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Ecological Characterization of the Lower Willamette River through Portland

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Report Preface

The Bureau of Environmental Services' (BES) Watershed Services Group has been working on an ecological characterization of the lower Willamette River to support a number of river planning efforts at BES and other bureaus, including the Bureau of Planning and Sustainability's (BPS) South Reach Plan. This full characterization report is organized around the four *Portland Watershed Management Plan* (City of Portland 2005) goals for hydrology, habitat, water quality, and biological communities and expands on the information compiled in a previous memo.

The habitat and biological sections of the characterization were completed and submitted as addenda to the Central City Plan in 2016. This report includes updates to the sections on habitat and biological communities, as well as new sections on hydrology and water quality to provide a more complete ecological characterization of the lower Willamette River through Portland.

Ecological Characterization of the Lower Willamette River through Portland

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1 Landscape setting

The lower Willamette River through Portland marks the confluence of the 13th largest river in the country[1] with the fourth largest river in the country. Many of the ecological properties and economic importance of this location are due to the juncture of these two large river basins. In many ways the lower Willamette – the reaches from Willamette Falls to the mouth – is defined by and distinct because of the proximity and influence of the Columbia River. The Missoula Floods that coursed down the Columbia River over 10,000 years ago scoured many of the morphological features that still define the structure of the lower Willamette River channel and surrounding areas, and its hydrology is daily and seasonally influenced by flows from the upper Columbia Basin, and the tidal effects transmitted from the coast.

The lower Willamette River is quite different in nature from the rest of the Willamette Basin above it. Just below the Falls and in the southern section of the South Reach, the river is naturally incised into steep bedrock walls that confine the narrow channel. The floodplain is very narrow or nearly non-existent, and the river reaches some of its greatest natural depths through this section (over 100 feet). However, as the Willamette approaches the Central Reach, landform constraints become less severe, the channel widens and, by the North Reach, conditions become increasingly influenced by the Columbia River. Historically the reduced landform constraints allowed the formation of floodplains and off-channel habitats, with large off-channel lakes such as Guilds, Doane, and Ramsey lakes. In particular, the Columbia Slough and Sauvie Island formed a large floodplain wetland complex near the confluence that provided high quality and extensive habitat for large numbers and types of biota at this ecological crossroads. For salmon, wildlife, and Native Americans, this segment was a historical gateway for one of the greatest salmon runs in the world. For birds, it is part of the Pacific flyway from north to south, and a key corridor between the coast and the interior of the Columbia Basin. For early settlements all along the river, the Willamette afforded transportation opportunities for both people and goods that contributed to the growth and prosperity of the basin over time.

The majority of the lower Willamette is in the Willamette Valley ecoregion (Figure 1). Thorson et al. (2003) describe this ecoregion as typically containing terraces and floodplains, scattered hills, buttes, and adjacent foothills. Historically, it was covered by prairies, oak savanna, coniferous forests, extensive wetlands, and deciduous riparian forests. The western bank of the lower Willamette is formed by the Tualatin Mountains, which are in the Coast Range ecoregion. This was historically a mosaic of western red cedar, western hemlock, and seral Douglas-fir blanketed inland areas of the Coast Range ecoregion (Thorson et al 2003).

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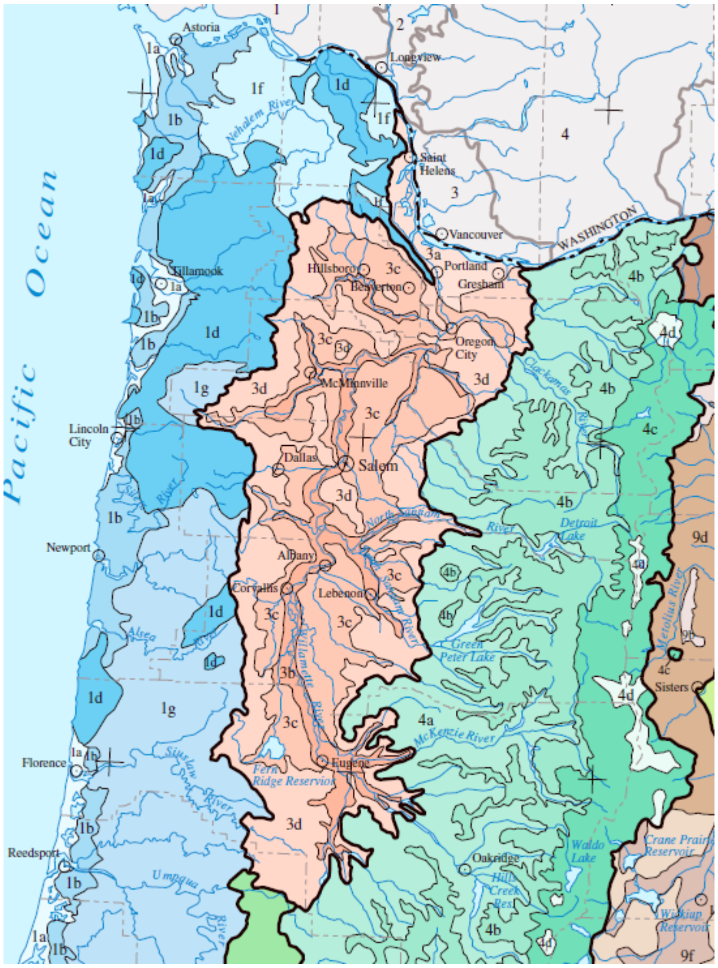
[1] The river is the 13th largest in the conterminous United States in terms of discharge and is the largest of all major United States rivers in terms of discharge per square mile of drainage area (Uhrich and Wentz 1999).

Figure 1: Ecoregions of the Willamette Valley. From Thorson et al. 2003.



1.1 Climate

Uhrich and Wentz (1999) describe the climate for the overall Willamette Basin, summarizing that the proximity to the Pacific Ocean and exposure to prevailing westerly winds produce cool, wet winters and warm, dry summers. In the lower Willamette area, winter is characterized by mild temperatures, cloudy skies, and rain. Freezing temperatures are rare. Spring is transitional: starting damp and cool in March, and turning more dry and warm after May, though overcast skies are common. Summer arrives in early July, when dry, warm afternoon highs in the 80s occur regularly. By early to mid- October, fall arrives with temperatures back into the 60s. As the night hours progress, the valley cools, and fog forms on clear nights.

Precipitation falls mostly as rain, with an average of only four days per year recording measurable snow. Nearly 90 percent of the annual rainfall occurs between mid-October and mid-May, and about 3 percent occurs in July and August, though this is variable across the area (NOAA 2010 pgs. 1 – 3). Destructive storms are rare, though thunderstorms can occur during any month. Thunderstorms in the winter and spring are weak; however, those in summer can produce lightning, strong winds and large hail.

1.2 Geologic History

The geologic history of the lower Willamette River is as fascinating and violent as any place on Earth. Like many coasts bordering a subduction zone, the Willamette Valley was created by the piling up of ocean volcanoes as the Juan de Fuca plate slid beneath the growing Pacific coastline around 35 million years ago (MYA). Tectonic folding and uplift further helped create a valley separated from the coast and Eastern Oregon.

Around 14 – 17 MYA, massive lava flows began to emerge from fissures across the landscape of eastern Washington, Idaho and Oregon. The lava flowed down the ancestral Columbia River to the coast, and in the process laid a thick basalt layer from Portland to Salem. This created Willamette Falls, and in so doing created a lower river much different in character from the basin above it.

The lower Willamette River was then repeatedly reshaped by a series of floods that are estimated to be the second largest floods ever to occur on Earth (O' Connor and Costa 2004). Madin (2009) describes the Missoula Floods:

> "Toward the end of the last ice age, the Portland Basin, Tualatin Basin, and Willamette Valley were swept by repeated colossal glacial outburst floods called Bretz, Missoula, or Ice Age Floods. These catastrophic events occurred between ca. 23–15 thousand years ago and dramatically reshaped the landscape of the Portland area. The outburst floods ended while sea level was still at its glacial low stand, so the Columbia and Willamette rivers in the Portland Basin flowed through canyons graded to that lower sea level. During the Holocene sea level rise, the canyons rapidly filled with alluvium to their current level, and the water surface of the Columbia and lower Willamette River are just at sea level today."[2]

The Missoula Floods burst out of the highly constrained Columbia River Gorge landscape and fanned across east Portland. The original landscape of east Portland was obliterated and reshaped; many of these flood features are still obvious today. Alameda Ridge is an enormous gravel bar that deposited behind Rocky Butte. Sullivan's Gulch – down which highways, light and heavy rail travel – is a remnant Missoula Flood channel.

One of the most transformative events for the lower Willamette channel – and indeed for the entire Willamette Basin – came when the flood waters carrying ice, sediment, trees and bus-sized boulders, slammed into the resistant Tualatin Mountains that were nearly perpendicular to its path. Given the northwest angle of the West Hills, more than half of the flood likely deflected and followed the Columbia's abrupt northward turn at Portland. Flow backed up at the narrows at Kalama, WA, and forced the flood over Willamette Falls to fill the Willamette Valley and create temporary Lake Allison. The fertile soil from the plains of eastern Washington settled and was deposited in the Willamette Valley over the course of dozens of Missoula Floods.

Many other geologic events are important to the lower Willamette's landscape. These include the formation and eruption of the Boring Lava Domes that formed Rocky and Powell buttes and Mt. Tabor, and the transport of wind-blown soils from eastern Washington that deposited throughout the West Hills draining to the river. These are described fully in Madin (2009).

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[2] http://www.geosociety.org/meetings/2009/SelfGuideFieldTrip.pdf

2 Hydrology

Patterns of flow in the Willamette River are critical to the ecological processes that shape the structure and function of the river and its floodplain. Daily, seasonal, and annual variations in flow affect:

- channel structure;
- substrate composition;
- the extent and composition of the floodplain;
- groundwater dynamics;
- the fate and transport of contaminants, nutrients, sediments, organic matter, and other materials;
- the composition of plant and animal communities, through effects on their distribution, behavior and physiology.

King County (Fuerstenberg 2003 and Cassin et al. 2003) provide an extensive review of the literature and a conceptual framework on the types of flow alterations and their effects on diverse aspects of ecological health.

2.1 Flow in the Lower Willamette River through Portland

Flow in the lower Willamette River is determined by a complex and dynamic set of factors. Portland is situated at the confluence of the Columbia River—the fourth largest river in the U.S. by discharge (Kammerer 1990)—with its second largest tributary, the Willamette River. Factors that influence flow in these two large river systems range across landscapes from the Rockies to the Pacific and from Canada to southern Oregon and Nevada, and cumulatively play a role in determining local patterns of flow.

Physically, the two rivers are located at a transitional point on a geomorphologically diverse landscape. The Columbia River abruptly changes from a highly constrained channel with minimal floodplain within the Columbia Gorge to an unconfined channel within a broad alluvial valley as it flows towards Portland. The Willamette River undergoes a similar transition, from a highly constrained channel within deep bedrock walls below Willamette Falls to a wider, less constrained channel as it hits the city boundary. The topographic constraints on both rivers open up considerably as they flow through Portland, and in particular the floodplain at the confluence was historically large, encompassing the entirety of Sauvie Island and the Columbia Slough (PNERC 2002). The joining of the two rivers also creates the largest secondary channel in the entire Willamette Basin when Multnomah Channel diverts from the mainstem 3.1 miles from the mouth. The Multnomah Channel carves a smaller meandering 21-mile channel between Sauvie Island and the Tualatin Mountains, creating a large deltaic island.

This combination of large rivers interacting, dynamic geomorphology within a transitional landscape, and tidal effects transmitted up the Columbia River from the ocean create some of the most complex hydrology in the Willamette Basin. Some of the basic patterns of flow in the lower Willamette, the major factors that shape these patterns, and the changes that have occurred over time in these patterns are described below.

The characteristics of flow in the lower Willamette River are determined by three major factors:

- Riverine flow from the Willamette River above Portland, determined by the cumulative contributions of flow from groundwater, tributaries, and rivers throughout the basin above it,
- Riverine and tidal flow in the Columbia River, and
- Local physical conditions in the channel, floodplains, tributaries and groundwater.

These factors are described below.

2.2 Flow in the Willamette River above Portland

Patterns of river flow in the Willamette Basin above Portland strongly reflect seasonal variation in precipitation. The basin experiences temperate marine climate with dry summers and wet winters. In the winter, warm moist air from the ocean tends to collide with cold continental air masses producing frequent rains and heavy snow packs in the Cascades. Mean annual precipitation within the basin increases with elevation, ranging from around 40-50 inches per year in the valley to almost 150 inches near the crests of the Coast and Cascade Ranges (PNERC 2002). Approximately 70–80 percent of precipitation falls between October and March; less than 5 percent in July and August (Figure 2).

This pattern is reflected in river flows from the upper basin into the lower Willamette River. Flows at Salem, used here as an indicator of upper basin flow patterns[3], show a sharp rise in the daily mean flows from October to December over the period of record as wet winter weather sets in (Figure 3). Daily mean flows tend to be highest between late November and January, then show a steady gradual decline from February to August. August typically exhibits the lowest average flows over the period of record, with flows gradually increasing in late August through September. Over the period from Oct. 1972 to Sept. 2000, the average flow at Salem was 22,729 cubic feet per second (cfs). The maximum measured flow over the entire period of record was 342,000 cfs on January 8, 1923; the minimum recorded flow was 2,480 cfs on August 8, 1940.

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[3] Salem is the USGS flow gauge furthest downstream in the upper basin with a substantial period of record (1909 – present). Eighty percent of the flow in the entire Willamette Basin originates upstream of Salem (Peter Klingeman, 2001; "Hydrology of the Willamette River and Impacts of Reservoirs"; presented at the Willamette River Watershed Conference).

Figure 2: Variation in monthly rainfall across the Willamette Basin. Based on PRISM 30-year monthly normals for precipitation (http://prism.oregonstate.edu/normals/).

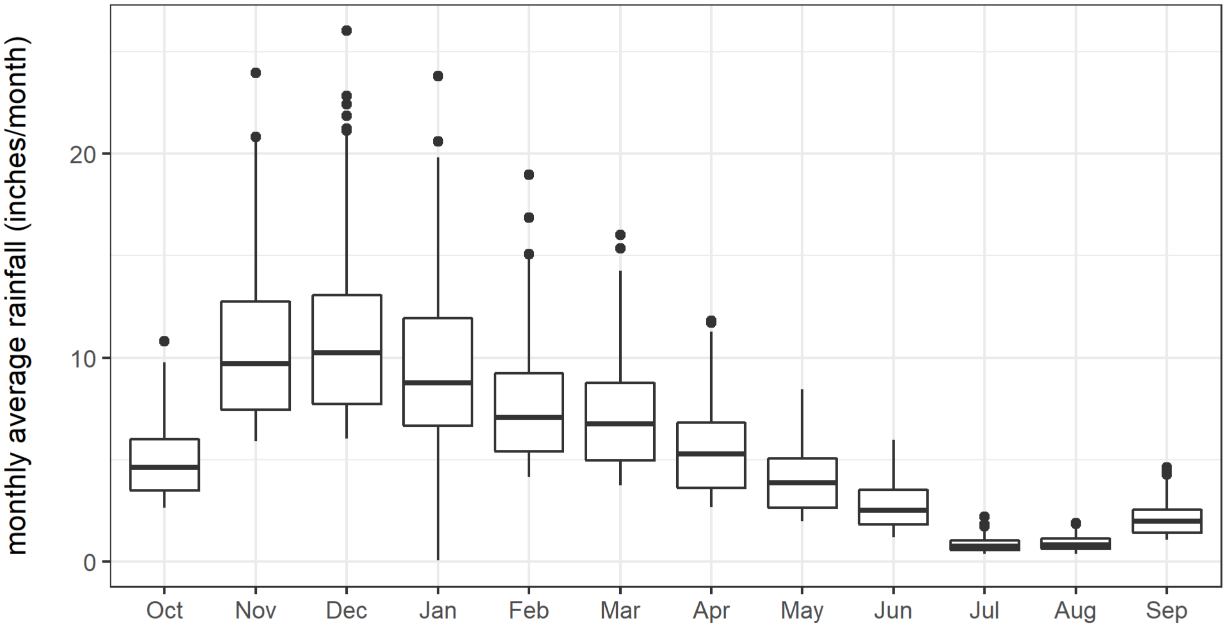
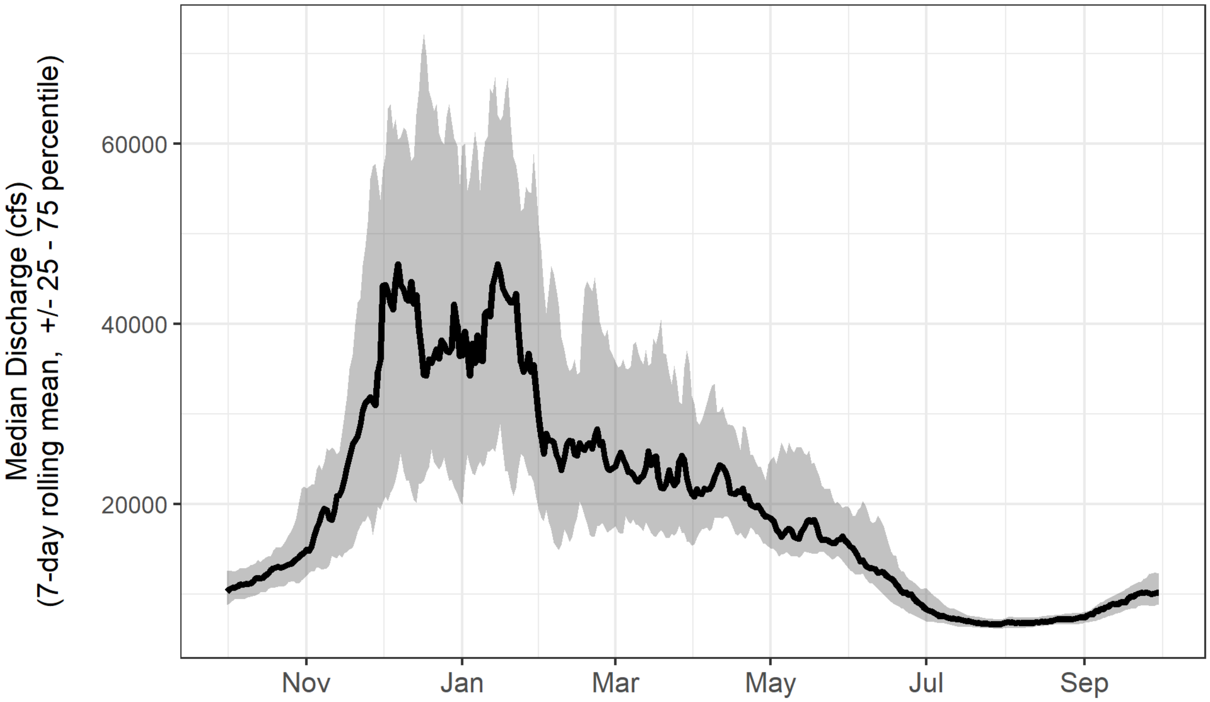


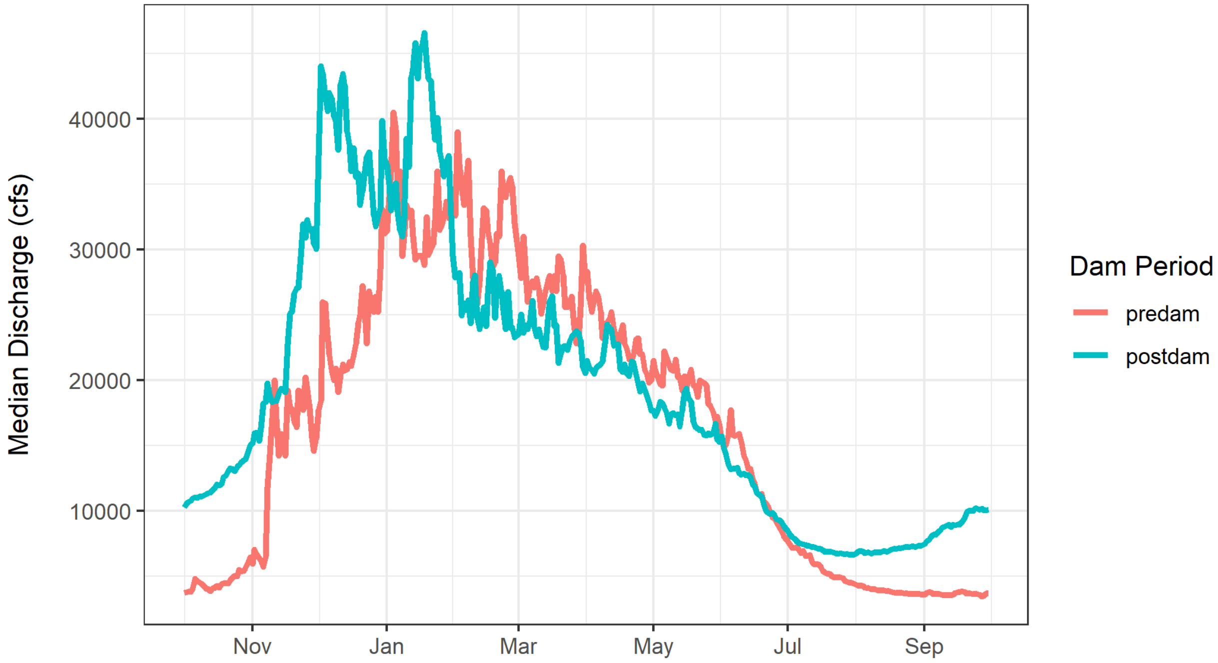
Figure 3: Annual hydrograph for the Willamette River at Salem. The black line is the median 7-day rolling mean flow, from Oct. 1972 to Nov. 2019 (the period of record at the Portland gauge, to allow comparison of the same time period), at the USGS Salem gauge (gauge #14191000). The rolling mean is intended to reduce the peakiness of the curve from short term individual high events, and capture flow conditions typical of that time of year. The grey area indicates the interquartile range (25th–75th percentile) in flow for that date.



Seasonal flow patterns in the Willamette Basin have changed due to the construction of dams and water management practices. Dam construction began in 1894 when the City of Portland constructed the first dams in the Willamette Basin for water supply purposes. The Willamette River basin has 11 major reservoirs with a combined capacity of 1.9 million acre-feet (Laenen and Risley 1995). The largest of these is Lookout Point on the middle fork of the Willamette River near Lowell with a storage capacity of 477,700 acre-feet. In total, there are 371 dams with a storage capacity of 2.7 million acres throughout the basin (PNERC 2002). The majority of dams and the largest reservoirs were constructed in the period between 1942 and 1969 (PNERC 2002, Gregory et al. 2019). The presence and operations of these dams has had a major effect on flow patterns in the upper basin flowing into Portland.

The effect of dams on flow patterns can be evaluated by comparing the "pre-dam" years (1909-1941) to "post-dam" (1968-present) years of record. Two of the larger differences between the pre- and post-dam periods are in the rising limb of the hydrograph and in the summer low flow period. Historically prior to dams the hydrograph started its increase in November and rose somewhat gradually compared to the post-dam period, reaching its maximum in early January (Figure 4). In the post-dam period, the rising limb starts a bit earlier in October and rises more rapidly, reaching a peak near the beginning of December. The descending limb of the hydrograph during the pre-dam period was somewhat higher than the post-dam period, meaning that late winter to early summer flows were somewhat higher before dams, but for both periods the rate of descent was roughly similar.

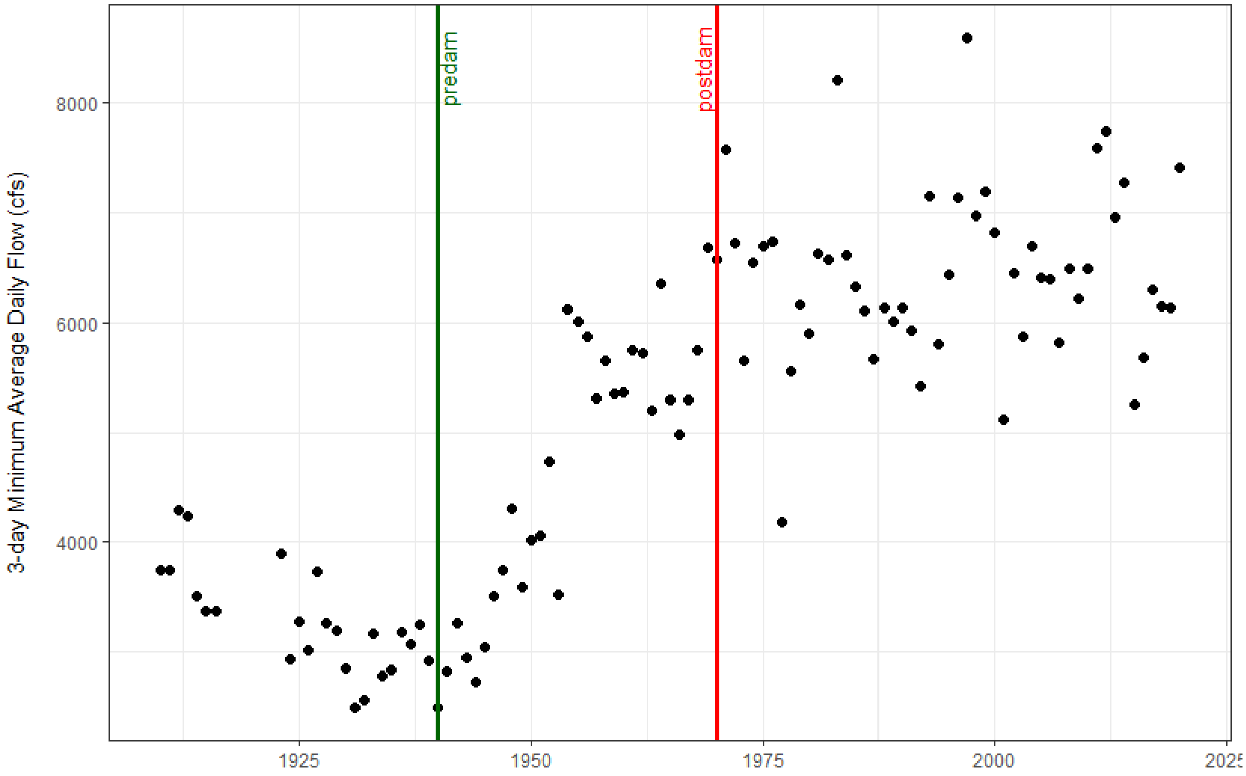
Figure 4: Comparison of the median of daily mean flow at Salem in the "pre-dam" (1909-1941) and "post-dam" (1968-present) periods. Source USGS gauge #14191000.



One of the most dramatic changes evident from this comparison is the markedly higher flows in the post-dam period during the summer low flow period. In the pre-dam period, the summer low flow period was marked by gradual decreases in flow until reaching a low in August. The lowest flows occurred from August to the end of September, with mean flows around 3,750 cfs during this period. Summer low flows during the post-dam period are much higher, occur earlier, and for a shorter period of time. Post-dam summer low flows begin around the middle of July and start to increase at the beginning of September. Mean low flow during this time is 6,933 cfs. Differences in the pre- and post-dam summer low flow periods are different enough that their interquartile ranges—the 25th to 75th percentile flows for that period—do not overlap: pre-dam low flows had an interquartile range of 3,335 to 4,454 cfs; the post-dam range is 6,391-7,639 cfs.

The marked change in summer low flows are best illustrated by plotting the annual 3-day minimum flow over time (Figure 5). Prior to dam construction, 3-day low flows were typically below 4,000 cfs (with two exceptions). As dam construction began, summer low flows began to rise dramatically, and by the beginning of the post-dam period summer low flows were typically above 5,000 cfs (with one exception).

Figure 5: The 3-day annual minimum flow over time at Salem. Source USGS gauge #14191000.

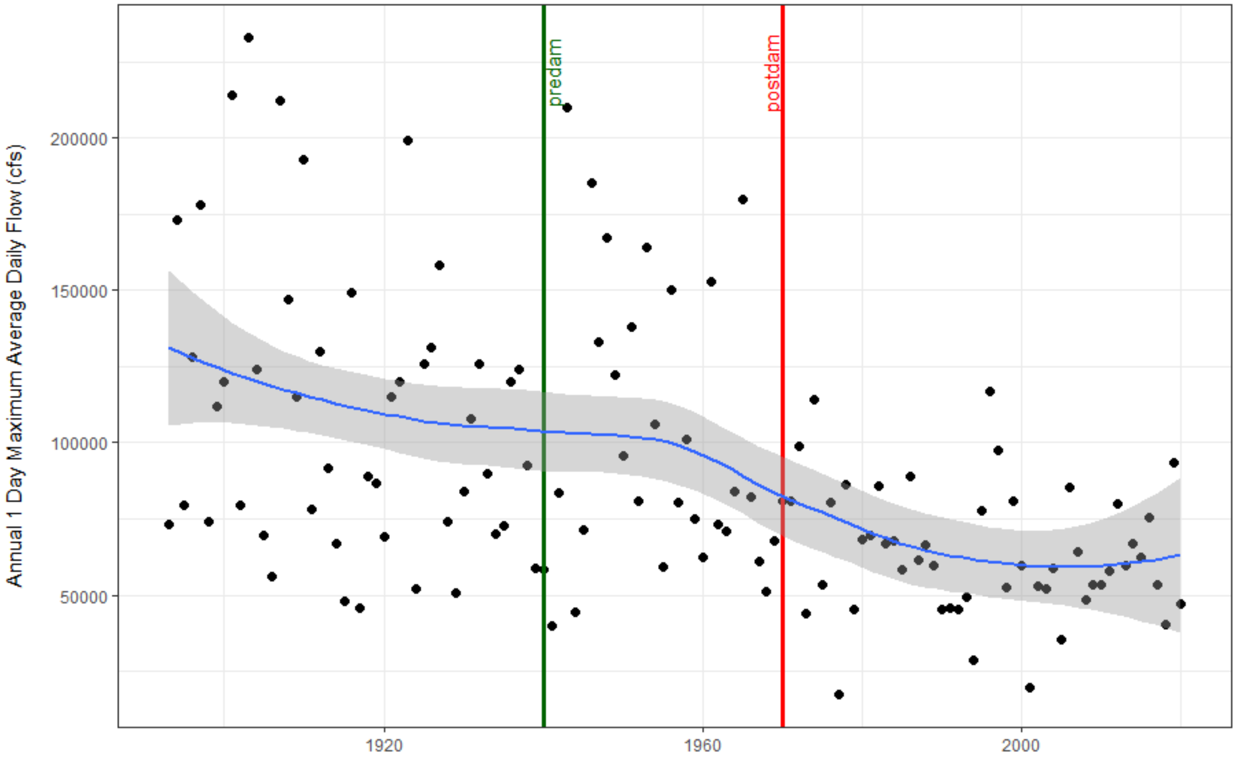


Another important change between pre-and post-dam periods is the reduction in peak flows. Dams have sharply reduced the peaks of large episodic floods that occurred during winter and spring prior to their construction. Data from the Albany gauge are most effective in showing changes in high flows, since the Albany period of record goes back to 1893 and the three largest floods and half of the ten largest floods occurred before the Salem gauge began operating in 1909. Gregory et al. (2019) used data from this gauge to document the changes in high flows due to the dams:

> "Of the 69 floods that would have exceeded the regulatory flood level after 1969, sixty did not reach flood stage… A historical unregulated flow with 10-year recurrence probability had a discharge of 5,600 m^3/s, but the same discharge has a 100-year recurrence probability after dam construction. The current regulated 2-year return flood discharge (1,980 m^3/s) is 40% lower than the historical unregulated 2-year return flood." (pg. 4)

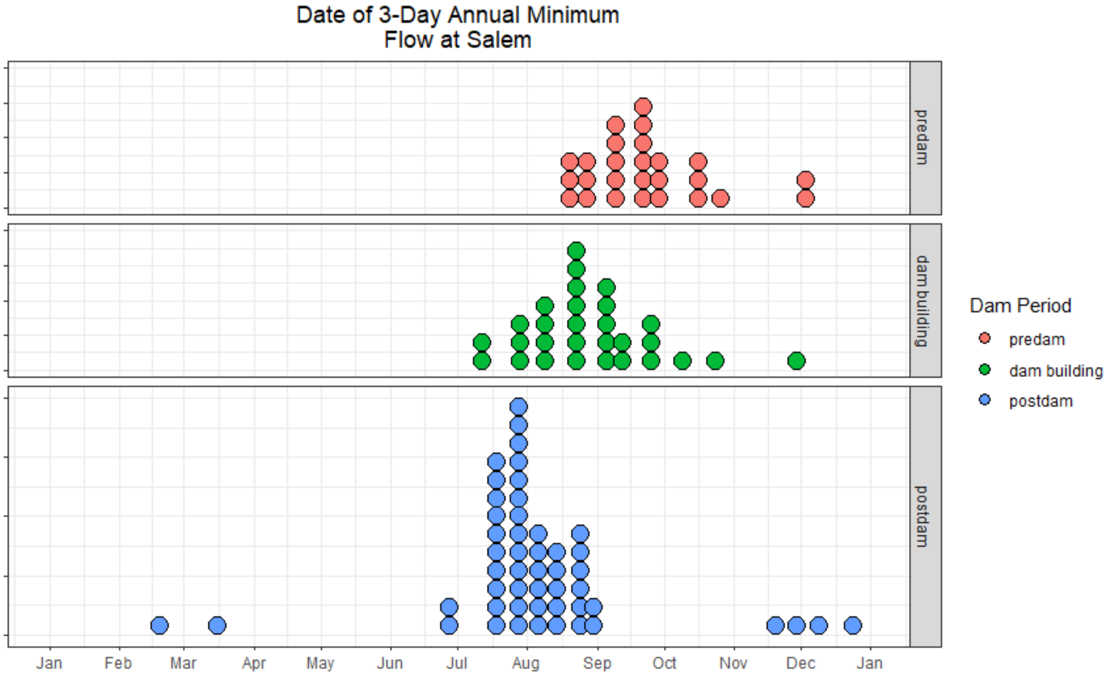
Figure 6 provides another illustration of these changes. Prior to the beginning of dam construction, 22 out of 48 years had 3-day maximum average daily flows above 100,000 cfs; only two out of 50 years had flows above that level after construction of the dams. Sixteen floods with flows above 125,000 cfs occurred before and during the construction of the dams, whereas no flood higher than 103,500 cfs occurred after dam construction.

Figure 6: Annual 3-Day maximum flows at the Albany gauge. The blue line is a loess fit to the data; the grey band is the standard error for the loess fit. Source: USGS gauge #14174000



As described earlier, the timing of the summer low flow has changed as well. In the pre-dam period 3-day minimum flows at Salem typically occurred from mid-August through September (Figure 7). During dam construction this began shifting earlier, and by the post-dam period the minimum flows typically occurred from mid-July through August.

Figure 7: The date of the 3-day average minimum flow at Salem in the pre-dam, dam building and post-dam periods. Source USGS gauge #14191000.



Taken together, these changes in high and low flows mean that the seasonal variability of flow within a year has been reduced. The average annual coefficient of variation (the standard deviation of flow for that year divided by the average flow for the year) has significantly decreased between the pre- and post-dam periods: the pre-dam median annual coefficient of variation was 1.02, the post-dam is 0.86, and the 25th percentile post-dam coefficient (0.96) is greater than the 75th percentile post-dam coefficient (0.93).

