Framework for the Development of the Columbia River Mainstem Fish Tissue and Water Quality Monitoring Program – Bonneville Dam to Canadian Border

December 27, 2022

Authors:

Timothy D Counihan, U.S. Geological Survey, Western Fisheries Research Center, Columbia River Research Laboratory, Cook, Washington, United States of America

Patrick W Moran, U.S. Geological Survey, Washington Water Science Center, Tacoma, Washington, United States of America

Ian Waite, U.S. Geological Survey, Oregon Water Science Center, Portland, Oregon, United States of America

Sherrie Duncan, Sky Environmental, Tacoma, Washington, United States of America

Laura Shira, Yakama Nation Fisheries, Yakima, Washington, United States of America

Principal Reviewers:

Dianne Barton, Columbia River Inter-Tribal Fish Commission, Watershed Department, Portland, Oregon, United States of America

Will Hobbs, Washington State Department of Ecology, Environmental Program, Olympia, Washington, United States of America

Mike Mulvey, Oregon Department of Environmental Quality, Portland, Oregon, United States of America

This project has been funded wholly or in part by the U.S. Environmental Protection Agency under assistance agreement RB01J72601 to Confederated Tribes and Bands of the Yakama Nation. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Executive Summary

The Columbia River provides important cultural, economic, and ecological services to a significant portion of the United States. Anadromous and resident fish species and other wildlife are integrated into the cultural traditions of all Tribes in the Columbia River Basin. Salmon, lamprey, sturgeon, and resident fish are an integral part of Tribal religion, culture, and physical sustenance. Despite concerns about the effect of contaminants on the aquatic ecosystem, the disproportionate effects of contaminants on members of Tribal sovereignties, and the known effects of contaminants on species protected under the Endangered Species Act, efforts to address toxic chemical pollution in the Columbia River have been limited. The lack of a dedicated contaminant monitoring program impedes evaluation and decision making regarding the health of the Columbia River ecosystem, as well as human health for Tribal members and others that consume fish and other biota from the Columbia River.

The purpose of this framework is to provide guidance for the development of a long-term program (Program) that provides the basis for assessing the status and trends of contaminants in fish, sediment, water, and invertebrates along the 962-kilometer length of the Columbia River from the Bonneville Dam upriver to the Canadian Border (Figure ES1).

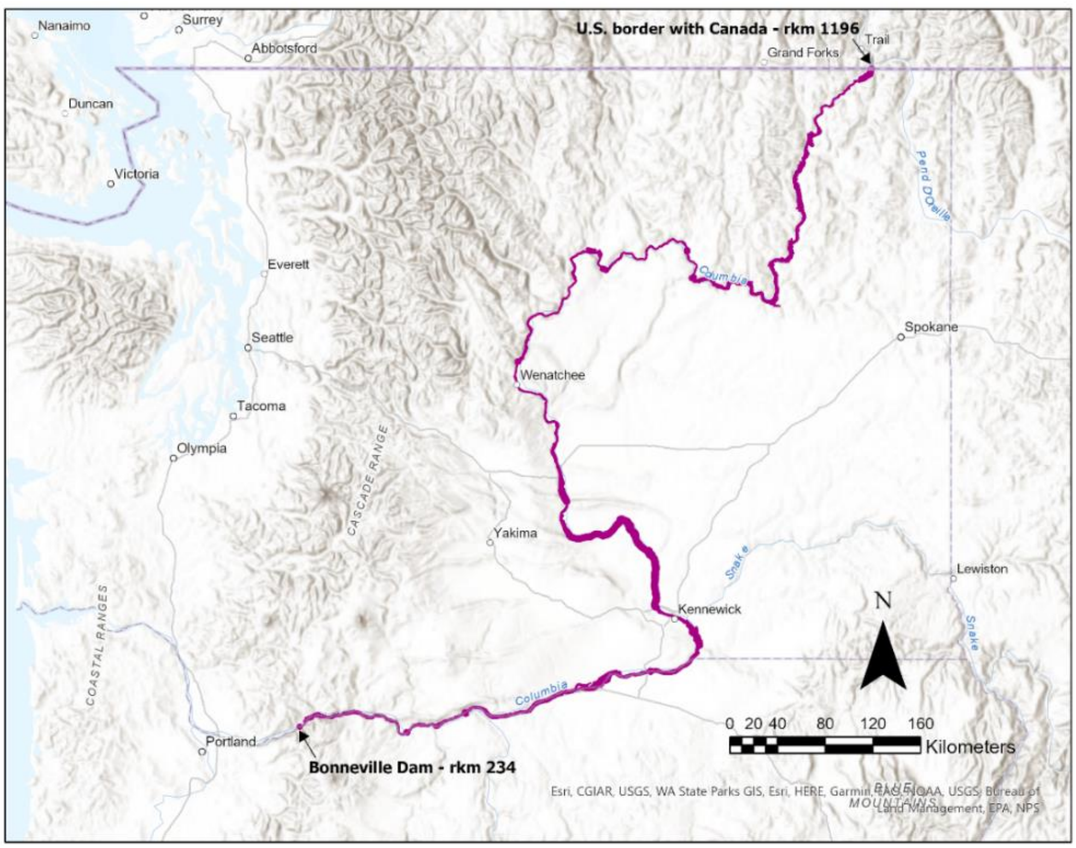

Figure ES1. The study area for the Columbia River Fish Tissue and Water Quality Monitoring Program that encompasses the Columbia River (purple) from Bonneville Dam (rkm 234) to the U.S. border with Canada (rkm 1196). Sources: Esri, CGIAR, USGS, WA State Parks, GIS, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

This framework will focus on four persistent and bioaccumulative classes of toxic contaminants:

- Mercury
- Polychlorinated biphenyls (PCBs)
- Dichlorodiphenyltrichloroethane (DDT)
- Polybrominated diphenyl ethers (PBDEs)

Media of interest in this framework include anadromous and resident fish, sediment, invertebrates, biofilm, and surface water.

Future consideration of additional contaminants could include pesticides, per or poly-fluoroalkyl substances, 6PPD-quinone, and contaminants of emerging concern (CECs), which comprises a diverse group of anthropogenic chemicals that include thousands of pharmaceuticals, hormones, illicit drugs, new pesticides, personal care products, flame retardants, artificial sweeteners, perfluorinated compounds, disinfection byproducts, ultraviolet filters, and other industrial chemicals.

This framework includes the vision, goals, and objectives for the Program. The vision for the Program is that it will *provide the basis for assessing the status and trends of contaminants in the Columbia River to guide ecosystem recovery resulting in clean, healthy fish for current and future generations*. The goals of the Program are to 1) conduct long-term monitoring to assess the spatial and temporal status and trends of toxics in fish, water, sediment, and other potential media in the Columbia River mainstem, from Bonneville Dam to the Canadian Border in perpetuity, 2) stimulate conversion of science into action by providing information to facilitate future decision making that improves ecosystem function and reduces contaminants in all levels of the food chain, and 3) adaptively manage the Program to address new key questions, incorporate new and emerging science advancements, and respond to community information needs.

To facilitate achieving these goals, this framework provides details on technical planning; community outreach and engagement; and adaptive management to promote understanding and improve future decision making over the long-term, including updating the Program with new and emerging science and community needs. Additionally, data associated with the Program will be made available to the public through the EPA Water Quality Exchange (https://www.epa.gov/waterdata/water-quality-data). Documents and other materials associated with the Program can be accessed via a website hosted by Yakama Nation Fisheries (https://yakamafish-nsn.gov/restore/projects/columbia-river-mainstem-water-quality-monitoring-program).

Although the Program is limited to the Columbia River upstream of the Bonneville Dam, collaboration with other entities that monitor contaminants in the Columbia River Basin, including the Columbia River estuary below Bonneville Dam, are also an important component of outreach. Our goal is to encourage efforts to ensure data comparability across programs and recognize that the growth and adaptive management of the Program considers basin-wide monitoring developments.

Table of Contents

Figures

Tables

Supplemental Materials

Acronyms

6PPD-Q	6PPD-quinone
BEST	USGS Biomonitoring of Environmental Status and Trends
CEC	Contaminants of Emerging Concern
CRB	Columbia River Basin
CRBRP	Columbia River Basin Restoration Program
CRITFC	Columbia River Inter-Tribal Fish Commission
CWA	Clean Water Act
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DDx	any or all of the six DDT isomers (p,p'-DDT; p,p'-DDD, p,p'-DDE; o,p'-DDT; o,p'-DDD; o,p'-DDE)
EIM	Environmental Information Management System
ESA	Endangered Species Act
GIS	geographic information system
GRTS	Generalized Random Tessellation Stratified
HASP	Health and Safety Plan
ISSPP	Invasive Species Spread and Prevention Plan
km	kilometers
LAEs	large aquatic ecosystems
NWIS	USGS National Water Information System
ODEQ	Oregon Department of Environmental Quality
OHA	Oregon Health Authority
PAHs	polycyclic aromatic hydrocarbons
PBDEs	polybrominated diphenyl ethers
PCBs	polychlorinated biphenyls
PFAS	Per- or poly-fluoroalkyl substances
PFOS	perfluorooctane sulfonic acid
Project Team	CRITFC, ODEQ, USGS, and WA Ecology
QAPPs	Quality Assurance Project Plans
rkm	river kilometers
SOPs	Standard Operating Procedures
USGS	U.S. Geological Survey
WA Ecology	Washington Department of Ecology
WDOH	Washington Department of Health
Working Group	Columbia River Basin Restoration Working Group
WQX	EPA Water Quality Exchange

Introduction

The Columbia River provides important cultural, economic, and ecological services to a significant portion of the United States. The importance of the Columbia River ecosystem to Tribal sovereignties in the Columbia River Basin (CRB) is well documented. Anadromous and resident fish species and other wildlife are integrated into the cultural traditions of all Tribes in the CRB. Salmon are an integral part of Tribal religion, culture, and physical sustenance (Sams, 2007). Fisheries and other water-related resources (e.g., irrigation water supply) have significant economic and recreational value to Tribal and non-Tribal entities (CRITFC, 1996; IEAB 2005). A 2005 report commissioned by the Northwest Power and Planning Council estimates, "The $109 million generated in the Pacific Northwest states of Washington, Oregon, and Idaho of personal income [from CRB anadromous salmonid production] may support about 3,633 jobs." (IEAB, 2005). The Columbia River also provides for many ecological services including hydropower, food, and recreation (Flores et al., 2017).

Many reaches of the Columbia River do not meet Washington and Oregon's water quality standards, yet routine monitoring of contaminants in Columbia River fish is rare. Washington's Department of Ecology (WA Ecology) has 26 Clean Water Act 303(d) listings for polychlorinated biphenyls (PCBs) and pesticides, (WA Ecology, 2022) on the Columbia River. Current and past industrial discharges into the Columbia River have resulted in contamination of sediments and water (USEPA, 2009). In a 2007 contaminants survey, approximately 16% of the Columbia River estuary area was in poor condition with respect to sediment contamination (Hayslip et al., 2007). In the lower Columbia River, Alvarez et al. (2014) found contaminants in passive water samplers showed trends of lower concentrations in rural areas to higher concentrations at more urbanized sites in the lower Columbia River. Counihan et al. (2014) found that reach-specific trends in contaminants in sediment samples agreed with trends in tissue concentrations observed in birds and fish (Henny et al., 2011; Nilsen et al., 2014). Nilsen et al. (2014) investigated food web transport pathways in the Columbia River Estuary and documented bioaccumulation of certain contaminants and potential negative effects in multiple levels of the ecosystem, including fish consumers.

Exposure of fish, wildlife, and people to contaminants within the Columbia River Basin has caused concern (USEPA, 2009). Contaminants measured in the past from Columbia River fish included PCBs, dioxins, furans, arsenic, mercury, and dichlorodiphenyldichloroethylene (DDE), a toxic breakdown product of the pesticide dichlorodiphenyltrichloroethane [DDT; (USEPA, 2009)]. A contaminants survey completed in the late 1990s detected 92 contaminants, suggesting a potential health threat to Tribe members and other people who eat fish from the Columbia River (USEPA, 2002). Contamination of Lake Roosevelt has been and is the subject of ongoing international negotiations to reduce pollution and clean up contamination (Besser et al., 2018). A survey for fish contaminants was completed for the Hanford Reach (Lerch et al., 2013). The Oregon Department of Environmental Quality (ODEQ) (Caton, 2012) found concentrations of DDTs and PCBs in resident fish that exceed ODEQ's human health criteria. In

March 2022, the U.S. Environmental Protection Agency (EPA) officially added Bradford Island, part of the Bonneville Dam complex in the Columbia River, as a Superfund site on the National Priorities List due to PCBs, toxic metals, and other chemical contamination found in upland areas, river sediments, and biota.

The Columbia River from the Bonneville Dam to the Canadian border is affected by 40 site- and resident fish species- specific Fish Consumption Advisories issued by the Washington Department of Health (WDOH) (https://www.doh.wa.gov/CommunityandEnvironment/Food/Fish/Advisories). Most recently, advisories were issued for lamprey and sturgeon in 2022. The Fish Consumption Advisories are due to elevated levels of mercury, PCBs, and pesticides in 19 species of fish (OHA, 2013; WDOH, 2012; WDOH, 2022). Tribal members consume fish at a much higher rate than other people, with historical, unsuppressed fish consumption rates upwards of 1,000 grams/day (Polissar et al., 2016). Tribal members are at significantly higher risk because fish consumption rates are more than 20 times higher than the average American rate (CRITFC, 1994). In the U.S., there are approximately 799 listed toxic cleanup sites with legacy contamination potentially discharging to surface water within a half mile of the Columbia River (Yakama Nation, 2022a). In addition, point and nonpoint sources from population centers, roads, dams, rail, and agriculture continue to contribute toxics to the Columbia River. The Columbia River contains many resources that are important to Tribes, including traditional treaty protected fishing areas. Detected PCBs in resident fish tissue are some of the highest in the nation. As a result, both the Oregon Health Authority (OHA) and WDOH issued a “DO NOT EAT ANY” resident fish advisory specific to the Bradford Island site (OHA, 2012). Resident fish tissue can comprise a significant portion of a Tribal member’s diet (CRITFC, 1994).

Despite concerns about the effect of contaminants on the aquatic ecosystem (USEPA, 2009), the disproportionate effects of contaminants on members of Tribal sovereignties (Harper and Walker, 2015), and the known effects of contaminants on species protected under the Endangered Species Act (ESA) (Lundin et al., 2019, Lundin et al., 2021; MacNeale et al., 2010), efforts to address the pollution by toxic chemicals in the Columbia River remain limited. There is currently no dedicated monitoring program on the Columbia River that specifically monitors the status and trends of contaminants in fish and water quality. The lack of a dedicated contaminant monitoring program impedes evaluation and decision making regarding the health of the river. There are currently no clear cleanup goals or benchmarks of progress for toxic reduction in the mainstem Columbia River. These concerns were recognized in the CRB Toxics Reduction Action Plan (USEPA, 2010); Initiative 3 (Conduct monitoring to identify sources and then reduce toxics) and Initiative 4 (Develop a regional, multi-agency research and monitoring program) of the Action Plan (USEPA, 2010) stress the need for monitoring.

The purpose of this framework document is to provide expert guidance for the development of a long-term program (hereafter Program) that provides the basis for assessing the status and trends of contaminants in fish, sediment, water, and other media in the Columbia River.

Management of the Columbia River in the U.S. is a Federal, multi-State, and Tribal partnership that requires leadership from each. To accomplish this, we collaborated with key stakeholders and others to develop a monitoring program framework for assessing the status and trends in contaminants in fish, sediment, invertebrates, and water. We also provide guidance for data management, including long-term storage and information sharing of publicly available monitoring data and metadata, community outreach and engagement, and adaptive management to promote understanding and improve future decision making. Over the long-term, it is expected that the Program will evolve with new and emerging science and community needs. This framework includes the vision, goals, and objectives for the Program; technical planning; community outreach and engagement, and adaptive management to promote understanding and improve future decision making over the long-term, including updating the Program with new and emerging science and community needs.

Policy and Planning Context

CWA Section 123

Congress amended the Clean Water Act (CWA) in 2016 by adding Section 123, which required the USEPA to establish a CRB Restoration Program (CRBRP). It was the first legislation to officially designate the national importance of restoring the CRB, one of our nation's largest watersheds. The legislation focuses on the U.S. portion of the CRB and provides a framework for future funding of toxic reduction, monitoring, and outreach actions. The legislation directed EPA to 1) establish a CRB Restoration Grant Program to support voluntary actions to reduce and assess toxics throughout the Basin; and 2) establish a Working Group representative of states, Tribal governments, and other entities in the Basin. See 33 U.S. Code § 1275 at www.govinfo.gov/content/pkg/USCODE-2016-title33/pdf/USCODE-2016-title33-chap26-subchapI-sec1275.pdf.

Columbia River Toxics Reduction Working Group

The EPA and many partners have been working together to reduce toxic contamination in the CRB. In 2005, EPA convened Tribal, federal, state, local, industry, and non-governmental partners to form the collaborative Columbia River Toxics Reduction Working Group, now referred to as the Columbia River Basin Restoration Working Group (Working Group) to share information, coordinate, and develop actions to identify, better understand, and reduce toxics in the CRB. The success of this basin-wide collaboration to reduce toxics created the foundation for the 2016 amendment to the CWA Section 123, creating the CRBRP. The Working Group has developed technical and informational products over the years that have helped guide the development of this Program framework (e.g., USEPA, 2009).

