish Samples at the Time of Collection in the Field. Washington State Department of Ecology, Olympia, WA. SOP Number EAP009. www.ecy.wa.gov/programs/eap/quality.html.

Sandvik, P. 2006b. Standard Operating Procedures for Resecting Finfish Whole Body, Body Parts, or Tissue Samples. Washington State Department of Ecology, Olympia, WA. SOP Number EAP007. www.ecy.wa.gov/programs/eap/quality.html.

Schultz, M., D. Barofsky, and J. Field. 2006a. Quantitative Determination of Fluorinated Alkyl Substances by Large-Volume-Injection Liquid Chromatography Tandem Mass Spectrometry – Characterization of Municipal Wastewaters. Environmental Science and Technology, Vol. 40: 289-295.

Schultz, M.M., C.P. Higgins, C.A. Huset, R.G. Luthy, D.F. Barofsky, and J.A. Field. 2006b. Fluorochemical Mass Flows in a Municipal Wastewater Treatment Facility. Environmental Science and Technology, Vol. 40: 7350-7357.

Simcik, M.F. and K.J. Dorweiler. 2005. Ratio of Perfluorochemical Concentrations as a Tracer of Atmospheric Deposition to Surface Waters. Environmental Science and Technology, Vol. 39: 8678-8683.

Sinclair, E. and K. Kannan. 2006. Mass Loading and Fate of Perfluoroalkyl Surfactants in Wastewater Treatment Plants. Environmental Science and Technology, Vol. 40: 1408-1414.

Sinclair, E., D. Mayack, K. Roblee, N. Yamashita, and K. Kannan. 2006. Occurrence of Perfluoroalkyl Surfactants in Water, Fish, and Birds from New York State. Archives of Environmental Contamination and Toxicology, Vol. 50: 398-410.

Stickel, L.F., S.N. Wiemeyer, and L.J. Blus. 1973. Pesticide Residues in Eggs of Wild Birds: Adjustment for Loss of Moisture and Lipid. Bulletin of Environmental Contamination and Toxicology, Vol. 9: 193-196.

Taniyasu, S., K. Kannan, Y. Horii, N. Hanari, and N. Yamashita. 2003. A Survey of Perfluorooctane Sulfonate and Related Perfluorinated Organic Compounds in Water, Fish, Birds, and Humans from Japan. Environmental Science and Technology, Vol. 37: 2634-2639.

Thomas, B.E., H.W. Hjalmarson, and S.D. Waltemeyer. 1994. Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States: U.S. Geological Survey Open-File Report 93–419.

Toschik, P.C., B.A. Rattner, P.C. McGowan, M.C. Christman, D.B. Carter, R.C. Hale, C.W. Matson, and M.A. Ottinger. 2005. Effects of Contaminant Exposure on Reproductive Success of Ospreys (Pandion haliaetus) Nesting in Delaware River and Bay, USA. Environmental Toxicology and Chemistry, Vol. 24: 617-628.

UW (University of Washington) Columbia River DART. Accessed 2009. Data Access in Real Time. www.cbr.washington.edu/dart/help/.

U.S. Geological Survey. Accessed 2009. StreamStats: A Water Resources Web Application. http://water.usgs.gov/osw/streamstats/Washington.html.

U.S. Geological Survey. Accessed 2009. USGS Real-Time Water Data for the Nation. http://waterdata.usgs.gov/nwis/rt.

Ward, W. 2007. Standard Operating Procedure for Collection and Analysis of pH Samples. Washington State Department of Ecology, Olympia, WA. SOP No. EAP031. www.ecy.wa.gov/programs/eap/quality.html.

Ye, X., M.J. Strynar, S.F. Nakayama, J. Varns, L. Helfant, J. Lazorchak, and A.B. Lindstrom. 2008. Perfluorinated Compounds in Whole Fish Homogenates from the Ohio, Missouri, and Upper Mississippi Rivers, USA. Environmental Pollution, Vol. 156: 1227-1232.

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# Appendices

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# Appendix A. Glossary, Acronyms, and Abbreviations

## Glossary

**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.

**Drainage Area:** 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.

**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, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (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 individual values.

**Lipophilic:** Having an affinity for, tending to combine with, or capable of dissolving in lipids.

**Lipophobic:** Lacking an affinity for, repelling, or failing to absorb or adsorb lipids.

**Nonpoint source:** Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, 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. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

**Octanol-water partition coefficient ($K_{ow}$):** Ratio of the concentration of a chemical in octanol and in water at equilibrium and at a specified temperature. The ratio is often used to help predict the extent a contaminant will bioaccumulate in fish.

**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.

**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:** Such 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.

**Proteinophilic:** Having an affinity for proteins.

**Surfactant:** Wetting agents that lower the surface tension of a liquid.

**Thalweg:** Line of fastest flow in a river or stream.

**Toxicokinetics:** The absorption, distribution, metabolism, storage, and excretion of chemicals in organisms.

**90th percentile:** A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

## Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

For definitions of the 13 perfluorinated compounds analyzed in this study, see Table 2.

| | |
|---|---|
| Ecology | Washington State Department of Ecology |
| EIM | Environmental Information Management database |
| EPA | U.S. Environmental Protection Agency |
| LOQ | Limit of quantitation |
| ORD | Office of Research and Development |
| PBT | persistent, bioaccumulative, and toxic substance |
| PFC | Perfluorinated compound |
| RM | River mile |
| RPD | Relative percent difference |
| SOP | Standard operating procedures |
| SRM | Standard reference materials |
| USGS | U.S. Geological Survey |
| WRIA | Water Resources Inventory Area |
| WWTP | Wastewater treatment plant |

*Units of Measurement*

| | |
|---|---|
| °C | degrees centigrade |
| cfs | cubic feet per second |
| g | gram, a unit of mass |
| g/day | grams per day |
| Kg | kilograms, a unit of mass equal to 1,000 grams |
| m | meter |
| mg | milligrams |
| mgd | million gallons per day |
| $mi^2$ | square miles |
| mL | milliliters |
| mm | millimeters |
| ng/g | nanograms per gram (parts per billion) |
| ng/Kg/day | nanograms per kilogram per day |
| ng/L | nanograms per liter (parts per trillion) |
| µs/cm | microsiemens per centimeter |
| ww | wet weight |

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# Appendix B. Study Location Descriptions

Table B-1. Study Location Descriptions for Water and Fish Samples Analyzed for PFCs in 2008.

| Waterbody | Latitude | Longitude | Waterbody ID | County | EIM "User Location ID" | WRIA | Location Description |
|---|---|---|---|---|---|---|---|
| Duwamish River | 47.48289 | -122.26054 | WA-09-1010 | King | DUWAMISH-PFC | 9 | Duwamish River at Foster Golf Links in Tukwila, RM 10. |
| Entiat River | 47.90645 | -120.47863 | WA-46-1020 | Chelan | ENTIAT-PFC | 46 | Entiat River at RM 26. |
| FDR Lake | 47.94843 | -118.90544 | WA-CR-1060 | Okanogan | FDR-PFC | 53 | F.D.R. Lake, upstream of Grand Coulee Dam, RM 601. |
| Lake Washington | 47.64747 | -122.30154 | WA-08-9340 | King | LKWASH-PFC | 28 | Lake Washington, in Seattle, at Montlake Cut, East of University of Washington Marina. |
| Lower Columbia River | 45.69518 | -122.77128 | WA-CR-1010 | Clark | LCR-PFC | 28 | Lower Columbia River near Vancouver, RM 98.4. |
| McNary Dam (Columbia River) | 45.94047 | -119.29741 | WA-CR-1026 | Benton | MCNARY-PFC | 31 | Columbia River at McNary Dam near Umatilla, Oregon, RM 292 |
| Nooksack River | 48.93655 | -122.44201 | WA-01-1010 | Whatcom | NOOKSACK-PFC | 1 | Nooksack River near Lynden, RM 18. |
| Puyallup River | 47.19788 | -122.26354 | WA-10-1020 | Pierce | PUYALLUP-PFC | 10 | Puyallup River at Sumner, RM 10. |
| Quinault River | 47.533177 | -123.6789 | WA-21-2020 | Jefferson | QUINAULT-PFC | 21 | Quinault River in Olympic National Park, RM 47. |
| Snohomish River | 47.91092 | -122.09873 | WA-07-1020 | Snohomish | SNOHOMISH-PFC | 7 | Snohomish River at Snohomish, behind visitor's center, RM 12.5. |
| South Fork Palouse River | 46.759887 | -117.22521 | WA-34-1020 | Whitman | SFPAL-PFC | 34 | South Fork Palouse River at Armstrong Rd, 2.8 miles northwest of Pullman. |
| Spokane River at Nine Mile | 47.77469 | -117.54461 | WA-54-1020 | Spokane | SPOKNM-PFC | 54 | Upstream side of Spokane River's Nine Mile Dam, RM 58.1. |
| Upper Columbia River | 48.921505 | -117.77439 | WA-CR-1060 | Stevens | UCR-PFC | 61 | Upper Columbia River at Northport, WA, near Canadian border, RM 735. |
| West Medical Lake | 47.579434 | -117.71165 | WA-43-9160 | Spokane | WMEDLK-PFC | 43 | West Medical Lake, near Medical Lake. |

Table B-2. Study Location Descriptions for Wastewater Treatment Plant Effluent Samples Analyzed for PFCs in 2008.

| Wastewater Treatment Plant | Latitude | Longitude | County | EIM "User Location ID" | WRIA | Location Description |
|---|---|---|---|---|---|---|
| Marine Park (Vancouver) | 45.61000 | -122.61805 | Clark | LCRWWTP-PFC | 28 | Marine Park Wastewater Treatment Facility Effluent (Vancouver, WA); discharges to Lower Columbia River. |
| Spokane | 47.69374 | -117.47204 | Spokane | SPWWTP-PFC | 54 | City of Spokane Wastewater Treatment Plant Effluent; discharges to Spokane River. |
| Sumner | 47.19965 | -122.25477 | Pierce | SUMWWTP-PFC | 10 | City of Sumner Wastewater Treatment Facility; discharges to White River upstream of confluence with Puyallup River. |
| Medical Lake | 47.56698 | -117.70340 | Spokane | WMLWWTP-PFC | 43 | City of Medical Lake Reclaimed Water Facility Effluent; discharges to West Medical Lake. |

# Appendix C. PFC Data Results

### Surface Water PFC Results

Table C - 1. PFC Surface Water Data (ng/L) Collected in Spring, 2008.