2.3 Flow in the Columbia River

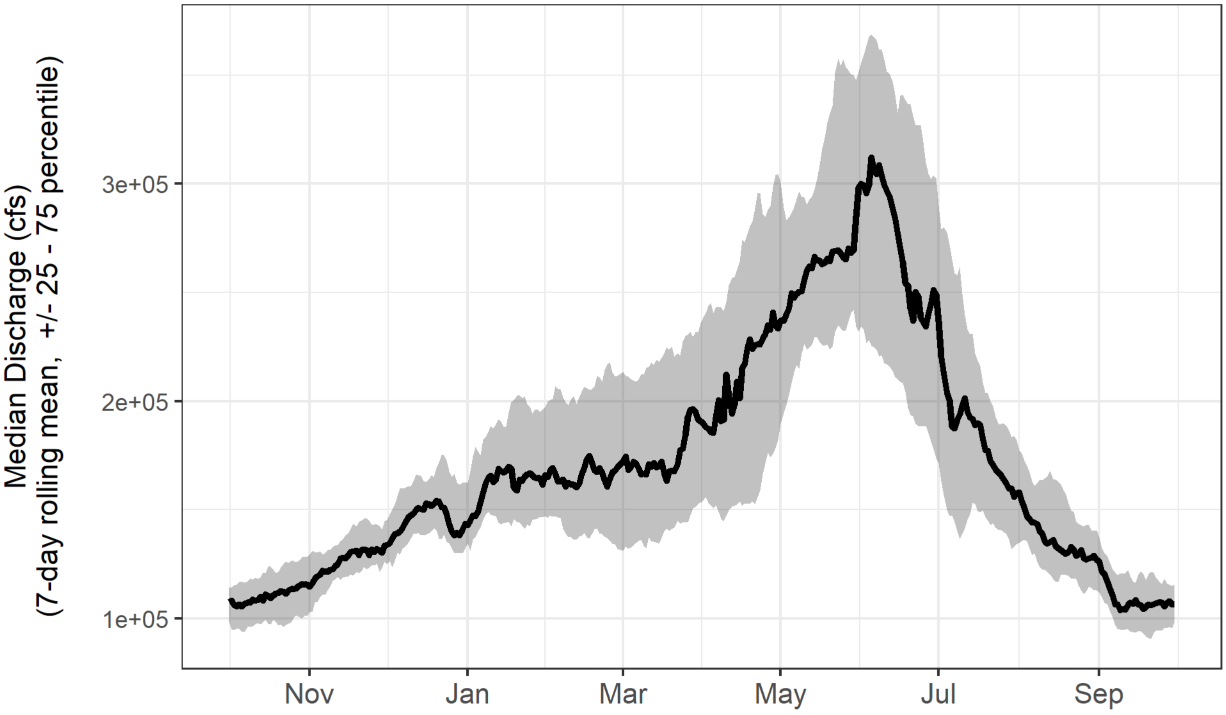
The second major factor affecting flow in the lower Willamette River through Portland is the pattern of flow in the Lower Columbia River. The Lower Columbia River essentially determines the baseline water level of the lower Willamette River. When water levels in the Lower Columbia River are higher than in the lower Willamette—typically during the Columbia's spring and early summer freshets—the lower Willamette will stop or even reverse flow as water levels equilibrate. When water levels are higher in the lower Willamette, backwater effects are reduced. Flow conditions in the Lower Columbia River therefore have a very strong influence on water levels, flow directions and velocity in the lower Willamette River. The Columbia River is also the pathway by which tidal flows are transmitted from the Columbia River estuary to the Willamette River. Lee and Risley (2002), who identify four major sections of the Willamette River, classify the reach below Willamette Falls as the tidal reach, and describe it as largely controlled by backwater from the Columbia River.

High flows occur later in the water year in the snowmelt-driven Columbia River than they do in the rainfall-driven Willamette River. Whereas flows in the Willamette River rapidly increase from November to December, Lower Columbia River flows increase more gradually, with steepest rises in flow from April to June. This is due to spring snowmelt runoff from the Cascade and Rocky

Mountain Ranges to tributaries of the upper and middle Columbia. The period of maximum flows is much shorter and more peaked than in the Willamette. Columbia River flows drop rapidly from peak flows in June to the period of lowest average flow during September through November. In addition to their mismatched periods of high flow, the hydrographs in the Willamette and Columbia are skewed to opposite sides of the water year: the most rapid changes in Willamette flow are the fall increases from November to December; in the Columbia the most rapid changes are the summer decreases from June to September.

Sixty percent of the flow in the Columbia River occurs between May and July. The average annual flow at the Dalles[4] is 177,900 cfs. A maximum flow of 1,230,000 cfs was recorded on June 6,1894. Eighteen ninety-four was one of the wettest years on record and flows throughout June of 1894 were high, as the 17 highest flows on record were recorded in late May and June of 1894. A minimum flow of 36,000 cfs was recorded on January 1937. January of 1937 was the driest month on record; nine of the ten lowest flows over the entire period of record were recorded in this month. This was a dry period caused by prolonged winter cold in the interior (Sherwood et al. 1990).

Figure 8: Annual hydrograph for the Columbia River at The Dalles. The black line is the median 7-day rolling mean flow, from Oct. 1972 – Nov. 2019 (the period of record at the Portland gauge, to allow comparison of the same time period), at the USGS gauge at The Dalles (gauge #14105700).



Like the Willamette River, flow in the Columbia River has undergone a number of dramatic changes over time in response to dam regulation and irrigation withdrawals. Dam building in the Columbia Basin began in 1909. Since then 29 major federal dams, dozens of large non-federal

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[4] The Dalles is the USGS flow gauge furthest downstream in the upper basin with a substantial period of record (1879 – present).

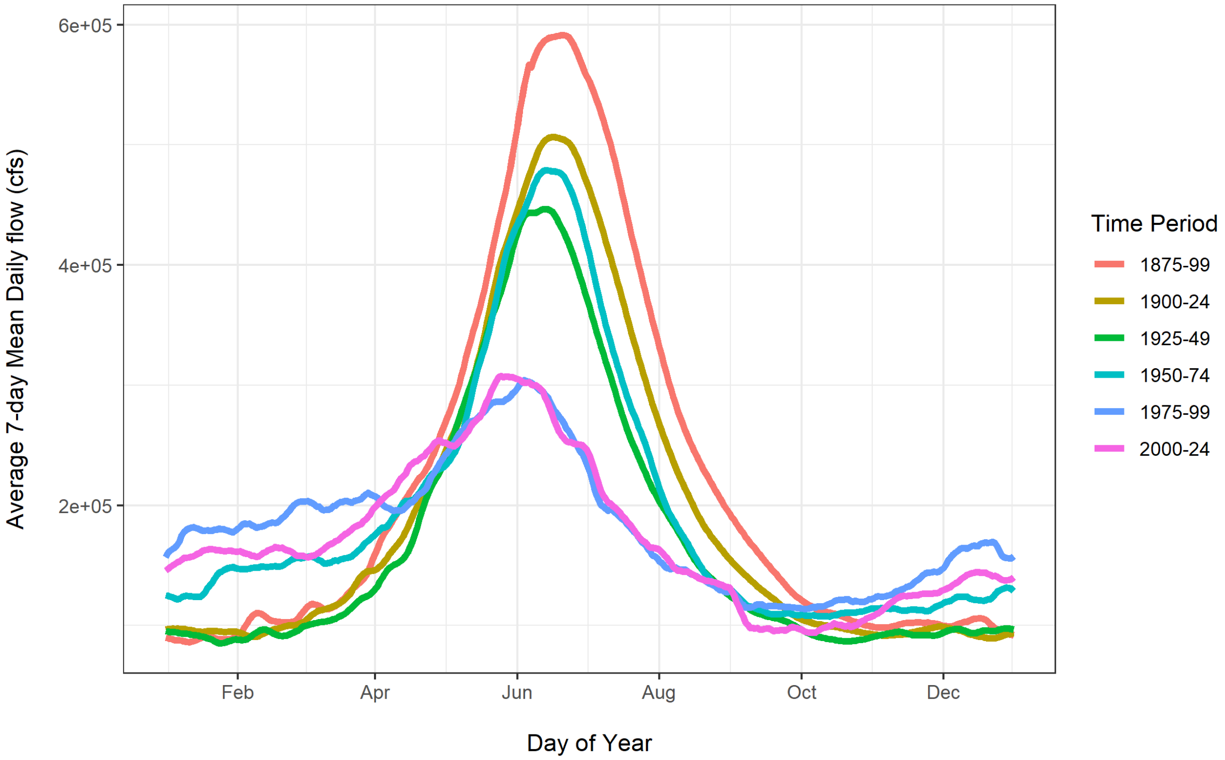
dams, and hundreds of smaller dams have been built (BPA 1991). Much of the dam construction occurred between 1933 and 1982, during which 21 large dams on the Columbia and Snake rivers were built (ISAB 2000). Flow regulation by dams became significant in about 1969; reservoir capacity doubled in the Columbia Basin between 1967 and 1975 (Sherwood et al. 1990).

The management of these dams has resulted in major changes in Columbia River flows, altering seasonal flow patterns. Naik and Jay (2010) note that the average annual Columbia River flow has been reduced by 17% since 1900 due to climate change and water withdrawals.

Flows during spring freshets (from April–July) have decreased by 50-55%, and winter flows (from August–March) have increased by 35% (ISAB 2002). Spring freshets now occur earlier, are of a smaller magnitude, and occur over a longer portion of the year than they did prior to dam regulation. Total annual flows have decreased by 15%, due to a combination of climate variability and irrigation withdrawals.

Some of the changes in the hydrograph over time are depicted in Figure 9. The hydrographs show that the spring-summer peak of the 7-day rolling mean of flows has decreased by almost half over time: from just under 600,000 cfs during the 1875-1899 period, to around 300,000 cfs under the current flow management regime. Seven-day minimum flows have increased from around 85-100,000 cfs in the pre-dam era to around 120-165,000 cfs post-dam. Figure 9 also shows that the biggest changes in low flows came between the 1925-49 and 1950-74 period, whereas the biggest change in high flows came later between the 1950-74 and 1975-99 periods.

Figure 9: Changes in the hydrograph for the Columbia River at The Dalles over time. The y-axis depicts the average for the 7-day running mean of daily flows. The colored lines depict 25-year intervals. Source: USGS gauge #14105700.

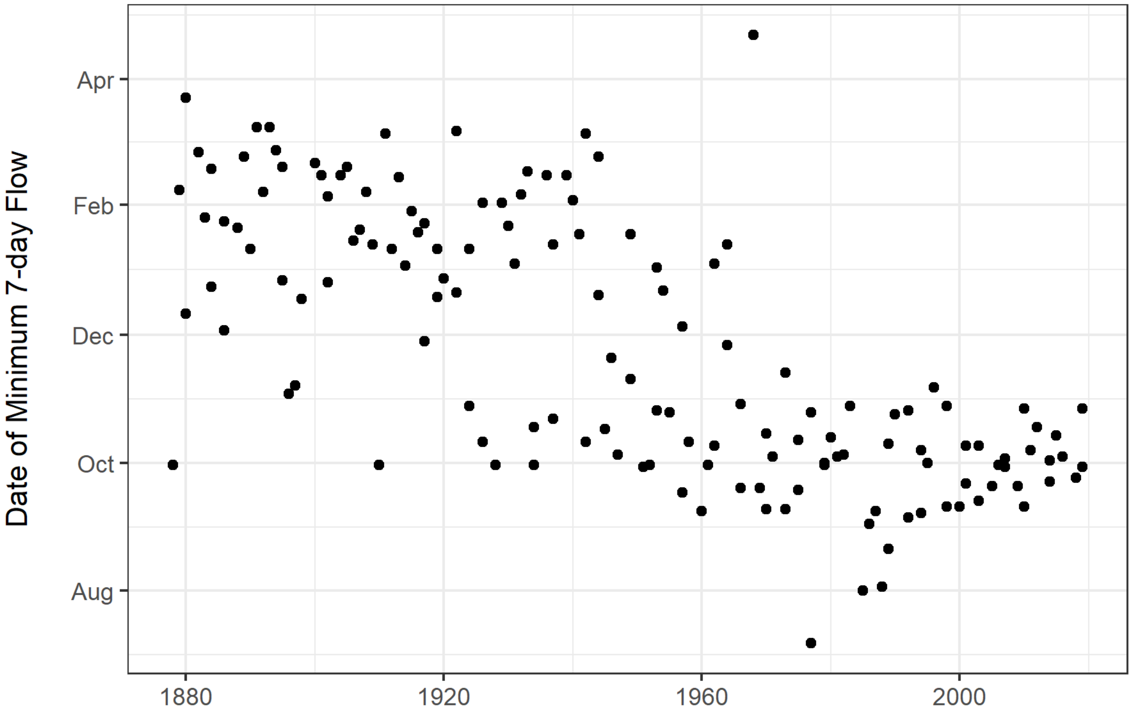


The period of the largest changes in high flows is consistent with the observation of Bottom et al. (2005), who noted that seven large dams high in the basin were completed between 1967 and 1973, and these more than doubled the storage capacity of the total dam system.

There has also been shift in the timing of minimum and maximum annual flows over time. The change in date of the maximum flow has been moderate and gradual: peak flow used to occur across the month of June, with occasional years with peaks in late May or early July. They now occur across the month of May and early June.

Changes in the date of the minimum flow changed more dramatically and suddenly. The date of the annual low flow typically occurred from December–April prior to 1920. From 1920-70 the annual minimum shifted earlier into the fall and currently occurs from September–November under the current flow regime (Figure 10).

Figure 10: Change over time in the date of the annual 7-day minimum flow in the Columbia River at The Dalles. The year on the y-axis has been divided into a July-June year to avoid splitting the year in the middle of the date changes. Source: USGS gauge #14105700.



2.4 Local Physical Conditions

While the larger patterns of flow in the lower Willamette River (e.g., the annual hydrograph, maximum and minimum flows) are determined by basin-wide natural factors such as climate and geology, and human factors such as dam management and irrigation, local conditions within Portland do have a strong and important influence on the way in which a given volume of water flows through this confluence area. The shape of the channel, the composition and configuration of the banks, and the configuration and composition of the floodplain and off-channel habitats all determine critical characteristics such as how frequently a given river flow accesses the floodplain;

the amount, duration, and locations where floodwaters can be stored; the configuration of the low flow channel; and local patterns of velocity, sediment transport, and other hydraulic factors. Beyond just the physical passage and storage of river flows, these factors also determine the nature of the interaction between the river and the floodplain and all the ecological interactions that are dependent on this (e.g., maintaining wetlands, seasonal patterns of vegetative growth, wet season use of floodplain habitats by aquatic species).

The existing conditions in the river channel and floodplain, and the way in which these have been changed from historical conditions is described in detail in the habitat section of this report (Section 3). To summarize, the channel and floodplain in the lower Willamette River have been extensively changed over the last 150 years. The channel has been deepened, narrowed, and simplified; the banks have been hardened and lined. Floodplain and off-channel habitats have been filled and banks steepened throughout the length of the river within Portland. Much of the floodplain storage has been lost over time due to these cumulative actions. Some of that flood storage capacity has been transferred to the main channel through deepening of the channel and steepening of the banks, but this precludes or diminishes many of the valuable ecological functions that occur when high river flows inundate the floodplain (e.g., sediment deposition, groundwater recharge, habitat use by aquatic species; Junk et al. 1989; Regier et al. 1989).

The impact of these physical changes on hydrology is that flow is now largely contained and constrained within the channel. The river currently accesses its floodplain far less frequently than it did historically. The width of the floodplain (PNERC 2002, Prescott et al. 2016), and the role of the floodplain in storing flood flows, has been greatly reduced. The concentration of flows into the main channel has altered the way in which the river accommodates and responds to high flow events. Reduction in the complexity of the channel and its banks and reduced frequency of floodplain interactions affects small-scale patterns of flow, velocity, and river hydraulics; flow is now probably more uniform across the channel because of the lack of structural channel complexity, although there are no historical data to evaluate these changes.

The local tributaries that flow into the lower Willamette River through Portland, and the nature in which the tributaries interact with the mainstem, have also been extensively altered. The discharge of some streams, such as former tributaries to Balch, have been re-routed from the Willamette mainstem to the combined sewer system and into the wastewater treatment plant. The confluences of many other tributaries that drain into this reach have been redirected into culverts or pipes for long sections before discharging into the mainstem (e.g., the Forest Park streams). The magnitude and seasonal distribution of the flows within the tributaries has also changed. Flows in Johnson Creek are now significantly "flashier" (Clark 1999). The Columbia Slough—once an extensive system of floodplain, off channel habitat, streams, lakes, and seasonal wetlands—now has heavily managed flow patterns that are highly altered from their historical condition. Flow in the Slough is controlled by pumping and levees that are maintained to provide flood control and drainage services. The seasonal patterns of flow in the middle and upper Slough are disconnected from the seasonal patterns of the Columbia and Willamette which historically had a large influence on them.

The tremendous changes in physical conditions through this reach have also likely altered the nature of groundwater recharge and discharge: the proliferation of impervious surfaces, vegetation removal, "urbanization" of soils (e.g., compaction, loss of organic matter), loss of wetlands, bank hardening, reduced floodplain connectivity, and other changes along the reach have decreased the ability of water to infiltrate into the soil and recharge groundwater. Reduced recharge coupled with the fact that many of these structures impede historical pathways of groundwater flow would likely result in reduced levels of groundwater discharge to the mainstem.

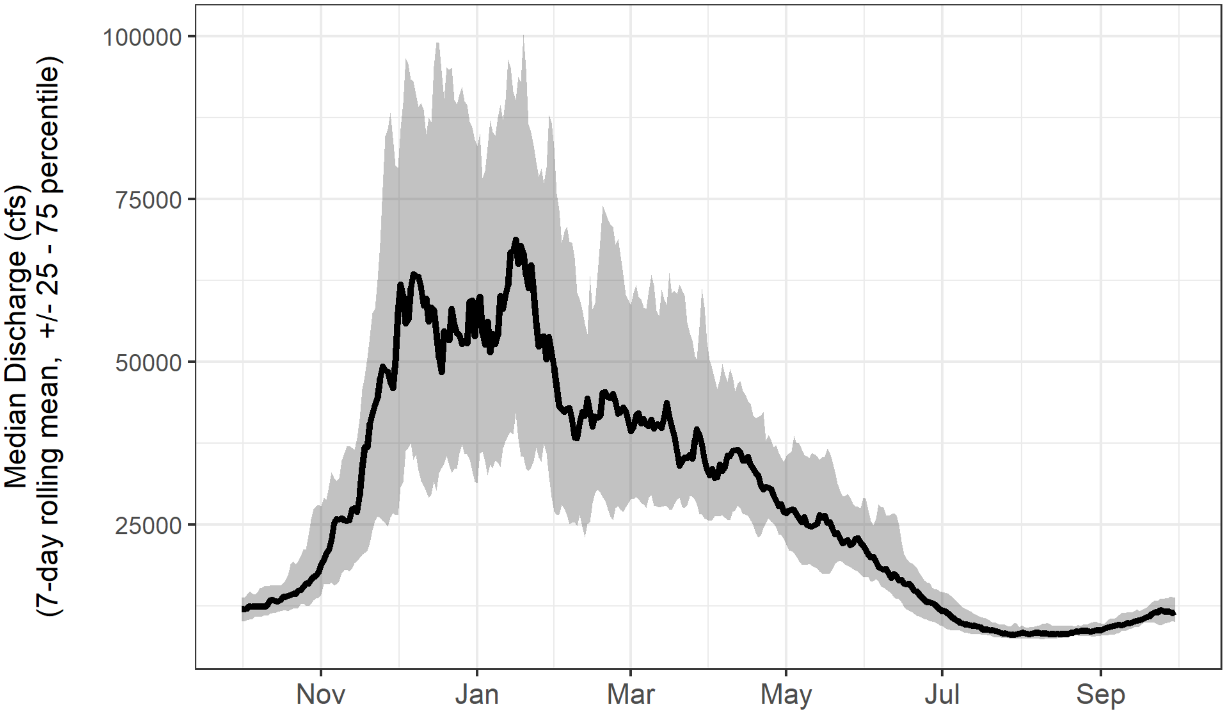
In sum, changes in physical conditions through this reach have altered the interaction between the river and its floodplain, groundwater recharge and discharge, small-scale patterns of flow and velocity, tributary inflows, and the nature of the interaction between the tributaries and the mainstem. Although these changes are not on the same scale as the large-scale changes due to dam management in the Columbia and Willamette rivers, they are nevertheless important components of how water flows through this section of the river and the ecological functions it performs in doing so.

2.5 The Cumulative Result – Flow in the Lower Willamette River at Portland

Patterns of flow in the lower Willamette River reflect the complex cumulative interaction of the three factors previously described: flow from the Willamette Basin, flow from the Columbia River, and local physical conditions in the channel, floodplains, tributaries, and groundwater.

The U.S. Geological Survey (USGS) has measured flow at Portland since 1973. The seasonal patterns of flow are very similar to patterns observed upstream at Salem (Figure 11). Annual minimum flows typically occur in August over the period of record. Average flow gradually increases in September, then rapidly increases from October to December. The highest average flows occur from December to January. Between January and February average flows begin to decrease, although high flows greater than 150,000 cfs can occur any time between late November and March. The maximum flow over the period of record at this gauge occurred on February 9, 1996, when flows reached 420,000 cfs during the flood of 1996. This flood produced the four highest daily average values ever measured in the Willamette River at Portland from February 8–11. The second largest measured flood occurred approximately one year later from Dec 31, 1996 – January 4, 1997, when flows reached a peak of 293,000 cfs on January 2nd. Average flow gradually decreases throughout the spring and summer to the lowest flow averages in August.

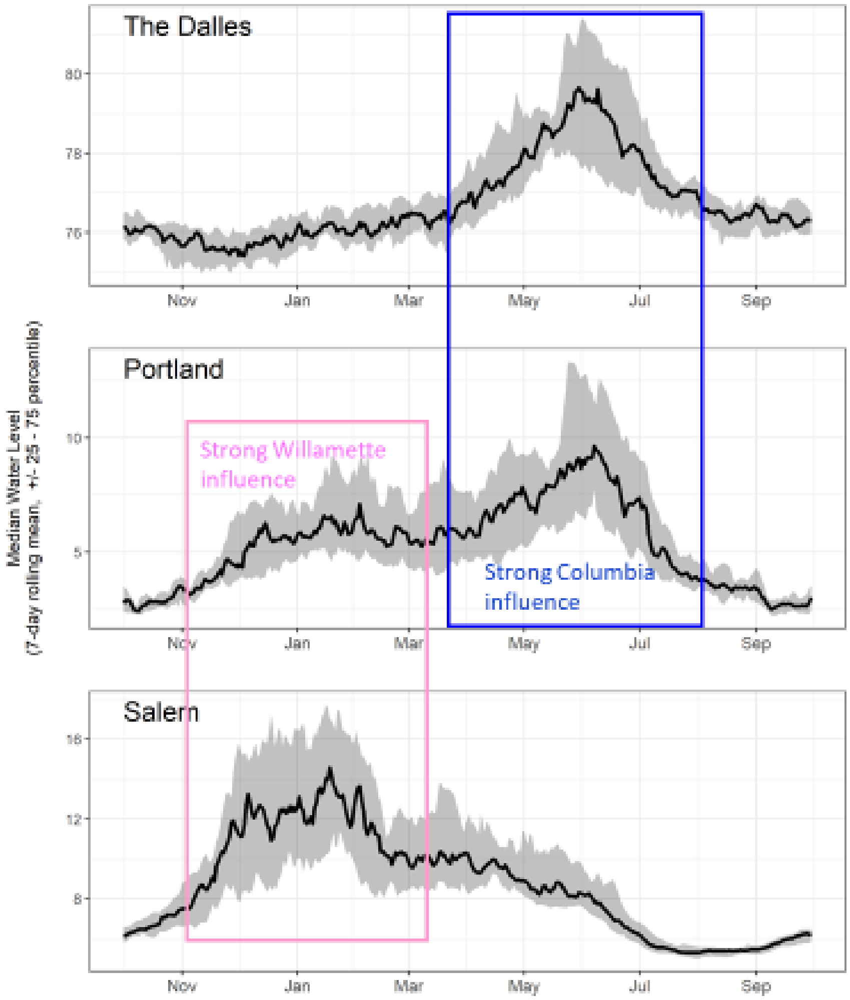
Figure 11: Annual pattern in flow for the lower Willamette River at Portland. The black line is the median 7-day rolling mean flow, from Oct. 1972–Nov. 2019, at the USGS Morrison gauge. The rolling mean is intended to reduce the peakiness of the curve from short term individual high events, and capture flow conditions typical of that time of year. The grey area indicates the interquartile range (25th–75th percentile) in flow for that date. Source: USGS gauge #14211720.



As water flows from the upper basin and reaches Portland, the effects of interactions with the Columbia River become increasingly strong towards the mouth of the Willamette. The seasonal hydrographs of the two river systems are noticeably different. The Columbia River experiences its highest flows in June, and lowest average flows in October–November. The Willamette River experiences highest average flows in December and January, and lowest average flows in August.

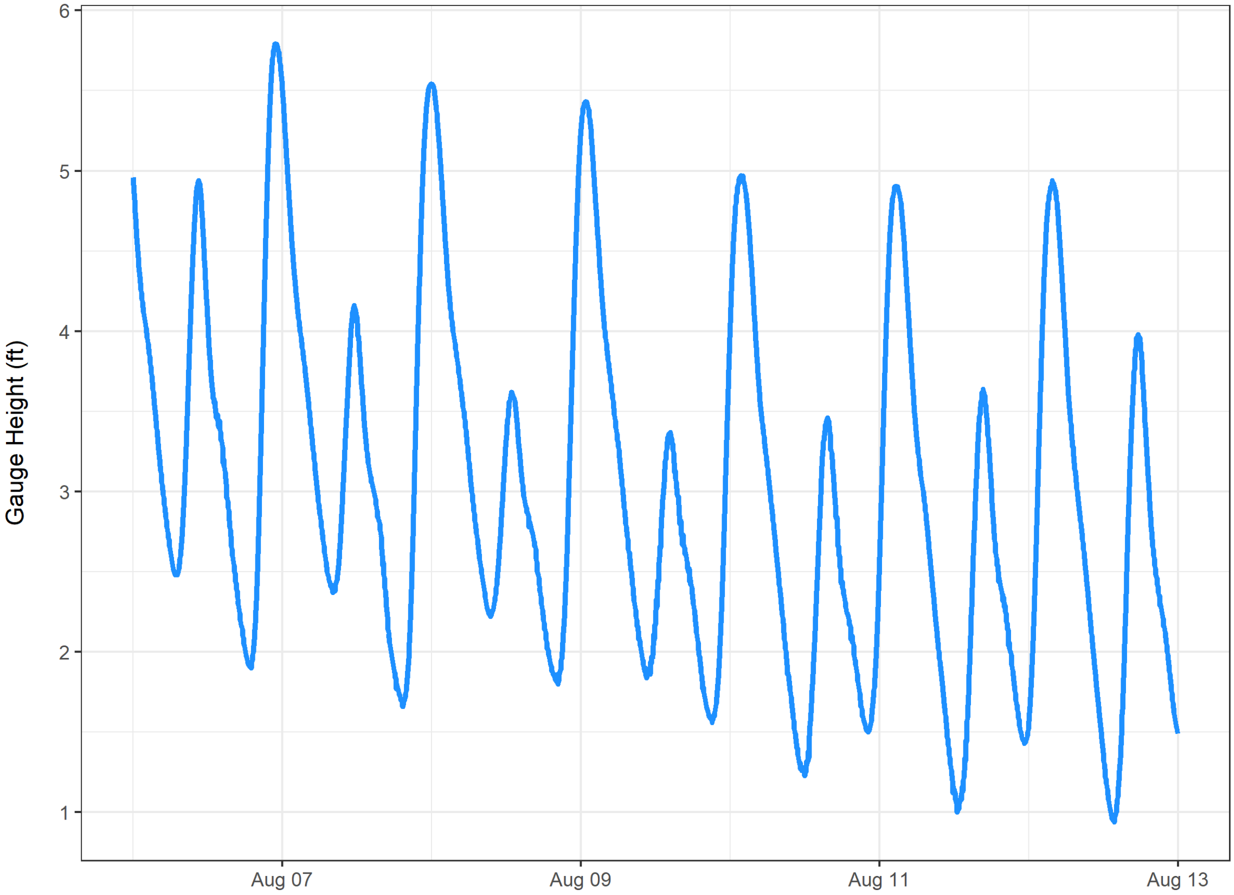
The mismatch in seasonal maxima and minima between the river systems means that the effects of the Columbia River on flow in the lower Willamette River will vary throughout the year. In spring and summer when spring freshets are occurring in the Columbia River system, the level of the Columbia River is likely to be high relative to the Willamette River and backwater effects are typically at their strongest (Figure 12). During these periods a given flow coming from the upper basin will result in higher water levels and lower velocities than the same flow in late fall and winter, when water levels in the Willamette are high relative to the Columbia and backwater effects are at their minimum. Figure 12 also makes it clear that the Columbia River has a larger effect on water levels in Portland than the Willamette: although the flow coming into Portland from the Willamette is highest in December–January, the highest water levels in Portland occur in May-June when the backwater effects from the Columbia River are highest. Water levels in May-June are approximately 75% higher than in December–January when Willamette flows are highest.

Figure 12: Comparison of water levels in the Columbia River at The Dalles, the Willamette River at Salem, and the lower Willamette River at Portland. Source: USGS gauges at Salem, The Dalles, and Portland.



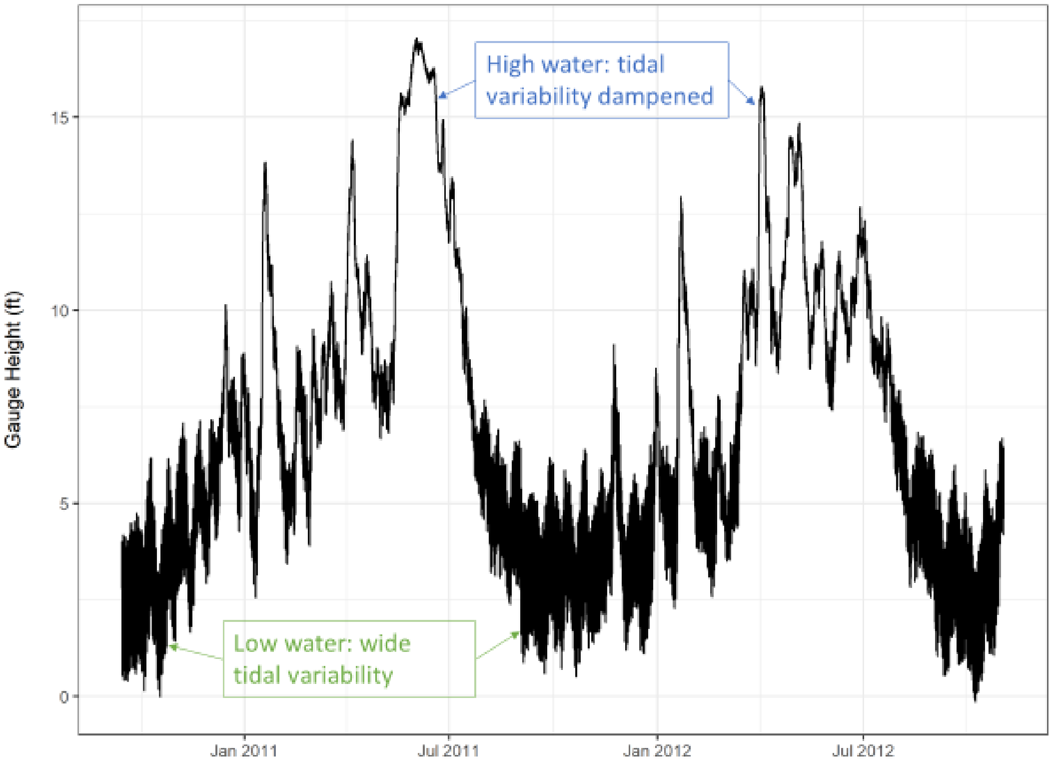
Interaction with the Columbia River is also what produces daily tidal fluctuations in the lower Willamette River. The Columbia River Estuary experiences mixed semi-diurnal tides, meaning that there are two cycles of high and low tides each day but the two high and low tides are of different height, with one cycle having greater tidal range than the other (Figure 13).

Figure 13: Water levels in the lower Willamette River at the Morison Bridge from Aug. 6–12, 2019. The graph shows an example of the mixed semi-diurnal pattern of tides transmitted up the Columbia from the estuary: within a given day the peaks of the two high tides and troughs of the two low tides are of different heights. Source: USGS gauge #14211720.



Tidal range in the lower Willamette River can vary from around 1 to 4 feet depending on the semi-diurnal tidal cycle, the phase of the spring-neap tidal period, and the amount of flow in the Willamette and Columbia rivers. Jay et al. (2015) provide an extensive and detailed account of the dynamics and factors affecting tidal variability in the Columbia and Willamette rivers. They note that tidal range varies inversely with river flow, and the Corps further elaborates that "[t]idal effects are noticed at harbor stages less than 12 feet, and are pronounced at stages less than 5 feet which are common in the summer and fall." (U.S. Army Corps of Engineers 2014) pg. 4). This is illustrated in Figure 14.

Figure 14: Water levels in the lower Willamette River from winter 2010-11 to fall 2012. Tidal variability is highest during low water periods and dampened during high water in the Columbia or Willamette rivers. Source: USGS gauge # 14211720.



Although flow reversals do not occur in the Columbia River as far upstream as the Willamette River confluence, tidal effects do alter velocity and water level as far upstream as the Bonneville Dam and these semi-daily fluctuations in water level are sufficient to cause flows to stop or even reverse in the lower Willamette through the tidal cycle. Water velocities are highest—and flow reversals least common—January through April when Willamette flows are high and Columbia flows are low (Figure 15). Water velocities are lowest and flow reversals most common from July to October when flow in both river systems are lowest and tidal effects which produce the flow reversals are most pronounced. Flow reversals can occur nearly 25% of the time during this period.

Figure 15: Mean water velocity by month at Portland. Based on data from 1/30-2017 – 12/31/19, the period of record available for web retrieval. Velocities below the red line indicate flow reversals. Source: USGS gauge #14211720.