The Columbia River

The study area for the Program encompasses 962 river kilometers (rkm) of the Columbia River from Bonneville Dam (rkm 234) to the U.S. border with Canada (rkm 1196) (Figure 1).

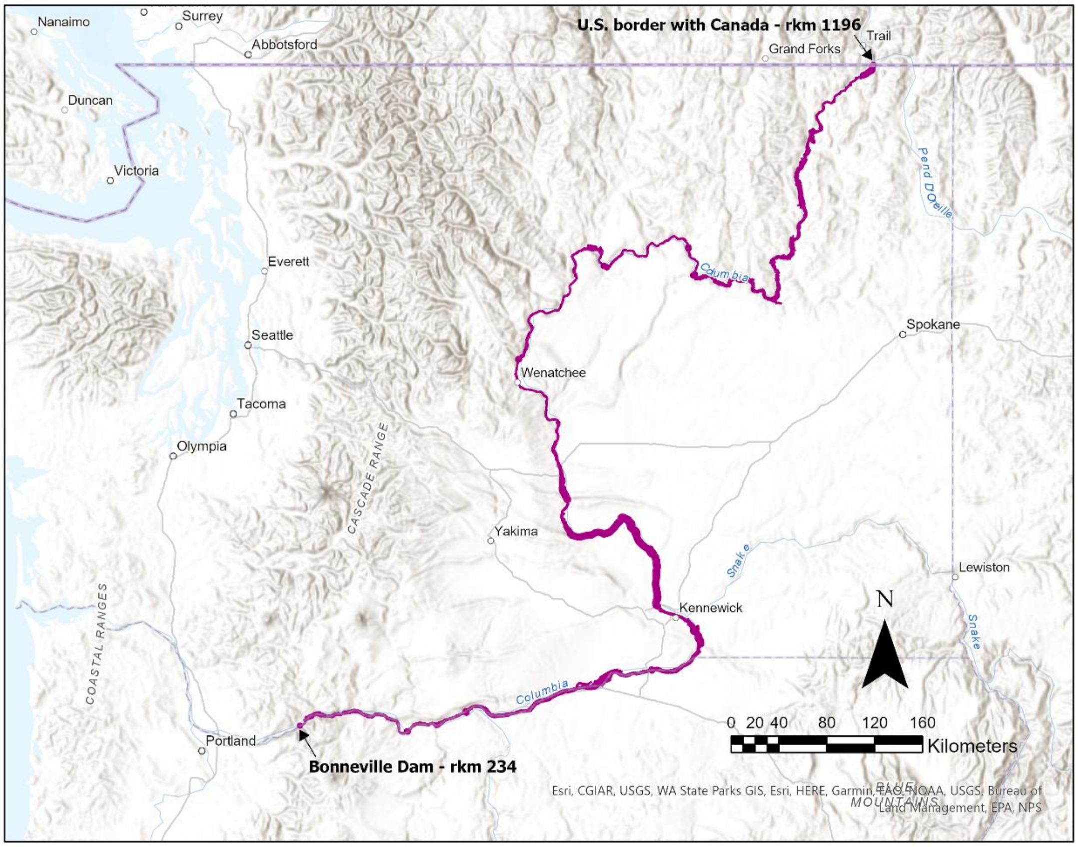

Figure 1. The study area for the Columbia River Fish Tissue and Water Quality Monitoring Program that encompasses the Columbia River (purple) from Bonneville Dam (rkm 234) to the U.S. border with Canada (rkm 1196). Sources: Esri, CGIAR, USGS, WA State Parks, GIS, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

The Columbia River drains 674,000 square kilometers of western North America, flowing 2,000 kilometers (km) from the river's headwaters at Columbia Lake in southeastern British Columbia, Canada, to its confluence with the northeast Pacific Ocean near Astoria, Oregon. In terms of drainage area, the Columbia River is the 39th largest river basin in the world (Vörösmarty et al., 2000), but it ranks within the top twenty with respect to mean discharge of primary rivers entering seas or oceans (Meade, 1996). By discharge volume, the Columbia River is the largest river to enter the northeast Pacific Ocean and conveys 77 percent of the total runoff from western North America (Hickey & Banas, 2003).

The river basin is high and steep compared to other large rivers; of the 50 largest rivers entering seas or oceans, it has the seventh highest mean elevation and the fifth highest slope (Vörösmarty et al., 2000). The Columbia River drains several physiographic provinces, including the middle and northern Rocky Mountains, Columbia Plateau, Cascade Range, and Pacific

Border (Benito & O'Connor, 2003; Fenneman & Johnson, 1946). The Columbia River includes parts of British Columbia, Canada; most of Idaho; large parts of Oregon and Washington; and small areas of Montana, Wyoming, Utah, and Nevada. The Columbia is one of the most hydroelectrically developed river systems in the world, generating more than 21 million kilowatts, annually.

The Columbia River is home to iconic anadromous fish species such as Chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, chum salmon *O. keta*, sockeye salmon *O. nerka*, steelhead trout *O. mykiss*, Pacific lamprey *Entosphenus tridentatus*, and western river lamprey *Lampetra ayresii*. Currently there are 12 ESA-listed stocks of anadromous fish species that are the subject of extensive and expensive recovery efforts. The Columbia River also supports resident fish populations that include white sturgeon *Acipenser transmontanus*, (which were diadromous prior to being landlocked by passage barriers created by the dams) that are North America's largest freshwater fish. The fisheries in the Columbia River provide significant economic benefits to the regional economy and cultural value to Tribal sovereign nations.

Program Development

The development of a monitoring and assessment program benefits from planning efforts that incorporate stakeholder's expectations and needs with program design elements. Such planning efforts have been a key step in several, successful long-term monitoring programs, such as the Puget Sound Ecosystem Monitoring and Assessment Program (Biedenweg et al., 2017), Upper Mississippi River (Bouska et al., 2018), the National Water Quality Assessment Program, and the EPA Environmental Monitoring and Assessment Program. Successful long-term monitoring programs often have several features in common including: 1) have well formulated and tractable questions that were posed before the monitoring program was initiated; 2) are guided by a rigorous statistical design that facilitates the evaluation of the questions, 3) have strong collaborative partnerships among key stakeholder groups; 4) produce data that have management relevance, 5) and have the ability to evolve and develop in response to new information or new questions (Lindenmayer & Likens, 2009).

To initiate the process of formulating the framework for the Program, representatives from the Yakama Nation, the Columbia River Inter-Tribal Fish Commission (CRITFC), ODEQ, the U.S. Geological Survey (USGS), and WA Ecology (collectively hereafter referred to as Project Team), developed a vision statement, goals, and objectives for the Program.

Vision Statement

Assess the status and trends of contaminants in the Columbia River to guide ecosystem recovery resulting in clean, healthy fish for current and future generations.

Goals and Objectives

Goal 1. Conduct long-term monitoring to assess the spatial and temporal status and trends of toxics in fish, water, sediment, and other potential media in the Columbia River mainstem, from Bonneville Dam to the Canadian Border in perpetuity.

- Objective 1) Conduct monitoring across the study area to identify areas with higher concentration of toxics in fish and other media.
- Objective 2) Conduct monitoring across the study area to identify areas with low concentrations of toxics in fish and other media that need protection.
- Objective 3) Conduct sampling periodically to assess whether toxic concentrations in fish and other media are improving, staying the same, or getting worse over time in the study area and in subdivisions of the study area.

Goal 2. Stimulate conversion of science into action by providing information to facilitate future decision making that improves ecosystem function and reduces contaminants in all levels of the food chain.

- Objective 1) Identify or design and implement a program-specific data management system, including long-term storage and information sharing.
- Objective 2) Engage and collaborate with the Project Team, key stakeholders, and organizations interested in improving the health and resilience of the Columbia River.
- Objective 3) Provide recommendations for further investigation, cleanup, source control, and restoration.
- Objective 4) Implement a Community Engagement and Outreach Plan.
- Objective 5) Support research into key questions, described below.

Goal 3. Adaptively manage the program to 1) address new key questions, 2) incorporate new and emerging science advancements, and 3) respond to community information needs.

- Objective 1) Conduct a periodic review of the Program to assess whether aspects of the monitoring design need to be adjusted (e.g., do more samples or additional contaminants need to be collected/analyzed to achieve the goals of the program).
- Objective 2) Conduct a periodic review of field and analytical methods to assess whether new technologies can be incorporated into the monitoring program.
- Objective 3) Conduct a periodic review of the program to assess whether there are new objectives or questions that need to be addressed.

Key Questions

- Are fish in the Columbia River safe to eat?
- What is the status (what is the condition now) and trends (comparisons over time) of contaminants in fish and other media?
- How are contaminants affecting the population viability of anadromous and resident fish species and other biota?

- How are contaminants affecting ecosystem components that affect fish populations?
- Are efforts to mitigate the introduction of toxic substances into CRB waters reducing the contamination of fish and other media in the Columbia River?
- Based on monitoring information, what areas need further investigation, cleanup, source control, restoration, and/or protection to support ecosystem and salmon recovery?

The vision statement, goals, and objectives developed by the Project Team indicate that the Program should provide information that addresses both ecosystem and human health and well-being concerns. The Project Team acknowledged that understanding the distribution and concentrations of contaminants in the Columbia River could be the first step towards understanding how contaminants are affecting various ecosystem components (e.g., benthic macroinvertebrates and plankton), that in turn affect fish populations. Since recovery of anadromous and resident fish species and other biota (e.g., native mussels) are important to stakeholders in the CRB, structuring a monitoring program that will provide information on how contaminants may be affecting the population viability of these biota is important. Similarly, as implied in the Vision Statement, it is also important to understand how contaminants in fish are affecting people that consume fish. This is especially true for Tribal members because fish constitute a high percent of their diet.

Contaminants of Concern

Four persistent and bioaccumulative classes of toxic contaminants, mercury, PCBs, DDT, and polybrominated diphenyl ethers (PBDEs), have been identified as the contaminants of greatest concern in the Columbia River by EPA's State of the River Report (USEPA, 2009). Using this determination as a guide, a logical starting point for the Program would be to evaluate the distribution and magnitude of these contaminants in media across the study area.

Mercury

Mercury is widespread in the environment, being released to the atmosphere from varied sources and transported globally. Natural sources of mercury include weathering of mercury-bearing rocks and soil, volcanic activity, forest fires, and degassing from water surfaces. Anthropogenic sources include combustion of fossil fuels, metal production, and industrial processes. Major sources of mercury in the Columbia River are varied. A chemical action plan for mercury developed by WA Ecology (Peele, 2003) identifies the major sources of mercury in Washington state as diesel fuel combustion, coal-fired power plants, oil refineries, and waste combustion. Also, elevated mercury methylation rates have been shown to occur in hydroelectric reservoirs (Mailman, 2006, Pestana, 2019). A privately owned smelting plant located in Trail, British Columbia has discharged between 1.6 and 3.6 tons of mercury into the Columbia River each year since the 1940s (Parrish, 2005). Other potential sources include atmospheric deposition from far-field sources (global-scale) as well as from more localized sources, such as the recently closed coal-fired power plant in Boardman, Oregon.

PCBs

PCBs are a group of 209 synthetic chemicals whose production in the United States was virtually banned in 1979 due to their toxicity and persistence in the environment; however, they continue to be an unintentional byproduct in numerous industrial processes (ex. paper pigmentation, titanium dioxide production). PCB-contaminated waste oil was also used throughout the country to control dust along roads and rail lines. Although no longer produced in the United States, significant quantities of PCBs remain in products that are still in use and contribute to ongoing, widespread releases of PCBs (dielectric fluids, transformers, capacitors, lubricants, paints, pigments in paints and inks, pesticides, plasticizers, wood treatment, light ballasts, electromagnets). Specific industry types continue to use PCBs (e.g., hydropower and rail) and are ongoing sources of PCBs to the Columbia and Snake rivers (ODEQ, 2003).

DDT

Chlorinated pesticides have been used for decades as insecticides in agricultural and home environments (Turusov et al., 2002). These compounds have low solubility in water and are not readily metabolized or excreted. Many of the Columbia River's major tributaries have elevated levels of chlorinated pesticides, especially DDT and metabolites, in their soils, river sediment, and freshwater fish due to historical and current agricultural practices (USEPA, 2009). DDT persists in the environment, accumulates in fatty tissues, and can cause adverse health effects in wildlife. DDT was a commonly used pesticide until it was banned in the U.S. except for emergency use in 1972 by the EPA.

PBDEs

PBDEs are a group of chemicals used as flame retardants in electronics, plastics, building materials, and textiles. There are 209 theoretically possible congeners of PBDEs. Like PCBs, PBDEs are resistant to physical, chemical, and biologic degradation and some bioaccumulate in aquatic environments. PBDEs appear to be transported and distributed in the global environment similarly to PCBs. Information on the possible health impacts of PBDEs comes from animal toxicity studies (USEPA, 2009). Efforts to locate sources of PBDEs in the CRB have been limited (USEPA, 2009). Flame retardant manufacturers in the U.S. voluntarily stopped producing PentaBDE used in furniture and OctaBDE used in electronic products in 2004. Manufacturers of DecaBDE committed to ending all uses in U.S. products by the end of 2013 (Pohl et al., 2017).

Other priority contaminants considered

Contaminants other than the four classes of toxic contaminants listed above were considered. In addition to the contaminants listed below, future consideration of additional contaminants to be assessed by the Program could include consulting EPA's 2007 Prioritization of Toxics in the Columbia River (see: https://www.epa.gov/columbiariver/prioritization-toxics-columbia-river), and/or EPA's 202 Contaminants of Concern Framework (https://www.epa.gov/columbiariver/columbia-river-basin-contaminants-concern-framework), or the results of future evaluations or the results of screening activities, or new and emerging science.

Pesticides

In addition to the historical use organochlorine pesticides previously mentioned (e.g., DDTs), other organochlorines such as the chlordanes (i.e., chlorinated cyclodienes and other chlordanes), aldrin, dieldrin, and toxaphene were discussed. These compounds are expected to have a much lower detection frequency than the DDT compounds but can be quantified using the same analytical methods as the DDx compounds. It is expected that several additional organochlorines will be measured within a broad organochlorine analytical method specifically aimed at DDT compounds.

Current use insecticides such as pyrethroids (i.e., bifenthrin, permethrin, esfenvalerate) and organophosphates (i.e., diazinon, malathion, azinphos-methyl) and neonicotinoids (imidacloprid, clothianidin and thiacloprid) were also discussed. These have much shorter environmental half-lives than the other contaminant class discussed so far, and - in general - lower bioaccumulation potential into tissues. However, they can sometimes be found at concentrations expected to be toxic to insects and fish (Sy et al., 2022). Consideration of these compounds for future monitoring, or perhaps as the focus of directed studies near known point sources, may be warranted

PFAS

Per- or poly-fluoroalkyl substances (PFAS) are of recent concern and were also discussed. Current reports indicate PFAS are associated with known sources, often industrial uses, and military and/or commercial airports. To date, the Pacific Northwest appears to have lower PFAS contamination than other parts of the country (Guelfo & Adamson, 2018). However, the human health safe consumption level was just lowered significantly (https://www.epa.gov/sdwa/drinking-water-health-advisories-has) and ecological impacts and benchmark concentrations for PFAS are still unclear. For example, a targeted survey of fish, water, and osprey eggs within the CRB, including the Columbia River, has shown that PFAS is widespread in various environmental media (Mathieu & McCall, 2017). Furthermore, the bioaccumulative compound perfluorooctane sulfonic acid (PFOS) persists across media, despite being phased out in the early 2000s. As such, as a class PFAS are a persistent, toxic group of contaminants that could be considered for future monitoring. As the analytical chemistry of these compounds is complex, it has been suggested that initial screening for PFOS alone, the most abundant of the congeners, might be a cost effective first step.

6PPD-Quinone

Another recently elevated contaminant of concern is 6PPD (p-phenylenediamine, the parent product), and its oxidation product 6PPD- quinone (6PPD-Q), are toxic chemicals found in tires and stormwater that can cause pre-spawn mortality of adult salmon, particularly coho salmon (Tian et al., 2021). Toxicity appears to mostly affect adults but there is indication that mortality to juveniles at low doses and exposure also occurs. Little is known about effects on other species, the sublethal effects on adults and juvenile salmon, or how the contaminant accumulates and remains in sediments.

Contaminants of Emerging Concern

There was consensus that the Program should consider monitoring, screening, and/or research activities that assess the presence, distribution, and effects of contaminants of emerging concern (CEC). Emerging contaminants are widespread in aquatic systems (Richardson & Kimura, 2016) and are causing concern because of the potential risks to human health and ecosystems (Glassmeyer et al., 2017). Contaminants of emerging concern enter surface waters through a variety of pathways including wastewater effluents, and from agricultural and industrial activities. Contacts and exchanges between aquifers, rivers, and sewage networks, and leaching from agricultural fields, can also be pathways for CECs to enter surface waters (Buerge et al., 2009; Lapworth et al., 2012). Emerging contaminants are actively used by businesses in the region. Unlike PCBs, PBDEs, and DDTs, that have been mostly banned, emerging contaminants could be subject to control by management actions and regulations.

