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Flame Retardants in Ten Washington State Lakes, 2017-2018

by
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Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area.

Study Location	WRIA	HUC
Lake Meridian	9	17110013
Lake Ozette	20	17100101
Lake Spokane	54	17010307
Lake Stevens	7	17110011
Lake Washington	8	17110012
Lake Whatcom	1	17110004
Mayfield Lake	26	17080005
Spanaway Lake	12	17110019
Vancouver Lake	28	17080003
West Medical Lake	43	17020013

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Abstract

During 2017-2018, the Washington State Department of Ecology (Ecology) conducted a study to characterize a broad range of flame retardants in the environment. Many flame retardants are of concern due to their persistence and adverse health effects, and little is known about their occurrence in Washington's environment.

In fall 2017 and spring 2018, Ecology collected surface water from 10 lakes for analysis of organophosphate flame retardants (OPFRs) and polybrominated diphenyl ethers (PBDEs). Bottom sediments from each of the 10 lakes were collected in spring 2018 for analysis of OPFRs, novel brominated flame retardants (NBFRs), Dechlorane analogs, and PBDEs. Ecology also collected freshwater fish from three of the lakes (Ozette, Spokane, and Washington) in fall 2017 for analysis of NBFRs, Dechlorane analogs, and PBDEs. Sample types and lakes were selected to maximize the potential for detecting target flame retardants.

OPFRs were present in the majority of lakes sampled. Tris (1-chloro-2-propyl) phosphate (TCPP) was the dominant OPFR in both water and sediments, with detected concentrations of 13.3-188 ng/L in water and 120-388 ng/g dry weight (dw) in sediments. Concentrations and detection frequencies of OPFRs in the 10 lakes were generally comparable to other waterbodies in North America.

NBFRs and Dechlorane analogs were largely undetected in sediment and fish tissue samples. Analytical reporting limits for some of the compounds in sediments were likely too high to capture environmentally relevant levels. The fish sampled in this study did not contain NBFRs and Dechloranes that have been detected in other waterbodies of North America. The exception to this was tetrabromo-*o*-chlorotoluene (TBCT), which was tentatively identified in just over half of the fish samples at 0.72-7.08 ng/g wet weight (ww).

PBDEs were mostly undetected in surface water but were frequently detected in sediments and fish tissue. Total PBDE (T-PBDE) concentrations in sediments and fish tissue in detected samples were in the range of 0.367-48.6 dw and 0.18-78.8 ng/g ww, respectively.

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Introduction

Background

Flame retardants are a broad class of chemicals used in consumer products, such as furniture and electronics, to prevent or slow the spread of fire. A group of these chemicals, polybrominated diphenyl ethers (PBDEs), were widely used in consumer and industrial products until regulatory restrictions were enacted in the 2000s. The restrictions came after growing concern that PBDEs were accumulating and dramatically increasing in people and the environment (Abbasi et al., 2015). Washington State developed a Chemical Action Plan (CAP) for the group of chemicals in 2006 (Ecology and DOH, 2006).

Chemical manufacturers in the U.S. voluntarily stopped production of two commercial formulations of PBDEs (Penta- and Octa-BDE) by 2004 and phased out most uses of Deca-BDE in 2012. Penta- and Octa-BDE formulations were primarily used in furniture and upholstery, and Deca-BDE was typically used in electronic housings. Following the phase out of PBDEs, manufacturers used replacement chemicals to continue to meet flammability standards. These replacement chemicals include halogenated flame retardants (containing bromine and/or chlorine bonded to carbon), organophosphate flame retardants (OPFRs; phosphate esters that sometimes contain bromine or chlorine), inorganic, and nitrogen-based compounds. Halogenated flame retardants include PBDEs, non-PBDE novel brominated flame retardants (NBFRs), and Dechlorane analogs.

PBDEs are persistent, bioaccumulative, and toxic (PBT) chemicals; many alternative flame retardants are expected to have similar physical-chemical properties. Zhang et al. (2016) estimated that about half of the halogenated and organophosphate flame retardants they modeled are similar to PBDEs and have a persistence and/or long-range transport potential of medium to high level of concern. Research has shown that several current-use halogenated flame retardants have the potential to bioaccumulate (Wu et al., 2011). OPFRs are much less bioaccumulative, but there are concerns about their persistence and toxicity (van der Veen and de Boer, 2012; Wei et al., 2015). The toxic effects of alternative flame retardants are still largely unknown. Several OPFRs are suspected to be carcinogenic and have neurotoxic, reproductive, and hormonal effects (Wei et al., 2015).

Many of the replacement flame retardants are not well-studied in the environment, though research in the last few years has grown considerably. Recent studies have detected alternative halogenated flame retardants and OPFRs in air, surface water, groundwater, sediments, and wildlife (Iqbal et al., 2017; Greaves and Letcher, 2017; Pantelaki and Voutsas, 2019).

Environmental Sources and Pathways

Major sources of flame retardants to the environment include manufacturing emissions and releases through consumer and industrial products (Wei et al., 2015). Flame retardants are used in a wide range of commercial products and may leach out of the product over time. This release occurs through volatilization, abrasion, and leaching during the use, disposal, or recycling of products (Wei et al., 2014). Environmental pathways include wastewater treatment plant (WWTP) effluent and septic systems, stormwater, and atmospheric deposition. Flame retardants

are often present in indoor dust (Dodson et al., 2012; Stapleton et al., 2009; Stapleton et al., 2008), which then enters the wastewater-stream through gray water (Schreder and La Guardia, 2014). Halogenated flame retardants (including PBDEs) and OPFRs are not completely removed through conventional WWTP processes, and thus are released to the aquatic environment in effluent (Kim et al., 2017). Wastewater discharge is thought to be the predominant pathway of OPFRs to surface water and groundwater, while wash-out from the atmosphere via precipitation may be important in remote areas (Wei et al., 2014). Urban stormwater has been shown to be a significant pathway of flame retardants, particularly during the wet season (Sutton et al., 2019).

In Washington State, where no known flame retardant manufacturing facilities exist, the predominant sources are likely related to the use and disposal of products. The major environmental pathways are likely WWTP effluent, stormwater, and atmospheric deposition.

Data on non-PBDE flame retardants in Washington's environment are limited. To help fill this data gap, Ecology carried out an exploratory study in 2017/2018 to evaluate the occurrence and concentrations of a large suite of flame retardants in 10 Washington State lakes. Data presented in this report will support agency prioritization of chemicals to be considered for efforts to reduce toxics in Washington State.

Study Design and Goals

In 2017 and 2018, Ecology collected environmental samples for analysis of flame retardants from the 10 lakes shown in Figure 1. Analyte suites and sample types were targeted to the media types where contamination potential was thought to be greatest. Ecology collected discrete surface water grab samples in fall 2017 and spring 2018 for analysis of OPFRs and PBDEs. Surface sediments were collected from the 10 sites in spring 2018 for analysis of OPFRs, NBFRs, Dechlorane analogs, and PBDEs. Freshwater fish of multiple species were collected from a subset of three of the lakes (Ozette, Spokane, and Washington) for analysis of NBFRs, Dechlorane analogs, and PBDEs. Table 1 displays the analyte group and timing of sample collection. The Quality Assurance (QA) Project Plan outlines the study goals, objectives, and methods in more detail (Mathieu, 2017).

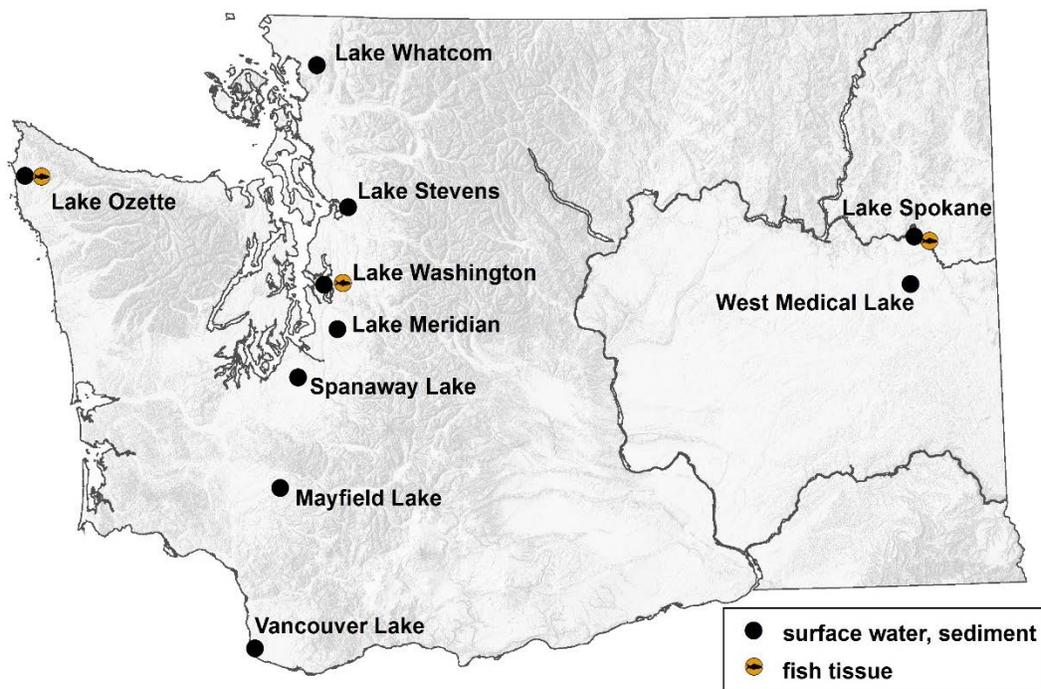


Figure 1. Study Locations for Surface Water, Sediment, and Fish Tissue Sampling.

Table 1. Timing of Sample Collection by Matrix and Analyte Group.

Analyte Group	Surface Water Samples Collected	Sediment Samples Collected	Fish Tissue Samples Collected
OPFRs	10/2017; 05/2018	05/2018	---
NBFRs, Decs	---	05/2018	10/2017
PBDEs	10/2017; 05/2018	05/2018	10/2017

OPFR = organophosphate flame retardant, PBDE = polybrominated diphenyl ether, NBFR = novel brominated flame retardant, Decs = Dechlorane analogs

Study Locations

This study was an exploratory investigation into potential flame retardant contamination in Washington lakes. Therefore, study sites were targeted to maximize the potential for detecting flame retardants. Ten lakes were selected for this study based on (1) contamination potential, (2) range of possible sources, (3) range of waterbody size and physical features, (4) access for sampling, and (5) historical data on legacy flame retardants. Table 2 displays the study sites, along with potential sources of flame retardants to the lakes.

Lake Ozette was selected as a reference site for this study, as the source of flame retardants in the lake are likely limited to atmospheric deposition. Lake Whatcom and Mayfield Lake represent waterbodies with a mix of contamination potential; with large undeveloped watersheds, local source inputs may be diluted in these waterbodies. Lake Spokane's watershed also contains a mix of land uses and potential sources in its watershed, but the river upstream has been identified as a hot spot of legacy flame retardant (PBDE) contamination (Johnson et al., 2006; Serdar and Johnson, 2006; Furl and Meredith, 2010).

Table 2. Waterbody Descriptions.

Study Location	County	Elevation (ft)	Watershed Area (acres)	Surface Area (acres)	WA: SA	Max Depth (ft)	Watershed Land Use	Potential Environmental Pathways
Lake Meridian	King	370	742	150	4.9	90	urban	stormwater
Lake Ozette	Clallam	29	49,600	7,300	6.8	320	forested	atmospheric deposition
Lake Spokane	Spokane	1,530	4,250,000	45,200	94	180	forested/brush /urban	stormwater/WWTP effluent
Lake Stevens	Snohomish	210	4,370	1,040	4.2	155	urban	stormwater
Lake Washington	King	20	300,000	21,500	14	214	urban	stormwater
Lake Whatcom	Whatcom	315	35,780	5,000	7.2	330	forested/ residential	stormwater/atmospheric deposition
Mayfield Lake	Cowlitz	450	896,000	2,200	407	190	forested/ residential	WWTP effluent/atmospheric deposition
Spanaway Lake	Pierce	320	10,880	280	39	28	urban	stormwater
Vancouver Lake	Clark	9.0	---	2,300	---	12	urban	stormwater
West Medical Lake	Spokane	2,420	1,178	220	5.4	35	brush steppe	WWTP effluent

WA:SA = watershed area to lake surface area ratio; WWTP = wastewater treatment plant

Methods

Sampling Collection and Preparation

Surface Water

Discrete surface water samples were collected from the deepest part of the lake or basin, following Ecology SOP EAP015: *Manually Obtaining Surface Water Samples* (Joy, 2006). Samples were collected 5-20 cm below the water surface in laboratory-provided pre-cleaned 1 L amber glass bottles using ‘clean hands, dirty hands’ protocol (Mathieu, 2017). Field staff used a polyethylene and stainless steel telescopic pole sampler to collect water samples at least 3 feet out from the bow of the research vessel. Following sample collection, sample bottles were placed inside plastic bags with zip-lock tops and stored in a cooler on ice until field staff returned to Ecology headquarters. Field staff measured and recorded water pH, conductivity, and temperature immediately following surface water collection. At headquarters, water samples were stored in a temperature-controlled, walk-in cooler and then shipped on ice to the laboratory within analytical holding times.

Sediments

Bottom sediments from each study location were collected using a petite ponar following Ecology SOP EAP040: *Obtaining Freshwater Sediment Samples* (Blakley, 2008). Field staff attempted to collect sediments from the deepest part of the lake or basin, as outlined in the QA Project Plan, at each site. However, at Lake Ozette, Lake Stevens, and Lake Whatcom the water column depth at the sampling site was too deep for field equipment; therefore, an alternative shallower site was used instead. See Appendix D for coordinates of sampling collections.

Sediment samples consisted of a composite of three separate petite ponar grabs from each site (within a 10-m radius). With each successful grab, field staff siphoned off overlying water and collected the top 0-2 cm of sediment, not touching the side of the sampler, with a stainless-steel spoon and transferred the sediment to a large stainless-steel mixing bowl. The three grab samples were then homogenized into a uniform consistency and color in the field, and subsampled into glass jars for analysis of flame retardants, and into plastic jars for total organic carbon (TOC). Sample jars were placed on ice in coolers in the field, then stored inside a temperature-controlled, walk-in freezer at Ecology headquarters. Frozen samples were then shipped to the laboratory.