| Sample ID | Waterbody | Collection Date | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08190011 | Columbia River at McNary Dam | 5/8/2008 | **1.04 J** | 1.0 U | **1.22** | **2.25** | **1.06** | 0.05 U | 0.05 U | 0.05 U | 0.05 U | 1.0 U | 0.05 U | **5.57 J** |
| 08190008 | Duwamish River | 5/7/2008 | **1.04 J** | 0.05 U | 1.0 U | **1.43** | 1.0 U | 0.05 U | 0.05 U | 0.05 U | 0.2 U | 1.0 U | 0.05 U | **2.47 J** |
| 08190009 | Entiat River | 5/7/2008 | **1.07 J** | 1.0 U | **1.24** | **3.71** | **1.18** | 0.05 U | 0.05 U | 0.05 U | 0.2 U | 1.0 U | 0.2 U | **7.20 J** |
| 08190005 | F.D.R. Lake | 5/6/2008 | 0.05 U | 1.0 U | 1.0 U | **1.63** | **1.19** | 0.05 U | 0.05 U | 0.05 U | 0.2 U | 1.0 U | 0.05 U | **2.82** |
| 08190007 | Lake Washington | 5/12/2008 | **1.58 J** | **1.12** | **5.83** | **4.22** | **3.60** | **1.52** | **0.52** | 0.05 U | **5.61** | **1.81** | **0.64 J** | **26.5** |
| 08190002 | Lower Columbia River | 5/5/2008 | **1.11 J** | 1.0 U | 1.0 U | 1.0 U | 1.0 U | 0.05 U | 0.05 U | 1.0 U | 0.2 U | 1.0 U | 0.2 U | **1.11 J** |
| 08190001 | Nooksack River | 5/12/2008 | **1.13 J** | 1.0 U | **2.90** | **4.02** | **1.99** | 0.05 U | 0.05 U | 0.05 U | 0.05 U | 1.0 U | 0.05 U | **10.0 J** |
| 08190017 | Puyallup River | 5/12/2008 | **1.08 J** | 1.1 U | **1.32** | **3.18** | **1.51** | 0.05 U | 0.2 U | 1.0 U | **0.64 J** | 1.0 U | 0.2 U | **7.73 J** |
| 08190004 | Quinault River | 5/6/2008 | **1.06 J** | 1.0 U | 1.0 U | **1.80** | 1.0 U | 0.05 U | 0.05 U | 1.0 U | **0.28** | 1.0 U | 0.05 U | **3.14 J** |
| 08190016 | South Fork Palouse River | 5/9/2008 | **1.51 J** | **1.27** | **7.64** | **3.78** | **10.5** | **2.97** | **3.62** | 1.0 U | **1.74** | **1.08** | **0.37** | **34.4** |
| 08190006 | Snohomish River | 5/7/2008 | **1.15 J** | 1.0 U | 1.0 U | **1.11** | 1.0 U | 0.05 U | 0.05 U | 1.0 U | 0.05 U | 1.0 U | 0.05 U | **2.26 J** |
| 08190015 | Spokane River at Ninemile Dam | 5/9/2008 | **1.02 J** | 1.0 U | **1.64** | **3.41** | **3.67** | 0.05 U | 0.2 U | 0.05 U | **0.23** | 1.0 U | 0.05 U | **9.97 J** |
| 08190010 | Upper Columbia River | 5/7/2008 | **1.09 J** | 1.0 U | **1.66** | **3.69** | **1.46** | 0.05 U | 0.05 U | 0.05 U | 0.2 U | 1.0 U | 0.05 U | **7.90 J** |
| 08190012 | West Medical Lake | 5/8/2008 | **4.92 J** | **16.7** | **95.6** | **28.1** | 1.0 U | **26.5** | **2.99** | 0.05 U | **6.54** | **3.33** | **0.57** | **185** |

Detected values are in bold.
J – Reported value is an estimate.
U – Analyte not detected at or above reported value.
UJ – Analyte not detected at or above the reported estimated value.

Table C - 2. PFC Surface Water Data (ng/L) Collected in Fall, 2008.

| Sample ID | Waterbody | Collection Date | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 083700029 | Columbia River at McNary Dam | 9/9/2008 | **0.55** | 0.5 U | **0.76** | **5.05** | 0.05 UJ | 0.5 U | 0.05 UJ | 0.05 UJ | 0.53 UJ | 0.5 U | 0.5 U | **6.35** |
| 083700026 | Duwamish River | 9/11/2008 | **0.78** | **1.12** | **1.9** | 3.21 UJ | **1.19** | **0.57** | 0.5 U | 0.05 UJ | 1.01 UJ | **0.84** | **0.74 J** | **7.13** |
| 083700027 | Entiat River | 9/8/2008 | 0.5 U | 0.5 U | 0.5 U | 0.95 UJ | **0.64** | 0.5 U | 0.5 U | 0.5 U | 0.66 UJ | 0.5 U | 0.5 U | **0.64** |
| 083700023 | F.D.R. Lake | 9/9/2008 | 0.5 U | 0.5 U | 0.5 U | 1.42 UJ | **2.03** | **0.60** | **0.88 J** | 0.05 UJ | 0.58 UJ | 0.5 U | **0.77 J** | **4.28 J** |
| 083700025 | Lake Washington | 9/11/2008 | **0.80** | 0.5 U | **2.54** | 2.38 UJ | **1.65** | **1.42** | 0.5 U | 0.05 UJ | **6.1** | **1.89** | **0.9 J** | **15.3** |
| 083700020 | Lower Columbia River | 9/12/2008 | 0.5 U | 0.5 U | **0.81** | 0.86 UJ | **1.59** | 0.5 U | 0.5 U | 0.5 U | 1.04 UJ | 0.5 U | **0.54 J** | **2.93 J** |
| 083700019 | Nooksack River | 9/12/2008 | 0.5 U | 0.5 U | 0.5 U | 1.29 UJ | **1.29** | 0.5 U | 0.5 U | 0.05 UJ | 0.72 UJ | 0.5 U | **0.56 J** | **1.85 J** |
| 083700035 | Puyallup River | 9/12/2008 | **0.62** | 0.5 U | 0.5 U | 2.14 UJ | 0.5 U | 0.5 U | 0.5 U | 0.05 UJ | 0.54 UJ | 0.5 U | 0.05 UJ | **0.62** |
| 083700022 | Quinault River | 9/8/2008 | 0.5 U | 0.5 U | 0.5 U | 1.6 UJ | 0.5 U | 0.5 U | 0.5 U | 0.05 UJ | 0.5 U | 0.5 U | **0.66 J** | **0.66 J** |
| 083700034 | S. Fork Palouse | 9/10/2008 | **3.14** | **2.46** | **24.0** | **6.88** | **12.4** | **13** | **2.7 J** | 0.05 UJ | **6.36** | **1.93** | **1.98 J** | **74.9** |
| 083700024 | Snohomish River | 9/11/2008 | 0.05 U | 0.5 U | 0.5 U | 0.97 UJ | 0.5 U | 0.5 U | 0.05 UJ | 0.05 UJ | 0.55 UJ | 0.5 U | 0.05 UJ | 0.97 U |
| 083700033 | Spokane River at Nine Mile | 9/10/2008 | **0.63** | 0.5 U | **1.82** | 3.3 UJ | **1.43** | **1.4** | 0.5 U | 0.5 U | **3.25** | **1.26** | **0.62 J** | **10.4** |
| 083700028 | Upper Columbia River | 9/9/2008 | 0.5 U | 0.5 U | 0.5 U | 0.9 UJ | 0.5 U | 0.5 U | 0.5 U | 0.5U | 0.67 UJ | 0.5 U | 0.5 U | 0.9 U |
| 083700030 | West Medical Lake | 9/10/2008 | **3.79** | **6.97** | **48.3** | **22.4** | **36.9** | **31.6** | **5.51** | **1.29 J** | **7.6** | **4.48** | **1.58 J** | **170** |

Detected values are in bold.
J – Reported value is an estimate.
U – Analyte not detected at or above reported value.
UJ – Analyte not detected at or above the reported estimated value.

**Wastewater Treatment Plant Effluent PFC Results**

Table C - 3. PFC Concentrations (ng/L) Measured in WWTP Effluent during Spring, 2008.

| Sample ID | Waterbody | Collection Date | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08190003 | Marine Park WWTP | 5/5/2008 | **6.25** | **3.56** | **16.5** | **4.13** | **14.5** | **3.78** | **0.72** | 0.05 U | **8.53** | **3.02** | 0.05 U | **61.0** |
| 08190014 | Spokane WWTP | 5/8/2008 | **13.3** | **17.9** | **128** | **35.3** | **141** | **31.4** | **3.27** | 0.05 U | **31.2** | **16.4** | 0.05 U | **418** |
| 082000018 | Sumner WWTP | 5/12/2008 | **12.3** | **10.6** | **86.9** | **7.65** | **45.2** | **21.4** | **2.40** | 0.05 U | **4.42** | **1.33** | **1.51** | **194** |
| 08190013 | West Medical Lake WWTP | 5/8/2008 | **3.63 J** | **6.89** | **79.5** | **13.3** | **59.7** | **28.7** | **2.13** | 0.05 U | **3.86** | **2.50** | 0.05 U | **200** |

Detected values are in bold.
J – Reported value is an estimate.
U – Analyte not detected at or above reported value.

Table C - 4. PFC Concentrations (ng/L) Measured in WWTP Effluent during Fall, 2008.

| Sample ID | Waterbody | Collection Date | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 083700021 | Marine Park WWTP | 9/12/2008 | **4.42** | **5.66** | **22.1** | 3.52 UJ | **10.9** | **12.6** | **1.91 J** | 0.05 UJ | **11.7** | **3.97** | 0.5 U | **73.3** |
| 083700032 | Spokane WWTP | 9/10/2008 | **3.67** | **7.72** | **36.6** | **12.9** | **29.8** | **16** | **2.8 J** | 0.05 UJ | **18.1** | **11.9** | **2.40 J** | **142** |
| 083700036 | Sumner WWTP | 9/12/2008 | **13.2** | **13.8** | **59.9** | **9.74** | **17.1** | **21.7** | **4.25 J** | 0.5 U | **9.36** | **2.72** | **3.15 J** | **155** |
| 083700031 | West Medical Lake WWTP | 9/10/2008 | **6.08** | **5.89** | **63.1** | **12.8** | **29.4** | **46.7** | **5.43** | 0.5 U | **10.2** | **2.19** | **6.58** | **188** |

Detected values are in bold.
J – Reported value is an estimate.
U – Analyte not detected at or above reported value.
UJ – Analyte not detected at or above the reported estimated value.