Contaminants of emerging concern are a diverse group of anthropogenic chemicals that include thousands of pharmaceuticals (Bottoni et al. 2010) and hormones, illicit drugs, new pesticides, personal care products, flame retardants (Nilsen et al. 2014), artificial sweeteners, perfluorinated compounds, disinfection byproducts, ultraviolet filters and other industrial chemicals (Geffel et al., 2019; Kasprzyk-Hordern et al., 2008; Lapworth et al., 2012; Petrovic et al., 2004; Richardson & Kimura, 2016; Zuccato & Castiglioni, 2009). Strategies to address the threat of CECs in the Columbia River to ecosystem and human health could involve a process that screens for CECs (Altenburger et al., 2019, Connon et al., 2019; Tang et al., 2020b), assesses cause-effect relationships, develops mitigation actions, and conducts subsequent effectiveness monitoring that assesses the efficacy of the mitigation (Altenburger et al., 2019). A similar prioritization process was recently suggested by the Puget Sound Partnership (James, 2015) for Puget Sound. While the assessment of CECs may fall outside the scope of the early stages of the Program, developing a process to identify and update regional efforts to prioritize chemicals informed by monitoring data warrants consideration as the Program develops.

Media of Interest

Sampling different ecosystem components can provide information on how contaminants are potentially affecting the ecology and population viability of important biota and human health. The Project Team identified a set of media that could provide insight into how the spatial distribution and temporal trends of contaminants across the study area are affecting the ecology of the Columbia River and human health. While multiple media were considered, monitoring contaminants in fish is considered a priority for the Program with other elements potentially being monitored, contingent on funding levels.

Fish

Fish are often used to assess how spatial and temporal trends in contaminants in aquatic systems are affecting ecosystems and human health. Two classes of fish were considered: anadromous and resident fish. Resident fish that complete their entire life history in lakes, rivers, and streams were considered because they live most of their lives in the river (as opposed to ocean migrants) and some species have high site fidelity and thus reflect the conditions (e.g., contamination) of the area and habitat where they are captured. Conversely, anadromous fish are born in freshwater, then migrate to the ocean as juveniles where they grow into adults before migrating back into freshwater to spawn. Because of the migratory life history of anadromous fish, attributing the level of contamination detected in anadromous fish species to the contamination of the habitat they are captured is not possible.

Adult salmon, lamprey, white sturgeon, and resident fish are important food items for Tribal members and recreational fishers. Adult salmon and other fish species such as steelhead trout *Oncorhynchus mykiss* and white sturgeon are commercially harvested; the level of contamination in anadromous fish tissues has human health implications. Juvenile anadromous salmonids captured in the Columbia River have spent their entire life in freshwater before migrating to the ocean. As they migrate though the Columbia River they feed and grow as they transition from living in freshwater to living in saltwater. Recent studies have documented pollutants in migrating juvenile salmonids (Arkoosh et al., 2011; Johnson et al., 2007; Sloan et al., 2010). In some cases, the level of contamination found in juvenile salmon can be high enough to affect their fitness when presented with disease challenges (Arkoosh et al., 2001; Arkoosh et al., 2015; Johnson et al., 2013). Further, measurement and modelling of contaminant-related reductions in growth rates amongst juvenile salmon were demonstrated by Lundin (Lundin et al., 2019, Lundin et al., 2021). Thus, the level of contamination in juvenile salmon has implications for the population viability of each stock.

Assessing contaminant levels in adult salmon was considered a priority because of their importance as a food item and consequently, the potential for their consumption to affect human health. Assessing contaminants in juvenile salmon was also supported because of the potential effects of contaminant burdens on fish condition (Lundin et al., 2021) and survivability. Similarly, the Project Team supported developing a program that monitors for resident fish species since they would provide information on site- or reach-specific contamination because of their increased site fidelity relative to anadromous fish species. Information on site- or reach-specific contamination could then be used to identify areas that need to either be protected, because they are not contaminated, or areas that need further investigation and potentially remediation because they are contaminated. Other anadromous and resident fish will likely be added to the Program through adaptive management. For example, lamprey and sturgeon are both important Tribal food items and will likely be included in future iterations of the Program.

Assessing contaminants in resident fish can also be used to infer both human and ecological health considerations. Fish collected during contaminant studies can be processed differently based on the objectives of the study. For example, if the goal of the study is to assess how the level of contaminants in fish may affect human health, fish filets may be collected and analyzed since that is the part of the fish typically consumed by humans. However, it should be noted that Tribal members and others often eat different portions of fish such as skin, fat, organs, and bones (CRITFC, 1994); so, analyzing whole body or additional tissues could be considered to assess risks to human health. If the objectives include an assessment of ecological effects, then assessing contaminants in the entire body may be desired since consumption by predators would not specifically select for fillets. Generally, resident fish will be sampled as fillets to assess human health effects and as whole body to assess ecological effects and to infer risks to human health for those that regularly consume other parts of fish (Herger et al., 2016). However, the ability to collect both types of tissues will depend on funding and the ability to catch enough fish in the appropriate taxa at each site. In addition to collecting tissues, other standard fish condition metrics will be recorded such as fish length, weight, and sex. Interrogating samples for stable isotopes of carbon and nitrogen, that are useful for examining trophic position when interpreting tissue concentrations in forage and predatory fish, could be considered.

Collecting other fish tissue components from sampled fish may also provide insight into the effects of contaminants. For example, liver disease is highly correlated with exposure to carcinogenic polycyclic aromatic hydrocarbons (PAHs) in some species (Johnson et al., 2010). Gonadal lesions are good indicators of reproductive impairment that can be caused by a wide range of chemicals, including PAHs, PCBs, DDTs, and certain metals, as well as synthetic estrogens (Jenkins et al., 2014). Other biological indicators can provide predictive covariate physiological effects measures (e.g., lipid content and classes, condition index and liver somatic index can be an indicator of nutritional status, plasma vitellogenin in male and juveniles can be an indicator of exposure to estrogenic compounds, histopathology of the liver, gonad, and spleen can be an indicator of toxicopathic lesions including cancer, gonad abnormalities, and other abnormalities). Otoliths can provide information on age and can be used to reconstruct environmental or diet history, identify nursery origin or stock, and provide information on migration and growth rates. Stomach content can be used to assess feeding strategies, diet makeup and fish health. These additional biologic measures in fish could be considered as the Program evolves.

Fish and other aquatic biota will accumulate contaminants differently based on their trophic position. Given that resident fish and other biotic communities differ over the geographic scope of the Program, collecting the same biota across all sites will not likely occur. To achieve the largest amount of comparability possible we will develop a species list that prioritizes each taxon for sampling based on knowledge of species found in the Columbia River and their trophic position in the ecosystem (e.g., Table 1). This will provide data related to different trophic groups (e.g., omnivore, predator, etc.). Trophic position is also a function of life stage

Table 1. Fish species found in the Columbia River classified with respect to their trophic guild and potential to be used in ecological (E) and human health (HH) evaluations.

Family	Scientific name	Common name	Guild	Evaluation
Acipenseridae	*Acipenser transmontanus*	white sturgeon	omnivore	E, HH
Catostomidae	*Catostomus macrocheilus*	largescale sucker	omnivore	E, HH
Centrarchidae	*Micropterus dolomieu*	smallmouth bass	predator	E, HH
Centrarchidae	*Micropterus salmoides*	largemouth bass	predator	E, HH
Cottidae	*Cottus sp.*	Cottid species	predator	E
Cyprinidae	*Acrocheilus alutaceus*	chiselmouth	grazer	E
Cyprinidae	*Cyprinus carpio*	common carp	omnivore	E
Cyprinidae	*Ptychocheilus oregonensis*	northern pikeminnow	predator	E, HH
Cyprinidae	*Richardsonius balteatus*	redside shiner	omnivore	E
Cyprinidae	*Rhinichthys cataractae*	longnose dace	omnivore	E
Cyprinidae	*Rhinichthys falcatus*	leopard dace	omnivore	E
Cyprinidae	*Rhinichthys osculus*	speckled dace	omnivore	E
Cyprinidae	*Mylocheilus caurinus*	peamouth	grazer	E
Percidae	*Stizostedion vitreum*	walleye	predator	E, HH
Percidae	*Perca flavescens*	yellow perch	Insectivore	E, HH
Petromyzontidae	*Entosphenus tridentatus*	Pacific lamprey	Parasite	E, HH
Petromyzontidae	*Lampetra ayresii*	western river lamprey	Parasite	E, HH
Petromyzontidae	*Lampetra richardsoni*	western brook lamprey	Adults do not feed	E, HH
Salmonidae	*Prosopium williamsoni*	mountain whitefish	planktivore	E, HH
Salmonidae	*Oncorhynchus spp.*	Chinook, coho, chum, sockeye, steelhead	predator, planktivore	E, HH

for fishes, thus, criteria for incorporating various size classes of anadromous and resident fish species will be developed.

Sediment

Current and past industrial discharges into the Columbia River have resulted in the contamination of sediments (USEPA, 2009). Contaminants in deposited sediments is a pathway for some toxic compounds to enter the foodweb via benthic organisms (Nakata et al., 2007), and bioaccumulate. Sediments are less mobile than water, and the importance of understanding the distribution of sediment contamination is underscored by research on sediment contamination conducted in other river systems with known contamination issues (Jaskuła & Sojka, 2022; Liber et al., 2019; Pandey et al., 2019, Siddiqui & Pandey, 2019; Tchatchouang et al., 2022; Wildi et al., 2004). Since both anadromous and resident fish in the Columbia River consume benthic invertebrates, understanding the level and distribution of contaminants in sediments could provide insight into areas that are important exposure pathways. This is especially true for white sturgeon that rely heavily on benthic organisms as a food source (Tashjian et al., 2006) and lamprey ammocetes that live in the sediment for up to seven years prior to outmigration to sea (Nilsen et al, 2015). Understanding what habitats are contaminated can also help identify mitigation opportunities and provide a direct link to site-specific contamination.

Invertebrates

Invertebrates, including benthic (e.g., amphipods, bivalves) and pelagic (e.g., zooplankton) organisms are important ecosystem components that are food items for, and that link contaminants in benthic sediments and water to, higher trophic levels (e.g., fish, birds, and people). Nilsen et al. (2014) investigated the quantity, spatial patterns, trophic transfer, and accumulation rates of chemicals in the Columbia River foodweb and found numerous organochlorine pesticides, both banned and currently used, and PBDEs. These two contaminant classes were present in multiple media and at concentrations exceeding environmental quality benchmarks in some cases. Recent studies have shown that sediments from Lake Roosevelt and the Upper Columbia River are contaminated with metals from smelting operations and may be affecting benthic macroinvertebrates (Besser et al., 2018). Invertebrates have also been shown to accumulate and be affected by microplastics that may affect trophic energy transfer and/or trophic interactions (Haegerbaeumer et al. 2019). Planktonic food webs, that are now prevalent in many areas of the Columbia River because of the effects of impoundment (Haskell et al., 2017) have also been shown to accumulate contaminants (Tang et al. 2020a). Since planktonic food webs are important to migrating juvenile salmon in the Columbia River (Haskell et al., 2017), accumulation of contaminants in prey could be affecting migrating juvenile salmon.

Biofilm

Biofilm is a collection of living and dead algae (periphyton), microbial biomass, and organic detritus, which contribute to the base of the food web in rivers and streams and thus are a link in the processing of contaminants into the food web (Hobbs et al., 2019). Hobbs et al. (2019)

found that the burden of metals in the biofilm matrix explained adverse impacts and variability in periphyton metrics and ecological integrity in macroinvertebrates. The importance of biofilms in the trophic transfer of contaminants into the food web is well documented (Berglund, 2003; Hill, 1997; Munoz et al., 2018; Stange & Swackhamer, 1994; Swackhamer & Skoglund, 1993). Other studies have found similar relations between contaminant concentrations in biofilms, and ecological integrity measures (Ancion et al., 2012; Mahler et al., 2020) have been recognized but understudied (Bonnineau et al., 2020).

Surface Water

Understanding water contamination is important for both ecological and human health. With respect to human health, the most direct risk is exposure via drinking water. Additional exposure pathways include exposure to pathogens or contaminants via the food chain (e.g., the result of irrigating crops with contaminated water and fertilizing with biosolids) or during recreation (e.g., swimming in polluted surface water) (Schwarzenbach et al., 2010). Exposure to toxic chemicals can also affect aquatic ecosystems by inducing shifts in community composition (e.g., through the loss of sensitive species) (Altenburger et al., 2019).

Survey Design Considerations

Survey design components include the processes from planning and sample location allocation through results reporting. Once the survey sampling design components are solidified, the analytical methods used to produce the metrics for the various media and analytes should be explicitly detailed in a project implementation plan. All components of the survey design would then be described in a data management plan (see below).

The Project Team considered survey design options that would address the Program goals and objectives. Assessing a very large and diverse river reach requires the development of a sample frame and sampling design that can describe the condition of resources within the study area (Herger et al., 2016). Understanding the spatial and temporal trends in contaminants across the study area is implicitly stated as a goal of the Program (see Goal 1). Different strategies for sampling the various media, how the media could contribute to the understanding of spatial and temporal trends in contaminants, and how contaminants could affect the Columbia River ecosystem, population viability of biota, and human health were considered. Since resident fish were suggested as a medium that would allow inferences to site- or reach specific contamination, several sampling designs that allocate sample locations over the study area were considered.

Resident Fish

To assess contamination in resident fish species across spatial and temporal scales covered in the Program, the Project Team concluded that there was a need for a sampling design that probabilistically allocated sampling locations across the study area in a spatially balanced way. Previous studies have probabilistically allocated samples to reaches of the Columbia River that are a subset of our study area. For example, Herger et al. (2016) in a prior assessment of contaminants in fish tissues in the Columbia River used a linear Generalized Random Tessellation Stratified (GRTS) sample frame to allocate sampling locations from Bonneville Dam (rkm 234) to Grand Coulee Dam (rkm 957). A sample design that is based on GRTS is a true probability design where each point has a known, non-zero probability of being included in the draw. Importantly, a GRTS design supports design-based inferences to the entire area or subsets of the study area, thus we will be able to estimate contaminant levels in the media sampled across the entire system once all reaches have been sampled. Additional details can be found in Diaz-Ramos et al. (1996), Stevens (1997), Stevens & Olsen (1999), and Stevens & Olsen (2004).

The Project Team concluded that developing a sample frame and sample design to allocate resident fish collection locations across the study area should be based on a linear GRTS design. Specifically, the sample frame will be based on a river-center line geographic information system (GIS) data layer developed from the high-resolution version of the National Hydrography Dataset (for examples of linear GRTS sample frames see: https://archive.epa.gov/nheerl/arm/web/html/design_intro.html#strms). The sampling frame will include every km-long segment of the Columbia River from Bonneville Dam to the Canadian border. The sample sites will be randomly selected from this sample frame in a manner that ensures the distribution of sites throughout the entire study reach (Stevens & Olsen, 2004). Since fish samples will be collected from shoreline habitats (Herger et al., 2016), the sample locations in the linear GRTS sample frame will be further allocated to either the left or right banks of the river. Some stakeholders have sampling locations that are important to them and/or that provide context to previous studies (e.g., Tribal fishing locations sampled in: USEPA, 2002). Depending on the nature of these non-probabilistically selected locations (e.g., they were not selected because of known issues with contaminants), some proportion may be considered as contributing to the information derived from the probabilistic sites and may have value as sites for targeted, localized trends.

Salmon

For adult salmon, sampling options considered included collecting fish at hydropower facilities, at in-river sites selected on a probabilistic sample allocation scheme and working with local Tribal fishers to collect salmon. The Project Team concluded that there was no real benefit in probabilistically allocating samples to specific habitats over the study area since adult salmon have experienced a myriad of habitats during their life history, including spending time in the ocean. Collecting adult fish at hydropower facilities, Tribal fishing sites, or purchasing them from Tribal fishers were the preferred options.

Like adult salmon, correlating fish tissue contamination in migrating juvenile salmon to the locations where they are captured is not valid. The Project Team suggests that juvenile salmon could be collected at hydropower facilities. However, since there may be contaminants that accumulate in juvenile salmon as they migrate through the mainstem Columbia River (e.g., from prey, see Erickson et al., 2008; Johnson et al., 2013; Lundin et al, 2021), and since juvenile salmon migrate through different habitats in the Columbia River, the Project Team suggested that collecting juvenile salmon at hydropower facilities that encompass the breadth of juvenile salmon migration routes could be informative.

Anadromous salmonids in the Columbia River comprise multiple species, populations, and stocks that migrate to and from a wide range of tributary and mainstem Columbia River habitats (Ford et al., 2011; Johnson et al., 2019). Adult and juvenile salmon migration timing varies by stock and species. Understanding the variability in contamination of various stocks and life histories would be informative. In addition to the spatial considerations, timing of collecting the adult and juvenile salmon was also discussed. There was consensus that collecting samples over the course of the adult and juvenile salmon migration timing would be beneficial and informative because information on different species and life histories would be collected. An alternative to the spatial and temporal collection strategies described above would be to use genetic stock identification tools (Hess et al., 2014; Jensen et al., 2021; Johnson et al., 2019) to provide information on stock origins of fish that are interrogated for contaminants.