Fish Tissue

Fish were collected from Lake Ozette, Lake Spokane, and Lake Washington via electrofishing, following Ecology SOP EAP009: *Collection, Processing, and Preservation of Finfish Samples* (Sandvik, 2014a). Two composites of the following three species were obtained: largemouth bass (Lake Ozette and Lake Washington), northern pikeminnow (Lake Ozette and Lake Spokane), and largescale sucker (Lake Spokane and Lake Washington). Fish lengths and weights were recorded in the field, and individuals were double-wrapped in aluminum foil with sample tags. Wrapped fish were stored in plastic bags on ice in coolers until transport to Ecology headquarters. Field staff collected all fish under scientific collection permits from the

Washington Department of Fish and Wildlife (WDFW), United States Fish and Wildlife Service (USFWS), and National Oceanographic Atmospheric Administration (NOAA).

Ecology staff processed and homogenized individual fish into 3-5 fish skin-on fillet composite samples at Ecology headquarters, following SOP EAP007: *Resecting Finfish Whole Body, Body Parts, or Tissue Samples* (Sandvik, 2014b). Fish were descaled, filleted, and ground three times or more until a consistent color and texture was reached. Homogenized samples were placed in laboratory-provided, pre-cleaned glass bottles, frozen, and sent to the laboratory with blue ice. After the fillets were removed, the sex of the fish was determined and recorded. Otoliths, scales, or opercula were removed during processing and sent to WDFW for age determination. Appendix C presents ancillary fish data collected with the samples.

Laboratory Analysis

Ecology's Manchester Environmental Laboratory (MEL) conducted all laboratory analyses with the exception of NBFRs and Dechlorane analogs in fish tissue, which was done by AXYS SGS. Samples were extracted and analyzed following the methods outlined in Table 3. Appendix E presents a complete list of compounds analyzed for this study. The OPFR analyte list contains organophosphate esters that function as flame retardants and/or plasticizers. For simplicity, the term OPFR is used for this analyte suite in this report.

MEL used a QuEChERS extraction method on sediment samples before OPFR, NBFR, and Dechloranes analysis. This extraction method is based on partitioning the sample by salting-out and creating an equilibrium between an aqueous and an organic layer. After extraction salts are added, the sample is shaken and centrifuged, and the sample is divided into three layers: soil-aqueous-acetonitrile. The acetonitrile is removed as the extract, then it is concentrated and cleaned up with dispersive solid phase extraction. Other matrix types were extracted by solid phase extraction (surface waters) and Soxhlet (PBDEs in sediment and all fish tissue) following standard EPA methods or AXYS in-house methods.

MEL modified existing EPA SW 8000 series methods, listed in Table 3, for analysis of OPFRs, NBFRs, and Dechlorane analogs. Isotopic dilution was used for all analyses other than PBDEs. PBDEs were analyzed following standard EPA methods.

Table 3. Laboratory Analysis Methods.

Matrix	Analyte	Median Reporting Limits*	Sample Prep Method	Extraction Description	Analytical Method	Analytical Instrument
Surface water	OPFRs	0.5-25 ng/L	SW 3535A	Solid Phase Extraction	SW8321BM	LC-MS/MS; isotopic dilution
	PBDEs	2.0-10 ng/L	SW 3535A	Solid Phase Extraction	SW8270D SIM	GC-MS
Sediment	OPFRs	2.1-17 ng/g dw	AOAC 2007.01	QuEChERS, dSPE cleanup	SW8321BM	LC-MS/MS; isotopic dilution
	NBFRs, Decs	1.4-11 ng/g dw	AOAC 2007.01	QuEChERS, dSPE cleanup	SW8270D	GC-MS/MS; isotopic dilution
	PBDEs	1.2-5.8 ng/g dw	EPA 3541	Soxhlet	SW8270D SIM	GC-MS
	TOC	0.1%	---	---	---	PSEP TOC
Fish tissue	NBFRs, Decs	0.2-46 ng/g ww	AXYS MLA-108	Soxhlet, cleanup by liquid-liquid extraction, GPC	AXYS MLA-108	GC-ECNI-MS; isotopic dilution
	PBDEs	0.2-1.2 ng/g ww	EPA 3541	Soxhlet	SW8270D SIM	GC-MS
	Lipids	0.10%	EPA 3541	Soxhlet	MEL SOP 730009	---

OPFR = organophosphate flame retardant, PBDE = polybrominated diphenyl ether, NBFR = novel brominated flame retardant, Decs = Dechlorane analogs, TOC = total organic carbon, LC = liquid chromatography, MS = mass spectrometry, GC = gas chromatography, PSEP TOC = Puget Sound Estuary Program, dSPE = dispersive solid phase extraction, GPC = gel permeation chromatography, ECNI = electron capture negative ion, SIM = selective ion monitoring, MEL = Manchester Environmental Laboratory, SOP = standard operating procedure.

Data Quality

MEL reviewed all laboratory results for this project to ensure analyses were conducted in accordance with the method, with no errors or omissions. Results of analyses conducted by MEL were reviewed by MEL's Organics Unit supervisor. MEL's Quality Assurance (QA) coordinator provided a stage 4 data validation review of the data generated by AXYS SGS. MEL provided written case narratives describing the analytical methods used, holding times, initial and ongoing calibrations, and results of quality control (QC) tests analyzed with each batch. All QC tests outlined in the QAPP were conducted, including laboratory control samples, method blanks, laboratory duplicates, matrix spikes, and matrix spike duplicates with each batch. Surrogates were analyzed with each sample for all analyses but PBDEs.

The project manager for this 2017-2018 study assessed the usability of the data after reviewing laboratory case narratives, final data packages, and field logs. All data were deemed usable as qualified for this study. All results between the method detection limit and method reporting limit are qualified "J" as estimated concentrations. Data generally met measurement quality objectives (MQOs) outlined in the QAPP. Appendix A provides a detailed summary of the QC test results and a comparison to MQOs.

Method Blanks

Several target OPFR analytes were detected in the method blanks for surface water and sediment analyses. Associated samples were considered not detected if results were less than 10 times the method blank contamination. The method blank analyzed with the fall 2017 surface water samples batch contained levels of TEBP, TBP, TPP, and TCPP that were well above the reporting limit; this substantially impacted the ability to measure those analytes in the environmental samples. MEL determined the source of the contamination after the fall water analysis and took action to address the problem for OPFR analyses of water and sediments in the following spring. Several OPFR analytes were still present in the spring method blanks, though concentrations were lower and typically below the method reporting limit.

Field Replicates and Blanks

One field replicate per sampling event (10-12 samples) was collected for surface water and sediment analyses. The majority of the field replicate results were either nondetect or less than five times the reporting limit. Four out of six paired results were within MQOs for relative percent difference (RPD) between the native sample and replicate sample (< 40%). Two RPDs were greater than 40%: PBDE-099 in sediments (43% RPD) and tricresyl phosphate (TCrP) in sediments (116%). RPDs for laboratory control sample (LCS) duplicates for those batches had RPDs of 10% and 0.5%, respectively. The difference in field replicate results for those samples were considered to be due to inhomogeneity of the sample matrix.

Field blanks were also collected with each surface water sampling event. Lab-provided blank water in 1-L jars were brought into the field and attached to the sampling device, and then blank water was poured into a new sample jar in the same manner as field samples. No OPFRs or PBDEs were detected above reporting limits in the fall water field blanks. In the spring sampling

event, one compound was detected: TEP at 6.52 ng/L. The field sample and field replicate collected at the same site (Lake Meridian) were both nondetects at reporting limits of 0.79 and 1.2 ng/L, and no further action was taken. All other TEP results from the spring sampling were similar to fall sampling results.

Results and Discussion

Sampling results, as well as comparisons with other findings, are presented by analyte group in the following sections. Appendix B provides all laboratory results for the sampling events. Summed, or total (T-), values and summary statistics include detected compounds only. Results qualified as estimates (“J”) are included in summed values and statistics.

Organophosphate Flame Retardants

Surface Water

Thirteen OPFRs were analyzed in surface water samples collected in fall 2017 and spring 2018. Table 4 and Figure 2 summarize results of the detected compounds.

In the fall water samples, TDCPP was the most commonly detected OPFR (80% of samples), followed by TCEP (70%) and TEP (50%). V6 was detected in two samples (20%) and TCPP and TEHP were each detected in only one sample. However, the low detection frequency for TCPP in the fall water samples was due to the elevated reporting limit resulting from method blank contamination. In the spring water samples, TCEP and V6 were detected in 70% of samples, TEP and TCPP in 60%, TDCPP in 30%, and TBP in 10%.

In both fall and spring samples, TCPP was present in the highest concentrations of the OPFRs, ranging from 13.3 to 188 ng/L. In samples where it was detected, TCPP made up 55%-98% of the total OPFR concentration. Concentrations of TEP and TCEP were in the 1-50 ng/L range, each making up about a third or less of the T-OPFR concentration. TDCPP concentrations were consistently in the 2-10 ng/L range, and V6 was detected at concentrations of less than 2 ng/L.

Table 4. Statistical Summary of Detected OPFR Concentrations in Surface Water (ng/L).

Analyte	Fall Samples (n = 10)			
	Det. Freq.	Min. (ng/L)	Max. (ng/L)	Median (ng/L)
TCEP	70%	0.833	37.5	3.31
TCPP	10%	179 J	179 J	---
TDCPP	80%	1.79 J	11.4	5.27 J
TEHP	10%	1.93	1.93	---
TEP	40%	5.54	51.8	7.385
V6	20%	0.26 J	1.3 J	0.78 J
T-OPFRs	80%	1.89 J	281 J	12.3 J

Not detected: EHDPP, TBEP, TBP, TCrP, TDBPP, TPP, TPrP

Analyte	Spring Samples (n = 10)			
	Det. Freq.	Min. (ng/L)	Max. (ng/L)	Median (ng/L)
TBP	10%	12.1	12.1	---
TCEP	70%	0.666	28.6	1.54
TCPP	60%	13.3 J	188 J	46.4 J
TDCPP	30%	6.37 J	7.13 J	6.4 J
TEP	60%	1.37	43.3	6.4
V6	70%	0.113 J	1.52 J	0.937 J
T-OPFRs	80%	0.189 J	268 J	41.5 J

Not Detected: EHDPP, TBEP, TCrP, TDBPP, TEHP, TPP, TPrP

OPFRs were detected in all samples except for those collected from Mayfield Lake and Lake Ozette. The highest total (T-) OPFR concentrations in both sampling events came from West Medical Lake. West Medical Lake receives wastewater treatment plant effluent (reclaimed water) and has no inflow or outflow. The continued input of effluent and the long water residence time give this waterbody high potential for flame retardant contamination relative to the other sites. The next highest T-OPFRs were measured in Lake Washington, Lake Stevens, and Lake Meridian surface waters, indicating that urban stormwater is also an important pathway of OPFRs.

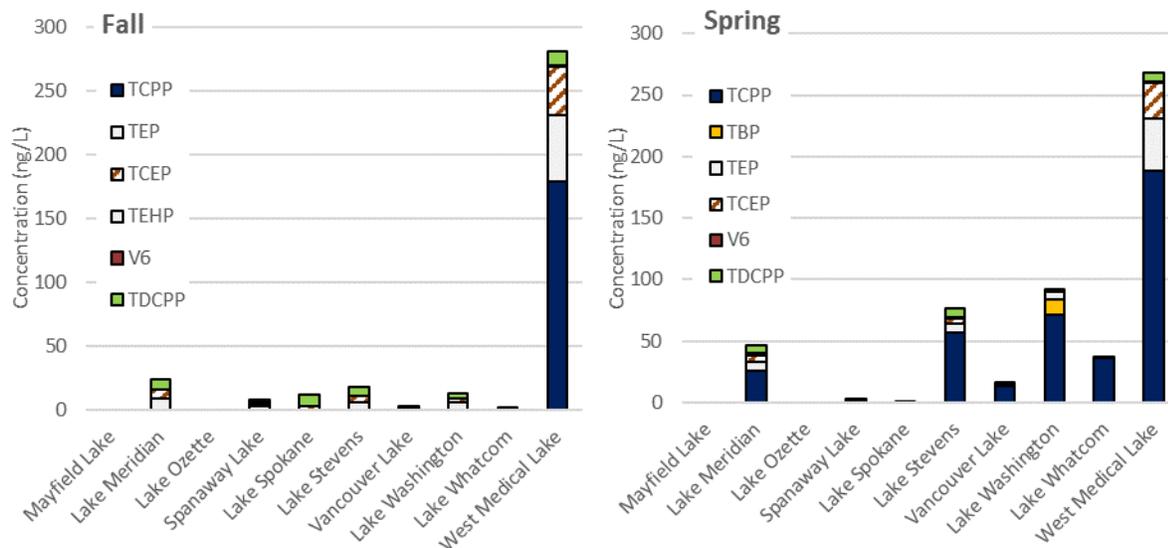


Figure 2. Summary of Detected OPFRs in Surface Water Samples.

Results below reporting limits excluded from figure.

Comparison to Other Studies

Table 5 presents OPFR concentrations from this study compared to other North American waterbodies. Similar to the Washington water samples in this study, TCPP was the dominant OPFR detected in surface waters collected from New York waterbodies and the San Francisco Bay (Kim and Kannan, 2018; Sutton et al., 2019), as well as Wisconsin stormwater (Burant et al., 2018). Detected TCPP concentrations in the Washington lakes were similar to the New York and San Francisco Bay samples, and about an order of magnitude higher than measured in the Great Lakes (Venier et al., 2014). TCPP was also frequently detected in U.S. rivers and reservoirs that serve as sources of drinking water at similar concentrations to the Washington lakes (Benotti et al., 2009).

TCEP was detected frequently in the Washington lakes, but at lower levels than other areas of the U.S. Median TCEP concentrations in New York rivers, New York lakes, and the San Francisco Bay were 14.6, 17.9, and 24 ng/L, respectively, compared to Washington's median of 1.8 ng/L (Kim and Kannan, 2018; Sutton et al., 2019). Maximum TCEP concentrations in the Washington lakes were about half those of New York waterbodies, San Francisco Bay, and Ontario streams and lakes (Kim and Kannan, 2018; Sutton et al., 2019; Hao et al., 2018). Benotti

et al. (2009) found TCEP in half of U.S. surface water drinking sources sampled, at concentrations in the 100-500 ng/L range.

