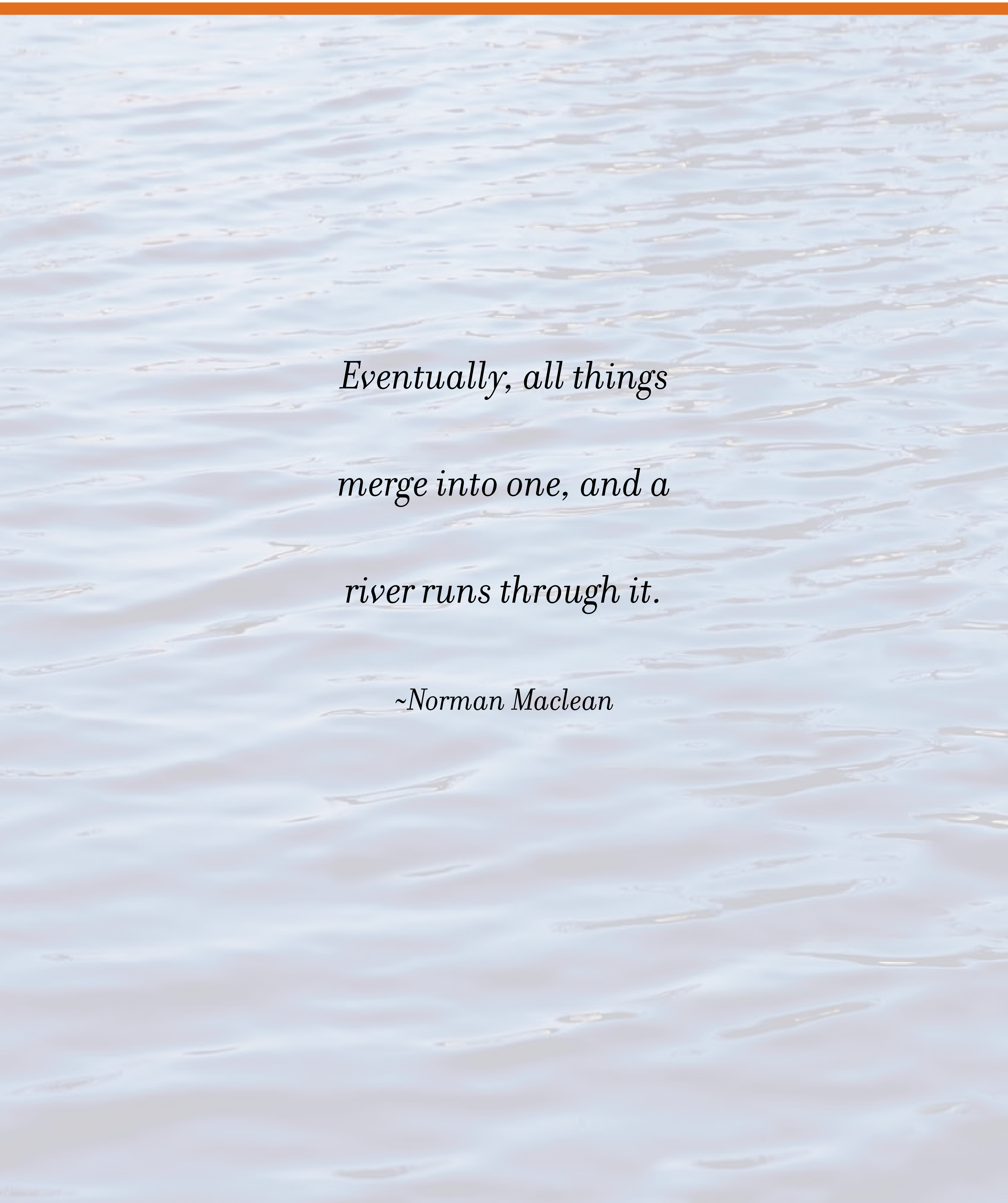
Lower Columbia River and Estuary Ecosystem Monitoring:

Water Quality and Salmon Sampling Report

Lower
Columbia
River Estuary
Partnership



Eventually, all things

merge into one, and a

river runs through it.

~Norman Maclean

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Introduction

An Ongoing Commitment

Reducing the impact of toxic contaminants on public health and ecosystem health is one of the Lower Columbia River Estuary Partnership's (Estuary Partnership) primary goals. Understanding the current and past conditions of the lower Columbia River is a critical part of the Estuary Partnership's efforts in toxic reduction.

The Estuary Partnership's predecessor program, the Lower Columbia River Bi-State Water Quality Program (Bi-State Program), investigated toxic contaminants and similar water quality issues in the lower river and estuary from 1989 to 1995. The Bi-State program generated a great deal of scientific data about contamination and other threats to the health of the lower Columbia. With hundreds of sampling sites monitored for several years, the Bi-State Program demonstrated that water and sediment in the lower Columbia and its tributaries have levels of toxic contaminants that are harmful to fish and wildlife (Tetra Tech, Inc. 1996). Contaminants of concern included dioxins and furans, heavy metals, polychlorinated biphenyls (PCBs), and organochlorine pesticides such as DDT. Results from the Bi-State Program studies—and the degradation the studies identified—supported the lower Columbia River and estuary's nomination to and acceptance into the U.S. Environmental Protection Agency's (USEPA) National Estuary Program in 1995, creating the Estuary Partnership. Other smaller scale investigations have supported the Bi-State Program findings.

The presence of toxic contaminants in the lower Columbia River is one of seven priority issues identified in the Estuary Partnership's guiding document, the *Comprehensive Conservation and Management Plan* (*Management Plan*, Estuary Partnership 1999a).[1] Approximately one-third of the actions called for in the *Management Plan* are designed to reduce or eliminate toxic and conventional contaminants in the lower river. Actions address a range of needs, from sustained long-term monitoring, assessment of trends, and identification of sources of toxic contaminants to specific actions to clean up hazardous waste sites, reduce polycyclic aromatic hydrocarbons (PAHs), eliminate toxics generated during manufacturing, and prevent impacts from accidental spills, such as requiring marinas to have spill prevention and cleanup plans in place.

What Is the Estuary Partnership's Study Area?

The Estuary Partnership's study area is the tidally influenced portion of the lower Columbia River, which stretches 146 miles from the Pacific Ocean (downstream of Astoria) upstream to Bonneville Dam. This includes the area at the mouth of the Columbia where fresh water and salt water mix, the lower, tidally influenced portions of tributaries to the Columbia (including the lower Willamette River in downtown Portland), and the Columbia River up to Bonneville Dam.

The lower river and estuary form a unique and beautiful ecosystem that, among other things, sustains endangered salmon during a critical stage in their life cycle. Some juvenile salmon forage in the shallow wetlands of the estuary for weeks or months, until they have grown large enough to survive at sea and have made the physiological transformation from freshwater to ocean-going fish. Other populations use the low-salinity, nutrient-rich plume waters in a similar way. To some extent, salmon serve as bellwethers of the overall health of the ecosystem. Other species also use the lower river and estuary. White and green sturgeon, Pacific lamprey, bald eagles and osprey, river otter, Columbian white-tailed deer, and many other native species rely on healthy estuarine habitats in the Columbia as places to feed, rest, take refuge from predators, and reproduce.

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[1] The Management Plan (Estuary Partnership 1999a) was developed from 1996 to 1999 with private-sector interests, local governments, state and federal agencies, and tribal representatives. A structure of committees, whose membership included scientists, community leaders, recreationists, government and tribal representatives, and the regulated community, used the results of the Bi-State Program studies and concurrent scientific work to define specific actions for the Estuary Partnership to address. The actions are the primary focus of the Management Plan and are the basis for the long-term work of the Estuary Partnership.

About the Estuary Partnership

The mission of the Lower Columbia River Estuary Partnership is to preserve and enhance the water quality of the lower Columbia River and estuary to support the area's biological and human communities. The Estuary Partnership became a National Estuary Program in 1995 and is one of only 28 in the country. The Estuary Partnership uses a watershed approach to cross political boundaries and bring together diverse parties to identify problems, define a course of action, and work collaboratively to implement actions through a regional framework. Funds from the states of Oregon and Washington and from Congress—through the National Estuary Program—support the organization's base operations and help it secure matching public and private dollars for restoration, education, and toxics monitoring and reduction projects. NOAA, USGS, Bonneville Power Administration, hundreds of individual citizens and more than 55 corporations and foundations are key participants and provide support to the Estuary Partnership.

In September 2006, USEPA officially designated the Columbia River one of the nation's Great Water Bodies. The Columbia joins Chesapeake Bay, the Great Lakes, the Gulf of Mexico, the South Florida Ecosystem, Long Island Sound, and Puget Sound as a national priority in USEPA's 2006-2011 Strategic Plan. Through this designation, USEPA is working with state and tribal entities—and the Estuary Partnership—to identify toxic reduction targets for the Columbia River Basin.

The *Aquatic Ecosystem Monitoring Strategy for the Lower Columbia River (Monitoring Strategy,* Estuary Partnership 1999b) was developed to implement the monitoring called for in the *Management Plan.* The *Monitoring Strategy* focuses on seven key topics: monitoring oversight; data management; conventional and toxic contaminants; habitat monitoring; exotic species; nutrients; and primary productivity and food web dynamics. This regional, collaborative, ecosystem-based strategy directs all monitoring efforts spearheaded by the Estuary Partnership. Having the strategy in place allows the Estuary Partnership to put the funds it secures directly into monitoring – and getting results. The Estuary Partnership provides a forum for coordination to improve regional efficiencies and avoid duplication of investments and efforts.

What Is the Estuary Partnership's Ecosystem Monitoring Project?

In recent years the Estuary Partnership has worked with its partners on a specific monitoring project in the *Monitoring Strategy* that examines both habitat and water quality as a way of assessing the lower river's health and important habitats for salmon. The project is known as the Ecosystem Monitoring Project.

The Estuary Partnership contracted with the U.S. Geological Survey (USGS) to collect and analyze water column and sediment samples and with NOAA Fisheries to conduct salmon sampling and develop models describing the transport, uptake, and ecological risks of toxic contaminants to salmon and their habitats.

The water quality monitoring portion of the project has three main components:

- Collection of water quality data from the water column, suspended sediment, and bed sediment at five sites in the lower Columbia River, including one on the lower Willamette River in Portland;
- Sampling of juvenile salmon at those same sites, plus one additional site at the confluence of the Willamette and Columbia rivers; and
- Development of conceptual and quantitative models that outline which toxics affect salmon populations, where those toxics exist in the river, juvenile salmon's degree of exposure, and the ecological risks that exposure poses to salmon, their predators, and prey.

The Ecosystem Monitoring Project focused specifically on juvenile salmon. Salmon and water quality samples were co-located so that levels of toxic contaminants observed in fish could more easily be correlated with environmental concentrations, and the study sampled for a variety of toxics, including "legacy" contaminants such as DDTs, PCBs, and PAHs and "emerging" contaminants such as flame retardants, pharmaceuticals, and personal care products, some of which act as hormone disruptors. Sampling techniques were designed to detect these and other toxic substances at very low concentrations, which is important when considering sublethal effects.

This report integrates the results of the water quality and salmon sampling to document the presence and effects of toxic contaminants on juvenile salmon in the lower Columbia River and estuary, including stocks listed under the Endangered Species Act.[2]

What Samples Were Collected, and What Toxics Did the Study Measure?

Different toxic contaminants tend to move through and accumulate in different parts of the environment—water, sediment, biota—depending on their chemical characteristics and source. The Ecosystem Monitoring Project collected water quality samples from the water column, from sediment suspended in the water column, and from sediment that settled on the streambed. In addition, semi-permeable membrane devices, or SPMDs, were deployed at four locations in the water column for a month at a time. Sometimes called "lipid bags," or "virtual fish," these fat-containing devices mimic the body fat of fish and absorb toxics that accumulate in fish, especially toxics that are present at low concentrations. Because concentrations of toxic contaminants can vary weekly, daily, or even hourly, and because a metabolized toxic may not appear in a tissue sample, SPMDs are useful in understanding the total amount of toxic contaminants that fish are exposed to during the time the SPMD is in the water.

Samples were analyzed for a variety of toxic contaminants:

- PCBs and PAHs;
- Trace elements, including copper, chromium, arsenic and lead;
- Pesticides currently used in the Columbia River Basin, such as the organophosphate pesticides diazinon and chlorpyrifos and the triazine pesticides atrazine and simazine;
- DDT, aldrin, dieldrin, and other legacy pesticides that are banned in the United States;
- Suspected hormone disruptors, such as bisphenol A, a common plasticizer;
- Polybrominated diphenyl ethers (PBDEs), a common class of flame retardants; and
- Antibiotics, antihistamines, analgesics, synthetic musks, and other pharmaceuticals and personal care products.

In addition, water quality samples were measured for other parameters such as temperature, pH, and salinity that can affect the toxicity or bioavailability of contaminants.

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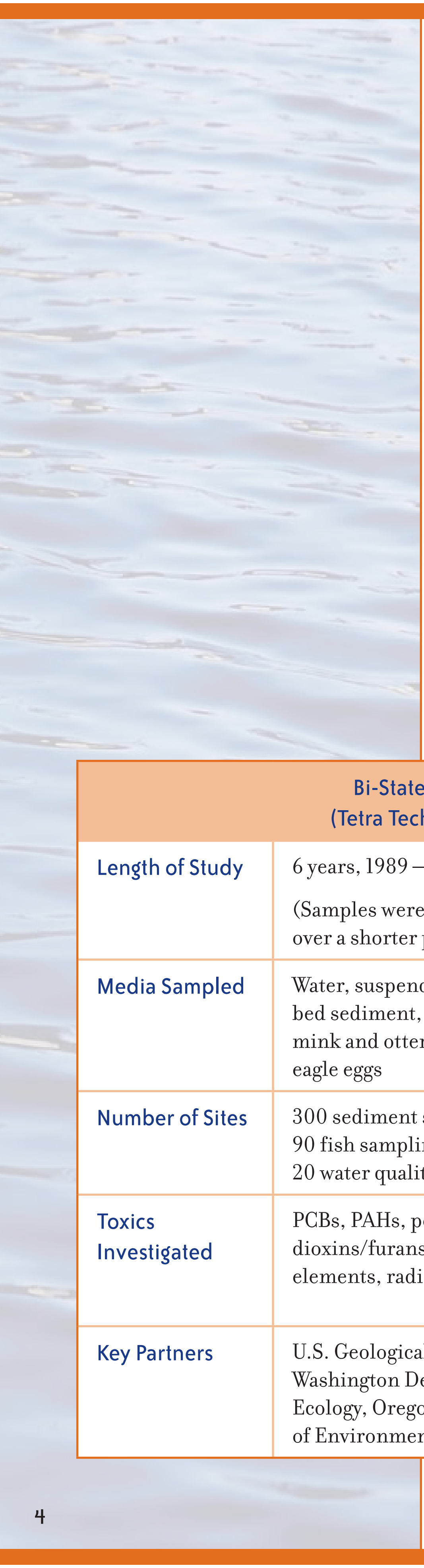
[2] Currently, 13 Columbia River Basin salmon and steelhead stocks are listed as threatened or endangered under the federal Endangered Species Act. All of these stocks use the estuary and plume as an essential link in their far-reaching life cycles.



Salmon samples, which were mostly of fall Chinook, included the following:

- Whole bodies of juvenile fish, to detect toxics that accumulate in tissue and body fat;
- Stomach contents, to determine whether the fish's prey was contaminated;
- Bile, to look for breakdown products of PAHs;
- Plasma, to reveal the exposure of male and juvenile fish to estrogens in the environment; and
- Genetic information, to determine which stock the fish belongs to and whether it came from a major urban/industrial basin or a primarily agricultural basin.

Samples also were collected of juvenile salmon—and their feed—in area fish hatcheries, to help compare the exposure profiles of wild and hatchery fish and better understand possible sources of toxic contaminants.

Some toxic contaminants known to be present in the lower river were not measured in this study—because of financial constraints, because the toxics already have been well studied, or because they are being regulated to some degree. As a result of these considerations, dioxins, furans, and radionuclides were not studied as part of the Ecosystem Monitoring Project.

	Bi-State Program (Tetra Tech, Inc. 1996)	USGS/Estuary Partnership (McCarthy and Gale 1999)	Estuary Partnership Ecosystem Monitoring Project
Length of Study	6 years, 1989 – 1995 (Samples were collected over a shorter period)	1 year, 1997 – 1998	3 years, 2004 – 2007 (Samples were collected over a shorter period)
Media Sampled	Water, suspended sediment, bed sediment, fish tissue, mink and otter tissue, bald eagle eggs	Water (using SPMDs), bed sediment	Water, suspended sediment, bed sediment, juvenile salmon tissue, stomach contents, bile, and plasma
Number of Sites	300 sediment sampling sites, 90 fish sampling sites, 20 water quality sites	9 water quality sites, 3 sediment sampling sites	5 joint water quality/salmon sampling sites plus one additional salmon sampling site
Toxics Investigated	PCBs, PAHs, pesticides, dioxins/furans, trace elements, radionuclides	PCBs, PAHs, pesticides, dioxins/furans	PCBs, PAHs, pesticides, trace elements, PBDEs (flame retardants), pharmaceuticals, and personal care products
Key Partners	U.S. Geological Survey, Washington Department of Ecology, Oregon Department of Environmental Quality	U.S. Geological Survey, Estuary Partnership	U.S. Geological Survey, NOAA Fisheries, Estuary Partnership

How Extensive Was the Study?

The Ecosystem Monitoring Project was a limited, focused effort that collected water quality and juvenile salmon samples from five sites over a one-year period.[3] Sites were distributed to suggest possible sources of toxic contaminants, with locations in the Columbia Gorge; in the Willamette River in downtown Portland; above and below Longview, Washington; and near Astoria, at the mouth of the river. Some sites were sampled monthly, while others were sampled seasonally.

In comparison, the Bi-State Program collected water quality samples from 20 sites, fish samples from 90 sites, and sediment samples from 300 sites located throughout the lower Columbia River and its tributaries. Samples were analyzed not just for PCBs, PAHs, and pesticides but also for dioxins, furans, and radionuclides. Mink and otter tissue and bald eagle eggs were sampled to determine how toxic contaminants affect native wildlife. Results were incorporated into an assessment of the overall health of the lower river that examined beneficial uses such as irrigation, drinking water, commerce, recreation, and fish and wildlife. The entire effort produced scores of technical reports over six years' time.

What We've Learned About Toxics in the Lower River

Findings of the Bi-State Program

As the only comprehensive, large-scale study of toxics and other ecosystem components in the lower river, the Lower Columbia River Bi-State Water Quality Program provided crucial background information for the Estuary Partnership's Ecosystem Monitoring Project. The Bi-State Program (Tetra Tech, Inc. 1996) concluded that:

- Dioxins and furans, metals, PCBs, PAHs, and pesticides impair the water, sediment, and fish and wildlife;
- Arsenic, a human carcinogen, exceeded both the USEPA ambient water quality criteria for protection of human health and the USEPA human health advisories for drinking water (Fuhrer et al. 1996);
- Sediment contamination was highest near urban and industrial areas, with contamination in excess of levels of concern for DDE (a breakdown product of DDT), PCBs, dioxins and furans, and PAHs;
- The amount of riparian habitat and tidal swamps and marshes has decreased by as much as 75 percent from historical levels; and
- Beneficial uses such as fishing, shellfishing, wildlife, and water sports are impaired.

In addition, the Bi-State Program demonstrated that many toxic contaminants are moving up the food chain and accumulating in the bodies of animals—and

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[3] Salmon samples also were collected at one additional site, at the confluence of the Columbia and Willamette rivers.

humans—that eat fish. For example, dioxins, furans, PCBs, and DDE are affecting river otter and mink in the lower river. Reproductive abnormalities were observed in river otters, some of whom had concentrations of PCBs that exceeded threshold levels. Also, nesting bald eagles showed evidence of accumulation of DDE and PCBs at levels that impair reproduction (Buck 1999). Lastly, the Bi-State Program concluded that people who eat fish from the lower Columbia over a long period of time are exposed to health risks from arsenic, PCBs, dioxins and furans, and DDT and its breakdown products (Tetra Tech, Inc. 1996).

Findings from Other Studies

The Estuary Partnership contracted with USGS and its National Stream Quality Accounting Network (NASQAN) Program in 1997 and 1998 to investigate toxic contaminants at nine sites along the lower Columbia and its tributaries. Consistent with the work of the Bi-State Program, this study revealed the presence of dioxins and furans, PCBs, PAHs, and DDT and other pesticides in the water and in bed sediment (McCarthy and Gale 1999). These results confirmed what many studies have indicated: toxic compounds are pervasive in the lower Columbia River and estuary and concentrations often are high enough to harm fish, river otters, bald eagles, other wildlife, and even humans.

Studies by USGS, the U.S. Army Corps of Engineers, and the Oregon Department of Environmental Quality have documented various toxic contaminants in bed and suspended sediment from the lower Columbia. Known toxic contaminants include trace elements (copper, cadmium, and zinc); dioxins and furans; PCBs; organochlorine pesticides such as dieldrin, lindane, chlordane, and DDT; and PAHs, which have been detected at levels that exceed state or federal sediment quality guidelines or are considered harmful to humans and aquatic life (Fuhrer and Rinella 1983, Fuhrer 1986, Harrison et al. 1995, Tetra Tech, Inc. 1996, U.S. Army Corps of Engineers 1999, Roy F. Weston, Inc. 1998, McCarthy and Gale 2001, Fuhrer et al. 1996, Oregon Department of Environmental Quality 1994).