**Fish Tissue PFC Results**

Table C - 5. Concentrations (ng/g) Measured in Fish Fillet Tissue during the 2008 PFC Survey.

| Sample ID | Waterbody | Species Code | Collection Date | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90100303 | Entiat River | BKT | 7/28/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100302 | | RBT | 7/28/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100315 | FDR Lake | SMB | 11/6/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100314 | | WAL | 11/6/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100307 | Lake Washington | LMB | 10/23/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | **33.58** | 5 U | 5 U | 33.58 |
| 90100310 | | LSS | 10/23/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | **11.14** | 5 U | 5 U | 11.14 |
| 90100309 | | PEA | 10/23/2008 | **5.5 J** | **7.15** | 5 U | 5 UJ | 5 U | 5 U | 5 U | **51.21** | 5 U | 5 U | 63.86 |
| 90100308 | | YP | 10/23/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | **22.45** | 5 U | 5 U | 22.45 |
| 90100305 | Lower Columbia River | LMB | 10/20/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | **75.54** | 5 U | 5 U | 75.54 |
| 90100306 | | LSS | 10/20/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100301 | Quinault River | CTT | 7/29/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100304 | Spokane River | LSS | 10/1/2008 | 5 UJ | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100311 | West Medical Lake | PS | 11/17/2008 | 5 U | 5 U | **7.50 J** | 5 UJ | 5 U | 5 U | 5 U | **12.29** | 5 U | 5 U | 19.79 |
| 90100312 | | RBT | 11/17/2008 | 5 U | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |
| 90100313 | | TENC | 11/17/2008 | 5 UJ | 5 U | 5 U | 5 UJ | 5 U | 5 U | 5 U | 10 U | 5 U | 5 U | 10 U |

Detected values are in bold.
J = Estimated value.
U = Compound not detected at or above limit of quantitation.
UJ = Compound not detected at or above estimated value.

Table C - 6. Concentrations (ng/g) Measured in Fish Liver Tissue during the 2008 PFC Survey.

| Sample ID | Waterbody | Species Code | Collection Date | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90100318 | Entiat River | BKT | 7/28/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 25 U |
| 90100317 | | RBT | 7/28/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 26 U |
| 90100330 | FDR Lake | SMB | 11/6/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 27 U |
| 90100329 | | WAL | 11/6/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | **47.62** | 10 U | 10 U | 47.62 |
| 90100322 | Lake Washington | LMB | 10/23/2008 | 10 U | 10.32UJ | 25 U | 10 U | 10 U | 10 U | 10 U | **257.1** | 10 U | 10 U | 257.1 |
| 90100325 | | LSS | 10/23/2008 | 10 U | 15.50UJ | 25 U | 10 U | 10 U | 10 U | 10 U | **100.34** | 10 U | 10 U | 100.34 |
| 90100324 | | PEA | 10/23/2008 | **20.99J** | **46.06** | 25 U | 10 U | 10 U | 10 U | 10 U | **363.17** | 10 U | 10 U | 430.22 |
| 90100323 | | YP | 10/23/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | **118.54** | 10 U | 10 U | 118.54 |
| 90100320 | Lower Columbia River | LMB | 10/20/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | **527.25** | 10 U | 10 U | 527.25 |
| 90100321 | | LSS | 10/20/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 25 U |
| 90100316 | Quinault River | CTT | 7/29/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 10 U | 25 U |
| 90100319 | Spokane River | LSS | 10/1/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | **20.79** | 10 U | 10 U | 20.79 |
| 90100326 | West Medical Lake | PS | 11/17/2008 | 10 U | 10 U | **21.03J** | 10 U | 10 U | 10 U | 10 U | **47.5** | 10 U | 10 U | 68.53 |
| 90100327 | | RBT | 11/17/2008 | 10 U | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | **65.19** | 10 U | 10 U | 65.19 |
| 90100328 | | TENC | 11/17/2008 | 10 UJ | 10 U | 25 U | 10 U | 10 U | 10 U | 10 U | **35.26** | 10 U | 10 U | 35.26 |

Detected values are in bold.
J = Estimated value.
U = Compound not detected at or above limit of quantitation.
UJ = Compound not detected at or above estimated value.

**Osprey PFC Data**

Table C - 7. Wet-weight (ng/g) Osprey Egg PFC Results (not corrected for moisture loss).

| Sample ID | Collection Date | PFDoDA | PFUnA | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C71C | 5/19/2008 | 5 U | **14.03** | **6.66** | **7.16** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **2.18** | **113.17** | 0.5 U | 0.5 U | **143.2** |
| C76A | 5/20/2008 | 5 U | **8.15** | **6.02** | **2.31** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **2.51** | **88.34** | 0.5 U | 0.5 U | **107.3** |
| C76B | 5/20/2008 | 5 U | **9.98** | **6.74** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | 1 U | **28.22** | 0.5 U | 0.5 U | **44.9** |
| C79 | 5/20/2008 | 5 U | **14.97** | **8.32** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **1.94** | **82.45** | 0.5 U | 0.5 U | **107.7** |
| C82 | 5/20/2008 | **5.44** | **12.12** | **7.02** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **5.97** | **354.99** | **0.77** | 0.5 U | **386.3** |
| C84 | 5/20/2008 | 5 U | **11.08** | **12.10** | **2.77** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **3.15** | **1047.95** | **2.15** | 0.5 U | **1079.2** |
| C105 | 5/20/2008 | 5 U | **8.57** | **9.53** | 0.5 U | 1 U | **0.92** | **0.92** | 5 U | 5 U | **5.32 J** | **80.38** | 0.5 U | 0.5 U | **105.6** |
| C108A | 5/20/2008 | **5.57** | **5.03** | **3.81** | **0.76** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **6.75** | **301.28** | **0.50** | 0.5 U | **323.7** |
| C111A | 5/20/2008 | 5 U | **7.87** | **5.24** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | 1 UJ | **73.12** | 0.5 U | 0.5 U | **86.2** |
| C112 | 5/20/2008 | **12.61 J** | **9.25** | **4.28** | 0.5 U | 0.2 U | 0.5 U | 0.5 U | 5 U | 5 U | 1 U | **35.60** | 0.5 U | 0.5 U | **61.7** |
| C113 | 5/20/2008 | 5 U | **3.94** | **2.28** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **1.68** | **35.36** | 0.5 U | 0.5 U | **43.3** |

Detected values are in bold.
J = Estimated value.
U = Compound not detected at or above limit of quantitation.
UJ = Compound not detected at or above limit of quantitation.

Table C - 8. Moisture Loss-corrected PFC Concentrations (ng/g) Measured in Osprey Eggs.

| Sample ID | Collection Date | PFDoA | PFUnA | PFDA | PFNA | PFOA | PFHpA | PFHxA | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | Sum PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C71C | 5/19/2008 | 5 U | **12.63** | **6.00** | **6.44** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **1.96** | **101.8** | 0.5 U | 0.5 U | **128.9** |
| C76A | 5/20/2008 | 5 U | **7.17** | **5.30 J** | **2.03** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **2.21** | **77.7** | 0.5 U | 0.5 U | **94.4** |
| C76B | 5/20/2008 | 5 U | **8.33** | **5.62** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | 1 U | **23.5** | 0.5 U | 0.5 U | **37.5** |
| C79 | 5/20/2008 | 5 U | **12.36** | **6.87** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **1.60** | **68.1** | 0.5 U | 0.5 U | **88.9** |
| C82 | 5/20/2008 | **4.79** | **10.68** | **6.19** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **5.26** | **312.8** | **0.68** | 0.5 U | **340.4** |
| C84 | 5/20/2008 | 5 U | **9.35** | **10.21** | **2.34 J** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **2.66** | **883.9** | **1.82** | 0.5 U | **910.3** |
| C105 | 5/20/2008 | 5 U | **7.36** | **8.18** | 0.5 U | 1 U | **0.80** | **0.80** | 5 U | 5 U | **4.57 J** | **69.0** | 0.5 U | 0.5 U | **90.8** |
| C108A | 5/20/2008 | **4.78** | **4.32** | **3.27** | **0.65** | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **5.80** | **258.7** | **0.43** | 0.5 U | **278.0** |
| C111A | 5/20/2008 | 5 U | **6.73** | **4.48** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | 1 UJ | **62.5** | 0.5 U | 0.5 U | **73.7** |
| C112 | 5/20/2008 | **10.67 J** | **7.83** | **3.63** | 0.5 U | 0.2 U | 0.5 U | 0.5 U | 5 U | 5 U | 1 U | **30.2** | 0.5 U | 0.5 U | **52.3** |
| C113 | 5/20/2008 | 5 U | **3.46** | **2.00** | 0.5 U | 1 U | 0.5 U | 0.5 U | 5 U | 5 U | **1.48** | **31.1** | 0.5 U | 0.5 U | **38.0** |

Detected values are in bold.
J = Estimated value.
U = Compound not detected at or above limit of quantitation.
UJ = Compound not detected at or above estimated value.

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# Appendix D. Ancillary Water Data

Table D - 1. Ancillary Water Data Measured at Surface Water and WWTP Sites in Spring, 2008.

| Site | Sample ID | Date | Time | Temp (° C) | pH | Conductivity (µs/cm) |
|---|---|---|---|---|---|---|
| **Surface Waters** | | | | | | |
| Duwamish River | 08190008 | 5/7/2008 | 15:30 | 8.9 | 6.57 | 47 |
| Entiat River | 08190009 | 5/7/2008 | 20:00 | 6.0 | 6.87 | 29 |
| FDR Lake | 08190005 | 5/6/2008 | 18:25 | 11.8 | 8.20 | 148 |
| Lake Washington | 08190007 | 5/12/2008 | 11:55 | 12.1 | 8.14 | 99 |
| Lower Columbia River | 08190002 | 5/5/2008 | 17:30 | 11.6 | 8.39 | 176 |
| McNary Dam | 08190011 | 5/8/2008 | 14:45 | 12.6 | 8.25 | 174 |
| Nooksack River | 08190001 | 5/12/2008 | 15:15 | 8.6 | 7.55 | 66 |
| Puyallup River | 08190017 | 5/12/2008 | 10:12 | 8.5 | 7.55 | 51 |
| Quinault River | 08190004 | 5/6/2008 | 18:25 | 6.5 | 7.63 | 79 |
| S.F. Palouse River | 08190016 | 5/9/2008 | 8:25 | 9.6 | 8.04 | 263 |
| Snohomish River | 08190006 | 5/7/2008 | 12:00 | 7.4 | 7.00 | 35 |
| Spokane River at Nine Mile | 08190015 | 5/9/2008 | 9:26 | 7.2 | 7.45 | 76 |
| Upper Columbia River | 08190010 | 5/7/2008 | 12:20 | 10.7 | 8.21 | 131 |
| West Medical Lake | 08190012 | 5/8/2008 | 11:15 | 12.5 | 9.21 | 905 |
| **Wastewater Treatment Plants** | | | | | | |
| Marine Park | 08190003 | 5/5/2008 | 10:15 | 19.6 | 6.85 | 767 |
| | 08190003 | 5/5/2008 | 16:15 | 25.0 | 6.80 | ---- |
| Spokane | 08190014 | 5/8/2008 | 9:15 | 16.9 | 7.23 | ---- |
| | 08190014 | 5/8/2008 | 15:55 | 15.8 | 6.96 | 689 |
| Sumner | 082000017 | 5/12/2008 | 9:20 | 16.0 | --- | 485 |
| | 082000017 | 5/12/2008 | 16:00 | 16.3 | --- | --- |
| West Medical Lake | 08190013 | 5/8/2008 | 10:25 | 14.3 | 7.29 | 667 |
| | 08190013 | 5/8/2008 | 17:00 | 15.3 | 7.08 | 663 |