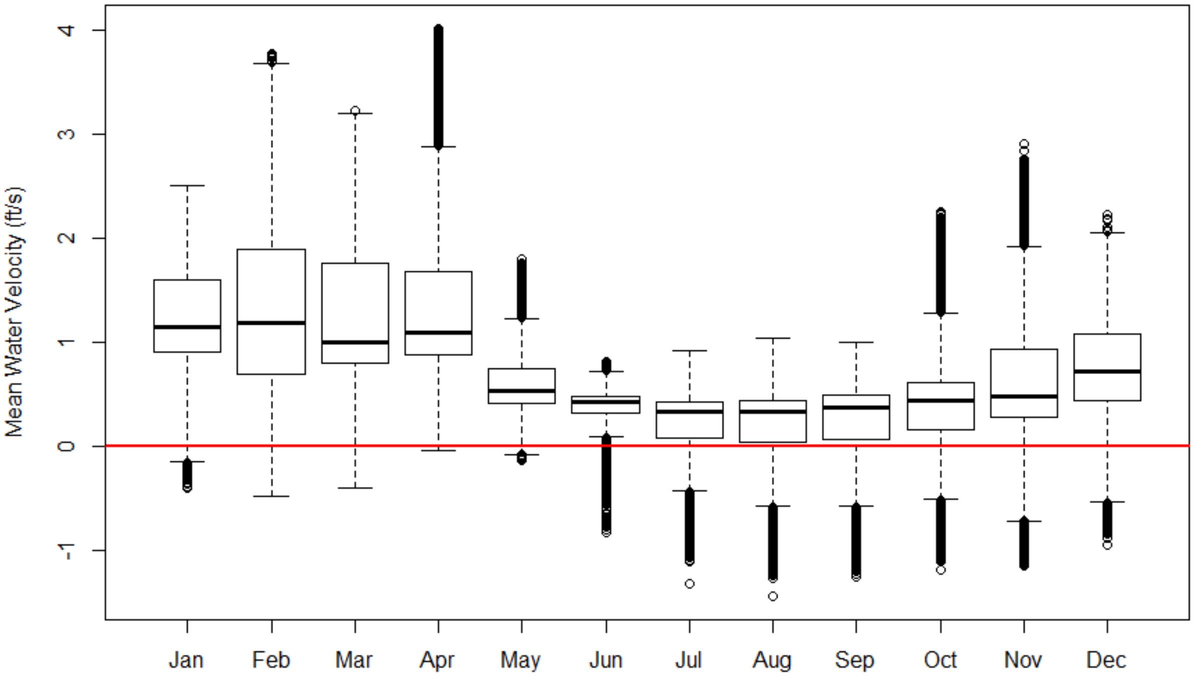
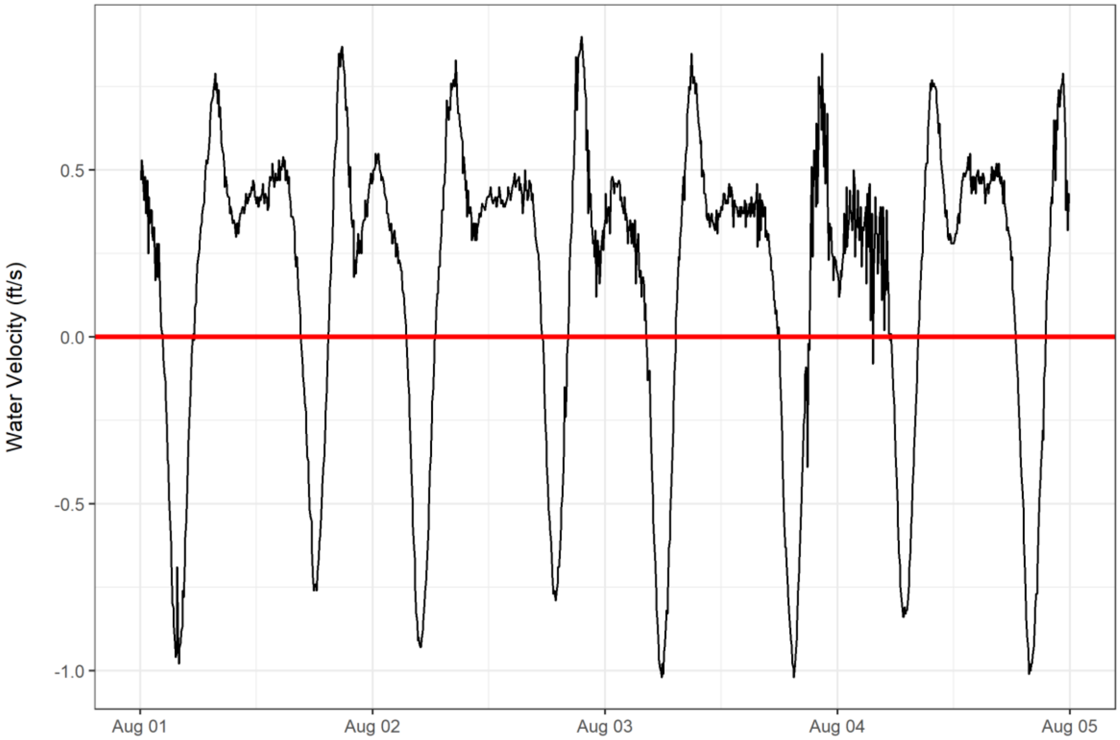


Figure 16: An example of summer flow reversals at Portland from August 2019. Velocities below the red line indicate flow reversals. Source: USGS gauge # 14211720.



Flow reversals tend to be very rapid and of short duration near the peak of the high tide (Figure 16). Flow is typically positive and somewhat consistent for most of the tidal cycle, then rapidly reverses to the peak negative flow and quickly returns to levels close to those before the flow reversal.

Tidal effects on flow and water levels in the lower Willamette River occur all the way up to Willamette Falls, but flow reversal becomes insignificant upstream of the Morrison Bridge (Limno-Tech 1997). The presence of tidal variability and semi-diurnal flow reversals has a number of implications for important ecological processes such as sediment and contaminant transport and inundation of habitats and vegetation at the water's edge.

Unfortunately, the gauge at Portland does not provide an adequate period of record for evaluating changes in flow patterns over time. USGS installed the gauge in 1973, after the most significant period of dam building[5] and after the most significant changes in flow had already occurred. The excellent periods of record at the Salem and Dalles gauges do provide some foundation on which to hypothesize how changes in flow over time in the Upper Willamette and Lower Columbia would affect local flow conditions. It is probable that water levels during the low flow period in the lower Willamette are markedly higher under current conditions than they were historically. Flow during low flow periods has increased in both river basins over this time, increasing the amount of water coming from the upper basin and the backwater effects from the Columbia River. Similarly, peak flows in both basins have been reduced, from December to April in the Willamette Basin and from April to July in the Columbia Basin. This has probably decreased peak flow events in the lower Willamette from December to April, and decreased the magnitude and duration of high water events due to backwater from the Columbia River from April to July. Together, these changes mean that the variability of flows and water levels in the lower Willamette River have been reduced, and the seasonal pattern in that variability has been altered.

2.6 Ecological Implications of Changes in Mainstem Flow at Portland

Flow regimes are critical to nearly all the ecological processes important in maintaining the health of the lower Willamette River. Understanding the changes in flow patterns that have occurred in response to human activities is a critical component in understanding the nature and dynamics of ecological problems in the river and its floodplain, the processes causing those problems, and the most appropriate and effective approaches for addressing them.

Human activities have had a number of profound effects on mainstem flow in the lower Willamette River—increasing flows during low water seasons, reducing the frequency and magnitude of peak flow events, altering the seasonal timing of flow changes, altering channel structure, filling or degrading floodplain and off-channel habitats, and limiting the ability of the river to access its floodplain. These significant changes have undoubtedly had profound and wide-ranging impacts on a number of processes critical to the riverine-floodplain ecosystem. Characterizing the entire range of probable impacts that such fundamental and important changes would have on ecosystem structure and function is beyond a scope that can be covered here[6], but some of the major implications are worth highlighting.

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[5] Henry Hagg was the only major dam constructed after this point, in 1975.

[6] Fuerstenberg (2003) and Cassin et al. (2003) provide comprehensive assessments of ecological responses to human alterations of flow regimes.

Seasonal variability in flow is one of the major environmental cues to which plant and animal life histories respond. Seasonal changes in water level define the patterns of inundation and exposure that create seasonal wetlands and are important signals for the onset of critical biological processes such as emergence, migration, and reproduction. Wetland plants, salmon, aquatic insects, and other plants and animals have adapted to the seasonal patterns of flow over thousands of years, and their life histories reflect this ecological history. The rapid, human-induced changes in flow patterns mean that many native species are no longer adapted to the range and timing of flow conditions, adversely affecting their productivity, behavior, and survival. Floodplain areas that normally would be exposed during the summer and develop into seasonal wetlands as exposure stimulates wetland plant growth are now no longer exposed in the amounts, frequencies, or timing that they were in the past because dry season water levels are considerably higher than they were historically. Many plants (for example, wapato *Sagittaria latifolia)* are critically dependent on this seasonal pattern and timing of exposure.

Reduction in the magnitude and frequency of peak flow events alters habitat-forming and –maintaining processes. Floods are critical for maintaining many elements of riverine habitat, including channel and floodplain morphology, substrate composition, and wood accumulations (Junk and others 1989; Regier and others 1989; Poff and others 1997). Reducing the frequency and size of floods affects a number of important ecological processes including transport of sediment and wood, the frequency of channel-forming flows, and the disturbance events needed to create a mosaic of diverse habitat patches that provide habitat suitable for a wider range of species.

The changes in flow entering Portland are exacerbated by the changes in local physical conditions. The frequency and duration with which a river accesses its floodplain is diminished not only because of reduced peak flows, but also because floodplain and off-channel habitats have been filled and banks steepened. Seasonal wetlands have been reduced not only because the range in seasonal flows has been reduced and smaller areas experience seasonal inundation and exposure, but also because the areas where these wetlands occurred have been filled or developed. This juxtaposition of multiple impacts increases the severity of these changes on ecological functions.

2.7 Future Changes

Dams were the major source of change in the hydrology of the lower Willamette River over the past century, but dam building has largely ceased in the Northwest for a number of reasons, including the listing of salmon under the Endangered Species Act. The major changes in hydrology looking forward will likely be due to climate change. A collaboration of federal agencies (RMJOC 2018) summarized a number of studies on regional impacts of climate change and note significant changes that will impact hydrology in the Columbia Basin: "as warming continues, Columbia River Basin snowpack is likely to decline, winter stream flows will tend to increase, peak seasonal snowmelt season (freshet) will tend to occur earlier in the spring, and summer flows will likely decrease." (BPA 2018, pg. 9). USGS (2018) also summarized findings from reports by regional agencies on changes in both the Willamette and Columbia rivers:

> "Projected future trends indicate an earlier peak in the spring freshet is likely on the mainstem, shifted on average by about 1 month, from a May to June peak in current conditions to a late April to early May peak in the 2040s. Concurrently, increases in winter (November–March) runoff volume in the Willamette Valley are plausible as

> well. Although the future spring Columbia River peak stage would not coincide with the stage of Willamette River winter flows, the rise on the Columbia River would begin earlier, effectively increasing 2040s winter discharges in the Columbia River at the time of the peak flow on the Willamette River. This pointed to a February 1996 type winter rain-on-snow event as being more likely to cause plausible extreme future floods than the spring freshet." (USGS 2018; pg. 41).

Most of these changes will continue trends away from the patterns that species have evolved with over millennia, changing the timing and magnitude of seasonal flow patterns. Lower summer flows is one change that actually reverses a trend away from historical conditions induced by dam management over the past century, but because of other changes in the Columbia Basin ecosystem it comes at a very heavy cost, increasing summer water temperatures in a system that is already too hot. Temperature is one of the most common reasons for water quality impairment across the Columbia Basin and is a major limiting factor for salmon populations across the basin (NMFS 2011, NMFS 2013, NMFS 2015).

3 Habitat

Adolfson (2003) provides a concise description of the historical natural setting of the lower Willamette River prior to human development: “Historically, the Willamette River in the Portland area comprised an extensive and interconnected system of active channels, open slack waters, emergent wetlands, riparian forest, and adjacent upland forests on hill slopes and Missoula Flood terraces. Prior to settlement, the river was embedded in the regional forest network, and intricately connected to the Columbia floodplains.” (p. 6)

This section provides an overview of historical and current aquatic and water-related habitat components of the north, central, and south reaches of the lower Willamette River. These habitat components include: shallow water habitat, floodplains, off-channel, riverbank condition, and vegetation (both riparian and upland). The section concludes with a summary of the terrestrial habitat priorities and habitat types by reach.

3.1 Bathymetry/Shallow Water Habitat

Originally the lower Willamette channel was a transitional zone from a highly constrained basalt trench from the Willamette Falls to the South Reach, then a gradually widening and less constrained channel as it reached the confluence with the Columbia River. The general course of the channel through Portland has likely been consistent over time since the Missoula Floods dramatically reshaped the area. The one exception to this was the mouth of the river, where the Columbia Slough and Sauvie Island provided low-lying areas that were reconfigured during floods. Early maps of the mouth show multiple islands and channels that have been lost as the main channel was simplified for navigation and development (Figure 17).

Bathymetric surveys have been completed in the lower Willamette River through Portland in 1888–1895[7], 2001[8] and 2004[9]. It is difficult to compare these datasets quantitatively, however. The 2004 data are the only survey tied to a vertical reference point—Ordinary High Water (OHW[10]). The 1888-95 and 2001 surveys are not tied to a specific datum or elevation—they were conducted during a period of summer low flow that would have been approximately near Ordinary Low Water (OLW). Summer low flows have changed from 1888 to the present due to hydrologic alteration of the Willamette and Columbia rivers caused by dams, and tides can vary water depths in Portland by up to 3 feet over a tidal cycle (Section 2). Therefore, comparison amongst the datasets is limited to more qualitative analyses.

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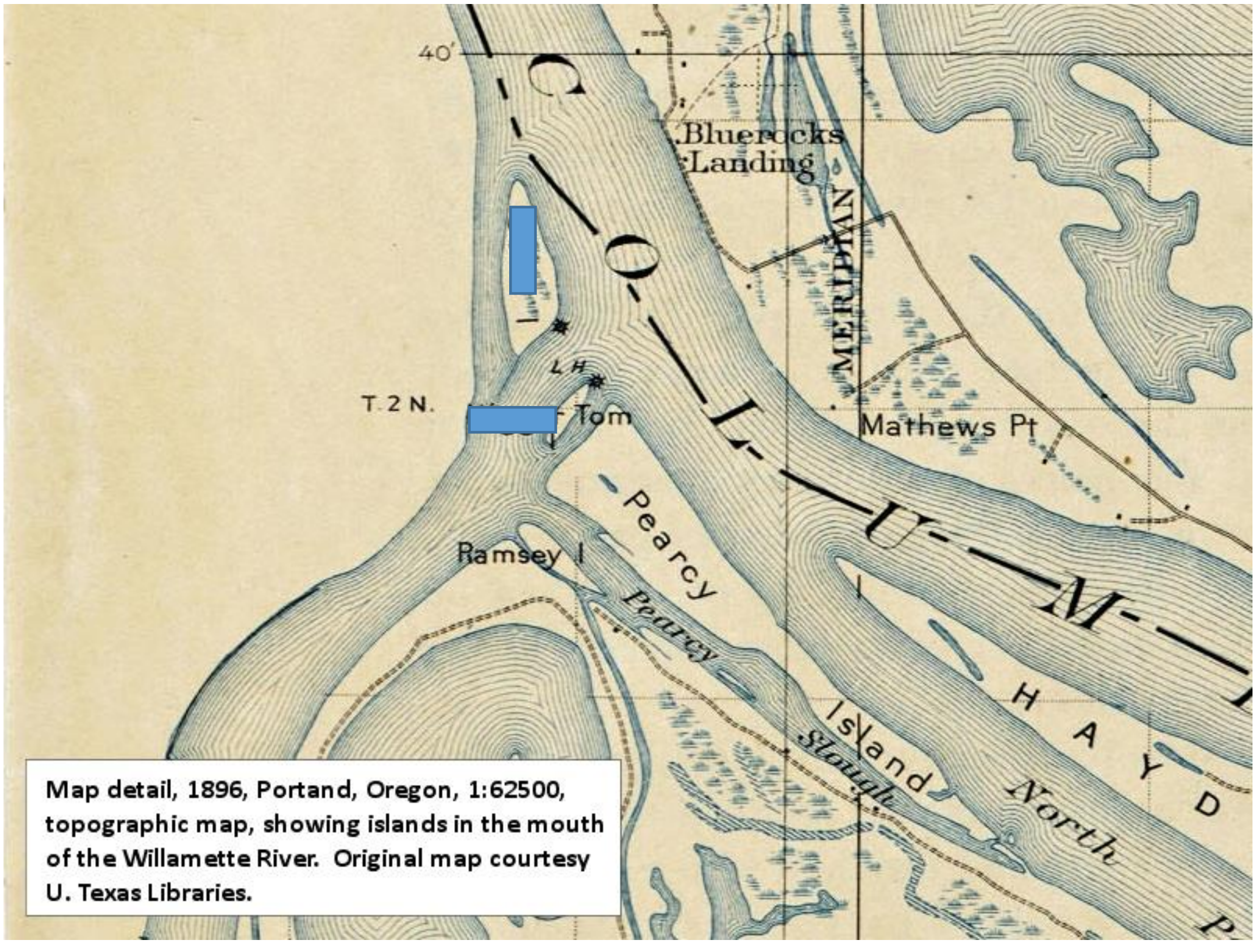
[7] Metadata: https://www.portlandmaps.com/metadata/index.cfm?&action=DisplayLayer&LayerID=52237 and http://www.fsl.orst.edu/pnwerc/wrb/metadata/ac1895p.html

[8] https://www.portlandmaps.com/metadata/index.cfm?&action=DisplayLayer&LayerID=53476

[9] https://www.portlandmaps.com/metadata/index.cfm?&p=1&s=abstract&b=9&c=50022&o=asc&action=DisplayLayer&LayerID=53396

[10] North American Datum of 1983/1991 (HPGN)

Figure 17: Map of the mouth of the Willamette River. Offensive historical names have been covered in the original map.



Map detail, 1896, Portand, Oregon, 1:62500, topographic map, showing islands in the mouth of the Willamette River. Original map courtesy U. Texas Libraries.

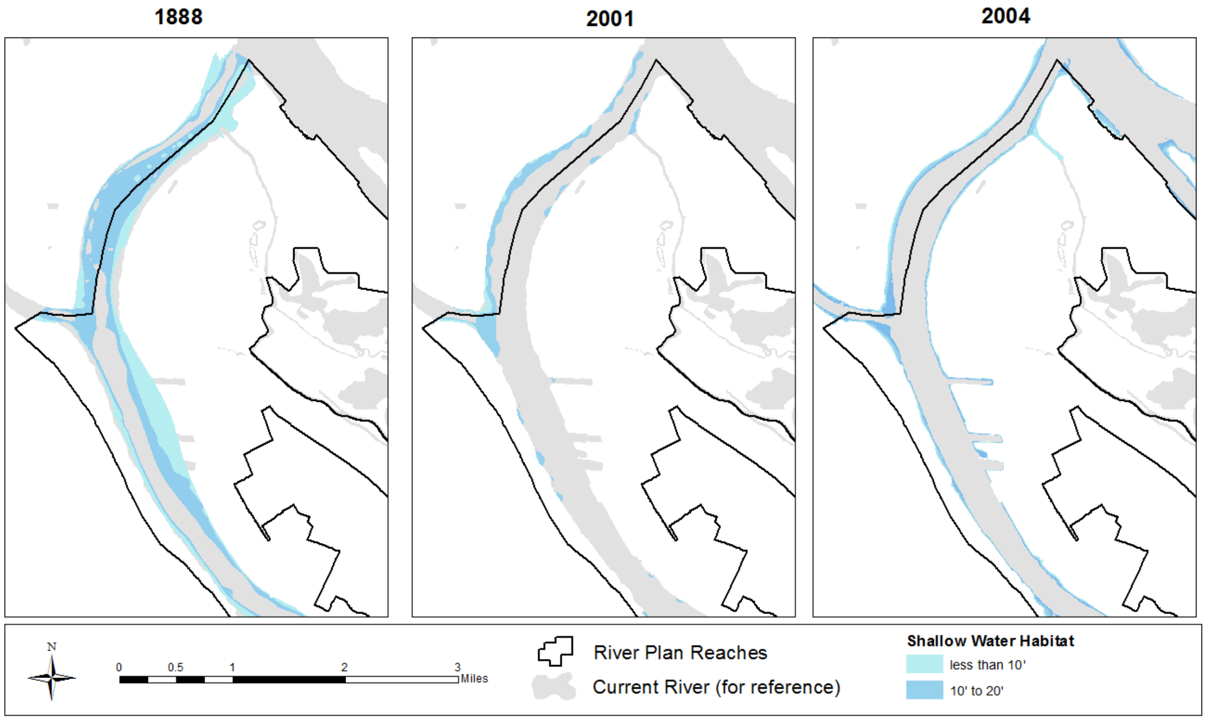
In order to provide a qualitative comparison of the changes in bathymetry over time, the data were mapped to address the question "how much shallow water habitat was present during the summer low flow conditions at the time of the survey?" For the purposes of this question shallow water was considered to be areas 20 feet deep or less during OLW. The 2004 OHW data were converted to OLW depths by subtracting 7.9 feet (Stillwater Sciences 2014). Comparison of shallow water habitat for the three reaches is described below.

3.1.1North Reach

The channel of the North Reach as it approached the confluence was the most dynamic and complex of the reaches from the falls to the mouth. The joining with the Columbia provided dynamic hydrology that reworked the low-lying topography through floods. Like the confluence of most Pacific Northwest rivers massive wood accumulations would have been present, and early settlers spent considerable time removing wood from the channel for navigation. It was noted that "Because the Willamette River provided the critical transportation route for moving wheat to Portland and then on to oceanic markets, the federal government funded the construction of a steam-powered "snag-puller" in 1869 to remove obstructions from the river." [11]

The earliest channel surveys showed extensive shallow water habitat from Multnomah Channel to the mouth (Figure 18). South of this area provided a more gradually sloping bathymetry, with more extensive shallow water habitat on the east shoreline (near the current terminal slips) than the west shoreline. The current channel conditions on both sides of the river in this area show very steepened slopes with a very narrow marginal band of shallow water during low flow conditions.

Figure 18: Shallow water habitat in the northern section of the North Reach.



Moving further upstream to the southern portion of the North Reach, historical comparison reveals one of the more dramatic changes in the channel. The historical channel flowed to the east of Swan Island—a proper island at the time—and what is currently the main channel was a secondary channel with the largest expanse of shallow water habitat across the entire lower Willamette mainstem. The main channel was filled and Swan Island connected to the eastern bank in order to

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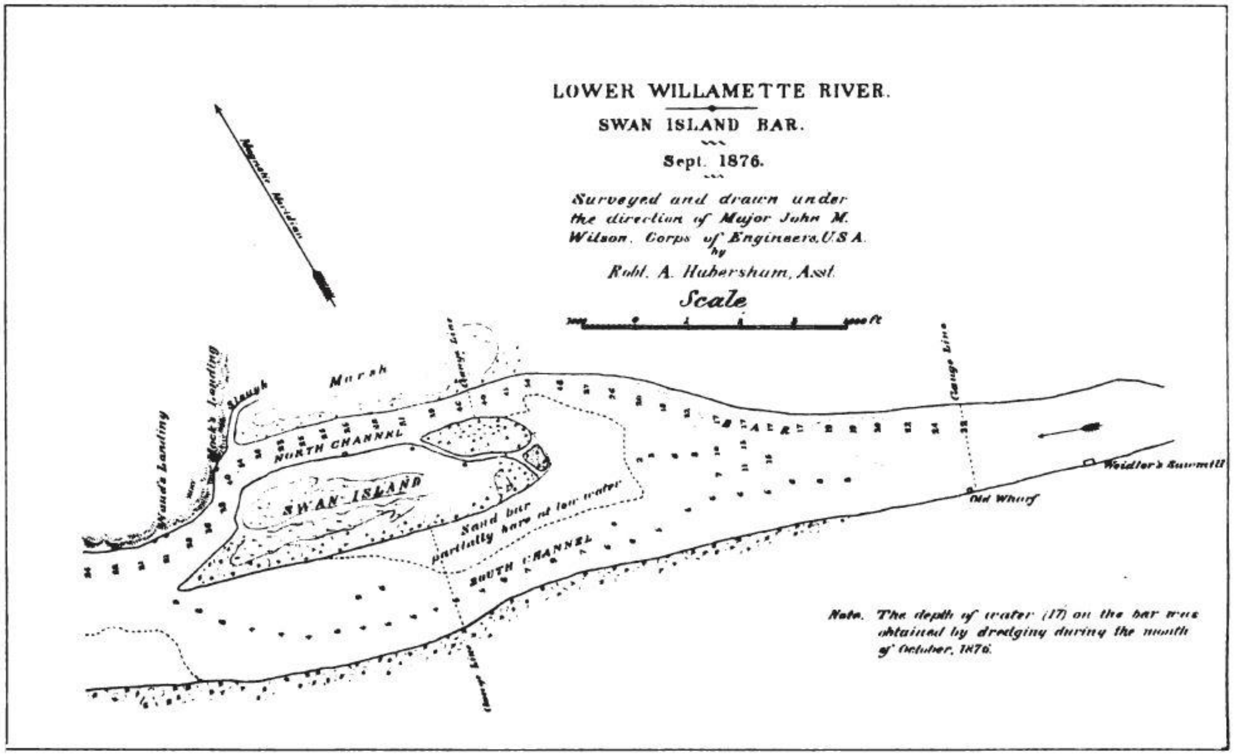
[11] Oregon Encyclopedia: http://www.oregonencyclopedia.org/articles/willamette_river/#.VtjPQubX-I4

build the original Portland Airport[12], the current main channel was directed through this former shallow water habitat, and Swan Island Lagoon was created out of the original main channel (Figure 19).

Figure 19: 1876 map of the original river configuration at Swan Island. The deeper main channel was historically to the east of Swan Island (towards the top of the map). Source: http://www.portlandwaterfront.org/timeline2.html.



The primary remaining shallow water habitats in this section are small alcoves, wider areas, or backwaters that provide room for more gradual channel slopes such as Willamette Cove, Terminal 1 and the end of Swan Island Lagoon (Figure 20).

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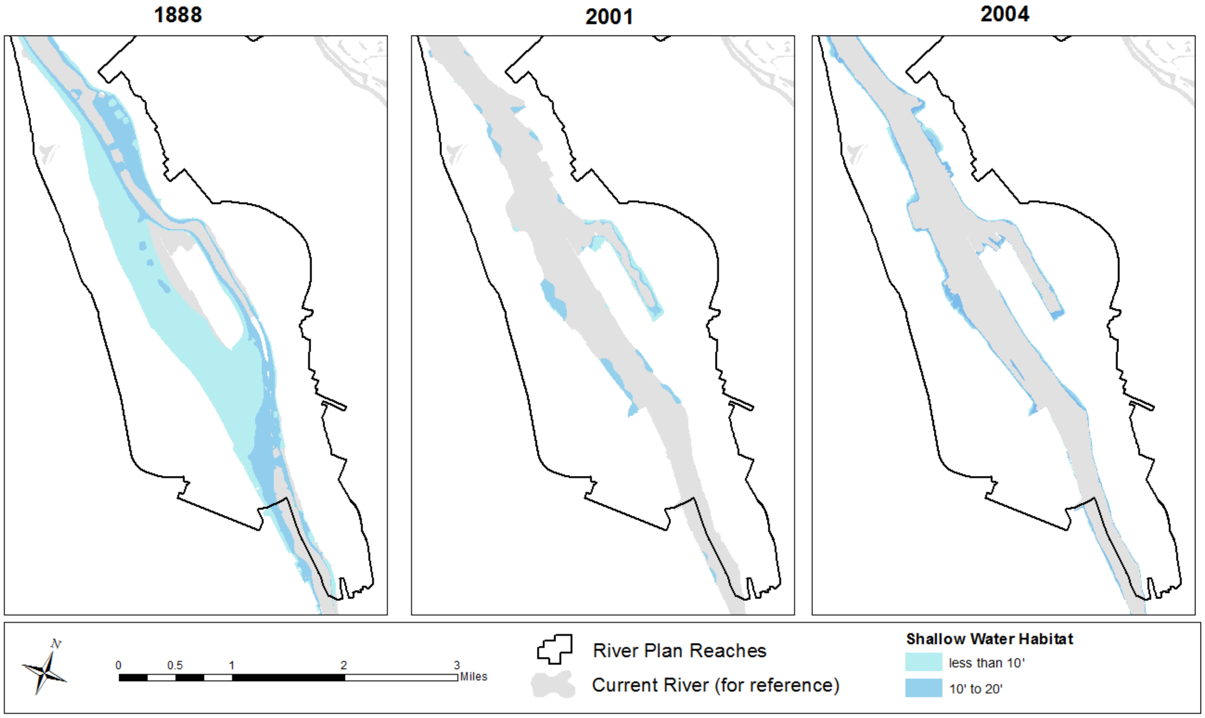
[12] Swan Island was first noted as Willow Island in 1844. Lt .Charles Wilkes did visit and chart Swan Island (the first to do so), calling it Oak Island in his diary and Willow Island a decade later when the four-volume account of his voyage was published. He said: “The grove of oak on this island was beautiful, forming an extensive wood, with no undergrowth. The species of oak that grows here is white oak, of very close grain.”

Figure 20: Shallow water habitat in the southern section of the North Reach.

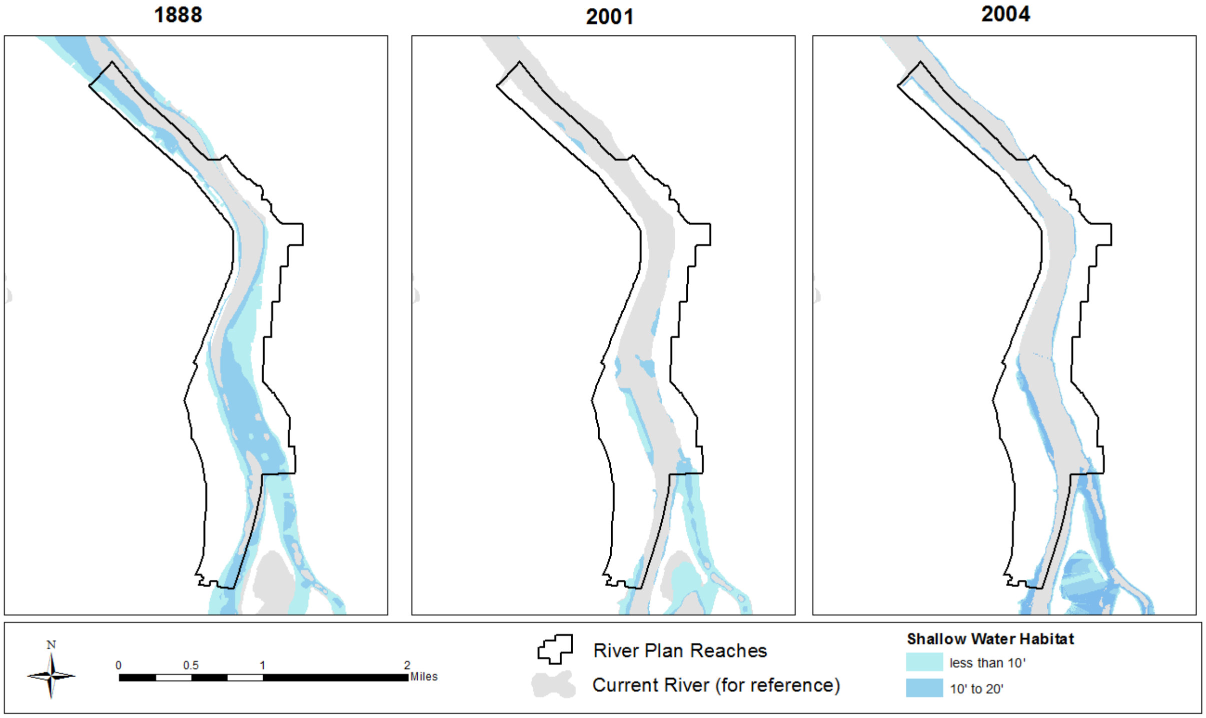


3.1.2Central Reach

The Central Reach was historically narrow and moderately constrained, with shallow water habitat across the channel downstream (north) of the tip of Ross Island. The thalweg (deepest portion of the channel) bounced back-and forth between the banks as it traversed this reach.

Currently, because of the downtown seawall, extensive riprapped banks, and steep channel slopes along this reach, shallow water habitat is limited to very small, steepened areas such as the northern half of South Waterfront and the east bank beneath the Hawthorne Bridge (Figure 21).

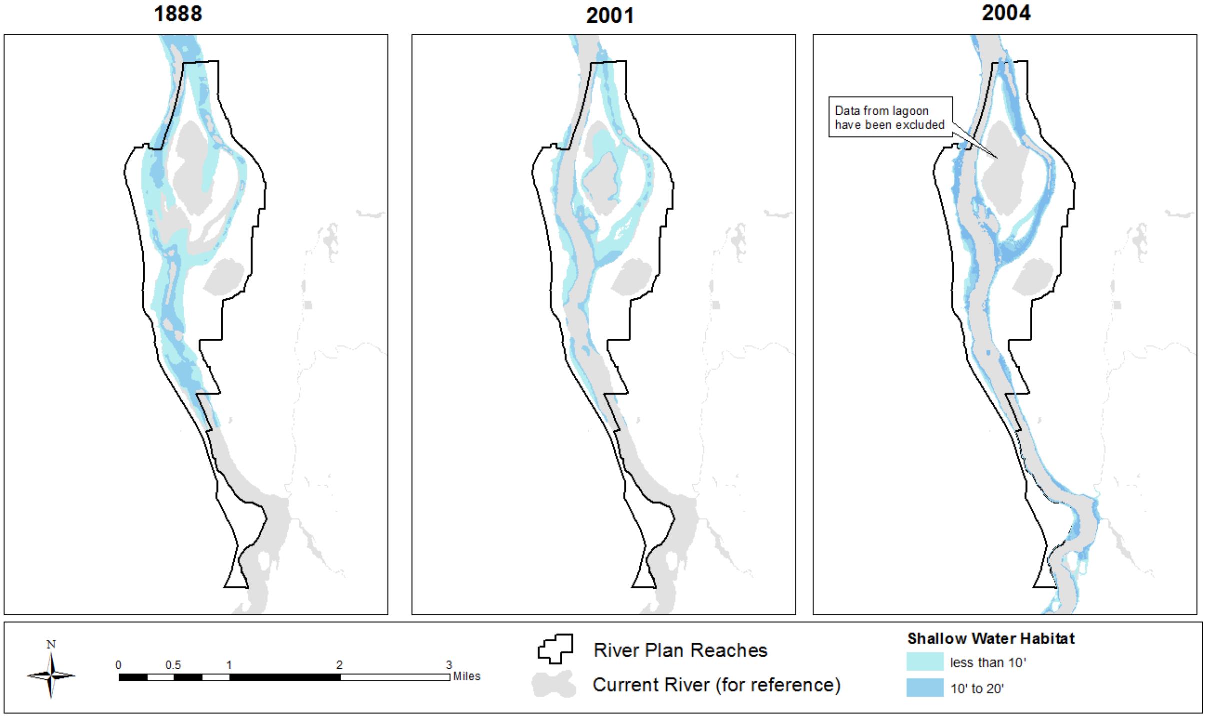
Figure 21: Shallow water habitat in the Central Reach.



3.1.3South Reach

The South Reach historically provided considerable shallow water habitat and channel complexity as the river flowed through and around Ross Island. Ross Island was originally a group of islands with shallow channels between them that changed form in response to large floods (see, for example, Figure 33). Most of the channel upstream of Ross Island other than the thalweg was less than 20 feet deep. Currently, much of the shallow water habitat upstream of Ross Island and in the main channel to the west of Ross Island has been lost, but Holgate Channel to the east of Ross Island provides one of the only secondary channels in the entire lower Willamette, and is mostly less than 20 feet along its course (Figure 22).

Figure 22: Shallow water habitat in the South Reach. Note: the 2004 data in Ross Island Lagoon are in error and are in the process of being corrected, and so have been excluded from the map.



3.2 Floodplains and Off-Channel Habitats

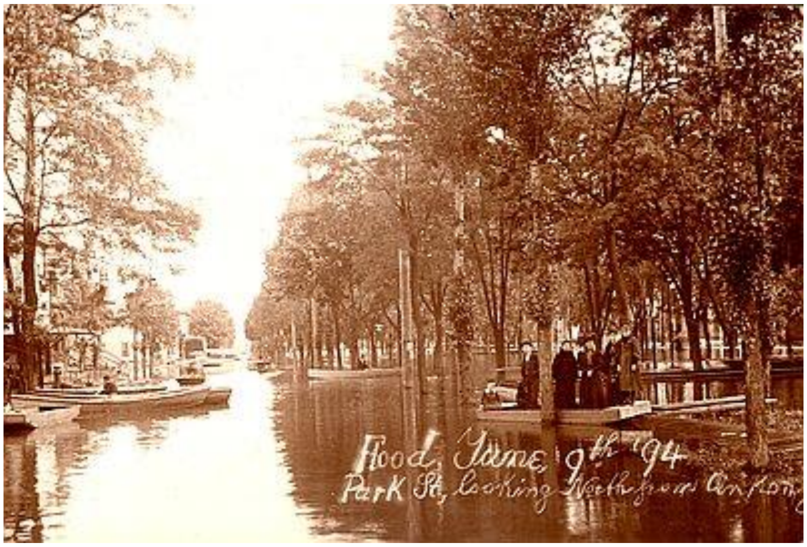
From Multnomah Channel to the mouth, the Willamette River formed the southern portion of a vast floodplain system that included Smith & Bybee Lakes, Sauvie Island, and the Multnomah Channel, and Vancouver Lake and what is now Ridgefield Wildlife Refuge across the river.