Additional studies show PCBs and DDTs are accumulating in the bodies of outmigrating juvenile salmon in the lower river. In Johnson (2007a), almost one-third of juvenile salmon had PCB concentrations that exceeded threshold levels for adverse health effects such as metabolic alterations, reduced growth, immune dysfunction, and reduced long-term survival (Meador et al. 2002, Casillas et al. 1995, 1998, Arkoosh et al. 1991, 1994, 1998). Amounts of DDT in some of the juveniles' bodies were at levels that could contribute to disruption of the endocrine and immune systems (Beckvar et al. 2005, Khan and Thomas 1998, Milston et al. 2003, Zaroogian et al. 2001).

Trace elements and pesticides are present in the water, suspended sediment, and bed sediment of the lower river, particularly in mud flats, tidal marshes and swamps, and other shallow areas where fine sediment settles out of slowmoving water (Fuhrer et al. 1996, McCarthy and Gale 1999, Fuhrer and Rinella 1983, Fuhrer 1986). Trace elements are transported to the lower river both dissolved in water and on suspended sediment from tributaries, particularly the Willamette River. Also, recent studies have verified that some banned pesticides are concentrating in fish and moving up the food chain to fish predators such as osprey (Johnson et al. 2007a, Henny et al. 2003).

Several pesticides that are currently used and are toxic or potentially toxic to fish are present in the water column in the lower river, typically at low levels and often in mixtures. These pesticides include simazine, atrazine, chlorpyrifos, metalochlor, diazinon, and carbaryl. Similar pesticides have been found in tributaries affected by agricultural and urban land uses (Fuhrer et al. 1996, Hooper et al. 1997).

Lastly, PBDEs were detected in mountain whitefish in the upper Columbia River Basin in 2000 at concentrations of up to 72 parts per billion—12 times the concentrations measured in 1992 (Rayne et al. 2003). This study laid the groundwork for other studies to determine whether PBDEs are present in the lower river at concentrations that affect fish and wildlife (Johnson et al. 2006, Henny et al. 2004).

The Bi-State Program, the work of the Estuary Partnership and U.S. Geological Survey (McCarthy and Gale 1999), and other studies have given an excellent picture of toxic contaminants in the water, sediment, and fish and wildlife of the Columbia River and estuary, but they were one-time assessments. What is missing is sustained, comprehensive monitoring of toxic contaminants in the lower river.

Questions That Remain

Toxic contaminants are a significant issue in the lower Columbia River and estuary, and the volume of scientific data about them is growing. But important questions about the distribution, concentration, and sources of toxic contaminants remain unanswered. In the case of salmon, we do not understand exactly how and where juvenile salmon are being exposed to toxic contaminants, the degree of their exposure, and how exposure patterns vary from one population to the next.

Habitat use plays a role in exposure patterns because toxic contaminants are distributed unevenly in the lower river, and different salmonid populations make use of different habitats (Fresh et al. 2005). For example, ocean-type salmon migrate to the lower river sometime during their first year of life and spend weeks or months foraging in shallow wetlands and side channels before heading out to sea. These salmon will be exposed to different toxics than stream-type salmon, which stay in upstream tributaries for their first year, move through the estuary over days or weeks, and spend a longer period in the plume waters before assuming a fully marine life. Although we currently can describe differences in exposure patterns with a broad stroke, additional information is needed about which stocks are being exposed to which toxic contaminants.

	Ocean-Type Salmon (fall Chinook, chum)	**Stream-Type Salmon** (coho, spring Chinook, steelhead)
	• Short freshwater residence • Longer estuarine residence • Longer ocean residence	• Long freshwater residence (>1 year) • Shorter estuarine residence • Shorter ocean residence
Size when entering estuary	Smaller	Larger
Primary habitat used	Shallow-water estuarine habitats, especially vegetated ones	Deeper, main-channel estuarine habitats; use plume more extensively
Adapted from Fresh et al. 2005 and NOAA Fisheries 2006.		

The Ecosystem Monitoring Project was designed with several questions in mind that remain unanswered from the Bi-State Program and other studies:

- How are toxic contaminants distributed spatially in the lower river and estuary, and at what concentrations?
- How do concentrations vary through time, both seasonally and annually?
- Are salmon exposed through water, suspended sediment, bed sediment, or prey?
- How does a salmon's uptake of toxic contaminants change as it moves downriver?
- Are toxic contaminants originating in the lower river and estuary, from upstream areas, from agricultural watersheds, or from urban and industrial watersheds?
- What emerging contaminants are present in the lower river and estuary, and where? What are their concentrations?
- How do exposure patterns differ by salmon stock, particularly for threatened and endangered populations?
- Are exposure patterns different for hatchery and wild fish? Are hatchery fish exposed to toxic contaminants through their feed?

Answering these questions is critical: with additional information on toxics in the lower river, management actions can be focused on reducing the exposure of the most vulnerable stocks—those listed as threatened or endangered—and aiding in their recovery.

Why Do Toxic Contaminants Matter?

Sublethal Effects on Salmon

Juvenile salmon arrive in the Columbia River estuary with a job to do: sustain themselves. Whether a juvenile is an ocean-type fish that forages in the estuary for weeks or months or a stream-type fish that spends more time in the plume waters, it must feed, increase in length, put on enough weight to survive in the ocean, and go through the physiological process that will allow it to live in salt water. During a juvenile's time in the estuary, it must avoid predators and withstand disease and parasites. When it returns to the estuary as an adult after years in the ocean, it must be able to adapt to fresh water once again, navigate back to its natal stream, find a mate, produce viable eggs or sperm, and reproduce.

Toxic contaminants interfere with each of these essential biological functions.

Although exposure to a toxic contaminant may not kill salmon directly, the sublethal effects of toxics are far from benign and may lead to indirect mortalities as juveniles become less able to negotiate their world (Fresh et al. 2005). For example, toxic contaminants can reduce a salmon's ability to swim, smell, and perceive and respond to the features of its environment. This makes it difficult for a juvenile to avoid predators such as northern pikeminnow, cormorants, Caspian terns, seals, and sea lions. (In recent decades, all of these predator populations have increased in the lower river as a result of ecosystem changes, loss of habitat elsewhere in the world, or legal protections.) Reduced swimming and sensory abilities also impair feeding, and some toxics inhibit the crucial weight gain that is a key predictor of salmon survival in the ocean. Exposure to toxic contaminants can suppress the immune system; disrupt hormones that influence smoltification and reproduction; alter homing behavior; and leave juveniles susceptible to infectious diseases and parasites. Finally, potential reproductive effects of toxics in adult salmon include production of fewer and smaller eggs, disruption of sperm production, less frequent spawning and egg fertilization, and reduced hatching success.

How serious are the sublethal effects of toxic contaminants? By some estimates, exposure to toxic contaminants causes delayed, disease-induced mortality of juvenile Chinook at rates of 1.5 to 9 percent, depending on how long fish reside in the estuary (Loge et al. 2005). These figures are for contaminant-related deaths induced by infectious disease only; if indirect mortalities related to other effects of toxic contaminants were included, such as the failure to avoid predators, the rate would be higher.

To put these mortality rates into perspective, the *Columbia River Estuary Recovery Plan Module* (NOAA Fisheries 2006) ranks management actions to address toxic contaminants in the top third of 22 suggested actions to improve juvenile salmonid survival in the lower Columbia River and estuary—just below actions

Adding Scientific Information to the Bi-State Program

Compared to the Bi-State Program, the Estuary Partnership's recent Ecosystem Monitoring Project is a limited, focused effort. When considering the results of this new work, it is important to keep in mind that it sampled fewer constituents, at far fewer sites, over a shorter period of time than the Bi-State Program did. This means that, although detection of a toxic contaminant in the Ecosystem Monitoring Project indicates that the toxic was indeed present in the lower river or estuary's water, sediment, or fish, the absence of a toxic contaminant does not mean that the toxic is not present in the lower river or estuary. Non-detects merely show that a toxic was not present at a particular location at the time it was being sampled, or that it was not present at a high enough concentration to be detected. The Estuary Partnership's Ecosystem Monitoring Project, which sampled water quality and juvenile salmon at five sites, needs to be expanded to include more sites in the lower river and estuary and sampling of resident fish and wildlife to provide a comprehensive picture of the effects of toxics in the lower river and estuary.

The Ecosystem Monitoring Project has implemented the Bi-State Program's recommendation for continued ambient monitoring. But the Estuary Partnership's water quality and salmon sampling is not at the scale called for by either the Bi-State Program or the Estuary Partnership's Monitoring Strategy (Estuary Partnership 1999b). The project does not replace the Bi-State Program data but adds to the body of knowledge on toxic contaminants in the lower Columbia River and estuary, especially for threatened and endangered salmon.

such as flow modifications, dike breaches, and habitat protection. Even if the rates of contaminant-related indirect mortality were only 5 percent, rather than the up to 9 percent estimated in Loge et al. (2005), removing this source of mortality could boost populations of endangered salmon.

The Implications of Persistence: Deposits, But No Withdrawals

Toxic contaminants affect more than just salmon. Many of the toxics in the lower river—including PCBs, DDT, other chlorinated pesticides such as aldrin and dieldrin, and several trace elements—are persistent, meaning that they do not readily break down. Rather, they remain relatively unchanged as they move through the environment. Most of these toxic contaminants are hydrophobic: instead of dissolving in or combining with water, they gravitate toward fat or sediment.

When a mayfly, an aquatic invertebrate, takes in a PCB molecule from the water or its diet, that molecule lodges in the insect's body fat and stays there, as do other PCB molecules the mayfly encounters. Over time, the mayfly accumulates more and more PCB molecules, until the PCB concentration in its body is much higher than the concentration in the surrounding water or sediment. This bioaccumulation is analogous to making regular deposits at the bank. If an organism cannot metabolize or excrete toxic contaminants faster than it takes them in, those toxics will build up in its body, making for a lot of deposits but few withdrawals.

A similar process occurs as animals prey on each other. A salmon that eats the mayfly acquires the insect's toxic burden—and that of all the other prey the salmon consumes. Again, toxics bioaccumulate in the salmon, and concentrations in its body become higher than those in its prey. In this way, toxics make their way up the food chain, with concentrations increasing at every step. Referred to as biomagnification, this process can result in top predators having exceedingly high levels of toxic contaminants in their tissue. For example, a study in Lake Ontario showed that PCB concentrations in herring gulls were 25 million times higher than concentrations in the surrounding lake water (Norstrom et al. 1978 as cited in Colborn et al. 1996).

In the lower Columbia River and estuary, persistent, bioaccumulative toxics are biomagnifying up the food chain to salmon and other fish and the animals that eat them—bald eagles, osprey, river otters, and humans. Biomagnification means that toxic contaminants can be a human health issue. Any human population that consumes Columbia River salmon regularly, for cultural reasons or for subsistence, is exposed to health risks from toxic contaminants. Of particular concern is the relationship between fish consumption by tribal members and the assumptions about consumption that underlie federal and state water quality standards. One survey found that adult tribal members consumed an average of 58.7 grams of fish a day—nine times more than the national fish consumption rate of 6.5 grams per day that the USEPA used to develop its human health-based water quality criteria (Columbia River Inter-Tribal Fish Commission 1994). Humans cannot escape the chemical and biological processes that take place in the lower Columbia River and estuary. In some cases, the arsenic, PCBs, dioxins and furans, and DDT breakdown products that are present in fish and wildlife are making their way up the food chain to people, too (Tetra Tech, Inc. 1996).

Summary

The Bi-State Program and other studies have confirmed that toxic contaminants such as PCBs, PAHs, DDT, and pesticides are present in the water, sediment, and biological organisms in the lower Columbia River and estuary, in some cases at concentrations high enough to be harmful to salmon and other fish and wildlife. Toxics are of concern for several reasons. In addition to causing outright mortality, exposure to toxics can impair growth and development, alter essential behaviors, and interfere with reproduction, even when present at relatively low concentrations. Also, persistent toxics tend to move up the food chain to top predators such as bald eagles and people, where concentrations can build up and cause health effects.

A key part of the Estuary Partnership's mission is to monitor toxic contaminants and reduce their impact. The Estuary Partnership studied the presence, distribution, and concentrations of toxic contaminants in the lower river for a year, focusing specifically on juvenile salmon. Although shorter and less comprehensive than the Bi-State Program, the Ecosystem Monitoring Project integrated water quality and salmon sampling and analyzed samples for contaminants such as DDTs, PCBs, PAHs, flame retardants, pharmaceuticals, and personal care products, some of which are suspected hormone disruptors and bioaccumulate up the food chain. The project has started to answer questions about how toxics are affecting juvenile salmon—particularly threatened and endangered populations—and to provide information useful in guiding management actions to aid in their recovery.

Background Information on Toxics

The Ecosystem Monitoring Project focused on specific contaminants of concern that are known or suspected to be present in the water, sediment, or fish and wildlife of the lower Columbia River and estuary. The contaminants of concern fall into six categories: toxics such as PCBs and PAHs that are associated with industrial activity, trace elements that can occur naturally or originate from human activities, "legacy" pesticides such as DDT that have been banned in the United States, pesticides that are currently being used in the Columbia River Basin, brominated flame retardants, and wastewater compounds such as pharmaceuticals and personal care products. These toxics are described below, followed by a discussion of their possible sources, how juvenile salmon are being exposed to toxics, and the potential effects of exposure, particularly sublethal effects. A more detailed list of sampled toxics is presented in Section 3, "Overview of Sampling."

Contaminants of Concern

PCBs

Polychlorinated biphenyls, or PCBs, are stable, nonflammable synthetic compounds that for decades were widely used as insulators and cooling compounds in electrical equipment such as transformers, capacitors, and fluorescent-lighting ballasts. They also were incorporated into lubricants, paints, varnishes, inks, pesticides, carbonless copy paper, and other consumer products because of their ability to preserve, protect, and waterproof. PCBs come in 209 different forms, or congeners (familiar trade names are Aroclor and Pyranol), and vary in their degree of toxicity and carcinogenicity. Some PCBs are structurally similar to dioxins, and these are considered the most toxic PCBs.

All PCBs are persistent, hydrophobic chemicals, meaning that they do not degrade readily or dissolve in water. Instead, they tend to bioaccumulate in body fat and biomagnify up the food chain. Although the United States banned the manufacture of PCBs in 1979 because they are carcinogenic and pose environmental and human health risks, their use in closed electrical equipment is still permitted. Over the years, PCBs have unintentionally been released to the environment, sometimes through spills. Today they can be found in the soil; air; water and sediment of lakes, rivers, and estuaries; and the bodies of fish, wildlife, and people.

PAHs

Polycyclic aromatic hydrocarbons, or PAHs, are persistent, widespread organic contaminants that exist in petroleum products or are created through the incomplete combustion of carbon-containing materials, such as wood, coal, fat, and tobacco. They also are created from the gasoline and diesel fuel that power our cars. PAHs are used in the manufacture of dyes, insecticides, and solvents and enter the environment through spills or atmospheric release during burning. Although PAHs most commonly attach to soil and sediment, they also can be found on particles suspended in the air or water. Some PAHs are relatively water soluble and acutely toxic, while others are lipophilic, meaning that they have an affinity for fat; these tend to bioaccumulate in certain organisms, such as invertebrates. However, PAHs do not bioaccumulate in vertebrates such as fish, birds, wildlife, and humans because these organisms can metabolize PAHs. Many PAHs, especially high molecular weight PAHs such as benzo(a)pyrene, are known or suspected carcinogens. Familiar PAHs include anthracene, fluoranthene, and naphthalene.

Trace Elements (Metals)

For the purposes of the Ecosystem Monitoring Project, trace elements are metals and similar substances that are toxic at fairly low concentrations and for which organisms have little or no biological need. These include *arsenic, copper, chromium, lead, mercury, and nickel*. Trace elements occur naturally, but they also have a variety of industrial applications and can be introduced to the environment through the atmosphere, soil, groundwater, or surface water as a result of human activities. Most trace elements can bioaccumulate in fish and wildlife.

Banned Organochlorine Pesticides

Several pesticides that have been banned in the United States can still be found in the fish and sediment of the lower Columbia River and estuary. These pesticides include the following:

DDT, DDE, and DDD. DDT is an organochlorine pesticide. Once its potent insecticidal properties were recognized in the late 1930s, it was widely used to control agricultural pests and reduce the incidence of mosquito-borne diseases such as typhus and malaria. DDT is highly persistent and resists dissolving in water. Thus it can persist for decades in soil and sediment, and it readily bioaccumulates and biomagnifies up the food chain. DDT is known to have acute and long-term effects on microorganisms, invertebrates, amphibians, fish, mammals, and birds, including (notoriously) the reproduction of bald eagles. In addition, USEPA classifies DDT as a probable human carcinogen. The manufacture and use of DDT was banned in the United States in 1972, but it and its breakdown products—DDE and DDD—are still found in the environment.

Aldrin and dieldrin. Aldrin and dieldrin are chlorinated insecticides that were developed in the 1940s as alternatives to DDT. They were widely used in the United States to control termites and other soil insects until they were banned in 1987 because of their toxicity to a variety of organisms, including humans. In the environment, aldrin breaks down quickly into dieldrin. Like DDT, dieldrin breaks down slowly, has low solubility in water, and persists in soil and sediment, from which it can move to organisms and bioaccumulate. When exposed to sunlight, dieldrin can transform into photodieldrin, a more toxic compound.

Chlordane. Chlordane is a persistent organochlorine pesticide made up of a mixture of related chemicals, such as heptachlor. It adheres strongly to soil, bed sediments, and suspended sediments and can remain intact for decades if it has little exposure to the atmosphere. Chlordane bioaccumulates readily in fish and wildlife and can commonly be found in human body fat. It is highly toxic to freshwater invertebrates and fish; in humans, it can affect the liver and the nervous and digestive systems. USEPA phased out the use of chlordane on food crops in 1978 and for termite control in 1988. Its use in the United States is now completely banned, but chlordane is still manufactured for export.

Pesticides in Current Use

Organophosphate, carbamate, triazine, and urea pesticides. These water-soluble pesticides are commonly used in agriculture, on lawns and gardens, and in horticulture. They typically enter the environment through irrigation and stormwater runoff. The organophosphates (diazinon, chlorpyrifos, malathion, and others) and carbamates (such as carbaryl and carbofuran) have sublethal effects on salmon's olfactory function and reproduction. Effects can be additive or synergistic when several pesticides occur together in the environment, such that the impacts of the mixture are greater than the impacts of any one pesticide would suggest.

Lindane and related compounds. This chlorinated hydrocarbon, also known as γ hexachlorocyclohexane (HCH), has mainly been used to control wood-inhabiting beetles and to treat people for fleas, lice, and scabies. Agricultural use of lindane was recently banned by the USEPA (it is a suspected carcinogen), but pharmaceutical use is still allowed. Lindane is moderately water soluble and may accumulate in sediment. It can be toxic to salmon at high concentrations (above 2 micrograms per liter [µg/L] in water) and at lower concentrations can affect growth, hormones, and the immune system. Lindane also is toxic to salmon prey.

PBDEs (Flame Retardants)

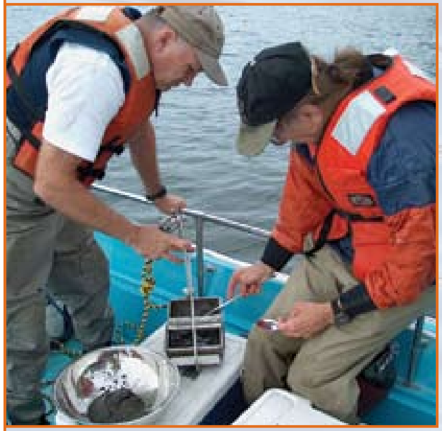
Polybrominated diphenyl ethers, or PBDEs, are a class of synthetic flame retardants used in plastics, cushions, and clothing. Chemically, PBDEs are similar to PCBs. Like PCBs, they come in 209 different forms, or congeners, depending on how many bromine atoms they have and how those bromine atoms are arranged. Only some of those congeners are commonly used in commercial flame retardants. The three commercial PBDE products—penta-BDE, octa-BDE, and deca-BDE—consist of a mixture of congeners.

Penta-BDE, which is generally more toxic than the octa and deca mixtures, is used in insulation and in foam for furniture, mattresses, and automobile seats. Octa-BDE is used in high-impact plastic products, including computer housings, kitchen appliance casings, and telephone handsets. Deca-BDE is used in carpets and drapes, in non-clothing fabrics, and in the plastic found in televisions, computers, stereos, and other electronics. Although deca-BDE itself is less toxic than penta or octa, it breaks down in the environment into more toxic and bioaccumulative forms.

PBDEs bioaccumulate in both freshwater and marine fish, and their effects on juvenile salmon are believed to be similar to those of PCBs, ranging from neurotoxicity to hormone disruption. PBDEs represent about 25 percent of the flame retardants produced worldwide and are considered an emerging contaminant. Because of their widespread use, their levels in the environment have continued to increase.

Pharmaceuticals and Personal Care Products

Nationally, pharmaceuticals and personal care products such as cosmetics, detergents, and deodorants are being identified more frequently in freshwater systems. Detected compounds include antibiotics, antihistamines, oral contraceptives, analgesics, sunscreen, insect repellant, synthetic musks, disinfectants, surfactants, plasticizers, and even caffeine. Many of these compounds enter the waterways through septic tanks and treated or untreated wastewater and pose developmental or toxic risks to salmon. Some mimic estrogens or other hormones, thus disrupting the endocrine system and possibly interfering with reproduction, growth and development. Some pharmaceuticals and personal care products bioaccumulate in fish and people; the synthetic musk HHCB is one notable example. Like PBDEs, pharmaceuticals and personal care products are considered emerging contaminants about which additional scientific information is needed.