TEP concentrations in the Washington lakes were within the range of TEP measured in waterbodies of New York and Ontario (Kim and Kannan, 2018; Hao et al., 2018), but higher than levels found in San Francisco Bay and the Columbia River (Sutton et al., 2019; Alvarez et al., 2014). The opposite was true for TDCPP, where concentrations and detection frequency in the current study were similar to those reported for the Great Lakes, but generally lower than the New York waterbodies and the San Francisco Bay.

In a non-targeted screening of a tributary to Lake Washington, Peter et al. (2019) identified TCPP and TBEP in the surface water and noted both were abundant during storm events. In our study, TCPP was detected in the surface water of Lake Washington, but not TBEP. In two studies of the Great Lakes area, TBEP was the most dominant OPFR found in surface waters (Venier et al., 2014; Hao et al., 2018). TBEP was not detected in any of the Washington lakes.

Table 5. Select OPFR Concentrations (ng/L) Measured in Surface Water from the U.S. and Canada Compared to Present Study Findings in Washington State Lakes.

Waterbody	Date	n =	TCPP (ng/L)		TCEP (ng/L)		TDCPP (ng/L)		TEP (ng/L)		Ref.
			DF	Range (median)	DF	Range (median)	DF	Range (median)	DF	Range (median)	
Washington lakes	2017/2018	20	35%	<LOQ-188 (< 25)	70%	< 0.5-37.5 (1.8)	55%	< LOQ-11.4	50%	< 0.5-51.8	This study
Lower Columbia River	2008-2010	8	38%	< 0.55-1.9 (< 0.55)	3%	< 0.1-2.3 (< 1.1)	13%	< 0.59-3.2 (<0.59)	0%	< 2.2	(1)
New York rivers	2016/2017	35	100%	3.3-214 (74.6*)	51%	< LOQ-79.5 (14.6*)	97%	< LOQ-86.7 (21.1*)	94%	< LOQ-24.8 (4.77*)	(2)
New York lakes	2016/2017	39	100%	4.67-329 (59.4*)	54%	< LOQ-123 (17.9*)	82%	< LOQ-159 (20.9*)	95%	< LOQ-92.1 (7.7*)	(2)
Great Lakes	2012	23	52%	< LOQ-17.1 (0.371)	52%	< LOQ-1.86 (0.05)	52%	< LOQ-6.66 (0.158)	---	---	(3)
Ontario urban streams and lakes	2014/2015	20	60%	<LOQ-2,010	20%	< LOQ-190	5%	130	15%	< LOQ-70	(4)
San Francisco Bay	2013	12	100%	46-2,900 (140)	100%	7.4-300 (24)	100%	14-450 (33)	33%	<0.2-3.2 (ND)	(5)

*mean. DF = detection frequency; LOQ = limit of quantitation. References: (1) Alvarez et al., 2014; (2) Kim and Kannan, 2018; (3) Venier et al., 2014; (4) Hao et al., 2018; (5) Sutton et al., 2019.

Sediment

Sediment samples were collected from the 10 lakes in spring 2018 and analyzed for 13 OPFRs. Table 6 summarizes the detected results, and Figure 3 shows the sediment OPFR concentrations by waterbody.

TEHP was detected most frequently in the sediment samples, with eight out of 10 samples containing TEHP above detection limits. TCrP was the second-most frequently detected OPFR in sediments, present in over half of the samples (60%). TBEP and V6 were detected in four samples (40%), and TBP, TPP, and TCPP were in three samples (30%). TCEP was detected in one sample.

TCPP was present in the highest amounts, with detected concentrations ranging from 120 to 388 ng/g dw. Maximum concentrations of TCrP and TBEP were 286 ng/g dw and 203 ng/g dw, respectively, but the majority of TCrP and TBEP results were in the range of 5-60 ng/g dw. TBP, TPP, and TCEP concentrations ranged from 10-35 ng/g dw. V6 was present in the lowest amounts, with all detections less than 5 ng/g dw.

Table 6. Statistical Summary of Detected OPFR Concentrations in Lake Sediments (ng/g dw).

Analyte	Sediment Samples (n = 10)			
	Det. Freq.	Min. (ng/g)	Max. (ng/g)	Median (ng/g)
TBEP	40%	24.4 J	203 J	46 J
TBP	30%	12.3	28.7	22
TCEP	10%	16.5 J	16.5 J	---
TCPP	30%	120	388	241
TCrP	60%	5.21 J	286 J	17.7 J
TEHP	80%	0.131 J	35.8	1.83 J
TPP	30%	10.5	33.9	25.9
V6	40%	1.27 J	4.92 J	3.4 J
T-OPFRs	90%	0.131 J	730 J	40.5 J

Not detected: EHDPP, TEP, TPrP, TDCPP, TDBPP

All sediments except for the sample collected from the reference site (Lake Ozette) contained OPFRs. Detected T-OPFRs in sediments ranged from 0.131-730 ng/g dw, with a median of 40.5 ng/g dw. Similar to water samples, the highest T-OPFR concentration among the sediment samples was found in the sample collected from West Medical Lake. Lake Meridian also had high OPFR levels, 644 ng/g dw, compared to the other nine sites. Three other urban lakes (Spanaway, Washington, and Stevens) had T-OPFR concentrations in the 40-200 ng/g dw range.

Lake Whatcom and Mayfield Lake sediments contained low levels of OPFRs (5.2 ng/g dw and 0.13 ng/g dw, respectively). These two lakes have large watersheds that are mostly forested and undeveloped, but receive some inputs of either urban/stormwater (Whatcom) or WWTP influent (Mayfield). Vancouver Lake and Lake Spokane both had trace levels of OPFRs, with T-OPFR concentrations of 0.2 ng/g dw. Both samples consisted of much coarser and sandier sediment than the other samples. Contaminant concentrations generally have an inverse relationship with sediment particle size, as larger sediment particles have lesser surface area for adsorption of contaminants relative to finer-grained sediments (Literathy et al., 1987). Total organic carbon was also relatively low in Lake Spokane (0.11%) and Vancouver Lake (1.57% samples); low TOC values are also associated with lower sediment contaminant concentrations (Nowell et al., 2013).

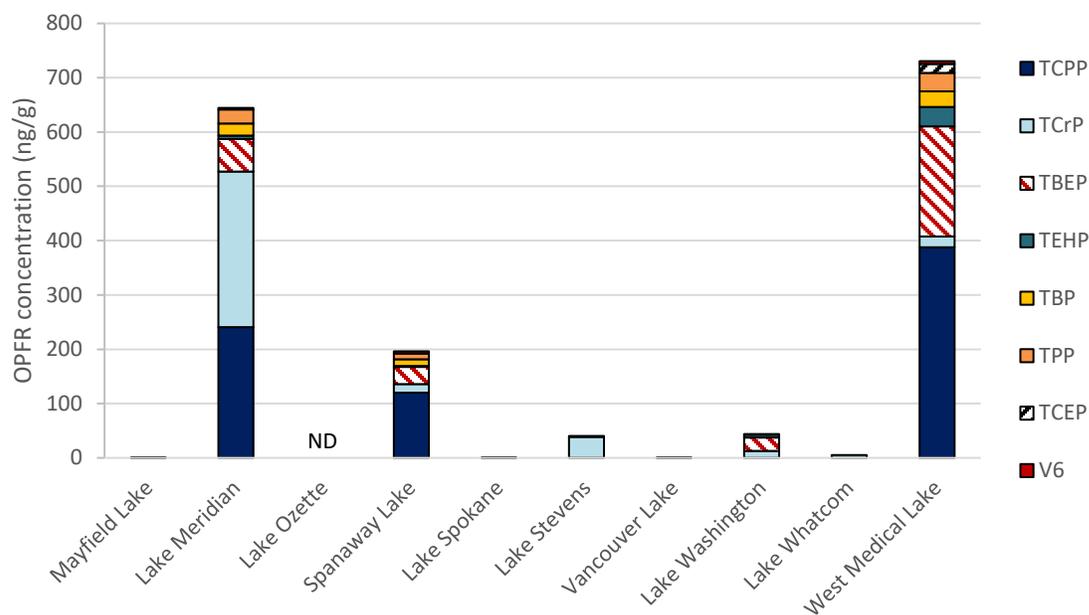


Figure 3. Detected OPFR Concentrations (ng/g dw) in Sediment Samples by Site, 2018. Results below reporting limits were excluded from figure. ND = all results nondetect for that site.

Comparison to Other Studies

A comparison of the current study’s OPFR concentrations with those from North America and European freshwater sediment is shown in Table 7. Other North American and European sediment studies have detected TCPP more frequently than our study, but at levels lower than our reporting limit (Cao et al., 2017; Sutton et al., 2017). While our present study detected TCPP in only three samples, it was present in the highest amounts and comparable to concentrations found in sediments collected from European waterbodies (Cristale et al., 2013; Guilivo et al., 2017; Leonards et al., 2011). Our TCPP concentrations were higher than TCPP reported in Great Lakes and San Francisco Bay sediments, though the San Francisco sediments were erosional, which are typically coarser than the depositional sediments analyzed in our study (Cao et al., 2017; Sutton et al., 2019). TCPP and TBEP have typically been observed as the most abundant and prevalent OPFRs in sediment studies (Pantelaki et al., 2019).

TEHP was the most commonly detected compound in the Washington sediments, with concentrations very similar to those reported in San Francisco Bay (Sutton et al., 2019) and European waterbodies (Guilivo et al., 2017; Leonards et al., 2011), and somewhat higher than found in the Great Lakes (Cao et al., 2017). Our study detected other compounds (TBP, TBEP, TCrP, and TPP) less frequently than other North American and European sediment studies, but detected results from our study were within the range of concentrations previously reported (Cao et al., 2017; Sutton et al., 2019; Guilivo et al., 2017; Leonards et al., 2011; Cristale et al., 2013).

Table 7. Select OPFR Concentrations (ng/g dw) Measured in Sediments from North America and Europe Compared to Present Study Findings in Washington State Lakes.

Waterbody, date	n	TCPP (ng/g dw)		TEHP (ng/g dw)		TBP (ng/g dw)		TBEP (ng/g dw)		TCrP (ng/g dw)		TPP (ng/g dw)		Ref.
		DF	Range (median)	DF	Range (median)	DF	Range (median)	DF	Range (median)	DF	Range (median)	DF	Range (median)	
WA lakes 2017/18	10	30%	< 1.0-388 (< 12)	80%	< LOQ-35.8 (1.8)	30%	< 0.64-28.7 (< 3.7)	40%	< 0.67-203 (< 6.9)	60%	< 0.3-286 (9.2)	30%	< 0.3-33.9 (< 1.96)	This study
Great Lakes, 2010-2013	88	70%	< LOQ-3.4 (0.3)	35%	< LOQ-8.4 (< LOQ)	97%	< LOQ-7.6 (0.5)	73%	< LOQ-23.7 (0.6)	92%	< LOQ-7.4 (0.7)	60%	< LOQ-9.0 (0.14)	(1)
San Francisco Estuary, 2014	10	100%	0.3-1.6 (0.5)	100%	2.3-20 (8.2)	100%	0.4-1.2 (0.6)	100%	0.5-4.8 (0.8)	100%	1.6-6.7 (3.4)	100%	0.4-7.5 (1.9)	(2)
European river basins, 2014/15	52	83%	< LOQ-53.7	79%	< LOQ-35.1	65%	< LOQ-42.6	73%	< LOQ-11	---	---	37%	< LOQ-9.7	(3)
Norway rivers and fjords, 2010	20	70%	< 0.15-54	100%	0.15-46	65%	< 0.12-6.7	100%	0.7-100	---	---	75%	< 0.1-6.8	(4)
Spain rivers, 2012	21	62%	< LOD-365 (29)	81%	< LOD-290 (9.5)	48%	< LOD-13 (< LOD)	0%	< LOD	---	---	86%	< LOD-23 (2.9)	(5)
European estuaries, 2013-15	32	100%	1.7-141 (15.4)	---	---	91%	< LOQ-4.1 (0.3)	88%	< LOQ-14.7 (4.8)	100%	0.1-6.6 (1.0)	100%	0.1-9.4 (0.9)	(6)

DF = detection frequency; LOQ = limit of quantitation. (1) Cao et al., 2017; (2) Sutton et al., 2019; (3) Guilivo et al., 2017; (4) Leonards et al., 2011; (5) Cristale et al., 2013; (6) Wolschke et al., 2018.

Novel Brominated Flame Retardants and Dechloranes

Sediment

Sediment samples were analyzed for a suite of NBFRs and Dechlorane analogs. None of the target compounds were positively identified and quantified in the sediment samples. One of the NBFRs (2,4,6-tribromophenyl allyl ether; ATE) was tentatively identified at 9.18 ng/g dw with an “NJ” qualification, in the Lake Meridian sample. ATE is a current-use flame retardant added to foamed and expanded polystyrene, which are used in dock floats, and has been reported in air and sewage sludge (Ma et al., 2012; cited by de Wit et al., 2011). ATE can also be formed through degradation of 2,3-Dibromopropyl 2,4,6-tribromophenyl ether (DPTE). No other samples contained ATE at reporting limits of 0.5-5.5 ng/g dw, and no samples contained DPTE.

Figure 4 displays the minimum, median, and maximum reporting limits for analysis of NBFRs and Dechloranes in sediment. The following NBFRs exhibited poor response on the instrument and therefore had higher reporting limits than the other compounds: 1,2-Bis(2,4,6-tribromophenoxy)ethane (BTBPE), 1,2-bis(2,3,4,5,6-pentabromophenyl)ethane (DBDPE), 2-Ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB), Bis(2-ethylhexyl) tetrabromophthalate (TBPH), and total 1,2-Dibromo-4-(1,2-dibromoethyl)cyclohexane (TBECH). Reporting limits for those compounds ranged from 3-25 ng/g dw. Three of the Dechlorane analogs had somewhat higher reporting limits (1.2-13 ng/g dw), while the reporting limits for the remaining target analytes were lower, ranging from 0.3-6 ng/g dw.