Sediment

Sediment contamination concentrations have been shown to be related to the sedimentation characteristics of the river channel (Counihan et al., 2014). The sedimentation in river channels varies laterally and longitudinally in the Columbia River based on the hydrogeomorphology of river reaches. Dams and other manmade structures also affect sedimentation patterns. Given the variability of sedimentation characteristics in the Columbia River, the Project Team concluded that using a linear GRTS sample frame may not characterize the variability in sediment contaminants, thus an area-based GRTS sample frame could be used to allocate sediment collection locations across the study area (for examples of areal GRTS sample frames see: https://archive.epa.gov/nheerl/arm/web/html/design_intro.html#strms). An alternative approach would be to probabilistically allocate samples to defined habitats with different sedimentation characteristics (e.g., based on hydrodynamic model predictions; see: Counihan et al., 2014). However, this would require the development of sediment transport models for all reaches in the study area. Although the development of sediment transport models may require significant effort in the short term, understanding the sedimentation characteristics of the Columbia River could help to streamline the sediment monitoring component of the Program.

Invertebrates

Understanding how contaminants in invertebrates relate to the fate and transport of contaminants in the Columbia River could provide insight about how and where contaminants are entrained to higher trophic levels (i.e., fish). Since sedimentation patterns likely affect the abundance and distribution of benthic invertebrates in the Columbia River (Buendia et al., 2013; Lorenz & Wolter, 2019), a scheme that couples the collection of benthic macroinvertebrates with the probabilistic allocation of spatially balanced sediment sampling locations would promote sampling habitats with different sedimentation characteristics.

Collecting plankton (e.g., macroplankton) could also provide information on the transfer of contaminants in the Columbia River food web. However, unlike benthic invertebrates that can provide a linkage to the habitat they are collected in, plankton in rivers are mostly transient in a particular location because they are transported by currents. In that respect, collecting plankton at probabilistically selected sample locations will not allow for the same inferences to specific habitats as can be made with benthic invertebrates. Plankton transport in the Columbia River is dynamic and complex because of the associated hydrodynamics. Coupling plankton collection to the probabilistically allocated sediment and benthic invertebrate sample locations makes sense in that the spatially balanced sample will include samples that capture lateral and longitudinal channel gradients. Having the allocation of sample locations capture the lateral and longitudinal gradients in Columbia River reservoirs could be important because of the predictable hydrodynamic consequences of impoundments that can affect plankton dynamics (Rizo et al., 2020).

Biofilm

Since biofilms are typically collected from hard substrates, coupling the collection of biofilms with sediment collection sites that are allocated to capture sites with finer sediments may not be feasible. However, coupling the collection of biofilms with probabilistically selected resident fish sampling locations may be beneficial because resident fish will be collected from shoreline areas. Additional tools, such as artificial substrates, could also be considered to increase site fidelity and improve standardization of sample areas among sites.

Surface Water

Monitoring surface water could contribute to an understanding of factors affecting important ecosystem components in the Columbia River. Discussions surrounding how to allocate water quality monitoring locations were coupled with discussions about how and why to collect the samples. Since there was interest in understanding the fate, transport, and uptake of contaminants in the Columbia River, the use of a passive or integrated water samplers was discussed. This approach to water sampling has several advantages; the period (usually days to weeks) can be controlled and replicated, the deployment and handling of the sampler can be standardized, and the device concentrates contaminants into a binding media that allows for measurement in a laboratory even if the water concentrations were too low to measure. Strategically placing passive sampling devices so that they capture the contributions of tributary systems and other point sources along lateral and longitudinal breadth of the study area could help to identify mitigation strategies.

How to sequence sampling to encompass the study area

Since the Program proposes to monitor a large geography, the implementation of the Program will likely require that the study area be stratified into areas that can be reasonably sampled in a year. The Project Team identified reaches of interest that include river reaches that are defined by the presence of dams (Figure 2 and Table S1) and that are delineated by the confluences of major tributaries that include important anadromous fish bearing tributaries (Table S2) that could provide valuable comparisons. Since management of the Columbia River often is done by reservoirs, or groups of reservoirs, structuring a sampling rotation that is based on groupings of reservoirs and the limited areas that are not impounded could provide a way to cycle through the study area over a prescribed period (e.g., five years). For example, the study area could be separated into five reservoir groups that are sampled every year such that the sampling locations in the study area are sampled in a five-year rotation (e.g., see Figure 2).

Status and Trends

The goals and objectives of the Program suggest that understanding both the status (what is the condition now) and trends (comparisons over time) in contaminants is desired. Designs that allow for the estimation of both status and trends have been formulated to assess other natural resources (Starcevich et al., 2018; van Dam-Bates et al., 2018). In addition to the GRTS sample allocation strategy, additional complexity can be incorporated into the monitoring design to facilitate the estimation of both the status and trends in important monitoring indicators. For example, revisit designs that consist of panels of sites that are to be visited annually, on a regular alternating basis, or only a single time can be formulated (Urquhart & Kincaid 1999). Revisit designs (e.g., rotating panel) have been used in combination with a GRTS sample frame to formulate survey designs to assess status and trends of environmental resources (Larsen et al., 2004).

Screening criteria

The Program goals and objectives encompass a wide range of activities that could result in many possible comparisons. Often the first comparison to be made with a measurement of contamination in sediment or fish tissue is to a criterion or guideline that indicates whether concern is warranted at a given concentration. Many of these screening values or guidelines exist for both human health and ecological health for the contaminants discussed above. These are often published by State or Federal or International science agencies. Since the goals and objectives of the Program include measuring and reviewing contaminants for both human health and ecological concerns, three sets of screening levels may need to be considered, 1) for human health considerations, 2) for ecological health considerations (in both fish and sediment sources) and 3) criteria specific to ESA-listed salmonids. Recent screening values from the states of Oregon, Washington, and relevant Federal agencies were reviewed. Example screening values are presented in Tables S3 through S5 to assist in establishing the necessary analytical chemistry detection limits. When multiple screening values were available/applicable, the most protective of the values is suggested as the analytical chemistry target range, in its respective category.

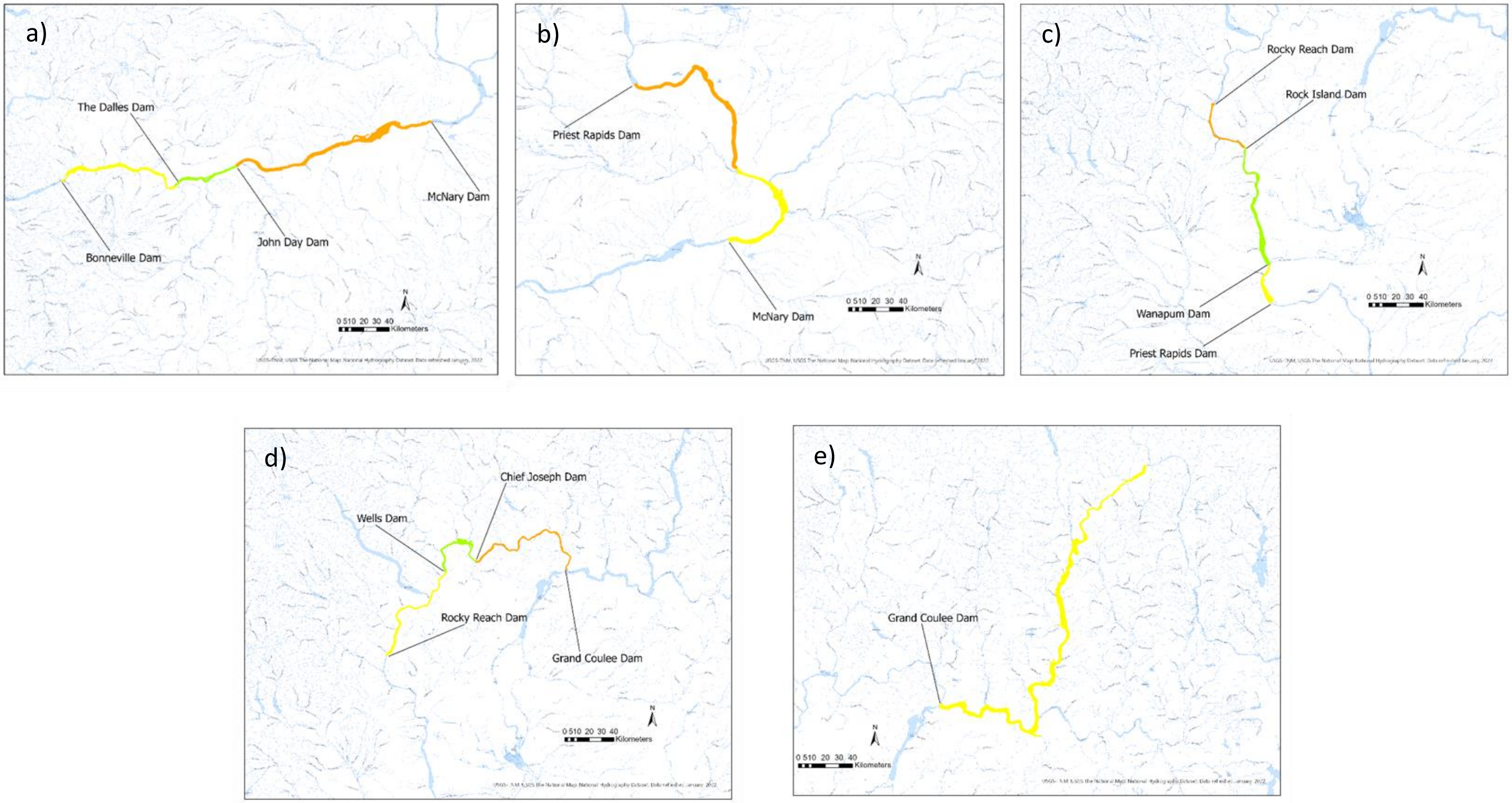

Figure 2. Example of reservoir groupings that would allow the study area, from Bonneville Dam to the international border with Canada, to be sampled in a 5-year rotation. Example groupings depicted are a) Bonneville, The Dalles, and John Day reservoirs; b) McNary reservoir and the Hanford Reach; c) Priest Rapids, Wanapum, and Rock Island reservoirs, d) Rocky Reach, Wells, and Chief Joseph reservoirs, and e) Lake Roosevelt. See Table S1 for additional details about the reaches. Source: USGS-TNM, USGS The National Map: USGS National Hydrography Dataset. Data refreshed January, 2022.

How much effort is needed?

Determining the number of samples needed per reservoir or per river reach to provide for meaningful comparisons is complicated by the myriad of questions that could be asked; more discussion is needed to prioritize the comparisons that are most important to stakeholders. After priority contaminants and media are identified, estimators and variances of status and trend metrics can then be used to estimate the needed effort. Sampling effort will then depend on the interaction of theoretical sampling properties, empirical measurements of the spatial and temporal variability of environmental responses, and desired monitoring performance expressed in terms of sampling precision (Skalski, 1990).

Screening criteria could be used as a starting guideline for estimating the level of sampling effort needed. For example, if stakeholders are concerned with fish health effects, stakeholders may wish to learn whether improvements are occurring in fish tissue contamination, perhaps from an unacceptable level based on screening criteria to an acceptable level over time for a sensitive species. The difference between existing contaminant levels and acceptable levels (e.g., based on screening values) could be used to define a desired minimum detectable difference (e.g., the minimum level of change that would suggest degradation or improvement). A probability of detecting this trend (i.e., statistical power) and an acceptable level of uncertainty (Type I error) within a specified time frame (e.g., 5-10 years) can be determined in a variety of ways to ensure timely detection (Urquhart et al., 1998; Wagner et al., 2022). Explicit statements of the minimum detectable trend, the time frame for detecting the minimum trend, power, and acceptable probability of Type I error (α) collectively can then form the quantitative sampling objective (Garman et al., 2012). Determining the level of effort needed for the Program will be informed as data collection proceeds (e.g., pilot study) and will evolve based on discussions with stakeholders and as the Program is adaptively implemented.

General recommendations for samples sizes needed to address the effects of contaminants on human health are offered by the WA Department of Health, Oregon Health Authority and USEPA regarding fish advisories. A series of guidance documents, beginning with peer-reviewed science articles (Stahl et al., 2009) and incorporated into guidance by WA Ecology and ODEQ and USEPA (USEPA, 2000) all share a common suggestion for sample sizes desired for fish tissue advisories. Specifically on a per-site basis the recommendations suggest that 3-5, 5-fish composite samples, where the 5-fish composites are created in order of fish size, (i.e., biggest 5 fish grouped as one composite, second next 5 fish grouped, etc.) should be collected. If funding allows or there is an identified need for more specific information, collecting data for individual fish could be considered.

Analytical Chemistry Methods

The analytical chemistry method (and laboratories) selected needs to be sufficient to address the goals and objectives of the study. The laboratory methods must be sensitive enough to address the primary intended uses of the data, and, ideally, likely secondary uses. As the envisioned uses of the data generated by the Program are several, more than one justification might be applied for which analytical method should be selected.

Permitting needs

Permits for sample collection will need to be obtained as required for the various media. Coordination with the relevant permitting entities is a necessary component of the Program.

Historical data

Historical data can provide the empirical basis for design decisions. Numerous studies by Federal, State, and other entities have documented concentrations of contaminants in fish, sediment, and the water of the Columbia River (Table S6). However, most studies target specific contaminants or focus on specific reaches. When viewed collectively, the historical efforts reveal a patchwork of objectives, sites, sampling media, fish species, collection timeframes, and analytical methods.

As a first step in preparing this framework, historical data from previous Columbia River mainstem sampling efforts from various agencies were retrieved, collated, and reviewed. These data sources included Washington Department of Ecology's Environmental Information Management System (EIM), USGS National Water Information System (NWIS) and USGS Biomonitoring of Environmental Status and Trends (BEST), as well as from the EPA Water Quality Exchange (WQX). Data from previous studies that met established criteria (Table S7) were retained, compiled, and examined for the potential to inform the initial design of the Program.

Overall, the historical data provide snapshots of concentrations in each media (e.g., sediment or tissue) at a given place and time and provide some insight into past levels of contamination. However, any use of these data for future survey design planning or trend analyses need to consider the specific procedural details of previous studies to assess the validity of using these data. Closer examination of the historical data revealed a few insights that were helpful for monitoring program design; however, the team also found multiple incompatibility issues. We were especially interested in determining variance within the datasets but found that this was complicated by methodological differences across studies or insufficient replications within and across temporal and spatial scales. Key insights as well as dataset concerns are listed below:

- First, there was historical data on some of the key contaminants that would be expected to drive human and ecological risk; namely mercury, PCBs, organochlorines, a few metals, and some polybrominated compounds. However, there was little to no historical data on per-and polyfluorinated substances.
- Second, when the data were limited to a particular species or medium (i.e., sediment), in a particular reservoir, for a particular contaminant, the breadth of historical measurements became limited. Summarizing data into broader categories, (e.g., all fish tissue) in a particular reservoir may allow more samples to be considered but insights

from such an approach would likely be confounded by the disparate fish species collected at each site.

- Third, concentrations in the historical data were generally low. Approximately 51 percent of the analytes interrogated in samples were reported as, "Analyte not detected at or above the reported result/estimate." Another 33 percent of the sample-analyte results were reported with greater uncertainty; usually due to a concentration measured that was near the reporting limit (i.e., "Analyte was positively identified; the reported result is an estimate."). Five percent of the sample-analyte results were an unqualified detection.
- Finally, there were relatively few instances of duplicate or triplicate samples that reported all measurements above the contaminant's reporting limit, possibly due to historical analytical methods with elevated reporting limits or inherent measurement variability.

Data Management and Reporting

Though it is beyond the scope of this framework to detail a data management plan for the Program, a comprehensive data management plan for the data generated by the Program will be essential for ensuring the data collected are complete, of the quality desired, available for analysis and sharing, and archived for future use (Sutter et al., 2015; Wilkinson et al., 2016). . The data management plan for the Program could encompass a wide range of activities from the documentation of procedures used to formulate the survey design to the final disposition and long-term storage of data generated by the Program (O'Donnell et al., 2021). For example, the data management plan could include components such as the standardization of spatial information (e.g., how to document accuracy of geographic locations and methods of recording locations, which should include any post-processing corrections), standardization of fields and field types in databases (e.g., defining database field names and field formats, defining formatting of date and time values, and definitions), establishing database controls (e.g., requiring data for specific columns before allowing a record insertion), detailing database storage, versioning, archiving, methods and standards for creating metadata, and data management and quality assurance and quality control procedures. In addition, repositories for planning documents, reports, and other associated research products need to be defined and established. In the interim, the Yakama Nation Fisheries and EPA's WQX websites will be used for providing public availability to Program documents and data, respectively.

Community Outreach and Engagement

In addition to this framework, an Outreach Messaging Framework, which included identifying and reaching out to stakeholders within the CRB and subject matter experts within and outside of the CRB, was developed to gather input and suggestions that were incorporated into our final products (Yakama Nation, 2022b). The Outreach Messaging Framework is intended to facilitate efforts to identify a lead agency, program strategy, data management system, and hosts of data. Continued coordination and collaboration with partners, stakeholders and affected citizens will support adaptive management of the Program and community outreach and engagement over time. Additional information on community outreach and engagement is provided below in the Planning and Implementation section. As part of our outreach efforts, we held several meetings with stakeholders during which they provided suggestions, questions, ideas, and topics for consideration as the Program matures (Table S8).