Sources of Toxic Contaminants

There are two primary types of contaminant sources: point sources and nonpoint sources. Point sources are discrete, identifiable sources of pollution from a single point of conveyance, such as a discharge pipe, that are regulated. Nonpoint sources are diffuse sources of pollution that do not have a single point of origin; examples include airsheds, agricultural lands, timberland, cities and towns, construction sites, dams, mines, and other areas where overland runoff can carry toxic contaminants to streams and rivers.

More than 100 point sources, such as chemical plants, pulp and paper mills, hydroelectric facilities, municipal wastewater treatment plants, and seafood processors, discharge directly into the lower Columbia River and estuary (Fuhrer et al. 1996). These discrete, identifiable sources are permitted to discharge certain amounts of conventional and toxic contaminants, including metals and synthetic organic compounds.

Potential nonpoint sources include the approximately 55 hazardous waste sites and landfills that are located within a mile of the Columbia River (Tetra Tech, Inc. 1996). Many of these sites can leach metals, PCBs, and other toxic

contaminants into groundwater or nearby surface water that eventually reaches the lower river and estuary. Marinas, moorages, and accidental spills can contribute toxic contaminants through direct release to waterways. Also, surface water runoff can transport PAHs, metals, and pesticides from streets, yards, and industries to the Columbia River and its tributaries.

In addition, DDT, other organochlorine pesticides, and pesticides in current use are entering the lower river and estuary from agricultural runoff, some of which originates outside the lower Columbia River Basin. The middle and upper Columbia are primary sources of DDT and other organochlorine pesticides in the estuary, as are tributaries such as the Yakima and Willamette rivers (Clark et al. 1998, Williamson et al. 1998, Hinck et al. 2006, Johnson and Norton 2005, McCarthy and Gale 1999). The Willamette is considered a primary contributor of agricultural and urban/industrial contaminants to the lower Columbia River and estuary.

How Toxic Contaminants Get to the Lower Columbia River

Tributary and mainstem water, groundwater, sediment suspended in river flow, air currents, migrating insects and animals—all can transport toxics to the lower river.

Airborne PAHs and other toxic contaminants reach the river through atmospheric deposition, either directly or by landing on tributary waters that carry the toxics to the lower river and estuary. Insects and other animals that move into the area bring toxic loads with them in their bodies. Just as juvenile salmon migrate hundreds of miles to the Columbia River estuary from far-flung tributaries in Oregon, Washington, Idaho, and Canada, so do waterborne toxic contaminants—either dissolved in river flow or carried on suspended sediment. Given these sometimes distant sources, the toxics in the estuary reflect not just the human activities around the lower river, but activities throughout the Columbia River Basin.

In some cases, toxic contaminants are discharged directly to waterways that flow into the Columbia. In others cases, surface water runoff transports toxics to tributaries, or toxics enter groundwater that then seeps into tributaries and eventually reaches the lower river. Regardless of the mechanism, the effect is the same: waterborne toxics move downstream to the estuary, where they sometimes collect. (They may also degrade, evaporate, or move out of the area.)

Where waterborne toxics go once they reach the lower Columbia depends on their chemical characteristics and the speed and flow patterns of the river. For the most part, water-soluble toxics remain dissolved in Columbia River flow, much of which moves through the river in deeper channels. Persistent, hydrophobic contaminants—those that bioaccumulate in fats—tend to arrive in the lower river and estuary clinging to sediments suspended in the water column. As the water slows down when it reaches bays and side channels, some of these sediments fall out and settle onto the fine bed sediment of mud flats, tidal marshes, and swamps. Other sediments remain suspended in faster water, or they become resuspended through the opposing action of incoming tides and downstream river flow. Once bioaccumulative toxics are lodged on sediment, they can be absorbed by zooplankton and invertebrates, from which they start moving up the food web to aquatic insects and beyond.

With toxic contaminants present in the water, on suspended and bed sediments, and the bodies of aquatic insects and other prey, the stage is set for salmon's uptake of toxic contaminants.

Water Solubility and Bioaccumulation of Toxic Contaminants

Not all toxics behave in the same way, especially when it comes to uptake by organisms. How readily a salmon takes in a toxic and what happens once it is in the fish's body depend on whether the toxic is primarily water soluble or bioaccumulative. Water-soluble contaminants tend to enter fish and other organisms relatively easily, where they can have toxic effects before being metabolized or excreted. Bioaccumulative toxics, on the other hand, have longer half-lives. They cling to particles and resist being taken up by organisms. Once they enter the body, they accumulate in fats and can remain there until the organism is eaten by an animal higher up in the food web.

Water-Soluble Toxics	Bioaccumulative Toxics
• Are hydrophilic—they dissolve readily in water	• Are hydrophobic and lipophilic—they dissolve readily in fats
• Tend to remain in solution	• Cling to bed and suspended sediments
• Are more bioavailable; can readily be taken up by organisms	• Are less bioavailable; resist uptake by organisms
• Can be metabolized and broken down into more benign components	• Are persistent; can remain in body fats until the end of the organism's life
• Can have shorter term (acute) health effects	• Can have longer term (chronic) health effects

Toxic contaminants exist along a continuum of water solubility and bioaccumulative properties. PCBs and DDT, for example, are strongly persistent and bioaccumulative, while many current-use pesticides, such as diazinon and chlorpyrifos, are less so. PAHs do not fall so neatly into either category because they bioaccumulate in invertebrates but can be metabolized by fish. However,

Mechanisms of Toxic Exposure

Gill uptake	Influenced by concentration of the toxic in the water and exposure time
Dermal sorption	Influenced by concentration of the toxic in the water, sediment, and exposure time
Ingestion	Influenced by concentration of the toxic in prey, consumption rate, and assimilation efficiency
Maternal transfer	Influenced by contaminant load in the mother

Mechanisms of Elimination of Toxics

Metabolization	Influenced by metabolization rate and contaminant half-life
Excretion	Influenced by assimilation efficiency and excretion rate

the metabolization process creates intermediate breakdown products that can be carcinogenic, mutagenic or cause cell death, so the effects of salmon's exposure to PAHs are a concern.

Contaminants can be more or less toxic or bioavailable depending on their form and the physical and chemical characteristics of the surrounding environment. When examining toxicity and bioavailability, factors such as water temperature, pH, and salinity must also be considered.

How Salmon Are Exposed to Toxics

A salmon fry hatches with toxic contaminants in its body from the fats and proteins it inherits from its mother, who deposits toxics during egg production. As the young salmon maneuvers and feeds, it takes in additional toxics in several ways: from the water that passes over its skin and through its gills, from bed sediment it ingests as it pursues bottom-dwelling prey, and from suspended sediment it swallows during feeding. The aquatic and terrestrial insects it eats also contain toxics, which then are absorbed into the fish's body. Even hatchery fish food contains toxic contaminants, particularly PCBs (Meador et al. 2002, Maule et al. 2007, Johnson et al. 2007b). Thus salmon are exposed to toxics through the essential behaviors they engage in to survive—foraging and feeding, resting on or near sediment, moving through the water locally or during migration, even simply being born. Because toxics are largely a product of human activities, their uptake in a salmon's body is where its daily activities and ours intersect. In a sense, salmon in the lower river become an expression of us and our society.

Maternal transfer and the ingestion of prey and sediments are the primary mechanisms through which salmon are exposed to bioaccumulative toxics, with the level of exposure being influenced by the concentration of toxic contaminants in the sediment, the amount of toxics in the bodies of prey, and the exposure time or volume of contaminated prey that is eaten. Water-soluble toxics enter primarily through the gills. The level of exposure is influenced by exposure time, along with the concentration of toxic contaminants in the water. Once toxics are in the body, they can accumulate in tissue, be excreted, or be metabolized and thus essentially cleared from the body.

The relationship between the rates of assimilation and elimination of toxics is crucial. If toxic contaminants are taken in more quickly than they can be metabolized or excreted, they will build up in the body. This is what happens with bioaccumulative toxics, which break down slowly, if at all, and can persist in body tissue for weeks, months, or years.

Exposure Profiles of Salmon Populations

Because toxic contaminants are unevenly distributed and different salmon populations use different habitats, the types and levels of toxics that juvenile salmon are exposed to in the lower Columbia River and estuary vary from one population to the next. Ocean-type juveniles rear in the lower river for weeks or months during their first year of life. They take refuge and forage in side channels, shallow marshes, and swamps—the very areas where bioaccumulative toxics can build up if contaminant sources are present. Given the habitat use and relatively long estuarine residence time of ocean-type juveniles, their contaminant exposure profiles tend to reflect toxics present in the habitat and prey species of the lower river. These toxics include both water-soluble toxics, such as pesticides currently being used, and bioaccumulative toxics, such as PCBs and DDT. Thus ocean-type juveniles experience both short-term and bioaccumulative toxicity.

Stream-type juveniles, on the other hand, spend most of their first year in freshwater tributaries. When they do migrate downstream, they move through the estuary more quickly than ocean-types do, using deeper water habitats and spending more time in the plume waters. Consequently, the exposure profile of stream types is more likely to reflect toxics in upstream tributaries and the water-soluble toxics in the river's deeper channels.

Another factor in the exposure profile is a population's geographic origin. Salmon from areas near Portland, Vancouver, and the Multnomah Channel are likely exposed to industrial contaminants, while populations that spawn in more rural areas—in the Youngs, Clatskanie, Elochoman, and Kalama rivers, for example—may take up fewer industrial contaminants. Populations from heavily agricultural watersheds, such as the Yakima and Snake River basins, are more likely to be exposed to agricultural pesticides, both legacy pesticides and those currently in use.

The Effects of Toxic Contaminants

Toxic contaminants affect salmon in different ways, depending on the contaminants' basic chemical makeup; the characteristics of the soil, water, and sediment in which they are found; their concentration in a salmon's body; and the length of time salmon are exposed. Some toxic contaminants can cause direct mortality; this is the case with high concentrations of PCBs, PAHs, metals such as lead and nickel, and lindane. Toxic contaminants present at lower concentrations can have sublethal effects that alter salmon's essential behavior and reduce overall health. Toxic contaminants may also change the type or amount of available prey, or even modify the surrounding habitat and change the composition of the ecosystem's biological communities.

Examples of Toxic Contaminants That Bioaccumulate in Salmon

- PCBs
- Copper
- Mercury
- Chromium
- Nickel
- DDTs
- Dieldrin/aldrin
- Chlordanes
- PBDEs (flame retardants)

Sublethal Behavioral and Health Effects

The sublethal effects of toxic contaminants alter growth, reproduction, and development and increase the likelihood of mortality from other causes, such as infectious disease, parasites, predation, exhaustion, and starvation. Although the way toxics infiltrate organisms may be more subtle than a sea lion biting a chunk of pink flesh from an adult salmon, their effects are just as real.

Several toxic contaminants, such as copper and organophosphate insecticides, disrupt salmon's olfactory system—their sense of smell. Salmon use olfaction to detect the amino acids given off by predators and prey, pheromones given off by potential mates, and chemical signals that guide migration. For salmon, olfaction is sometimes more important than vision in perceiving and responding to features of the environment. Thus, disruption of olfactory function can impair a salmon's ability to avoid predators, feed, navigate back to its natal stream, and reproduce.

Toxic contaminants also can mimic hormones or alter a salmon's own hormones. PCBs, for example, lower the thyroid hormones that help trigger smoltification (the physiological process that allows anadromous fish to adapt to a saltwater environment) and govern osmoregulation (the process that maintains the proper concentrations of salts and water in a fish's body) (LeRoy et al. 2006, Brown et al. 2004, Casillas et al. 1995, Zoeller 2005). Hormone disruptors such as DDT, natural and synthetic estrogens, plasticizers, surfactants, and synthetic musks can inappropriately spur or suppress estrogenic activity, which in turn has reproductive effects—sometimes at very small doses (Melnick et al. 2002, Tapiero et al. 2002). Disruption of sperm production and changes in the sex ratio of offspring are both possible results of exposure to estrogen-like compounds. Other reproductive effects of toxic contaminants include reduced egg production (copper) (Munnkittrick and Dixon 1989), reduced viability of sperm (chromium) (Billard and Roubaud 1985), smaller egg size, lower fertilization rates, and reduced hatching success (PCBs and PAHs) (Carls et al. 2005, Feist et al. 2005, Incardona et al. 2005, Johnson et al. 1998, Rice et al. 2001).

Additive and Synergistic Effects

With certain toxic contaminants, such as organophosphate insecticides, toxicity can be additive, meaning that their impact is equivalent to the sum of the contaminant concentrations present, rather than the concentration of any individual compound. For example, when common pesticides such as diazinon, chlorpyrifos, and carbaryl occur together, even if each is at a relatively low concentration, their combined concentration can have toxic effects on fish and wildlife (Scholz et al. 2006). Although more data are needed on this subject, it appears that additive effects may be occurring with PBDEs, PCBs, and classes of wastewater compounds, such as environmental estrogens, that operate through similar modes of action.

Other toxic contaminants have synergistic effects, such that their combined toxicity is greater than predicted based on the sum of the contaminants present. This is a possibility when copper is found concurrently with mercury, aluminum, iron, or certain pesticides (Eisler 1998). Some studies suggest that this may also be true for various combinations of pesticides in current use (C. Laetz, pers. comm. 2007, Anderson and Zhu 2004, Denton et al. 2003). Synergistic and additive effects, hormone disruption, and sublethal effects on behavior all serve as reminders that the correlation between the concentration of a toxic contaminant in the environment and its impact on fish and wildlife may not be direct.

Effects Related to Growth, Prey Base, and Productivity

How toxic contaminants affect salmon overall growth is key. Gaining weight and length is one of the most important things juvenile salmon do in the estuary—particularly ocean-type salmon, that spend weeks or months rearing there. In fact, juvenile growth is a critical determinant of marine survival. In one study, wild fish that were below a certain size when they migrated to the ocean did not return to spawn (Zabel and Williams 2002). Many toxic contaminants reduce juvenile salmon's ability to forage, capture prey, and grow.

The problem is compounded by the effects of contaminants on prey species. Most of the toxic contaminants in the lower river have toxic effects on stoneflies, midges, crustaceans, and other aquatic invertebrates that juveniles feed on. This is understandable because many toxic contaminants were specifically designed to kill or impair the growth and reproduction of insects. Because salmonid growth is largely determined by the availability of prey species, reductions in the prey base can have important consequences to salmonid survival—and productivity (Chapman 1966, Mundie 1974).

Fish size has been correlated to reproductive success and egg size (Healey and Heard 1983, Beacham and Murray 1987). The smaller a female is, the fewer eggs she produces and the smaller they are. So even if smaller, slower-growing salmon survive to adulthood, their reproduction tends to be less successful. This means that toxic contaminants that affect the growth rate of individual salmon may reduce population numbers over the long term, through gradual impairment to reproduction, generation after generation.

Effects on the Ecosystem and Beyond

The effects of toxic contaminants extend beyond salmon. Herbicides and severe atmospheric pollution can limit the growth of aquatic and streamside vegetation, some of which support prey species. Together, changes in vegetation, the presence of toxics, and their direct effects on salmon prey and habitat open the door for the establishment of invasive, pollution-tolerant plants and animals. This can lead to further shifts in the composition of biological communities and the types and amount of food and habitat available to native species.

The Cycle Starts Again

What happens after a persistent chemical reaches the top of the food chain? For the most part, persistent, bioaccumulative toxics remain in a top predator's body until the animal dies and decomposes, at which point the toxics are re-released to the environment. The contaminants then are free to be absorbed by another microorganism or invertebrate and start their journey up the food chain all over again, causing toxic effects to a new set of individual organisms along the way.

Salmon are a link between the world of microorganisms, insects, and small fish species and the world of top predators. By eating salmon, species such as river otter and bald eagle take in persistent, bioaccumulative toxics that entered the ecosystem at the microscopic level months or perhaps even years before. As these compounds build up in a predator's body, they can affect its health, reproduction, and survival, both individually and as a species.

People are top predators, too. They take in toxic contaminants such as PCBs when they eat salmon. Human consumption of salmon brings some persistent toxics full circle—from their manufacture (by people) to their release to the environment and subsequent biomagnification up the food chain, until they reach people once again. Toxic contaminants do have negative health effects, particularly for people such as Columbia River tribal members who eat much more salmon than the average U.S. citizen. Potential human health effects of toxics in the lower river include immune system dysfunction, lower fertility, developmental abnormalities, and increased risk of cancer.

Summary

PCBs, PAHs, trace elements, pesticides, flame retardants, pharmaceuticals, and personal care products—all are contaminants of concern in the lower river because of their carcinogenic, lethal, or sublethal effects on fish, wildlife, and humans. These toxics are released to the environment through permitted industrial and municipal discharges, but also from diffuse sources associated with human activities in the Columbia River Basin: our industry and commerce, transportation, housing and urban development, agriculture, and waste disposal.

Toxics reach the lower river through the air, surface water, suspended sediments, groundwater, and even contaminated insects and animals. Once there, toxics can be taken up by juvenile salmon through prey, water, and sediment. Ocean-type juveniles in particular are vulnerable to persistent, bioaccumulative toxics such as PCBs, PAHs, DDT, and PBDEs because these toxics tend to build up in the sediment of the shallow areas where ocean-type juveniles rear.

The sublethal effects of toxic contaminants are many, and in some cases toxicity is additive or even synergistic. Toxics studied in this project can impair juvenile salmon growth and development, affect immune function, act as hormone disruptors, and reduce reproductive success, even at low concentrations. Toxics also can alter salmon sensory abilities (particularly olfaction, or smell) and behavior, making it difficult for juveniles to swim, feed, avoid predators, and navigate their migratory path. Additionally, there is concern that toxic contaminants—some of which were designed specifically to kill insects and plants—may be changing the type or amount of available prey in the lower river, modifying the surrounding vegetation, and shifting the composition of the ecosystem's biological communities to nonnative, pollution-tolerant species. Although the effects of toxics on an individual salmon may be subtle, over time the impacts at the population level can be profound. This is particularly true with persistent, bioaccumulative toxics, which can remain in the environment for decades, recirculating and bioaccumulating in salmon and other organisms—including people—for years or decades.

Examples of Sublethal Effects on Salmon Behavior

Effect*	Toxic Contaminant
Disrupted feeding	Chromium, mercury
Reduced swimming ability	Lead, aldrin/dieldrin
Hyperactivity and abnormal surfacing	Aldrin/dieldrin
Reduced response to stimuli	Chromium, mercury
Difficulty avoiding predators	Organophosphate and carbamate pesticides, copper
Altered homing/migration	Organophosphate and carbamate pesticides
Less frequent spawning	Copper
Reduced egg fertilization	Current-use pesticides

* Effect varies according to level of exposure.

Examples of Sublethal Effects on Salmon Health

Effect*	Toxic Contaminant
Reduced olfactory function	Copper, pesticides
Immune suppression	PCBs, DDT, copper, chromium, lindane
Reduced growth	PAHs, DDT, copper, arsenic, chromium, mercury, lead, lindane, aldrin/dieldrin, caffeine
Disrupted smoltification	Arsenic
Hormone disruption	PCBs, DDT, bisphenol A, synthetic and natural estrogens, cadmium
Disrupted reproduction	PCBs, PAHs, DDT, copper, chromium, mercury
Cellular damage	Copper, chromium, nickel, lead, mercury
Physical/developmental abnormalities	PAHs, DDT, copper, lead, mercury, arsenic

* Effect varies according to level of exposure.

Overview of Sampling

A Deliberate Design

The body of scientific information on toxic contaminants in the lower Columbia River and estuary certainly is growing, yet important questions remain unanswered: How prevalent are emerging contaminants such as PBDEs and pharmaceuticals? How are these and other toxic contaminants distributed throughout the lower river, and how does their distribution change through time? Are toxic contaminants present at concentrations that affect salmon? Which salmon stocks are affected, and by which contaminants? Where and how are exposures occurring?

The Estuary Partnership's Ecosystem Monitoring Project was designed with particular features to help answer these questions.

Feature: Strategic sampling sites.

Rationale: Locating sampling sites above and below urban and industrial areas and key tributaries sheds light on where toxics are entering the lower river and where exposures are likely to be greatest. The data can be correlated with other information, such as historical data from the same sites to reveal changes in toxic contaminants over time or salmon habitat use patterns to develop risk profiles for different salmon stocks.

Feature: Sampling of water, suspended and bed sediments, and juvenile salmon; analyzing samples for similar classes of toxic contaminants.

Rationale: Sampling water, suspended and bed sediments, and juvenile salmon provides information on both water-soluble and bioaccumulative toxics, shows how toxic contaminants are moving through the environment and the food chain, and aids in understanding the exposure patterns of different salmon stocks. Looking for the same toxics in both juvenile salmon and their environment gives insight into how exposures are occurring and whether toxics that are present at low concentrations are actually bioaccumulating in juvenile salmon.

Feature: Water quality sampling during high and low river flows.

Rationale: Seasonal sampling shows how contaminant levels vary through time, with different volumes and sources of flow (such as agricultural or winter storm runoff).

Feature: Collection of juvenile salmon during the spring and summer, using beach seines near the riverbank.

Rationale: This combination of timing and sampling technique yields mostly ocean-type subyearlings, primarily fall Chinook. Because ocean-type salmon frequent shallow estuarine habitats for much of their first year, their contaminant profiles are likely to reflect the toxics present in the lower river—as opposed to toxics in the tributaries, where stream-type juveniles spend their first year and gain much of their toxic load.