Table D - 2. Ancillary Data Measured at Surface Water and WWTP Sites in Fall, 2008.

| Site | Sample ID | Date | Time | Temp (° C) | pH | Conductivity (µs/cm) |
|---|---|---|---|---|---|---|
| **Surface Waters** | | | | | | |
| Duwamish River | 083700026 | 9/11/2008 | 9:45 | 15.6 | 6.65 | 185 |
| Entiat River | 083700027 | 9/8/2008 | 22:00 | 12.1 | 6.85 | 39 |
| FDR Lake | 083700023 | 9/9/2008 | 12:00 | 20.6 | 7.76 | 135 |
| Lake Washington | 083700025 | 9/11/2008 | 15:15 | 21.5 | 6.11 | 105 |
| Lower Columbia River | 083700020 | 9/12/2008 | 16:12 | 20.8 | 7.62 | 144 |
| McNary Dam | 083700029 | 9/9/2008 | 13:55 | 21.5 | 8.18 | 73 |
| Nooksack River | 083700019 | 9/12/2008 | 12:42 | 12.9 | 7.91 | 90 |
| Puyallup River | 083700035 | 9/12/2008 | 16:30 | 15.0 | 7.9 | --- |
| Quinault River | 083700022 | 9/8/2008 | 13:51 | 13.1 | 7.18 | 99 |
| S.F. Palouse River | 083700034 | 9/10/2008 | 8:35 | 14.1 | 7.44 | 688 |
| Snohomish River | 083700024 | 9/11/2008 | 13:18 | 16.8 | 6.18 | 50 |
| Spokane River at Nine Mile | 083700033 | 9/10/2008 | 10:15 | 14.4 | 8.28 | 289 |
| Upper Columbia River | 083700028 | 9/9/2008 | 17:05 | 18.5 | 7.91 | 145 |
| West Medical Lake | 083700030 | 9/10/2008 | 17:45 | 19.3 | 9.03 | 1015 |
| **Wastewater Treatment Plants** | | | | | | |
| Marine Park | 083700021 | 9/12/2008 | 9:41 | 22 | 7.24 | 871 |
| | 083700021 | 9/12/2008 | 14:45 | 23.1 | 7.26 | 927 |
| Spokane | 083700032 | 9/10/2008 | 8:40 | 19.6 | 7.13 | 744 |
| | 083700032 | 9/10/2008 | 15:47 | 21.3 | 6.79 | 752 |
| Sumner | 083700036 | 9/12/2008 | 8:45 | 20.6 | 6.95 | --- |
| | 083700036 | 9/12/2008 | 15:58 | 21.1 | 6.97 | --- |
| West Medical Lake | 083700031 | 9/10/2008 | 7:35 | 18.3 | 6.89 | 750 |
| | 083700031 | 9/10/2008 | 17:10 | 19.8 | 6.83 | 733 |

# Appendix E. Case Narratives

**Data Qualifier Codes**

U - The analyte was analyzed for, but was not detected above the reported sample quantitation limit.

J - The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.

UJ - The 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.

*Manchester Environmental Laboratory*
7411 Beach Drive East, Port Orchard Washington 98366

August 3, 2010

| | |
|---|---|
| Subject: | Surface Water – Spring |
| Samples: | "First WA Samples" |
| Laboratory: | EPA |
| Project Officer: | Chad Furl |
| By: | Karin Feddersen |

# *Data Review for Perfluorinated Organic Compounds Analysis*

## Summary

Data from these analyses were reviewed for qualitative and quantitative precision and accuracy.

Samples were prepared and analyzed according to EPA's SOP EMAB-114.

Results have been reported in nanograms per Liter (ng/L).

Results reported as ND have been revised to 0.05 U as per Manchester Laboratory's reporting conventions and in accordance with the information from Shoji Nakayama's email to Chad Furl on July 29, 2009, 2:27 PM. Results reported as <LOQ have been revised to the LOQ value for the analyte and U, as per the same email.

## Holding Times

The SOP allows storage of samples at ambient temperatures for a minimum of 4 weeks if preserved with nitric acid. Extraction and analysis took place within this time frame. As the lab provided no case narrative, there is no information stating whether samples were verified upon receipt to be preserved.

## Blanks

Certain target compounds were detected in the laboratory blank below the reporting limits. Results for the blank have been added to the Excel spreadsheet.

## Calibration

According to EPA's SOP: "Analysis of standard solutions should result in a best fit regression coefficient of determination ($r^2$) of 0.99 or greater, using a minimum of six independent concentrations that bracket the sample analysis". C10 had an $r^2$ of 0.986, and PFBS had an $r^2$ of

0.969 for the first set of samples. In addition only 5 standards were used for C12, C11, C10, C9, C8, C7, C6, PFDS, and PFHS. The low standard was excluded as it did not meet the residual criteria (±30% of their expected values.) All of the remaining standards were within ±30% of their expected values with one exception; C10 in the 1 ng/L standard. All detected results for C10 close between this value and the next standard (5 ng/L) have been qualified as estimates.

In addition, the linearity of the curve is severely compromised for some analytes. The correlation coefficient was less than 0.995 for C10 and less than 0.99 for PFBS.

The retention time window was set as ±0.07 min (4.2 sec).

**Internal Standard (IS) Recoveries**

No recoveries were calculated for the labeled compounds in these samples. No QC limits have been established.

**On-going Precision and Recovery (OPR) or Laboratory Control Sample (LCS)**

Target analyte recoveries were within ±20% of the expected values.
Labeled compound recoveries were not evaluated as no QC criteria have been established.

A field spike was also analyzed; recoveries ranged from 23.9% to 113%.

**Duplicate**

Duplicate analyses were performed on the samples for Lake Washington and Upper Columbia River.

*Manchester Environmental Laboratory*
7411 Beach Drive East, Port Orchard Washington 98366

October 26, 2009

| | |
|---|---|
| Subject: | Surface Water – Fall 2009 |
| Samples: | "Second WA Samples" |
| Laboratory: | EPA |
| Project Officer: | Chad Furl |
| By: | Karin Feddersen |

# *Data Review for Perfluorinated Organic Compounds Analysis*

## Summary

Data from these analyses were reviewed for qualitative and quantitative precision and accuracy.

Samples were prepared and analyzed according to EPA's SOP EMAB-114.

Results have been reported in nanograms per Liter (ng/L).

Results reported as ND have been revised to 0.05 UJ as per Manchester Laboratory's reporting conventions and in accordance with the information from Shoji Nakayama's email to Chad Furl on July 29, 2009, 2:27 PM. These results are below the quantitation limit based on the lowest standard used for quantitation.

Results reported as <LOQ have been revised to the LOQ value for the analyte and U, as per the same email.

## Holding Times

The SOP allows storage of samples at ambient temperatures for a minimum of 4 weeks if preserved with nitric acid. Extraction and analysis took place within this time frame. As the lab provided no case narrative, there is no information stating whether samples were verified upon receipt to be preserved.

## Blanks

Results for the method blank have been added to the Excel spreadsheet.C7 and PFOS were detected in the laboratory blank. Results in the samples that are less than 10 times the blank contamination have been qualified "UJ".

**Calibration**

The linearity of the curve is severely compromised for some analytes. According to EPA's SOP: "Analysis of standard solutions should result in a best fit regression coefficient of determination ($r^2$) of 0.99 or greater, using a minimum of six independent concentrations that bracket the sample analysis". C12 had an $r^2$ of 0.5 and PFBS had an $r^2$ of 0.989 for the second set of samples. In addition only 5 standards were used for quantifying all analytes except C12, which used only for standards. The second lowest standard was excluded for low internal standard responses.

All of the standards were within ±30% of their expected values with several exceptions.

C12, C4, PFBS, and PFDS in the low (0.5 ng/L) standard.

C12 was not detected in any of the samples and these results are therefore unaffected.

All detected results for C4, PFBS, and PFDS that were between this value and the next standard (5 ng/L) have been qualified as estimates.

The retention time window was set as ±0.07 min (4.2 sec).

**Internal Standard (IS) Recoveries**

No recoveries were calculated for the labeled compounds in these samples. No QC limits have been established.

**On-going Precision and Recovery (OPR) or Laboratory Control Sample (LCS)**

Target analyte recoveries were within ±20% of the expected values, with one exception. C12 low spike recovered at 131%. However, C12 was not detected in any of the samples above the LOQ. Therefore, no results were affected.

Labeled compound recoveries were not evaluated as no QC criteria have been established.

A field spike was also analyzed; recoveries ranged from 84% to 104%.

**Duplicate**

Duplicate analyses were performed on the samples for West Medical Lake, foamy; and lower Columbia River.

*Manchester Environmental Laboratory*
7411 Beach Drive East, Port Orchard Washington 98366

December 28, 2009

| | |
|---|---|
| Subject: | Tissue Fillets |
| Laboratory: | EPA |
| Project Officer: | Chad Furl |
| By: | Karin Feddersen |

## *Data Review for Perfluorinated Organic Compounds Analysis*

### Summary

Data from these analyses were reviewed for qualitative and quantitative precision and accuracy.

Samples were prepared and analyzed according to EPA's SOP EMAB-114.

Results have been reported in nanograms per gram (ng/g).

The Limit of Quantitation (LOQ) is set at the lowest calibration standard. Results reported as ND and those as reported <LOQ have been revised to the LOQ value for the analyte and qualified U.

### Holding Times

The SOP does not discuss storage of samples or extracts of this matrix.

### Blanks

No analytes were detected above the LOQ (10 ng/g for PFOS and 5 ng/g for all others) in either the method blank (reagent water) or in the matrix blank.

### Calibration

According to EPA's SOP: "Analysis of standard solutions should result in a best fit regression coefficient of determination ($r^2$) of 0.99 or greater, using a minimum of six independent concentrations that bracket the sample analysis". Six concentrations were used for all analytes. The $r^2$ was greater than 0.99 for all analytes except PFHS. PFHS was not detected above the LOQ in any samples, therefore the results are unaffected.

All of the standards used in quantitation were within ±30% of their expected values, with several individual exceptions. Since the average value was used to quantitate the samples, the average

recovery was used to evaluate whether to apply qualification. All averages were within ±30% of their expected values; therefore no qualification was warranted.

**Internal Standard (IS) Recoveries**

No recoveries were calculated for the labeled compounds in these samples. No QC limits have been established.

**On-going Precision and Recovery (OPR) or Laboratory Control Sample (LCS)**

A Tilapia blank matrix was fortified at two concentrations for each reported analyte. All recoveries were within ±20% of the expected values with several exceptions.