Adaptive Management

The ability to adaptively manage the Program is crucial to ensure the long-term relevance of information produced by the Program. The data collected by the Program should be periodically reviewed and assessed to ensure that the survey design and field and analytical methods are resulting in data that inform the Vision Statement, Goals, and Objectives of the Program. Periodic review of the list of contaminants of greatest concern will help to ensure that the Program stays relevant and is addressing current problems. The media and/or fish species sampled may be updated as well. For example, lamprey and white sturgeon are important Tribal food items and will likely be investigated in future iterations of the Program. To facilitate a periodic critical review of the Program, results could be summarized, reported, and reviewed every five years, or at the completion of a rotation that samples the entire study area. As part of this review, the stakeholder list could be reviewed and updated as needed. Stakeholders could then review the results in the context of the goals, objectives, and specific questions and the adequacy of the sample allocation scheme (i.e., sample size) to discern the magnitude of the spatial and temporal differences desired (Radinger et al., 2019). The data management plan will need to be reviewed and possibly amended, as part of the adaptive management strategy. The procedure for amending or updating any component of the Program, such as SOPs or analytical methods, should then be explicitly stated and documented. A key component of the Program involves the use of the data and information by interested groups working to recover the Columbia River and its resources. The Program should continue outreach and coordination and use the information learned from others conducting work in the CRB and elsewhere to improve and refine the Program.

Informing Recovery Efforts

One of the primary drivers behind the development of the Program was to produce information that will help to assess whether contamination of the Columbia River ecosystem is getting better or worse. The goals and objectives of the Program reflect the desire to assess the status and trends of contaminants in various media in the Columbia River. The monitoring activities suggested in this framework can provide insight to this question in the context of ongoing habitat, ecosystem, and salmon recovery efforts. The identification of recovery opportunities, above and beyond those already occurring is also a stated objective under Program Goal 2. The Project Team recognized that one of the uses of the monitoring information collected would be to identify areas to conduct further investigation, cleanup, source control, restoration, and/or protection activities. Although enacting the ecosystem and salmon recovery actions is beyond the scope of the Program, generating information that would suggest the need for additional studies or recovery actions is an important and prescribed outcome of the Program. If ecosystem and salmon recovery actions are implemented, then effectiveness monitoring directed at assessing pre- and post- ecological conditions should be considered.

Climate related impacts to habitat, fish, and humans may be exacerbated by climate change factors such as high summer water temperatures (Patra et al., 2015). This Program would provide valuable information and data that can be used to inform and reduce stressors to human health and the environment, including salmon, a treaty reserved resource. For example, if major contamination issues in the mainstem Columbia River are identified, cleanup, restoration, and protection activities that could improve resilience and adaptation to climate change can be activated. Cleanup of contaminants or the prevention of their release into the mainstem Columbia River could aid salmon by reducing stressors from contamination.

Diagnostic Research

Documenting relative differences in contamination across the media and geographic scope of the study area may not be sufficient to assess the true effects of contamination on the Columbia River ecosystem. For example, while surveys of sediment contamination in Puget Sound, Washington suggested that a relatively small proportion of Puget Sound sediments were contaminated (e.g., based on Washington State Management Standard), diagnostic studies that arose from issues identified by monitoring data suggested that spawned herring *Clupea pallasii* eggs in areas where sediment PAH levels were otherwise considered acceptable can accumulate concentrations of PAHs well above levels associated with egg and larval toxicity (West et al., 2014; West et al., 2019). While conceiving of and funding directed research that explores cause and effect relationships can seem outside the scope of the Program, the utility of the monitoring results could be enhanced substantially by obtaining and linking information on the occurrence of both chemicals and potentially adverse biological effects (Altenburger et al., 2019; Connon et al., 2019). Directed diagnostic studies could indicate the need for more, or less, intensive monitoring in an area or suggest screening criteria to assess whether mitigation is resulting in improved conditions for target species that monitoring could inform.

Planning and Implementation

Development of the Program will involve a phased and integrated approach that includes technical planning, outreach to partners and stakeholders, and strategic planning to ensure Program continuity, and an adaptive management component that refines the Program as new information arises. All these focus areas will have some overlap, but they also complement each other in efforts to establish, house, and sustain a user-friendly Program of this scale for perpetuity.

Phased Approach

The Program will be developed through a phased plan that includes the following three phases:

Phase 1 (Year 1 and 2 – expected completion 9/30/2022): Phase I included reviewing relevant, existing datasets, soliciting feedback on research needs and priorities from key stakeholders, formulating a written conceptual design and distributing it for stakeholder review, and addressing stakeholder comments to produce a framework and a preliminary budget for guiding initial sampling efforts. Phase 1 also resulted in an Outreach Messaging Framework.

Phase 2 (Year 3 and Year 4 – expected completion 9/30/2024) will comprise two efforts Phase 2A – Planning, Outreach and QAPP Development and Phase 2B – Field Data Collection, Analytical, and Reporting. These efforts will inform the overall development of the Program. Phase 2A will involve production of Quality Assurance Project Plans (QAPPs) for sampling fish, water, sediment, and invertebrates and further refinement of the budget. Phase 2A will also involve combining geo-spatial data and probabilistic sample site selection methods to detail the sampling design of the Program, developing Standard Operating Procedures (SOPs), collaborating with State and Federal partners, and obtaining permits for fish and field sampling. The products of Phase 2A include a 5-year QAPP and sample allocation scheme that will be applicable to the entire Columbia River study area from Bonneville Dam to the Canadian border, SOPs, Invasive Species Spread and Prevention Plan (ISSPP), Health and Safety Plan (HASP), and Federal and State Fish Collection Permits needed to conduct a pilot study in Bonneville Reservoir. Finally, Phase 2A will implement the Outreach Messaging Framework and continue efforts to identify a lead agency, program strategy, data management system and hosts of data as well as development of a Strategy/Implementation/Business Plan for the Program. All materials developed in Phase 2A will be used to implement the Pilot Study proposed in Phase 2B, which will include fish tissue and sediment sampling on an approximately 50-mile stretch of the Columbia River: Bonneville Reservoir (Bonneville Dam to The Dalles Dam).

Phase 3 (Year 5 and beyond): Implement Program and Adaptive Management. Phase 3 will fully implement the Program developed through the first two phases. The Program will continue annually including data management and community engagement and outreach activities. The exact scope and effort of Phase 3 is expected to be consistent with Phases 1 and 2, but the details will be budget dependent.

Technical Planning and Implementation

Technical planning is the primary focus of this framework document. The development of the Program framework for the Columbia River Mainstem Fish Tissue and Water Quality Monitoring Program is the first step in a multi- step process that will need to be completed as the Program moves toward implementation (Figure 3). With the completion of the framework, the next step will entail the formulation of detailed procedures that are necessary for conducting the Program. These detailed procedures include developing survey design specifics (e.g., how much to sample where), field methods (e.g., how to collect the various media in the field), laboratory methods and standards (e.g., how to assess the samples collected), data usability (e.g. identifying approaches to assessing the censoring of data and validation), how the data will be analyzed (e.g., detailing statistics and metrics that will be reported), and how and where the data will be stored (e.g., how are the data archived and available going forward).

Once these detailed procedures are formulated (e.g., in a Quality Assurance Project Plan), the procedures will start to be vetted through the conduct of a pilot study. With the completion of the pilot study, the detailed procedures will be updated based on the findings (e.g., what worked and what didn't). The scope of the pilot study will be commensurate with the level of funding available. Consequently, vetting methods and protocols for the collection of all sampling media and contaminant classes discussed here will be constrained. As the Program develops and as additional funding becomes available, protocols and methods for other media and contaminants will need to be evaluated.

The evaluation of data conducted as part of the Program will focus on addressing the goals and objectives presented in this framework. Additional evaluation is possible but will rely heavily on collaboration with other outside parties and data users. In addition, this Program is intended to provide and share information and data useful for other stakeholders to answer questions and make decisions specific to their needs. Any media and components not addressed initially due to funding constraints will be maintained as a priority for future funding cycles, which is like the trajectory of some other programs have taken. For example, Johnson et al. (2010) suggested that data gaps for the Puget Sound Ecosystem Monitoring and Assessment Program included data on phytoplankton and zooplankton and benthic invertebrates; efforts to assess this data gap have only recently begun.

Once the procedures are updated using information collected during the pilot study, the Program would move towards the implementation phase that would begin the first rotation of sampling through the study area. As envisioned in Figure 3, the implementation cycle of the Program would occur over the course of five years. Included in the process is an adaptive management loop where the details and results of the Program will be evaluated in the context of information that is produced. As indicated in the Adaptive Management section above, all aspects of the Program would be assessed and amended if needed.

Outreach Planning and Implementation

Outreach planning overlaps and complements technical and strategic planning but focuses on development of materials and identifies audiences for outreach efforts. Outreach efforts have included collaboration with stakeholders within the CRB and subject matter experts within and outside of the CRB to gather input and suggestions. In addition, an Outreach Messaging Framework was drafted to facilitate efforts to identify a lead agency, program strategy, data management system, and hosts of data as well as development of a Strategy/Implementation/Business Plan for the Program. Phase 1 input from these outreach efforts was incorporated into this technical framework document as well as summarized in greater detail in an Outreach Technical Memo (Yakama Nation, 2022b). Phase 2 (Pilot Study) and Phase 3 (Implementation of the Long-Term Monitoring Program) will continue to be informed by the Outreach Messaging Framework and expand upon outreach efforts. Continued coordination and collaboration with partners, stakeholders and affected citizens will support adaptive management of the Program and community outreach and engagement over time.

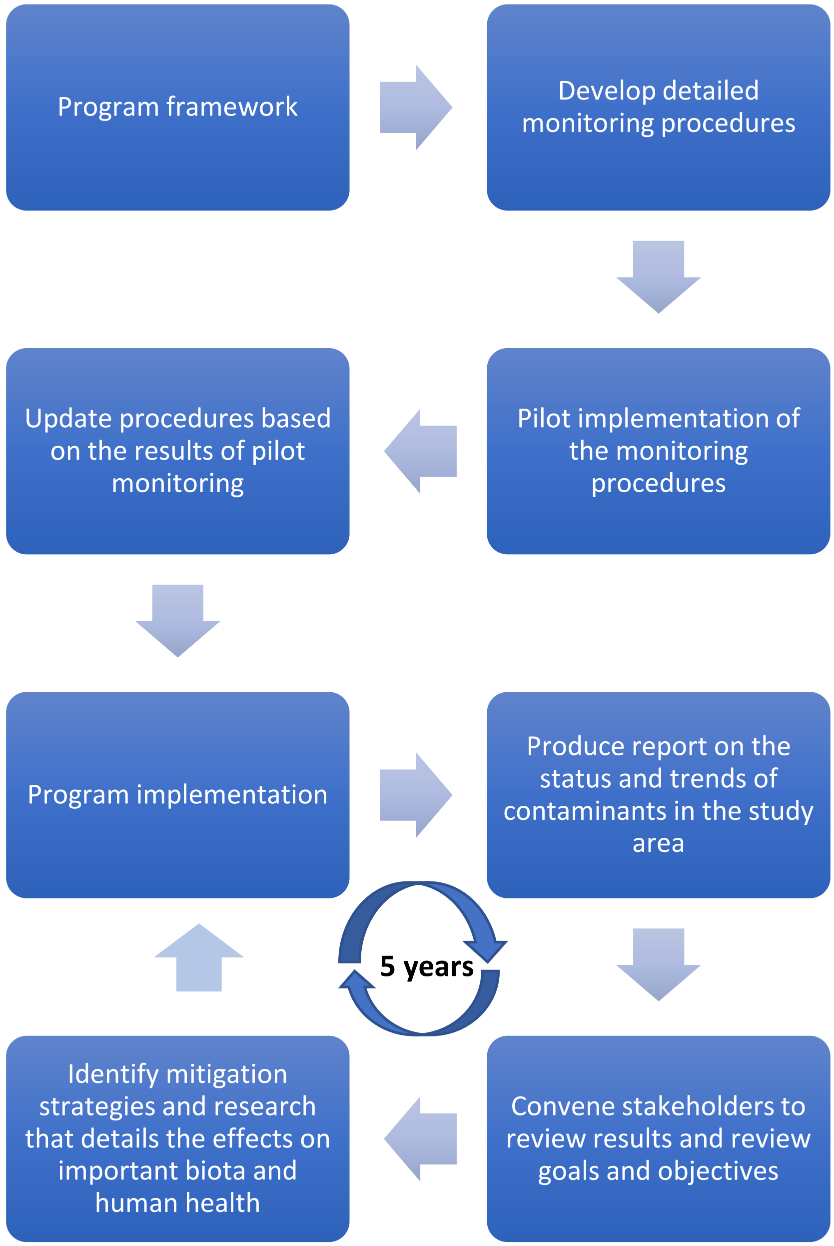

Figure 3. Flow diagram describing the progression of the development of the Columbia River Mainstem Fish Tissue and Water Quality Monitoring Program from the conceptualization of the framework to program implementation and an adaptive management feedback loop.

Although this framework is limited to the Columbia River upstream of the Bonneville Dam, collaboration with other entities that monitor contaminants in the CRB, including the Columbia River estuary below Bonneville Dam, are also an important component of outreach. Our goals are to encourage efforts to ensure data comparability across programs and recognize that the growth and adaptive management of this Program considers basin-wide monitoring developments.

Strategic Planning and Implementation

For the long-term goals of the Program to be successful, stable leadership and funding are needed to conduct the work. Although the CRB was designated as one of 10 nationally designated "large aquatic ecosystems" (LAEs) in 2006, funding for monitoring did not become available until the 2016 CWA Section 123 amendment. Other national LAEs with established, funded monitoring programs include the Puget Sound, Chesapeake Bay, Great Lakes Basin, Gulf of Mexico, Long Island Sound, South Florida, Lake Champlain Basin, Pacific Islands, and San Francisco Bay Delta Estuary.

In parallel with the technical and outreach pathways of the Program development, a strategic plan for funding, housing, development, investments, and implementation will be developed. The strategic plan will necessarily incorporate the technical and outreach planning components but will focus on strategy and logistics for initiating a large long-term program that will continue in perpetuity. For example, topics to be explored include monetary, physical, personnel, management needs: exploring possible pathways for meeting those needs; outlining steps for pursuing short and long-term funding, housing of the Program, outreach and collaboration needed at higher management or government-to-government levels.

Conclusions

Understanding the extent that imperiled stocks of Pacific salmon, other fishes such as lamprey and white sturgeon, and the ecosystem necessary for their continued viability, are contaminated with toxic substances is important. While other aquatic systems in the United States have dedicated programs to monitor the status, trends, and effects of contaminants (e.g., Connon et al., 2019; West et al., 2017), there is no comprehensive contaminants assessment program for the Columbia River. The Columbia River drains a significant portion of the United States, produces electricity that is distributed to much of the western United States, provides important recreational opportunities that support local and regional economies, and is the home to animals and fish that are of cultural significance to local Tribal sovereign nations. Pacific salmon, and other anadromous and resident fish, constitute a significant portion of food for Tribal members that fish in the Columbia River and its tributaries. Fish consumption advisories on the Columbia River negatively affect the cultural traditions of Tribes in the CRB. The completion of this framework is the first step in establishing whether measurable progress is being made from the reduction and removal efforts in the rest of the Columbia River Basin. Implementing this Program will help to answer the basic question, is the contamination of the Columbia River getting better or worse?

References

Altenburger, R., Brack, W., Burgess, R. M., Busch, W., Escher, B. I., Focks, A., . . . Ait-Aissa, S. (2019). Future water quality monitoring: improving the balance between exposure and toxicity assessments of real-world pollutant mixtures. *Environmental Sciences Europe, 31*(1), 1-17.

Alvarez, D., Perkins, S., Nilsen, E., & Morace, J. (2014). Spatial and temporal trends in occurrence of emerging and legacy contaminants in the Lower Columbia River 2008–2010. *Science of the Total Environment, 484*, 322-330.

Ancion, P. Y., Lear, G., Dopheide, A., & Lewis, G. D. (2013). Metal concentrations in stream biofilm and sediments and their potential to explain biofilm microbial community structure. *Environmental Pollution, 173*, 117-124. doi:10.1016/j.envpol.2012.10.012

Arkoosh, M. R., Clemons, E., Huffman, P., & Kagley, A. N. (2001). Increased susceptibility of juvenile Chinook salmon to vibriosis after exposure to chlorinated and aromatic compounds found in contaminated urban estuaries. *Journal of Aquatic Animal Health, 13*(3), 257-268. doi:Doi 10.1577/1548-8667(2001)013<0257:Isojcs>2.0.Co;2

Arkoosh, M. R., Strickland, S., Van Gaest, A., Ylitalo, G. M., Johnson, L., Yanagida, G. K., . . . Dietrich, J. P. (2011). Trends in organic pollutants and lipids in juvenile Snake River spring Chinook salmon with different outmigrating histories through the Lower Snake and Middle Columbia Rivers. *Science of the Total Environment, 409*(23), 5086-5100. doi:10.1016/j.scitotenv.2011.08.031

Arkoosh, M. R., Van Gaest, A. L., Strickland, S. A., Hutchinson, G. P., Krupkin, A. B., & Dietrich, J. P. (2015). Dietary Exposure to Individual Polybrominated Diphenyl Ether Congeners BDE-47 and BDE-99 Alters Innate Immunity and Disease Susceptibility in Juvenile Chinook Salmon. *Environmental Science & Technology, 49*(11), 6974-6981. doi:10.1021/acs.est.5b01076

Benito, G., & O'Connor, J. E. (2003). Number and size of last-glacial Missoula floods in the Columbia River valley between the Pasco Basin, Washington, and Portland, Oregon. *Geological Society of America Bulletin, 115*(5), 624-638.