Feature: Identification of prey species and measurement of contaminant concentrations in the stomach contents of juvenile salmon.

Rationale: Looking at the concentrations of toxic contaminants in prey that juveniles have eaten shows whether diet is a major source of exposure. Identifying the types of prey consumed by salmon provides insight into whether toxics are coming from the land, the water, or bed sediment, and whether the type of prey juveniles eat affects their exposure to toxics.

Feature: Genetic analysis of juvenile salmon.

Rationale: Correlating a juvenile salmon's stock of origin with the contamination in its body clarifies how exposure patterns differ for upriver and downriver stocks, and between salmon from primarily agricultural watersheds and salmon from urban/industrial watersheds.

Feature: Examination of the otolith (ear bone) from collected salmon to determine age.

Rationale: Correlating age with contaminant concentration in the body reveals how quickly juveniles are taking up toxics from their environment and may point to contaminant hot spots in the lower river. Otolith rings may also be used to estimate growth rates in juvenile salmon—something that could be affected by exposure to toxic contaminants or by the impact of toxics on prey availability.

Feature: Sampling of juvenile salmon and fish food from area hatcheries.

Rationale: Comparing contamination levels in juveniles at the hatchery with contamination levels in free-swimming juveniles clarifies how much contamination is coming from the lower river itself as opposed to hatchery feed, maternal transfer, or other sources.

Feature: Deployment of semi-permeable membrane devices (SPMDs) in the river for a month at a time.

Rationale: SPMDs can measure low concentrations of bioaccumulative toxics in the water column as they vary through the day, week, or month. Because even very small amounts of some toxics can be harmful to aquatic life, detecting toxic contaminants at low concentrations is important. Compositing and analyzing whole salmon bodies also helps detect low concentrations of toxic contaminants.

Feature: Analysis of water quality and salmon samples for flame retardants, artificial estrogens, pharmaceuticals, and other emerging contaminants.

Rationale: Emerging contaminants are being detected in U.S. waterways (including the upper Columbia River) at an increasing rate, but they have not been well studied in the lower river. Many emerging contaminants are harmful to aquatic life at low concentrations, have synergistic or additive effects, or bioaccumulate and thus can biomagnify up the food chain.

The methodologies used to sample water, sediment, and salmon in the lower Columbia River and estuary are summarized below. (See also Morace [2006] and Johnson et al. [2007a and 2007b]).

How Water Quality Sampling Was Conducted

Monthly Water Quality Sampling

To identify water quality trends through time, water quality samples were collected monthly for a year (May 2004 to April 2005) at three locations:

- **Warrendale, Oregon,** in the Columbia River Gorge just downstream of Bonneville Dam. This site provides data on the quality of water as it enters the lower river from upstream sources, including the agricultural Yakima and Snake river watersheds. Also, because Warrendale was a sampling site for the National Stream Quality Accounting Network (NASQAN) program from 1974 to 2000, there are historical data for this site to document long-term changes in water quality;
- **The Lower Willamette River,** near the Morrison Bridge in downtown Portland. Sampling of the lower Willamette captures contaminant inputs from the lower Columbia River's largest tributary—one that receives both agricultural and urban/industrial runoff. The lower Willamette River site is a former NASQAN site and a current National Water Quality Assessment (NAWQA) program sampling site; and
- **Beaver Army Terminal,** on the Columbia River downstream of Longview, Washington, and the Cowlitz River. A NASQAN site since 1974, Beaver was included in part to characterize water quality below the lower river's major urban/industrial areas.

Monthly water quality samples from the Warrendale, Lower Willamette, and Beaver Army Terminal sites were analyzed for the following:

- Trace elements;
- A select list of 52 pesticides such as atrazine, chlorpyrifos, and malathion that are currently being used in the Columbia River Basin;
- Nutrients;
- Chlorophyll a, pheophytin A, and biomass;
- Bacteria;
- Carbon species;
- Suspended sediment concentrations; and
- Field parameters, including pH, water temperature, and dissolved oxygen.

Also as part of the monthly sampling, suspended sediment from one site—Beaver Army Terminal—was analyzed for organochlorine pesticides such as DDT, aldrin/dieldrin, and endosulfan.

Monthly sampling at the three sites was supplemented by quarterly analysis for an expanded list of pesticides, such as 2,4-D, and their breakdown products that were too costly to be analyzed monthly. Quarterly analysis also included examination of trace elements on suspended sediments.

Water Quality Sampling (May 2004 –April 2005)
At Warrendale, Lower Willamette, and Beaver Army Terminal

	Water Column	Suspended Sediments
Constituents Analyzed Monthly	Selected pesticides, trace elements, nutrients, chlorophyll *a*, pheophytin A, biomass, bacteria, carbon species, suspended sediment concentrations, field parameters	Organochlorine pesticides such as DDTs, chlordanes, lindane, aldrin/dieldrin, and endosulfans (Beaver Army Terminal site only)
Additional Constituents Analyzed Quarterly	Expanded list of pesticides and their breakdown products	Trace elements

Standard depth- and width-integrating techniques were used to collect and composite the monthly water quality samples, with the exception of bacteria samples, which were collected as “grab samples” from the left and right banks and the center of flow. Sampling, processing and analytical techniques are described in Morace (2006).

Seasonal Water Quality Sampling

In addition to monthly sampling, seasonal water quality sampling was conducted at five sites in the lower river to better understand contaminant conditions during high and low river flows. During low flows, less water is available in rivers to dilute toxic contaminants. Thus, both point sources of toxic contaminants (such as those in urban and industrial areas) and nonpoint sources (such as agricultural runoff) can have a greater impact on water quality conditions and aquatic health during low flows than they do during other times of the year. Sampling during high flows typically reveals dissolved contaminants that enter the river directly from overland runoff or contaminants that bind to soil and sediment and then enter the river as a result of erosion during winter storms.

For the Ecosystem Monitoring Project, low-flow sampling took place in August 2004 and high-flow sampling occurred in April 2005. Under typical weather conditions, the highest flows in the Willamette River occur during winter storms, from November to January, while Columbia River high flows coincide with snowmelt, typically between April and June. However, the winter of 2005 was unseasonably dry, with spring storms beginning in early April. For this reason, the high-flow samples for both the Willamette and Columbia river sites were collected in April 2005.

Seasonal samples from the water column were analyzed for the same toxic contaminants as the monthly samples, but they also were analyzed for pharmaceuticals (including antibiotics), wastewater compounds such as insect repellant and synthetic musks, and an expanded list of pesticides and their breakdown products.

The following sites were sampled seasonally:

- **Warrendale, Lower Willamette, and Beaver Army Terminal;**
- **Columbia City, Oregon,** downstream of Multnomah Channel's entrance to the Columbia. Because of financial constraints, sampling at Columbia City was discontinued after the August 2004 low-flow sampling; and
- **Point Adams, Oregon,** located at River Mile 4 near the mouth of the Columbia. Sampling at this site was not depth- and width-integrated like the other sites. A depth-integrated point sample was obtained instead because of the site's location in the estuary proper. This site is directly influenced by the ocean and saltwater conditions.

Water Quality and Salmon Sampling Sites

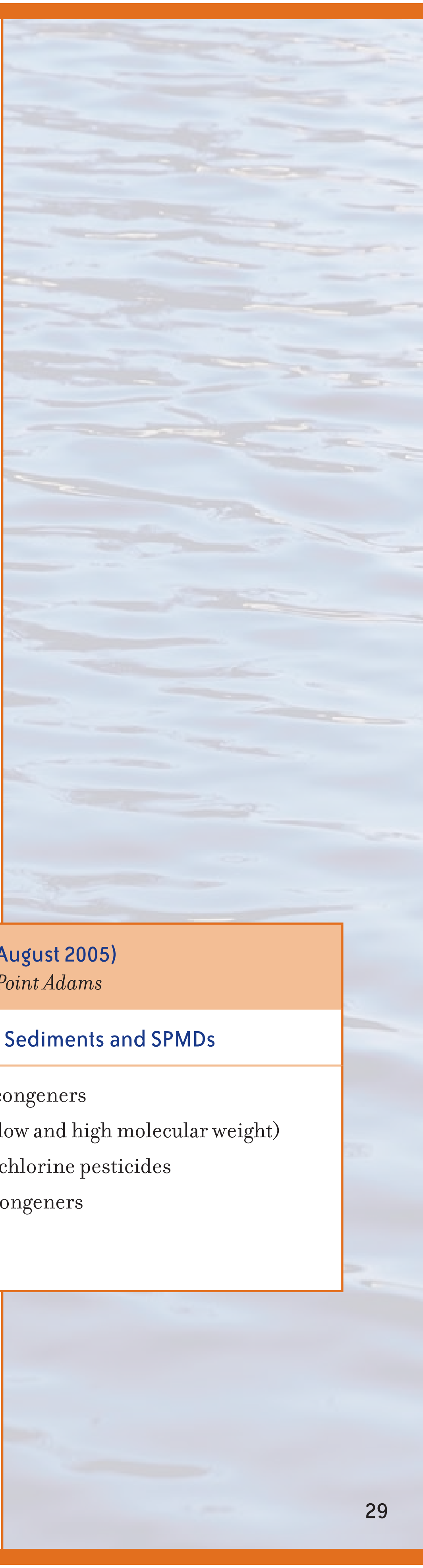
Both the Columbia City and Point Adams sites have been used previously for water quality or fish sampling, so historical data on these sites are available for comparison (Fuhrer et al. 1996, Tetra Tech, Inc. 1996, Johnson and Norton 2005, Johnson 2007a).

Seasonal sampling also included collection of suspended sediment during high and low river flow (April and August 2005). For this sampling, water was collected using depth- and width-integrating sampling techniques and then filtered. The resulting sediment was analyzed for all 209 PCB congeners; PAHs; organochlorine pesticides such as DDT, aldrin/dieldrin, and endosulfan; and a select group of 11 PBDE congeners, using techniques cited in Morace (2006).

Semi-Permeable Membrane Devices

In April and August 2005, SPMDs were deployed at four sites—Warrendale, Lower Willamette, Beaver Army Terminal, and Point Adams—to measure dissolved, bioaccumulative toxics present in the water during high and low flows. As described earlier, SPMDs mimic the fatty tissue of fish and help detect bioaccumulative toxics present at low or variable concentrations over time. The amount of a toxic contaminant that the SPMD picks up while it is deployed in the river represents the amount that a fish, if it were stationary, would be exposed to during that same time period.

SPMDs were positioned in the water column for approximately one month, and the extracts from the SPMDS were analyzed for all 209 PCB congeners; PAHs; organochlorine pesticides such as DDT, aldrin/dieldrin, and endosulfan; and a select group of 11 PBDE congeners, using techniques cited in Morace (2006).



Seasonal Water Quality Sampling with SPMDs (April and August 2005)

At Warrendale, Lower Willamette, Beaver Army Terminal, and Point Adams

	Water Column	Suspended Sediments and SPMDs
Constituents—High and Low Flows	Monthly constituents, plus: • 137 additional pesticides and their breakdown products • 49 antibiotics • 24 other pharmaceuticals • 63 other wastewater compounds	• 209 PCB congeners • 16 PAHs (low and high molecular weight) • 21 organochlorine pesticides • 11 PBDE congeners

Summary of Water Quality Sampling Activities

(May 2004 – April 2005, August 2005)

Sampling Month and Site Name	Filtered Water				Suspended Sediment and SPMDs				
	Trace elements	Pesticides	Pharmaceuticals	Other wastewater compounds	Trace elements	PAHs	PCBs	Organochlorine Pesticides	PBDEs
Monthly *(May 2004 – April 2005)*									
Warrendale	x	x			x[1]				
Lower Willamette	x	x			x[1]				
Beaver Army Terminal	x	x			x[1]			x	
August 2004 (low flow)[2]									
Warrendale	x	x	x	x					
Lower Willamette	x	x	x	x					
Columbia City	x	x	x	x	x				
Beaver Army Terminal	x	x	x	x					
Point Adams	x	x			x				
April 2005 (high flow)									
Warrendale	x	x	x	x	x	x	x	x	x
Lower Willamette	x	x	x	x	x	x	x	x	x
Beaver Army Terminal	x	x	x	x	x	x	x	x	x
Point Adams	x	x	x	x	x	x	x	x	x
August 2005 (low flow)[2]									
Warrendale						x	x	x	x
Lower Willamette						x	x	x	x
Beaver Army Terminal						x	x	x	x
Point Adams						x	x	x	x

1 Sampling of trace elements on suspended sediments occurred only during August and November of 2004 and February and April of 2005.

2 August low-flow sampling was split between 2004 and 2005 because of financial considerations.

How Salmon Sampling Was Conducted

Monthly Salmon Sampling

To learn how toxic contaminants in the water and suspended sediments are actually affecting salmon, salmon sampling was conducted at the same sites used for water quality sampling, plus one additional site at the confluence of the Willamette and Columbia rivers. Beach seines were used to collect subyearlings every month over a six-month period, from April to September 2005. The majority of collected juveniles were fall Chinook, an ocean-type salmon that typically spends much of its first year rearing in the estuary.

The juvenile salmon were weighed and measured, and a variety of samples were collected for analysis to detect contaminants of concern in the lower river. Most of these contaminants are persistent, bioaccumulative toxics. Some mimic hormones and thus disrupt the endocrine system. Test strips developed by Frontier Sciences were used in the field to screen salmon blood for vitellogenin, a yolk protein that in male and juvenile fish indicates exposure to natural and artificial estrogens in the environment. PCBs, PAHs, organochlorine pesticides, and PBDEs were analyzed using gas chromatography/mass spectrometry, while PAH metabolites in bile were analyzed using high-performance liquid chromatography/fluorescence detection. More information on analysis methodologies is available in Johnson et al. (2007a and 2007b).

Monthly Salmon Sampling (April – September 2005)

At Warrendale, Lower Willamette, Willamette/Columbia Confluence, Columbia City, Beaver Army Terminal, and Point Adams

Sample Collected	To Analyze For…
Whole bodies (composited)	• Lipid content and class • 40 PCB congeners • PAHs (low and high molecular weight) • Organochlorine pesticides: DDTs, chlordanes, lindane, aldrin/dieldrin, endosulfans, etc. • 10 PBDE congeners
Stomach contents (composited)	• Taxonomy of prey species • 40 PCB congeners • PAHs (low and high molecular weight) • Organochlorine pesticides: DDTs, chlordanes, lindane, aldrin/dieldrin, endosulfans, etc. • 10 PBDE congeners
Bile	PAH metabolites
Plasma	Vitellogenin
Fin clips	Genetic stock of origin
Otolith (ear bone)	Age and growth rate
Length and weight	Fish size distribution, condition

Additional sampling will occur in summer 2007 to capture data on yearling salmon, which represent mostly larger, stream-type juveniles that commonly use the deeper channels of the estuary and plume waters.

Seasonal Sampling of Bed Sediments

Sediments from the streambed were collected at the six salmon sampling sites in April and September of 2005 for future analysis for PCBs, PAHs, organochlorine pesticides, and PBDEs. At each site, bed sediment was collected with a bottom "grab-sampler" in the same area where the beach seining took place.

One-Time Hatchery Sampling

In May 2005, juvenile salmon and hatchery fish food were collected from seven area fish hatcheries: Priest Rapids, Klickitat, Spring Creek, Little White Salmon, Washougal, Cowlitz, and Elochoman. Again, the collected salmon were juvenile Chinook, sampled prior to hatchery release. The hatchery juveniles were sampled and analyzed in the same manner, for the same constituents, as the free-swimming juveniles collected during the monthly salmon sampling.

Fish food from the hatcheries was analyzed for bioaccumulative toxics such as PCBs, PAHs, DDTs, and PBDEs.

Summary

The water quality and salmon sampling components of the Ecosystem Monitoring Project were designed to work together. Correlating the water quality and salmon sampling data helps tell a larger story of where toxic contaminants are in the lower river, where they may be coming from, how they move—both spatially and through the food chain—and how they may be affecting juvenile salmon and other native species.

An added benefit comes from testing at several historical sampling sites in the lower river, in that the new data can serve as a springboard for additional studies, outside the scope of this project, of long-term contaminant trends in the lower river and risk profiles for individual salmon stocks. The resulting information will be useful in understanding how potential management actions address toxic contaminants, to the benefit of imperiled salmon stocks.

Summary of Sampling

Sites, Frequencies, and Constituents

Site	Water Column (monthly)	Water Column (seasonally)	Suspended Sediment, SPMDs (seasonally)	Bed Sediment (seasonally)	Juvenile Salmon (monthly)[1]
Warrendale	Trace elements Selected pesticides Field parameters, nutrients, bacteria, other constituents	Additional pesticides Pharmaceuticals Other wastewater compounds	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs Vitellogenin
Lower Willamette	Trace elements Selected pesticides Field parameters, nutrients, bacteria, other constituents	Additional pesticides Pharmaceuticals Other wastewater compounds	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs Vitellogenin
Willamette/ Columbia River Confluence				PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs Vitellogenin
Columbia City[2]		Monthly constituents Additional pesticides Pharmaceuticals Other wastewater compounds		PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs Vitellogenin
Beaver Army Terminal	Trace elements Selected pesticides Field parameters, nutrients, bacteria, other constituents	Additional pesticides Pharmaceuticals Other wastewater compounds	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs Vitellogenin
Point Adams		Monthly constituents Additional pesticides Pharmaceuticals Other wastewater compounds	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs	PCBs PAHs Organochlorine pesticides PBDEs Vitellogenin

[1] Salmon sampling included lipid content and prey taxonomy.

[2] Seasonal water quality sampling at Columbia City was conducted just once, in August 2004.

PCBs, PAHs, Trace Elements, and Pesticides

Analyzed in Water or Salmon Samples (Partial List)

PCBs	PAHs	Trace Elements	Pesticides	
PCBs 17, 18, 28, 31, 33, 44, 49, 52, 66, 70, 74, 82, 87, 95, 99, 101/90, 105, 110, 118, 128, 138, 149, 151, 153/132, 156, 158, 170/190, 171, 177, 180, 183, 187, 191, 194, 195, 199, 205, 206, 208, 209; plus 169 additional congeners in water quality samples only	Acenaphthene	Aluminum	Aldrin	Endosulfan
	Acenaphthylene	Antimony	Atrazine	EPTC
	Anthracene	Arsenic	Benomyl	Ethoprop
	Benzo(*a*)anthracene	Barium	Carbaryl	Heptachlor
	Benzo(*a*)pyrene	Beryllium	alpha-Chlordane	Hexachlorobenzene
	Benzo(*b*)fluoranthene	Cadmium	Chlorpyrifos	Lindane
	Benzo(*ghi*)perylene	Chromium	CIAT	Malathion
	Benzo(*k*)fluoranthene	Cobalt	Clopyralid	Metolachlor
	Chrysene	Copper	2,4-D	Metribuzin
	Dibenzo(*a,h*)anthracene	Lead	Dacthal	Metsulfuron methyl
	Fluoranthene	Manganese	DCPA	Mirex
	Fluorene	Mercury	4,4'-DDD	1-Naphthol
	Indeno(1,2,3-*cd*)pyrene	Molybdenum	4,4'-DDE	Pentachlorophenol
	Naphthalene	Nickel	4,4'-DDT	Prometon
	Phenanthrene	Silver	Diazinon	Simazine
	Pyrene	Uranium	Dicamba	Sulfometuron-methyl
		Zinc	Dieldrin	Triclopyr
			Diuron	Trifluralin

Emerging Contaminants

Analyzed in Water or Salmon Samples (Partial List)

PBDEs	Pharmaceuticals	Other Wastewater Compounds	Use
BDE 28	Acetaminophen	Acetophenone	fragrance, cigarette additive
BDE 47	Amoxicillin	Anthraquinone	dye, seed treatment, bird repellant
BDE 49[1]	Anhydro-erythromycin	Bisphenol A	plasticizer
BDE 66	Ciprofloxacin	Caffeine	stimulant
BDE 85	Codeine	Camphor	fragrance, anti-itch agent
BDE 99	Diphenhydramine	Cotinine	cigarette derivative
BDE 100	Doxycycline	para-Cresol	wood preservative
BDE 138[2]	Erythromycin	DEET	insect repellant
BDE 153	Fluoxetine	HHCB	synthetic musk
BDE 154	Ibuprofen	Menthol	peppermint flavoring, anti-itch agent
BDE 183	Miconazole	Methyl salicylate	wintergreen flavoring, fragrance, liniment
BDE 209[2]	Norfloxacin	para-Nonylphenol	detergent metabolite
	Oxytetracycline	Tetrachloroethylene	dry-cleaning agent, degreaser
	Penicillin	Tri(2-chloroethyl) phosphate	plasticizer, flame retardant
	Tetracycline	Triclosan	antibacterial agent in soaps and detergents
	Trimethoprim		
	Tylosin		
	Warfarin		

[1] Analyzed in salmon samples only.

[2] Analyzed in water quality samples only.

Results and Integration

Comparing concentrations in water and fish to established water quality standards and estimated thresholds for health effects on juvenile salmon advances understanding about which toxic contaminants are contributing to declines in salmon populations and how juvenile salmon exposure to those toxics can be reduced. The results of the water quality and salmon sampling are presented below, followed by a comparison to standards and thresholds and a look at conclusions that can be drawn when water quality and salmon sampling results are considered together.