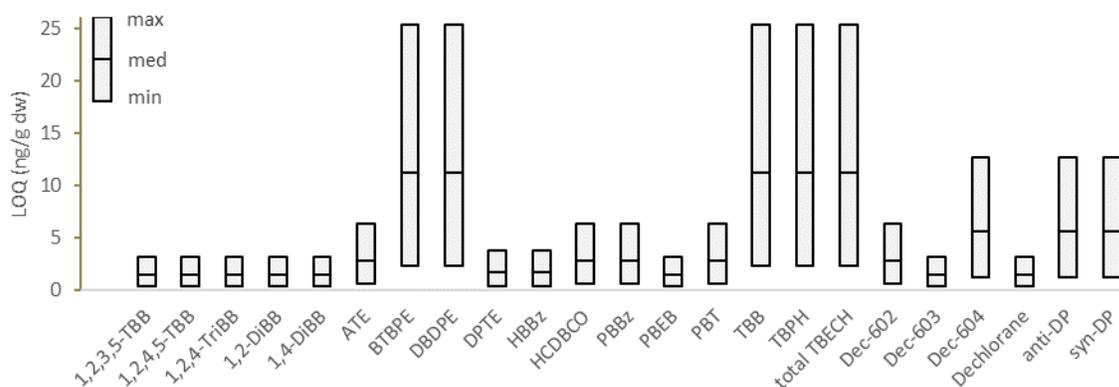


Figure 4. Reporting Limits (ng/g dw) for Analysis of Novel Brominated Flame Retardants and Dechlorane Analogs in Sediment Samples.

Comparison to other studies

High reporting limits likely hampered the ability to detect many of the NBRs and Dechloranes in the Washington lake sediments. Several of the analytes have been found in other sediments collected in North America at concentrations below our reporting limits. Sutton et al. (2019) reported detections of BTBPE, hexabromobenzene (HBBz), TBB, and TBPH in San Francisco Bay sediments at maximum concentrations of 0.07, 0.79, 0.04, and 0.48 ng/g dw, respectively, all well below our lowest reporting limit. Dechlorane plus® anti (*anti-DP*) and Dechlorane 602 (Dec-602) were also frequently detected in that study, with maximum concentrations of 1.3 and 0.25 ng/g dw, respectively. Pentabromoethylbenzene (PBEB), pentabromobenzene (PBBz), DBDPE, Dechlorane 603 (Dec-603), Dechlorane 604 (Dec-604), and hexachlorocyclopentadienyl-dibromocyclooctane (HCDBCO) were not detected by Sutton et al. (2019) at reporting limits 1-2 orders of magnitude below this study's.

In the Great Lakes, Yang et al. (2012) detected DBDPE, BTBPE, and HBBz at maximum concentrations of 2.8, 8.3, and 0.43 ng/g dw, close to our reporting limits for those compounds. PBEB, 2,3,4,5,6-Pentabromotoluene (PBT), TBEC, HCDBCO, and tetrabromo-*o*-chlorotoluene (TBCT) were detected in the Great Lakes at concentrations well below our reporting limits (Yang et al., 2012).

A previous Ecology study analyzed four of the NBRs in sediment cores collected from Lake Meridian, Lake Whatcom, and Williams Lake at much lower reporting limits than the current study (Mathieu and McCall, 2016). That study detected BTBPE, HBBz, and PBEB in several samples, with concentrations in the 0.4-1.1 ng/g dw range.

Fish Tissue

Fish tissue samples were analyzed for 24 NBRs and Dechlorane analogs. Of the compounds analyzed, none were positively identified and quantified. Figure 5 displays the minimum, median, and maximum reporting limits for fish tissue.

Two of the NBRs (TBCT and DPTE) were tentatively identified because the target compounds did not meet the ion abundance ratio and reported with an "NJ" qualification. TBCT was tentatively identified in just over half of the fish samples (7 of 12, or 58%) at concentrations

ranging from 0.428-7.08 ng/g ww (median = 0.79 ng/g ww). All Lake Spokane samples and three out of four Lake Washington samples contained the tentatively-identified TBCT, while none of the reference Lake Ozette fish did. TBCT is an additive flame retardant that contains both bromine and chlorine. Little information exists on its use as a flame retardant, though it has been suggested as a replacement for Deca-BDE (Lopez et al., 2011) and may be a transformation product of other flame retardants (EFSA, 2013).

DPTE was tentatively identified in one sample, a largescale sucker composite collected from Lake Spokane, at 39.4 ng/g ww. DPTE was used as a flame retardant until the mid-1980s, and it does not appear to be currently manufactured (Ma et al., 2012).

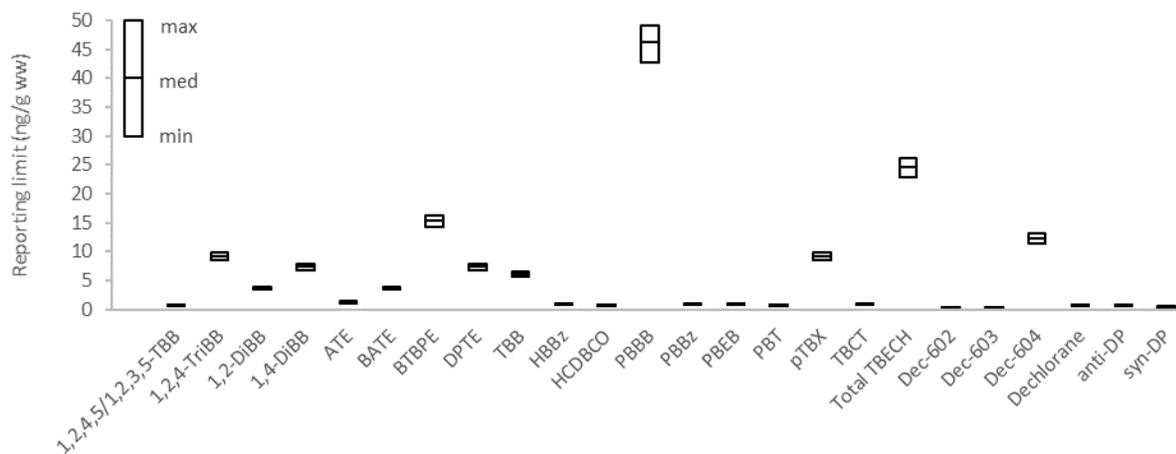


Figure 5. Reporting Limits (ng/g ww) for Analysis of Novel Brominated Flame Retardants and Dechlorane Analogs in Fish Tissue.

Comparison to Other Studies

Reporting limits for this study were in the low ng/g (ppb) range, while a previous study of Washington state freshwater fish reported multiple detections of HBBz, PBEB, DBDPE, and BTBPE in the low ng/kg (ppt) range (Mathieu and Wong, 2016). The Mathieu and Wong (2016) study used a high-resolution analytical method that was more sensitive, while the current study used a GC-ECNI-MS method that identified a broader suite of flame retardants.

Other studies in North America analyzed NBRFRs and Dechlorane analogs using GC-ECNI-MS and reported at similar limits to ours. In a study of 58 common carp and largemouth bass fillets collected from Illinois waterbodies, Widelka et al. (2016) detected HBBz, TBB, TBCT, Dec-603, and Dec-604 in over 60% of the samples. In a Great Lakes study of 65 walleye and trout whole-body samples, the authors frequently detected PBT, TBCT, *anti*-DP, *syn*-DP, Dec-602, and Dec-603 (Wu et al., 2019). With the exception of TBCT, our study did not detect these compounds in fish samples.

Widelka et al. (2016) frequently detected TBCT in Illinois common carp and largemouth bass, at concentrations from <0.8-30 ng/g lw (lipid weight; wet weight not reported), with a median of 2.1 ng/g lw (Widelka et al., 2016). For comparison, the Washington fish samples had lipid-normalized TBCT concentrations in the 40-225 ng/g lw range. TBCT was also detected in almost

all walleye and trout composites collected from the Great Lakes at similar wet weight concentrations found in our study: 0.09-6.77 ng/g ww (Wu et al., 2019).

Polybrominated Diphenyl Ethers

Surface Water

Thirteen PBDE congeners were analyzed in surface water samples collected during the fall and spring sampling events. PBDEs were largely undetected in the surface water samples. Only one congener (BDE-209) was detected, in one sample. No other samples, fall or spring, contained PBDE congeners at reporting limits of 2.0 ng/L (BDE-47 through -100) and 4.0 ng/L (BDE-138 through -191), and 10 ng/L (BDE-209).

The West Medical Lake surface water sample collected in the fall contained 156 ng/L of BDE-209. This result is higher than has typically been reported for surface water PBDEs in Washington State. Johnson et al. (2006) measured PBDEs via semi-permeable membrane devices in several Washington waterbodies and found all congener concentrations were below 1.0 ng/L. PBDE concentrations in most freshwater samples collected from tributaries to Puget Sound were also below 1.0 ng/L; however, one sample from a commercial watershed had a BDE-209 concentration of 224 ng/L (Herrera, 2011).

Sediment

The same 13 PBDE congeners were analyzed in sediment samples collected from the Washington lakes in spring. Table 8 provides a summary of detected PBDE concentrations, and Figure 6 displays the concentrations by waterbody.

The congeners BDE-047, -049, -099, -100, -153, and -209 were detected in 50%, 40%, 30%, 20%, 10%, and 30% of sediment samples, respectively. Other congeners were undetected in the sediments. PBDE concentrations of all detected congeners, except for BDE-209, ranged from 0.22-3.24 ng/g dw. BDE-209 was detected only in three samples, but at higher concentrations than the other congeners: 6.44-40.6 ng/g dw. BDE-209 was detected in sediments collected from Mayfield Lake, Lake Washington, and Lake Meridian.

The highest T-PBDE concentration was measured in the Lake Meridian sample (48.6 ng/g dw), followed by Lake Washington (18.5 ng/g dw), and Mayfield Lake (6.4 ng/g dw). Low T-PBDE levels (0.3-2.0 ng/g dw) were found in Lake Stevens, Spanaway Lake, Lake Whatcom, and West Medical Lake. No PBDEs were detected in Lake Ozette, Lake Spokane, or Vancouver Lake. The lack of detections in the Lake Spokane and Vancouver Lake sediments is likely due to the coarse grain size of the samples and low TOC. The Lake Washington sample was also low in TOC, but still had fairly high PBDE concentrations.

Table 8. Statistical Summary of Detected PBDE Concentrations in Lake Sediments (ng/g dw).

Analyte	Sediment Samples (n = 10)			
	Det. Freq.	Min. (ng/g)	Max. (ng/g)	Median (ng/g)
PBDE-047	50%	0.367 J	3.24	0.866
PBDE-049	40%	0.222 J	0.396 J	2.16 J
PBDE-099	30%	0.754 J	1.85 J	1.48
PBDE-100	20%	0.449 J	0.729 J	0.589 J
PBDE-153	10%	0.488 J	0.488 J	---
PBDE-209	30%	6.44	15	40.6
T-PBDEs	70%	0.367 J	48.6 J	2.03 J

Not detected: PBDE -066, -071, -138, 154, -183, -184, -191

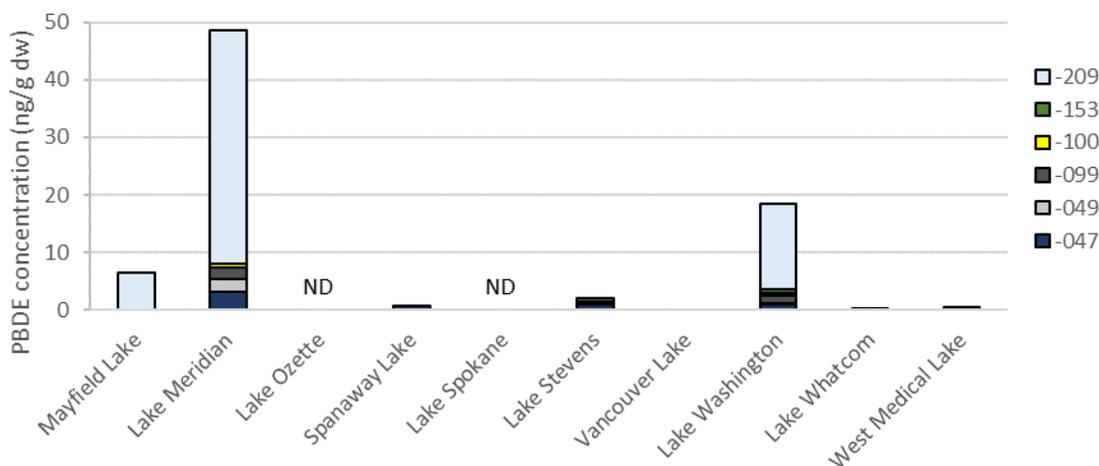


Figure 6. Detected PBDE Concentrations (ng/g dw) in Sediment Samples by Site, 2018. Results below reporting limits were excluded from figure. ND = all results nondetect for that site.

Comparison to Other Studies

In 2015, an Ecology study analyzed PBDEs in sediment cores collected from Lake Meridian and Lake Whatcom (Mathieu and McCall, 2016). Sample collection and laboratory methods differed between that study and our current 2018 study. In the Lake Meridian sediment core, T-PBDEs increased from the 1980s up to 32 ng/g dw in 2013. Our surface sediment sample collected in 2018 close to the same site had a T-PBDE concentration of 48.6 ng/g dw. While most of the individual congener concentrations were similar between the 2015 sediment core results and our surface sediment sample, BDE-209 was much higher in our 2018 sample (40.6 ng/g dw).

The Lake Whatcom sediment core showed T-PBDEs increasing from the 1980s through the 2010s as well, with a concentration at the top of the core (2013) of 8.2 ng/g dw. Our 2018 Lake Whatcom sediment sample was collected in an area of the lake with coarser grain size and had a much lower T-PBDE concentration, 0.367 ng/g dw.

Fish Tissue

Thirteen PBDE congeners were analyzed in the fish tissue samples. Table 9 provides a summary of detected PBDE concentrations in fish tissue, and Figure 7 shows the concentrations measured in each sample.

Of the 13 PBDE congeners analyzed, six were detected in fish tissue samples. BDE-47 was detected the most frequently (83%), followed by BDE-100 (75%) and BDE-049 (67%). BDE-154 was present in half the samples, while BDE-153 and -099 were detected in less than half of the fish tissue samples.

Typical of PBDE profiles in biota, BDE-47 made up the majority of the T-PBDE concentration in all samples, with concentrations of up to 62.3 ng/g ww and a median of 10.8 ng/g ww. BDE-100 was the next most abundant congener, with a median detected value of 4.55 ng/g ww.