Through Portland the floodplains are bounded by the Willamette Escarpment and the Tualatin Mountains. The channel and floodplain widen as the river flows through Portland, where landform constraints become less severe, and conditions become increasingly influenced by the Columbia River. Historically the reduced landform constraints allowed the formation of floodplains and off-channel habitats through Portland, with large off-channel lakes such as Guilds Lake, Doane Lake, and Ramsey Lake. Tributaries, including the Columbia Slough, and Miller, Doane, Balch and Tanner creeks were all connected to the mainstem. Prior to development, the mouth of the Willamette River provided one of the most extensive floodplain and off-channel habitats below the Falls. The Oregon History Project (Toll 2003) describes the city before construction of the dams:

> "The Willamette Valley was periodically flooded by late spring thaws in the Cascades. Portland's business district was overrun in 1853, 1854, 1862, 1871, and most severely in 1876 and 1894. On June 24, 1876, the water flooded stores along Second Street, reaching a high-water mark of twenty-five feet. In June 1894, the waters reached Northwest Tenth and Glisan and Southwest Sixth and Washington streets, a high water mark of over thirty-three feet…

> Boats floated through the downtown like gondolas in Venice, conveying produce and people to the second story of three and four story masonry buildings. Unlike fires, which city officials tried to prevent with building codes and to fight with a professional force, floods seemed inevitable. Prevention of floods awaited the construction by the city of higher walls along the waterfront and ultimately the construction of dams on the upper Willamette by the Army Corps of Engineers."

Figure 23: Picture of the 1894 flood inundating the North Park Blocks. Source: http://www.oregonencyclopedia.org/articles/willamette_flood_1894_/#.V1fMcZErI2w



Along its length, riparian forests, mudflats, off-channel streams, lakes and wetlands were connected to the river during seasonal high flows. In-channel islands such as Sauvie, Swan, and Ross islands provided high quality fish and wildlife habitat that would change configuration in response to floods. The historical floodplain provided storage for floodwaters and sediment, nutrient exchange, as well as groundwater and wetland recharge. The floodplain also served as a source of organic matter and food supply (e.g., insects) to the Willamette River, and as a refuge for fish and wildlife during floods, providing slower flows and hiding spaces to avoid the high flows of the main channel.

Processes that have led to changes from historical to current floodplain conditions primarily involve the placement of fill and structures to support industrial, commercial, transportation and residential development of the floodplain. Placement of fill alters floodplain function by disturbing native vegetation, modifying absorption rates, and isolating the floodplain from the channel, thereby reducing the frequency of inundation from flooding events. The placement of structures in the floodplain – buildings, roads, pipes and utilities – cover the floodplain, diminish or eliminate its ability to provide many functions to the river, and introduce pollutants.

As a result of these processes, off-channel habitat in the lower Willamette River is one of the habitat types most greatly diminished in quantity and quality from historical condition. Floodplain fill, vegetation removal, bank and channel alterations, and urban development have destroyed floodplain, off-channel, and riverine habitats or greatly altered their structure and function. Large off-channel lakes such as Guilds Lake and Ramsey Lake were filled to provide land for downtown and port development, while Doane Lake was reduced in size and its connection to the river severed. At the same time, tributaries all along the lower river were piped underground to support development and disconnected from the mainstem channel. Most of the tributaries draining the Tualatin Mountains (West Hills) into the Willamette from the west have been disconnected by the presence of long culverted or piped sections.

The Portland Harbor Remedial Investigation (EPA 2016) describes many of the areas which received fill:

> "Anthropomorphic fill blankets much of the lowland area next to the river and is predominantly dredged river sediment, including fine sand and silty sand. Hydraulic dredge fill was used to fill portions of the flood plain, such as Doane Lake, Guild’s Lake, Kittridge Lake, Mocks Bottom, Rivergate, and a number of sloughs and low-lying areas. The fill also was used to connect Swan Island to the east shore of the Willamette River and to elevate or extend the bank along significant lengths of both sides of the riverfront by filling behind artificial and natural silt and clay flood levee dike structures. Rocks, gravel, sand, and silt also were used to fill low-lying upland and bank areas. The thickness of this unit ranges from 0 to 20 or more feet." (pg 3-3).

This section provides an overview of historical and current floodplain conditions of the North, Central, and South reaches of the lower Willamette River. Information is presented by reach, first for the east, and then the west bank.

3.2.1North Reach – East Bank

The floodplain on the eastern shore at the confluence with the Columbia consisted of a portion of Ramsay Lake, cottonwood and ash riparian forest, wetlands (emergent, forested, and scrub-shrub), and prairie (GLO vegetation surveys, Graves, et al. 1995). The largest of the tributaries flowing into the North Reach joined the Willamette at the northern tip of this subwatershed. The Columbia Slough, a 19-mile 32,700 acre watershed which was originally a large series of wetlands, lakes and channels, formed the floodplain of the Columbia mainstem and the Willamette mouth. Based on a visual estimate of 1964 and 1996 flooding events depicted in Hulse et al. (2002), an estimated 90% of this area was covered during historical floods. Ramsey Lake - the largest of the off-channel lakes in the lower Willamette at approximately 650 acres, was nestled between the lower several miles of the Slough to the east and the Willamette mainstem to the west, forming a large floodplain wetland complex. Vegetation surveys suggest these wetlands were connected to the main channel through marshy areas to the south in what is currently the International Slip and Schnitzer Steel.

Upstream of the confluence, topography increasingly constrained the channel and floodplain. In wider areas such as Willamette Cove and Mocks Bottom, the floodplain included wider bottomlands and wetlands at the foot of these escarpments. At Mocks Bottom an extensive floodplain historically bordered the main channel to the east, and contained a large marsh and forested wetland complex (Figure 24). When considered with the Guilds Lake bottomland on the opposite bank the Willamette River, the floodplain would have been over 2 miles wide at this point.

Extensive fill along the eastern banks has greatly reduced the extent of floodplain. Ramsey Lake and much of the low-lying land along the Rivergate area have been filled for industrial development. Small remaining pockets that are either in the Federal Emergency Management Agency (FEMA) 100 year floodplain or that were inundated in the 1996 flood include the lower lying areas of Kelley point Park, the low-lying areas surrounding International Slip, and the end of the Swan Island lagoon and southern end of Swan Island where the original main channel was filled to connect Swan Island to the eastern bank.

3.2.2North Reach – West Bank

Along the west bank of the North Reach a broad Willamette River floodplain historically existed from the confluence with the Columbia River to the Multnomah Channel that included large portions of Sauvie Island. Flooding may have extended up to 1,000 feet or more from the river at the marsh area south of the Miller Creek confluence. Historical maps show wetlands and an off-channel waterbody where Miller Creek joins the Multnomah Channel (Figure 24).

Upstream of the Multnomah Channel, the floodplain was constrained throughout the Linnton area as the channel flows near the base of the Tualatin Mountains, and flooding was limited to areas near the bank. South of Linnton on the west bank across from St Johns, the Tualatin Mountains begin to diverge from the main channel and a shelf of low lying bottomlands are present between the base of the mountains and the channel. It was on these bottomlands that the extensive off-channel floodplain lakes were present, from north to south including Doane Lake, Kittridge Lake and Guilds Lake, the latter an old cut-off meander of the historical channel. Along the length of the Tualatin Mountains a large number of perennial and intermittent streams flowed down the flanks of the West Hills onto the floodplain platform below, often passing through lakes and wetlands along the way.

With a few exceptions, the current 100-year floodplain does not extend much beyond the existing channel boundaries (FEMA 1982 and 1986), due to filling for industrial and commercial use. The mouth of lower Miller Creek and the wetlands on the north and south of the PGE property are still subject to Willamette River flooding, and portions of the Morse Brothers, Owens Corning and Linnton Plywood properties were either flooded in 1996 or are within the 100-year FEMA floodplain. Sauvie Island – nearly all of which would have flooded under historical conditions – has been diked and much of its interior has been disconnected from the river. Much of the former Alder Creek Lumber property is outside of the dike and experiences flooding. This property was recently purchased by Wildlands, Inc., restored, and is being used to provide credits for Natural Resource Damage Assessment liabilities by providing high quality off-channel and floodplain habitats that are well-connected to the mainstem.[13]

Miller Creek, at the junction with the Multnomah Channel, is the only creek draining Forest Park with any fish passage. Miller Creek is a forested, high quality watershed largely contained within Forest Park, the largest forested park within city limits in the country. The connection of Miller Creek to the Willamette is compromised by culverts underneath the railroad, and lower channel alterations including the redirection of the channel into the back end of a marina. The Oregon

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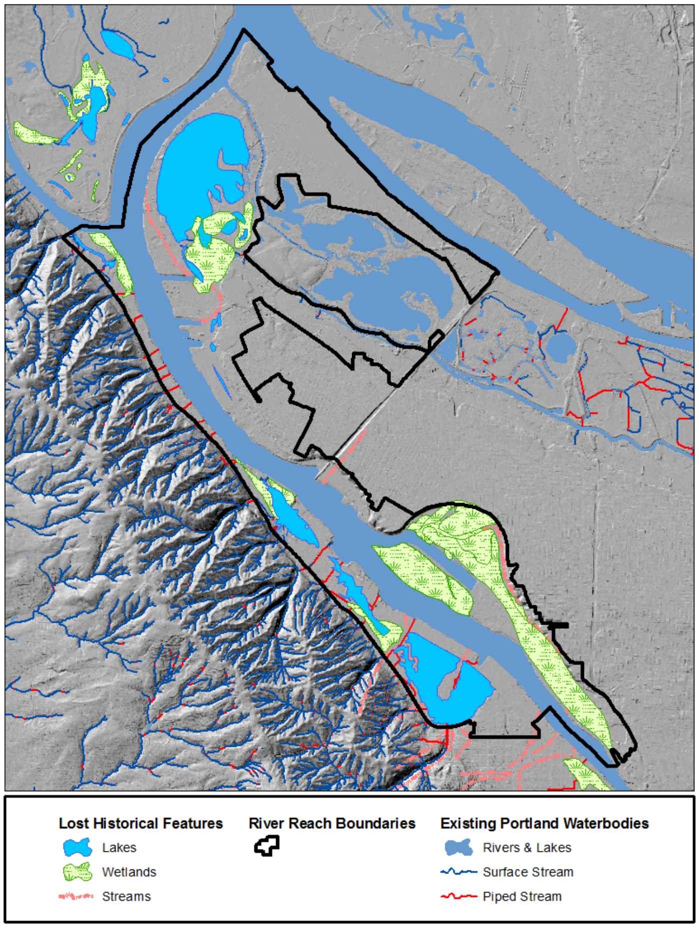
[13] https://www.fws.gov/oregonfwo/Contaminants/PortlandHarbor/Documents/AlderCreekFactSheet.pdf

Department of Transportation replaced the culvert under Highway 30 with a bridge in 2003. Improvements to the confluence and lower channel are being developed as part of the Natural Resources Damage Assessment settlements.

All other Forest Park streams—Doane, Saltzman, Balch and numerous unnamed perennial and seasonal streams—are piped from the foot of the West Hills under Highway 30 (and associated industrial development) and disconnected from the Willamette River (Figure 24). Doane Lake across from Willamette Cove was mostly filled during development, and the remnant portion is separated from the river and other habitats on all sides by railroad berms. Guilds Lake, the largest lake on the west side, and Kittridge Lake were completely filled.

Figure 24: Historical off-channel lakes, wetlands and streams that have been lost over time in the North Reach.



3.2.3Central Reach – East Bank

The East bank of the Central Reach was described by Harvey Scott in 1890:

> “From Albina southward the surface sinks by small degrees, broken here and there by ravines, until at the site of East Portland, three profound chasms or gulches, unite to form an illuvial bottom, making easy ingress from the river, but a bad water front. The first of

> these on the north is Sullivan's Gulch, fifty feet deep and two hundred yards across; its bed a morass. It is down this cleft that the O. R. & N. R. R. finds a passage from the plain to the river level. Next south is Asylum Gulch, leading back to a powerful spring which leaps from under the plain behind, giving birth to a stream of water sufficient for the supply of the water works of East Portland. A mile south of this is Stephens Gulch, bearing off another clear stream, of many times the volume of the foregoing, which also springs bodily from the ground. It is by this depression that the O. & C. R. R. passes out of the city. South of the mouth of Stephens Gulch, the ground once more rises, gaining an altitude about the same as that of Albina, and it is called Brookland[14]. … The strip of alluvium in front of East Portland, at the mouth of the gulches, is but a few hundred paces across, and thence the surface rises easily, nowhere attaining an elevation of more than one hundred feet, and develops into a plain with many variations of surface leading out three miles further to Mt. Tabor."

The historical floodplain in the east side of the Central Reach was not extensive, based on imagery (Hulse et al. 2002), vegetation descriptions (Christy et al. 2000), and the Coast Survey maps. It was generally limited to the shoreline, though the river would flood into the three the gulches; for example, in Sullivans Gulch as far up as the present location of NE 16th Avenue (City of Portland Bureau of Planning, 1993).

The Surveyor General's Office map from 1852 indicates a creek flowing east to west in the approximate location of the current SE Belmont Street. This creek enters a lake at approximately the location of the current SE 12th and Morrison Streets (Surveyor General's Office, 1852). This was likely Asylum Creek –mentioned in Harvey Scott's description above and also known as Hawthorne Springs (Figure 25)—which was mentioned in the Oregon Journal in 1929[15]:

> "Interesting history of the Central East Side is recalled by completion of the Grand Central Public market, which occupies what once was the course of Asylum creek, a stream originating near Mount Tabor and meandering through the East Side past an insane asylum on what is now East 10th street, to the Willamette River near Oak Street.
>
> …Man-made alterations, made principally since 1900, have changed the terrain of the Central East Side section considerably. Grand Avenue ran along the crest of a bluff overlooking the river, and was regarded as "high land." It was a broad peninsula extending northward to Stark Street, where the declivity of Asylum creek caused a dip in the land.
>
> Another indentation of water into the east Side was Stephens slough and creek, over which the Inman-Poulsen mill now stands. Asylum creek, which passed through the center of the district, arose near Mt. Tabor, passed along the southern line of Lone Fir cemetery and in a southwesterly course went to East 12th and Hawthorne, swinging abruptly into a northwesterly course. At 12th and Hawthorne the stream was fed by a spring, which

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[14] Currently the Brooklyn neighborhood – the bluffs on the east bank above Ross Island.

[15] 1 The Oregon Journal (Portland), 8 November 1929, page 31, col. 1. As found at: http://www.lenzenresearch.com/GCPMsite.pdf

> produced 1,000,000 gallons of water daily. This spring is still in action and has created an engineering problem for the city engineer and nearby residents"

The historical floodplain was filled and developed for the settlement of East Portland and the Central Eastside Industrial District. Currently, I-5 and industrial land occupy much of the floodplain closest to the river. A portion of the area under the I-5 freeway along the railroad tracks and SE 2nd Avenue flooded during the 1996 event, though development has effectively eliminated floodplain function in this area.

Figure 25: Picture of slough at Hawthorne Springs.

Figure 26: Oregon General Land Office Cadastral Survey Map; digital image, University of Oregon Map Library (libweb.uoregon.edu/map/map resources/about_glo.html). The map shows an off-channel lake and streams on the west side, and streams flowing through ravines on the east.

3.2.4Central Reach – West Bank

The 1964 flood extended up to a half mile inland from the Willamette River downtown and in what is now referred to as the South Waterfront area, and the quote in the introduction to this section make it clear that earlier floods regularly inundated downtown streets.

Tanner Creek was one of the few named creeks that flowed into the Central Reach on the west side. Tanner Creek flowed into Couch Lake, a low, swampy area within the floodplain that extended from just south of the Steel Bridge to the Fremont Bridge. (Figure 32; *Portland Online, re: Tanner Creek* http://www.portlandonline.com/bes/index.cfm?c=dbijg).

Figure 27: A map depicting Tanner Creek's origins in the West Hills and discharge into historical Couch Lake before flowing into the Willamette.

© Oregon Historical Society - indicating the original flow of Tanner Creek

Other unnamed streams are currently piped underground and would have also provided off-channel habitat in this reach. There was also an unnamed lake and stream just north of Ross Island on what is now South Waterfront. (Figure 32).

Fill for development of downtown limits the floodplain to the channel with a few small exceptions on the west side. Just south of Terminal 1 and south of the Fremont Bridge flooded in the 1996 flood up to Front Ave. Plywood walls and sandbagging kept the 1996 flood from overtopping the seawall, but most of South Waterfront flooded[16] and is included in the FEMA 100-year floodplain.

No tributaries currently join the mainstem above ground in the Central Reach. The off-channel habitat present in this reach was quickly filled in the early development of downtown and East Portland, and no off-channel habitat of any type currently exists in this segment. Tanner Creek is currently piped underground and flows through a pipe to discharge beneath the former Centennial Mills site. The Portland Parks Bureau daylighted a small portion of Tanner Creek to construct Tanner Springs Park[17], and the Portland Harbor Natural Resource Damage Assessment Trustees have advocated for daylight and restoration of the confluence with the Willamette.[18]

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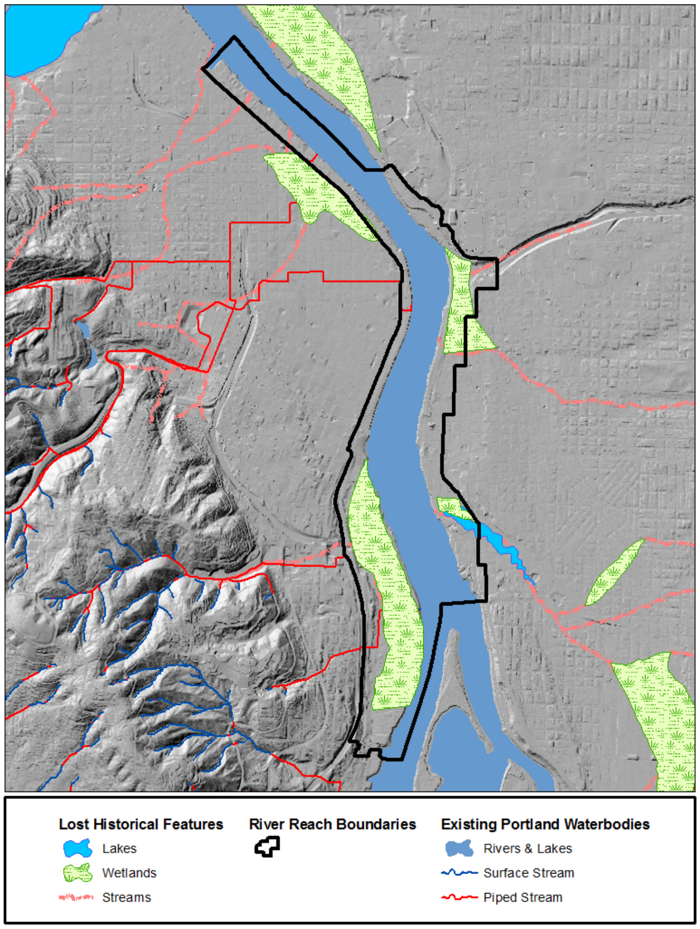
[16] Note: an error in the mapping data excludes South Waterfront from the 1996 flood footprint, but aerial photos of the event show much of the area inundated during the flood.

[17] https://www.portlandoregon.gov/parks/finder/index.cfm?propertyid=1273&action=viewpark

[18] http://www.fws.gov/oregonfwo/contaminants/portlandharbor/Documents/RestorationPort_AppA.pdf

Figure 28: Historical off-channel lakes, wetlands and streams that have been lost to development over time in the Central Reach.



3.2.5South Reach – East Bank

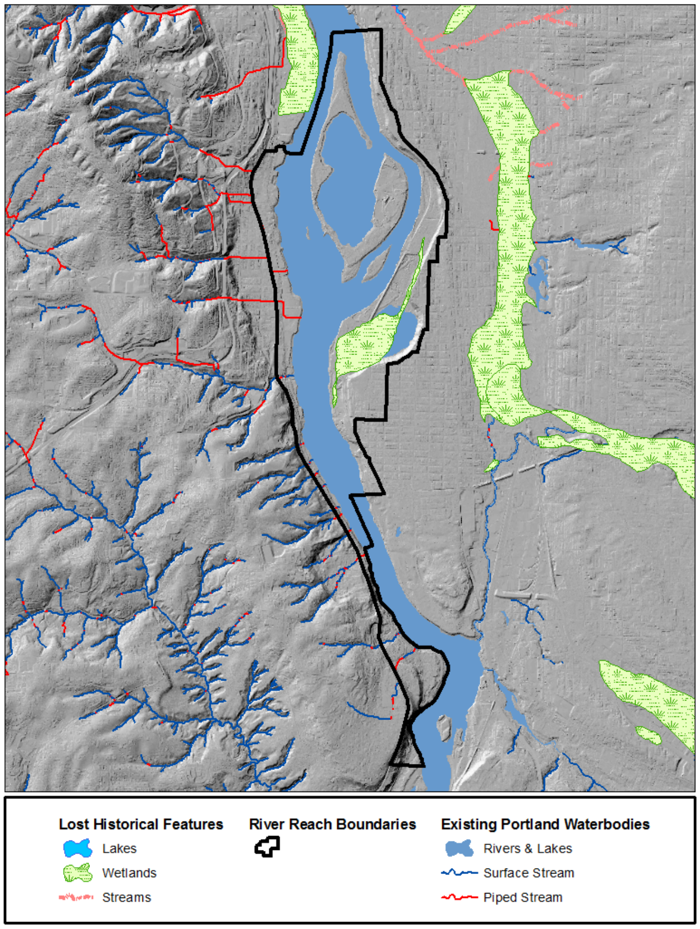
On the east side of the South Reach Oaks Bottom—a large marsh, scrub-shrub, and forested wetland complex – bordered the main channel and extended approximately 2,000–2,500 east to the bluffs. This wetland complex (~ 292 total acres) was fed by springs and tributaries coming from the uplands.

The Willamette Park/Ross Island/Oaks Bottom complex provided a high-quality combination of in-channel gravel islands, secondary channel, and off-channel habitat. In-channel islands and gravel deposits typically have a strong hyporheic connection to the river, and provide important functions for river health. The flow of river water through the gravel cools and cleans the water, and fish are often found at the upwelling sites common on these features. The island and Oaks Bottom wetland complex would have been inundated under flood flows, providing high quality habitat and refuge.

Although outside the boundaries of the South Reach and the city limits of Portland, Johnson Creek is a major tributary to the lower Willamette River. This creek—particularly the lower portion of this watershed with the abundant groundwater flow provided by Crystal Springs, would have provided valuable off-channel habitat and cool water refuge to juvenile salmon migrating through the lower river.

Ross Island provides the greatest amount of remaining connected off-channel habitat in the lower Willamette River through Portland (Figure 29). The Holgate Channel provides relatively high-quality secondary channel, although bank erosion is prominent along the eastern bank of the channel. The interior lagoon within Ross Island has actually increased in size and depth due to mining activities. Although the mining activities have considerable impacts on the quality of habitat in the lagoon, the island still provides high quality off-channel habitat relative to the rest of the reaches. In general, having a habitat complex of the quality and diversity of Ross Island and Oaks Bottom in such close proximity to the heart of downtown is an invaluable resource that is rare in urban areas across the country.

Figure 29: Historical off-channel lakes, wetlands and streams that have been lost to development over time in the South Reach.



The confluence with Johnson Creek still provides valuable off-channel habitat, but the impacts to Johnson Creek and in particular the excessive heating of Crystal Springs have diminished the quality of lower Johnson as an off-channel refuge.

3.2.6 South Reach – West Bank

At the south end of South Waterfront in the vicinity of Cottonwood Cove the topography narrowed the historical floodplain considerably. To the south the floodplain expanded again as the topography curved away from the river in the Johns Landing area, the 1964 and 1996 floods covered the majority of what is now Willamette Park up to the rail line. The historical floodplain is estimated to be 1000–1500 feet wide in this area. The historical floodplain in the Stephens Creek and Riverview areas was constrained by the base of the Tualatin Mountains and the basalt trench through which the main channel flows (Hulse et al., 2002), and is therefore limited to only a very narrow frontage of the Willamette River. The banks in this subwatershed did not substantially overflow during historical (1861–1890) or recent floods (1940–1996) (Hulse et al. 2002). There were a number of small tributaries draining the West Hills and joining the mainstem along the length of this segment, the largest of these being Stephens Creek.

Many of the small tributaries draining the west side have been piped underground, and all of them pass through culverts and are disconnected from the mainstem. The lower portion of Stephen's Creek contains one of the highest quality remaining examples of bottomland forests surrounding tributary confluences with the mainstem and contains one of the more diverse salmonid assemblages of the tributary sites sampled so far within the City of Portland (ODFW 2002). This confluence has been extensively restored. A Combined Sewer Overflow pipe running along the stream was removed in 2008[19], the channel and floodplain improved and revegetated, and a culvert below the trail was replaced with a bottomless culvert that allowed fish, amphibian and other wildlife passage to an additional section of the creek.

3.3 Bank Condition

ODFW documented bank composition in the ODFW fish study (ODFW 2005). Over time the City of Portland has filled in some gaps in the ODFW survey (e.g., Swan Island Lagoon) and extended the survey out into the Columbia river shoreline within Portland. The results of both surveys are show and summarized in Figure 30. The results within each reach are described in the sections that follow.

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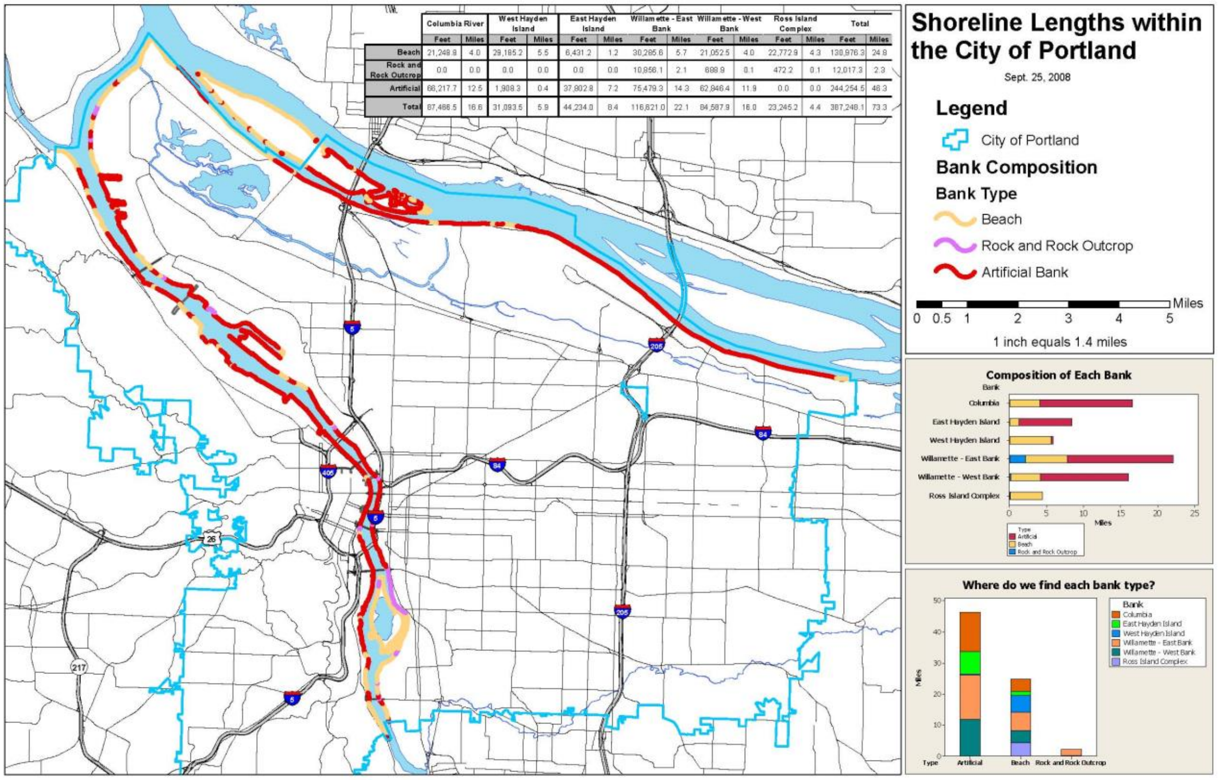
[19] https://www.portlandoregon.gov/bes/index.cfm?&a=192593

Figure 30: River bank composition along the Willamette and Columbia rivers through Portland.



	Columbia River		West Hayden Island		East Hayden Island		Willamette - East Bank		Willamette - West Bank		Ross Island Complex		Total	
	Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles
Beach	21,248.8	4.0	29,185.2	5.5	6,431.2	1.2	30,285.6	5.7	21,052.5	4.0	22,772.9	4.3	130,976.3	24.8
Rock and Rock Outcrop	0.0	0.0	0.0	0.0	0.0	0.0	10,856.1	2.1	688.9	0.1	472.2	0.1	12,017.3	2.3
Artificial	66,217.7	12.5	1,908.3	0.4	37,802.8	7.2	75,479.3	14.3	62,846.4	11.9	0.0	0.0	244,254.5	46.3
Total	87,466.5	16.6	31,093.5	5.9	44,234.0	8.4	116,621.0	22.1	84,587.9	16.0	23,245.2	4.4	387,248.1	73.3

3.3.1 North Reach

Historical. As discussed previously, the North Reach was one of the most unconstrained reaches below Willamette Falls. The low-lying floodplains and delta islands and dynamic river processes probably resulted in significant channel movement, and therefore, changing bank conditions. The *Willamette River Inventory* (Adolfson 2003) states that the river was historically a half mile wide with a large shoal along the east river bank, across from the Linnton subwatershed in the North Reach. Surveys from the 1800's indicate that the banks in the North Reach were dominated by beaches (59% of the bank length), followed by wetlands (33%) and steep banks (7%; Figure 31).

Current. Although the length of beach habitat has been reduced by over half of what was present historically, the reach currently retains a significant portion of beach habitat (25% of total reach length), particularly along the eastern bank of the north end of the reach and near the mouth of Multnomah Channel. However, no wetland habitat remains[20], and 73% of the banks have been converted to artificial bank structures such as rip rap and seawall. Bank hardening is most prevalent along the dock and industrial facilities throughout this reach (Figure 31). Banks have

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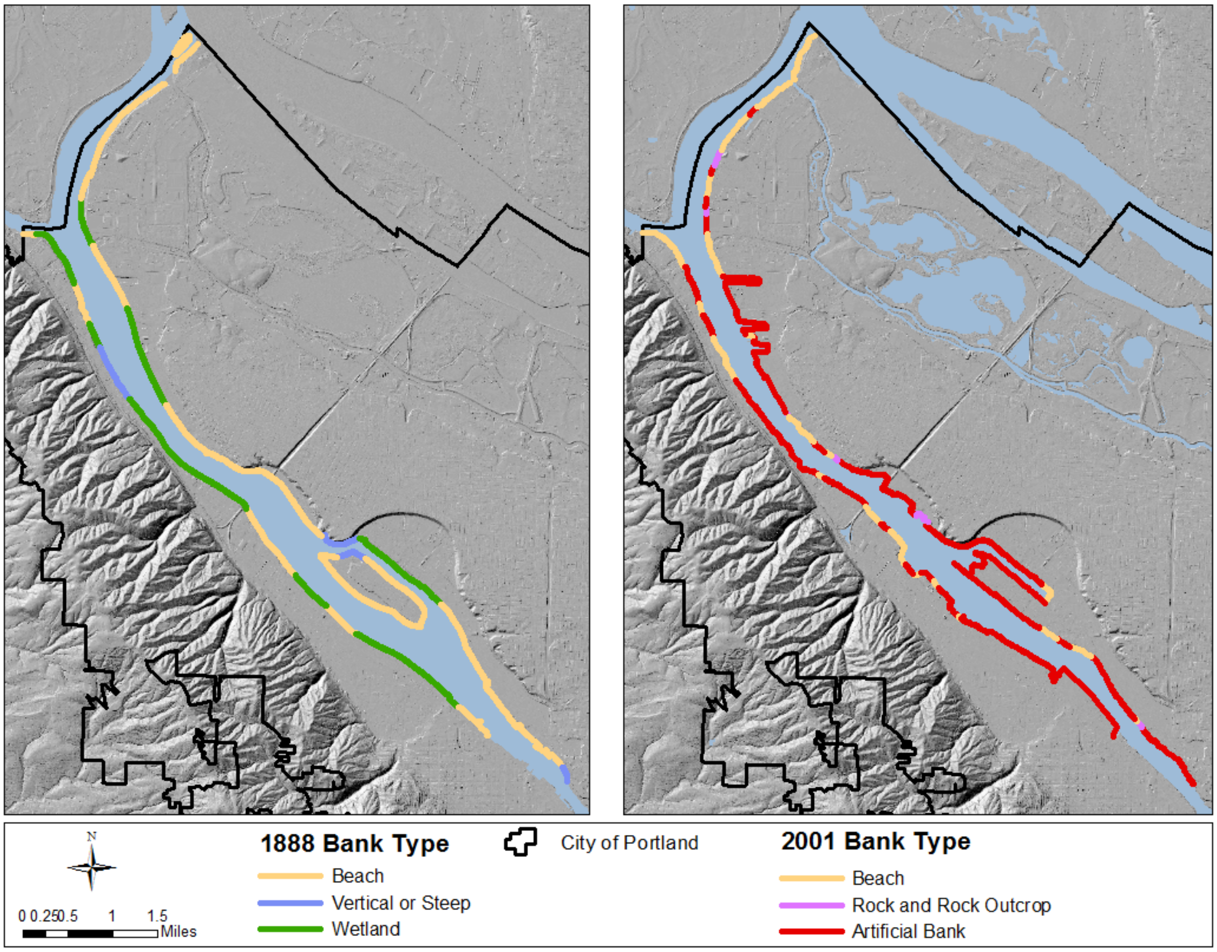
[20] Note that one exception would be the wetlands at the Portland General Electric. The banks are correctly classified as beach, but wetlands are present just beyond the banks.

been diked and steepened with dredge fill over the years, which has further confined the channel and limited connection to the floodplain.

Figure 31: Changes in bank types along the North Reach of the lower Willamette River. Artificial banks now comprise 73% of the segment length, and wetlands are largely absent as a bank type.



1888			2001		
Bank	**Length**	**Percent**	**Bank**	**Length**	**Percent**
Beach	71977	59%	Beach	32408	25%
Vertical or Steep	8930	7%	Rock	3707	3%
Wetland	40623	33%	Artificial Bank	95346	73%

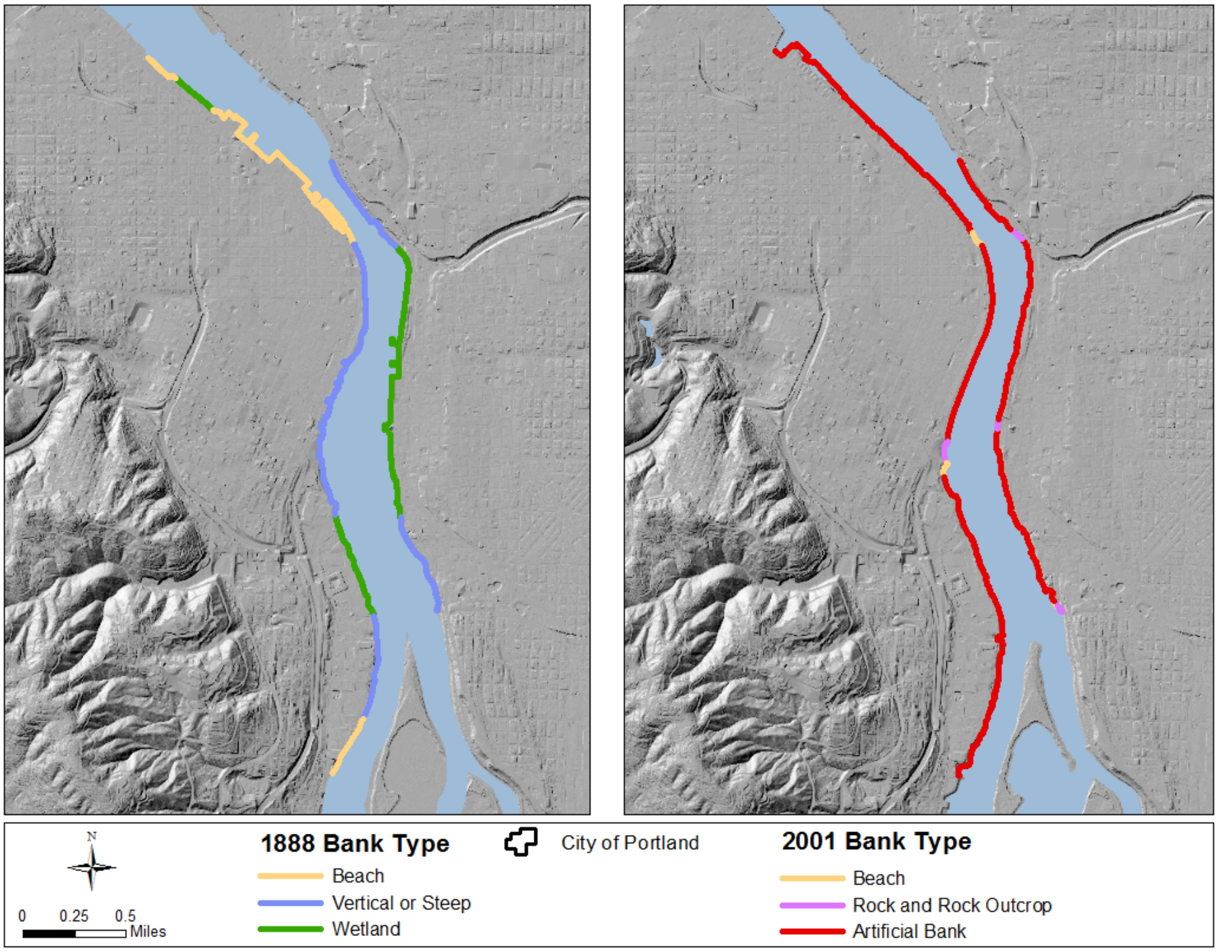
3.3.2Central Reach

Historical. The Central Reach was historically moderately constrained. Surveys from 1888 indicate that the banks in this segment were equally divided between wetlands and vertical or steep banks, with steep banks dominating the west bank and wetlands along the east bank (Figure 32). Wetlands on the west bank were primarily along the low shelf provided in what is currently South Waterfront. On the east bank wetlands comprised about two-thirds of the reach, from Sullivan's

Gulch to the south. Beaches were not nearly as prevalent in this reach as in the north and south reaches.