Results of Water Quality Sampling

Results are from analyses of water, suspended sediment, and extracts from semi-permeable membrane devices (SPMDs) deployed in the lower river in 2004 and 2005. The methodology used for water quality sampling is described in Section 3 of this document and in Morace (2006). Water column and suspended sediment samples were collected from three sites every month from May 2004 to April 2005. Additional sampling to characterize contaminant levels during high (April 2005) and low (August 2004 and 2005) river flows was performed at these and one additional site. These samplings included not only obtaining water column and suspended sediment samples but also deploying SPMDs. Monthly samples were analyzed for pesticides and trace elements, while the low- and high-flow samples were analyzed for additional organochlorine pesticides, pharmaceuticals, other wastewater compounds, PCBs, PAHs, and PBDEs. A fifth site was sampled only in August 2004.

Several classes of toxic contaminants were detected in the lower river at multiple locations, most commonly at low concentrations (relative to the laboratory reporting limits). The fact there were detections at all in rivers as large as the Columbia and Willamette suggests that toxic contaminants are widespread in the Columbia River Basin, including in the lower river. It is also likely that toxics are present at considerably higher concentrations near their sources.

Key Findings from the Water Quality Sampling

- PCBs, PAHs, organochlorine pesticides, and PBDEs were found at all sites.
- Most toxic contaminants were detected at low concentrations.
- The most frequently detected pesticides were atrazine, simazine, and metolachlor, which are suspected hormone disruptors. These pesticides were detected at quantifiable concentrations.
- Caffeine was present at all sites. Other frequently detected wastewater compounds were bisphenol A (a plasticizer), HHCB (a synthetic musk), trimethoprim (an antibiotic for people and fish), and anhydro-erythromycin (a breakdown product of the antibiotic erythromycin, used for people and animals).

Non-Detects and "NQ"

A toxic may be present in the lower river even if it was not detected in water, sediment, or fish samples. Sampling captures data only on toxics collected from an individual location, at a certain time, under specific conditions. Non-detects may also be a reflection of the limitations of laboratory measurement—it is possible that a toxic was actually present in a sample but at a concentration too low to be detected.

In some cases, laboratory instruments revealed the presence of a toxic contaminant, but its concentration was lower than could be quantified. This report indicates such detections with "NQ," for "not quantifiable." "NQ" means that the toxic contaminant was present in the sample but that its concentration cannot be reported with the same level of confidence as contaminants present at higher concentrations.

- Warrendale, at the upstream end of the lower Columbia, had the fewest different types of PCBs and PBDEs and the lowest concentrations of these contaminants. PAHs at Warrendale were lower than at other sites.
- The Willamette River is a major source of toxic contaminants. Pesticides were found most often and at the highest concentrations at the Lower Willamette site, PAH and PBDE levels at the site were high, and several wastewater compounds were detected there, including the suspected hormone disruptors bisphenol A, HHCB, and tri(2-chloroethyl)phosphate.

Most Frequently Detected Pesticides and Breakdown Products in Filtered Water
(May 2004 – April 2005)

Atrazine	• 17 detections — at Warrendale, Lower Willamette, Beaver Army Terminal, and Point Adams. • Detections during all months except late summer/early fall. • Concentrations up to 0.096 µg/L — in the Lower Willamette in April 2005.
Simazine	• 10 detections — all in the Lower Willamette. • Detections during most months of the year, except July, September, and November. • Concentrations up to 0.042 µg/L— in the Lower Willamette in April 2005.
Metolachlor	• 9 detections — at Warrendale, Lower Willamette, and Beaver Army Terminal. • Detections primarily during spring/ summer, with two winter detections. • Concentrations up to 0.009 µg/L — in the Lower Willamette in February 2005. • Most detections below the method reporting limit.
CIAT (deethylatrazine, a breakdown product of atrazine)	• 6 detections — at Warrendale, Lower Willamette, and Beaver Army Terminal. • Detections during early spring/summer, with one winter detection. • One quantifiable detection of 0.006 µg/L — in the Lower Willamette in April 2005. • Most detections below the method reporting limit.
EPTC	• 6 detections — at Warrendale, Lower Willamette, and Beaver Army Terminal. • Detections in May, June, and July. • Most detections were quantifiable (0.004 – 0.006 µg/L).
DCPA	• 5 detections — at Warrendale and Beaver Army Terminal during June and July. • One quantifiable detection of 0.003 µg/L — at Beaver Army Terminal in June 2005. • Most detections below the method reporting limit.
Diuron	• 5 detections — at Lower Willamette, Beaver Army Terminal, and Point Adams. • Higher concentrations than other compounds. • Concentrations up to 0.27 µg/L — in the Lower Willamette in April 2005. • Detections at Beaver Army Terminal (0.04 µg/L) and Point Adams (0.03 µg/L) in April 2005.
Other Compounds	The following compounds were detected three times or less, usually at concentrations below the method reporting limit: • Bentazon, bromacil, bromoxynil, carbaryl, chlorpyrifos, 2,4-D, dicamba, 3,4-dichloroaniline, ethoprop, hexazinone, malathion, MCPA, metribuzin, metsulfuron-methyl, 1-naphthol, OIET, prometon, pronamide, sulfometuron-methyl, triclopyr, and trifluralin.

Pharmaceuticals Detected in Filtered Water—*Summary* *(August 2004 and April 2005)*

Contaminant	Number of Detections	Concentration (µg/L)	Where	When	
				Low Flow (August)	High Flow (April)
Anhydro-erythromycin	4	0.057	Warrendale	X	NS
		0.091	Lower Willamette	X	
		0.047	Columbia City	X	
		0.065	Beaver Army Terminal	X	
Trimethoprim	3	NQ	Warrendale	X	
		0.006	Lower Willamette	X	
		0.005	Beaver Army Terminal	X	
Acetaminophen	1	0.17	Beaver	X	
Diphenhydramine	1	NQ	Point Adams	NS	X
Tylosin	1	NQ	Beaver	X	

NQ = Not quantified; the compound was detected, but at a concentration below the method reporting limit.
NS = Not sampled.

Other Wastewater Compounds Detected in Filtered Water—*Summary* *(August and November 2004, February and April 2005)*

Contaminant	Number of Detections	Concentration (µg/L)	Where	When			
				8/04	11/04	2/05	4/05
Caffeine	8	NQ	Warrendale			X	X
		NQ – 0.046	Lower Willamette		X	X	X
		0.032	Columbia City	X	NS	NS	NS
		0.018	Beaver Army Terminal				X
		NQ	Point Adams				X
HHCB	2	NQ	Lower Willamette	X	NS	NS	
		NQ	Beaver Army Terminal		NS	NS	X
Bisphenol A	2	0.1	Lower Willamette	X	NS	NS	
		0.1	Beaver Army Terminal	X	NS	NS	
Anthraquinone	1	NQ	Columbia City	X	NS	NS	NS
DEET	1	0.1	Lower Willamette	X	NS	NS	
Tri(2-chloroethyl) phosphate	1	0.1	Lower Willamette	X	NS	NS	

NQ = Not quantified; the compound was detected, but at a concentration below the method reporting limit.
NS = Not sampled.

Toxic Contaminants Discovered in Water, Suspended Sediment, and SPMDs

PCBs. Analysis of suspended sediment and the SPMD extracts revealed the presence of PCBs at all four sites during both high and low flows, although concentrations on suspended sediment was low in April. PCBs were found uniformly in the lower river, except at Warrendale, which is at the upstream

Toxic Contaminants on Suspended Sediment—*Summary*
(April and August 2005)

	High Flow (April)			Low Flow (August)		
Contaminant	Location	Sum[1] (ug/kg)	Number of Detections[2]	Location	Sum[1] (ug/kg)	Number of Detections[2]
PCBs	Warrendale	0	29	Warrendale	0	19
	Lower Willamette	0	53	Lower Willamette	1.8	39
	Beaver Army Terminal	0	35	Beaver Army Terminal	0.4	26
	Point Adams	0	39	Point Adams	1.4	41
PAHs	Warrendale	0	0	Warrendale	0	0
	Lower Willamette	0	0	Lower Willamette	0	0
	Beaver Army Terminal	0	0	Beaver Army Terminal	0	0
	Point Adams	0	0	Point Adams	0	0
Organochlorine Pesticides	Warrendale	0	0	Warrendale	0	0
	Lower Willamette	0	0	Lower Willamette	0	0
	Beaver Army Terminal	0	0	Beaver Army Terminal	0	0
	Point Adams	0	0	Point Adams	0	0
PBDEs	Warrendale	0	10	Warrendale	0	7
	Lower Willamette	0	10	Lower Willamette	0	8
	Beaver Army Terminal	0	11	Beaver Army Terminal	0	9
	Point Adams	84	11	Point Adams	0	10

[1] Sum of the mass of analytes detected at concentrations at or above the reporting limit.
[2] For PCBs and PBDEs, the number of detections indicates the number of congeners detected.

end of the lower Columbia River. Warrendale had the fewest different PCB congeners and some of the lowest total amounts of PCBs. This suggests that the most important sources of PCBs in the river come from within the lower Columbia River Basin (including the Willamette subbasin), rather than from upstream.

Toxic Contaminants in SPMD Extracts—*Summary*
(April and August 2005)

	High Flow (April)			Low Flow (August)		
Contaminant	Location	Sum[1] (ng/SPMD)	Number of Detections[2]	Location	Sum[1] (ng/SPMD)	Number of Detections[2]
PCBs	Warrendale	11-14	14-18	Warrendale	4	26
	Lower Willamette	5-27	15-34	Lower Willamette	47-54	88-93
	Beaver Army Terminal	27-29	30-34	Beaver Army Terminal	46	87
	Point Adams	47	41	Point Adams	28-33	79-82
PAHs—Low Molecular Weight	Warrendale	0	0	Warrendale	0	1
	Lower Willamette	0	0-1	Lower Willamette	90-100	1
	Beaver Army Terminal	0	0	Beaver Army Terminal	80	1
	Point Adams	0	4	Point Adams	100	1
PAHs—High Molecular Weight	Warrendale	0	0	Warrendale	0	1
	Lower Willamette	0	0-1	Lower Willamette	1,000	3
	Beaver Army Terminal	0	0	Beaver Army Terminal	800	3
	Point Adams	0	2	Point Adams	600-700	3
Organochlorine Pesticides	Warrendale	0	1-2	Warrendale	0	0
	Lower Willamette	0	0-1	Lower Willamette	0	0
	Beaver Army Terminal	0	0-1	Beaver Army Terminal	0	0
	Point Adams	0	2	Point Adams	0	2
PBDEs	Warrendale	0.2-0.3	9	Warrendale	0	3
	Lower Willamette	10-34	9	Lower Willamette	40-43	10-11
	Beaver Army Terminal	0.4	9	Beaver Army Terminal	16	10
	Point Adams	12	9	Point Adams	5-6	10

[1] Sum of the mass of analytes detected at concentrations at or above the reporting limit.

[2] For PCBs and PBDEs, the number of detections indicates the number of congeners detected.

Note: Multiple values are shown because at some sites more than one SPMD was deployed and results varied between SPMDs.

The Chemical Structure and Toxicity of PCBs

The 209 different congeners of PCBs can be classified by how many chlorines they have. In the Ecosystem Monitoring Project, PCB congeners from the tri, tetra, penta, and hexa classes were detected, indicating PCBs with three, four, five, and six chlorines, respectively. Generally, PCBs with many chlorines are more toxic than PCBs with few chlorines, but toxicity is also affected by the arrangement of chlorines. The chemical structure of some PCBs is similar to that of dioxins, which makes these PCBs particularly toxic.

The majority of the PCBs were from the tetra- and pentachlorinated congener groups. But the PCB congener that was detected at the highest concentration in the SPMDs (except during the April Willamette River deployment) was the dichlorinated congener PCB 11. PCB 11 has been a dominant congener in other studies in the lower river. For example, unpublished data from the U.S. Army Corps of Engineers show PCB 11 as a chief congener in Asian clam tissue collected from the same reaches of the Columbia and Willamette where the Ecosystem Monitoring Project sites are located; the clam sampling occurred in August and September of 2005 (T. Sherman, pers. comm. 2005). PCB 11 also was prominent in SPMDs deployed in the Willamette River and in the lower Columbia River between Bonneville Dam and Longview during May and June of 2004 (Johnson and Norton 2005).

PCB 11 is not among the 12 PCB congeners that are considered most toxic to fish and birds: tetrachlorinated PCBs 77 and 81; pentachlorinated PCBs 105, 114, 118, 123, and 126; hexachlorinated PCBs 156, 157, 167, 169; and heptachlorinated PCB 189. Of these 12 most toxic congeners, only PCB 77 was detected in the lower river—on suspended sediment from Point Adams in August 2004.

PCBs are widespread throughout the lower river and are available for fish uptake from the water column.

PAHs. PAHs were found in water column samples and SPMD extracts, but not on suspended sediment. Several naphthalene compounds were detected in the water, primarily from Beaver Army Terminal in April. During high flow, PAHs were detected in the SPMDs at the Willamette and Point Adams sites. During low flow, PAHs were detected at all sites. Concentrations during low flow were similar to those measured during the winter of 1998 (McCarthy and Gale 1999). High molecular weight PAHs, which result from combustion, were found more often than low molecular weight PAHs.

Trace Elements. A variety of trace elements, including arsenic, chromium, copper, and lead, were detected in the water column of the lower river but were not measured in the salmon samples. Arsenic concentrations were higher in the lower Columbia River than in the lower Willamette River, and concentrations of most trace elements were higher at Point Adams than at upstream sampling sites.

Copper and a few other elements were detected at concentrations that may represent a hazard to juvenile salmon under certain conditions. Copper concentrations ranged from 0.7 to 3.8 µg/L, with the median concentration at Warrendale, the Lower Willamette, and Beaver Army Terminal being 1.0 µg/L. Concentrations of as low as 1 to 2 µg/L have been shown to inhibit salmon olfactory function (Baldwin et al. 2003, Sandahl et al. 2007), and levels within the range seen in this project have been associated with hormonal and immune system changes, reduced growth, and fry mortality in trout species (Munoz et al. 1991, Dethloff et al. 2001, Sauter et al. 1976, Welsh et al. 2000). Nickel, silver, and zinc also were detected at concentrations high enough to have health effects. Chromium, which can affect salmon feeding, predator avoidance, the immune system, and reproduction, was detected only once, at the Lower Willamette site. Although the concentrations found did not exceed USEPA water quality standards, levels are high enough to affect species.

Pesticides. Pesticides and their breakdown products were found in water from sites throughout the lower Columbia River, with the highest concentrations and most frequent detections occurring at the Lower Willamette site. Virtually all of the pesticides detected are ones that are currently in use in the Columbia River Basin; the exception was the detection of DDT on suspended sediment at Beaver Army Terminal in October 2004.

The most frequently detected pesticides were atrazine, simazine, and metolachlor; another pesticide of note, diuron, occurred less frequently but at concentrations comparable to atrazine. Atrazine and simazine frequently were detected at quantifiable levels at the Lower Willamette site and are available

PCB Congener Classes Detected on SPMDs
(April and August 2005)

	High Flow (April)		Low Flow (August)	
Congener or Class	Location	Sum[1] (ng/SPMD)	Location	Sum[1] (ng/SPMD)
PCB 11	Warrendale	8.2-8.8	Warrendale	4.0
	Lower Willamette	0.4-1.3	Lower Willamette	6.2-6.4
	Beaver Army Terminal	8.4	Beaver Army Terminal	7.8
	Point Adams	12.4	Point Adams	5.8-6.8
Tri-chlorinated	Warrendale	0.4	Warrendale	0
	Lower Willamette	0-6.0	Lower Willamette	6.7-8.0
	Beaver Army Terminal	7.0-7.1	Beaver Army Terminal	6.7
	Point Adams	8.0	Point Adams	3.3-4.5
Tetra-chlorinated	Warrendale	0.9-2.3	Warrendale	0
	Lower Willamette	3.2-11.9	Lower Willamette	13.2-17.5
	Beaver Army Terminal	7.8-8.6	Beaver Army Terminal	17.1
	Point Adams	15.0	Point Adams	9.5-11.0
Penta-chlorinated	Warrendale	1.4-1.8	Warrendale	0
	Lower Willamette	1.8-6.3	Lower Willamette	13.6-14.0
	Beaver Army Terminal	2.6-3.6	Beaver Army Terminal	9.9
	Point Adams	8.8	Point Adams	6.8-7.9
Hexa-chlorinated	Warrendale	0-0.4	Warrendale	0
	Lower Willamette	0-1.6	Lower Willamette	5.8-5.9
	Beaver Army Terminal	0.8-1.2	Beaver Army Terminal	3.6
	Point Adams	2.3	Point Adams	2.2-2.7

[1] Sum of the mass of analytes detected at concentrations at or above the reporting limit.
Note: Multiple values are shown because at some sites more than one SPMD was deployed and results varied between SPMDs.

Low and High Molecular Weight PAHs

What is the difference between low and high molecular weight PAHs? The two categories of PAHs have different chemical structures, sources, exposure pathways, and toxicity levels.

Low molecular weight PAHs (LMW PAHs) are less toxic and less persistent than high molecular weight PAHs. Low molecular weight PAHs typically come from petroleum products, such as gasoline or diesel fuel, that spill into the waterway or enter through stormwater runoff from urban areas. They are more water soluble than high molecular weight PAHs, which may explain why naphthalene—a low molecular weight PAH—was detected in the water column.

High molecular weight PAHs (HMW PAHs) have four or more rings in their molecular structure and originate primarily from combustion. Common sources of PAHs are vehicle exhaust fumes, coal tar, and municipal or industrial activities that involve combustion. High molecular weight PAHs tend to be more toxic and persistent than low molecular weight PAHs. They enter rivers and streams through stormwater runoff and atmospheric deposition.

for fish uptake. These pesticides can mimic or block natural hormones and interfere with reproduction and development in aquatic biota (Hayes et al. 2006). Pesticides were found most often in the Willamette during the rainy season—late fall, winter, and spring—which suggests that stormwater runoff plays an important role in transporting these toxic contaminants to the river. This is consistent with the findings of other researchers, including Fuhrer et al. (1996) and Rinella and Janet (1998). The Willamette River is an important source of these toxics to the lower river.

Pharmaceuticals and Personal Care Products. Pharmaceuticals, personal care products, and similar compounds also appear to be widespread in the lower Columbia River. Caffeine was detected most frequently, at least once at each site. Other compounds that were detected more than once were bisphenol A (a plasticizer), HHCB (a synthetic musk), the antibiotic trimethoprim, and anhydro-erythromycin, a breakdown product of erythromycin. The Lower Willamette and Beaver Army Terminal sites showed the widest range of these compounds, including the insect repellant DEET, acetaminophen, and tylosin, a veterinary antibiotic. Several compounds found in the lower river are suspected hormone disruptors. These include bisphenol A, HHCB, and tri(2-chloroethyl)phosphate, which was detected at the Lower Willamette site.

PBDEs (flame retardants). Eleven PBDE congeners (out of 209) were analyzed in this study, and all 11 were found on suspended sediments and SPMD extracts. During the April high-flow sampling, quantifiable concentrations of multiple PBDE congeners were found on suspended sediment collected from Point Adams.

During deployment of the SPMDs in August and April, most of the 11 congeners were detected at all four sites. The lowest concentrations were at Warrendale and the highest were in the lower Willamette River. Samples collected during high flow in April from the Lower Willamette and Point Adams sites showed considerably higher PBDE concentrations than samples from Warrendale or even Beaver Army Terminal.

Of the 11 different PBDEs tested for, congeners BDE 47 and BDE 99 were measured at the highest concentrations. These congeners are ingredients in the leading commercial penta-PBDE mixture. BDE 47 is the most frequently detected PBDE congener in people, fish, and other organisms (USEPA 2006); BDE 99 also is frequently detected. Chemically, PBDEs are similar to PCBs and are believed to have similar effects on juvenile salmon, ranging from neurotoxicity to hormone disruption.

Results of Salmon Sampling

The results of the salmon sampling show which specific toxics juvenile salmon in the lower river are absorbing, the level of those toxics in their tissue and prey, geographic patterns of exposure, and which salmon stocks are being exposed. This information is critical to understanding how toxics are affecting salmon in the lower river and how exposures could be reduced.

Analyses were done on the whole bodies, plasma, bile, and stomach contents of juvenile Chinook collected monthly from the same sites where water quality samples were collected, plus one additional site at the confluence of the Willamette and Columbia rivers.[1] Samples were analyzed for PCBs, PAHs, organochlorine pesticides such as DDT, PBDEs, and vitellogenin, a yolk protein that indicates exposure to estrogen. Lipid content, age, and genetic origin also were examined. Chinook juveniles and fish food collected from seven area hatcheries in May 2005 also were analyzed for the same compounds to better understand possible sources of toxics. For details on methodologies, see Section 3 of this document or Johnson et al. (2007a or 2007b).

Key Findings from the Salmon Sampling

- PCBs, PAHs, DDTs, and PBDEs were detected in both the bodies and stomach contents of juvenile salmon, indicating that prey are a source of exposure to these bioaccumulative toxics.
- The highest concentrations of PCBs, PAHs, and PBDEs were observed in salmon from sites near the more industrialized areas of the lower Columbia River: lower Willamette River, the confluence of the Columbia and Willamette rivers, Columbia City, and Beaver Army Terminal. Concentrations of toxic contaminants in fish from these areas were comparable to those in fish from other urban areas in the Pacific Northwest, such as Seattle. Fish at Warrendale showed generally low concentrations of these toxics.
- PCBs, PAHs, and DDTs in some salmon were above estimated threshold levels for health effects.
- Vitellogenin, normally found in adult females, was evident in juvenile salmon from the lower Willamette and the confluence of the Willamette and Columbia Rivers. This indicates exposure to estrogen-like compounds that may impair salmon growth, development, and reproduction.
- PBDE levels in salmon from the lower Willamette River were higher than those found in other species of fish that live year-round in the lower Columbia and Yakima rivers, based on a study conducted in 2005 by the Washington Department of Ecology (Johnson et al. 2006).
- Hatcheries contribute to the total amount of PCBs and DDTs in juvenile salmon, but the lower Columbia River appears to be a more important source of these contaminants, especially in areas of the river that have significant industrial activities.
- Although the majority of salmon sampled were from Lower Columbia and Willamette River stocks, fish from Snake River, Upper Columbia, and Middle Columbia stocks were observed at nearly all of the sampling sites.
- Upriver salmon stocks appear to be absorbing PCBs and PBDEs while rearing in the urbanized tidal freshwater sites in the lower Willamette and Columbia rivers.