T-PBDEs were detected in all Lake Spokane and Lake Washington fish samples. Lake Spokane largescale sucker samples had the highest T-PBDE concentrations, both greater than 60 ng/g ww. T-PBDEs in Lake Spokane northern pikeminnow and Lake Washington largescale suckers were in the 10-20 ng/g ww range, while T-PBDEs in largemouth bass from Lake Washington were less than 3.0 ng/g ww. PBDEs were detected only in two of the Lake Ozette fish samples, at trace levels (< 0.2 ng/g ww).

Table 9. Statistical Summary of Detected PBDE Concentrations in Fish Samples (ng/g ww).

Analyte	Fish Samples (n = 12)			
	Det. Freq.	Min. (ng/g)	Max. (ng/g)	Median (ng/g)
PBDE-047	83%	0.073 J	62.3	10.8
PBDE-049	67%	0.084 J	1.21	0.795
PBDE-099	25%	0.112 J	0.464	0.162 J
PBDE-100	75%	0.08 J	12.7	4.55
PBDE-153	33%	0.312 J	0.539	0.416 J
PBDE-154	50%	0.682	2.69	1.235
T-PBDEs	83%	0.183 J	78.8 J	15.9

Not detected: PBDE -066, -071, -138, -183, -184, -191, -209

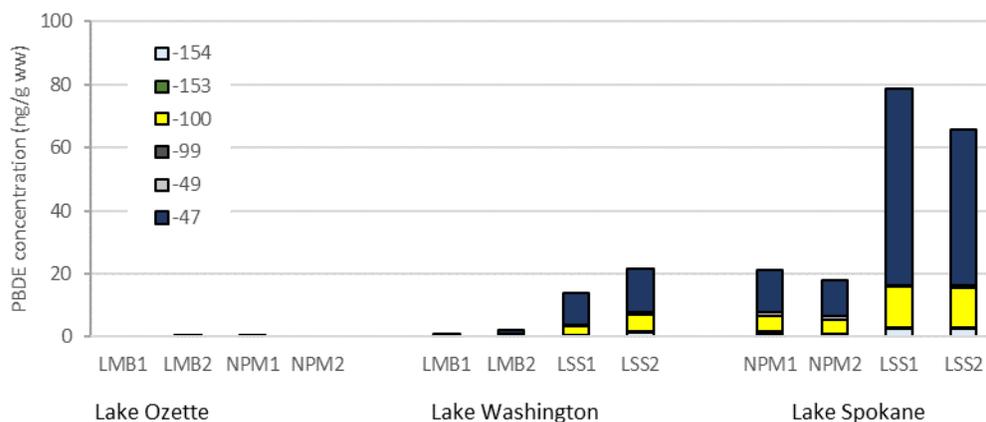


Figure 7. Detected PBDE Concentrations (ng/g ww) in Fish Fillet Composites by Site, 2017. Results below reporting limits were excluded from figure.

Comparison to Other Studies

The fish tissue samples measured for this study were within the range of T-PBDEs previously reported in a statewide survey of Washington freshwater fish in 2005-2006 (Johnson et al., 2006). Johnson et al. (2006) had identified fish from the Spokane River as containing the highest PBDE concentrations in the state, followed by Lake Washington. A direct comparison of historical PBDE levels measured previously in Lake Spokane is not possible due to differences in species, fish sizes, and sample types (fillet vs. whole body). However, previous studies with limited sample sizes have suggested a decline in PBDE levels of fish tissue in the Spokane River (Furl and Meredith, 2010; Johnson et al., 2012).

Largemouth bass samples collected from Lake Washington for our study contained low concentrations of T-PBDEs and were comparable to levels measured in largemouth bass fillets collected from Lake Washington in 2004 and 2006 (Seiders et al., 2007; Seiders et al., 2008). While no direct comparison with largescale suckers was possible, T-PBDE concentrations measured in the 2017 Lake Washington largescale sucker composites were within the range of previous T-PBDE levels of common carp fillets between 2005 and 2015 (Johnson et al., 2006; Seiders et al., 2007, Johnson and Friese, 2012; Seiders and Deligeannis, 2018). Seiders and Deligeannis (2018) found a statistically significant decrease in T-PBDE levels in large cutthroat trout collected from Lake Washington in 2005 and 2015, but not in other species.

In 2004 and 2007, Ecology collected fillet samples of multiple fish species from Lake Ozette (Seiders et al., 2007; Seiders and Deligeannis, 2009). All fillet samples from Lake Ozette analyzed in the past studies, as well as our current study, had T-PBDE concentrations of 0.5 ng/g ww or less, or were not detected at all. The Lake Ozette PBDE concentrations are also within the range of background levels of PBDEs in fish fillets analyzed from remote lakes in Northeastern Washington (range = 0.07-2.96 ng/g ww; median = 0.76 ng/g ww) (Johnson et al., 2011). All current study samples from Lake Ozette, and largemouth bass samples from Lake Washington, were within this background range.

Ecological Significance

Few guidelines or thresholds exist to determine the ecological significance of the flame retardant concentrations measured in this report. The European Union developed practical no effects concentrations (PNECs) for several of the OPFRs detected in this study (ECHA, 2019a-h). PNECs indicate a concentration below which adverse ecological effects are not likely to occur.

In water samples, maximum concentrations were 4 orders of magnitude lower than PNECs for TEP and V6, 3 orders of magnitude lower for TBP, TCEP, and TCPP PNECs, and 1 order of magnitude lower than the TDCPP PNEC (Figure 9).

In sediment samples, maximum concentrations in the Washington lakes were 2 orders of magnitude lower than PNECs for TBP, TCrP, TPP, and V6, and 1 order of magnitude lower than PNECs for TCEP and TCPP. The closest value to OPFR thresholds in this study was TBEP in a sediment sample collected from West Medical Lake; the sample result was 203 ng/g, while the PNEC is 804 ng/g.

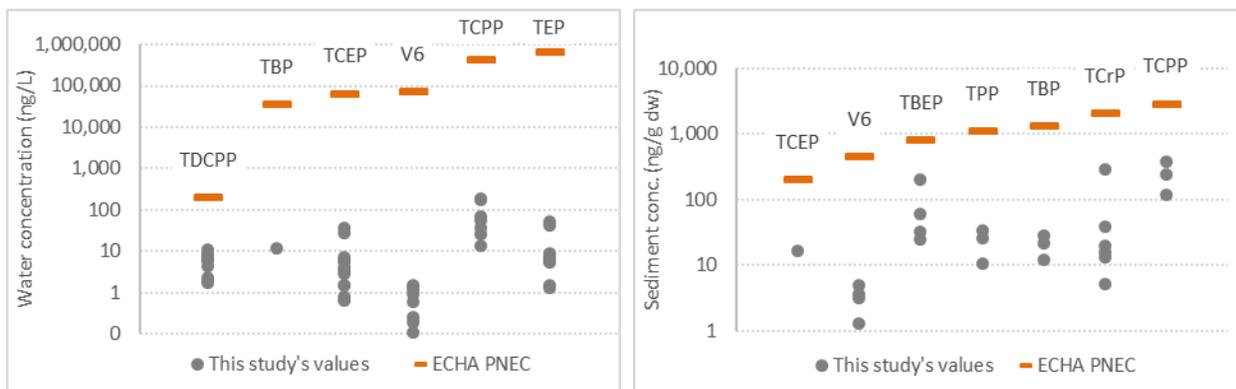


Figure 8. OPFR Concentrations Measured in this Study (gray circles) and the European Union's Practical No Effects Concentrations (orange bars).

Canada developed Federal Quality Guidelines (FEQGs) for PBDEs in water, sediment, and fish tissue that assess whether aquatic organisms (vertebrates, invertebrates, and plants) are protected from adverse effects (Environment Canada, 2013).

Sediment samples collected from Lake Meridian, Lake Stevens, and Lake Washington had one or more congener with concentrations above the FEQG, indicating that environmental quality is impacted in those lakes (Figure 10). Congeners exceeding the FEQG for sediment were BDE-099, BDE-100, and BDE-209.

Fish tissue samples collected from Lake Spokane and Lake Washington were above FEQGs for PBDE concentrations in fish tissue for both aquatic quality and wildlife diet. Six fish tissue samples exceeded both BDE-100 thresholds, and Lake Spokane largescale sucker samples exceeded the BDE-047 threshold for wildlife diet.

The two Lake Spokane largescale sucker samples also exceeded Washington State Department of Health's (DOH's) Screening Level for BDE-047 based on neurobehavioral effects for high consumer populations (40 ng/g ww). This screening level is used by DOH in assessing waterbodies for fish consumption advisories, after taking into account risk management and risk

communication. While the sample size in this study would be too low for DOH to make an assessment, the screening level exceedances give the reader a human health risk context for the PBDE levels.

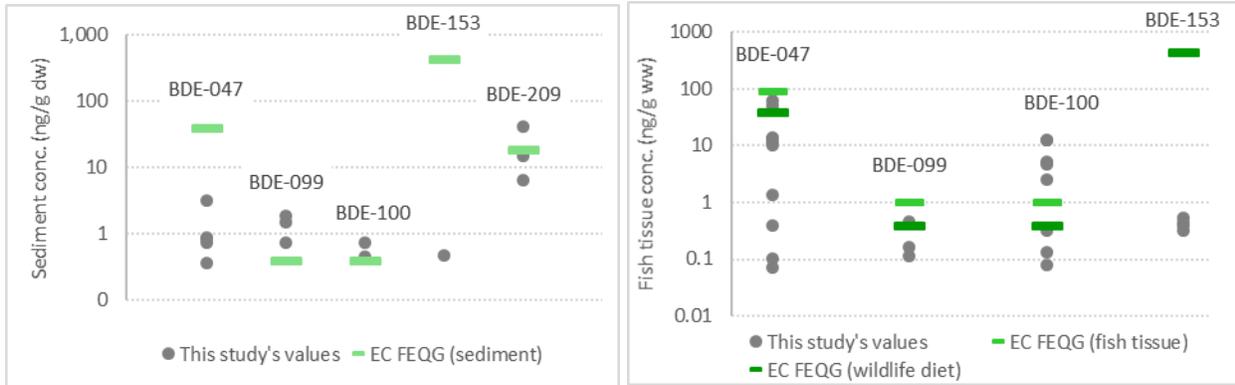


Figure 9. Sediment and Fish Tissue PBDE Concentrations Measured in this Study (gray circles) and Environment Canada's Federal Environmental Quality Guidelines (EC FEQG) (green bars).

Summary and Conclusions

During 2017-2018, Ecology collected surface water, sediments, and fish tissue for analysis of a broad suite of flame retardants. Sediments and surface water were collected from 10 lakes in Washington state, and fish fillet samples were collected from 3 of the lakes. Results from this study fill a data gap on our understanding of current levels of flame retardants in Washington's environment. Conclusions of this study include:

- OPFRs were present in the majority of lakes sampled. TCPP was the dominant OPFR compound in both water and sediments, with detected concentrations of 13.3-188 ng/L in water and 120-388 ng/g dw in sediments. TCEP, TDCPP, TEP, and V6 were also frequently detected in surface waters, and TEHP, V6, TCrP, and TPP were frequently found in sediments. OPFR results were generally comparable to other waterbodies in North America.
- NBFRs and Dechlorane analogs were largely undetected in sediment and fish tissue samples. Elevated reporting limits for BTBPE, DBDPE, TBB, TBPH, and total TBECH in sediments hampered our ability to provide meaningful comparison to other studies in North America. Other studies in North America have reported these compounds at concentrations below our reporting limits in freshwater sediments.
- Reporting limits for NBFRs and Dechlorane analogs in fish tissue were generally comparable to other studies in North America. Washington State fish did not contain Dechlorane analogs or many of the NBFRs that have been reported in fish from other waterbodies in North America.
- TBCT was tentatively identified in just over half of the fish samples at 0.72-7.08 ng/g ww. These levels are similar to concentrations of TBCT reported in freshwater fish from Illinois and the Great Lakes. TBCT appears to be a common contaminant in freshwater fish at relatively low levels.
- PBDEs were mostly undetected in surface water, but frequently detected in sediments and fish tissue. Detected T-PBDE concentrations in sediments and fish tissue were in the range of 0.367-48.6 dw and 0.18-78.8 ng/g ww, respectively.
- Of the 10 lakes sampled, flame retardants were highest in West Medical Lake, followed by Lake Meridian, Lake Washington, and Lake Stevens. This suggests wastewater treatment plant (WWTP) effluent and urban inputs are important sources or pathways of OPFRs and PBDEs to the lakes studied. The remote lakes, Lake Ozette and Mayfield Lake, contained trace or undetectable levels of flame retardants, indicating atmospheric deposition sources were not significant at the levels we were able to measure.
- Individual OPFR concentrations measured in this study were 1 to 4 orders of magnitude lower than practical no effects levels derived by the European Union, suggesting OPFR concentrations detected in this study present low environmental risk. Several PBDE congeners exceeded Canada's environmental concentration guidelines, indicating potential adverse effects.

Recommendations

Results of this 2017-2018 study support the following recommendations:

- Ecology's efforts to prioritize chemicals for action should consider the environmental occurrence of compounds documented in this report. OPFRs appear to be persistent and at higher total concentrations than PBDEs in some environmental matrices.
- This study was designed to target waterbodies with high contamination potential, primarily urban lakes. Because OPFRs were detected in these high-potential areas, further investigation into other waterbody types, such as rivers and the Puget Sound, is warranted. In addition, future studies should consider additional matrix types like stormwater and groundwater.
- Future research should identify methods with lower reporting limits for TCPP, NBFRs, and Dechlorane analogs. Although TCPP was detected in the highest amounts, the detection frequency was lower than other compounds because of elevated reporting limits for TCPP. Lower reporting limits for NBFRs and Dechlorane analogs in sediments would allow for comparison to other areas of North America and improve our ability to characterize environmental levels.

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Appendices

Appendix A. Data Quality Summary

Table A-1. Organophosphate Flame Retardant (OPFR) Data Quality Summary.