Berglund, O. (2003). Periphyton density influences organochlorine accumulation in rivers. *Limnology and Oceanography, 48*(6), 2106-2116. doi:DOI 10.4319/lo.2003.48.6.2106

Besser, J. M., Steevens, J., Kunz, J. L., Brumbaugh, W. G., Ingersoll, C. G., Cox, S., . . . MacDonald, D. (2018). Characterizing toxicity of metal-contaminated sediments from the Upper Columbia River, Washington, USA, to benthic invertebrates. *Environmental Toxicology and Chemistry, 37*(12), 3102-3114.

Biedenweg, K., Harguth, H., & Stiles, K. (2017). The science and politics of human well-being: a case study in cocreating indicators for Puget Sound restoration. *Ecology and Society, 22*(3).

Bonnineau, C., Artigas, J., Chaumet, B., Dabrin, A., Fabure, J., Ferrari, B. J., . . . Miege, C. (2020). Role of biofilms in contaminant bioaccumulation and trophic transfer in aquatic ecosystems: current state of knowledge and future challenges. *Reviews of Environmental Contamination and Toxicology Volume 253*, 115-153.

Bottom, D. L., Hinton, S. A., Teel, D. J., Curtis Roegner, G., Johnson, L. L., & Sandford, B. P. (2021). The Abundance and Distribution of Hatchery and Naturally Produced Chinook

Salmon in Columbia River Estuary Nearshore Habitat. *North American Journal of Fisheries Management, 41*(5), 1549-1571.
Bottoni, P., Caroli, S. and Caracciolo, A.B. (2010). Pharmaceuticals as priority water contaminants. *Toxicological & Environmental Chemistry, 92*(3), 549-565.
Bouska, K. L., Houser, J. N., De Jager, N. R., & Hendrickson, J. (2018). Developing a shared understanding of the Upper Mississippi River. *Ecology and Society, 23*(2).
Buendia, C., Gibbins, C. N., Vericat, D., Batalla, R. J., & Douglas, A. (2013). Detecting the structural and functional impacts of fine sediment on stream invertebrates. *Ecological Indicators, 25*, 184-196.
Buerge, I. J., Buser, H.-R., Kahle, M., Muller, M. D., & Poiger, T. (2009). Ubiquitous occurrence of the artificial sweetener acesulfame in the aquatic environment: an ideal chemical marker of domestic wastewater in groundwater. *Environmental Science & Technology, 43*(12), 4381-4385.
Caton, L. (2012). Regional Environmental Monitoring and Assessment Program: 2009 Lower mid-Columbia River Ecological Assessment Final Report.
Connon, R. E., Hasenbein, S., Brander, S. M., Poynton, H. C., Holland, E. B., Schlenk, D., . . . Scholz, N. L. (2019). Review of and recommendations for monitoring contaminants and their effects in the San Francisco Bay− Delta. *San Francisco Estuary and Watershed Science, 17*(4).
Counihan, T. D., Waite, I. R., Nilsen, E. B., Hardiman, J. M., Elias, E., Gelfenbaum, G., & Zaugg, S. D. (2014). A survey of benthic sediment contaminants in reaches of the Columbia River Estuary based on channel sedimentation characteristics. *Science of the Total Environment, 484*, 331-343.
CRITFC (Columbia River Inter-Tribal Fish Commission). (1994). A Fish Consumption Survey of the Umatilla, Nez Perce, Yakama, and Warm Springs Tribes of the Columbia River Basin. Technical Report no. 94–3: Columbia River Intertribal Fish Commission Oregon.
CRITFC (Columbia River Inter-Tribal Fish Commission). (1996). Wy-Kan-Ush-Mi Wa-Kish-Wit: Spirit of the Salmon. *Vol. II: Subbasin Plans*.
Darnthamrongkul, W., & Mozingo, L. A. (2020). Challenging anthropocentric stormwater management: Advancing legislation for environmental sustainability in the United States. *Water Security, 10*, 100064.
Diaz-Ramos, S., Stevens Jr, D., & Olsen, A. (1996). EMAP statistics methods manual. *US Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory. Corvallis, OR*.
Erickson, R. J., Nichols, J. W., Cook, P. M., & Ankley, G. T. (2008). Bioavailability of chemical contaminants in aquatic systems. *The toxicology of fishes, 9*, 54.
Fenneman, N., & Johnson, D. (1946). Physiographic divisions of the conterminous US Washington. *DC: US Geological Suvey*.
Flores, L., Mojica, J., Fletcher, A., Casey, P., Christin, Z., Armistead, C., & Batker, D. K. (2017). *The Value of Natural Capital in the Columbia River Basin: A Comprehensive Analysis*. Retrieved from http://www.columbiana.org/PDFs/CRBV-FINAL-DIGITAL.pdf
Ford, M. J., Albaugh, A., Barnas, K., Cooney, T. D., Cowen, J., Hard, J. J., . . . Myers, J. M. (2011). Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest.

Garman, S. L., Schweiger, E. W., & Manier, D. J. (2012). Simulating future uncertainty to guide the selection of survey designs for long-term monitoring. *Design and Analysis of Long--term Ecological Monitoring Studies*, 228-249.

Gefell, D., Annis, M., Banda, J., Bellamy, A., Choy, S., Hummel, S., . . . Tucker, W. (2019). *Ecological hazard assessment of contaminants of emerging concern in the US Great Lakes Basin: Part A–screening assessment of relative hazard to fish from surface water exposures to fourteen contaminants of emerging concern in the Great Lakes basin*.

Glassmeyer, S. T., Furlong, E. T., Kolpin, D. W., Batt, A. L., Benson, R., Boone, J. S., . . . Kostich, M. S. (2017). Nationwide reconnaissance of contaminants of emerging concern in source and treated drinking waters of the United States. *Science of the Total Environment, 581*, 909-922.

Guelfo, J. L., & Adamson, D. T. (2018). Evaluation of a national data set for insights into sources, composition, and concentrations of per-and polyfluoroalkyl substances (PFASs) in US drinking water. *Environmental Pollution, 236*, 505-513.

Haegerbaeumer, A., Mueller, M.-T., Fueser, H., & Traunspurger, W. (2019). Impacts of micro- and nano-sized plastic particles on benthic invertebrates: a literature review and gap analysis. *Frontiers in Environmental Science, 7*, 17.

Harper, B. L., & Walker Jr, D. E. (2015). Comparison of Contemporary and Heritage Fish Consumption Rates in the Columbia River Basin. *HUMAN ECOLOGY*, 225-236.

Haskell, C. A., Beauchamp, D. A., & Bollens, S. M. (2017). Linking functional response and bioenergetics to estimate juvenile salmon growth in a reservoir food web. *Plos One, 12*(10), e0185933.

Hayslip, G., Edmond, L., Partridge, V., Nelson, W., Lee, H., Cole, F., . . . Caton, L. (2007). *Ecological Condition of the Columbia River Estuary*. Retrieved from https://archive.epa.gov/emap/archive-emap/web/pdf/columbia.pdf

Henny, C. J., Grove, R. A., Kaiser, J. L., Johnson, B. L., Furl, C. V., & Letcher, R. J. (2011). Wastewater dilution index partially explains observed polybrominated diphenyl ether flame retardant concentrations in osprey eggs from Columbia River Basin, 2008–2009. *Ecotoxicology, 20*(4), 682-697.

Herger, L. G., L. Edmond, and G. Hayslip. (2016). *Mid-Columbia River fish toxics assessment: EPA Region 10 Report.* (EPA-910-R-17-002). Retrieved from https://www.epa.gov/sites/default/files/2017-03/documents/mid-columbia-river-fish-toxics-assessment-march2017.pdf.

Hess, J. E., Campbell, N. R., Matala, A. P., & Narum, S. R. (2016). Genetic assessment of Columbia River stocks. *Columbia River Inter-Tribal Fish Commission annual report*.

Hess, J. E., Whiteaker, J. M., Fryer, J. K., & Narum, S. R. (2014). Monitoring stock-specific abundance, run timing, and straying of Chinook salmon in the Columbia River using genetic stock identification (GSI). *North American Journal of Fisheries Management, 34*(1), 184-201.

Hickey, B. M., & Banas, N. S. (2003). Oceanography of the US Pacific Northwest coastal ocean and estuaries with application to coastal ecology. *Estuaries, 26*(4), 1010-1031.

Hill, W., & Napolitano, G. (1997). PCB congener accumulation by periphyton, herbivores, and omnivores. *Archives of environmental contamination and toxicology, 32*(4), 449-455.

Hudiburgh, G. (2020). The Clean Water Act *Fundamentals of Aquatic Toxicology* (pp. 717-733): CRC Press.

James, A., Brandenberger, J., Dutch, M., Hardy, J., Lester, D., Norton, D., O'Neill, S., Redman, S., Schultz, I., Sullivan, C., West, J. (2015). *Contaminants of Emerging Concern: A Prioritization Framework for Monitoring in Puget Sound*. Puget Sound Ecosystem Monitoring Program, Toxics Workgroup. In Collaboration with: Columbia River Toxics Reduction Workgroup. Retrieved from https://www.eopugetsound.org/sites/default/files/features/resources/CEC_Prioritization_White_Paper_2015-02-28.pdf

Jaskuła, J., & Sojka, M. (2022). Assessment of spatial distribution of sediment contamination with heavy metals in the two biggest rivers in Poland. *Catena, 211*, 105959.

Jenkins, J. A., Olivier, H., Draugelis-Dale, R., Eilts, B., Torres, L., Patiño, R., . . . Goodbred, S. L. (2014). Assessing reproductive and endocrine parameters in male largescale suckers (Catostomus macrocheilus) along a contaminant gradient in the lower Columbia River, USA. *Science of the Total Environment, 484*, 365-378.

Jensen, A. J., Schreck, C. B., Hess, J. E., Bohn, S., O'Malley, K. G., & Peterson, J. T. (2021). Application of Genetic Stock Identification and Parentage-Based Tagging in a Mixed-Stock Recreational Chinook Salmon Fishery. *North American Journal of Fisheries Management, 41*(1), 130-141.

Johnson, A., Seiders, K., Deligeannis, C., Kinney, K., Sandvik, P., Era-Miller, B., & Alkire, D. (2006). PBDE flame retardants in Washington rivers and lakes: concentrations in fish and water, 2005–06. Washington State Dept. *Ecology, Publ*(06-03), 027.

Johnson, B. M., Johnson, M. S., & Thorgaard, G. H. (2019). Salmon genetics and management in the Columbia River Basin. *Northwest Science, 92*(sp5), 346-363.

Johnson, L., Bravo, C., O'Neill, S., West, J., Myers, M. S., Ylitalo, G., & Collier, T. (2010). A Toxics-Focused Biological Observing System for Puget Sound. *Olympia, WA: Washington State Department fo Ecology*.

Johnson, L. L., Anulacion, B. F., Arkoosh, M. R., Burrows, D. G., da Silva, D. A., Dietrich, J. P., . . . Ylitalo, G. M. (2013). Effects of legacy persistent organic pollutants (POPs) in fish—current and future challenges. *Fish physiology, 33*, 53-140.

Johnson, L. L., Ylitalo, G. M., Sloan, C. A., Anulacion, B. F., Kagley, A. N., Arkoosh, M. R., . . . Collier, T. K. (2007). Persistent organic pollutants in outmigrant juvenile chinook salmon from the Lower Columbia Estuary, USA. *Science of the Total Environment, 374*(2-3), 342-366.

Kasprzyk-Hordern, B., Dinsdale, R. M., & Guwy, A. J. (2008). The occurrence of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs in surface water in South Wales, UK. *Water research, 42*(13), 3498-3518.

Lapworth, D., Baran, N., Stuart, M., & Ward, R. (2012). Emerging organic contaminants in groundwater: a review of sources, fate and occurrence. *Environmental Pollution, 163*, 287-303.

Larsen, D. P., Kaufmann, P. R., Kincaid, T. M., & Urquhart, N. S. (2004). Detecting persistent change in the habitat of salmon-bearing streams in the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences, 61*(2), 283-291.

Lerch, J., Hulstrom, L., & Sands, J. (2013). *Remedial Investigation of Hanford Site Releases to the Columbia River–13603*.

Liber, Y., Mourier, B., Marchand, P., Bichon, E., Perrodin, Y., & Bedell, J.-P. (2019). Past and recent state of sediment contamination by persistent organic pollutants (POPs) in the Rhône River: Overview of ecotoxicological implications. *Science of the Total Environment, 646*, 1037-1046.

Lindenmayer, D. B., & Likens, G. E. (2009). Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends in Ecology & Evolution, 24*(9), 482-486.

Lorenz, S., & Wolter, C. (2019). Quantitative response of riverine benthic invertebrates to sediment grain size and shear stress. *Hydrobiologia, 834*(1), 47-61.

Lundin, J. I., Chittaro, P. M., Ylitalo, G. M., Kern, J. W., Kuligowski, D. R., Sol, S. Y., . . . Neely, R. M. (2021). Decreased Growth Rate Associated with Tissue Contaminants in Juvenile Chinook Salmon Out-Migrating through an Industrial Waterway. *Environmental Science & Technology, 55*(14), 9968-9978.

Lundin, J. I., Spromberg, J. A., Jorgensen, J. C., Myers, J. M., Chittaro, P. M., Zabel, R. W., . . . Scholz, N. L. (2019). Legacy habitat contamination as a limiting factor for Chinook salmon recovery in the Willamette Basin, Oregon, USA. *Plos One, 14*(3), e0214399.

Macneale, K. H., Kiffney, P. M., & Scholz, N. L. (2010). Pesticides, aquatic food webs, and the conservation of Pacific salmon. *Frontiers in Ecology and the Environment, 8*(9), 475-482.

Mahler, B. J., Schmidt, T. S., Nowell, L. H., Qi, S. L., Van Metre, P. C., Hladik, M. L., . . . May, J. (2020). Biofilms provide new insight into pesticide occurrence in streams and links to aquatic ecological communities. *Environmental Science & Technology, 54*(9), 5509-5519.

Mailman, M., Stepnuk, L., Cicek, N., & Bodaly, R. D. (2006). Strategies to lower methyl mercury concentrations in hydroelectric reservoirs and lakes: A review. *Science of the Total Environment, 368*(1), 224-235.

Mathieu, C., & McCall, M. (2016). Survey of Per-and Poly-fluoroalkyl Substances (PFASs) in Rivers and Lakes. 2016. *Olympia, Washington, 64*.

Meade, R. H. (1996). River-sediment inputs to major deltas *Sea-level rise and coastal subsidence* (pp. 63-85): Springer.

Munoz, G., Fechner, L. C., Geneste, E., Pardon, P., Budzinski, H., & Labadie, P. (2018). Spatio-temporal dynamics of per and polyfluoroalkyl substances (PFASs) and transfer to periphytic biofilm in an urban river: case-study on the River Seine. *Environmental Science and Pollution Research, 25*(24), 23574-23582.

Nilsen, E., Zaugg, S., Alvarez, D., Morace, J., Waite, I., Counihan, T., . . . Mesa, M. (2014). Contaminants of legacy and emerging concern in largescale suckers (Catostomus macrocheilus) and the foodweb in the lower Columbia River, Oregon and Washington, USA. *Science of the Total Environment, 484*, 344-352.

Nilsen, E. B., Hapke, W. B., McIlraith, B., & Markovchick, D. (2015). Reconnaissance of contaminants in larval Pacific lamprey (Entosphenus tridentatus) tissues and habitats in the Columbia River Basin, Oregon and Washington, USA. *Environmental Pollution, 201*, 121-130.

O'Donnell, M. S., Edmunds, D. R., Aldridge, C. L., Heinrichs, J. A., Monroe, A. P., Coates, P. S., . . . Christiansen, T. J. (2021). Synthesizing and analyzing long-term monitoring data: A greater sage-grouse case study. *Ecological Informatics, 63*, 101327.

ODEQ (Oregon Department of Environmental Quality). (2003). *Fact Sheet: Sources of Polychlorinated Biphenyls.* Oregon Department of Environmental Quality. Retrieved from https://www.oregon.gov/deq/FilterDocs/ph-SourcePCBs.pdf

OHA. (2013). *Fish Consumption Advisory, Middle Columbia River. Oregon Health Authority and Washington State Department of Health Fact Sheet*. Oregon Health Authority. Retrieved from https://www.oregon.gov/oha/PH/HealthyEnvironments/Recreation/Documents/Mid-Columbia/MiddleColumbiaFactSheet.pdf

OHA (Oregon Health Authority). (2012). Bonneville Dam Fish Advisory. Retrieved from https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/RECREATION/FISHCONSUMPTION/Pages/Bonneville.aspx

Pandey, L. K., Park, J., Son, D. H., Kim, W., Islam, M. S., Choi, S., . . . Han, T. (2019). Assessment of metal contamination in water and sediments from major rivers in South Korea from 2008 to 2015. *Science of the Total Environment, 651*, 323-333.