Current. The Central Reach has the highest percentage of artificial bank structures (93%), with only a few short stretches where natural bank remains. Seawall, unclassified fill, and vegetated rip rap are the most common bank types in this segment. Wetlands have been entirely eliminated and beach habitat has been reduced ten-fold from historical lengths.

Figure 32: Changes in bank types along the Central Reach of the lower Willamette River. Artificial banks now comprise 93% of the segment length, and wetlands are absent as a bank type.



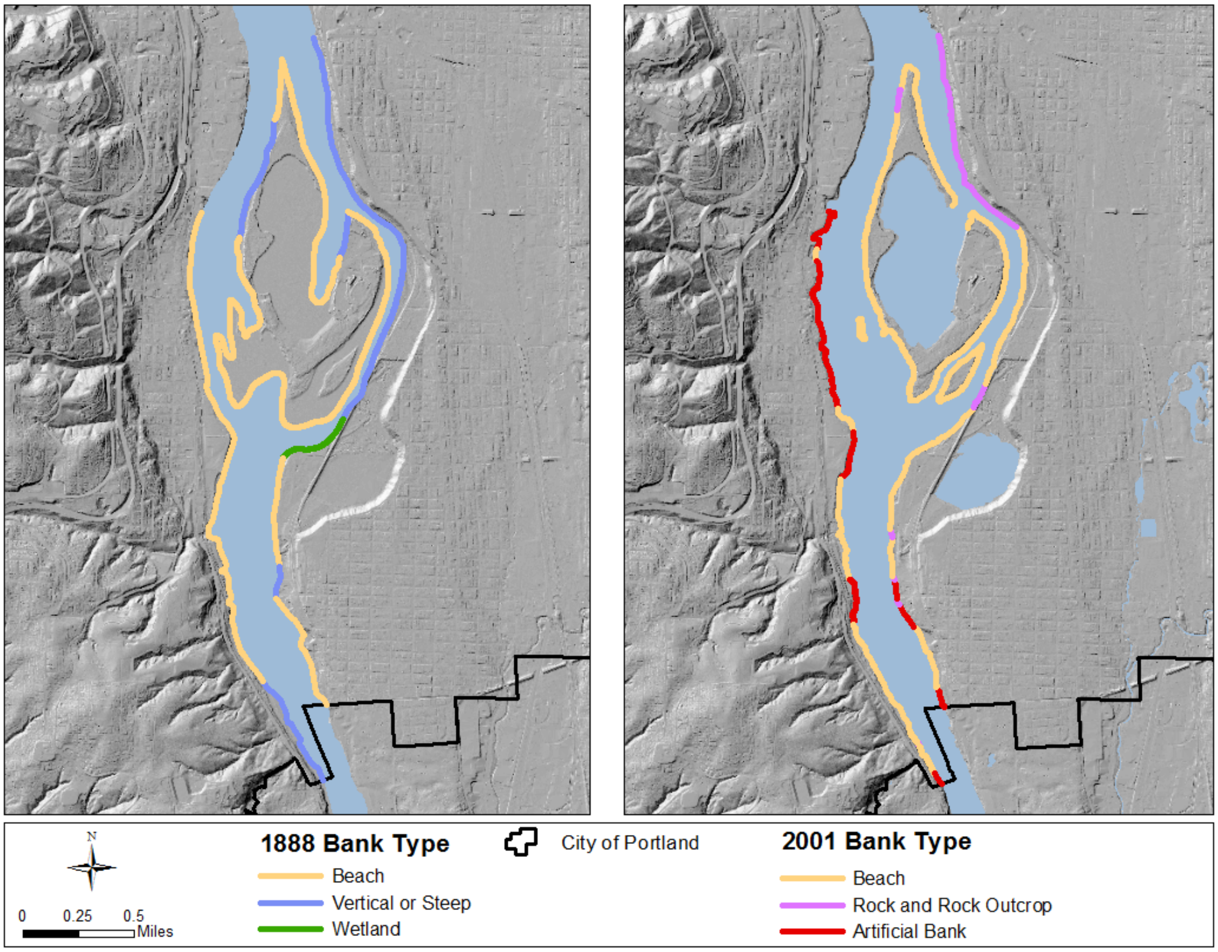
1888			2001		
Bank	**Length**	**Percent**	**Bank**	**Length**	**Percent**
Beach	11156	28%	Beach	1048	3%
Vertical or Steep	16110	40%	Rock	1389	4%
Wetland	12574	32%	Artificial Bank	33526	93%

Figure 33: An historical aerial photo from 1926 showing Oaks Bottom and Ross Island. Consistent with the bank survey, the banks adjacent to the southern tip of Ross Island are low-lying, and the wetland appears to be hydrologically connected to the mainstem, whereas the banks further north along Holgate channel appear steeper.

3.3.3South Reach

Historical. The nature of the north and south sections of the South Reach – the upstream Sellwood section and the downstream Ross Island section – are very different. The channel was historically confined in the upstream Sellwood portion, the most restricted portion within the management area. The channel is less confined upon reaching Ross Island and Oaks Bottom. Surveys from 1888 indicate that the banks in the South Reach were dominated by beaches (69% of the bank length, primarily on the west bank and around Ross Island), followed by steep banks (28%, primarily on the east bank around Ross Island; Figure 34). Wetlands did not appear to be common along the banks of this reach (4%), but did occur at the southern end between Ross Island and Oaks Bottom.

Figure 34: Changes in bank types along the South Reach of the lower Willamette River. Artificial banks now comprise 17% of the segment length, and wetlands are largely absent as a bank type. Note that the interior of Ross Island is not included in 2001, since these are changing in adjustment to past mining and along the south from restoration.



1888			2001		
Bank	**Length**	**Percent**	**Bank**	**Length**	**Percent**
Beach	43620	69%	Beach	40601	71%
Vertical or Steep	17808	28%	Rock	6921	12%
Wetland	1824	3%	Artificial Bank	9452	17%

Current. The South Reach currently has slightly more beach habitat (71% of the bank length) than historically. This is in part due to differences in how banks were categorized in the two surveys – the 2001 survey did not have a "steep" category. Much of the shoreline along the Holgate Channel and northern part of Oaks Bottom is considered beach in the recent survey, in spite of the fact that the banks are steep due to the railroad berm separating Oaks Bottom form the mainstem. Twenty-three percent of the banks have been converted to artificial bank structures such as rip rap and seawall, by far the lowest of any of the segments. Bank hardening is most prevalent along the western shore opposite of Ross Island, along South Waterfront and Willamette Park.

3.4 Vegetation

As stated in Christy and others (2009) assessment of vegetation change in Portland: "Urbanization has had inevitable and predictable effects on the region's vegetation. Wetlands have declined locally by 97 percent, coniferous forest by 92 percent, prairie and savanna by 90 percent, riparian and wetland forest by 58 percent, and oak communities of any sort by 40 percent." (pg. 2)

3.4.1North Reach

Based on surveys in the 1850's, the northern half of the North Reach was a vast complex of forested, scrub shrub, and prairie wetlands (Figure 35). The west hills and Willamette Escarpment formed the edges of the riparian area contributed to the diverse plant communities that supported the bountiful Willamette River wildlife.

Many forested and woodland areas both near the river and in the uplands had recently burned. The history of vegetation in the Portland area includes the indigenous people that managed vegetation for thousands of years before approximately 1840. The Cowlitz and Upper Chehalis Indians of the Puget lowlands and the Kalapuya tribes of the Willamette Valley regularly set fires to favor plants on which they depended for food and medicine. Important savanna plants were camas (*Camassia* sp.), wild onion (*Allium* sp.), and tarweed (*Madia* sp.). Some woodlands were deliberately left unburned to provide areas where deer, elk, grouse, and other game would concentrate. The remnant of the diverse habitats is noted in detail in the 1852 maps. (2012, Biodiversity Guide).[21]

Sauvie Island provided extensive wetland prairie habitat, with isolated patches of emergent wetlands and ponds. Ash-mixed deciduous forest occurred along the riparian portion of the island closest to the main channel and Multnomah Channel.

The most obvious change from the historical condition has been the large-scale removal and transformation of vegetation throughout the riparian and upland areas adjacent to the North Reach. Over time the floodplains and riparian areas have been filled and cleared of vegetation to provide industrial and port facilities along the mainstem, and agricultural and residential uses along Sauvie Island. In addition, physical and hydrological changes[22] have reduced the frequency with which the river interacts with the floodplain. This represents a major shift in conditions and stress to vegetation adapted to regular inundation, and so remaining or newly establishing vegetation in the riparian and floodplain reaches has adapted to these altered conditions.

Relative to the adjacent uplands—where Forest Park still provides a large contiguous upland forest—the riparian and floodplain areas of the North Reach have few remaining vegetated patches of significant size. The *Willamette River Inventory* (Adolfson 2003) describes the composition and nature of these few remaining habitat areas, which include Kelley Point Park, remnant riparian forest, and the Harborton Forest and Wetlands. These areas are generally

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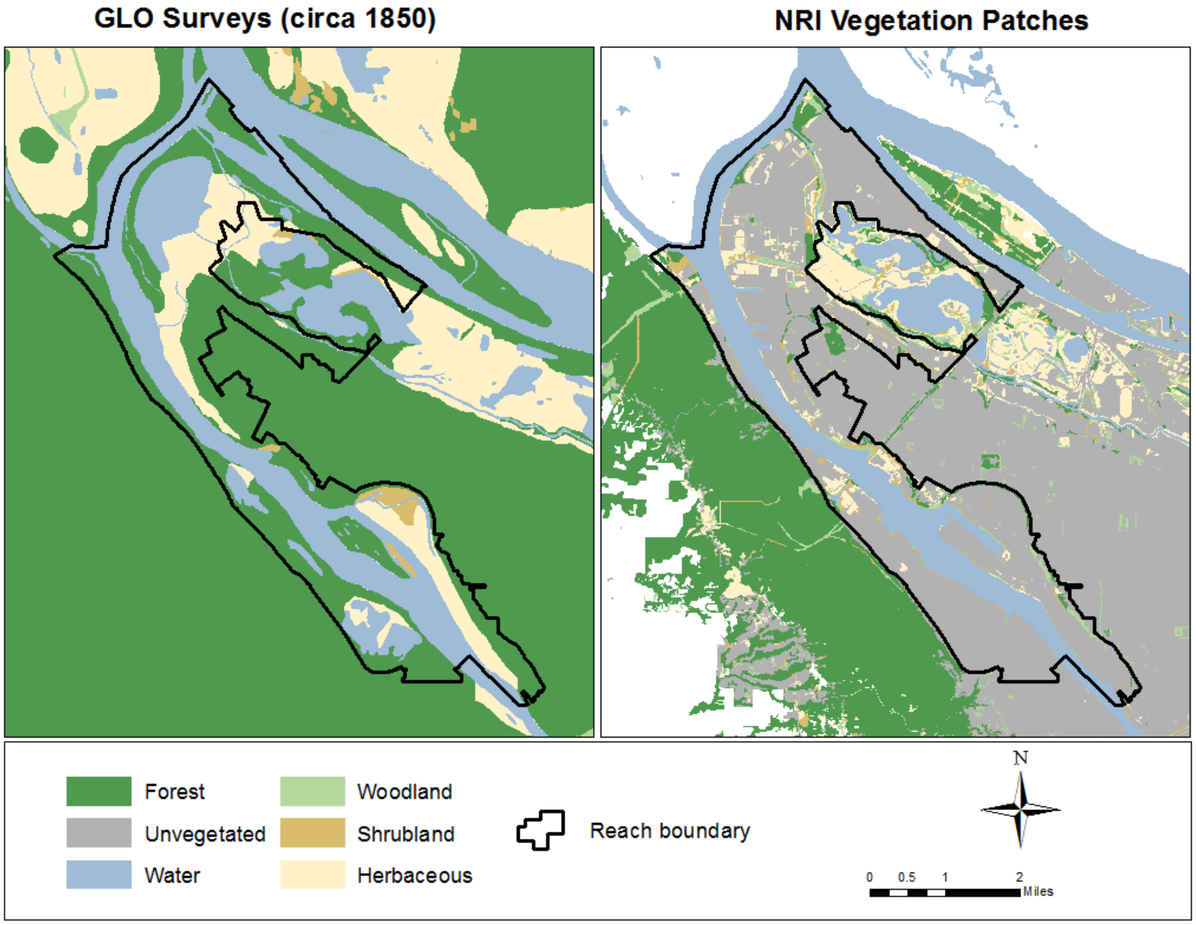
[21] The Intertwine Alliance. 2012. Biodiversity Guide for the Greater Portland-Vancouver Region. A. Sihler, editor. The Intertwine Alliance, Portland, OR. www.theintertwine.org

[22] Filling floodplains and the reduced range of flows (reduced peak flows and higher summer low flows. The will be described in the hydrology chapter of the full report.

comprised of bottomland forest, shrub and meadow structures. Cottonwood with willow, snowberry, and blackberry understory are prominent, with ash in the Linnton/Harborton area.

Figure 35: Historical and current vegetation in the North Reach. Note that in the current NRI Vegetation Patches panel, "unvegetated" means that if any vegetation is present, it is of a size smaller than the 1/2 acre threshold used in the NRI.



3.4.2Central Reach

Historically the vegetation was a diverse assemblage in the short Central Reach. Mixed conifer, red alder-mixed conifer, and prairie covered the western banks; Douglas fir-white oak, mixed conifer, and shrubland covered the eastern banks (Figure 36[23]). An emergent wetland was located at the mouth of Sullivan's Gulch. The 1850's vegetation maps show some small off-channel lakes that are not evident in the 1888 channel survey. These may have been filled by the 1888 survey, by which point downtown had undergone significant development. As in the North Reach the diversity of the vegetation was driven by disturbances such as floods and fire. The open woodlands and

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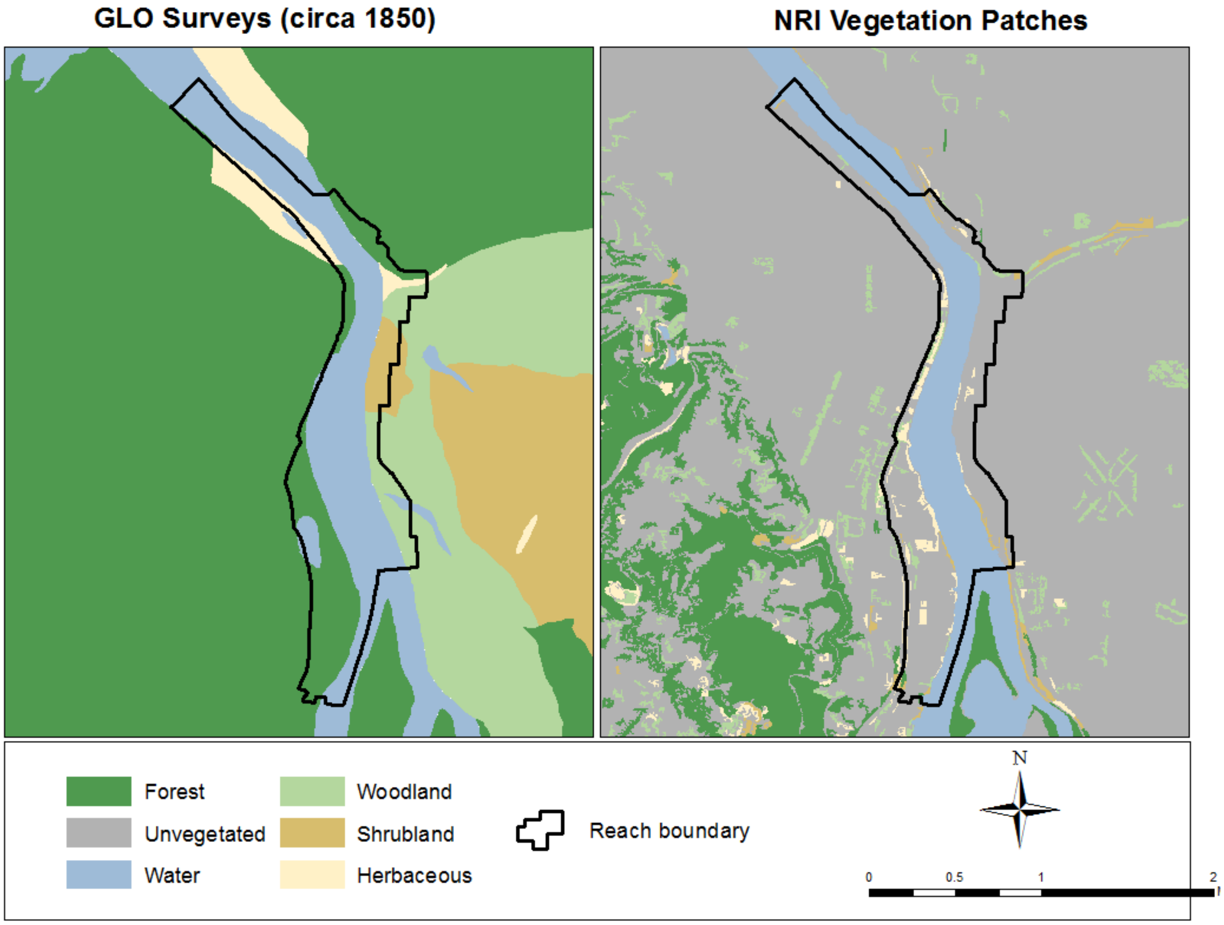
[23] Note that for comparison to the current Natural Resources Inventory the historical data are aggregated into the NRI categories (Forest, Woodland, etc.). However, the original GLO data did provide more detailed species composition and the species mentioned are from these more detailed data.

prairies on the east side were unhospitable landscapes for the typical coniferous forest of the NW, high water tables, and frequent fire maintained open woodlands and prairies. The lake at the confluence of Marquam Gulch provided wetlands functions in the Willamette River floodplain and suggests that the high water table in this area influenced the vegetation community of the riparian area.

Figure 36: Historical and current vegetation in the Central Reach. Note that in the current NRI Vegetation Patches panel, "unvegetated" means that if any vegetation is present, it is of a size smaller than the 1/2 acre threshold used in the NRI.

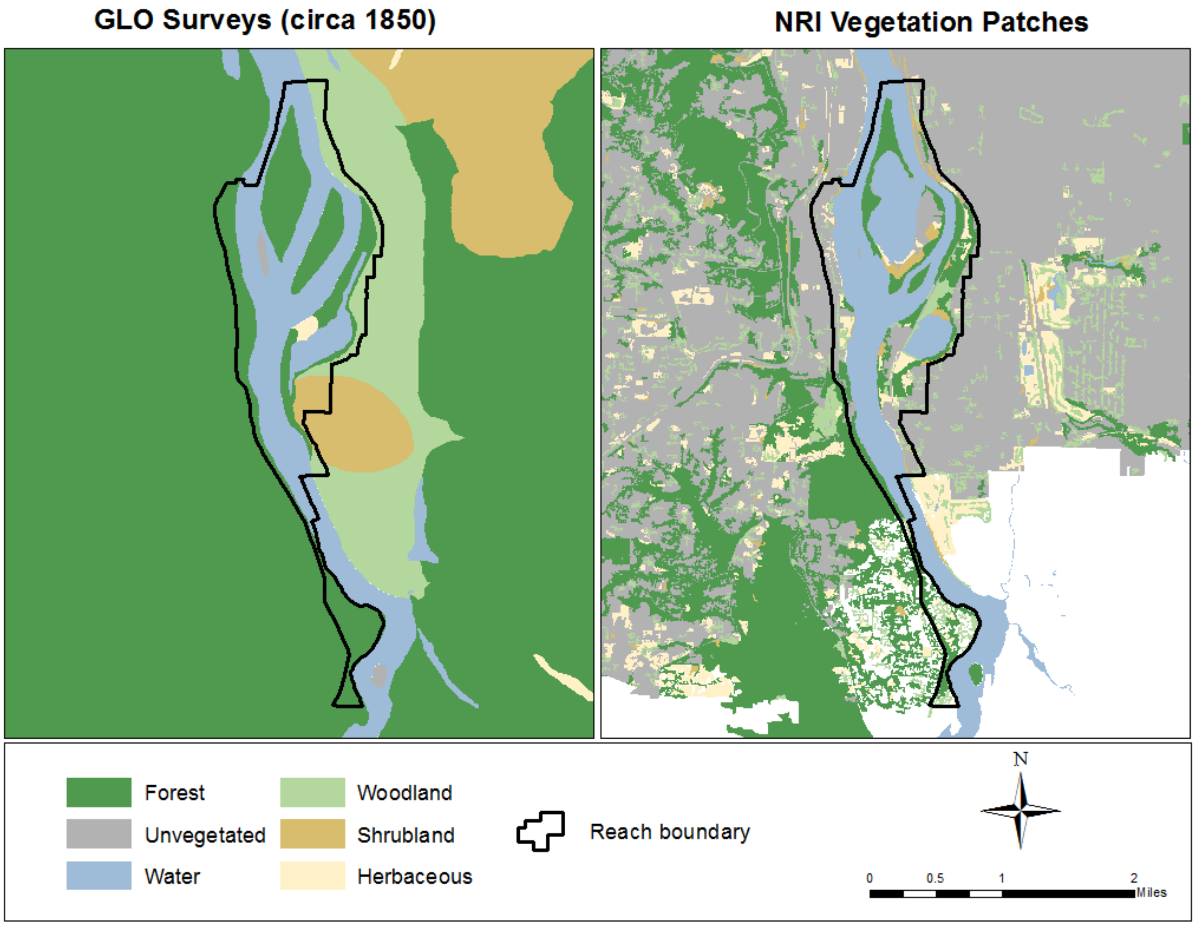


The Central Reach was the first reach to experience large scale vegetation removal as the city was platted and developed. The current density of street trees is actually higher than is evident in many of the early historical photos of downtown, although of no comparison to the amount, diversity, or composition of vegetation present in the 1850's survey. Little significant vegetation remains in the riparian areas of the Central Reach (Figure 36).

3.4.3South Reach

The western banks of the South Reach were dominated by mixed conifer, with a small patch of ash mixed deciduous riparian forest. That small patch is at Willamette Park which is home to 2-300-year-old Oregon white oak. Aerial views of the park in the 1949 Memorial Day flood show the oaks in standing water. Oak woodlands are tolerant of winter and spring flooding and this is a good example of long-lived oaks in the River's floodplain. The vegetation of the eastern banks was more varied, with mixed conifer, Douglas fir-white oak, savanna, and prairie present. Ash-mixed deciduous was present on Ross Island and in Oaks Bottom (Figure 37).

Figure 37: Historical and current vegetation in the South Reach. Note that in the current NRI Vegetation Patches panel, "unvegetated" means that if any vegetation is present, it is of a size smaller than the 1/2 acre threshold used in the NRI.



The South Reach still retains some vegetation in close proximity to the channel at Willamette Park, Powers Marine Park, Ross Island, Oaks Park, and Oaks Bottom. In addition, the physical and hydrological changes described earlier have reduced the frequency with which the river interacts with the floodplain. This represents a major shift in conditions and stress to vegetation adapted to regular inundation, and so remaining or newly establishing vegetation in the riparian and floodplain reaches would have to adapt to these altered conditions. There are remnant ancient oaks in the floodplain wetlands of Dunthorpe (Fielding Wetlands).

The *Willamette River Inventory* describes the composition and nature of these few remaining habitat areas, which include Ross Island, Oaks Bottom, Cottonwood Bay, Stephens Creek, Willamette Park, and Powers Marine Park. These areas are generally comprised of bottomland forest, shrub and wetland areas. Cottonwood with willow, red osier dogwood, and blackberry understory are prominent, with foothill savanna/oak woodland and conifer/hardwood forests also present.

3.5 Habitat Types

The Bureau of Environmental Services (BES) identified and mapped key natural resource features as part of the Portland Watershed Management Plan's terrestrial work (the Terrestrial Ecology Enhancement Strategy), including resources in the lower Willamette River (BES 2010). Anchor habitats, special status habitats, special status species and habitat corridors were defined, identified, and in some cases, mapped. Special status habitats in the lower Willamette include:

- herbaceous wetlands
- upland prairie and native grasslands
- oaks woodlands
- interior forests
- late successional conifer forests
- bottomland hardwood forests and riparian habitats

Some of these features are mapped with the BPS NRI process, including Special Habitat Areas. BES completed additional mapping, summarized for the lower Willamette River in Table 1.

Table 1: Natural resource features identified as part of the terrestrial Ecology Enhancement Strategy.

NORTH REACH				
Site	**Anchor**	**Species Assemblages**	**Special Status Habitats**	
			Interior Forest	**Oak Woodland**
Kelly Point	✓	✓		
Ramsey Wetland Complex	✓	✓		
Harborton Forest & Wetland Complex	✓	✓		
Burlington Bottoms	✓	✓		
West Wye & Powerline Wetlands		✓		
Forest Park	✓	✓	✓	✓
Westside Wildlife Corridor[1]	✓	✓	✓	✓
Doane Lake & Wetlands	✓	✓		
Willamette Bluff Oak Corridor[2]		✓		✓
Balch Creek		✓		
Balch Creek Headwaters[5]			✓	

CENTRAL REACH				
Site	**Anchor**	**Species Assemblages**	**Special Status Habitats**	
			Interior Forest	**Oak Woodland**
Westside Wildlife Corridor[1]	✓	✓		✓
Cottonwood Bay[3]		✓		
Marquam Nature Park			✓	
SOUTH REACH				
Westside Wildlife Corridor[1]	✓	✓		✓
Willamette Park		✓		✓
Riverview Cemetery	✓		✓	
Ross Island	✓			
Oaks Bottom Wildlife Refuge	✓	✓		✓
South Portland Waterfront[4]	✓	✓		
Waverly Country Club				✓
Elk Rock Island	✓	✓		✓
Elk Rock Cliff		✓		✓
Tryon Creek State Natural Area	✓	✓	✓	
Willamette Bluff Oak Corridor[4]		✓		✓

1. Council Crest, Marquam Nature Park, Terwilliger Wilds, Stephens Creek Canyon, George Himes Park, Forest Park, Tryon Creek State Natural Area
2. Univ of Portland, Mock's Crest, Willamette Cove, Baltimore Woods, Marquam Oaks, Dunthrope Oaks, Oaks Bottom Bluff, Elk Rock Island & Cliff
3. West river shoreline across from Ross Island
4. Moorage Park & Powers Marine Park
5. Metro properties, Audubon Society of Portland Sanctuary, and private forest lands outside City of Portland

4 Water Quality

BES has operated an ambient water quality monitoring program on the Willamette River since the 1990s. As part of this program, BES collects water quality samples to assess river conditions under different seasonal states and river flows. The monitoring data are used to identify whether the portion of the Willamette River flowing through Portland is attaining the applicable water quality standards and can be used to assess trends in different parameters over time.

This section provides a summary of the water quality data collected as part of the Bureau's Willamette River ambient water quality monitoring program. In addition to the water quality summary, this report provides an assessment of water quality trends observed at the mainstem ambient monitoring sites. Extensive monitoring of the Willamette River has been conducted as part of the Portland Harbor clean-up effort (EPA, 2016). A more extensive summary of the sediment data collected as part of the Portland Harbor monitoring effort is included in Section 4.7.

4.1 Designated Beneficial Uses

Multiple designated beneficial uses apply to the lower Willamette River. These represent the "purpose or benefit to be derived from a water body as designated by the Water Resources Department or the Water Resources Commission" (340-041-0002(17)). For the lower Willamette River in Portland, the designated beneficial uses include (340-041-0340 Table 340A):

- Public and private domestic water supply
- Industrial water supply
- Irrigation
- Livestock watering
- Fish and aquatic life
- Wildlife and hunting
- Fishing
- Boating
- Water contact recreation
- Aesthetic quality
- Hydro power
- Commercial navigation and transportation

The water quality standards that apply to this segment of the Willamette are based on the designated beneficial uses listed above. In addition, fish designation uses also apply. The lower 50 miles of the Willamette River has been designated a salmon and steelhead migration corridor from the confluence with the Columbia River to Newberg (OAR 340-041-0028 Figure 340A).

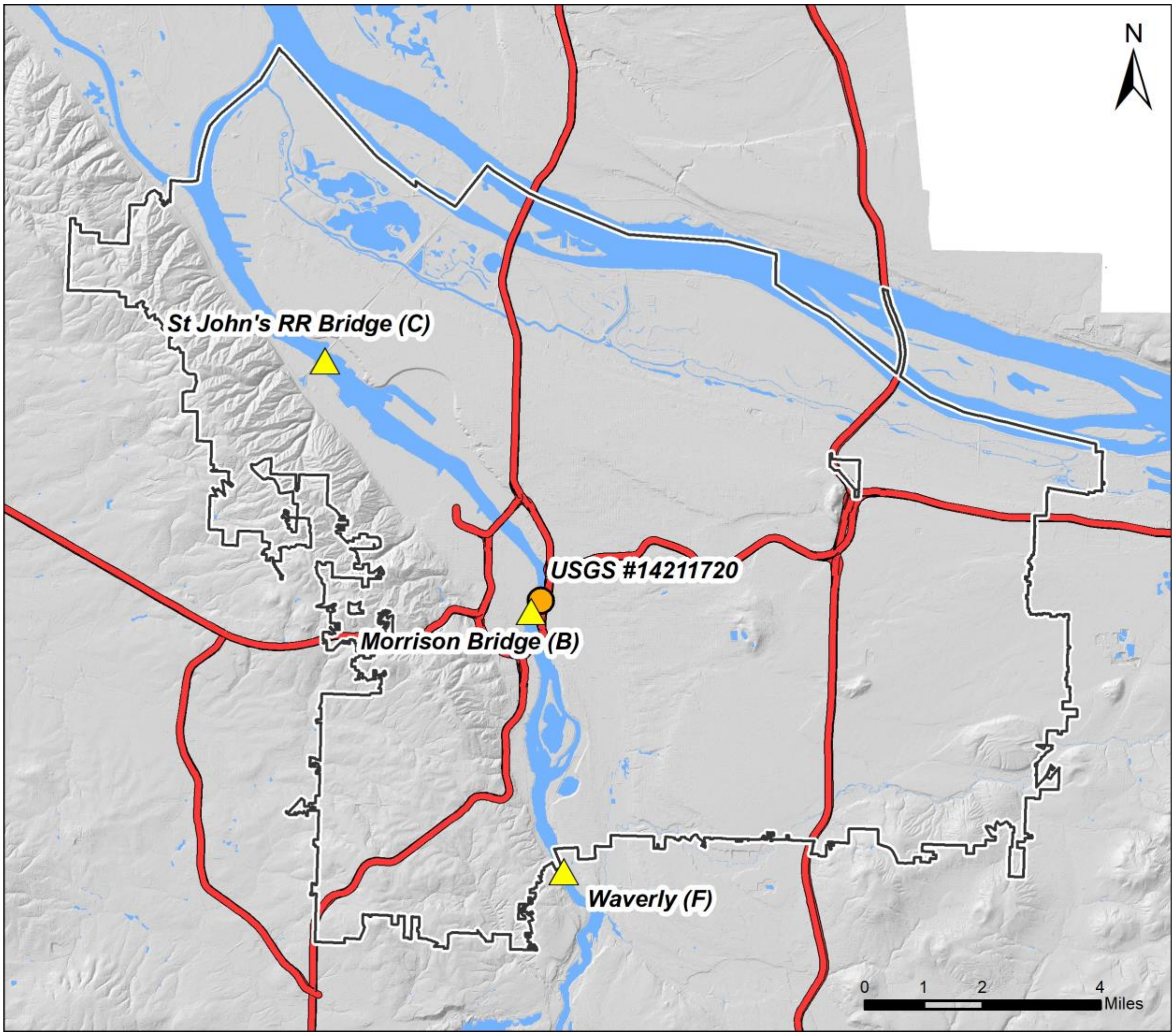
4.2 Sampling Approach and Monitoring Locations

The ambient water quality monitoring program operated by BES has evolved over time. Since the beginning of the program, BES has sampled six different monitoring stations along the Willamette River (Table 2). The sites provide information on water quality at different points along the Willamette River in Portland. Currently, there are three active Willamette river stations, capturing conditions at different locations throughout the city. All samples are collected from approximately 10 feet below the water surface.

Table 2. Active and discontinued BES sampling sites on the mainstem Willamette River.

Site ID	Location Description	Year Last Sampled	Status
A	Tryon Creek Bridge - River Mile 20.0	2000	Discontinued
F	Waverly Country Club - River Mile 17.4	--	Active
B	Morrison St Bridge - River Mile 12.7	--	Active
E	Swan Island - River Mile 8.8	1999	Discontinued
C	St John's RR Bridge - River Mile 6.8	--	Active
D	South Kelly Point Park - River Mile 1.1	2011	Discontinued

Figure 38. Location of the active Willamette River monitoring stations and the USGS stream gauge (#14211720).



Past analyses of data from the monitoring sites has informed changes to ambient monitoring program. Sampling at the Kelly Point Park station (D; river mile 1.1) was discontinued in 2011. Analysis of the samples from this site revealed that the observed conditions were highly influenced by conditions in the Columbia River. Sample collection at the Tryon Creek bridge station (A; river mile 20.0) was discontinued due to problems associated with sampling near the discharge point from the Oak Lodge wastewater treatment facility. Sampling of the Swan Island station (E; river mile 8.8) was suspended in 1999 due to budget restrictions.

The original sampling approach employed by the ambient monitoring program included the collection of samples from three locations across the channel (east, middle, and west) at each monitoring station. *In situ* measurements were recorded at each of the three points across the channel (east, middle, and west) at each monitoring station and samples for other analytes (except *E. coli* and nutrient samples) were collected as a composite of samples from the three points across the channel. In 2013, BES staff assessed the difference between the east/middle/west composite samples and single grab samples collected from the middle of the channel. The analysis found no differences in concentrations between the single grab samples and the composite samples across all analytes (Abrams, 2013). Based on the results of the analysis, the east/middle/west composite sampling was discontinued. Since 2013, only grab samples from the middle of the river have been collected.