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[1] Bed sediment was sampled as part of this study, but results are not yet available. Other results to be released at a later date include analysis of otoliths and the taxonomy of prey found in salmon stomachs.

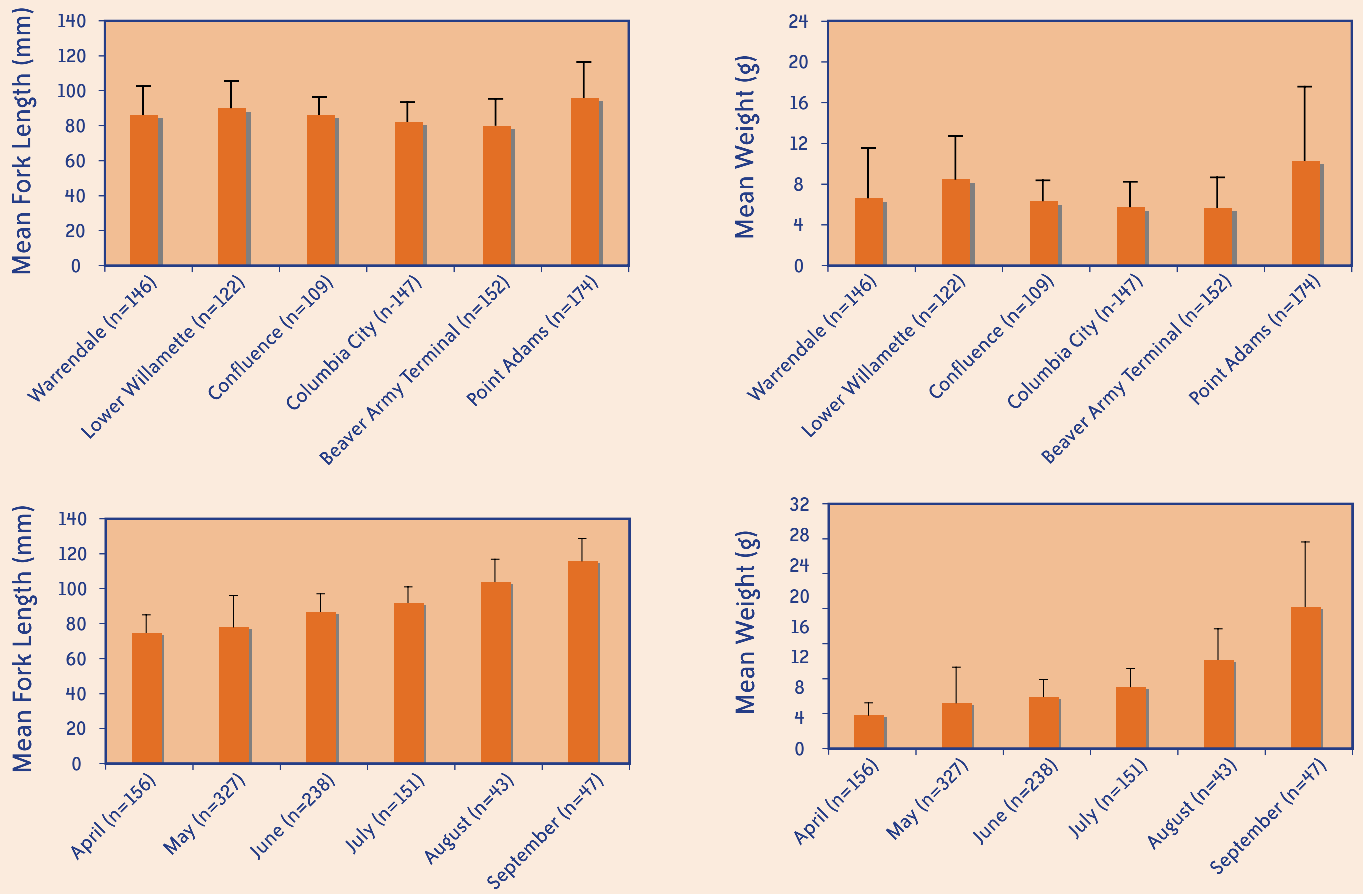
Salmon Size and Lipid Content

The largest juvenile salmon were generally found at Point Adams, near the mouth of the Columbia River, but otherwise fish length and weight did not differ considerably from site to site. However, there was a clear seasonal pattern in salmon size. As the season progressed from April to September, fish length and weight tended to increase. This trend was most marked among juveniles collected at the Beaver Army Terminal site.

Lipid content (body fat) in field-collected juveniles varied from 0.6 to 5.4 percent, with the highest mean levels in fish from Point Adams and the lowest in fish from Beaver Army Terminal. Again, there was a seasonal pattern: average percentages were lowest (from 1.3 to 1.7 percent) in April and May and highest (from 2.3 to 2.8 percent) in June, July, and August.

Salmon Length and Weight

Individual Juvenile Chinook Salmon Sampled

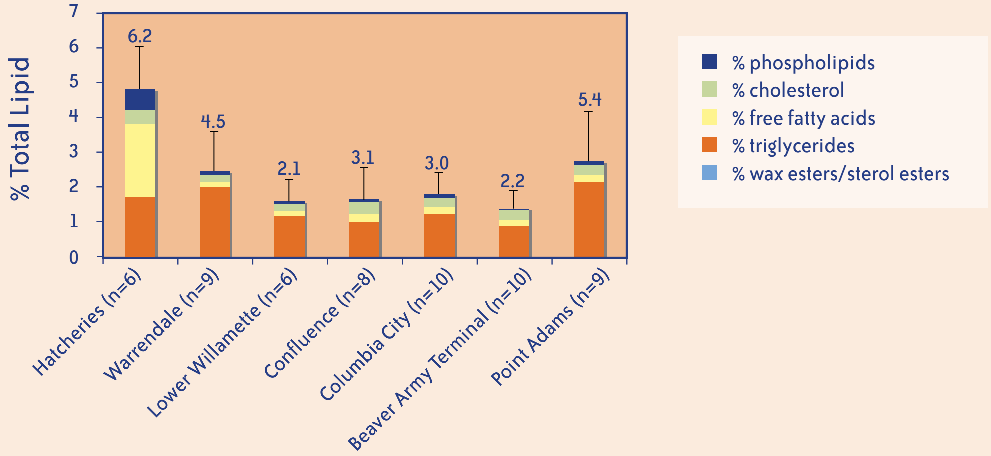


Bars show mean + 1 standard deviation. n = number of individual juvenile Chinook Salmon sampled.

Most of the lipids in field-collected salmon bodies consisted of triglycerides and cholesterol, which accounted for 65 percent and 20 percent, respectively, of total lipids. Normally, as the season progresses and fish put on weight, the ratio of triglycerides to cholesterol increases. This pattern was observed in samples collected in the lower river, although there were geographic variations. Triglycerides were highest and cholesterol lowest among the Point Adams fish, while the situation was reversed in the Beaver Army Terminal fish, whose lipid profiles were similar to those of malnourished fish.

Salmon Lipid Content

Composite Samples of 5-10 Juvenile Chinook Salmon



Bars show mean + 1 standard deviation. The maximum value for the site is shown above each bar.
n = number of composite samples.

Lipid Content and Contaminant Concentrations in Whole Bodies

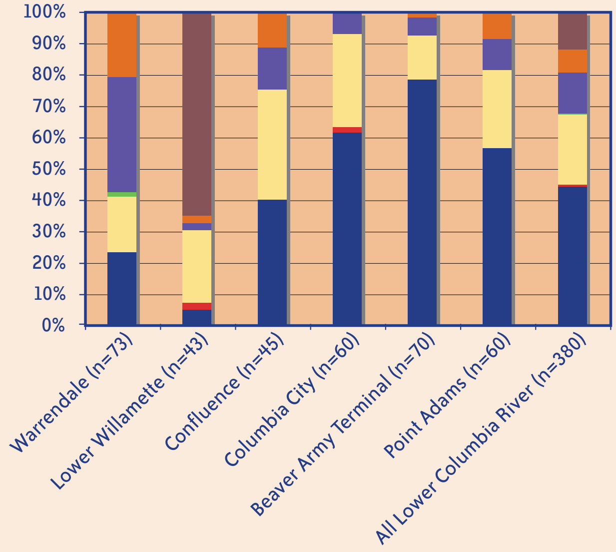
Composite Samples of 5-10 Juvenile Chinook Salmon

Hatchery	Lipid Content (%)	∑PCBs (ng/g wet wt)	∑DDTs (ng/g wet wt)	∑PBDEs (ng/g wet wt)
Cowlitz State Hatchery	4.7	7.3	8.7	NQ
Elochoman State Hatchery	5.3	14	4.8	NQ
Klickitat State Hatchery	6.2	12	8.1	NQ
Little White Salmon National Hatchery	4.3	7.5	8.1	NQ
Priest Rapids State Hatchery	5.1	58	15	NQ
Spring Creek National Hatchery	2.6	14	5.5	0.71

Washougal State Hatchery was not included in the table because fish samples were not analyzed. NQ = not quantified; the compound was detected, but at a concentration below the method reporting limit.

Lipid amounts generally were higher in hatchery-collected fish (2.6 to 6.2 percent) than in field-collected fish (0.6 to 5.4 percent). This higher lipid content in hatchery fish provides energy reserves, but it also facilitates the uptake of bioaccumulative toxics, which are stored in body fat. As long as fat stores remain high, the risk to the fish is low. But when hatchery juveniles enter the river and mobilize their fat for energy, these bioaccumulative toxics are released in the body, potentially increasing the risk of health effects. Exposure levels in the hatchery fish sampled in the Ecosystem Monitoring Project generally were low, but the lipid-contaminant interaction is worth considering when evaluating hatchery practices.

Genetic Origin of Juvenile Chinook Salmon



n = number of individual juvenile Chinook Salmon sampled.

Most of the juvenile salmon collected in this study were from lower Columbia River stocks, but a range of other salmon stocks also were represented. At the Lower Willamette and Confluence sites, most of the fish were from Willamette River stocks. At the Warrendale site, juveniles commonly were from Middle Columbia, Upper Columbia, and Snake River stocks. However, upriver stocks were not limited to the Warrendale site. Juveniles from Middle Columbia, Upper Columbia, and Snake River stocks were collected at nearly every sampling site. This demonstrates that these upriver stocks are feeding and rearing in the urban and industrialized sites in the tidal freshwater portion of the lower river.

Toxic Contaminants Detected in Juvenile Salmon

PCBs—Present in Whole Bodies and Stomach Contents. PCBs were detected in the bodies and stomach contents of salmon from every sampling site, suggesting that prey are a source of PCB exposure throughout the lower river. Levels were particularly high in the stomach contents of fish from the Lower Willamette and Confluence sites, which are affected by urban and industrial activities. Whole body PCB concentrations were lowest at Warrendale and highest at Beaver. Smaller, lower weight fish tended to have higher total amounts, or body burdens, of PCBs.

Among the different salmon stocks, concentrations of PCBs were highest in salmon from the Lower Columbia and Snake River stocks. The Snake River salmon do not appear to be bringing these high PCB loads with them from upriver because concentrations in the bodies of juveniles from Warrendale—where upriver stocks enter the lower Columbia River—were low. This suggests that Snake River stocks are absorbing significant amounts of PCBs as they rear in the tidal freshwater portions of the lower river.

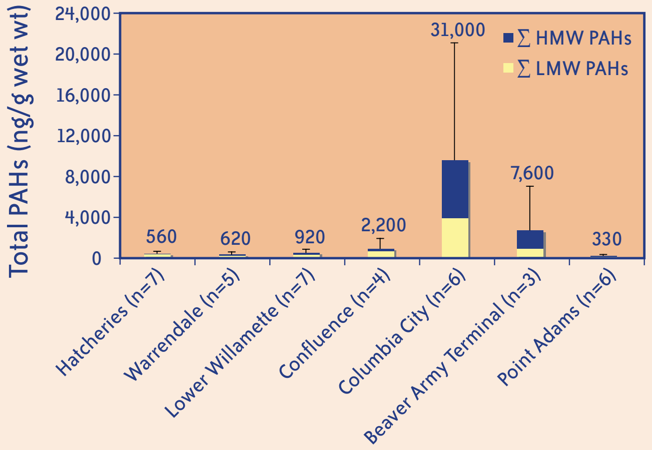
PCBs also were detected in hatchery fish and their feed at concentrations similar to those observed in fish from rural estuaries in the Pacific Northwest. Comparison of PCB concentrations in the hatchery- and field-collected fish suggests that the hatchery is an important source of PCBs for fish using the less industrial areas of the lower river. However, for juveniles at sites where industrial activity is high, the lower river is a more important source of PCBs.

PAHs—Present in Bile and Stomach Contents. PAHs or their metabolites were measured in the bile and stomach contents of salmon from all the sampling sites, which emphasizes the pervasiveness of these contaminants and points to prey as a source of exposure. Both low and high molecular weight PAHs were detected. The highest levels were measured at the Lower Willamette, Confluence, Columbia City, and Beaver Army Terminal sites, with especially high concentrations of total PAHs (>10,000 nanograms per gram [ng/g] wet weight) in the stomach contents of fish at Columbia City.

PAHs or their metabolites were detected in hatchery feed and the bile of hatchery fish but at levels similar to those in fish and prey from uncontaminated areas and below levels associated with health effects. Most of the PAHs were low molecular weight compounds that could have come from gasoline, diesel fuel, or other petroleum products used around the hatcheries. High molecular weight PAHs—the type associated with combustion—were rarely found in hatchery feed.

PAHs in Salmon Stomach Contents

Composite Samples from 5-10 Juvenile Chinook Salmon



Bars show mean + 1 standard deviation. The maximum value for the site is shown above the bar. n = number of composite samples.

Low and High Molecular Weight PAHs in Whole Bodies and Metabolites in Bile

Composite Samples of 10 Juvenile Chinook Salmon

Hatchery	∑LMW PAHs (ng/g wet wt in bodies)	∑HMW PAHs (ng/g wet wt in bodies)	LMW PAH metabolites (ng/g bile)	HMW PAH metabolites (ng/g bile)
Cowlitz State Hatchery	30	NQ	520	14,000
Elochoman State Hatchery	25	NQ	390	9,900
Klickitat State Hatchery	39	NQ	410	10,000
Little White Salmon National Hatchery	37	0.35	NS	NS
Priest Rapids State Hatchery	41	0.5	620	16,000
Spring Creek National Hatchery	26	NQ	745	16,000

Washougal State Hatchery was not included in the table because fish samples were not analyzed. NQ = not quantified; the compound was detected, but at a concentration below the method reporting limit. NS = not sampled.

DDTs—Present in Whole Bodies and Stomach Contents. Like PCBs and PAHs, DDTs were measured in the bodies and stomach contents of salmon from all the sampling sites, but concentrations were fairly similar among the different salmon stocks. From site to site, there was less variation in DDT levels than there was for PCBs, PAHs, or PBDEs. This relative uniformity emphasizes how pervasive and evenly distributed DDTs are in the lower Columbia River.

Concentrations in stomach contents averaged from 13 to 42 ng/g wet weight, with the lowest averages at the Lower Willamette site and the highest at Point Adams. These averages are relatively high compared to measurements in salmon from other estuaries in the Northwest. For whole body samples, DDT concentrations were lowest in fish from Warrendale and the Lower Willamette sites and highest in fish from Beaver Army Terminal. The relatively high body burdens in fish from the Beaver site may reflect the gradual accumulation of DDTs in juveniles as they move downriver. Some DDT compounds that can act as hormone disruptors were found in the stomach contents and whole bodies of juvenile salmon collected in the lower river.

DDT concentrations in the feed and bodies of juveniles from the hatcheries were below levels that would suggest health effects. Comparison of the hatchery concentrations with the higher concentrations observed in field-collected juveniles indicates that land use activities in the Columbia River Basin, rather than hatcheries, are the major source of DDTs.

Contaminant Concentrations in Feed Samples

One Food Sample was Measured from Each Hatchery

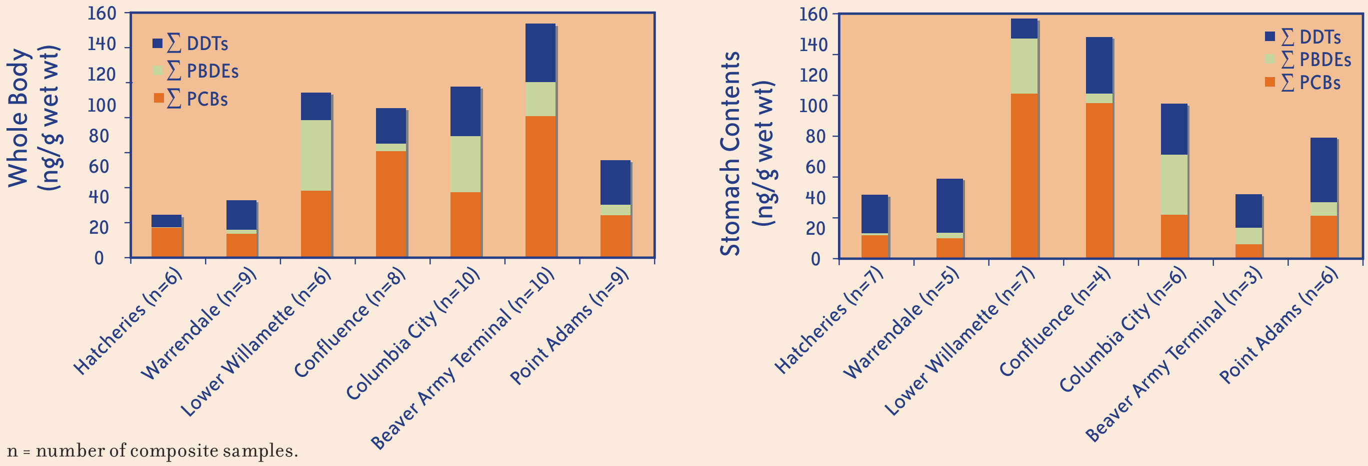
Hatchery	∑PCBs (ng/g wet wt)	∑DDTs (ng/g wet wt)	∑PBDEs (ng/g wet wt)	∑LMW PAHs (ng/g wet wt)	∑HMW PAHs (ng/g wet wt)
Cowlitz State Hatchery	15	39	1	350	58
Elochoman State Hatchery	6	9.8	NQ	140	9.7
Klickitat State Hatchery	22	31	0.79	140	9.9
Little White Salmon National Hatchery	25	31	2.9	490	68
Priest Rapids State Hatchery	10	36	0.95	500	61
Spring Creek National Hatchery	20	9.9	2.6	340	53
Washougal State Hatchery	5.3	19	NQ	96	3.7

NQ = not quantified; the compound was detected, but at a concentration below the method reporting limit.

PDBEs—Present in Whole Bodies and Stomach Contents. Juvenile salmon from every sampling site had PBDEs in their bodies and stomach contents. This points to prey as a source of exposure. Concentrations in stomach contents were highest in fish from the Lower Willamette and Columbia City sites.

Contaminant Concentrations in Salmon and Salmon Diet

Composite Samples of 5-10 Juvenile Chinook Salmon/Salmon Stomach Contents



n = number of composite samples.

Whole body PBDE concentrations ranged from < 1 to 93 ng/g wet weight. Fish from Warrendale, Confluence, and Point Adams showed the lowest average concentrations (from 2 to 7 ng/g wet weight), while fish from the Willamette sites showed the highest. However, whole body PBDE concentrations in salmon from Columbia City and Beaver Army Terminal also were elevated.

Among the different salmon stocks, the highest PBDE concentrations were seen in Willamette River stocks—an indication of the influence of rearing in the urban environment of Portland. PBDEs were also high in the Lower Columbia and Middle Columbia stocks. This finding, combined with the fact that PBDE concentrations were relatively low in juveniles at the Warrendale site, suggests that the Middle Columbia stocks are absorbing much of their PBDE load while rearing in the tidal freshwater areas of the lower river.

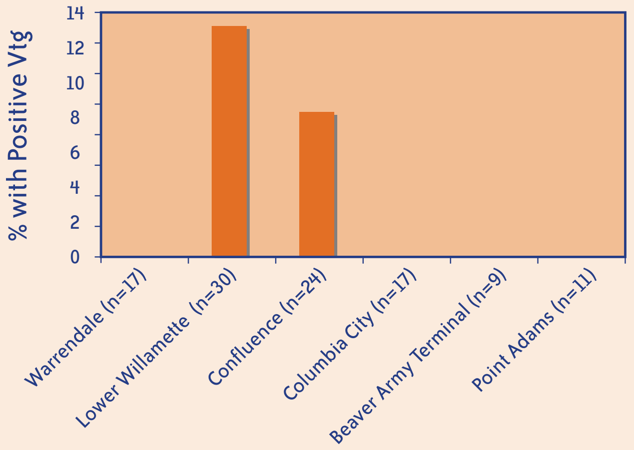
The lower Columbia River is the most likely source of PBDE exposure for juveniles, as PBDEs were rarely detected in hatchery feed and were present in the bodies of hatchery juveniles only at low levels.