Parrish, A. L. (2005). Trail smelter déjà vu: extraterritoriality, international environmental law, and the search for solutions to Canadian-US transboundary water pollution disputes. *BUL Rev., 85*, 363.

Patra, R. W., Chapman, J. C., Lim, R. P., Gehrke, P. C., & Sunderam, R. M. (2015). Interactions between water temperature and contaminant toxicity to freshwater fish. *Environmental Toxicology and Chemistry, 34*(8), 1809-1817.

Peele, C. (2003). *Washington State Mercury Chemical Action Plan*. (03-03-001). Retrieved from https://apps.ecology.wa.gov/publications/summarypages/0303001.html.

Pestana, I. A., Azevedo, L. S., Bastos, W. R., & de Souza, C. M. M. (2019). The impact of hydroelectric dams on mercury dynamics in South America: A review. *Chemosphere, 219*, 546-556.

Pohl, H. R., Odin, M., McClure, P. R., Zaccaria, K., Llados, F., Kawa, M., & Citra, M. (2017). Toxicological profile for polybrominated diphenyl ethers (PBDEs).

Polissar, N., Salisbury, A., Ridolfi, C., Callahan, K., Neradilek, M., Hippe, D., & Beckley, W. (2016). A fish consumption survey of the Nez Perce Tribe: Vols. I-III.

PSAT (Puget Sound Action Team). (2007). Puget Sound update: Ninth report of the Puget Sound Ambient Monitoring Program: Puget Sound Action Team Olympia, WA.

Radinger, J., Britton, J. R., Carlson, S. M., Magurran, A. E., Alcaraz-Hernández, J. D., Almodóvar, A., . . . Oliva-Paterna, F. J. (2019). Effective monitoring of freshwater fish. *Fish and Fisheries, 20*(4), 729-747.

Richardson, S. D., & Kimura, S. Y. (2016). Water analysis: emerging contaminants and current issues. *Analytical chemistry, 88*(1), 546-582.

Rizo, E. Z. C., Liu, P., Niu, H., Yang, Y., Lin, Q., Papa, R. D. S., . . . Han, B.-P. (2020). Zooplankton in a continuous waterscape: environmental and spatial factors shaping spring zooplankton community structure in a large canyon reservoir at the tropic of cancer. *Hydrobiologia, 847*(17), 3621-3635.

Sams, C. F. (2007). Wakanish Naknoowee Thluma:'Keepers of the Salmon'. *Oregon Historical Quarterly, 108*(4), 644-648.

Scherer, C., Weber, A., Stock, F., Vurusic, S., Egerci, H., Kochleus, C., . . . Wagner, M. (2020). Comparative assessment of microplastics in water and sediment of a large European river. *Science of the Total Environment, 738*, 139866.

Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., Von Gunten, U., & Wehrli, B. (2010). Global water pollution and human health. *Annual review of environment and resources, 35*(1), 109-136.

Siddiqui, E., & Pandey, J. (2019). Assessment of heavy metal pollution in water and surface sediment and evaluation of ecological risks associated with sediment contamination in the Ganga River: a basin-scale study. *Environmental Science and Pollution Research, 26*(11), 10926-10940.

Skalski, J. R. (1990). A design for long-term status and trends monitoring. *Journal of Environmental Management, 30*(2), 139-144.

Sloan, C. A., Anulacion, B. F., Bolton, J. L., Boyd, D., Olson, O. P., Sol, S. Y., . . . Johnson, L. L. (2010). Polybrominated diphenyl ethers in outmigrant juvenile Chinook salmon from the lower Columbia River and Estuary and Puget Sound, Washington. *Archives of environmental contamination and toxicology, 58*(2), 403-414.

Stahl, L. L., Snyder, B. D., Olsen, A. R., & Pitt, J. L. (2009). Contaminants in fish tissue from US lakes and reservoirs: a national probabilistic study. *Environmental Monitoring and Assessment, 150*(1), 3-19.

Stange, K., & Swackhamer, D. L. (1994). Factors affecting phytoplankton species-specific differences in accumulation of 40 polychlorinated biphenyls (PCBs). *Environmental Toxicology and Chemistry: An International Journal, 13*(11), 1849-1860.

Starcevich, L., McDonald, T., Chung-MacCoubrey, A., Heard, A., Nesmith, J., & Philippi, T. (2018). Trend estimation for complex survey designs of water chemistry indicators from Sierra Nevada Lakes. *Environmental Monitoring and Assessment, 190*(10), 1-19.

Stevens Jr, D. L. (1997). Variable density grid-based sampling designs for continuous spatial populations. *Environmetrics: The official journal of the International Environmetrics Society, 8*(3), 167-195.

Stevens Jr, D. L., & Olsen, A. R. (2004). Spatially balanced sampling of natural resources. *Journal of the American statistical Association, 99*(465), 262-278.

Stevens Jr, L., & Olsen, A. R. (1999). Spatially restricted surveys over time for aquatic resources. *Journal of Agricultural, Biological, and Environmental Statistics*, 415-428.

Sutter, R. D., Wainscott, S. B., Boetsch, J. R., Palmer, C. J., & Rugg, D. J. (2015). Practical guidance for integrating data management into long-term ecological monitoring projects. *Wildlife Society Bulletin, 39*(3), 451-463.

Swackhamer, D. L., & Skoglund, R. (1993). Bioaccumulation of PCBs by algae: kinetics versus equilibrium. *Environmental Toxicology and Chemistry: An International Journal, 12*(5), 831-838.

Sy, N. D., Wheeler, S. S., Reed, M., Haas-Stapleton, E., Reyes, T., Bear-Johnson, M., . . . Xiong, Y. (2022). Pyrethroid insecticides in urban catch basins: A potential secondary contamination source for urban aquatic systems. *Environmental Pollution, 314*, 120220.

Tang, J., Wang, S., Tai, Y., Tam, N. F., Su, L., Shi, Y., . . . Zhang, X. (2020a). Evaluation of factors influencing annual occurrence, bioaccumulation, and biomagnification of antibiotics in

planktonic food webs of a large subtropical river in South China. *Water research, 170*, 115302.
Tang, Y., Zhong, Y., Li, H., Huang, Y., Guo, X., Yang, F., & Wu, Y. (2020b). Contaminants of emerging concern in aquatic environment: occurrence, monitoring, fate, and risk assessment. *Water Environment Research, 92*(10), 1811-1817.
Tashjian, D. H., Teh, S. J., Sogomonyan, A., & Hung, S. S. (2006). Bioaccumulation and chronic toxicity of dietary l-selenomethionine in juvenile white sturgeon (Acipenser transmontanus). *Aquatic Toxicology, 79*(4), 401-409.
Tchatchouang Chougong, D., Ngueutchoua, G., Henock Dicka, E., Ekoa Bessa, A. Z., Youbouni Ghepdeu, G. F., Bilounga, U. J. F., . . . Armstrong-Altrin, J. S. (2022). Distributions of trace metals and radionuclides contamination in alluvial sediments from the Lobé River in Cameroon. *Earth Systems and Environment, 6*(1), 121-139.
Tian, Z., Zhao, H., Peter, K. T., Gonzalez, M., Wetzel, J., Wu, C., . . . Hettinger, R. (2021). A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon. *Science, 371*(6525), 185-189.
Turusov, V., Rakitsky, V., & Tomatis, L. (2002). Dichlorodiphenyltrichloroethane (DDT): ubiquity, persistence, and risks. *Environmental health perspectives, 110*(2), 125-128.
Urquhart, N. S., & Kincaid, T. M. (1999). Designs for detecting trend from repeated surveys of ecological resources. *Journal of Agricultural, Biological, and Environmental Statistics*, 404-414.
Urquhart, N. S., Paulsen, S. G., & Larsen, D. P. (1998). Monitoring for policy-relevant regionaltrends over time. *Ecological Applications, 8*(2), 246-257.
USEPA (U.S. Environmental Protection Agency). (2000). *Guidance for assessing chemical contaminant data for use in fish advisories*. Retrieved from https://www.epa.gov/sites/default/files/2018-11/documents/guidance-assess-chemical-contaminant-vol2-third-edition.pdf
USEPA (U.S. Environmental Protection Agency). (2002). *Columbia River basin fish contaminant survey, 1996-1998*. Retrieved from https://www.epa.gov/sites/default/files/documents/columbia_fish_contaminant_survey_1996-1998.pdf
USEPA (U.S. Environmental Protection Agency). (2009). *Columbia River Basin: state of the river report for toxics*. Retrieved from https://www.epa.gov/sites/default/files/documents/columbia_state_of_the_river_report_jan2009.pdf
USEPA (U.S. Environmental Protection Agency). (2010). *Columbia River Toxics Reduction Action Plan*. Retrieved from https://www.epa.gov/sites/default/files/documents/columbia_river_toxics_action_plan_sept2010.pdf
van Dam-Bates, P., Gansell, O., & Robertson, B. (2018). Using balanced acceptance sampling as a master sample for environmental surveys. *Methods in Ecology and Evolution, 9*(7), 1718-1726.
Vörösmarty, C., Fekete, B. M., Meybeck, M., & Lammers, R. B. (2000). Geomorphometric attributes of the global system of rivers at 30-minute spatial resolution. *Journal of Hydrology, 237*(1-2), 17-39.

WA Ecology (Washington Department of Ecology). (2013). Fish Consumption Rates, Technical Support Document. Version 2.0 Final. January 2013, Pub. 12-09-058. *Washington Department of Ecology*.

WA Ecology (Washington State Department of Ecology). (2022). Water quality assessment & 303(d) list. Retrieved from https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d

Wagner, T., McLaughlin, P., Smalling, K., Breitmeyer, S., Gordon, S., & Noe, G. B. (2022). The statistical power to detect regional temporal trends in riverine contaminants in the Chesapeake Bay Watershed, USA. *Science of the Total Environment, 812*, 152435.

WDOH (Washington Department of Health). (2012). *Human Health Evaluation of Contaminants in Upper Columbia River Fish.* . (DOH 334-317). Olympia, Washington: Washington State Department of Health.

WDOH (Washington Department of Health). (2022). Fish Consumption Advisories. Retrieved from https://doh.wa.gov/community-and-environment/food/fish/advisories

West, J. E., Carey, A. J., Ylitalo, G. M., Incardona, J. P., Edmunds, R. C., Sloan, C. A., . . . O'Neill, S. M. (2019). Polycyclic aromatic hydrocarbons in Pacific herring (Clupea pallasii) embryos exposed to creosote-treated pilings during a piling-removal project in a nearshore marine habitat of Puget Sound. *Marine Pollution Bulletin, 142*, 253-262.

West, J. E., O'Neill, S. M., Ylitalo, G. M., Incardona, J. P., Doty, D. C., & Dutch, M. E. (2014). An evaluation of background levels and sources of polycyclic aromatic hydrocarbons in naturally spawned embryos of Pacific herring (Clupea pallasii) from Puget Sound, Washington, USA. *Science of the Total Environment, 499*, 114-124.

West, J. E., O'Neill, S. M., & Ylitalo, G. M. (2017). Time trends of persistent organic pollutants in benthic and pelagic indicator fishes from Puget Sound, Washington, USA. *Archives of environmental contamination and toxicology, 73*(2), 207-229.

Wildi, W., Dominik, J., Loizeau, J. L., Thomas, R. L., Favarger, P. Y., Haller, L., . . . Peytremann, C. (2004). River, reservoir and lake sediment contamination by heavy metals downstream from urban areas of Switzerland. *Lakes & Reservoirs: Research & Management, 9*(1), 75-87.

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., . . . Bourne, P. E. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data, 3*(1), 1-9.

Yakama Nation. (2022a). Yakama Nation Brownfields Project. Retrieved from https://yakamafish-nsn.gov/restore/projects/yakama-nation-brownfields-project

Yakama Nation. (2022b). Columbia Mainstem Fish Tissue and Water Quality Monitoring Program Outreach Framework. Retrieved from https://yakamafish-nsn.gov/restore/projects/activity/outreach-and-education

Zuccato, E., & Castiglioni, S. (2009). Illicit drugs in the environment. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 367*(1904), 3965-3978.

Supplemental Materials

Table S1. Reservoirs and river reaches delineated by the presence of dams on the mainstem Columbia River from Bonneville Dam to the international border with Canada, State, Geographic Names Information System (GNIS) ID, and river kilometer (rkm) range.

River reach	State	GNIS_ID	rkm
Bonneville Reservoir	Washington, Oregon	01159124	234-308
The Dalles Reservoir	Washington, Oregon	01118771	308-348
John Day Reservoir	Washington, Oregon	01513298	348-470
McNary Reservoir	Washington, Oregon	01513411	470-549
Hanford Reach	Washington	.	549-639
Priest Rapids Reservoir	Washington	01507636	639-668
Wanapum Reservoir	Washington	01509280	668-730
Rock Island Reservoir	Washington	01530360	730-762
Rocky Reach Reservoir	Washington	01519365	762-830
Wells Reservoir	Washington	01524248	830-872
Chief Joseph Reservoir	Washington	01507959	872-956
Lake Roosevelt (Grand Coulee to the Canadian Border)	Washington	01534225	956-1196

Table S2. Anadromous salmonid bearing tributaries to the mainstem Columbia River from Bonneville Dam to the international border with Canada, State, and Geographic Names Information System (GNIS) ID.

Tributary	State	GNIS_ID
Rock Creek	Washington	1525121
Wind River	Washington	1533062
White Salmon River	Washington	1528090
Hood River	Oregon	1143705
Klickitat River	Washington	1521728
Deschutes River	Oregon	1140916
John Day River	Oregon	1144304
Umatilla River	Oregon	1157874
Walla Walla River	Washington	1513408
Snake River	Washington	1533479
Yakima River	Washington	1528343
Crab Creek	Washington	1506353
Wenatchee River	Washington	1527909
Entiat River	Washington	1519362
Methow River	Washington	1523034
Okanogan River	Washington	1523981

Table S3. Human Health Screening Levels (in mg/kg wet weight tissues) to inform detection limits.

Analyte	EPA Screening Value for fish tissue contaminants and General Population#	EPA Screening Value for tissue contaminants and Subsistence Fishers^
Total Chlordanes	10.7	2.85
Total DDT	11.1	2.94
Dieldrin	0.235	0.0624
Mercury+	14	3.71
Total PCBs+	1.88	0.499
Total PBDEs	0.125	0.033*
PFOA+	0.419	0.143
PFOS+	0.279	0.0742

[All values calculated from the USEPA 2021 Regional Screening Value calculator- default settings, chronic exposure; # General Population assumes 59.7 g/day; ^Subsistence Fishers assumes 225 g/ day; *value may not be economically attainable at lab; +based on non-cancer risk]

USEPA (2021) Regional Fish Consumption Screening Levels (Spring 2021). Online Calculator (TR=1E-06, THQ=1.0 pdf table). Accessed online on Nov 15, 2022.

Table S4. Ecological Risk Screening Values for Sediment and Critical Tissue Levels in Fish Tissue.

Analyte	Ecological Screening Value for Sediment (ESV)†(EPA 2018).	Screening Value for tissues for fish and wildlife predators† (ODEQ 2007).
Total Chlordanes	0.06	56
Total DDXs	4.2	54
DDE	1.0	54
Deildrin	1.9	n/a
Mercury	0.17	47
Methyl Mercury (wildlife)	4.5 E-4	Not available, see Mercury
Selenium	0.72	24
Total PCBs#	14	170
Dioxin-like PCBs	5.0 E-4	n/a
Total PBDEs	n/a	n/a
PFOS	1.4x10-3 (Tree Swallow *Tachycineta bicolor*)	n/a

Note: Where multiple ESVs were presented, the lowest (or most sensitive) endpoint value was selected. †Values as ug/kg sediment dry weight @ 1% OC, or ug/kg wet weight for tissues.

ODEQ (2007) Guidance for Assessing Bioaccumulative Chemicals of Concern in Sediment, January 2007, updated October 2020. Environmental Cleanup Program, Oregon Department of Environmental Quality,

USEPA (2018) Supplemental Guidance to ERAGS: Region 4, Ecological Risk Assessment. Originally published November 1995 and updated March 2018,
Region 4 Risk Assessment Resources. Superfund Division, EPA Region 4.

Table S5. ESA Listed Salmonids Tissue Analytical Targets- (Recommended Detection Limits for ESA-listed fish).

Analyte	Screening value for tissue levels for fish health (ug/kg wet weight)	Reference	Application Precedence
Mercury	200	Beckvar 2005	many
PCBs	100	Berninger & Tillit 2018	Snoqualmie, Portland Harbor, Eighteen Mile Creek
PBDEs	7-10	Arkoosh et al. (2015, 2018)	Portland Harbor
DDT	20	Beckvar & Lotufo 2011	Chinook salmon *Oncorhynchus tshawytscha*
Dieldrin	200	Shubat & Curtis 1986	Rainbow trout *Oncorhynchus mykiss*
Chlordane	710	Beckvar & Lotufo 2011	Chinook salmon

Arkoosh, M. R., Van Gaest, A. L., Strickland, S. A., Hutchinson, G. P., Krupkin, A. B., & Dietrich, J. P. (2015) Dietary exposure to individual polybrominated diphenyl ether congeners BDE-47 and BDE-99 alters innate immunity and disease susceptibility in juvenile Chinook salmon. *Environmental Science & technology, 49(11), 6974-6981*.