In addition to changes to monitoring locations, BES has made adjustments to the frequency of sample collection over time. At the beginning of the program, BES collected Willamette River samples on a weekly basis. In July 2000, the sampling frequency was reduced to twice per month and then reduced to monthly sampling at the beginning of 2003. Not all analytes have been sampled at the same frequency. For example, some metals were collected during each sampling event, while others were collected on a quarterly basis. More detailed information on the sampling frequency of each analyte is included in the summary below.

Water quality data are also recorded by the USGS in Portland. The USGS operates a continuous stream gauge at the Morrison Bridge (USGS# 14211720). In addition to flow, the gauge records chlorophyll concentrations, conductivity, dissolved oxygen, dissolved organic matter, *in vivo* fluorescence as a measure of cyanobacteria, pH, nitrate, and turbidity.

4.3 Water Quality Data Summary

This section provides a summary of the water quality data collected to date at the three active Willamette River monitoring stations. The summaries are presented by site for each analyte. Based on the findings from the prior comparison of the east/middle/west composites to the single grab samples (Abrams, 2013), the composite samples and mid-river grab samples are presented and summarized together.

4.3.1Field Measures

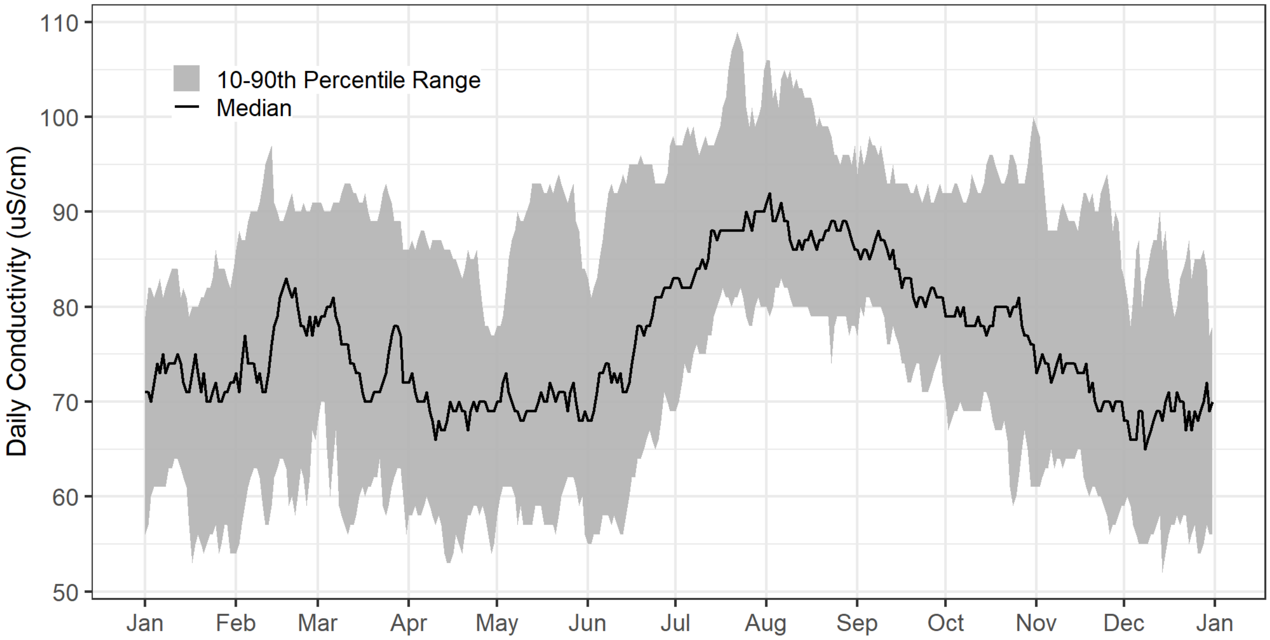
Conductivity, dissolved oxygen, pH, Secchi depth, and temperature are all measured in the field at each monitoring station. Field measures are collected *in situ* at the same time as the grab samples. Where applicable, these readings are used to calculate parameter-dependent water quality criteria, such as ammonia and copper. Additionally, continuous conductivity, dissolved oxygen, and water temperature data are also collected by the USGS at the Morrison Bridge station.

4.3.1.1 Conductivity

Conductivity, or specific conductance, in freshwater systems is a measure of the water's ability to conduct electricity. As the ion content of the water increases, its resistance to electrical current declines. Conductivity is a good measure of the presence of inorganic acids, bases, and salts that readily dissociate in aqueous solutions. The underlying geology of an area often drives the abundance of dissolved solids that influence the conductivity of a waterway. Additionally, changes in conductivity, particularly increases, can serve as an indicator of possible pollutant sources. For example, activities such as the application of de-icers on roadways can impact rivers and streams, resulting in a substantial increase in conductivity. Dramatic increases in conductivity can negatively impact aquatic organisms.

Oregon DEQ has not established water quality criteria for conductivity. The USGS records conductivity at the Morrison Bridge station every 30 minutes, beginning in 2009. Conductivity in the Willamette varies across the year. Conductivity is typically highest in the summer months when discharge in the river is lowest. When flows begin to increase in the fall, conductivity in the Willamette begins to decrease.

Figure 39. Willamette River daily median and 10th–90th percentile range of conductivity recorded by the USGS at the Morrison Bridge (USGS# 14211720) from 2009 to present.

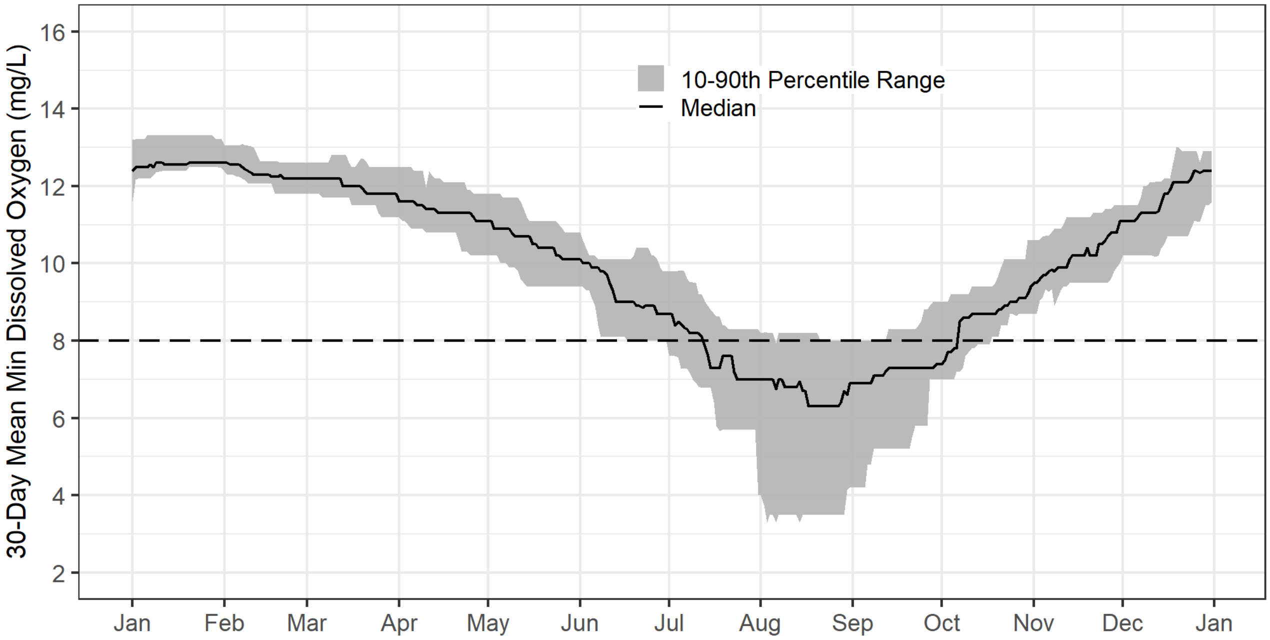


4.3.1.2 Dissolved Oxygen

Dissolved oxygen is essential for fish and other aquatic biota. The concentration of dissolved oxygen in rivers and streams can be affected by instream oxygen demands (biochemical oxygen demand (BOD), chemical oxygen demand (COD), and sediment oxygen demand (SOD)), water temperature, barometric pressure, and stream flow conditions. For water bodies identified by DEQ as supporting cold-water aquatic life, the 30-day mean minimum dissolved oxygen concentration may not be less than 8.0 mg/L and the absolute minimum concentration may not drop below 6.0 mg/L (OAR 340-041-0016 – Table 21).

The USGS records dissolved oxygen concentrations at the Morrison Bridge station every 30 minutes. The data presented below are based on continuous measurements collected by the USGS as they provide a more complete picture of the variability in Willamette River dissolved oxygen concentrations than the *in situ* measurements collected as part of the ambient monitoring program.

Figure 40. Median and 10th–90th percentile range of 30-day mean minimum dissolved oxygen concentrations recorded by the USGS at the Morrison Bridge (USGS# 14211720) from 2009 to present. The dashed line represents the 8 mg/L criterion for cold-water aquatic life.



Over the period of record, the Willamette River did not meet the 30-day mean minimum dissolved oxygen criterion of 8 mg/L approximately 18% of the time—732 days since the beginning of 2009. These excursions occurred during the summer months of July, August, and September. Dissolved oxygen concentrations below the 8 mg/L criterion were observed in every year on the Willamette with the exception of 2010 and 2012.

4.3.1.3 pH

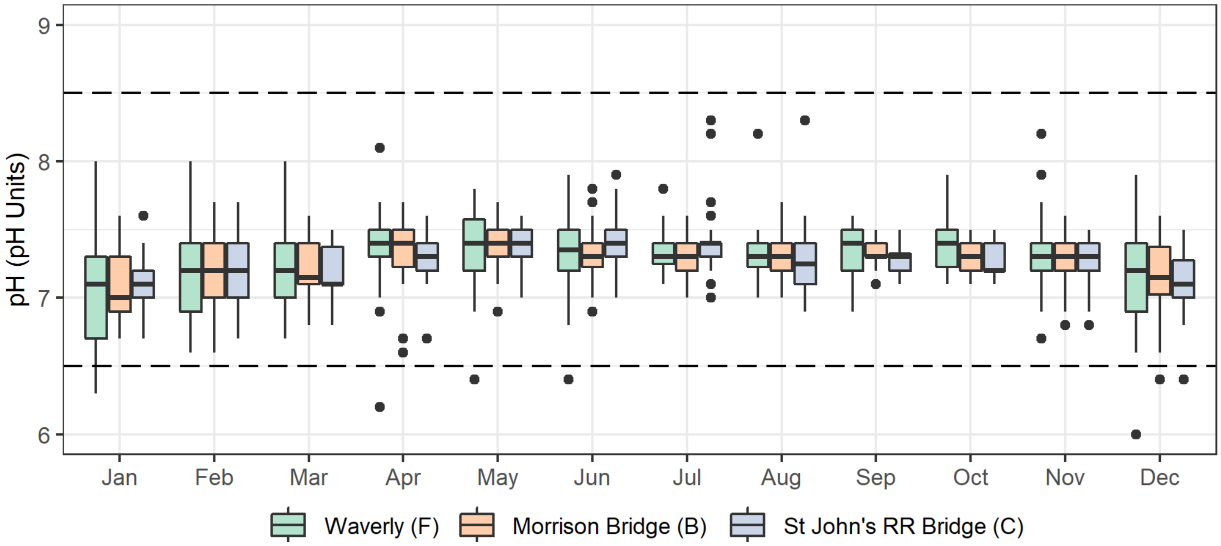
The pH of a water body is a measure of the hydrogen ion concentration or hydrogen ion activity in the water and serves as a measure of the water's acidity. The pH of water determines the solubility and biological availability of many chemical constituents such as nutrients and heavy metals. As such, pH is important in aquatic systems as it is a controlling factor in many chemical reactions.

The Oregon Administrative Rule (OAR 340-041-0345 (1)(b)) specifies the numeric criteria for the pH of freshwater: pH values may not fall outside the range of 6.5 to 8.5 for all basin waters in the Willamette Basin.

Table 3. Summary statistics for pH measured at the three Willamette River sites.

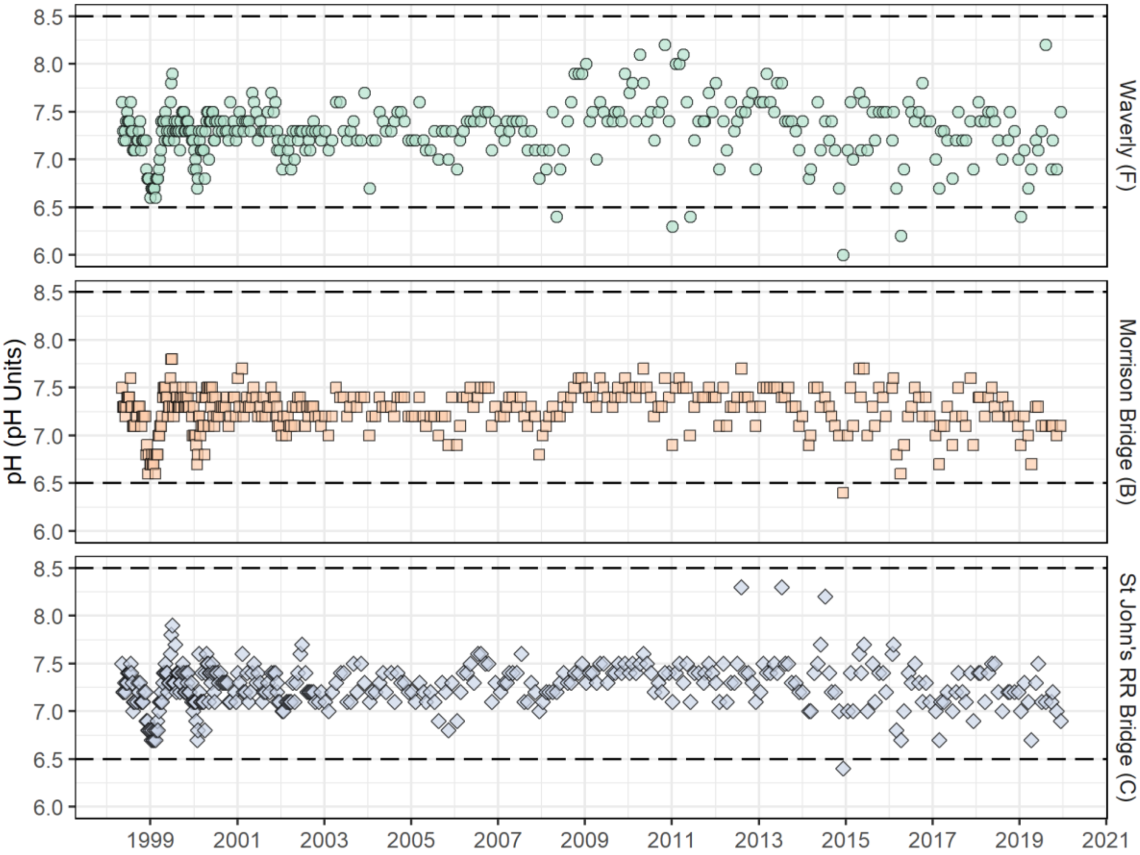
pH (pH Units)								
Site	**Number of Samples**	**Mean**	**Min**	**10th Percentile**	**50th Percentile**	**90th Percentile**	**Max**	**% Exceedance**
F	368	7.3	6.0	6.9	7.3	7.6	8.2	1.3
B	369	7.3	6.4	7.0	7.3	7.5	7.8	0.2
C	368	7.3	6.4	7.0	7.3	7.5	8.3	0.3

Figure 41. Seasonal pH pattern. The dashed lines represent the upper and lower water quality criteria.



In situ pH measurements at the three Willamette stations rarely fell outside the required range for the basin. There was minimal variability in pH observed between the three stations. Additionally, pH did not change substantially across the year, however, lower pH readings were more frequently observed during the winter months.

Figure 42. pH measured at the three Willamette River sites since 1998. The dashed lines represent the upper and lower water quality criteria.



4.3.1.4 Secchi Depth

Secchi depth is a measure of water clarity and serves as an estimate of how deeply sunlight can penetrate the water column. Water clarity is dependent on the abundance of particles in the water column. A large concentration of algae or sediment particles in the water can reduce the transparency of the water, allowing less light to penetrate the water column. A Secchi disc is black and white disc (8-inch diameter) that is lowered into the water column. The depth at which the disc can no longer be seen from the surface is the Secchi depth.

As part of the Willamette River monitoring effort, BES has measured the Secchi depth at all three stations since 1998. Oregon DEQ has not established water quality criteria for water clarity.

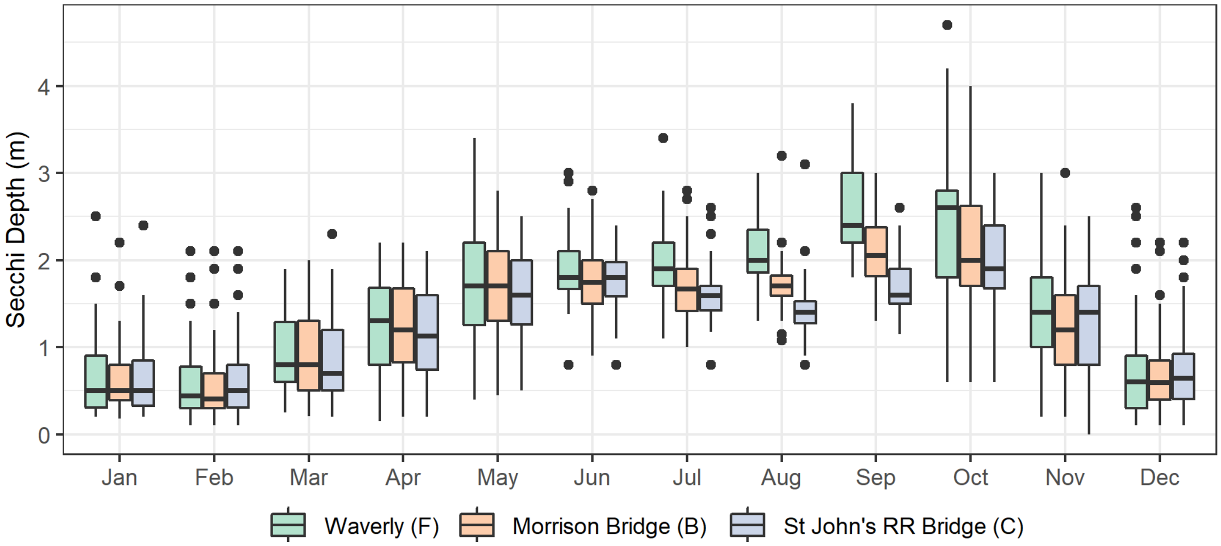
Table 4. Secchi depth summary statistics at the three Willamette River sites since 1994. Higher values represent greater water clarity.

Secchi Depth (m)

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
F	437	1.6	0.1	0.4	1.7	2.6	4.7	NA
B	459	1.4	0.1	0.4	1.5	2.2	4.0	NA
C	458	1.3	0.0	0.4	1.4	2.1	3.1	NA

Over the course of the year, Secchi depths at the three stations have varied, with the highest values typically observed in the fall (September and October). For most of the year, water clarity does not differ between the Willamette stations. In the summer months, however, the Secchi depth is typically highest at the upstream Waverly station (F), with water clarity decreasing as you move downstream with the poorest water clarity frequently observed at the St John's Railroad Bridge station (C).

Figure 43. Seasonal distribution of Secchi depth measurements at the three Willamette River sites. Higher values represent greater water clarity.



In addition to the seasonal pattern in water clarity that is evident above, there is also evidence of an increase in summertime Secchi depths, particularly at the upstream Waverly station (F), over the period of record (Figure 44). A more detailed analysis of the observed trend is described in Section 4.4.5.

Figure 44. Recorded Secchi depth measurements at the three Willamette River sites since 1994.

4.3.1.5 Temperature

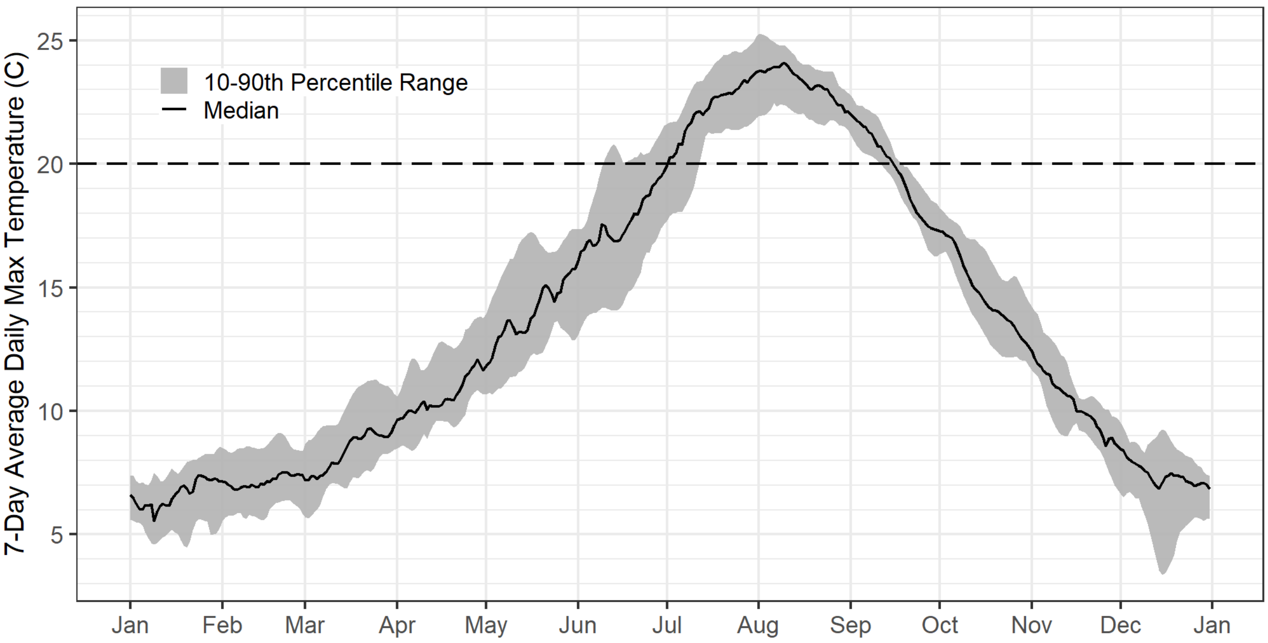
Water temperature plays an important role in the biological cycles of aquatic organisms, particularly for cold water species, such as salmonids. Water temperature also influences chemical reactions, nutrient cycling, and factors into toxicity calculations for some analytes. Water temperatures in streams are driven by multiple factors, including solar radiation, ambient air temperature, riparian vegetation and shading, channel morphology, groundwater inflows and hyporheic exchange, and stream discharge.

The lower 50 miles of the Willamette River are designated as a salmon and steelhead migration corridor (OAR 340-041-0028 Figure 340A). This area extends from the confluence with the Columbia River to the confluence of Chehalem Creek in the Newberg Pool. The Oregon Administrative Rules (OAR 340-041-0028 (4)(d)) specifies a biologically based numeric criterion for streams identified as salmon and steelhead migration corridors: the seven-day average daily maximum (7DADM) temperature may not exceed 20°C. In addition to the numeric criterion, a narrative criterion applies to the migration corridor, requiring that “these water bodies must have cold water refugia that are sufficiently distributed so as to allow salmon and steelhead migration without significant adverse effects from higher water temperatures elsewhere in the water body.”

Water temperature is recorded every 30 minutes by the USGS at the Morrison Bridge station. Continuous measurements at the station began in 2001, however, water temperature was not recorded at the gauge during the period from 2006 to 2008. As part of BES' ambient monitoring program water temperature is recorded at each monitoring station and it is these *in situ* readings that are used in this analysis to calculate variable water quality limits for other parameters. The continuous USGS temperature data are presented below as they provide a more complete view of the conditions in the Willamette and can be used to assess attainment of the water quality criterion.

In Portland, water temperatures in the Willamette River typically begin exceeding the 20°C migration criterion in early July and remain above the criterion until mid-September. Since November 2001, the temperatures have exceeded the criterion on 1,133 days (approximately 21% of the period of record). In the recent years, however, earlier exceedances of the criterion have been observed—in the past five years the Willamette River began exceeding the criterion in June. Water temperatures begin cooling in September and no exceedances of the criterion have been observed in October.

Figure 45. Willamette River median and 10th–90th percentile range of the 7-day average daily maximum (7DADM) water temperatures recorded by the USGS at the Morrison Bridge station (USGS# 14211720) from November 2001 to present. The dashed line represents the 20°C criterion for salmon and steelhead migration.



The exceedances of the migration criterion occur when salmon, steelhead, and Pacific lamprey are present in the lower river, impacting both adult and juvenile life stages (Table 5). Juvenile life stages of coho salmon, spring and fall Chinook, steelhead trout, and Pacific lamprey are subject to the pressures of excess temperatures as they migrate through the river during the summer. Similar pressure also applies to returning adult coho, spring and fall Chinook, and Pacific lamprey.

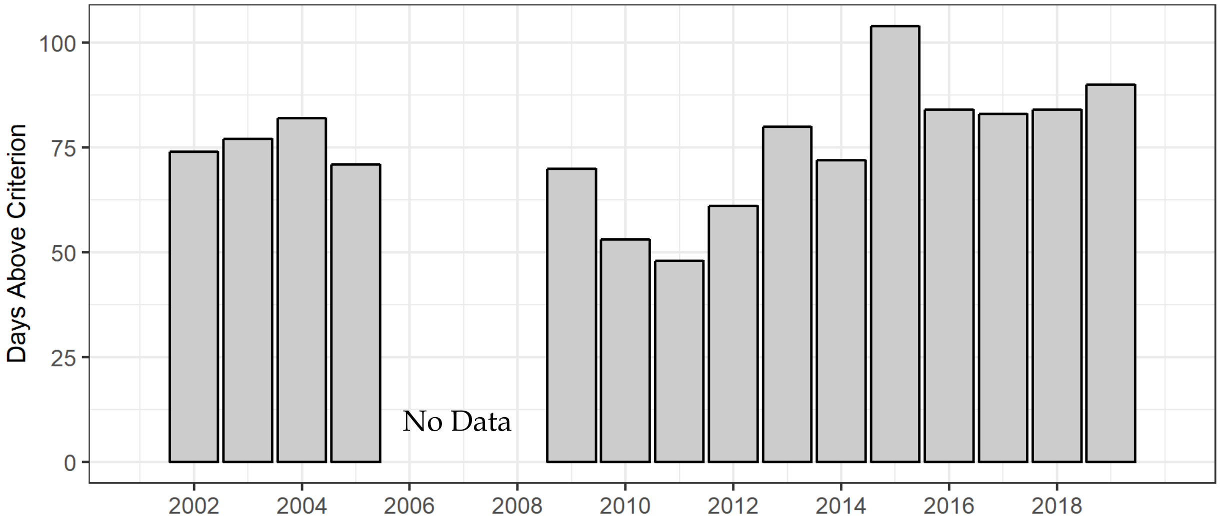
Table 5. Timing of fish and salmon presence in the Willamette River at different times of the year for both adult and juvenile life stages.

Seasonal Presence of Fish Life Stages in the Lower Willamette

<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td rowspan="2">Spring Chinook</td><td></td><td colspan="6">Adult Migration</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="12">Juvenile Rearing and Migration (12-24 months with primary outmigration in the spring)</td></tr>
<tr><td rowspan="2">Fall Chinook</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Adult Migration</td><td></td><td></td></tr>
<tr><td colspan="7">Juvenile Rearing and Migration</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Steelhead</td><td colspan="4">Adult Migration</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Adult Migration</td></tr>
<tr><td colspan="12">Juvenile Rearing and Migration (18-24 months outmigration in spring of the following year)</td></tr>
<tr><td rowspan="2">Coho</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Adult Migration</td></tr>
<tr><td colspan="12">Juvenile Rearing and Migration (18 months outmigration in fall of the following year)</td></tr>
<tr><td rowspan="2">Pacific Lamprey</td><td></td><td></td><td></td><td></td><td colspan="4">Adult Migration</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="12">Juvenile Rearing in spawning grounds (1-3 years) and Migration (Feb-June)</td></tr>
</table>

The total number of days that exceed the temperature criterion has varied from year to year. The smallest number of days in a year that exceeded the temperature criterion (48 days) occurred in 2011, and the greatest number of days exceeding the criterion (104 days) occurred in 2015 (Figure 46).

Figure 46. Number of days exceeding the 7DADM temperature criterion. The water temperature was not recorded at the USGS stream gauge from 2006 to 2008.



4.3.2 Conventional Parameters

BES' Willamette River monitoring has included the collection of *E. coli*, hardness, total dissolved solids (TDS), total suspended solids (TSS), and total solids (TS) samples since the inception of each monitoring station. Total organic carbon (TOC), however, was not added to the list of analytes until 2012. The results for these parameters are presented below.

4.3.2.1 E. coli

Escherichia coli (*E. coli*) is a species of fecal coliform bacteria that live in the gastrointestinal tract of warm-blooded animals, including humans. *E. coli* concentrations are used as an indicator of the potential for the presence of human pathogens including bacteria, viruses, and protozoa which are associated with the presence of sewage.

For water bodies identified by DEQ as supporting freshwater contact recreation, no single sample may exceed 406 *E. coli* organisms/100 mL and the monthly geometric mean (based on a minimum of 5 samples) may not exceed 126 *E. coli* organisms/100 mL (OAR 340-041-0009(1)(a)). These numeric criteria apply to the lower Willamette River in Portland. *E. coli* samples collected as part of the ambient monitoring program were not collected at the necessary frequency to assess the Willamette River sites for attainment of the monthly geometric mean water quality criterion; as such, all three sites were evaluated using the 406 *E. coli* organism/100 mL criterion in this assessment.

It is important to note that BES' ambient monitoring program is not designed to assess or detect discharges associated with combined sewer overflows, but rather captures overall water quality conditions of the river. The samples summarized below reflect the ambient conditions of the Willamette River throughout the year over the past two decades.

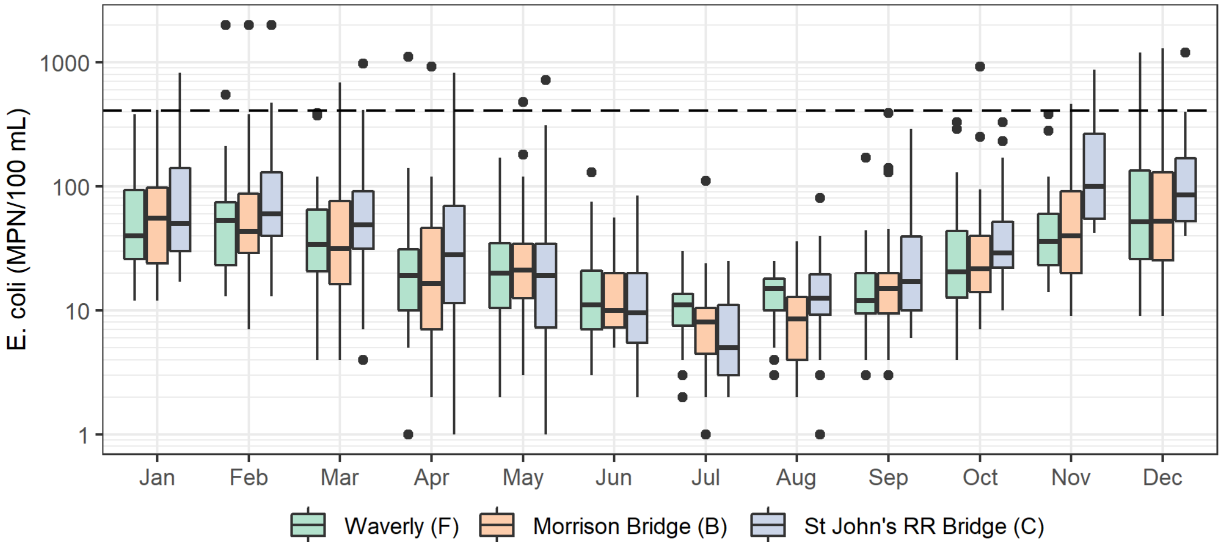
Table 6. Summary statistics for *E. coli* samples from the three Willamette River sites.

***E. coli* (MPN/100 mL)**

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
F	366	58	1	7	20	120	2,000	1.4
B	368	62	1	5	20	120	2,000	3.5
C	367	84	1	5	32	196	2,000	4.3

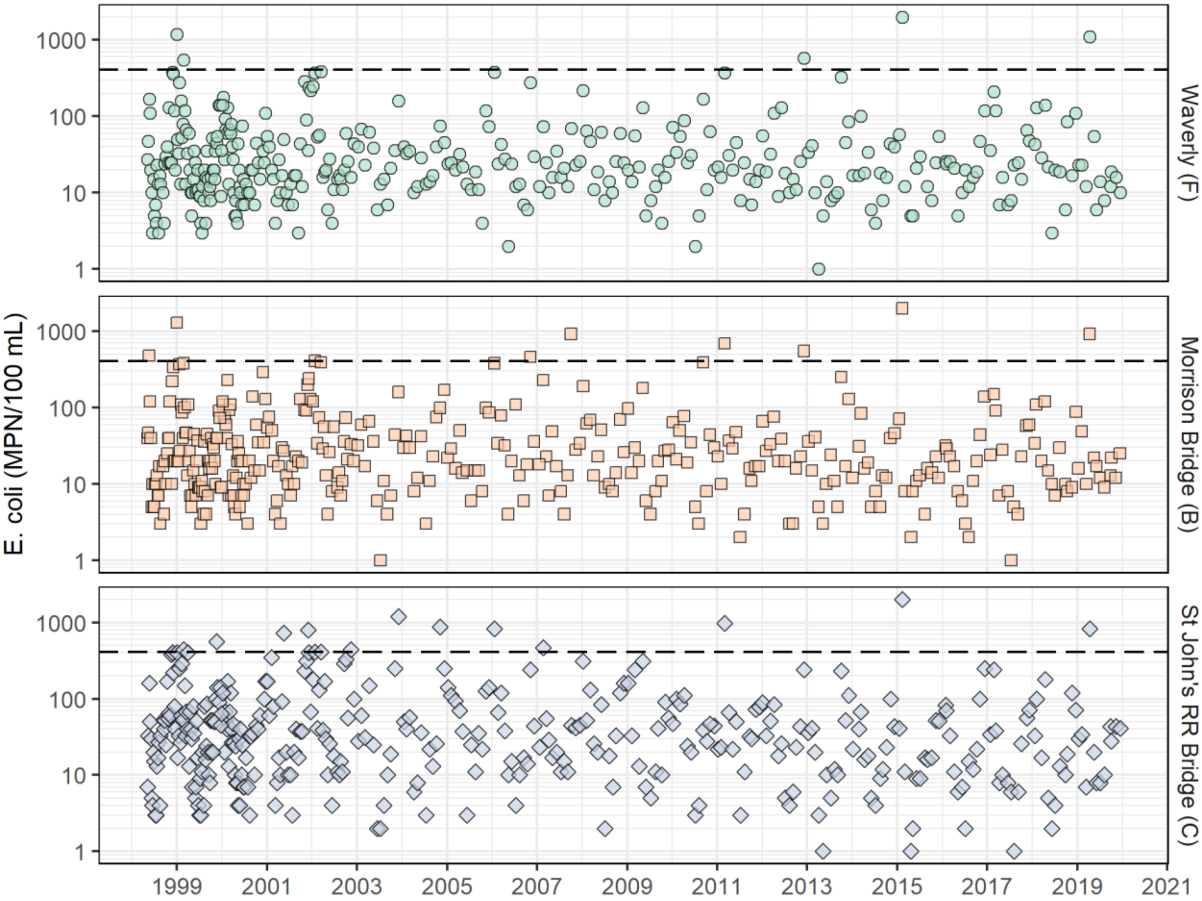
Over the 20-year period of record, *E. coli* concentrations typically did not exceed the single sample maximum limit of 406 *E. coli* organisms/100 mL, with less than 5% of samples exceeding the limit. Generally, the upstream site at Waverly (F) had the lowest *E. coli* concentrations, while the most downstream site at the St John's Railroad Bridge (C) had the highest *E. coli* concentrations.