Sampling Event	Analyte	Matrix	Lab Duplicates		Laboratory Control Standards		Surrogate Standards		Matrix Spike/MSD Recovery		Matrix Spike/MSD RPD	
			MQO (RPD)	Pass?	MQO (% recov.)	Pass?	MQO (% recov.)	Pass?	MQO (% recov.)	Pass?	MQO (RPD)	Pass?
Fall	OPFRs	Surface Water	≤ 40% if concentrations > 5x QL	Yes (a)	50 - 150 ¹ 70-130 ²	Mostly (b)	40-140 ⁴	Yes	50-150 ¹ 70-130 ²	Mostly (c)	≤ 40% if concentrations > 5x QL	Yes
Spring	OPFRs	Surface Water	≤ 40% if concentrations > 5x QL	Yes (d)	50-150 ¹ 70-130 ²	Mostly (e)	40-140 ⁴	Mostly (f)	50-150 ¹ 70-130 ²	Mostly (g)	≤ 40% if concentrations > 5x QL	Mostly (h)
Spring	OPFRs	Sediment	≤ 40% if concentrations > 5x QL	Yes	50-150 ¹ 70-130 ²	Mostly (i)	40-140 ⁴	Mostly (j)	50-150 ¹ 70-130 ²	Mostly (k)	≤ 40% if concentrations > 5x QL	Yes

¹V6, TDCPP, TDBPP, TCrP, EHDPP, TEHP, TBEP; ²TEP, TCEP, TPrP, TCPP, TPP, TBP; ³≤ 5 ng/sample for TCEP and TBP; ≤ 100 ng/sample for TBEP; ⁴d12-TCEP, d21-TPrP, d18-TCPP, d15-TDCPP, d27-TBP; 15-130% for d15-TEP; 50-130% for 13C18-TPP

(a) Due to sample size limitations, a field replicate was analyzed instead of a lab duplicate. Field replicate RPDs were below 40%.

(b) TCPP recovery was 154%. One sample was qualified 'J' as an estimate.

(c) TPP and TCPP recoveries were greater than MQOs in QAPP, but lower than MEL method acceptance limits. All TPP were nondetects and not qualified. TCPP was already qualified for LCS recovery.

(d) Due to sample size limitations, a field replicate was analyzed instead of a lab duplicate. No paired results were both > 5x QL.

(e) TCPP LCS recovery was 185%. Five samples were qualified 'J' as estimates.

(f) 19% of surrogate results were outside MQOs. Three TDCPP results were qualified 'J' based on high surrogate recovery. Nondetect results for EHDP, TEBP, TEP, TCrP, and TPP were qualified 'UJ' based on low surrogate recoveries.

(g) 12% of MS/MSD recoveries were outside MQOs. Nondetect results for EHDP, TEBP, TCrP were qualified 'UJ' based on low MS/MSD recoveries. One TEHP result was qualified 'J' for high MS recovery.

(h) MS/MSD RPDs were high for TEBP, EHDPP, TCrP. All associated results were nondetects.

(i) TCPP LCS recovery was lower than QAPP MQOs, and TDCPP LCS recovery was higher than QAPP MQOs, but both recoveries met MEL acceptance limits.

(j) TDCPP surrogate recovery was high, but all sample results were nondetect.

(k) TEHP MS recovery was high, one sample was qualified 'J' as estimate. Other samples were already qualified for being below the MRL.

Table A-2. Novel Brominated Flame Retardants and Dechlorane Analogs Data Quality Summary.

Sampling Event	Analyte	Matrix	Lab Duplicates		Laboratory Control Standards		Surrogate Standards		Matrix Spike/MSD Recovery		Matrix Spike/MSD RPD	
			MQO (RPD)	Pass?	MQO (% recov.)	Pass?	MQO (% recov.)	Pass?	MQO (% recov.)	Pass?	MQO (RPD)	Pass?
Spring	Hal-FRs	Sediment	≤ 40% if concentrations > 5x QL	Yes	50-150 ¹	Mostly (a)	30-160	Mostly (b)	50-150 ¹	Mostly (c)	≤ 40% if concentrations > 5x QL	Yes
Fall	Hal-FRs	Fish Tissue	≤ 40% if concentrations > 5x QL	Yes (d)	50-150 ²	Mostly (e)	40-160 ³	Yes	50-150 ²	Mostly (f)	≤ 40% if concentrations > 5x QL	Yes

¹50-200% for Dec 604, TBB, PBBB; 70-130% for Dechlorane, *anti*-DP and *syn*-DP, Dec 602, HBBz; 30-180% for DPTE; 20-150% for BEHTBP; 15-160 for 1,2- and 1,3- DiBB; 5-150% for 1,2,4-TriBB.

²60-140% for Dechlorane, *anti*-DP and *syn*-DP, TBB, T-TBECH, HBBz, PBBz; 70-130% for BTBPE; 40-160% for Dec 604, ATE, BATE, BPTe; 40-150% for HCDBCO; 30-170% 1,2,4,5-TBB, 1,2,3,5-TBB, 1,2,4-TriBB, 1,4-DiBB; 20-180% for PBBB; 10-170% for 1,2-DiBB.

³30-170% for 13C12-BTBPE.

(a) TBECH LCS recovery was low; all results were nondetect and qualified 'UJ'. DPTE, DBDPE, BTBPE, TBB, and HCDBCO LCS recoveries were high, but all results were nondetect and not affected/qualified.

(b) BTBPE D34, *syn*-DP, and *anti*-DP had high surrogate recoveries, but all results were nondetect. Four 1,2-DBB and 1,4-DBB surrogate recoveries were low; affected samples were qualified 'UJ'.

(c) TBECH and HCDBCO MS recoveries were low; associated results were qualified 'UJ'. DBDPE, Dec 603, Dec 604, DPTE, and TBB MS recoveries were high, but all results were nondetect and not affected/qualified.

(d) No paired results were > 5x QL. However, trace amounts (lower than lowest calibration standard) were found in the duplicate analysis, while the source results were nondetect.

(e) DPTE LCS recovery was low; associated results were qualified 'UJ'. ATE, BATE, and TBB recoveries were high, but all results were nondetect and not affected/qualified.

(f) DPTE MSD recovery was low; associated results were already qualified 'UJ'. BATE and TBB MS/MSD recoveries were high, but all results were nondetect and not affected/qualified.

Table A-3. Polybrominated Diphenyl Ether (PBDE) Data Quality Summary.

Sampling Event	Analyte	Matrix	Lab Duplicates		Laboratory Control Standards		Surrogate Standards		Matrix Spike/MSD Recovery		Matrix Spike/MSD RPD	
			MQO (RPD)	Pass?	MQO (% recov.)	Pass?	MQO (% recov.)	Pass?	MQO (% recov.)	Pass?	MQO (RPD)	Pass?
Fall	PBDEs	Surface Water	≤ 50%	Yes (a)	50-150	Mostly (b)	50-150	Mostly (c)	50-150	Mostly (d)	≤ 40%	Mostly (e)
Spring	PBDEs	Surface Water	≤ 50%	Yes (f)	50-150	Yes	50-150	Yes	50-150	Yes	≤ 40%	Yes
Spring	PBDEs	Sediment	≤ 50%	Yes	50-150	Yes	50-150	Yes	50-150	Yes	≤ 40%	Yes
Fall	PBDEs	Fish Tissue	≤ 50%	Yes	50-150	Yes	50-150	Yes	50-150	Mostly (g)	≤ 40%	Yes

(a) Due to sample size limitations, a field replicate was analyzed instead of a lab duplicate. All results were nondetect.

(b) PBDE-138, -183, -191 LCS recoveries were high, but all results were nondetect and not affected/qualified.

(c) All congeners for two samples had low surrogate recoveries; associated results were nondetects and qualified 'UJ'.

(d) PBDE-138, -183, -191, and -209 MS/MSD recoveries were high, but all results were nondetect and not affected/qualified.

(e) PBDE-49 and -71 RPDs were high, but all results were nondetect and not affected/qualified.

(f) Due to sample size limitations, a field replicate was analyzed instead of a lab duplicate. All results were nondetect.

(g) PBDE-99, -138, -153, -183, -184, -191, and -209 MS/MSD recoveries were high, but all results were nondetect and not affected/qualified.

Appendix B. Laboratory Results

Table B-1. OPFR Concentrations (ng/L) in Surface Water Collected in Fall 2017.

Analyte	Mayfield Lake	Lake Meridian	Lake Ozette	Spanaway Lake	Lake Spokane	Lake Stevens	Vancouver Lake	Lake Washington	Lake Whatcom	West Medical Lake
EHDPP	0.493 U	0.495 U	0.498 U	0.49 U	0.493 U	0.493 U	0.493 U	0.493 U	0.495 U	0.495 U
TBEP	22.3 U	62.2 U	30.9 U	31.6 U	37.1 U	47.1 U	17.7 U	36.2 U	31.8 U	41.3 U
TBP	1.06 U	2.66 U	3.99 U	1.87 U	2.13 U	4.71 U	4.59 U	20.6 U	4.65 U	3.03 U
TCEP	0.493 U	7.51	0.498 U	0.833	3.31	5.84	1.53	2.91	0.495 U	37.5
TCPP	24.6 U	24.8 U	24.9 U	24.5 U	24.6 U	33.6 U	24.6 U	38.3 U	24.8 U	179 J
TCrP	0.493 U	0.495 U	0.498 U	0.49 U	0.493 U	0.493 U	0.493 U	0.493 U	0.495 U	0.495 U
TDBPP	4.93 U	4.95 U	4.98 U	4.9 U	4.93 U	4.93 U	4.93 U	4.93 U	4.95 U	4.95 U
TDCPP	4.93 U	7.79	4.98 U	2.31 J	8.21	6.2	1.79 J	4.34 J	1.89 J	11.4
TEHP	0.493 U	0.495 U	0.498 U	1.93	0.493 U	0.493 U	0.493 U	0.493 U	0.495 U	0.495 U
TEP	0.493 U	8.89	0.498 U	2.58 U	0.947 U	5.54	0.493 U	5.88	0.495 U	51.8
TPP	1.38 U	2.66 U	0.629 U	1.73 U	1.52 U	2.62 U	1.04 U	1.5 U	1.26 U	0.783 U
TPrP	0.493 U	0.495 U	0.498 U	0.49 U	0.493 U	0.493 U	0.493 U	0.493 U	0.495 U	0.495 U
V6	0.493 U	0.495 U	0.498 U	0.26 J	0.493 U	0.493 U	0.493 U	0.493 U	0.495 U	1.3 J

Full compounds names are included in Appendix D. J: Compound was positively identified and the associated value is an estimated concentration. U: Compound not detected at or above reported value. Detected values are bolded and highlighted in green.

Table B-2. OPFR Concentrations (ng/L) in Surface Water Collected in Spring 2018.

Analyte	Mayfield Lake	Lake Meridian	Lake Ozette	Spanaway Lake	Lake Spokane	Lake Stevens	Vancouver Lake	Lake Washington	Lake Whatcom	West Medical Lake
EHDPP	0.493 UJ	0.505 U	0.498 U	0.712 UJ	0.515 U	0.515 U	0.498 U	0.498 U	0.495 U	0.5 U
TBEP	0.982 UJ	4.04 U	1.14 U	3.69 UJ	11 U	3.12 U	2.54 U	7.81 U	1.54 U	17.3 U
TBP	0.518 U	2.36 U	0.518 U	0.816 UJ	1.52 U	2.01 U	0.933 U	12.1	0.722 U	1.8 U
TCEP	0.493 U	5.71	0.498 U	0.722	0.515 U	4.13	0.666	1.54	0.682	28.6
TCPP	24.6 U	25.3 J	24.9 U	24.6 U	25.8 U	56.8 J	13.3 J	71.8 J	36 J	188 J
TCrP	0.493 UJ	0.755 U	0.498 U	2.58 UJ	0.515 U	0.519 U	0.498 U	0.746 U	0.495 U	0.5 U
TDBPP	4.93 UJ	5 UJ	4.98 UJ	4.93 UJ	5.15 UJ	5.15 UJ	4.98 UJ	4.98 UJ	4.95 UJ	5 UJ
TDCPP	4.93 U	6.37 J	4.98 U	4.93 U	5.15 U	7.13 J	4.98 U	4.98 U	4.95 U	6.4 J
TEHP	0.493 UJ	0.5 UJ	0.498 UJ	0.493 UJ	0.515 UJ	0.515 UJ	0.498 UJ	0.498 UJ	0.495 UJ	0.5 UJ
TEP	0.493 U	7.5	0.498 U	1.37	0.536 U	6.94	1.52	5.83	0.92 U	43.3
TPP	0.787 U	2.16 U	0.498 U	1.17 UJ	0.956 U	1.83 U	0.609 U	2.61 U	1.15 U	0.671 U
TPrP	0.493 U	0.5 U	0.498 U	0.493 U	0.515 U	0.515 U	0.498 U	0.498 U	0.495 U	0.5 U
V6	0.493 U	1.44 J	0.498 U	0.113 J	0.189 J	1.24 J	0.613 J	0.937 J	0.495 U	1.52 J

Full compounds names are included in Appendix D. J: Compound was positively identified and the associated value is an estimated concentration.
 U: Compound not detected at or above reported value. UJ: Compound not detected at or above estimated value.
 Detected values are bolded and highlighted in green.

Table B-3. OPFR Concentrations (ng/g dw) in Lake Sediment Samples Collected in Spring 2018.

Analyte	Mayfield Lake	Lake Meridian	Lake Ozette	Spanaway Lake	Lake Spokane	Lake Stevens	Vancouver Lake	Lake Washington	Lake Whatcom	West Medical Lake
EHDPP	7.63 U	65.2 U	13 U	40.5 U	2.57 U	25.8 U	5.51 U	11.2 U	16.8 U	62.3 U
TBEP	1.91 UJ	60.1 J	3.24 UJ	31.8 J	0.665 UJ	9.6 UJ	1.38 UJ	24.4 J	4.19 UJ	203 J
TBP	1.91 U	22	3.24 U	12.3	0.642 U	6.45 U	1.38 U	2.89 U	4.19 U	28.7
TCEP	3.82 U	32.6 U	6.48 U	20.3 U	1.28 U	12.9 U	2.76 U	5.6 U	8.38 U	16.5 J
TCPP	6.39 U	241	5.63 U	120	1.01 U	33.4 U	5.26 U	15.7 U	8 U	388
TCrP	1.37 UJ	286 J	1.62 UJ	15.8 J	0.321 UJ	38.7 J	0.689 UJ	13.1 J	5.21 J	19.5 J
TDBPP	7.63 UJ	65.2 UJ	13 UJ	40.5 UJ	2.57 UJ	25.8 UJ	5.51 UJ	11.2 UJ	16.8 UJ	62.3 UJ
TDCPP	7.63 U	65.2 U	13 U	40.5 U	2.57 U	25.8 U	5.51 U	11.2 U	16.8 U	62.3 U
TEHP	0.131 J	6.32 J	1.62 U	1.9 J	0.211 J	1.76 J	0.235 J	5.03 J	2.1 U	35.8
TEP	0.954 U	8.15 U	1.62 U	5.07 U	0.321 U	3.22 U	0.689 U	1.4 U	2.1 U	7.79 U
TPP	0.954 U	25.9	1.62 U	10.5	0.321 U	4.78 U	0.692 U	1.89 U	2.1 U	33.9
TPrP	1.91 U	16.3 U	3.24 U	10.1 U	0.642 U	6.45 U	1.38 U	2.8 U	4.19 U	15.6 U
V6	0.954 U	3.17 J	1.62 U	3.64 J	0.321 U	3.22 U	0.689 U	1.27 J	2.1 U	4.92 J

Full compounds names are included in Appendix D. J: Compound was positively identified and the associated value is an estimated concentration.
 U: Compound not detected at or above reported value. UJ: Compound not detected at or above estimated value.
 Detected values are bolded and highlighted in green.