C10 recovered high in the high standard, indicating a possible similar high bias in the samples. Non-detect results are unaffected. Detected results have been qualified as estimates, “J”.

C9 recovered low in the low standard indicating a possible similar low bias in the samples. This analyte was not detected above the LOQ in any of the samples. All results have been qualified as estimates, “UJ” at the LOQ.

Labeled compound recoveries were not evaluated, as no QC criteria have been established for them.

**Matrix Spikes**

Samples SPKRLSS and WMLTENC were fortified with each reported analyte. Recoveries were within ±20% of the expected values with several exceptions.

C9 was biased high in both spikes. C10 was biased high in both spikes. Non-detect results are unaffected by a potential high bias. C9 was not detected above the LOQ in the corresponding source sample. C10 was qualified as an estimate, “J” in WMLTENC.

C7 was biased low in SPKRLSS SPIKE. C12 was biased low in WMLTENC SPIKE. C7 and C12 had acceptable recoveries in the QC spikes (LCS), indicating the low bias may be due to matrix effects.

C7 and C12 were not detected above the LOQ in the corresponding source samples. The result for C7 has been qualified “UJ” in SPKRLSS. The results for C12 have been qualified “UJ” in sample WMLTENC and SPKRLSS.

Labeled compound recoveries were not evaluated, as no QC criteria have been established for them.

**Duplicate**

Duplicate analyses were performed on samples ENTRBBT and WASHLYP.

*Manchester Environmental Laboratory*
7411 Beach Drive East, Port Orchard Washington 98366

December 28, 2009

Subject: Tissue livers

Laboratory: EPA

Project Officer: Chad Furl

By: Karin Feddersen

## *Data Review for Perfluorinated Organic Compounds Analysis*

### Summary

Data from these analyses were reviewed for qualitative and quantitative precision and accuracy.

Samples were prepared and analyzed according to EPA's SOP EMAB-114.

Results have been reported in nanograms per gram (ng/g).

The Limit of Quantitation (LOQ) is set at the lowest calibration standard. Results reported as ND and those as reported <LOQ have been revised to the LOQ value for the analyte and qualified U.

### Holding Times

The SOP does not discuss storage of samples or extracts of this matrix.

### Blanks

A small amount of several analytes appeared to be present close to the LOQ in the method blank (reagent water) and in the matrix blank. Samples with values close to the LOQ for these analytes are also suspect. Therefore, reporting limits for C11 have been raised to the level detected for these samples, and qualified "UJ".

### Calibration

According to EPA's SOP: "Analysis of standard solutions should result in a best fit regression coefficient of determination ($r^2$) of 0.99 or greater, using a minimum of six independent concentrations that bracket the sample analysis". The $r^2$ was greater than 0.99 for all analytes except C6 and PFHS. Neither analyte was detected above the LOQ in any samples; therefore the results are unaffected.

All of the standards used in quantitation were within ±30% of their expected values, with several individual exceptions. Since the average value was used to quantitate the samples, the average recovery was used to evaluate whether to apply qualification. Only the average recovery for PFHS was affected. Since PFHS was not detected above the LOQ in any samples, quantitation was not affected and no qualification was warranted.

**Internal Standard (IS) Recoveries**

No recoveries were calculated for the labeled compounds in these samples. No QC limits have been established.

**On-going Precision and Recovery (OPR) or Laboratory Control Sample (LCS)**

A Tilapia blank matrix was fortified at two concentrations for each reported analyte. All recoveries were within ±20% of the expected values with several exceptions.

C12 and C6 recovered high in the low standard, and C9 recovered high in the high standard, indicating a possible similar high bias in the sample results. Non-detect results are unaffected by a potential high bias. Only C12 was detected above the LOQ in one of the samples, WASHLPEAL. This result has been qualified as an estimate, "J".

Labeled compound recoveries were not evaluated, as no QC criteria have been established for them.

**Matrix Spikes**

Samples WASHLLMBL and WMLTENCL were fortified with each reported analyte. Recoveries were within ±20% of the expected values with one exception.

PFBS was biased high in WASHLLMBL SPIKE. PFBS had acceptable recoveries in the QC spikes (LCS). Non-detect results are unaffected by a potential high bias. This analyte was not detected above the LOQ in the corresponding source sample.

Labeled compound recoveries were not evaluated, as no QC criteria have been established for them.

**Duplicate**

Duplicate analyses were performed on samples ENTRBKTL and WASHLLSSL.

*Manchester Environmental Laboratory*
7411 Beach Drive East, Port Orchard Washington 98366

October 28, 2009

| | |
|---|---|
| Subject: | Osprey Eggs |
| Laboratory: | EPA |
| Project Officer: | Chad Furl |
| By: | Karin Feddersen |

## *Data Review for Perfluorinated Organic Compounds Analysis*

### Summary

Data from these analyses were reviewed for qualitative and quantitative precision and accuracy.

Samples were prepared and analyzed according to EPA's SOP EMAB-114.

Results have been reported in nanograms per gram (ng/g).

The Limit of Quantitation (LOQ) is set at the lowest calibration standard. Results reported as ND and those as reported <LOQ have been revised to the LOQ value for the analyte and qualified U.

### Holding Times

The SOP does not discuss storage of samples or extracts of this matrix..

### Blanks

Results for the method blank (reagent water) and matrix blank (chicken egg white) have been added to the Excel spreadsheet. A small amount of C12 was detected in the matrix blank, but not the method blank.

### Calibration

According to EPA's SOP: "Analysis of standard solutions should result in a best fit regression coefficient of determination ($r^2$) of 0.99 or greater, using a minimum of six independent concentrations that bracket the sample analysis". Only 5 standards were used for quantifying C12.

All of the standards used in quantitation were within ±30% of their expected values.

**Internal Standard (IS) Recoveries**

No recoveries were calculated for the labeled compounds in these samples. No QC limits have been established.

**Matrix Spikes**

Samples C113, C88, C105, C111A, C112, and C76B were fortified with 50 ng/g of each target analyte. Recoveries were within ±20% of the expected values, with several exceptions.

C12 recoveries were low in C88 and C112. PFDS recoveries were low in C113 and C111A. Results in the native sample have been qualified as estimates.

C11 and C10 recoveries were high in C105 and C111A. These analytes were not detected in the native samples. Therefore, no results were affected.

Labeled compound recoveries were not evaluated as no QC criteria have been established.

No field spike was analyzed.

**Duplicate**

Duplicate analyses were performed on samples C108A, C71C, C76A, C79, and C82.

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# Appendix F. Quality Assurance Data

**Water and WWTP Effluent**

Table F - 1. Water and WWTP Effluent Field Trip Spike Recoveries (%).

| Sampling Season | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA |
|---|---|---|---|---|---|---|---|
| Spring | 24% | 47% | 78% | 62% | 69% | 73% | 74% |
| Fall | 84% | 103% | 96% | 91% | 94% | 92% | 97% |
| Sampling Season | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | |
| Spring | 113% | 113% | 50% | 98% | 96% | 89% | -- |
| Fall | 100% | 104% | 72% | 87% | 88% | 90% | -- |

Table F - 2. Water and WWTP Effluent Laboratory Blanks.

| Sampling Season | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA |
|---|---|---|---|---|---|---|---|
| Spring | 1.0 U | 1.0 U | 1.04 UJ | 1.0 U | 1.0 U | 1.0 U | 1.0 U |
| Fall | 5.0 U | 0.50 U | 0.50 U | 0.50 U | 0.50 U | 0.5 | 0.50 U |
| Sampling Season | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | |
| Spring | 0.2 U | 0.2 U | 0.2 U | 0.2 U | 0.16 U | 0.2 U | -- |
| Fall | 0.50 U | 0.50 U | 0.50 U | 0.26 | 0.50 U | 0.50 U | -- |

Table F - 3. Water and WWTP Effluent Laboratory Control Sample Recoveries (%).

Spring

| Spike Amount | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA |
|---|---|---|---|---|---|---|---|
| 5.0 ng/L | 104% | 92% | 92% | 93% | 89% | 117% | 98% |
| 50 ng/L | 90% | 83% | 86% | 90% | 83% | 91% | 87% |
| Spike Amount | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | |
| 5.0 ng/L | 106% | 94% | 91% | 89% | 99% | 95% | -- |
| 50 ng/L | 109% | 102% | 86% | 92% | 95% | 90% | -- |

Fall

| Spike Amount | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA |
|---|---|---|---|---|---|---|---|
| 5.0 ng/L | 131% | 106% | 86% | 101% | 94% | 95% | 89% |
| 50 ng/L | 89% | 101% | 86% | 97% | 93% | 91% | 94% |
| Spike Amount | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | |
| 5.0 ng/L | 100% | 100% | 107% | 93% | 97% | 104% | -- |
| 50 ng/L | 95% | 98% | 94% | 91% | 91% | 89% | -- |

Table F - 4. Water and WWTP Effluent Replicates (RPD).

| Sample ID | Waterbody | Collection Date | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA |
|---|---|---|---|---|---|---|---|---|---|
| 08190010 | UCR | 5/7/2008 | 14.8%* | 21.4%* | 11% | NC | 12% | 14% | 37.4%* |
| 08190014 | Spokane WWTP | 5/8/2008 | NC | NC | 15% | 28% | 23% | 8% | 1% |
| 08190007 | Lake Washington | 5/12/2008 | NC | NC | 9% | 26% | 11% | 11% | 10% |
| 083700030 | West Medical Lake | 9/10/2008 | NC | NC | 2% | 8% | 2% | 7% | 3% |
| 083700020 | LCR | 9/12/2008 | NC | NC | 7.7* | NC | 28% | NC | 34% |
| Sample ID | Waterbody | Collection Date | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | Sum PFCs |
| 08190010 | UCR | 5/7/2008 | NC | NC | NC | NC | NC | NC | 4.3%* |
| 08190014 | Spokane WWTP | 5/8/2008 | 2% | 17% | NC | 23% | 25% | NC | 13% |
| 08190007 | Lake Washington | 5/12/2008 | 12% | 36% | NC | 14% | 5% | 104.8%* | 1.1% |
| 083700030 | West Medical Lake | 9/10/2008 | 5% | 5% | 47% | 12% | 4% | 4% | 0.9% |
| 083700020 | LCR | 9/12/2008 | 14.8%* | 63%* | NC | NC | NC | 8% | 20.2%* |

* = Value calculated using < LOQ and quantified values (< LOQ set to LOQ for RPD calculation).
NC = Not Calculated, analyte not detected or < LOQ in both samples.
RPD = Relative Percent Difference (max-min)/(mean)*100.
UCR = Upper Columbia River.
LCR = Lower Columbia River.

**Fish Fillet and Liver**

Table F - 5. Fish Fillet and Liver Matrix Spike Recoveries (%).