Pharmaceuticals and Other Wastewater Compounds—Evidence of Exposure Found in Blood. To look for signs of exposure to pharmaceuticals and other wastewater compounds in juvenile salmon, blood samples were screened for vitellogenin, a yolk protein that indicates exposure to estrogen-like compounds, such as certain pharmaceuticals and personal care products. Normally, vitellogenin is present only in adult female fish.

Vitellogenin was found in blood samples of juvenile salmon from the Lower Willamette and Confluence sites, but not in juveniles from Warrendale, Columbia City, Beaver Army Terminal, or Point Adams. This is consistent with the high number of detections of compounds at the Lower Willamette site, including bisphenol A and other compounds with known or suspected estrogenic activity. However, these findings differ from those of USGS in its 1998 Biomonitoring of Environmental Status and Trends (BEST) study, which saw vitellogenin induction in male bass, carp, and large-scale sucker from Warrendale but not in fish from the Portland area (Hinck et al. 2006). This discrepancy may be a reflection of different exposure pathways and patterns in resident fish as compared to juvenile salmon.

Salmon Vitellogenin Production

Individual Juvenile Chinook Salmon



Lower Willamette sample includes fish from near the Morrison Street Bridge and from a nearby site at river mile 7. n = number of individual juvenile Chinook Salmon sampled.

The specific compounds that are causing vitellogenin production in juveniles from the lower Willamette River are unknown. DDT compounds that act as hormone disruptors were found at low concentrations in the stomach contents and whole bodies of juvenile salmon collected at the Lower Willamette site. Also, the suspected hormone disruptors bisphenol A and HHCB were detected in the water column during water quality sampling, also at low levels. These and other hormone disruptors that were not measured in this study but may be present in the river, such as synthetic estrogens and surfactants, may be acting together to induce vitellogenin production in juveniles from the Lower Willamette site.

Comparing Concentrations to Standards and Thresholds

Water quality standards have been established for a few of the toxic contaminants measured in this project. For many of the other toxics studied, current scientific literature provides a basis for estimating threshold levels for health effects on juvenile salmon. Toxic contaminants present at concentrations above threshold levels may be harming juvenile salmon in the lower Columbia River, as described below.[2] (See Section 2 for information on sublethal effects to juvenile salmon.)

PCBs. Total PCB levels in the whole bodies of some fish were at or above the estimated threshold level of 2,400 ng/g lipid, above which health effects such as delayed mortality, biochemical alterations, and immune dysfunction have been observed (Meador et al. 2002). The highest total PCB concentration measured was 39,000 ng/g lipid in a fish sample from Beaver Army Terminal. These threshold values are expressed as ng/g lipid because the lipid content of the animal can affect the toxicity of PCBs and other bioaccumulative compounds.

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[2] These threshold levels have not yet been incorporated into regulatory guidelines.

PAHs. PAH levels in the stomach contents of juvenile salmon from the Columbia City and Beaver Army Terminal sites, which were over 7,000 ng/g wet weight, may be high enough to be of concern. Similar concentrations have been associated with impaired growth and immune system function in juvenile salmon from contaminated sites in Puget Sound (Arkoosh et al. 1991 and 1998, Casillas et al. 1995 and 1998). In the laboratory, juvenile salmon with dietary PAH concentrations comparable to those found in samples from the lower river showed changes in metabolism, growth, blood chemistry, and fatty acid profiles, which were similar to those in starving animals (Meador et al. 2006). Although it is not certain that toxic contaminants caused these effects, lipid profiles in salmon from Beaver Army Terminal were akin to those in PAH-exposed laboratory fish.

DDTs. There is less information about the threshold level for health effects of DDTs on juvenile salmon than there is about threshold levels for PCBs and PAHs. The Ecosystem Monitoring Project uses an estimated DDT threshold concentration of 5,000 to 6,000 ng/g lipid. This is based on the typical lipid content of salmonids in laboratory studies and resulting DDT threshold level expressed for wet weight proposed by Beckvar et al. (2005). Some composite samples of fish from Beaver Army Terminal had DDT concentrations at this threshold level—up to 5,500 ng/g lipid.

Pesticides in Current Use. Studies have shown that individual pesticides currently being used, such as the organophosphate insecticide chlorpyrifos, can affect salmon's olfactory function at concentrations as low as 0.5 µg/L (Sandahl et al. 2005). In the Ecosystem Monitoring Project, individual pesticides were detected in the water column at concentrations ranging from 0.003 to 0.27 µg/L. Although these levels are low, they may still be of concern, particularly because pesticides were frequently found together. Given that pesticides were detected at all sites and often in combination, their additive effects could be significant. Toxic contaminants such as carbamate and organophosphate pesticides can have additive effects on olfactory function when they occur together in the environment (Scholz et al. 2006).

PBDEs. PBDEs appear to be pervasive in the lower river and are thought to have effects similar to those of PCBs, which they chemically resemble (Eriksson et al. 2001, Hale et al. 2001). Because these flame retardants are an emerging contaminant, little is known about the threshold level for health effects on juvenile salmon. At some sampling sites in the Ecosystem Monitoring Project, PBDEs are present at high levels relative to other parts of the Northwest. For example, PBDEs concentrations in juveniles from the Lower Willamette site were as high as or higher than those in juveniles from urban estuaries in Puget Sound (Ylitalo et al. 2007). Also, PBDE levels in juveniles from the Lower Willamette site were higher than levels measured in whole bodies of resident fish from the lower Columbia and Yakima rivers by the Washington Department of Ecology in 2005 (Johnson et al. 2006).

Toxics and Lipid Content

The amount and type of lipids, or body fat, in juvenile salmon are important indicators of overall health. Low lipid levels and certain lipid ratios can mean that juveniles are not getting enough to eat. In the lower Columbia, this could be the result of exposure to toxic contaminants, which can interfere with a juvenile's ability to feed and put on weight. Toxics also may be reducing the amount of available prey in the lower river.

Bioaccumulative toxic contaminant concentrations are generally measured in juvenile salmon bodies in nanogram per gram of salmon tissue. However, the lipid content of the fish can have an important influence on the toxicity of the contaminants, because toxics can be bound in lipids where they are not available to cause harmful effects. The same concentration of a contaminant will be more toxic in a fish with low lipid content than in a fish with high lipid content. Because of this, tissue effect levels are often adjusted for the amount of lipid the fish contained, so are expressed as ng/g lipid rather than ng/g wet weight.

Estrogenic Compounds, as Indicated by Vitellogenin. The presence of vitellogenin in juvenile or male fish can indicate exposure to estrogen-like compounds at levels that disrupt the endocrine system and interfere with growth, development, and reproduction. Additional scientific information is needed to determine whether the vitellogenin levels observed in this project represent a level of estrogen exposure that would be a threat to the health of juvenile salmon.

Concentrations and Estimated Thresholds for Health Effects in Juvenile Salmon

Toxic Contaminant	Threshold	Exceeded?	Concentration Range
PCBs	2,400 ng/g lipid (in whole bodies)	Yes	33 - 39,000 ng/g lipid
PAHs	~7,000 ng/g wet weight total (in diet)	Yes	34 - 10,000 ng/g wet weight
Copper	0.2 – 2 µg/L in water (for impacts on olfaction)	Yes	0.7 – 3.8 µg/L in water
DDTs	5,000 – 6,000 ng/g lipid (in whole bodies)	Yes	78 - 5,500 ng/g lipid
Pesticides in Current Use	~0.5 µg/L in water for chlorpyrifos (for impacts on olfaction)	No	0.003 – 0.27 µg/L in water column, for various pesticides
PBDEs	None established	NA	< 1 - 93 ng/g wet weight (whole bodies)
Estrogenic Compounds/ Vitellogenin	None established; varies based on contaminant	NA	0 - 20 ng/mL vitellogenin (in blood)

Integration of Water Quality and Salmon Sampling Results

Looking at the water quality and salmon sampling results together gives a more comprehensive picture of how toxics—particularly bioaccumulative ones—are moving through the lower river and food chain and affecting juvenile salmon.

PCBs, PAHs, and PBDEs are widespread in the lower river, both geographically and in the food chain.

PCBs, PAHs, and PBDEs were found at virtually all sites, in both water quality and salmon samples, including salmon stomach contents. This indicates that PCBs, PAHs, and PBDEs are moving from the physical environment (river water and suspended sediment) into salmon prey species and from there into the tissue of juvenile salmon, where in some cases they are bioaccumulating to concentrations that pose health risks. Juveniles may also be absorbing PCBs, PAHs, and PBDEs directly, through the water they swim in and the sediment they encounter while rearing in the lower Columbia River and estuary.

Although PCBs and PAHs were known to be present in the lower Columbia River and estuary prior to this study, the emergence of PBDEs is relatively new. Their occurrence throughout the lower river suggests that these flame retardants are being actively released. This is not surprising, given how widely used PBDEs are in plastics, furniture, and other consumer goods. Although the effects of PBDEs on salmon are not well understood, their levels in the environment are increasing and PBDE concentrations in salmon at the Lower Willamette site are among the highest in the Pacific Northwest. Concern about the possible health effects of PBDEs are great enough that some states, including Washington and California, have banned their manufacture and sale. Oregon has banned the sale of penta and octa mixtures and is investigating alternatives to deca-BDE.

The urban and industrial portions of the lower river contribute significantly to juvenile salmon's toxic loads.

The Willamette River and the more urban and industrial stretches of the lower Columbia River contribute to the exposure of juvenile salmon to toxic contaminants. Water quality and salmon samples from Warrendale, at the upstream end of the study area, consistently showed lower concentrations of toxic contaminants than samples from other sites, while samples from the tidal freshwater sites—the Lower Willamette, Confluence, Columbia City, and Beaver Army Terminal—generally had higher concentrations. Given their location downstream of the lower river's major population centers, these sites are affected by releases of toxic contaminants associated with urban and industrial activities. In fact, PCBs, PAHs, and PBDEs all were detected in the water (as measured with SPMDs), on sediments, and in salmon from these sites, with concentrations in fish generally being higher than at other sites.

Juveniles from upriver salmon stocks are absorbing toxic contaminants during their time in the lower Columbia River.

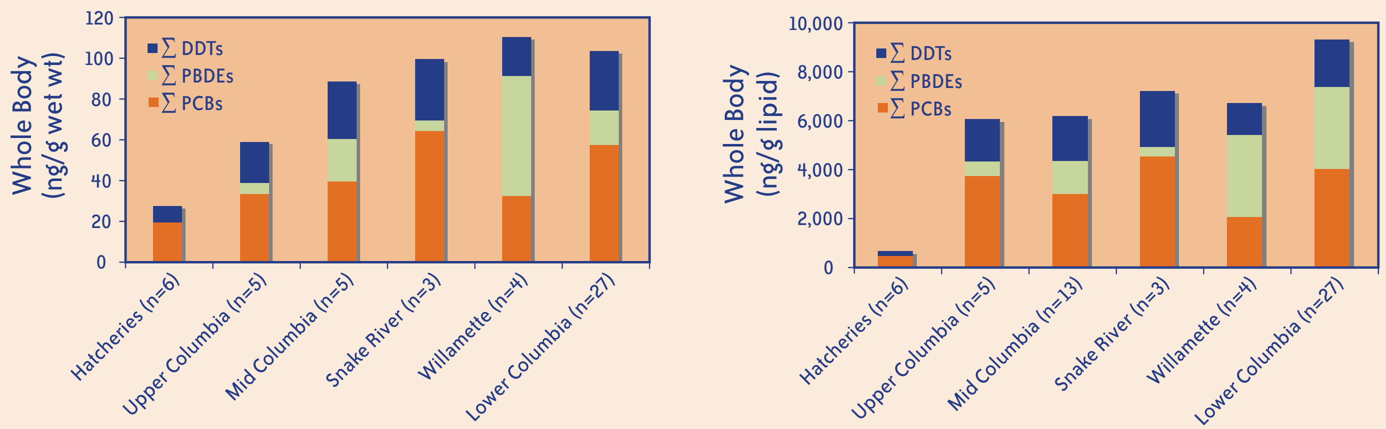
The difference between concentrations in samples from Warrendale and those from sites farther down the river suggests that much of the contaminant load seen in juvenile salmon is coming from the lower Columbia River and that upriver stocks are absorbing toxics as they forage in the lower river. Juveniles from upriver stocks collected at Warrendale, at the upstream end of the study area, showed relatively low concentrations of PCBs and PBDEs, but concentrations increased as these stocks moved downstream. In the end, juveniles from Snake River and Middle Columbia stocks had some of the highest levels of PCBs and PBDEs, respectively. This finding is consistent with patterns observed in the water quality samples: contaminant concentrations at Warrendale were generally low, while sites in the tidal freshwater portion of the lower river had higher concentrations. Little is known about upriver stocks' contaminant exposure before they reach the lower river and estuary, and the number of juveniles from upriver stocks sampled during this effort was relatively small. However, this study suggests the lower river and estuary may be a significant source of toxic contaminants for juveniles from upriver stocks.

Juvenile salmon in the lower river are accumulating DDT in their tissue.

DDT was measured at relatively high levels in salmon samples (both stomach contents and body tissue) but was detected during water quality sampling only a few times and at very low concentrations. This could be explained by the bioaccumulation of DDT in individual organisms, followed by biomagnification of DDT up the food chain. The result is that DDT concentrations in predators such as salmon can be orders of magnitude higher than concentrations in the surrounding environment.

Contaminants in Salmon Stocks

Composite Samples of 5-10 Juvenile Chinook Salmon



n = number of composite samples.

The origin of the DDT in salmon samples is unclear. If DDT were coming from major point sources, it would have been detected more frequently in the water quality samples. It is likely that the concentrations observed in juvenile salmon reflect recirculation of DDT that entered the environment some time ago. Although DDT was measured in hatchery fish food, hatchery feed appears to be only a minor contributor to the body burdens of DDT measured in juvenile salmon. Additional study is needed to understand other sources of DDT in the lower river.

Juvenile salmon are exposed to estrogen-like compounds in the lower river.

This study found suspected hormone-disrupting contaminants in water quality samples throughout the lower river and vitellogenin in the blood of juveniles from the Lower Willamette and Confluence sites. Vitellogenin was not detected in salmon samples collected from Warrendale, where the concentrations of most toxic contaminants were relatively low. Again, this suggests the lower river contributes significantly to juvenile salmon toxics exposure.

The specific hormone disruptors that are causing the vitellogenin production in juveniles are unknown. Possibilities include the plasticizer bisphenol A and the synthetic musk HHCB, both of which were detected in water samples collected from the lower Willamette River. In addition, natural and synthetic human hormones, hormones used in animal feedlots, certain DDT compounds that were present in the salmon samples, and other estrogen-like compounds can find their way into the environment and affect fish and wildlife. Several of these contaminants are pharmaceuticals or personal care products that reach the river through wastewater.

Summary

Results of the water quality and salmon sampling confirm toxics such as PCBs, PAHs, DDT, and PBDEs are widespread in the study area and in some cases, concentrations of toxic contaminants are above threshold levels for effects on juvenile salmon growth, sensory abilities, and disease resistance. An important source of toxic contaminants for juvenile salmon is the tidal freshwater portion of the lower river, between Portland and Beaver Army Terminal, where salmon are exposed to toxics in part through diet. Genetic analysis showed juvenile salmon from a variety of stocks—including Snake River, Upper Columbia, and Middle Columbia stocks—use the tidal freshwater area for rearing and feeding, and these fish are accumulating toxics during their time in the lower river. Juvenile salmon also showed evidence of exposure to hormone disruptors, which could be explained by the presence of PBDEs, bisphenol A, HHCB, and other estrogen-like compounds detected in the water and sediment of the lower river.

Water Quality and Salmon Sampling Summary

Beaver Army Terminal

- Highest PCBs in salmon
- Lowest lipid content

Point Adams

- PBDEs on sediment
- Low PAHs in salmon
- Largest fish, with highest lipid content

Columbia City

- Highest PAHs in salmon stomach contents

Confluence

- Vitellogenin detected

All Sites

- Pesticides and wastewater compounds in the water
- DDTs in salmon and stomach contents
- PCBs and PAHs in SPMDs, salmon, and stomach contents
- PBDEs on sediment, in SPMDs, and in salmon and stomach contents

Lower Willamette

- Pesticides frequently detected in water
- High PBDEs in SPMDs and salmon bodies
- Low DDTs in salmon bodies
- High PAHs in salmon bile
- Vitellogenin detected

Warrendale

- Lowest PCBs and PBDEs on sediment and in SPMDs
- Lowest PCBs in salmon
- Low PAHs, DDTs, and PBDEs in salmon

Next Steps

The Ecosystem Monitoring Project has provided new data on juvenile salmon exposure to toxic contaminants in the lower Columbia River and estuary. Results of the water quality and salmon sampling have added to our understanding of which toxics are present in the lower river, their distribution, juvenile salmon exposure levels, some of the sources of that exposure, and which salmon stocks are affected by toxics in the lower river. Research found the presence of emerging contaminants such as PBDEs and wastewater compounds, which appear to be ubiquitous in the lower river. The results of the Ecosystem Monitoring Project suggest several steps to improve scientific understanding of toxics in the lower river and help reduce their impact over the long term.

Conduct long-term monitoring of toxics in the lower river.

Individual studies have answered some questions about the effects of toxics on salmon in the lower river, but many important questions about where and how fish and wildlife are being exposed remain unanswered. Comprehensive, long-term monitoring comparable in scope to the Lower Columbia River Bi-State Water Quality Program is needed to better understand existing conditions in the lower river, fill data gaps, and identify appropriate toxics reduction and contaminant cleanup actions. Most importantly, long-term sustained monitoring is needed to establish trends in contaminant levels and locations, to better understand where to direct funds and target toxic reduction efforts, and to determine the effectiveness of reduction actions over time.

Continue monitoring emerging contaminants, such as PBDEs and wastewater compounds, including pharmaceuticals and personal care products.

Emerging contaminants are pervasive in the lower river, yet they are poorly understood. Some of them are affecting juvenile salmon endocrine systems, as evidenced by the presence of vitellogenin in blood samples. There is an ongoing need for better detection methods for emerging contaminants; increased understanding of their sources, pathways of exposure, and impacts; and exploration of possible management actions to reduce exposure by salmon, other fish and wildlife, and people.

Support implementation of toxics reduction actions.

Some toxics reduction programs are already in place. These include the Washington Department of Agriculture’s pesticide take-back program, Clark County’s pharmaceuticals take-back program, the Superfund cleanup of Portland Harbor, the Oregon Department of Environmental Quality’s Pesticide Stewardship Partnerships, and Oregon’s Clean Marina program, which encourages marinas to use best management practices to prevent spills and protect water quality. These programs can be expanded to help prevent toxics from entering streams and rivers. However, these are initial steps and additional, more comprehensive reduction actions will likely be necessary.

Incorporate existing information about toxics into habitat restoration planning.

Many habitat restoration projects involve reconnecting waterways and allowing juvenile salmon to access historical habitat cut off by dikes or poorly functioning culverts. If contaminant levels in the reconnected areas are high, habitat restoration can increase juveniles' exposure to toxics, possibly to harmful levels. The potential for increased exposure to toxic contaminants should always be considered as habitat restoration projects are planned.

Fill specific data gaps.

The Ecosystem Monitoring Project raised questions about the following topics, which should be explored as part of additional, long-term monitoring efforts.

- **Toxics in the tidal freshwater portion of the lower river.** Juvenile salmon are taking up considerable amounts of toxic contaminants in the most industrialized areas of the lower river, from Portland to below Longview. Which habitats juvenile salmon are using in this area and how juveniles are being exposed is unclear. Better understanding of contaminant uptake in the tidal freshwater portion of the lower river would assist in planning cleanup and source reduction actions.
- **Pathways of exposure.** Juvenile salmon in the lower river are absorbing toxics from the prey they eat, but diet is just one possible pathway of exposure. More information is needed about whether juveniles are being exposed primarily through water, sediment, or prey; how exposure pathways may differ for different toxics; and whether toxics are entering the lower river through air deposition, direct discharge to rivers or streams, stormwater runoff, groundwater, migration of contaminated organisms into the lower river, or other mechanisms. This information would provide insight into possible sources of contamination.
- **Source identification.** The Ecosystem Monitoring Project did not identify sources of toxics in the lower river; understanding sources will be important in selecting management actions to reduce juveniles' exposure. Which actions prove most effective—regulation, voluntary actions such as drug and pesticide take-back programs and best management practices, cleanup of contaminant hot spots, or other actions—will depend on where toxics in the lower river are originating and how they are reaching juvenile salmon.
- **Toxics in prey.** Diet is a source of exposure to toxics for juvenile salmon in the lower river, yet little information is available on which prey species juveniles are consuming and how their diet changes as they age and move down the river to the estuary and ocean. Obviously, different toxics reduction measures would be suggested if juveniles' dietary exposures were occurring mostly from terrestrial insects that fall into the water rather than from aquatic organisms that are picking up toxics from the water and sediment. Correlating information on prey species with vegetation monitoring and juveniles' use of different habitats could point to particular contaminated sites in the lower river where cleanup would benefit juvenile salmon and their prey.