Table B-4. Novel Brominated Flame Retardants and Dechlorane Analogs Concentrations (ng/g dw) in Lake Sediment Samples Collected in Spring 2018.

Analyte	Mayfield Lake	Lake Meridian	Lake Ozette	Spanaway Lake	Lake Spokane	Lake Stevens	Vancouver Lake	Lake Washington	Lake Whatcom	West Medical Lake
TOC	3.2%	14.3%	4.55%	13.60%	0.11%	13.7%	1.57%	1.03%	7.62%	8.16%
1,2,3,5-TBB	0.7 U	2.92 U	1.4 U	2.74 U	0.286 U	2.39 U	0.495 U	1.19 U	1.46 U	1.34 U
1,2,4,5-TBB	0.7 U	2.92 U	1.4 U	2.74 U	0.286 U	2.39 U	0.495 U	1.19 U	1.46 U	1.34 U
1,2,4-TriBB	0.7 U	2.92 U	1.4 U	2.74 U	0.286 U	2.39 U	0.495 U	1.19 U	1.46 U	1.34 U
1,2-DiBB	0.7 U	2.92 U	1.4 U	2.74 UJ	0.286 UJ	2.39 U	0.495 U	1.19 UJ	1.46 U	1.34 UJ
1,4-DiBB	0.7 U	2.92 U	1.4 U	2.74 UJ	0.286 UJ	2.39 U	0.495 U	1.19 UJ	1.46 U	1.34 UJ
ATE	1.4 U	9.18 NJ	2.81 U	5.47 U	0.573 U	4.77 U	0.989 U	2.38 U	2.92 U	2.68 U
BTBPE	5.6 U	23.3 U	11.2 U	21.9 U	2.29 U	19.1 U	3.96 U	9.53 U	11.7 U	10.7 U
DBDPE	5.6 U	23.3 U	11.2 U	21.9 U	2.29 U	19.1 U	3.96 U	9.53 U	11.7 U	10.7 U
Dec 602	1.4 U	5.84 U	2.81 U	5.47 U	0.573 U	4.77 U	0.989 U	2.38 U	2.92 U	2.68 U
Dec 603	0.7 U	2.92 U	1.4 U	2.74 U	0.286 U	2.39 U	0.495 U	1.19 U	1.46 U	1.34 U
Dec604	2.8 U	11.7 U	5.61 U	10.9 U	1.15 U	9.55 U	1.98 U	4.77 U	5.85 U	5.36 U
Dechlorane	0.7 U	2.92 U	1.4 U	2.74 U	0.286 U	2.39 U	0.495 U	1.19 U	1.46 U	1.34 U
<i>anti</i> -DP	2.8 U	11.7 U	5.61 U	10.9 U	1.15 U	9.55 U	1.98 U	4.77 U	5.85 U	5.36 U
<i>syn</i> -DP	2.8 U	11.7 U	5.61 U	10.9 U	1.15 U	9.55 U	1.98 U	4.77 U	5.85 U	5.36 U
DPTE	0.84 U	3.5 U	1.68 U	3.28 U	0.344 U	2.86 U	0.593 U	1.43 U	1.75 U	1.61 U
HBBz	0.84 U	3.5 U	1.68 U	3.28 U	0.344 U	2.86 U	0.593 U	1.43 U	1.75 U	1.61 U
HCDBCO	1.4 U	5.84 U	2.81 UJ	5.47 U	0.573 U	4.77 U	0.989 U	2.38 U	2.92 U	2.68 U
PBBZ	1.4 U	5.84 U	2.81 U	5.47 U	0.573 U	4.77 U	0.989 U	2.38 U	2.92 U	2.68 U
PBEB	0.7 U	2.92 U	1.4 U	2.74 U	0.286 U	2.39 U	0.495 U	1.19 U	1.46 U	1.34 U
PBT	1.4 U	5.84 U	2.81 U	5.47 U	0.573 U	4.77 U	0.989 U	2.38 U	2.92 U	2.68 U
TBB	5.6 U	23.3 U	11.2 U	21.9 U	2.29 U	19.1 U	3.96 U	9.53 U	11.7 U	10.7 U
TBPH	5.6 U	23.3 U	11.2 U	21.9 U	2.29 U	19.1 U	3.96 U	9.53 U	11.7 U	10.7 U
total TBECH	5.6 UJ	23.3 UJ	11.2 UJ	21.9 UJ	2.29 UJ	19.1 UJ	3.96 UJ	9.53 UJ	11.7 UJ	10.7 UJ

Full compounds names are included in Appendix D. U: Compound not detected at or above reported value. UJ: Compound not detected at or above estimated value. NJ: Compound was tentatively identified and the result is an estimated value. Detected values are bolded and highlighted in green.

Table B-5. Novel Brominated Flame Retardants and Dechlorane Analogs Concentrations (ng/g ww) in Freshwater Fish Samples Collected in Fall 2017.

Analyte	1801013-1	1801013-2	1801013-3	1801013-4	1801013-5	1801013-6	1801013-7	1801013-8	1801013-9	1801013-10	1801013-11	1801013-12
	Lake Ozette	Lake Ozette	Lake Ozette	Lake Ozette	Lake Spokane	Lake Spokane	Lake Spokane	Lake Spokane	Lake Washington	Lake Washington	Lake Washington	Lake Washington
	LMB	LMB	NPM	NPM	LSS	LSS	NPM	NPM	LMB	LMB	LSS	LSS
1,2,4,5/1,2,3,5-TBB	0.156 UJ	0.157 UJ	0.152 UJ	0.149 UJ	0.156 UJ	0.156 UJ	0.164 UJ	0.157 UJ	0.143 UJ	0.148 UJ	0.145 UJ	0.15 UJ
1,2,4-TriBB	4.69 UJ	4.71 UJ	4.55 UJ	4.48 UJ	4.69 UJ	4.67 UJ	4.91 UJ	4.72 UJ	4.28 UJ	4.43 UJ	4.35 UJ	4.49 UJ
1,2-DiBB	1.87 UJ	1.88 UJ	1.82 UJ	1.79 UJ	1.88 UJ	1.87 UJ	1.96 UJ	1.89 UJ	1.71 UJ	1.77 UJ	1.74 UJ	1.8 UJ
1,4-DiBB	3.75 UJ	3.77 UJ	3.64 UJ	3.58 UJ	3.75 UJ	3.74 UJ	3.93 UJ	3.78 UJ	3.43 UJ	3.55 UJ	3.48 UJ	3.59 UJ
ATE	0.625 UJ	0.628 UJ	0.607 UJ	0.597 UJ	0.626 UJ	0.623 UJ	0.655 UJ	0.629 UJ	0.571 UJ	0.591 UJ	0.58 UJ	0.599 UJ
BATE	1.87 UJ	1.88 UJ	1.82 UJ	1.79 UJ	1.88 UJ	1.87 UJ	1.96 UJ	1.89 UJ	1.71 UJ	1.77 UJ	1.74 UJ	1.8 UJ
BTBPE	7.81 UJ	7.85 UJ	7.59 UJ	7.47 UJ	7.82 UJ	7.78 UJ	8.18 UJ	7.87 UJ	7.14 UJ	7.39 UJ	7.25 UJ	7.49 UJ
Dec 602	0.0937 UJ	0.0942 UJ	0.091 UJ	0.0896 UJ	0.0938 UJ	0.0934 UJ	0.0982 UJ	0.0944 UJ	0.0856 UJ	0.0886 UJ	0.087 UJ	0.0899 UJ
Dec 603	0.0937 UJ	0.0942 UJ	0.091 UJ	0.0896 UJ	0.0938 UJ	0.0934 UJ	0.0982 UJ	0.0944 UJ	0.0856 UJ	0.0886 UJ	0.087 UJ	0.0899 UJ
Dec 604	6.25 UJ	6.28 UJ	6.07 UJ	5.97 UJ	6.26 UJ	6.23 UJ	6.55 UJ	6.29 UJ	5.71 UJ	5.91 UJ	5.8 UJ	5.99 UJ
Dechlorane	0.312 UJ	0.314 UJ	0.303 UJ	0.299 UJ	0.313 UJ	0.311 UJ	0.327 UJ	0.315 UJ	0.285 UJ	0.295 UJ	0.29 UJ	0.3 UJ
<i>anti</i> -DP	0.312 UJ	0.314 UJ	0.303 UJ	0.299 UJ	0.313 UJ	0.311 UJ	0.327 UJ	0.315 UJ	0.285 UJ	0.295 UJ	0.29 UJ	0.3 UJ
<i>syn</i> -DP	0.156 UJ	0.157 UJ	0.152 UJ	0.149 UJ	0.156 UJ	0.156 UJ	0.164 UJ	0.157 UJ	0.143 UJ	0.148 UJ	0.145 UJ	0.15 UJ
DPTE	3.75 UJ	3.77 UJ	48.7 UJ	5.44 UJ	39.4 NJ	3.74 UJ	3.93 UJ	3.78 UJ	3.49 UJ	3.55 UJ	3.48 UJ	5.11 UJ
TBB	3.12 UJ	3.14 UJ	3.03 UJ	2.99 UJ	3.13 UJ	3.11 UJ	3.27 UJ	3.15 UJ	2.85 UJ	2.95 UJ	2.9 UJ	3 UJ
HBBz	0.469 UJ	0.471 UJ	0.455 UJ	0.448 UJ	0.469 UJ	0.467 UJ	0.491 UJ	0.472 UJ	0.428 UJ	0.443 UJ	0.435 UJ	0.449 UJ
HCDBCO	0.312 UJ	0.314 UJ	0.303 UJ	0.299 UJ	0.313 UJ	0.311 UJ	0.327 UJ	0.315 UJ	0.285 UJ	0.295 UJ	0.29 UJ	0.3 UJ
PBBB	23.4 UJ	23.6 UJ	22.8 UJ	22.4 UJ	23.5 UJ	23.4 UJ	24.5 UJ	23.6 UJ	21.4 UJ	22.2 UJ	21.8 UJ	22.5 UJ
PBBZ	0.469 UJ	0.471 UJ	0.455 UJ	0.448 UJ	0.469 UJ	0.467 UJ	0.491 UJ	0.472 UJ	0.428 UJ	0.443 UJ	0.435 UJ	0.449 UJ
PBEB	0.469 UJ	0.471 UJ	0.455 UJ	0.448 UJ	0.469 UJ	0.467 UJ	0.491 UJ	0.472 UJ	0.428 UJ	0.443 UJ	0.435 UJ	0.449 UJ
PBT	0.312 UJ	0.314 UJ	0.303 UJ	0.299 UJ	0.313 UJ	0.311 UJ	0.327 UJ	0.315 UJ	0.285 UJ	0.295 UJ	0.29 UJ	0.3 UJ
pTBX	4.69 UJ	4.71 UJ	4.55 UJ	4.48 UJ	4.69 UJ	4.67 UJ	4.91 UJ	4.72 UJ	4.28 UJ	4.43 UJ	4.35 UJ	4.49 UJ
TBCT	0.469 UJ	0.471 UJ	0.455 UJ	0.448 UJ	1.06 NJ	0.866 NJ	0.975 NJ	0.722 NJ	0.428 UJ	1.89 NJ	4.74 NJ	7.08 NJ
Total TBECH	12.5 UJ	12.6 UJ	12.1 UJ	11.9 UJ	12.5 UJ	12.5 UJ	13.1 UJ	12.6 UJ	11.4 UJ	11.8 UJ	11.6 UJ	12 UJ

Full compounds names are included in Appendix D. UJ: Compound not detected at or above estimated value. NJ: Compound was tentatively identified and the result is an estimated value. Detected values are bolded and highlighted in green.

Table B-7. PBDE Concentrations (ng/L) in Surface Water Collected in Fall 2018.

Analyte	Mayfield Lake	Lake Meridian	Lake Ozette	Spanaway Lake	Lake Spokane	Lake Stevens	Vancouver Lake	Lake Washington	Lake Whatcom	West Medical Lake
047	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-049	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-066	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-071	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-099	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-100	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-138	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-153	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-154	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-183	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-184	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-191	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-209	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	156

Full compounds names are included in Appendix D. U: Compound not detected at or above reported value. Detected values are bolded and highlighted in green.

Table B-7. PBDE Concentrations (ng/L) in Surface Water Collected in Spring 2018.

Analyte	Mayfield Lake	Lake Meridian	Lake Ozette	Spanaway Lake	Lake Spokane	Lake Stevens	Vancouver Lake	Lake Washington	Lake Whatcom	West Medical Lake
047	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-049	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-066	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-071	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-099	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-100	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
-138	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-153	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-154	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-183	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-184	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-191	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
-209	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U

Full compounds names are included in Appendix D. U: Compound not detected at or above reported value.

Table B-8. PBDE Concentrations (ng/g dw) in Lake Sediment Samples Collected in Spring 2018.