Fillet

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| 90100304 | 91% | 110% | 125% | 157% | 116% |
| 90100313 | 44% | 83% | 153% | 133% | 108% |
| Sample ID | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| 90100304 | 72% | 102% | 96% | 93% | 103% |
| 90100313 | 99% | 113% | 109% | 95% | 108% |

Liver

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| 90100322 | 93% | 95% | 104% | 103% | 103% |
| 90100328 | 78% | 92% | 106% | 94% | 107% |
| Sample ID | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| 90100322 | 107% | 98% | 115% | 112% | 147% |
| 90100328 | 101% | 105% | 86% | 108% | 103% |

Table F - 6. Fish Fillet and Liver Laboratory Control Sample Recoveries (%).

Fillet

| Control Sample | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| Low | 100% | 97% | 111% | 75% | 98% |
| High | 90% | 114% | 144% | 113% | 111% |
| Control Sample | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| Low | 83% | 96% | 101% | 113% | 100% |
| High | 102% | 98% | 102% | 98% | 111% |

Liver

| Control Sample | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| Low | 153% | 91% | 98% | 96% | 111% |
| High | 96% | 102% | 90% | 124% | 103% |
| Control Sample | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| Low | 91% | 172% | 90% | 93% | 111% |
| High | 104% | 107% | 85% | 84% | 84% |

Low control sample – PFOS spiked at 50 ng/g, all other 10 ng/g.
High control sample – PFOS spiked at 400 ng/, all other 40 ng/g.

Table F - 7. Fish Fillet Duplicate Samples (RPD).

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| 90100302 | 5U | 5U | 5U | 5UJ | 5U |
| 90100302 D | 5U | 5U | 5U | 5UJ | 5U |
| RPD = | NC | NC | NC | NC | NC |
| Sample ID | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| 90100302 | 5U | 5U | 10U | 5U | 5U |
| 90100302 D | 5U | 5U | 10U | 5U | 5U |
| RPD = | NC | NC | NC | NC | NC |

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| 90100308 | 5U | 5U | 5U | 5UJ | 5U |
| 90100308 D | 5U | 5U | 5U | 5UJ | 5U |
| RPD = | NC | NC | NC | NC | NC |
| Sample ID | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| 90100308 | 5U | 5U | 22.45 | 5U | 5U |
| 90100308 D | 5U | 5U | 17.41 | 5U | 5U |
| RPD = | NC | NC | 25% | NC | NC |

NC – Not Calculated (both samples less than limit of quantification).

Table F - 8. Fish Liver Duplicate Samples (RPD).

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| 90100318 | 10U | 10U | 25U | 10U | 10U |
| 90100318 D | 10U | 10U | 25U | 10U | 10U |
| RPD = | NC | NC | NC | NC | NC |
| Sample ID | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| 90100318 | 10U | 10U | 10U | 10U | 10U |
| 90100318 D | 10U | 10U | 10U | 10U | 10U |
| RPD = | NC | NC | NC | NC | NC |

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA |
|---|---|---|---|---|---|
| 90100325 | 10U | 15.50UJ | 25U | 10U | 10U |
| 90100325 D | 10U | 15.46UJ | 25U | 10U | 10U |
| RPD = | NC | 0.26% | NC | NC | NC |
| Sample ID | PFHpA | PFHxA | PFOS | PFHS | PFBS |
| 90100325 | 10U | 10U | 100.34 | 10U | 10U |
| 90100325 D | 10U | 10U | 62.62 | 10U | 10U |
| RPD = | NC | NC | 46% | NC | NC |

**Osprey Eggs**

Table F - 9. Osprey Egg Laboratory Matrix Spike Recoveries (%).

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA |
|---|---|---|---|---|---|---|---|
| C113 | 97% | 107% | 104% | 99% | 94% | 83% | 110% |
| C88 | 25% | 106% | 116% | 110% | 99% | 93% | 91% |
| C105 | 115% | 137% | 122% | 108% | 95% | 85% | 104% |
| C111A | 102% | 128% | 125% | 102% | 108% | 99% | 90% |
| C112 | 78% | 108% | 118% | 101% | 100% | 84% | 99% |
| C76B | 104% | 111% | 116% | 105% | 103% | 90% | 89% |
| Sample ID | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS | |
| C113 | 99% | 86% | 74% | 90% | 97% | 97% | |
| C88 | 98% | 91% | 88% | 83% | 103% | 98% | |
| C105 | 119% | 117% | 85% | 108% | 103% | 97% | |
| C111A | 104% | 117% | 73% | 116% | 100% | 92% | |
| C112 | 93% | 86% | 83% | 89% | 97% | 92% | |
| C76B | 84% | 81% | 90% | 102% | 101% | 95% | |

Table F – 10. Osprey Egg Duplicates (RPD).

| Sample ID | PFDoDA | PFUnDA | PFDA | PFNA | PFOA | PFHpA | PFHxA |
|---|---|---|---|---|---|---|---|
| C82 | 8% | 17% | 25% | NC | NC | NC | NC |
| C84 | NC | 15% | 14% | 57% | NC | NC | NC |
| C108A | 8% | 14% | 30% | 19% | NC | NC | NC |
| C71C | NC | 2% | 2% | 13% | NC | NC | NC |
| C76A | NC | 8% | 84% | 4% | NC | NC | 10% |
| C79 | 15% | 39% | 8% | NC | NC | NC | NC |

| Sample ID | PFPeA | PFBA | PFDS | PFOS | PFHS | PFBS |
|---|---|---|---|---|---|---|
| C82 | NC | NC | 19% | 9% | 43% | NC |
| C84 | NC | NC | 15% | 23% | 6% | NC |
| C108A | NC | NC | 6% | 9% | NC | NC |
| C71C | NC | NC | 10% | 7% | NC | NC |
| C76A | NC | NC | 15% | 1% | 4% | NC |
| C79 | NC | NC | 30% | 4% | NC | NC |

NC – Not Calculated (both samples less than limit of quantification).

# Appendix G. Names of Fish Species Analyzed

Table G - 1. Common and Scientific Names of Fish Species Analyzed for PFCs in 2008.

| Common Name | Scientific Name | Family Name | Ecology Species Code |
|---|---|---|---|
| Brook trout | *Salvelinus fontinalis* | Salmonidae | BKT |
| Cutthroat trout | *Oncorhynchus clarki* | Salmonidae | CTT |
| Largemouth bass | *Micropterus salmoides* | Centrarchidae | LMB |
| Largescale sucker | *Catostomus macrocheilus* | Catostomidae | LSS |
| Peamouth | *Mylocheilus caurinus* | Cyprinidae | PEA |
| Pumpkinseed | *Lepomis gibbosus* | Centrarchidae | PMP |
| Rainbow trout | *Oncorhynchus mykiss* | Salmonidae | RBT |
| Smallmouth bass | *Micropterus dolomieu* | Centrarchidae | SMB |
| Tench | *Tinca tinca* | Cyprinidae | TENCH |
| Walleye | *Stizostedion vitreum* | Percidae | WAL |
| Yellow perch | *Perca flavescens* | Percidae | YP |

# Appendix H. Biological Data on Fish Samples

Table H - 1. Biological Data on Fish Samples Analyzed for PFCs by Waterbody.

| Waterbody | Species | Collect Date | Sample Number (muscle tissue) | Sample Number (liver tissue) | Total Length (mm) | Weight (gm) | Age |
|---|---|---|---|---|---|---|---|
| Entiat River | Rainbow trout | 7/28/2008 | 90100302 | 90100317 | 213 | 95 | 5 |
| | | 7/28/2008 | 90100302 | 90100317 | 211 | 104 | 4 |
| | | 7/28/2008 | 90100302 | 90100317 | 223 | 122 | 5 |
| | Brook trout | 7/28/2008 | 90100303 | 90100318 | 177 | 62 | 3 |
| | | 7/28/2008 | 90100303 | 90100318 | 109 | 88 | 4 |
| F.D.R. Lake | Smallmouth bass | 11/6/2008 | 90100315 | 90100330 | 269 | 276 | 2 |
| | | 11/6/2008 | 90100315 | 90100330 | 265 | 264 | 2 |
| | | 11/6/2008 | 90100315 | 90100330 | 260 | 253 | 2 |
| | | 11/6/2008 | 90100315 | 90100330 | 265 | 288 | 2 |
| | | 11/6/2008 | 90100315 | 90100330 | 271 | 284 | 2 |
| | Walleye | 11/6/2008 | 90100314 | 90100329 | 341 | 304 | 2 |
| | | 11/6/2008 | 90100314 | 90100329 | 345 | 297 | 2 |
| | | 11/6/2008 | 90100314 | 90100329 | 322 | 257 | 2 |
| | | 11/6/2008 | 90100314 | 90100329 | 370 | 371 | 2 |
| | | 11/6/2008 | 90100314 | 90100329 | 334 | 302 | 2 |
| Lake Washington | Largemouth bass | 10/23/2008 | 90100307 | 90100322 | 218 | 136 | 1 |
| | | 10/23/2008 | 90100307 | 90100322 | 221 | 142 | 1 |
| | | 10/23/2008 | 90100307 | 90100322 | 233 | 159 | 1 |
| | | 10/23/2008 | 90100307 | 90100322 | 211 | 125 | 1 |
| | | 10/23/2008 | 90100307 | 90100322 | 192 | 91 | 1 |
| | Yellow perch | 10/23/2008 | 90100308 | 90100323 | 190 | 72 | 2 |
| | | 10/23/2008 | 90100308 | 90100323 | 193 | 75 | 2 |
| | | 10/23/2008 | 90100308 | 90100323 | 212 | 99 | 2 |
| | Peamouth | 10/23/2008 | 90100309 | 90100324 | 292 | 243 | 7 |
| | | 10/23/2008 | 90100309 | 90100324 | 264 | 157 | 5 |
| | | 10/23/2008 | 90100309 | 90100324 | 301 | 225 | 7 |
| | | 10/23/2008 | 90100309 | 90100324 | 322 | 295 | 11 |
| | | 10/23/2008 | 90100309 | 90100324 | 304 | 284 | 8 |
| | Largescale sucker | 10/23/2008 | 90100310 | 90100325 | 440 | 1018 | 8 |
| | | 10/23/2008 | 90100310 | 90100325 | 455 | 1052 | 9 |
| | | 10/23/2008 | 90100310 | 90100325 | 491 | 1284 | 8 |
| | | 10/23/2008 | 90100310 | 90100325 | 505 | 1390 | 11 |
| Lower Columbia River | Largemouth bass | 10/20/2008 | 90100305 | 90100320 | 204 | 132 | 1 |
| | | 10/20/2008 | 90100305 | 90100320 | 211 | 109 | 1 |
| | | 10/20/2008 | 90100305 | 90100320 | 222 | 165 | 1 |
| | | 10/20/2008 | 90100305 | 90100320 | 215 | 141 | 1 |
| | | 10/20/2008 | 90100305 | 90100320 | 190 | 93 | 1 |
| | Largescale sucker | 10/20/2008 | 90100306 | 90100321 | 490 | 1137 | 12 |
| | | 10/20/2008 | 90100306 | 90100321 | 475 | 1002 | 10 |
| | | 10/20/2008 | 90100306 | 90100321 | 495 | 1089 | 10 |
| | | 10/20/2008 | 90100306 | 90100321 | 414 | 805 | 11 |