Figure 47. Seasonal pattern of *E. coli* concentrations for the three Willamette River sites from 1998 to 2019.



Willamette River *E. coli* concentrations were consistently lower in the summer months and higher during the wet winter months at all three stations. While a seasonal pattern in *E. coli* concentrations is detectable from the sampling, no temporal trend over the 20-year period is evident.

Figure 48. *E. coli* concentrations at the three Willamette River sites since 1998. The dashed line represents the 406 organisms per 100mL water quality criterion.



4.3.2.2 Hardness

Hardness in rivers and streams is a measure of the abundance of metallic cations, particularly calcium and magnesium, and is expressed as the concentration of calcium carbonate ($CaCO_3$). The hardness in natural systems is largely derived from contact with soils and rock formations. While there are no water quality criteria for hardness, it is used to calculate the water quality criteria for many metals.

Table 7. Summary statistics for hardness samples from the three Willamette River sites.

Hardness (mg CaCO3/L)

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
F	445	25.7	0.0	21.8	25.2	29.4	46.0	*NA*
B	484	25.8	0.0	21.8	25.8	29.5	51.2	*NA*
C	491	26.3	0.0	21.6	26.2	30.4	91.6	*NA*

Hardness in the Willamette River is not highly variable; however, the concentration of calcium carbonate is typically slightly higher and less variable during the summer when flows are lowest. The concentration of calcium carbonate did not differ between the three monitoring stations. Hardness concentrations have changed very little over the 20-year period of record. Samples collected at the three stations have been consistently measured between 20 and 30 mg $CaCO_3$/L.

Figure 49. Seasonal pattern of hardness concentrations for the three Willamette River sites since 1994.

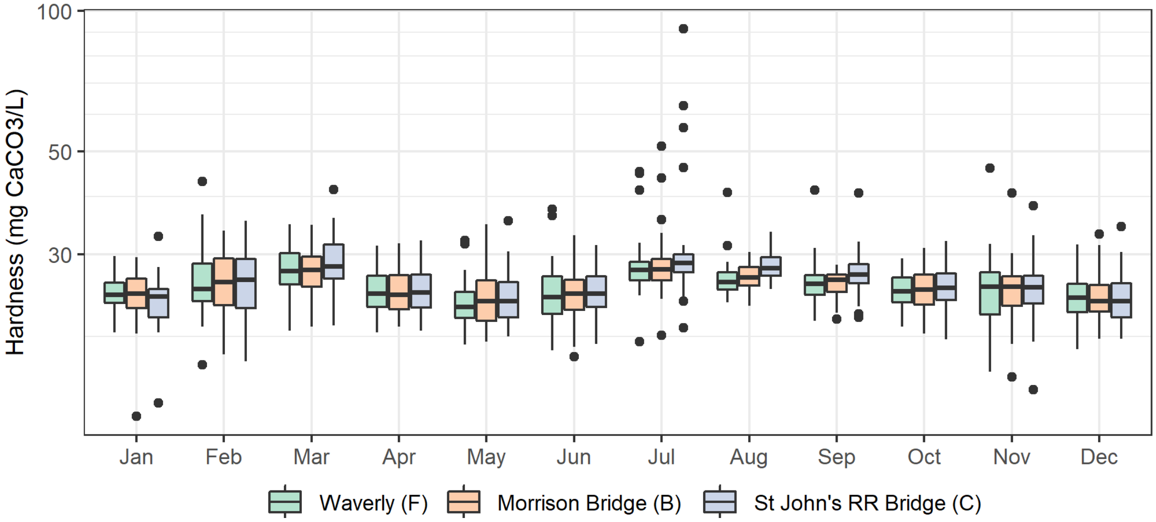
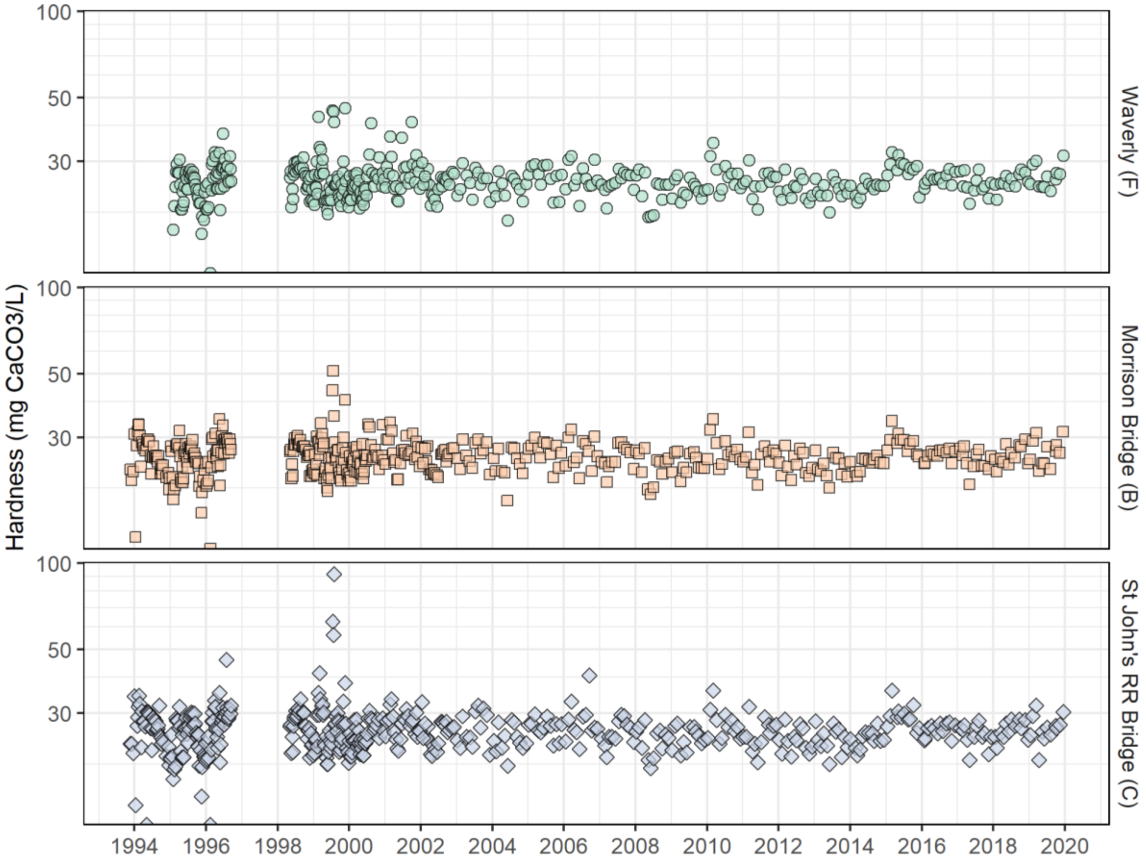


Figure 50. Hardness concentrations at the three Willamette River sites since 1994.



4.3.2.3 Total Organic Carbon

The concentration of total organic carbon (TOC) is a measure of the organically bound carbon in the water column. In surface waters, this may include carbon that is bound in vegetation, algae, or other organic matter. TOC is not a measure of oxygen demand; however, it can serve as an indicator of abundant nutrient sources that promote undesirable algal or aquatic macrophyte growth. TOC is a parameter of concern for drinking water as the organic compounds in the water column may react with disinfectants to produce compounds that are potentially toxic or carcinogenic. Oregon DEQ has not established water quality criteria for TOC.

Table 8. Summary statistics for total organic carbon samples from the three Willamette River sites.

Total Organic Carbon (mg/L)

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
F	97	1.5	1.1	1.2	1.4	2.1	2.8	*NA*
B	97	1.5	1.1	1.2	1.4	2.1	2.8	*NA*
C	97	1.5	1.1	1.2	1.4	2.1	2.8	*NA*

TOC samples were first collected in 2012. Over the eight years of sampling, very little variability in TOC concentrations between the three monitoring stations has been observed. While the variability between the three stations is negligible, Willamette TOC concentrations are typically observed to decrease as flows in the river decrease. Over the period of record, there is no evidence of a temporal trend in TOC concentrations.

Figure 51. Seasonal pattern of total organic carbon concentrations for the three Willamette River sites since 2012.

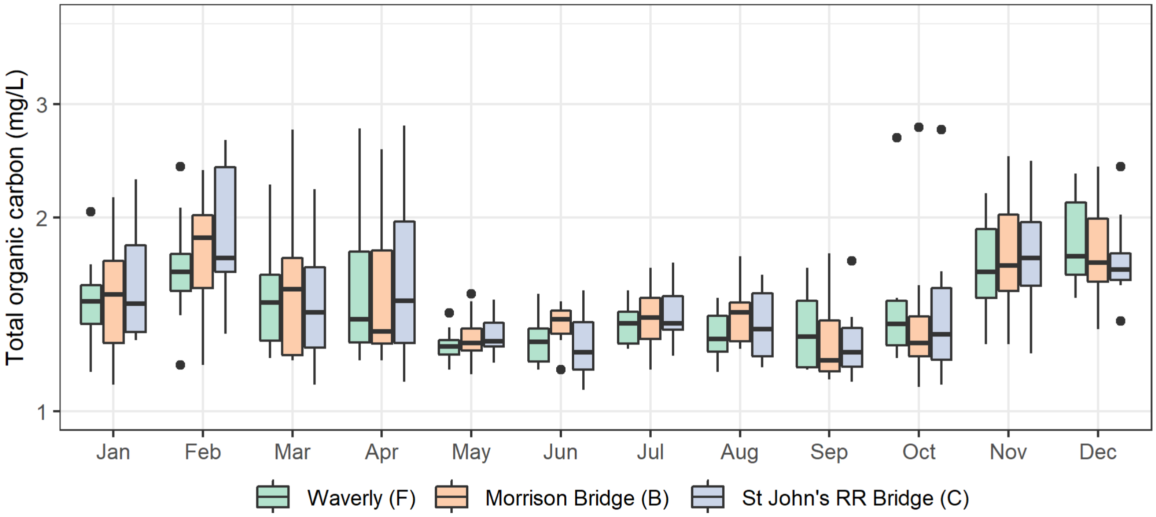
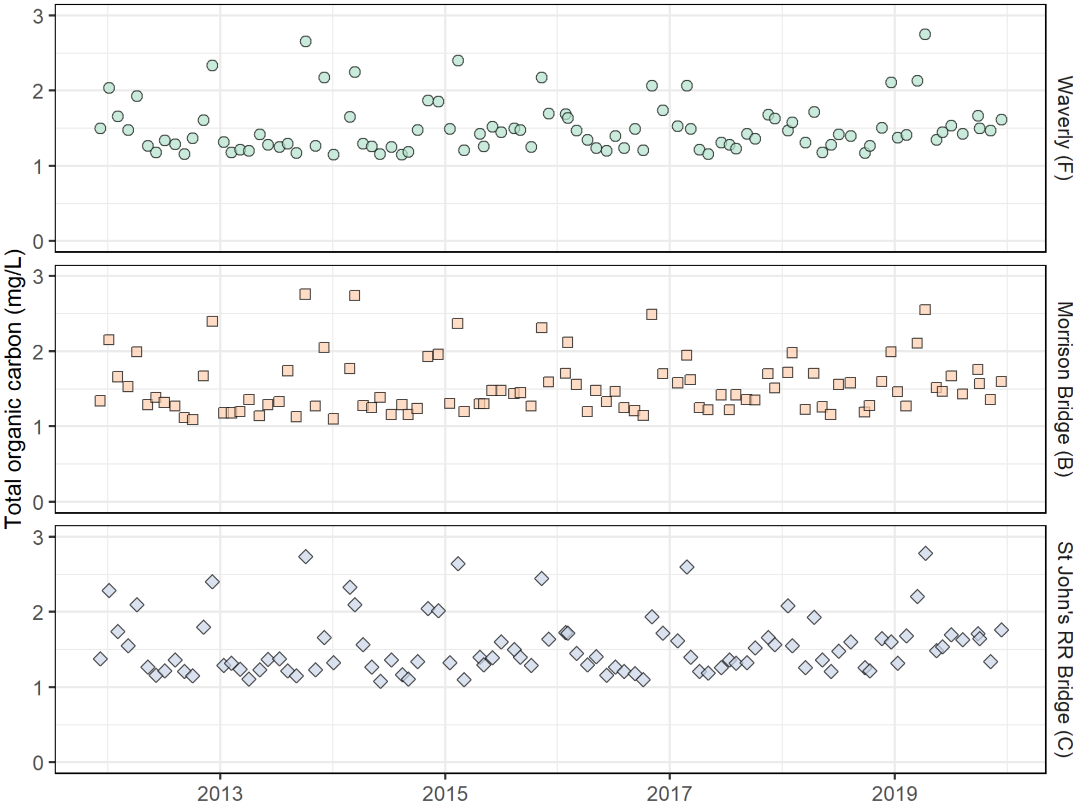


Figure 52. Total organic carbon concentrations at the three Willamette River sites since 2012.



4.3.2.4 Total Suspended Solids

The concentration of total suspended solids (TSS) is a measure of the particulates present in the water column. TSS includes both inorganic and organic particulate matter and can originate from both natural and anthropogenic sources. TSS is important in aquatic systems as elevated concentrations can have a negative impact on instream habitat and aquatic organisms. Additionally, other pollutants, such as metals and organic compounds, can adsorb to sediment particles and be transported to the stream in surface runoff.

Oregon DEQ has not established water quality criteria for TSS that apply to all water bodies. Rather, TSS is frequently used as a surrogate parameter for other pollutants of concern. The Johnson Creek TMDL for pesticides uses TSS as a surrogate and set a guidance value of 20 mg/L for TSS concentrations. In BES' Watershed Health Index (WSHI), a TSS concentration of 43 mg/L or greater corresponds to conditions that are not properly functioning.

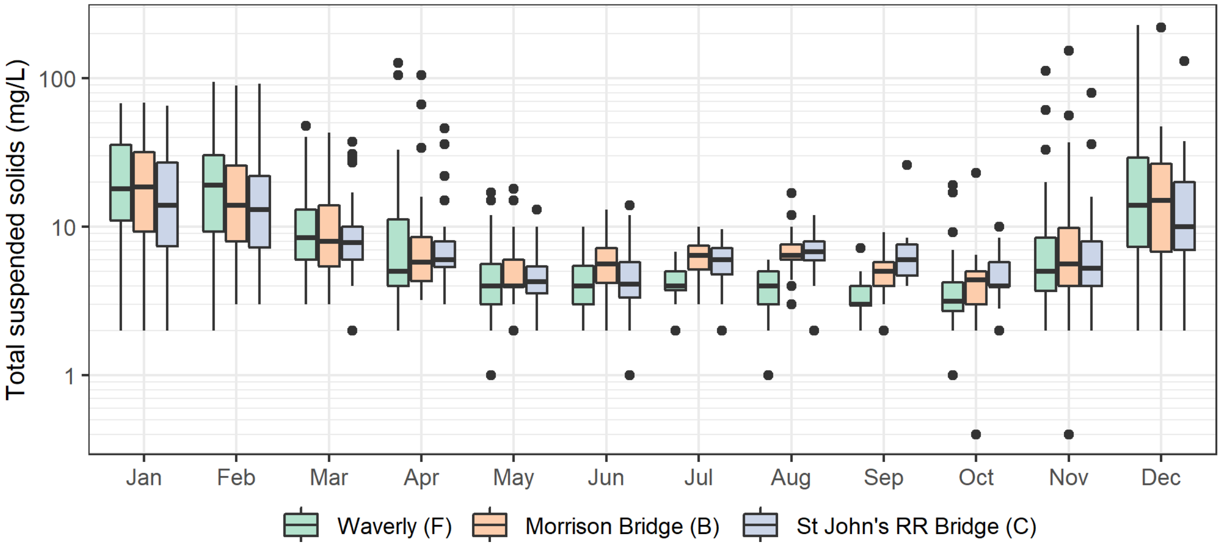
Table 9. Summary statistics for total suspended sediment samples from the three Willamette River sites.

Total Suspended Solids (mg/L)

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
F	445	10.7	1.0	2.8	5.0	23.5	229.0	*NA*
B	485	11.1	0.4	3.3	6.0	24.5	220.0	*NA*
C	491	9.4	1.0	3.2	6.0	18.0	130.0	*NA*

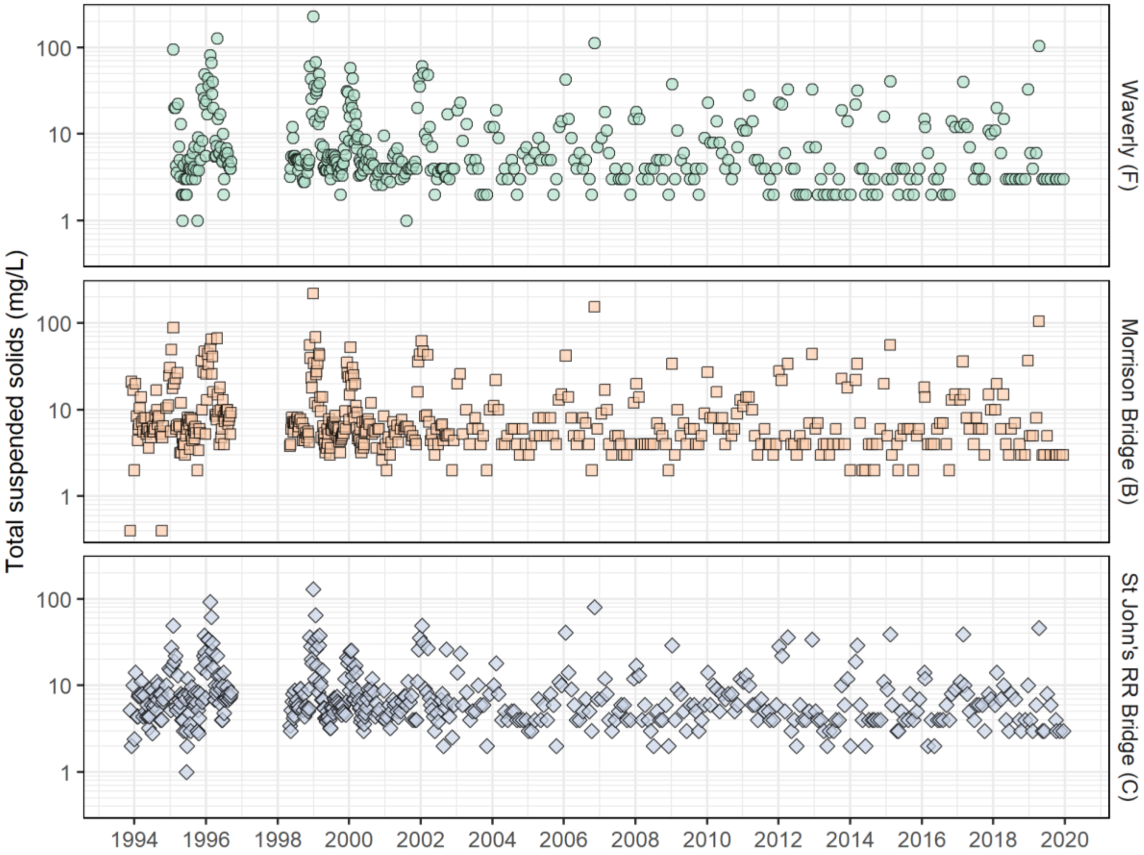
Over the 20-year period of record, mean Willamette River TSS concentrations at the three stations ranged from 9 to 11 mg/L. Throughout most of the year TSS concentrations did not vary between stations; however, during the summer months TSS concentrations were slightly higher at the two downstream stations (Morrison Bridge and St John's RR Bridge).

Figure 53. Seasonal pattern of total suspended solids concentrations for the three Willamette River sites since 1994.



TSS concentrations vary across the year, with the highest concentrations observed during periods of higher river flows. There is no evidence of any temporal trends in TSS concentrations over the 20-year period of record.

Figure 54. Total suspended solids concentrations at the three Willamette River sites since 1994.



4.3.2.5 Total Dissolved Solids

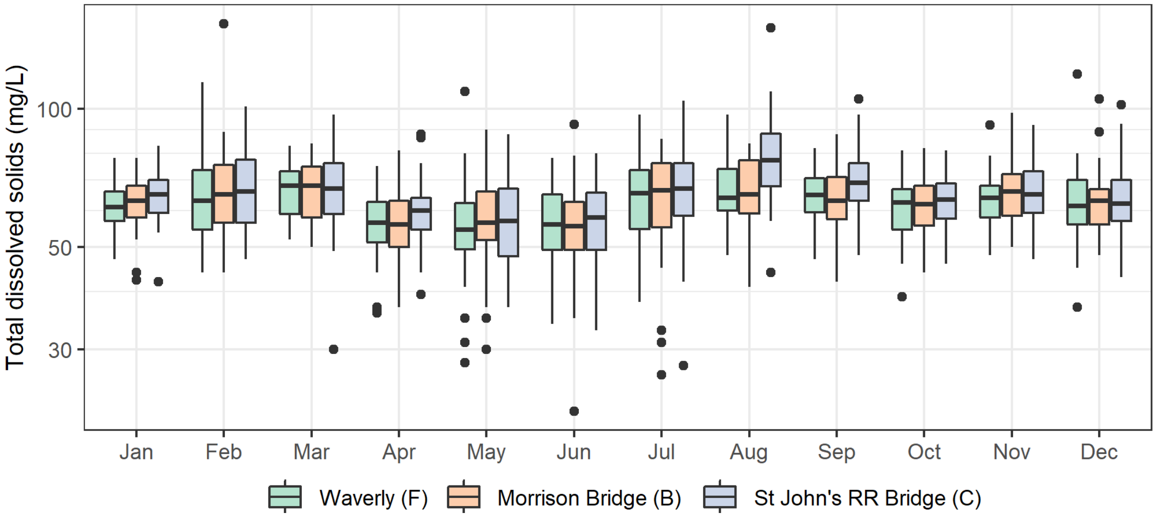
Total dissolved solids (TDS) is a measure of the portion of the solids in the water column that pass through a 2.0 µm filter. These are the very small particles and can include smaller clay particles. These include the particles that are not captured in the measure of TSS. High concentrations of TDS can result in decreased water clarity. Oregon DEQ has not established TDS water quality criteria for surface waterbodies.

Table 10. Summary statistics for total dissolved solids samples from the three Willamette River sites.

Total Dissolved Solids (mg/L)

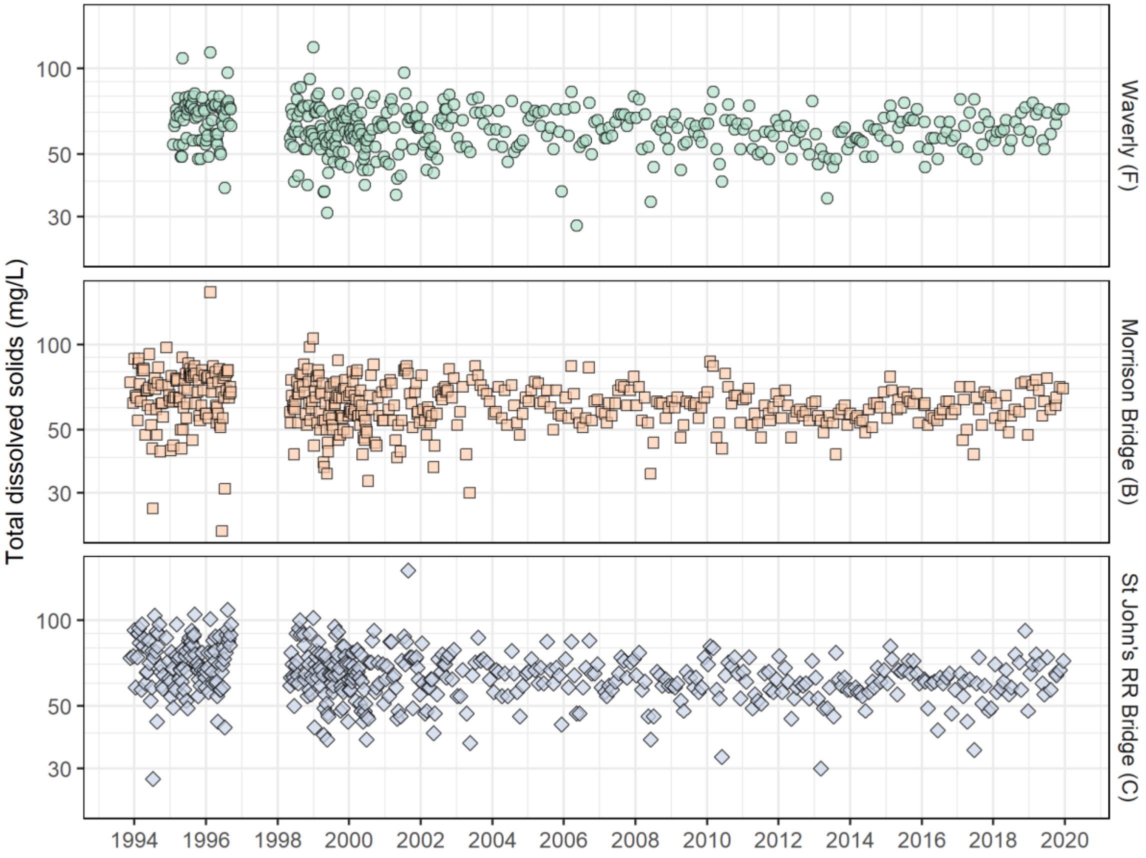
Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
F	445	62.1	28.0	48.0	62.0	75.0	119.0	*NA*
B	483	62.8	22.0	49.0	62.0	78.0	153.0	*NA*
C	489	65.6	27.6	49.0	64.0	84.0	150.0	*NA*

Figure 55. Seasonal pattern of total dissolved solids concentrations for the three Willamette River sites since 1994.



Generally, there was little difference in TDS concentrations between the three stations. TDS concentrations varied little across the year, however, TDS concentrations at all three sites were consistently lowest during the spring. There was no evidence of a change in TDS concentrations over time at any of the three Willamette stations.

Figure 56. Total dissolved solids concentrations at the three Willamette River sites since 1994.



4.3.2.6 Total Solids

Total solids (TS) is a measure of the particulate content in the water column. It includes the dissolved, suspended, and settleable particulate forms. As with TDS and TSS, elevated TS concentrations reduce water clarity and may transport other pollutants that are adsorbed to sediment particles. Oregon DEQ has no established water quality criteria for TS.

Table 11. Summary statistics for total sediment samples from the three Willamette River sites.

Total Solids (mg/L)

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
F	368	71.1	32.0	52.0	68.0	86.9	348.0	*NA*
B	394	72.3	32.8	54.0	71.0	91.0	325.0	*NA*
C	392	73.3	36.4	54.1	71.0	94.0	232.0	*NA*

While TS concentrations do vary over the course of the year, there is little difference in TS concentrations between the three stations. The seasonal TS pattern follows the combined pattern of the TDS and TSS. Increases in TSS during the winter drive the corresponding increase in TS concentrations at the three Willamette stations. As with the TDS and TSS concentrations, there is no evidence that TS concentrations are changing over time.

Figure 57. Seasonal pattern of total solids concentrations for the three Willamette River sites since 1994.

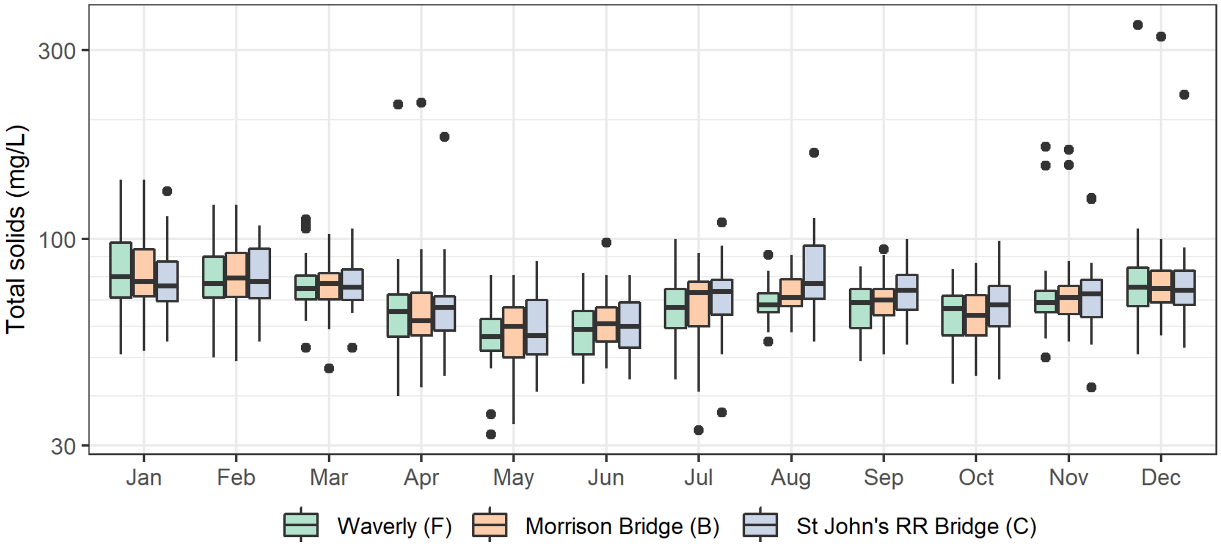
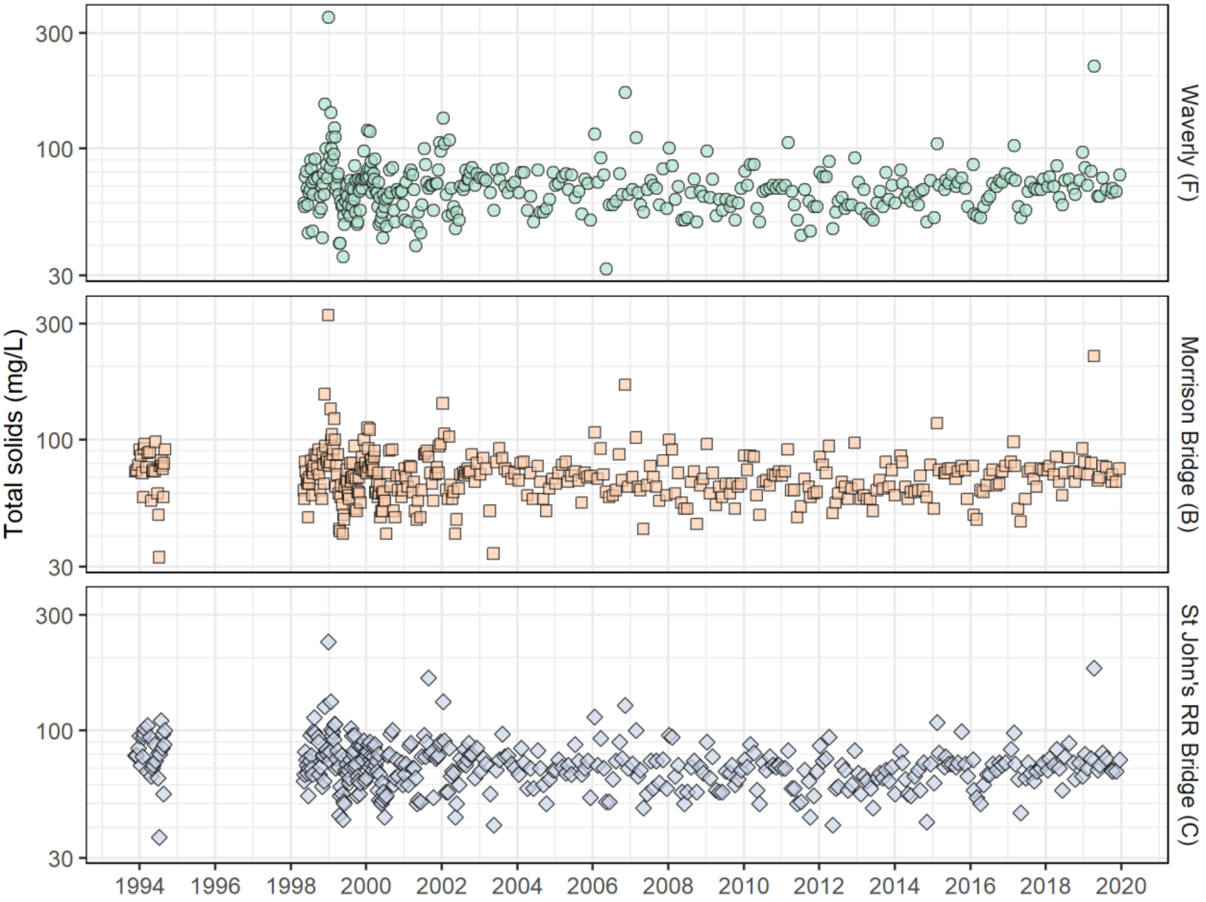
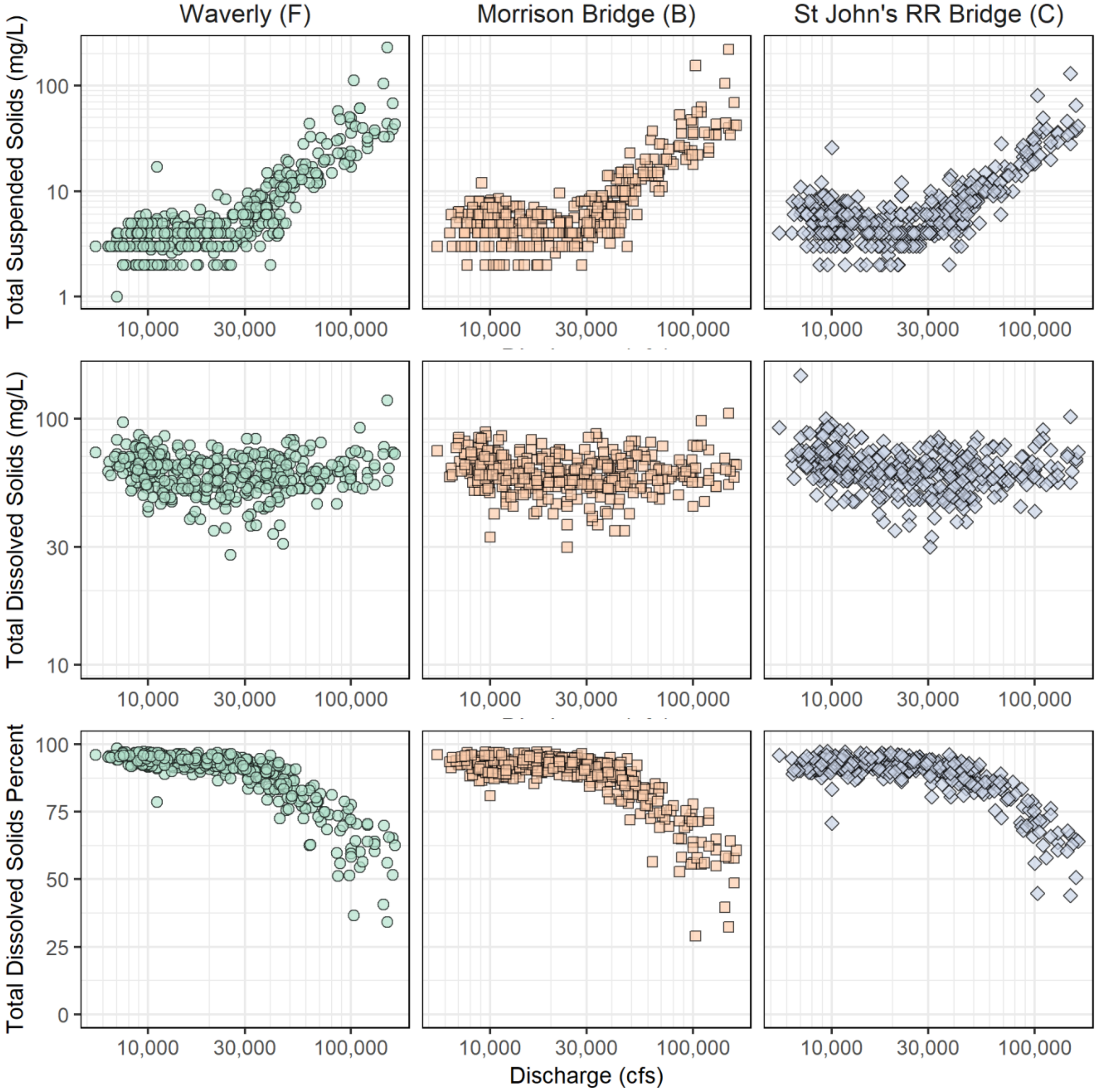


Figure 58. Total solids concentrations at the three Willamette River sites since 1994.