Analyte	Mayfield Lake	Lake Meridian	Lake Ozette	Spanaway Lake	Lake Spokane	Lake Stevens	Vancouver Lake	Lake Washington	Lake Whatcom	West Medical Lake
-047	0.532 U	3.24	1.15 U	0.756 J	0.245 U	0.904 J	0.404 U	0.866	0.367 J	1.1 U
-049	0.532 U	2.16 J	1.15 U	2.29 U	0.245 U	0.378 J	0.404 U	0.222 J	1.24 U	0.414 J
-066	0.532 U	2.65 U	1.15 U	2.29 U	0.245 U	1.72 U	0.404 U	0.825 U	1.24 U	1.1 U
-071	0.532 U	2.65 U	1.15 U	2.29 U	0.245 U	1.72 U	0.404 U	0.825 U	1.24 U	1.1 U
-099	0.532 U	1.85 J	1.15 U	2.29 U	0.245 U	0.745 J	0.404 U	1.48	1.24 U	1.1 U
-100	0.532 U	0.729 J	1.15 U	2.29 U	0.245 U	1.72 U	0.404 U	0.449 J	1.24 U	1.1 U
-138	1.06 U	5.3 U	2.31 U	4.57 U	0.491 U	3.44 U	0.807 U	1.65 U	2.47 U	2.21 U
-153	1.06 U	5.3 U	2.31 U	4.57 U	0.491 U	3.44 U	0.807 U	0.488 J	2.47 U	2.21 U
-154	1.06 U	5.3 U	2.31 U	4.57 U	0.491 U	3.44 U	0.807 U	1.65 U	2.47 U	2.21 U
-183	1.06 U	5.3 U	2.31 U	4.57 U	0.491 U	3.44 U	0.807 U	1.65 U	2.47 U	2.21 U
-184	1.06 U	5.3 U	2.31 U	4.57 U	0.491 U	3.44 U	0.807 U	1.65 U	2.47 U	2.21 U
-191	1.06 U	5.3 U	2.31 U	4.57 U	0.491 U	3.44 U	0.807 U	1.65 U	2.47 U	2.21 U
-209	6.44	40.6	5.76 U	11.4 U	1.23 U	8.61 U	2.02 U	15	6.18 U	5.51 U

Full compounds names are included in Appendix D. J: Compound was positively identified and the associated value is an estimated concentration.
 U: Compound not detected at or above reported value. Detected values are bolded and highlighted in green.

Table B-8. PBDE Concentrations (ng/g dw) in Lake Sediment Samples Collected in Spring 2018.

Analyte	1801013-1	1801013-2	1801013-3	1801013-4	1801013-5	1801013-6	1801013-7	1801013-8	1801013-9	1801013-10	1801013-11	1801013-12
	Lake Ozette	Lake Ozette	Lake Ozette	Lake Ozette	Lake Spokane	Lake Spokane	Lake Spokane	Lake Spokane	Lake Washington	Lake Washington	Lake Washington	Lake Washington
	LMB	LMB	NPM	NPM	LSS	LSS	NPM	NPM	LMB	LMB	LSS	LSS
-047	0.222 U	0.073 J	0.103 J	0.214 U	62.3	49.5	13.2	11.3	0.386	1.32	10.3	14.1
-049	0.222 U	0.219 U	0.215 U	0.214 U	0.745	0.849	1.21	1.03	0.084 J	0.253	0.451	0.844
-066	0.222 U	0.219 U	0.215 U	0.214 U	0.212 U	0.221 U	0.218 U	0.219 U	0.221 U	0.218 U	0.217 U	0.219 U
-071	0.222 U	0.219 U	0.215 U	0.214 U	0.212 U	0.221 U	0.218 U	0.219 U	0.221 U	0.218 U	0.217 U	0.219 U
-099	0.222 U	0.112 J	0.215 U	0.214 U	0.212 U	0.221 U	0.218 U	0.219 U	0.162 J	0.464	0.217 U	0.219 U
-100	0.222 U	0.219 U	0.08 J	0.214 U	12.7	12.4	5.03	4.55	0.134 J	0.325	2.51	5.12
-138	0.444 U	0.438 U	0.429 U	0.427 U	0.425 U	0.443 U	0.435 U	0.437 U	0.442 U	0.436 U	0.434 U	0.438 U
-153	0.444 U	0.438 U	0.429 U	0.427 U	0.393 J	0.439 J	0.539	0.437 U	0.442 U	0.436 U	0.434 U	0.312 J
-154	0.444 U	0.438 U	0.429 U	0.427 U	2.69	2.54	1.05	0.957	0.442 U	0.436 U	0.682	1.42
-183	0.444 U	0.438 U	0.429 U	0.427 U	0.425 U	0.443 U	0.435 U	0.437 U	0.442 U	0.436 U	0.434 U	0.438 U
-184	0.444 U	0.438 U	0.429 U	0.427 U	0.425 U	0.443 U	0.435 U	0.437 U	0.442 U	0.436 U	0.434 U	0.438 U
-191	0.444 U	0.438 U	0.429 U	0.427 U	0.425 U	0.443 U	0.435 U	0.437 U	0.442 U	0.436 U	0.434 U	0.438 U
-209	1.11 U	1.09 U	1.07 U	1.07 U	1.06 U	1.11 U	1.09 U	1.09 U	1.11 U	1.09 U	1.08 U	1.09 U

Full compounds names are included in Appendix D. J: Compound was positively identified and the associated value is an estimated concentration.
 U: Compound not detected at or above reported value. Detected values are bolded and highlighted in green.

Appendix C. Ancillary Data on Fish Samples

Table C-1. Biological and Composite Data on Fish Samples Analyzed for this Study.

Waterbody	Species	Collection Date	Sample ID	Number of Fish in Composite	Lipids-MEL (%)	Mean Fish Length (mm)	Mean Fish Weight (g)	Mean Fish Age (yr)
Lake Ozette	Largemouth bass	10/17/2017	1801013-01	5	0.74	292	356	2.0
Lake Ozette	Largemouth bass	10/17/2017	1801013-02	5	1.06	381	882	3.4
Lake Ozette	Northern pikeminnow	10/17/2017	1801013-03	3	0.78	330	348	9.0
Lake Ozette	Northern pikeminnow	10/17/2017	1801013-04	3	0.58	373	349	10
Lake Spokane	Largescale sucker	10/10/2017	1801013-05	5	2.47	475	1138	14
Lake Spokane	Largescale sucker	10/10/2017	1801013-06	5	2.18	529	1493	17
Lake Spokane	Northern pikeminnow	10/11/2017	1801013-07	5	2.15	393	602	10
Lake Spokane	Northern pikeminnow	10/11/2017	1801013-08	5	1.56	426	760	11
Lake Washington	Largemouth bass	10/3/2017	1801013-09	5	0.81	215	148	1.0
Lake Washington	Largemouth bass	10/3/2017	1801013-10	3	1.27	343	755	2.7
Lake Washington	Largescale sucker	10/3/2017	1801013-11	5	3.29	499	1424	11
Lake Washington	Largescale sucker	10/3/2017	1801013-12	5	3.15	507	1455	11

Appendix D. Sample Collection Locations.

Table D-1. Coordinates of Surface Water, Sediment, and Fish Tissue Sampling Locations.

Waterbody	County	Surface water sampling location*		Sediment sampling location*		Centroid of fish sampling location*	
Lake Meridian	King	47.363	-122.154	47.363	-122.154	---	---
Lake Ozette	Clallam	48.082	-124.646	48.107	124.651	48.0967	-124.634
Lake Spokane	Spokane	47.812	-117.796	47.812	-117.796	47.83	-117.626
Lake Stevens	Snohomish	48.008	-122.092	48.011	-122.093	---	---
Lake Washington (south basin)	King	47.520	-122.252	47.520	-122.252	47.518	-122.234
Lake Whatcom (basin 1)	Whatcom	48.761	-122.407	48.759	-122.406	---	---
Mayfield Lake	Cowlitz	46.506	-122.578	46.506	-122.578	---	---
Spanaway Lake	Pierce	47.113	-122.449	47.113	-122.448	---	---
Vancouver Lake	Clark	45.674	-122.716	45.674	-122.730	---	---
West Medical Lake	Spokane	47.575	-117.711	47.575	-117.711	---	---

*NAVD88 decimal degree

Appendix E. Analytes Measured

Table E-1. Analytes Names and Median Reporting Limits for this study by Matrix.

Analyte Group	Chemical Name	CAS Number	Acronym	Surface Water Median LOQ (ng/L)	Sediment Median LOQ (ng/g dw)	Fish Tissue LOQ Median (ng/g ww)
OPFRs	2-Ethylhexyl diphenyl phosphate	1241-94-7	EHDPP	0.5	17	---
	Tetrakis(2-chlorethyl)dichloroisopentyldiphosphate	38051-10-4	V6	0.5	2.1	---
	Tributyl phosphate	126-73-8	TBP	0.5	4.2	---
	Tricresyl phosphate	1330-78-5	TCrP	0.5	2.1	---
	Triethyl phosphate	78-40-0	TEP	0.5	2.1	---
	Triphenyl phosphate	115-86-6	TPP	0.5	2.1	---
	Tripropyl phosphate	513-08-6	TPrP	0.5	4.2	---
	Tris(1,3-dichloro-2-propyl) phosphate	13674-87-8	TDCPP	4.9	17	---
	Tris(2,3-dibromopropyl) phosphate	126-72-7	TDBPP	4.9	17	---
	Tris(2-butoxyethyl) phosphate	78-51-3	TBEP	0.5	4.2	---
	Tris(2-chloroethyl) phosphate	115-96-8	TCEP	0.5	8.4	---
	Tris(2-chloroisopropyl) phosphate	13674-84-5	TCPP	25	4.2	---
	Tris(2-ethylhexyl) phosphate	78-42-2	TEHP	0.5	2.1	---
NBFRs and Decs	Dechlorane (Mirex)	2385-85-5	Dechlorane	---	1.4	0.6
	Dechlorane plus® (DP) Anti	135821-74-8	<i>anti</i> -DP	---	5.6	0.6
	Dechlorane plus® (DP) Syn	135821-03-3	<i>syn</i> -DP	---	5.6	0.3
	Dechlorane 602	31107-44-5	Dec-602	---	2.8	0.2
	Dechlorane 603	13560-92-4	Dec-603	---	1.4	0.2
	Dechlorane 604 component A	34571-16-9	Dec-604	---	5.6	12
	Hexachlorocyclopentadienyl-dibromocyclooctane	51936-55-1	HCDBCO	---	2.8	0.6
	2,4,6- Tribromophenyl allyl ether	3278-89-5	ATE	---	2.8	1.2
	2-Bromoallyl 2,4,6-tribromophenyl ether	99717-56-3	BATE	---	---	3.7
	2,3-Dibromopropyl 2,4,6-tribromophenyl ether	35109-60-5	DPTE	---	1.7	7.4
	1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1	BTBPE	---	11	15
	2-Ethylhexyl 2,3,4,5-tetrabromobenzoate	183658-27-7	TBB	---	11	6.2
	1,2-Dibromo-4-(1,2-dibromoethyl)cyclohexane	3322-93-8	total TBECH	---	11	25
	Hexabromobenzene	87-82-1	HBBz	---	1.7	0.9
	Pentabromobenzene	608-90-2	PBBZ	---	2.8	0.9
	1,2,4,5-Tetrabromobenzene	636-28-2	1,2,4,5-TBB	---	1.4	---
	1,2,3,5-Tetrabromobenzene	634-89-9	1,2,3,5-TBB	---	1.4	---
	1,2,4-Tribromobenzene	615-54-3	1,2,4-TriBB	---	1.4	9.2
	1,2-Dibromobenzene	583-53-9	1,2-DiBB	---	1.4	3.7
	1,4-Dibromobenzene	106-37-6	1,4-DiBB	---	1.4	7.4
	2,3,4,5,6-Pentabromotoluene	87-83-2	PBT	---	2.8	0.6
	Pentabromoethylbenzene	85-22-3	PBEB	---	1.4	0.9
	1,2-bis(2,3,4,5,6-pentabromophenyl)ethane	84852-53-9	DBDPE	---	11	---
	Bis(2-ethylhexyl)tetrabromophthalate	26040-51-7	TBPH	---	11	---
	Pentabromobenzyl bromide	38521-51-6	PBBB	---	---	46
	Tetrabromo-p-xylene	23488-38-2	pTBX	---	---	9.2

Analyte Group	Chemical Name	CAS Number	Acronym	Surface Water Median LOQ (ng/L)	Sediment Median LOQ (ng/g dw)	Fish Tissue LOQ Median (ng/g ww)
	Tetrabromo-o-chlorotoluene	39569-21-6	TBCT	---	---	0.9
PBDEs	polybrominated diphenyl ether 047	5436-43-1	BDE-047	2.0	1.2	1.2
	polybrominated diphenyl ether 049	243982-82-3	BDE-049	2.0	1.2	0.2
	polybrominated diphenyl ether 066	189084-61-5	BDE-066	2.0	1.2	0.2
	polybrominated diphenyl ether 071	189084-62-6	BDE-071	2.0	1.2	0.2
	polybrominated diphenyl ether 099	60348-60-9	BDE-099	2.0	1.2	0.2
	polybrominated diphenyl ether100	189084-64-8	BDE-100	2.0	1.2	0.2
	polybrominated diphenyl ether 138	182677-30-1	BDE-138	4.0	2.3	0.4
	polybrominated diphenyl ether 153	68631-49-2	BDE-153	4.0	2.3	0.4
	polybrominated diphenyl ether 154	207122-15-4	BDE-154	4.0	2.3	0.4
	polybrominated diphenyl ether 183	207122-16-5	BDE-183	4.0	2.3	0.4
	polybrominated diphenyl ether 184	117948-63-7	BDE-184	4.0	2.3	0.4
	polybrominated diphenyl ether 191	446255-30-7	BDE-191	4.0	2.3	0.4
	polybrominated diphenyl ether 209	1163-19-5	BDE-209	10	5.8	1.1

LOQ = limit of quantitation

Appendix F. Glossary, Acronyms, and Abbreviations

Glossary

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

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

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

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
LOQ	limit of quantitation
MEL	Manchester Environmental Laboratory
NBFR	novel brominated flame retardants
PBDE	polybrominated diphenyl ethers
OPFR	organophosphate flame retardants
PBT	persistent, bioaccumulative, and toxic substance
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
SRM	Standard reference materials
T-	total- (summed value)
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
g	gram, a unit of mass
ng/g dw	nanograms per gram dry weight (parts per billion)
ng/g ww	nanograms per gram wet weight (parts per billion)
ng/L	nanograms per liter (parts per trillion)
ppt	parts per trillion