| Waterbody | Species | Collect Date | Sample Number (muscle tissue) | Sample Number (liver tissue) | Total Length (mm) | Weight (gm) | Age |
|---|---|---|---|---|---|---|---|
| Quinault River | Cutthroat trout | 7/29/2008 | 90100301 | 90100316 | 305 | 223 | 4 |
| | | 7/29/2008 | 90100301 | 90100316 | 285 | 176 | 3 |
| | | 8/28/2008 | 90100301 | 90100316 | 235 | 105 | 3 |
| | | 8/28/2008 | 90100301 | 90100316 | 280 | 194 | 3 |
| Spokane River at Nine Mile Dam | Largescale sucker | 10/1/2008 | 90100304 | 90100319 | 485 | 1198 | 10 |
| | | 10/1/2008 | 90100304 | 90100319 | 486 | 1410 | 7 |
| | | 10/1/2008 | 90100304 | 90100319 | 585 | 1904 | 11 |
| | | 10/1/2008 | 90100304 | 90100319 | 562 | 1943 | 13 |
| West Medical Lake | Pumpkinseed | 11/17/2008 | 90100311 | 90100326 | 150 | 89 | 3 |
| | | 11/17/2008 | 90100311 | 90100326 | 151 | 79 | 3 |
| | | 11/17/2008 | 90100311 | 90100326 | 152 | 85 | 3 |
| | | 11/17/2008 | 90100311 | 90100326 | 145 | 67 | 3 |
| | | 11/17/2008 | 90100311 | 90100326 | 148 | 77 | 3 |
| | Rainbow trout | 11/17/2008 | 90100312 | 90100327 | 385 | 529 | 1 |
| | | 11/17/2008 | 90100312 | 90100327 | 343 | 369 | 1 |
| | | 11/17/2008 | 90100312 | 90100327 | 429 | 703 | 1 |
| | | 11/17/2008 | 90100312 | 90100327 | 352 | 477 | 1 |
| | Tench | 11/17/2008 | 90100313 | 90100328 | 320 | 480 | 3 |
| | | 11/17/2008 | 90100313 | 90100328 | 321 | 509 | 3 |
| | | 11/17/2008 | 90100313 | 90100328 | 334 | 567 | 4 |

# Appendix I. Flow Data and Sampling Dates

Flow data were compiled from the USGS National Weather Information System (retrieved from http://waterdata.usgs.gov/wa/nwis on 1/22/09) and the University of Washington's Columbia River Data Access in Real Time website (retrieved from www.cbr.washington.edu/dart/ on 1/22/09). At the time of data retrieval, flow data were considered provisional and subject to change.

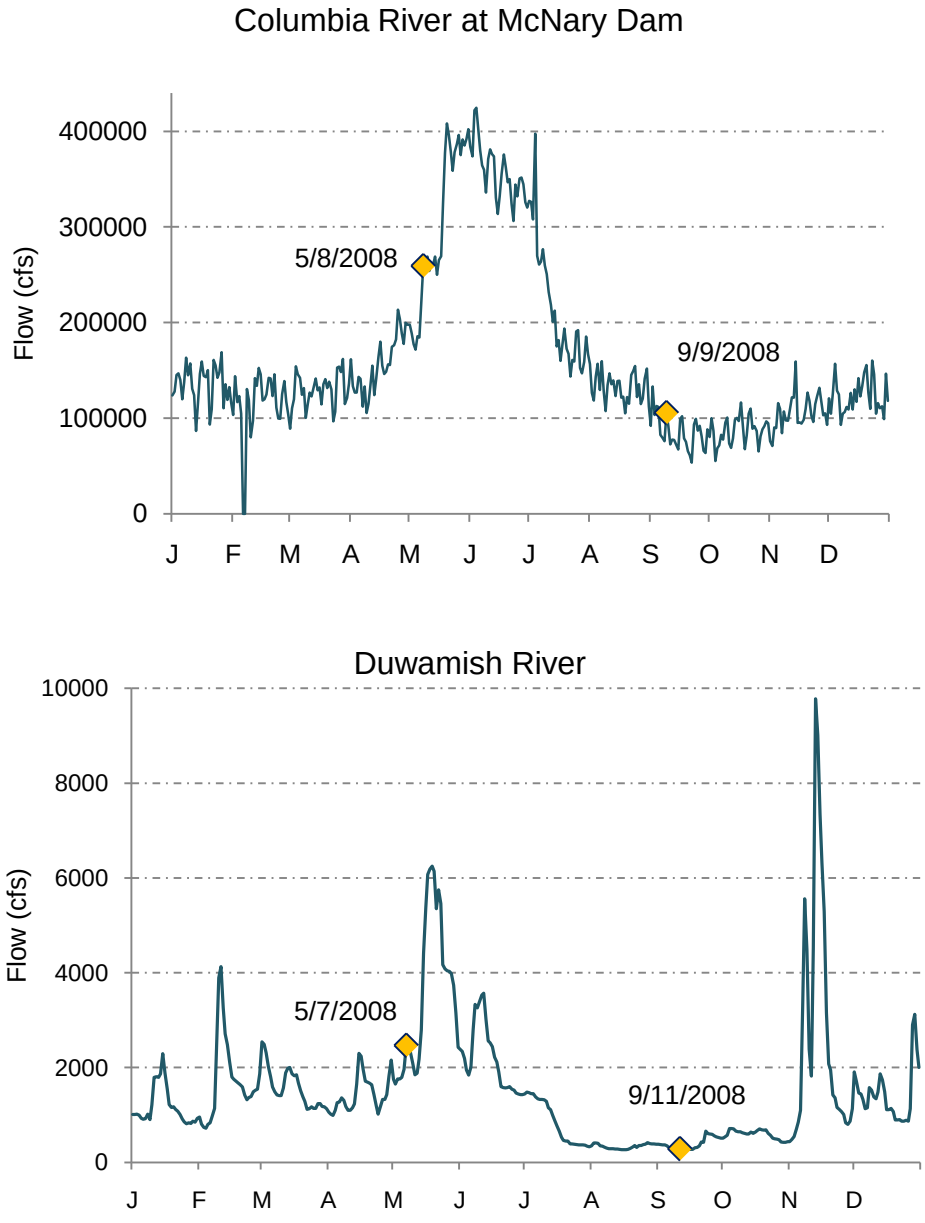


Figure I-1. Flow Data and Sampling Dates for the 2008 PFC Survey.

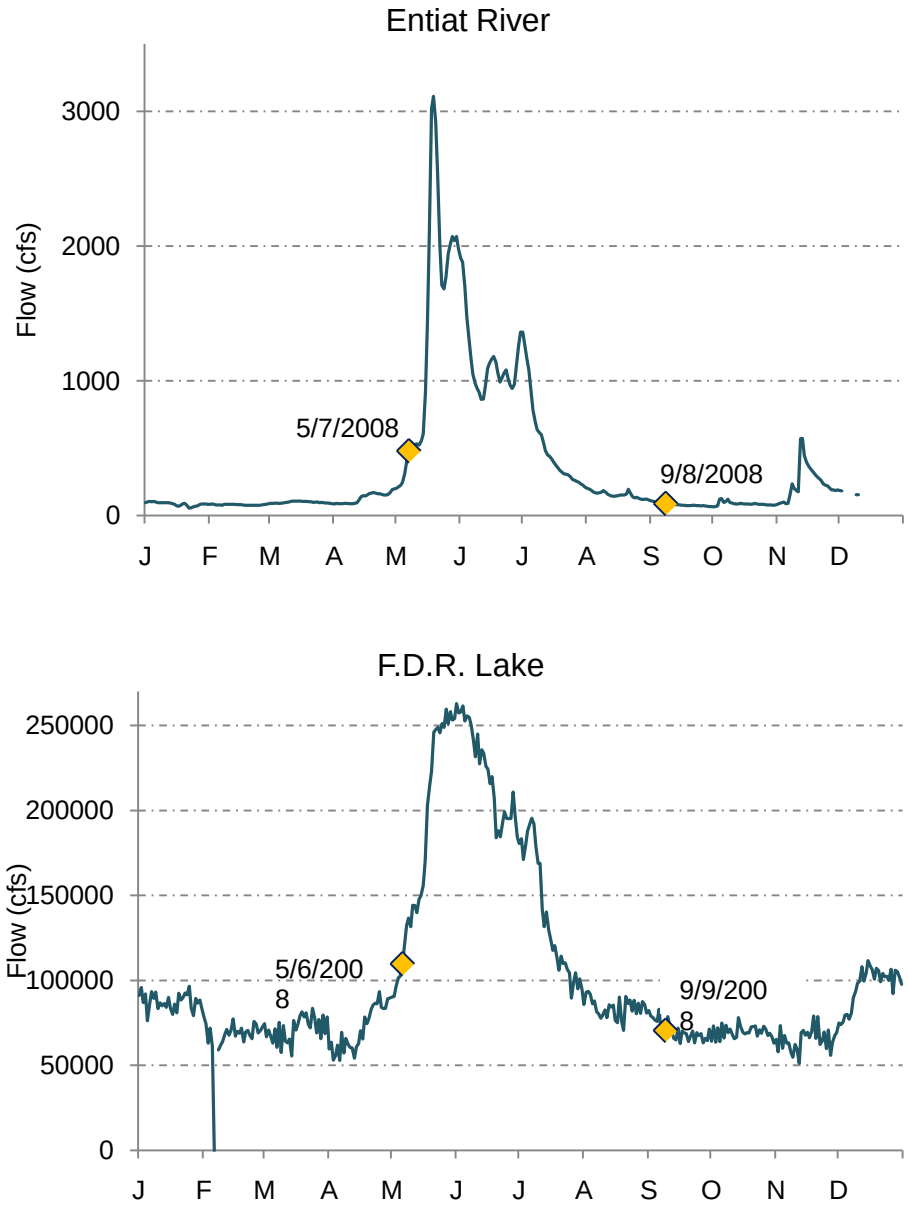


Figure I-1 (continued). Flow Data and Sampling Dates for the 2008 PFC Survey.