- **Combined effects of toxics and other stressors.** Exposure to toxics in the lower river and the stress associated with dam passage leaves juveniles more susceptible to disease and results in increased mortality (Loge et al. 2005). This shows how toxics can combine with other stressors to reduce numbers of juvenile salmon, presumably by altering their immune function, growth and development, and sensory abilities. Studying the combined effects of toxics and other stressors in the lower river could help quantify how much indirect mortality is resulting from juveniles' exposure to toxics and how serious a problem toxics actually are to species recovery.
- **Toxics in the middle and upper Columbia and major tributaries.** Although juveniles from upriver stocks are acquiring much of their contaminant load during residency in the lower river, they already have PCBs, PAHs, DDT, and PBDEs in their bodies when they arrive. More information is needed about contaminant exposures in the middle and upper Columbia River and major tributaries to determine whether contaminant sources in these areas can be reduced.

A Matter of Choice…and Coordinated Effort

Findings in this study demonstrate that juvenile salmon in the lower river are exposed to toxics through normal activities required for survival: ingesting food, resting on or near sediment, moving through the water locally or across long distances. Many of these toxic contaminants are the result of a variety of dispersed human activities: use of pesticides, land use patterns, river alterations, and the personal care products and pharmaceuticals we use. While salmon cannot consciously alter their behavior to avoid short- or long-term exposure to toxic contaminants, we can use human ingenuity to adopt activities, practices or products that are less harmful to salmon and other fish and wildlife in the lower river.

The Estuary Partnership will use the findings of the Ecosystem Monitoring Project as a basis for future monitoring efforts, to identify additional reduction actions, and to secure broader investments in the lower river.

Some changes are already occurring. USEPA recently designated the Columbia River one of the nation's seven Great Water Bodies, recognizing both the Columbia's significance to the nation and its level of degradation. Among other things, this designation means that the Columbia will be the focus of a USEPA Toxics Reduction Strategy. Bonneville Power Administration and the Northwest Power and Conservation Council are expanding their investments in the lower river by supporting additional work in the Ecosystem Monitoring Project. USGS and NOAA Fisheries have added invaluable expertise in measuring toxic contaminants in water and biota, and contributing to an improved understanding of the significance of toxics in the Columbia River ecosystem. Oregon and Washington are increasing their efforts on the water bodies within their state boundaries.

The findings of this study were presented at the USGS and Estuary Partnership conference “Science to Policy: Many Perspectives, One River,” on May 7-9, 2007 where scientists, community leaders, and educators took part in a forum on bridging science and policy needs in the lower river. Such dialog, the findings of this Ecosystem Monitoring Project, and the combined efforts of BPA, USGS, NOAA Fisheries, the Northwest Power and Conservation Council, USEPA, and the States of Oregon and Washington position the lower Columbia River for a level of investment that could result in meaningful reductions in toxic exposure—for salmon, other fish and wildlife, and people.

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Glossary

Additive. Of or relating to a group of toxic contaminants acting together so that their combined toxicity is equal to the sum of the effect of each individual contaminant.

Aldrin. A persistent carcinogenic and mutagenic pesticide that is chemically similar to dieldrin and breaks down into dieldrin; aldrin was banned in the United States in 1987.

Bioaccumulation. The uptake and accumulation of toxic contaminants in tissues, typically through ingestion or direct bodily contact.

Bioavailability. The degree to which a substance can be absorbed into an organism's body.

Bioconcentration. The uptake of waterborne toxic contaminants by an organism. In fish, bioconcentration occurs primarily through the gills.

Biomagnification. The uptake of toxic contaminants via diet, when toxics in tissue residues are passed up through the food web as predators feed on prey. Biomagnification increases tissue concentrations from one level of the food web to the next.

Biota. Living organisms; the plants, animals, fungi, and microorganisms in a given area.

Body burden. The total amount of a chemical—particularly a bioaccumulative toxic—present in an organism at a given time.

Chlordane. A persistent organochlorine pesticide made up of a mixture of related chemicals, such as heptachlor. Chlordane bioaccumulates in fish, wildlife, and humans and is toxic to freshwater fish and invertebrates. Although its use in the United States is banned, it is still manufactured for export.

Chlorinated organic compounds. Chemicals created by heating or burning chlorine-containing compounds in the presence of organic (carbon-containing) materials.

Composite. To combine material from several individual samples; of or relating to a sample created in this way.

Contaminant. A substance that is not naturally present in the environment and that causes adverse effects to the environment, or a naturally occurring substance that is present at concentrations high enough to cause adverse effects to the environment.

Conventional contaminants. Suspended solids, fecal coliform bacteria, biochemical oxygen demand, pH, nutrients, and other water pollutants that are commonly found in stormwater runoff and are well understood by scientists.

DDD. A breakdown product of DDT.

DDE. A breakdown product of DDT.

DDT. Dichloro-diphenyl-trichloroethane; a persistent organic pollutant and probable human carcinogen that was widely used as an insecticide in the United States until it was banned in 1972.

Dieldrin. A persistent, chlorinated insecticide that is toxic to a variety of organisms, including humans; dieldrin was banned in the United States in 1987.

Dioxins and furans. Two classes of persistent, chlorinated organic compounds; dioxins and furans are extremely toxic and are known carcinogens and endocrine disruptors.

Emerging contaminants. Newly recognized contaminants such as pharmaceuticals, personal care products, and flame retardants that enter the environment via municipal, agricultural, and industrial wastewater sources and pathways; emerging contaminants have not been well studied and may act as endocrine disruptors or have other toxic effects, even at low concentrations.

Endocrine disruptor. Exogenous substances that alter the production or action of hormones in the body and thus have the capacity to interfere with growth, reproduction, development, and behavior.

Estrogenic. Of or relating to the female hormone estrogen; acting like estrogen.

Exogenous. Originating outside an organism or system.

Hydrophilic. Able to unite with or absorb water; easily dissolved in water. Hydrophilic compounds tend to remain in solution; although they are easily taken up by organisms, they tend to be less persistent in tissues than hydrophobic compounds.

Hydrophobic. Repelling, tending not to combine with, or incapable of dissolving in water. Hydrophobic compounds typically are associated with suspended sediments or particulate matter in the water column, or with bed sediments; although hydrophobic compounds are less bioavailable than water-soluble compounds, once they are taken up by organisms they tend to concentrate in lipid-rich tissues and may biomagnify through the food web as contaminated organisms are eaten by their predators.

Industrial contaminants. Harmful substances that result from industrial activities and processes.

Insecticide. A chemical that is used to kill, repel, or prevent the growth of insects.

Legacy pesticides. Pesticides that are still found in the environment in spite of the fact that their production, distribution, or use has been banned in the United States.

Lindane. A chlorinated hydrocarbon used as an insecticide and pharmaceutical; also known as γ-hexachlorocyclohexane (HCH). Lindane is a suspected carcinogen and acutely toxic to salmonids and their prey.

Lipids. Fats or fat-like compounds.

Lipophilic. Having an affinity for fat.

Mutagenic. Causing mutations.

National Stream Quality Accounting Network (NASQAN). A national water quality monitoring program by the U.S. Geological Survey that provides ongoing characterization of the concentrations and flux of sediment and chemicals in the nation's largest rivers.

National Water Quality Assessment (NAWQA) Program. A U.S. Geological Survey program that investigates the spatial extent of water quality, how water quality changes with time, and how human activities and natural factors affect water quality in 50 major U.S. river basins and aquifer systems.

Nonpoint source. A diffuse source of pollution that does not have a single point of origin; examples include agricultural lands, timberland, cities and towns, construction sites, dams, mines, and other areas where overland runoff can carry pollutants to streams and rivers.

Ocean-type. Of or relating to salmonids that enter the estuary as fry or fingerlings and stay in the estuary for weeks or months before entering the ocean; examples are chum and subyearling Chinook.

Olfactory function. A fish's sense of smell, which influences its ability to find prey, avoid predators, home, and reproduce.

Organochlorine pesticides. Pesticides (such as DDT, chlordane, aldrin, dieldrin, and lindane) that contain chlorine.

Organophosphate pesticides. Pesticides (such as chlorpyrifos, diazinon, and malathion) that contain phosphorus.

Otolith. A small bone in the ear that can be examined to reveal a fish's age.

Persistence. The ability of a chemical substance to remain in an environment in an unchanged form; used to describe compounds that accumulate (in water, soil, sediment, or tissue) and do not easily degrade.

Pesticide. Chemicals that are used to eliminate organisms that interfere with human activities and are considered pests. Pesticides include insecticides, which are toxic to insects; fungicides, which are toxic to fungi; and herbicides, which are weed killers.

Plasticizer. Additives that soften plastics or other materials so that they are more flexible. Phthalates and bisphenol A are common plasticizers.

Plume. The layer of Columbia River water in the nearshore Pacific Ocean.

Point source. A discrete, identifiable source of pollution from a single point of conveyance, such as a discharge pipe.

Polybrominated diphenyl ethers (PBDEs). Persistent, man-made, bromine-based chemicals used as flame retardants in electronics, building materials, seat cushions, and clothing; PBDEs are similar toxicologically to PCBs.

Polychlorinated biphenyls (PCBs). Synthetic chlorinated, aromatic compounds that are toxic but have been widely used in industrial and consumer applications because they are stable and nonflammable; the manufacture of PCBs was banned in the United States in 1979.

Polycyclic aromatic hydrocarbons (PAHs). Persistent, widespread organic pollutants that exist in petroleum products such as gasoline and diesel fuel or are created through the incomplete combustion of carbon-containing materials, such as coal, wood, fat, and tobacco.

Prey base. The major types of food organisms that are eaten by an animal.

Salmonid. Any member of the family Salmonidae, which includes the salmon, trout, char, whitefish, and grayling of North America.

Semipermeable membrane devices (SPMDs). A long, flat, plastic tube containing oil that is designed to mimic the parts of animals where toxic contaminants bioconcentrate. The special plastic of the SPMD allows toxic contaminants to pass through, like membranes of animal cells. The oil inside is similar to a highly purified fish fat. The toxic contaminants dissolve in this oil just as they do in the fats of a fish.

Smoltification. The physiological process that allows anadromous fish to adapt to a saltwater environment.

Stream-type. Of or relating to salmonids that rear in freshwater for a year or more before entering the ocean.

Sublethal effects. Effects that do not cause mortality directly but that reduce an organism's health, fitness, sensory abilities, or reproduction, particularly if that reduction contributes to indirect mortality via predation, disease, parasites, exhaustion, or starvation.

Surfactants. Wetting agents used in detergents, fabric softeners, and emulsifiers; as carriers for pesticides; and in various other products. Alkylphenols are common surfactants.

Synergistic. Of or relating to a group of toxic contaminants acting together so that their combined toxicity is greater than the sum of the effect of each individual contaminant.

Threshold level. The concentration of a toxic contaminant in the physical environment or in biota above which the contaminant is harmful to an organism.

Toxic contaminants/Toxics. Substances that cause death, disease, birth defects, or other health problems or impairments in organisms that ingest, inhale, or absorb them.

Trace elements. Naturally occurring chemical elements that are usually found at very low concentrations in rocks, soil, and water; although biota need minimum amounts of some trace elements for healthy growth, trace elements also can be toxic, even at low concentrations.

Vitellogenin. An estrogen-induced yolk protein that is normally found only in females with developing eggs; measurements of vitellogenin in the blood of male and juvenile salmonids provide information on exposure to estrogenic compounds.

Wastewater compounds. Pharmaceuticals, personal care products, and similar compounds that enter the waterways through septic tanks and treated or untreated wastewater; includes hormones and antibiotics for use in humans and animals and industrial byproducts.

Lower Columbia River Estuary Partnership

The lower Columbia River and estuary was designated an "Estuary of National Significance" in 1995, one of only 28 in the nation to receive the distinction. The National Estuary Program was authorized in the 1987 amendments to the Clean Water Act and is administered by the US Environmental Protection Agency (USEPA). Its purpose is to protect nationally significant estuaries that have been degraded by human activity.

Using a watershed approach, the Estuary Partnership works across political boundaries with 28 cities, nine counties, 38 school districts and the states of Oregon and Washington over an area that stretches 146 miles from Bonneville Dam to the Pacific Ocean. The Estuary Partnership is a public-private 501(C)(3) non-profit corporation with a Board of Directors representing the diverse interests and geography of the lower river. The Estuary Partnership is the leading two state entity working with the private sector and local, state, federal, and tribal governments to address issues in the lower Columbia River.

Lower
Columbia
River Estuary
Partnership

The Estuary Partnership Goals Are:

- Protect the ecosystem and species-restoring 16,000 acres of wetlands and habitat by 2010 and promoting improvements in stormwater management.
- Reduce toxic and conventional pollution-conducting long term monitoring and advocating to eliminate persistent bioaccumulative toxics, bringing water bodies up to water quality standards, reduce hydrocarbon and heavy metal discharges and reduce bacterial contamination.
- Provide information about the river to a range of audiences- providing applied learning programs for children and building federal, state, local, public and private coordination.

USEPA, the States of Oregon and Washington, NOAA Fisheries, USGS, Bonneville Power Administration, hundreds of individual citizens and over 55 corporations and foundations are key participants and provide support to the Estuary Partnership.

The Lower Columbia River Estuary Partnership monitors water quality, sediment, fish, wildlife, and habitat in the lower Columbia River and estuary. Ecosystem monitoring is a key element of the Estuary Partnership's Comprehensive Conservation and Management Plan. Action 28 of its Management Plan calls for the Estuary Partnership, with its partners, to implement sustained long term monitoring in the lower river to assess trends and define actions to reduce and eliminate contaminants. The Estuary Partnership developed a long term monitoring strategy in 1999 as part of the Management Plan. Members from many different natural resources disciplines comprise the Estuary Partnership Science Work Group which guides implementation of the monitoring strategy. The strategy establishes sustained monitoring to assess trends impacting public and ecosystem health; expands understanding of current conditions, fills existing data gaps, identifies areas where toxics may be accumulating, assesses the sources of these contaminants, and evaluates effectiveness of toxics reduction projects over time. The monitoring strategy advances knowledge about the river and directs Estuary Partnership on-the-ground toxics reduction and pollution prevention projects, including its current focus on expanding existing drug take back programs and pesticide collection sites and initiating precision pesticide application to remove and reduce toxics.

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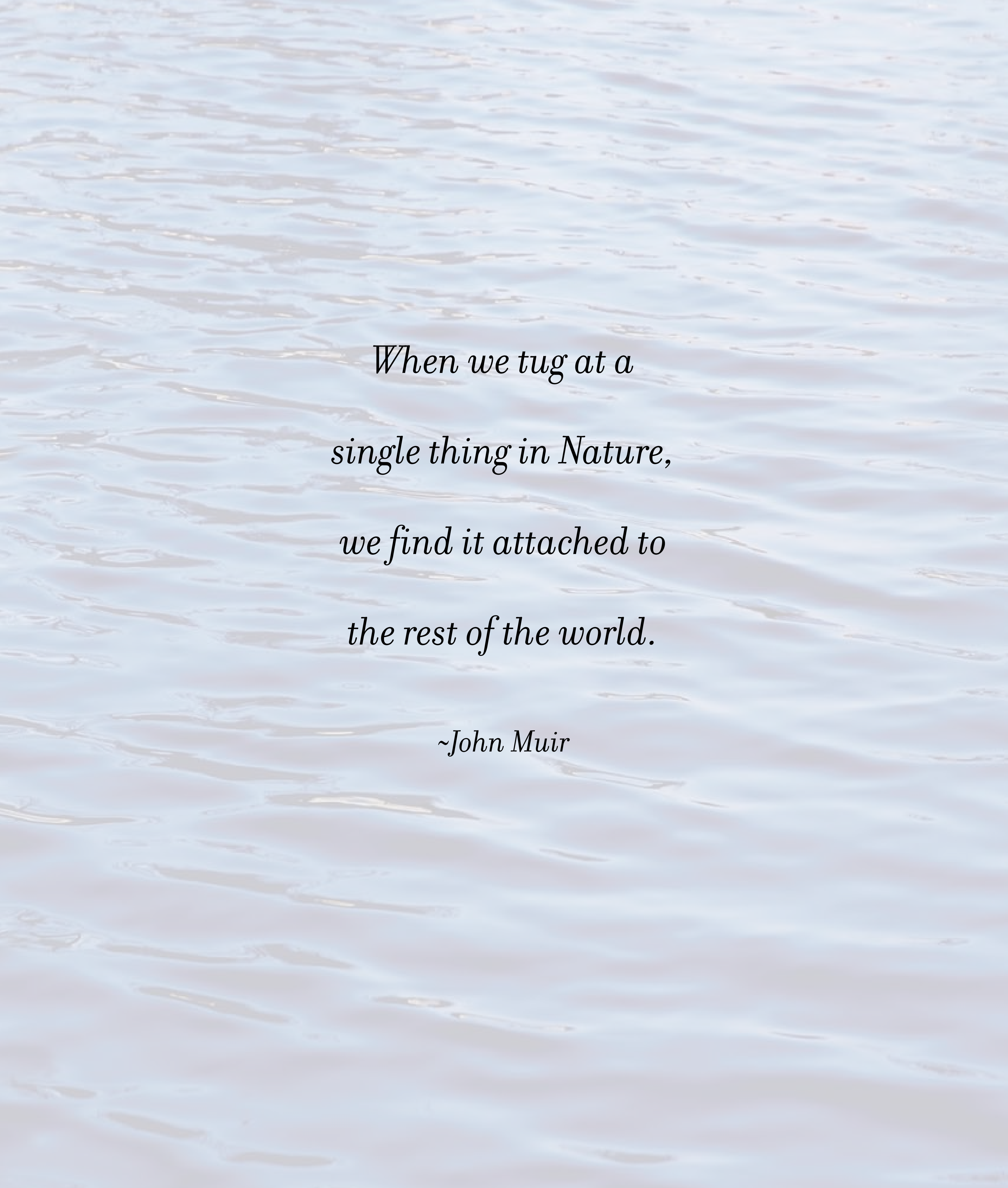


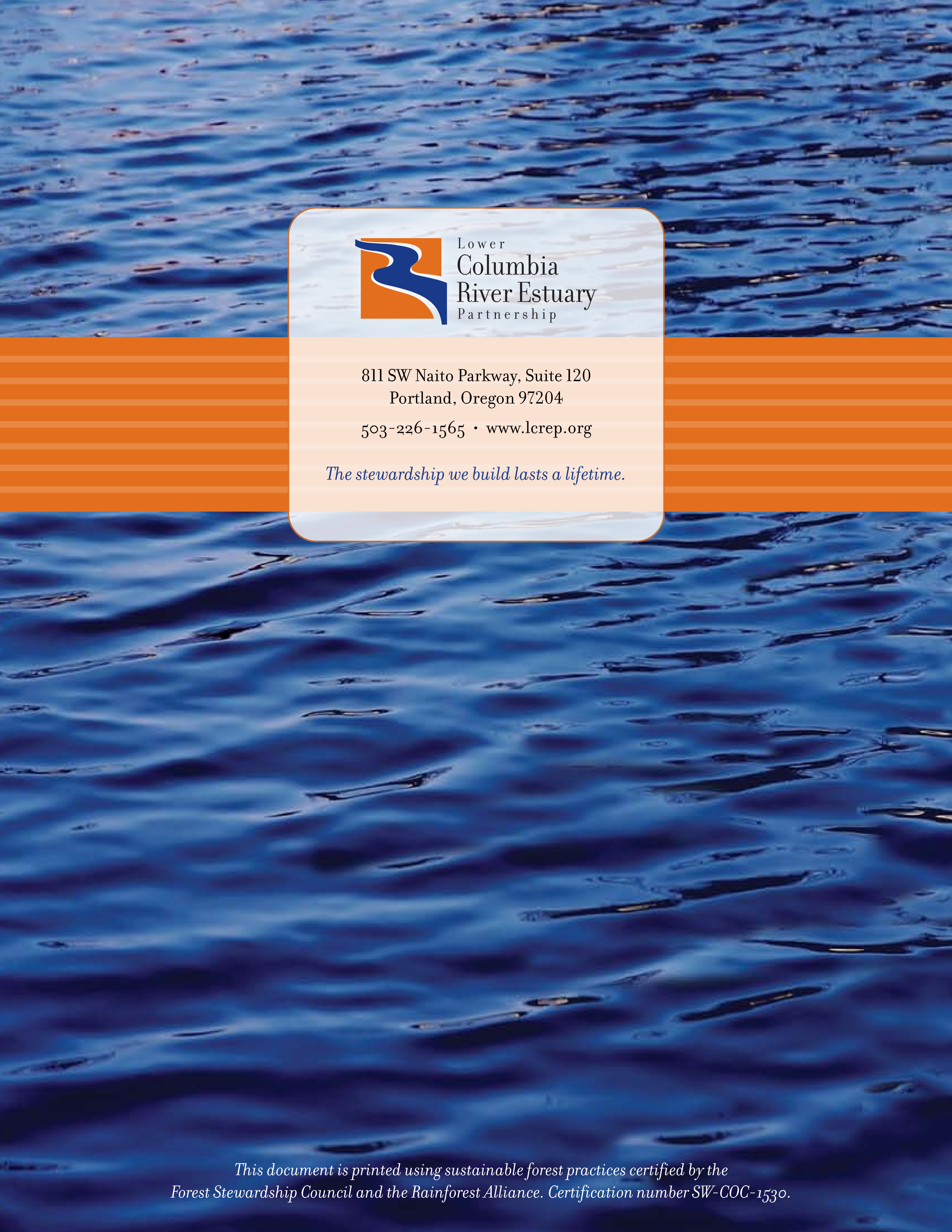
When we tug at a

single thing in Nature,

we find it attached to

the rest of the world.

~John Muir



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The stewardship we build lasts a lifetime.

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