Arkoosh, M.R., Van Gaest, A.L., Strickland, S.A., Hutchinson, G.P., Krupkin, A.B., Hicks, M.B., Dietrich, J.P. 2018. Dietary exposure to a binary mixture of polybrominated diphenyl ethers alters innate immunity and disease susceptibility in juvenile Chinook salmon (Oncorhynchus tshawytscha), *Ecotoxicology and Environmental Safety, 163, p96-103, doi.org/10.1016/j.ecoenv.2018.07.052.*

Beckvar, N., Dillion, T.M., Read, L.B. 2005. Approaches for linking whole-body fish tissue residues of mercury or ddt to biological effects thresholds. *Environmental Toxicology and Chemistry, 24(8), 2094-2105.*

Beckvar, N., & Lotufo, G. R. (2011). DDT and other organohalogen pesticides in aquatic organisms. *Environmental Contaminants in Biota: Interpreting Tissue Concentrations*, *2*, 47-101.

Berninger, J.P., Tillitt, D.E. 2018. Polychlorinated Biphenyl tissue-concentration thresholds for survival, growth, and reproduction in fish, Critical Review. *Environmental Toxicology and Chemistry, 38(4)*, *712-736.*

Shubat, P. J., & Curtis, L. R. (1986). Ration and toxicant preexposure influence dieldrin accumulation by rainbow trout (Salmo gairdneri). *Environmental Toxicology and Chemistry, 5(1), 69-77.*

Table S6. Contaminant studies in the Columbia River from Bonneville Dam to the U.S border with Canada that were evaluated as historical data. PCB=polychlorinated biphenyl. PCB abbreviations: A=aroclors, C=congeners. DDx= any or all of the six DDT isomers (p,p'-DDT; p,p'-DDD, p,p'-DDE; o,p'-DDT; o,p'-DDD; o,p'-DDE). Dx/Fr=dioxins and furan compounds. PBDE=polybrominated diphenyl ethers.

Reference	Target Analytes					
	PCB	DDx	Hg	PBDE	Dx/Fr	Other
Washington Department of Ecology. (2020) River and stream water quality monitoring. Washington Department of Ecology, Olympia WA. https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Water-quality-monitoring			x			x
Seiders, K., C. Deligeannis, M. McCall, and P. Sandvik. (2015) Freshwater Fish Contaminant Monitoring Program: Annual Report for 2013. Washington State Department of Ecology, Olympia, WA. Publication No. 15-03-016. https://fortress.wa.gov/ecy/publications/SummaryPages/1503016.html	A, C	x	x	x	x	
U.S. Department of Energy. (2012) Remedial Investigation of Hanford Site Releases to the Columbia River: Columbia River Component Risk Assessments. Richland, WA. U.S. Department of Energy Publication Number DOE/RL-2010-117, Volumes I and II. https://pdw.hanford.gov/document/0092299; https://pdw.hanford.gov/document/0090731; https://pdw.hanford.gov/document/0090730	C	x	x		x	x
Teck American Incorporated. (2013) Upper Columbia River: Final Fish Tissue Data Summary and Data Gap Report. Prepared by three consultants: Exponent of Bellevue, WA, Parametrix of Bellevue, WA, and Integral Consulting, Inc. of Seattle WA. February 2013.	C	x	x	x	x	x
Caton, L. (2012). Regional Environmental Monitoring and Assessment Program: 2009 Lower mid-Columbia River Ecological Assessment Final Report. https://www.oregon.gov/deq/FilterDocs/Col2009remapFminusApp.pdf	C	x	x	x		x

Table S6. Contaminant studies in the Columbia River from Bonneville Dam to the U.S border with Canada that were evaluated as historical data. PCB=polychlorinated biphenyl. PCB abbreviations: A=aroclors, C=congeners. DDx= any or all of the six DDT isomers (p,p'-DDT; p,p'-DDD, p,p'-DDE; o,p'-DDT; o,p'-DDD; o,p'-DDE). Dx/Fr=dioxins and furan compounds. PBDE=polybrominated diphenyl ethers.

Reference	Target Analytes					
	PCB	DDx	Hg	PBDE	Dx/Fr	Other
Herger, L. G., L. Edmond, and G. Hayslip. (2016). Mid-Columbia River fish toxics assessment: EPA Region 10 Report. (EPA-910-R-17-002). https://www.epa.gov/sites/default/files/2017-03/documents/mid-columbia-river-fish-toxics-assessment-march2017.pdf	C	x	x	x	x	x
U.S. Environmental Protection Agency. (2007) Phase 1 Fish Tissue Sampling Data Evaluation Upper Columbia River Site CERCLA RI/FS. U.S. Environmental Protection Agency, Region 10, Seattle, WA. Prepared by CH2MHill and ecology and environment, inc. Contract No 68-S7-04-01. https://semspub.epa.gov/work/10/1274727.pdf	A, C		x		x	x
Seiders, K., C. Deligeannis, and P. Sandvik. (2007) Washington State Toxics Monitoring Program: Toxic Contaminants in Fish Tissue and Surface Water in Freshwater Environments, 2004-2005. Washington State Department of Ecology, Olympia, WA. Publication No. 07-03-024. June 2007. https://apps.ecology.wa.gov/publications/documents/0703024.pdf	A, C	x	x	x	x	
Munn, M. D. (2000). Contaminant Trends in Sport Fish from Lake Roosevelt and the Upper Columbia River, Washington, 1994-1998. US Department of the Interior, US Geological Survey. https://wa.water.usgs.gov/pubs/wrir/wrir00-4024.pdf	A, C		x		x	
U.S. Environmental Protection Agency. (2002) Columbia River Basin Fish Contaminant Survey, 1996-1998. U.S. Environmental Protection Agency, Region 10, Office of Water, Seattle, WA. Publication No. EPA-910/R-02-006. https://www.epa.gov/sites/default/files/documents/columbia_fish_contaminant_survey_1996-1998.pdf	A, C	x	x	x	x	x

Table S6. Contaminant studies in the Columbia River from Bonneville Dam to the U.S border with Canada that were evaluated as historical data. PCB=polychlorinated biphenyl. PCB abbreviations: A=aroclors, C=congeners. DDx= any or all of the six DDT isomers (p,p’-DDT; p,p’-DDD, p,p’-DDE; o,p’-DDT; o,p’-DDD; o,p’-DDE). Dx/Fr=dioxins and furan compounds. PBDE=polybrominated diphenyl ethers.

	Target Analytes					
Reference	PCB	DDx	Hg	PBDE	Dx/Fr	Other
Munn, M.D., S.E. Cox, and C.J. Dean. (1995) Concentrations of Mercury and Other Trace Elements in Walleye, Smallmouth Bass, and Rainbow Trout in Franklin D. Roosevelt Lake and the Upper Columbia River, Washington, 1994. Open-File Report 95-195. https://pubs.usgs.gov/of/1995/0195/report.pdf			x			x
Serdar, D., A. Johnson, and S. Magoon, 1991. Polychlorinated Dioxins and Furans in Columbia River Sportfish: Chief Joseph Dam to McNary Dam. Washington State Department of Ecology, Olympia, WA. Publication No. 91-49. November 1991. https://apps.ecology.wa.gov/publications/documents/9149.pdf	A, C				x	
Hinck, J.E., Schmitt, C.J., Bartish, T.M., Denslow, N.D., Blazer, V.S., Anderson, P.J., Coyle, J.J., Dethloff, G.M., Tillitt, D.E. (2004) Biomonitoring of Environmental Status and Trends (BEST) Program: Environmental Contaminants and their Effects on Fish in the Columbia River Basin. Columbia Environmental Research Center, US Geological Survey, Sci. Invest. Rep. 2004-5154, 125pp. https://www.cerc.usgs.gov/pubs/center/pdfdocs/best-columbia_river.pdf	x	x	x			x

Table S7. Quality Criterion used to screen data from previous studies of contaminants in the Columbia River

Quality Criterion	Description/Definition
Completeness	All data reviewed will be checked to ensure presentation of results are complete.
Relevance	Data sources specific to the topic being investigated will be considered for use. Sources that most closely represent the topic/data of interest are the most relevant.
Reliability	The information/data source is reliable. For example, this criterion includes at least one of the following acceptance specifications: • The information or data are from a peer-reviewed, government, or industry-specific source. • The source is published. • The author is engaged in a relevant field such that competent knowledge is expected (i.e., the author writes for an industry trade association publication versus a general newspaper). • The information was presented in a technical conference where it is subject to review by other industry experts.
Representativeness / Content	The information/data source is representative in its content. Examples of source content can include extent of data (e.g., what geographical area does it cover, over what period) and level of documentation describing the generation of the data.

Table S8. Suggestions, questions, ideas, and topics for consideration as the Program matures provided by stakeholders during outreach activities.

Suggestions, questions, ideas, and topics
2D GC (lab in Canada) full elemental ICPSI scan to identify organic pollutants that are unregulated contaminants (e.g., by compound class, approximate concentrations, inert ingredients in pesticides (e.g., chlorate, hexachlorobenze)), willing to put in own money.
Salmon - as important food source for Tribal people. Lamprey that rear in sediments in the Basin.
Characterize toxics in adult salmon returning to selected areas.
Characterize toxics in juvenile salmon and their rearing habitat (sediment, invertebrate prey) in selected areas.
Characterize toxics in juvenile lamprey and their rearing habitat (sediment, invertebrate prey) in selected areas.
Mouths of tributaries (e.g., Walla Walla) - areas of sediment buildup.
Characterize concentrations of toxics in sediments deposited by major tributaries (e.g., Okanogan, Wenatchee, Yakima, Walla Walla, Umatilla, John Day, Deschutes Rivers). (about 15 samples per location, 7 tributaries = 105 samples)
Repeat EPA/CRITFC study at Tribal fishing areas.
Estimate change in toxics in fish since 1998 EPA/CRITFC study Bonneville to Priest Rapids Dams.
Aluminum, pulp, and paper mills influences: Test specific known legacy and current contaminant release points. For example: NPDES permitted outfalls, sewage treatment plants, Arlington hazardous waste facility, aluminum, pulp, and paper mills influences.
Characterize concentrations of toxics in sediments near major point sources and hazardous waste facilities (e.g., municipal and industrial NPDES outfalls, Arlington and other hazardous waste sites). (about 3 per site over 20 sites = 60 samples)
White Bluffs (e.g., Lock Island) - Chinook salmon spawning area.
Farming influences - time testing to evaluate the impact of pesticide release.

Table S8. Suggestions, questions, ideas, and topics for consideration as the Program matures provided by stakeholders during outreach activities.

Suggestions, questions, ideas, and topics
Dams - sources of inadvertent release of oils.
Characterize past releases of toxic substances from dams and conduct monitoring to characterize impacts.
How have suspended sediment concentrations and loads changed over time for the major tributaries?
How are concentrations of sediment-bound DDT and PCBs near major tributaries changing over time? (e.g., Okanogan, Wenatchee, Yakima, Walla Walla, Umatilla, John Day, and Deschutes rivers).
How do levels of dioxins/furans in fish and sediment today compare to those in the 1990s when pulp mills were still discharging these contaminants?
What effect are the tributary TMDLs for toxic contaminants having on the main stem? (i.e., Okanogan, Yakima, and Walla Walla rivers).
Add ecological and human health impacts of chemicals of concern to stakeholders.
Consider discussing other chemical classes and why they weren't considered to be of concern or reference a discussion elsewhere that supports conclusions.
Do you want to say anything about non-legacy PCBs such as PCB-11 that are the result of pigment manufacturing and that have been an issue for the Spokane River?
Anything about organophophate insecticides or herbicides?
Discuss how to deal with non-detects when reviewing historical data.
Selection of analytical methods.
Quinone transformation product 6PPD-quinone (Tian et al. 2020) from car tire dust.
With the focus on the Mainstem, how will monitoring in tributary watersheds be promoted, supported, and integrated?

Table S8. Suggestions, questions, ideas, and topics for consideration as the Program matures provided by stakeholders during outreach activities.

Suggestions, questions, ideas, and topics
I'm wondering how land use may be weighed in determining the distribution of monitoring locations in the long-term monitoring.
The monitoring of the major tributaries need to be included in a long term monitoring strategy. How will they be incorporated in the plan?
Is there a good understanding of other monitoring efforts going on within the basin? (PNNLs WHONDRS, USGS, others)
For the approximately 80-mile stretch of Columbia that runs through the Columbia River Gorge National Scenic Area, the Columbia River Gorge Commission may be able to assist with Land Use data layers if there is interest as you develop your objectives.
It might help with knowing existing monitoring locations and add toxics to it.
Upper Columbia River and metals from Tech Cominco and other sources - Colville and Spokane Tribes to provide in writing a suggested approach/prioritization on how to address metals in UCR in long-term monitoring program.
Estimate change in toxics in fish since 2008 Energy study: McNary to Wanapum Dams (about 30 locations).
Estimate change in toxics in fish and other media since 1980s: esp. using 2005 and 2009 EPA studies: Lake Roosevelt (60+ locations).
Estimate change in toxics in sediment since 2008 EPA study: McNary Dam into Lake Wallula (about 40 locations).
Estimate change in toxics sediment since 1940s/1960s using sediment cores from multiple reservoirs behind dams (about 3 samples per reservoir).

Table S8. Suggestions, questions, ideas, and topics for consideration as the Program matures provided by stakeholders during outreach activities.

Suggestions, questions, ideas, and topics
Estimate change in toxics in fish since 2008 EPA/ODEQ study (about 40 locations).
Sample harvestable fish that are consumed - salmon, lamprey, sturgeon, suckers, bass.
Speciate mercury - isotopes (for Tech Cominco RI and overall source ID).
Compare similar species, do not lump stats.
Juvenile salmon very important to tribes, determine which species.
Figure out how to handle species that travel and stay put (e.g., rainbow trout vs. steelhead).
Build in a buffer for co-locating, fish are less important to co-locate.
Evaluate by habitat (riverine, transitional, lacustrine) and landscape scale (dam to dam, trib to trib).
Time of year fish sampling is important because different species are mobile seasonally.
PFAS
Fish organs
Build with modeling in mind (e.g., fish models).
Quinone (tires)
PFAS
Targeted organ tissue sampling for metals.

Table S8. Suggestions, questions, ideas, and topics for consideration as the Program matures provided by stakeholders during outreach activities.

Suggestions, questions, ideas, and topics
Collect a generous amt of tissue and take applications from other research projects.
Cd in UCR in kidneys.
Pb in whole body (not fillets).
Minimum of fillet and whole body.
Endocrine disrupters at sewage treatment OFs.
Juvenile, take otolith and lipids.
Source identification of mercury - speciation (isotopes).
Results appropriate for incorporation into 303d WQ assess work, which can trigger action.
Include tributaries in sampling.
Equal distribution of sampling across 600 miles.
Seek long-term funding for entire basin, not just mainstem.
Tech Cominco pollutants.
Sampling reintroduction areas.

Table S8. Suggestions, questions, ideas, and topics for consideration as the Program matures provided by stakeholders during outreach activities.

Suggestions, questions, ideas, and topics
Two documents to help guide COC prioritization: (1) 2/17/2007 Prioritization of Toxics in the Columbia River, Columbia River Toxics Workgroup and (2) July 2014 Columbia River Toxics Reduction Working Group: Strategy for Measuring, Documenting and Reducing Chemicals of Emerging Concern, EPA
Suggest collaboration with WSU grad students.
Include D/F (especially for fish tissue) - currently generated, poorly regulated, e.g., pulp/paper still large generator even though chlorine bleaching largely eliminated.
Standardized/umbrella QAPP, sharing of SOPs would be helpful Columbia River-wide, frequent updates needed, could have more individualized SAPs for specific areas, clearing house for SOPs for folks building their own project specific QAPPs. Document repository (such large docs)? How to make it accessible - why do groups do things in different ways and how to select methods? Goal - data comparability.
Laboratory round-robins.
Compile a list of standards: ex. OHA, WA DOH, ODEQ, WA ECY.
Compile a list of toxicity thresholds.
Need for design (basin-wide) - COC list, locational? Need to first agree on objectives (e.g., Columbia Habitat monitoring has basin-wide design/protocol/database, but sampling done by individual entities.
Data Gaps - contaminants of emerging concern - 6ppd-quinone.
Gaps - source identification, next step management actions needed.

Table S8. Suggestions, questions, ideas, and topics for consideration as the Program matures provided by stakeholders during outreach activities.

Suggestions, questions, ideas, and topics
Data Gaps - Juvenile salmonids - need more data.
Funding / conditions flexibility and long-term dedication needed - options focused grant opportunities (e.g., monitoring focused RFA, need CWA changes (EPA can't do, up to individual entities).
TCSCA emerging contaminants – phthalates.
Acute releases from point sources.
Timing of releases – e.g., pesticides.
Post data to EPA Exchange Network's WQX data system, create a new dashboard to access CRB data from the WQX.
Need protocols for WQX data submissions.