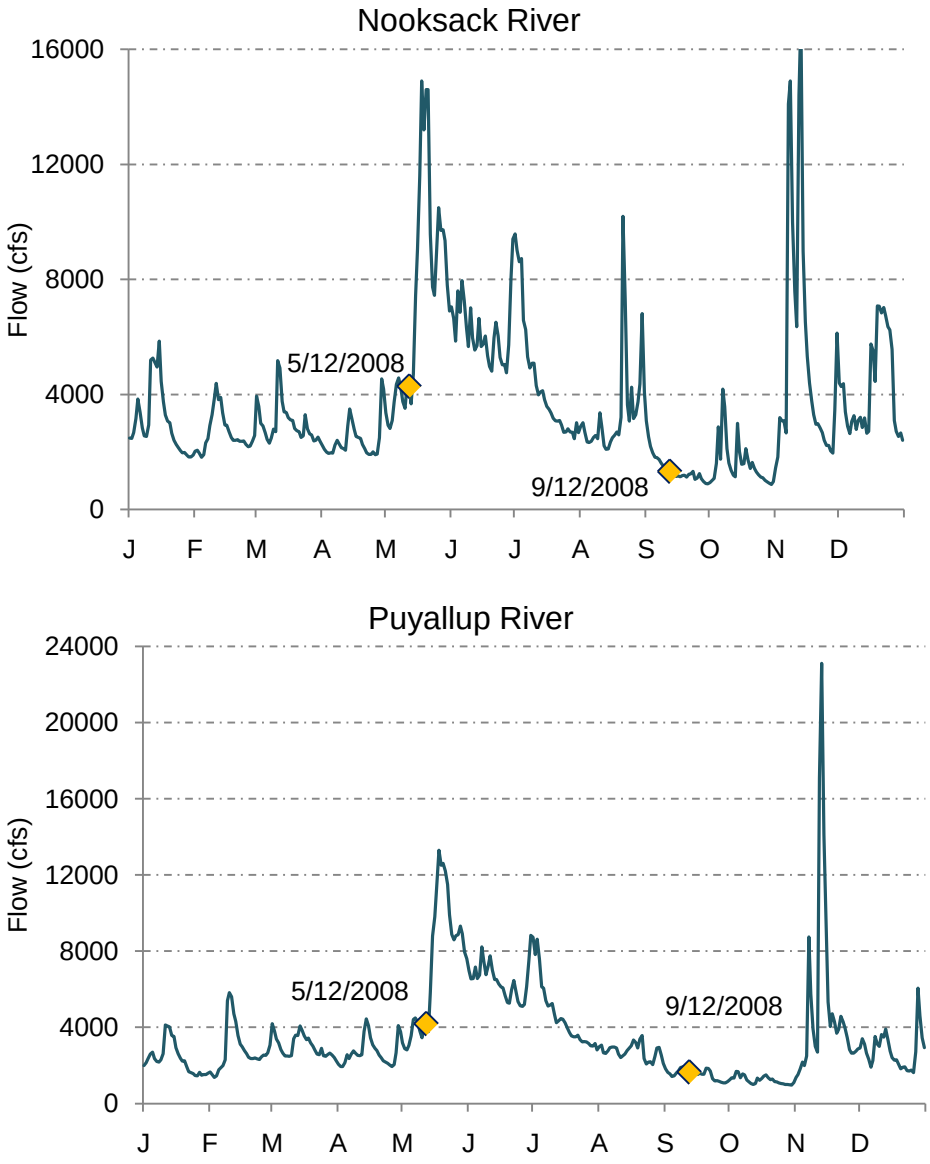


Figure I-1 (continued). Flow Data and Sampling Dates for the 2008 PFC Survey.

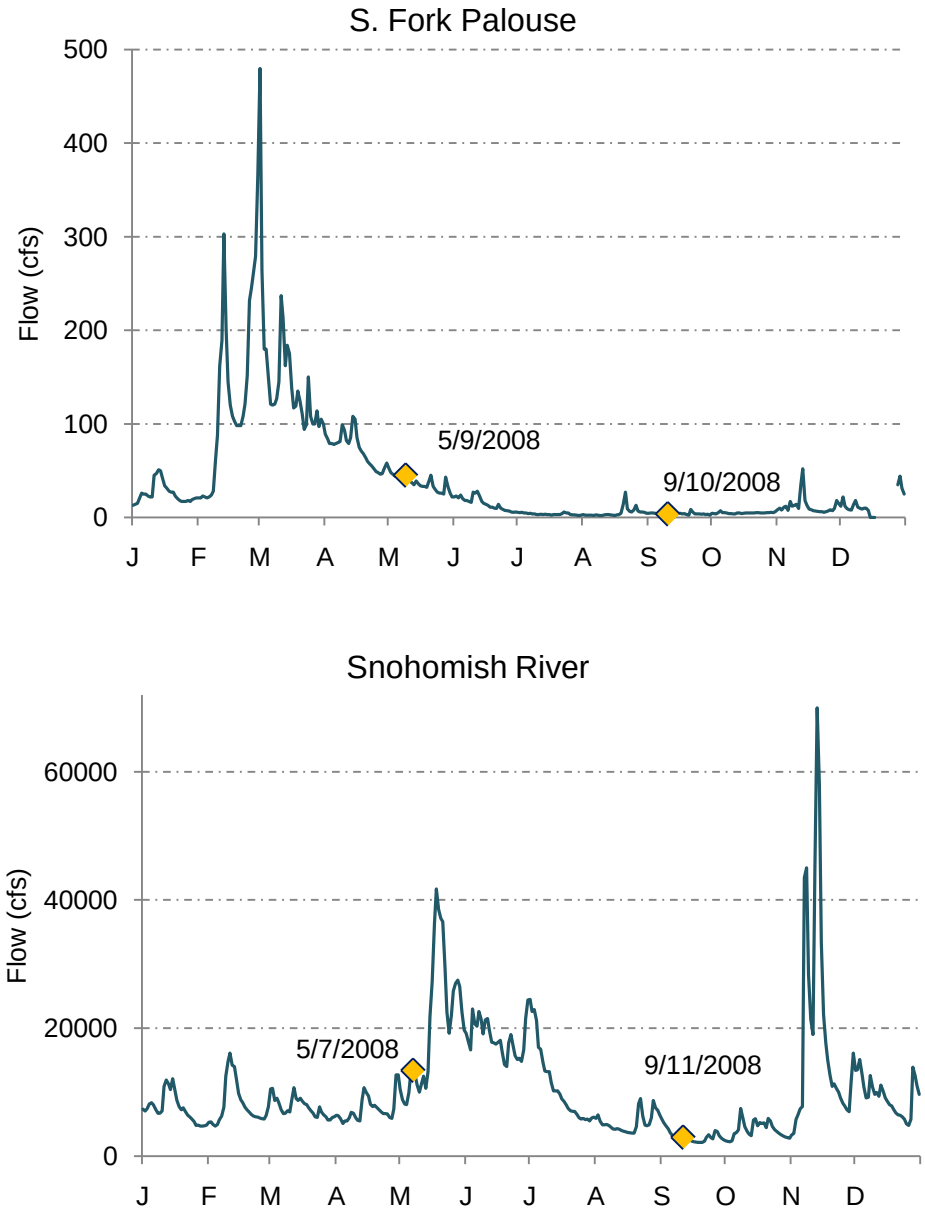


Figure I-1 (continued). Flow Data and Sampling Dates for the 2008 PFC Survey.

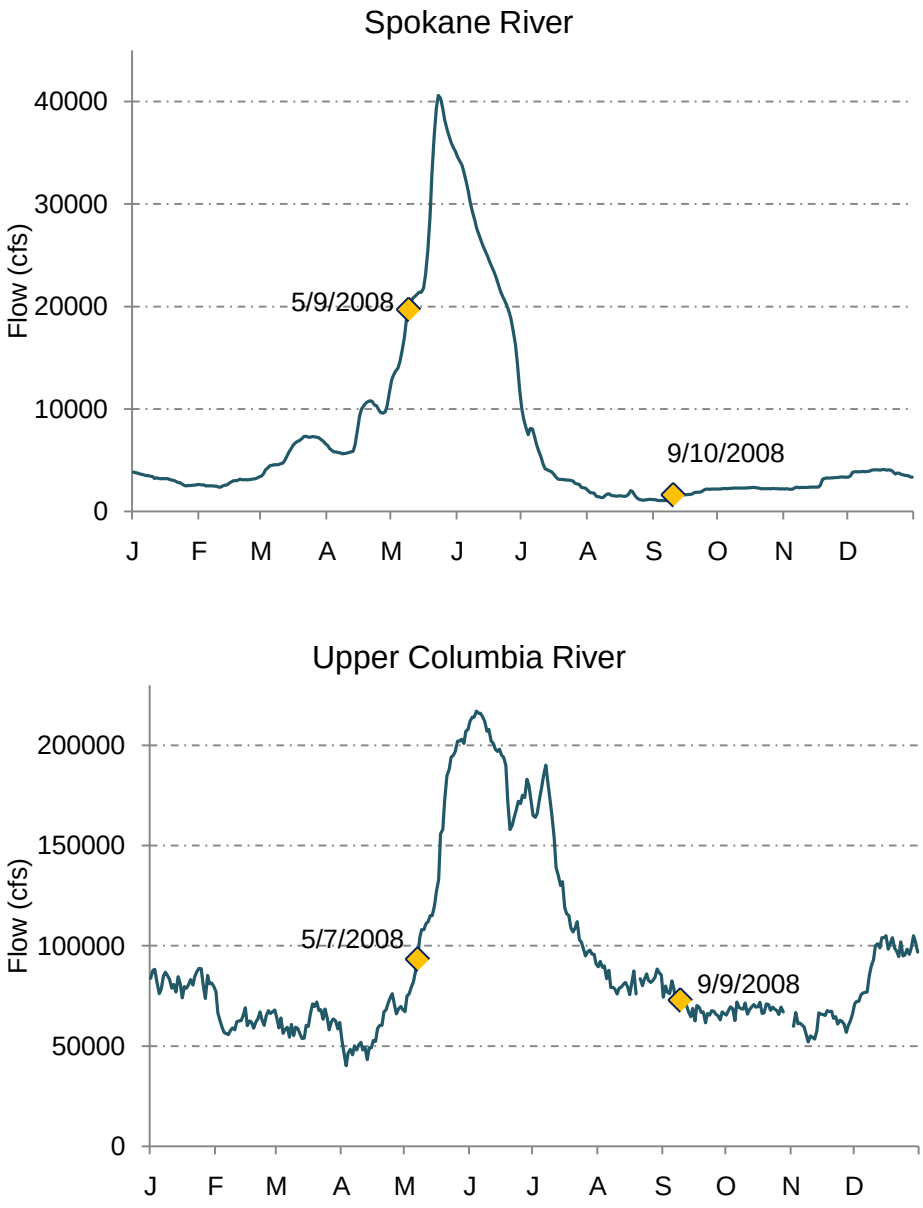


Figure I-1 (continued). Flow Data and Sampling Dates for the 2008 PFC Survey.