In Portland, Willamette River sediment loads are dominated by fine particulate matter—at all three stations the dissolved concentration represented more than 50% of the measured total solids concentrations for almost the entire period of record. While TDS concentrations did not vary with discharge, TSS concentrations exhibited a different pattern. At lower mean daily flows, TSS concentrations were relative constant and did not vary substantially with discharge. In contrast to TDS, when mean daily Willamette River flows increased over 30,000 cfs, TSS concentrations began increasing with the increase in flow. While TSS concentrations increased with higher flows, the dissolved fraction did not fall below 90% until river flows exceeded 50,000 cfs (Figure 59).

Figure 59. Relationships between discharge and total suspended solids, total dissolved solids, and the dissolved percentage of the total solids measured at the three Willamette River sites since 1998.



4.3.3 Metals

Routine sampling for metals has been conducted since the 1990s at all three stations. Both total and dissolved samples for copper, lead, and zinc are currently collected at all three stations. Arsenic, cadmium, chromium, iron, nickel, and selenium samples (both total and dissolved) were collected from 2000 to 2010. Total and dissolved silver samples were collected for two years, from 2000 to 2002. Mercury samples were first collected in 2003 at all three of the stations. Only total mercury samples are collected.

The sampling frequency for the different metals has varied across the period of record. At the beginning of the sampling period, copper, lead, and zinc samples were collected on a weekly basis. In mid-2000, the sampling frequency for these three metals was reduced to twice per month. As with the other metals, arsenic, cadmium, chromium, iron, and nickel were sampled twice per month until mid-2002, after which the sampling frequency for these metals was reduced to once per quarter. Similarly, mercury samples were collected quarterly until mid-2011 when the sampling frequency for mercury was increased to monthly.

In this report, the analysis of metal samples collected by BES has been restricted to those samples analyzed by BES' Water Pollution Control Laboratory from 2000 onwards. In 2000, the techniques employed in the laboratory were modified to reduce issues associated with sample contamination. As such, metal samples analyzed prior to 2000 are considered suspect and have not been included in this analysis.

The aquatic life water quality criteria for toxic pollutants (OAR 340-041-8033 – Table 30) includes acute and chronic criteria for dissolved arsenic, cadmium, chromium, copper, lead, nickel, selenium, silver, and zinc. The water criteria for iron and mercury are based on the total fraction of each metal. For each of the metals, the acute criterion is applied as a one-hour average concentration and the chronic criterion is applied as a 96-hour average concentration. Neither the acute nor chronic criteria may be exceeded more than once every three years. The results below present the frequency that the samples exceed the applicable chronic criteria. There is not a sufficient number of samples available to calculate a 96-hour average concentration, as such, the exceedances of the chronic criteria presented below are based on an evaluation of each individual sample and represent a conservative assessment of the possible excursion frequency.

4.3.3.1 Arsenic

Arsenic is a chemical element that occurs as part of many minerals. Arsenic is frequently used in alloys of lead used for ammunition and car batteries. Arsenic has also been used as a chemical preservative added to wood to protect it against biological degradation. Prior to the mid-2000s, the primary treatment used in wood preservation was chromated copper arsenate (CCA; Stook et al., 2005). Due to leaching and toxicity concerns, industries began phasing out the use of CCA-treatment in 2004. Even with the gradual decrease in usage, CCA-treated wood still represented more than 75% of the preserved wood used in the U.S. in 1996 (Stook et al., 2005). In Florida alone, Khan et al. (2006) estimated that the existing treated wood in use will release approximately 12,000 tons of arsenic into the environment over its anticipated 40-year lifespan.

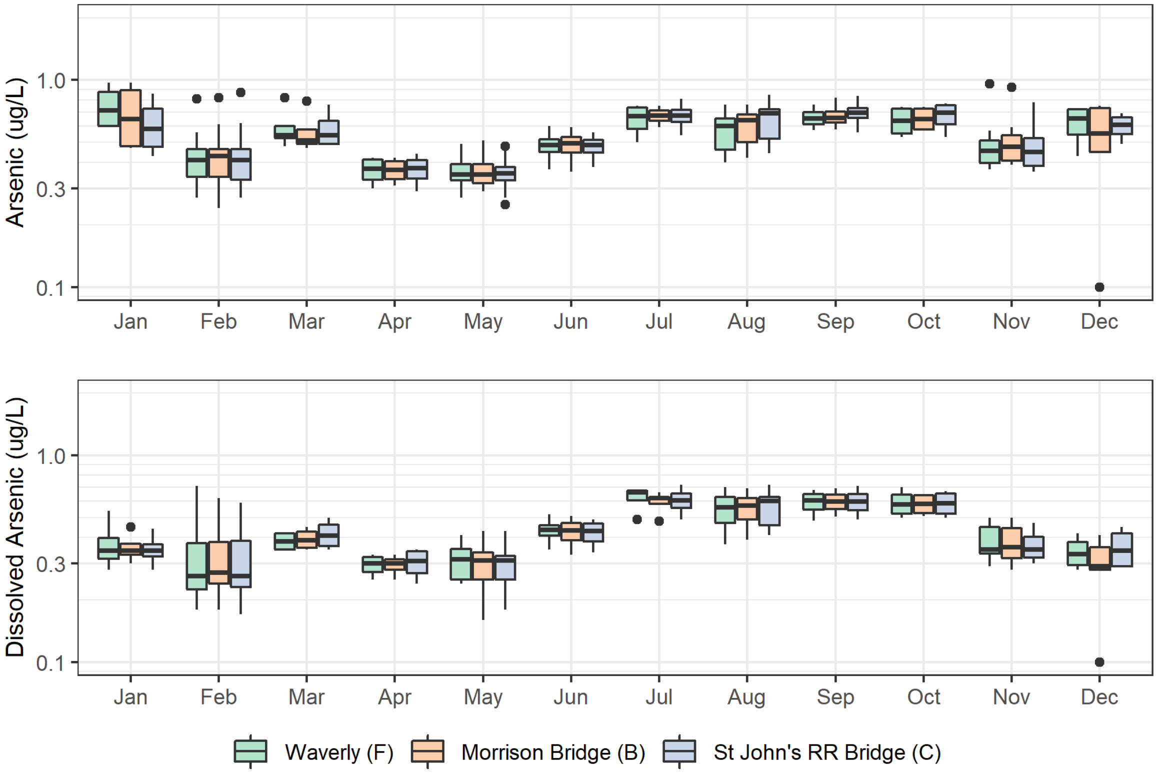
The water quality criteria for arsenic are expressed in terms of the dissolved concentration in the water column. The acute and chronic criteria for dissolved arsenic are 340 µg/L and 150 µg/L respectively. In addition to the freshwater aquatic life criteria, DEQ has established a human health criterion for total inorganic arsenic of 2.1 µg/L.

Table 12. Summary statistics for total and dissolved arsenic samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Arsenic (µg/L)								
F	80	0.52	0.27	0.34	0.49	0.74	0.97	*NA*
B	81	0.52	0.10	0.33	0.50	0.75	0.97	*NA*
C	79	0.53	0.25	0.34	0.49	0.76	0.87	*NA*
Dissolved Arsenic (µg/L)								
F	80	0.42	0.18	0.25	0.38	0.64	0.71	0.0
B	81	0.41	0.10	0.25	0.39	0.62	0.69	0.0
C	79	0.42	0.17	0.25	0.40	0.63	0.72	0.0

Arsenic concentrations at the three Willamette stations remained far below both the acute and chronic water quality criteria throughout the sampling period. Little to no variability in both total and dissolved concentrations were observed between the three stations. Arsenic in the Willamette is primarily observed in a dissolved form, with more than 75% measured as dissolved arsenic.

Figure 60. Seasonal pattern in total and dissolved arsenic concentrations at the three Willamette River sites from 2000 to 2010.



Arsenic concentrations varied somewhat with the season, with higher concentrations seen in the summer and early winter. There is no evidence of a temporal trend in either the total or dissolved arsenic concentrations.

Figure 61. Total arsenic concentrations at the three Willamette River sites since from 2000 to 2010.

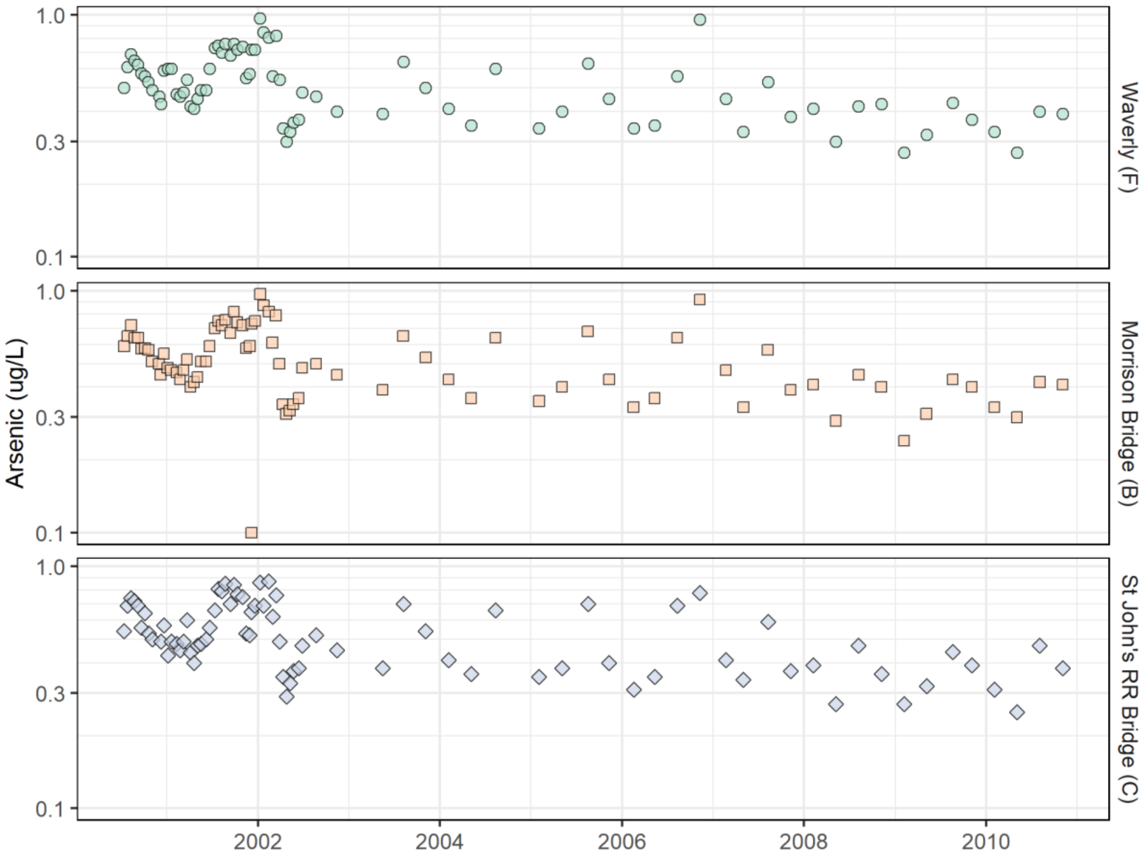
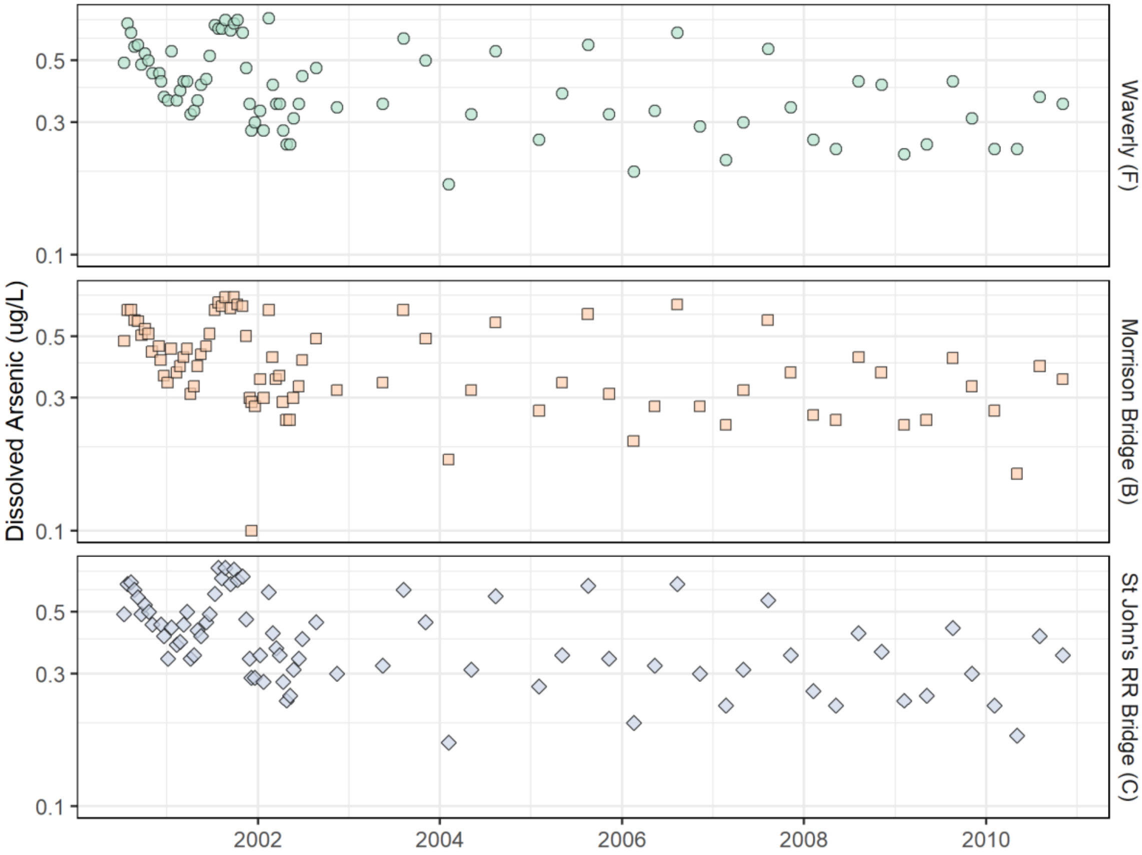


Figure 62. Dissolved arsenic concentrations at the three Willamette River sites from 2000 to 2010.



4.3.3.2 Cadmium

Cadmium is a soft and malleable metal that is resistant to corrosion. Cadmium has been used as protective plating for other metals such as steel to prevent corrosion. Additionally, cadmium is used in paint pigments to create bright and durable colors. Elevated levels of cadmium in the air were recently identified in the Portland area associated with emissions from factories manufacturing stained-glass (Donovan et al., 2016). Cadmium is also found in coal which when burned emits cadmium into the air.

The water quality criteria for cadmium are a function of hardness in the water column. Unlike most other metals, the acute criterion is based on total recoverable cadmium, while the chronic criterion is based on dissolved cadmium.

Cadmium was measured above the detection limit once (0.115 µg/L) and dissolved cadmium was consistently below detection during the period of record. The detection limits for both total and dissolved cadmium were below the calculated acute criteria. The calculated chronic cadmium criterion ranged from 0.08 µg/L to 0.13 µg/L. For many of the samples the calculated criterion was lower than the analytical detection limit.

Table 13. Summary statistics for total and dissolved cadmium samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
Cadmium (µg/L)								
F	80	0.047	0.020	0.020	0.020	0.100	0.100	0.0
B	81	0.047	0.020	0.020	0.020	0.100	0.100	0.0
C	79	0.047	0.020	0.020	0.020	0.100	0.115	0.0
Dissolved Cadmium (µg/L)								
F	80	0.044	0.010	0.010	0.020	0.100	0.100	0.0
B	81	0.043	0.010	0.010	0.020	0.100	0.100	0.0
C	79	0.043	0.010	0.010	0.020	0.100	0.100	0.0

4.3.3.3 Chromium

Chromium is found naturally in the environment. It is used frequently in metal alloys, including stainless steel and chrome plating, due to its anti-corrosive properties and resistance to rusting. Chromium is also used as a pigment in glassmaking.

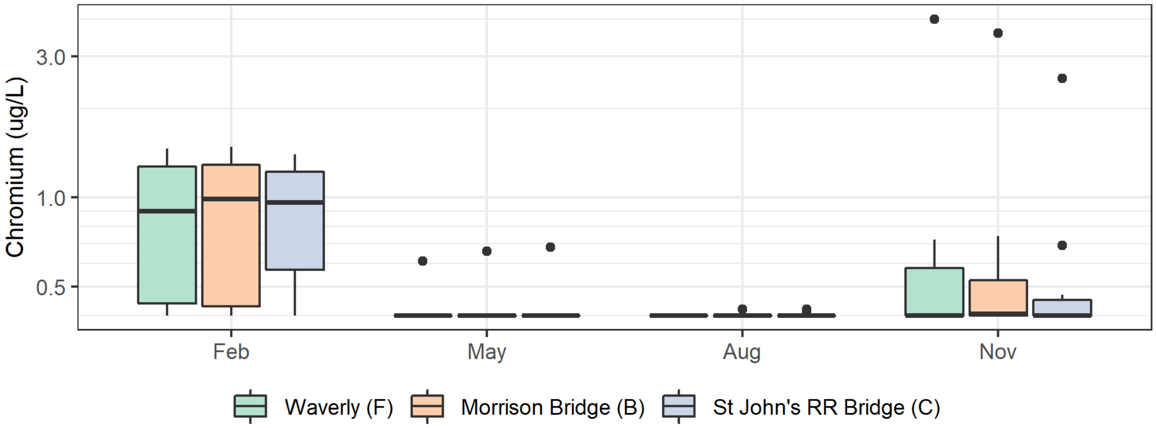
DEQ has established water quality criteria for both trivalent, Cr(III), and hexavalent chromium, Cr(VI). The water quality criteria for chromium are expressed in terms of the dissolved concentration in the water column. For trivalent chromium, the acute and chronic criteria are based on hardness in the water column. The acute and chronic criteria for hexavalent chromium are 16 µg/L and 11 µg/L respectively. Hexavalent chromium is highly toxic and is a known carcinogen.

Table 14. Summary statistics for total and dissolved chromium samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
Chromium (µg/L)								
F	40	0.62	0.40	0.40	0.40	1.08	4.00	*NA*
B	40	0.61	0.40	0.40	0.40	1.04	3.58	*NA*
C	40	0.58	0.40	0.40	0.40	1.08	2.52	*NA*
Dissolved Chromium (µg/L)								
F	40	0.40	0.20	0.40	0.40	0.40	0.41	0.0
B	40	0.40	0.20	0.40	0.40	0.40	0.40	0.0
C	40	0.40	0.20	0.40	0.40	0.40	0.44	0.0

The samples collected as part of the ambient monitoring program are analyzed for total and dissolved chromium, but do not distinguish between the chromium species. Consequently, comparing the Willamette samples to the trivalent or hexavalent criteria represents a conservative assessment by assuming that all of the measured chromium is present entirely in each form when assessing attainment of the two criteria. Chromium was not frequently detected during the sampling period and concentrations did not differ between the three stations. Dissolved chromium was measured above the 0.4 µg/L detection limit only twice over the ten years of sampling. No exceedances of either the trivalent or hexavalent criteria were observed over the sampling period.

Figure 63. Seasonal pattern in total and dissolved chromium concentrations at the three Willamette River sites since 2000.



4.3.3.4 Copper

Copper is a soft, ductile metal with high electrical conductivity. Given its conductive properties, copper is the primary conductor used in electrical wiring. Copper has been used in vehicle brake pads as a friction material to slow or stop the movement of a motor vehicle. As a result of the friction generated when braking, particles from the brake pads erode and are deposited on roadways and carried by stormwater runoff to nearby rivers and streams.

Copper is also biostatic, that is it inhibits the growth of bacteria and other organisms. As such, it is used as a preservative to protect wood from biological degradation and added to roofing materials to prevent the growth of moss and algae (Winters & Graunke, 2014). A significant export of copper in runoff from asphalt singles has be documented (Clark et al., 2008; Mendez et al., 2011; Winters & Graunke, 2014).

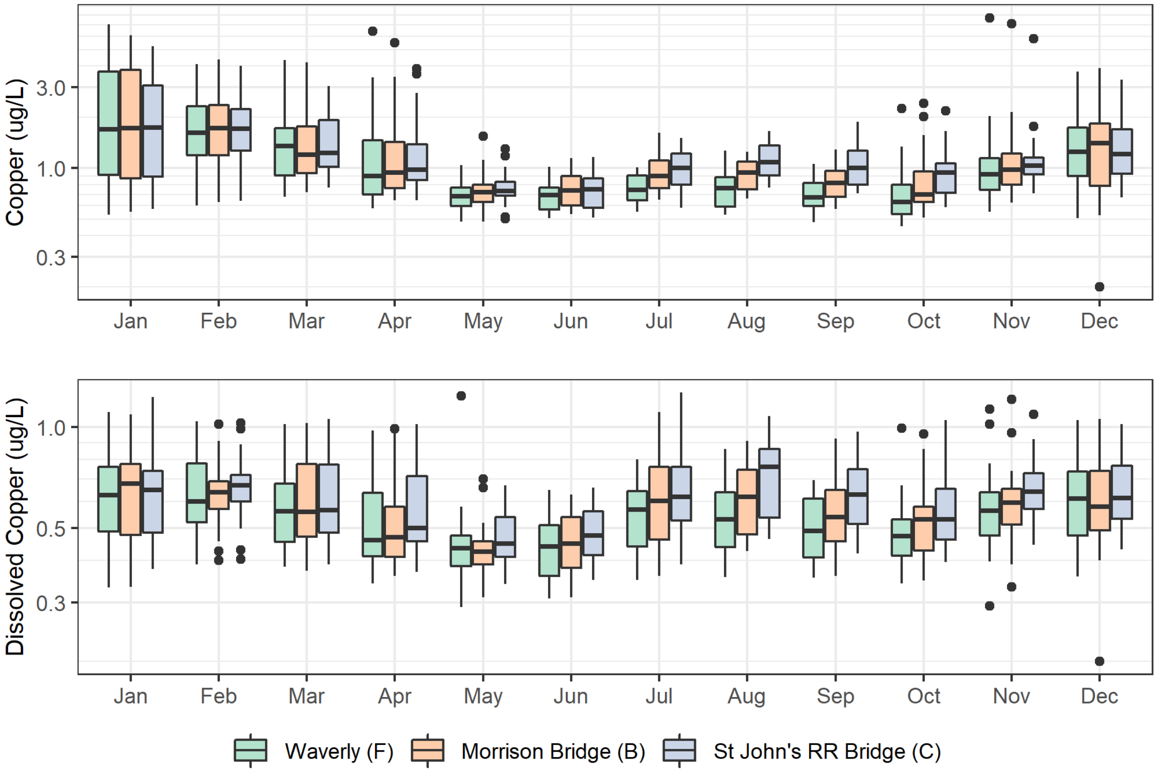
The water quality criteria for copper are expressed in terms of the dissolved concentration in the water column. The acute and chronic criteria for dissolved copper are calculated using the Biotic Ligand Model and are a function of the concentration of ions, alkalinity, organic carbon, pH, and temperature at the time of the sample. At lower concentrations, metals such as copper can negatively affect aquatic life (McIntyre et al., 2012). For example, Sandahl et al. (2007) found that copper concentrations as low as 2 µg/L affected the sensory physiology and predator avoidance behaviors of juvenile coho salmon.

Table 15. Summary statistics for total and dissolved copper samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Copper (µg/L)								
F	290	1.2	0.5	0.6	0.8	2.3	7.7	*NA*
B	291	1.3	0.2	0.6	0.9	2.4	7.1	*NA*
C	289	1.3	0.5	0.7	1.0	2.1	5.8	*NA*
Dissolved Copper (µg/L)								
F	290	0.6	0.3	0.4	0.5	0.8	1.2	2.1
B	291	0.6	0.2	0.4	0.5	0.8	1.2	0.7
C	289	0.6	0.3	0.4	0.6	0.9	1.3	0.3

The calculated acute copper criteria ranged from 0.3 to 15.1 µg/L (mean: 3.5 µg/L) and the calculated chronic criteria ranged from 0.21to 9.4 µg/L (mean: 2.17 µg/L). Both total and dissolved copper concentrations varied little between the three stations. Dissolved copper concentrations rarely exceeded 1 µg/L. Since 2000, only 9 samples across all three stations exceeded the calculated chronic dissolved copper criterion. The majority of these exceedances (6 of 9) were observed at the most upstream site (Waverly; site F).

Figure 64. Seasonal pattern in total and dissolved copper concentrations at the three Willamette sites since 2000.



Total copper concentrations exhibited a seasonal pattern, with higher concentrations observed during periods of high flows (Figure 64). Dissolved copper concentrations reflected somewhat of the same pattern, but with smaller seasonal increases during high flows. In addition to the seasonal pattern seen in total copper concentrations, there is also evidence that total copper concentrations have been decreasing, particularly at the upstream Waverly station (F), over the period of record (Figure 65). A more detailed analysis of the observed trend is described in Section 4.4.

Figure 65. Total copper concentrations at the three Willamette River sites since 2000.

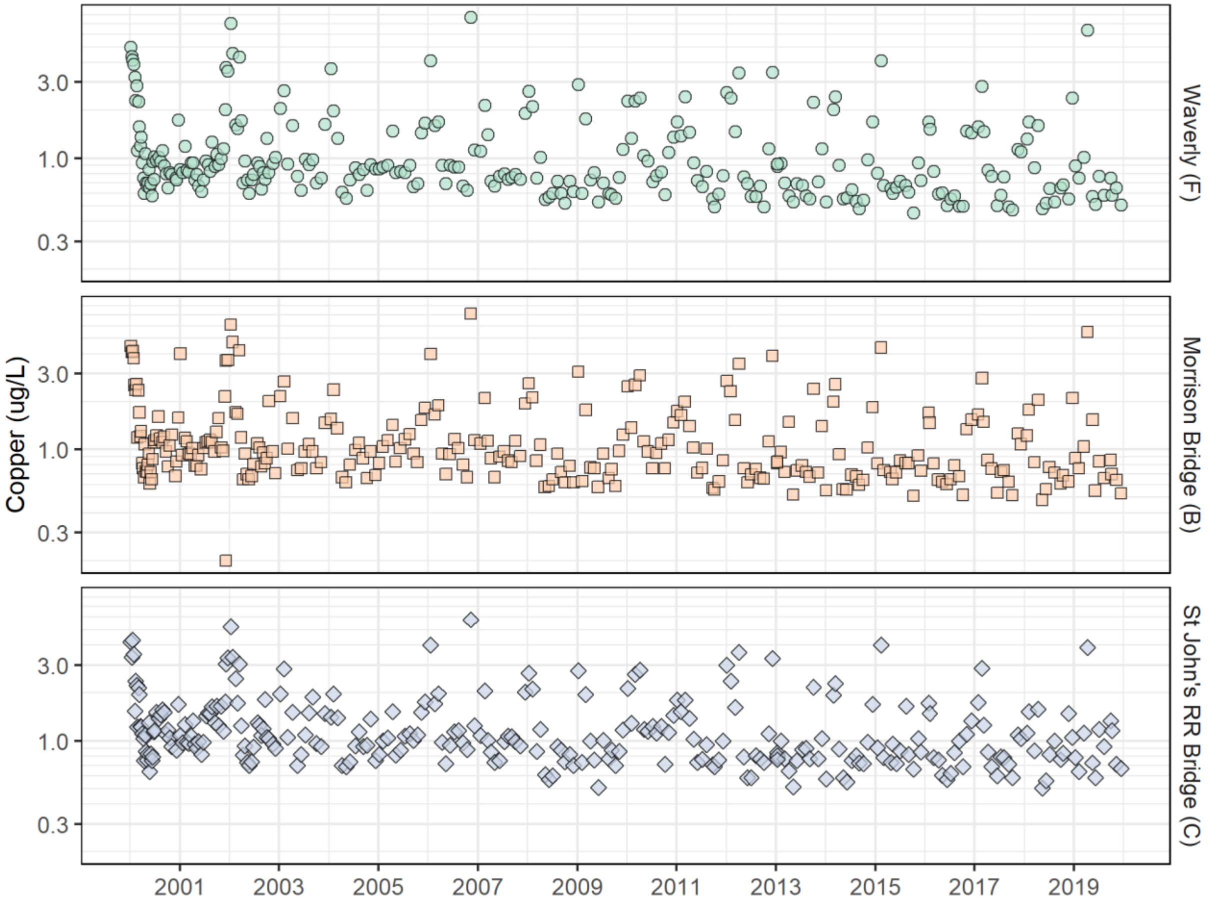
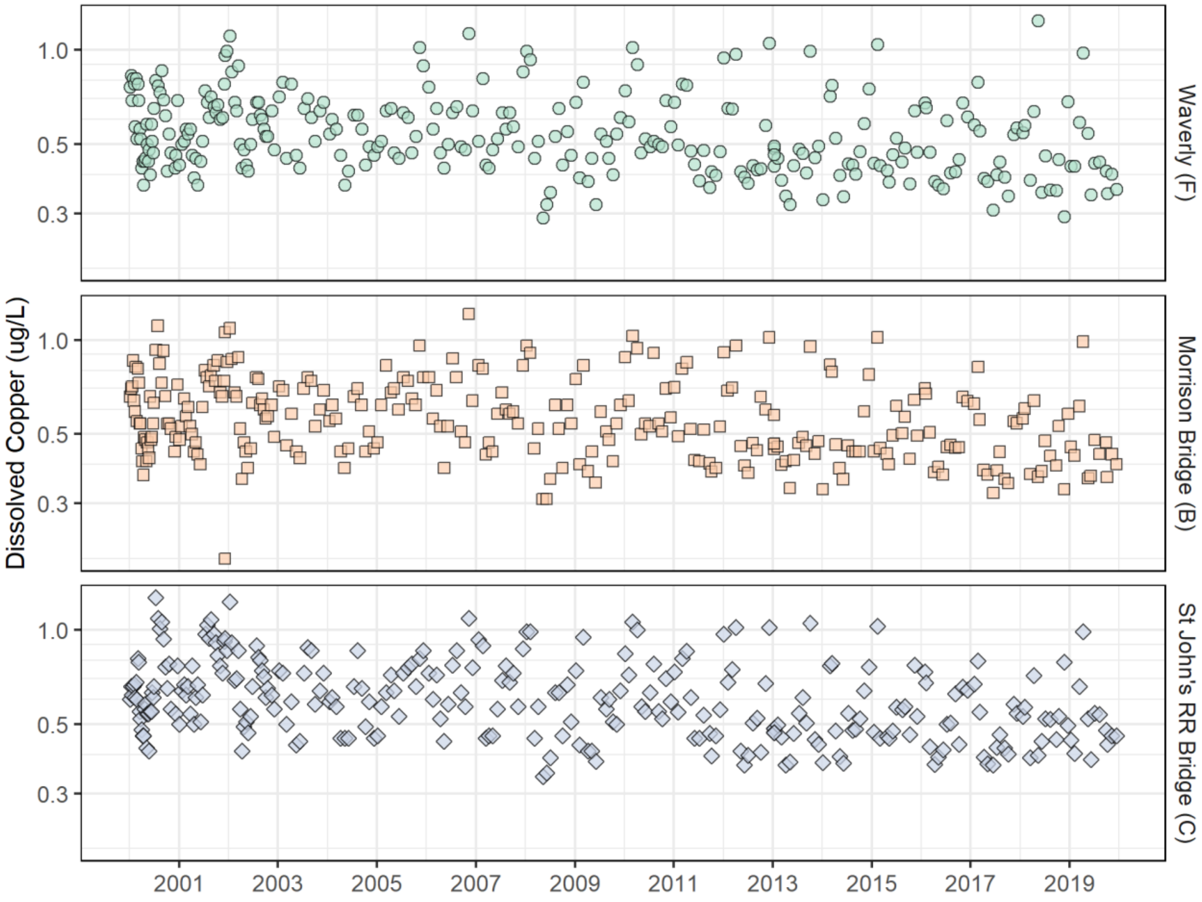


Figure 66. Dissolved copper concentrations at the three Willamette River sites since 2000.



4.3.3.5 Iron

Iron is an abundant element in the earth's crust and naturally occurs in aquatic systems. Given its abundance and useful properties it is the most widely used metal. Iron is frequently combined with other elements to make steel as pure iron is quite soft.

While iron is an essential micronutrient, used in proteins such as hemoglobin, excess iron in freshwater systems can be toxic to aquatic life. The water quality criteria for iron are expressed in terms of the total concentration in the water column. The chronic criterion for total iron is 1,000 µg/L. No acute criterion for iron has been established.

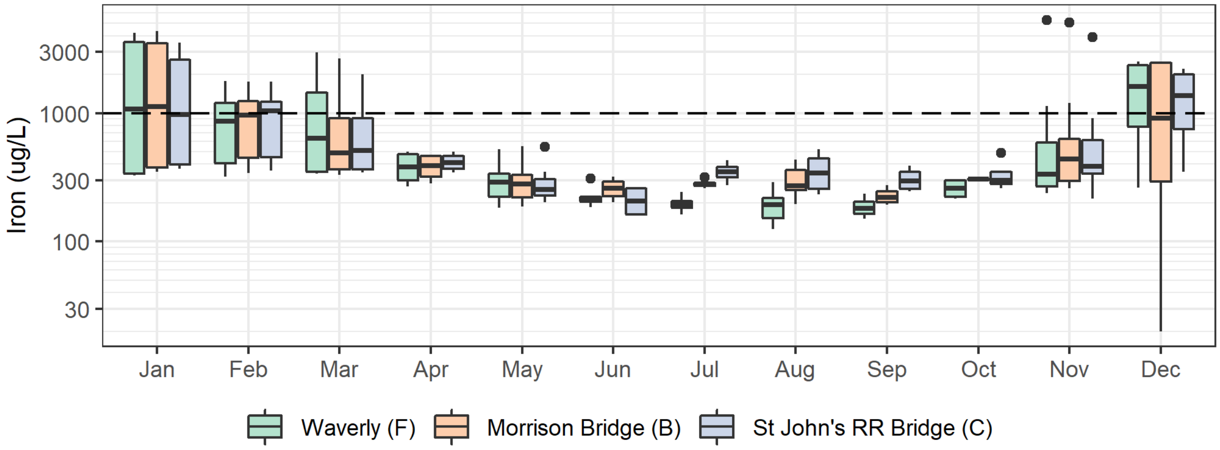
Total iron concentrations exceeded the 1,000 µg/L criterion at all three stations. These exceedances (13-14% of samples; Table 16) were observed only during the fall and winter, with lower concentrations consistently observed during periods of low flow. Over the ten years of sampling, iron was typically observed in particulate form—dissolved iron concentrations were consistently lower by an order of magnitude (Table 16).

Table 16. Summary statistics for total and dissolved iron samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Iron (μg/L)								
F	81	621	125	177	291	1,360	5,300	13.2
B	81	645	20	220	326	1,440	5,040	13.7
C	79	613	158	236	364	1,320	3,890	14.3
Dissolved Iron (μg/L)								
F	81	74	20	28	87	109	190	*NA*
B	81	73	20	26	85	105	179	*NA*
C	79	72	18	25	83	105	188	*NA*

It is important to note that beginning in mid-2002 the frequency of iron sampling was reduced to quarterly sampling and then discontinued entirely in 2010. As such, many of the months illustrated in the graph below include a limited number of samples.

Figure 67. Seasonal pattern in total and dissolved iron concentrations at the three Willamette River sites from 2000 to 2010.



There is no evidence of a temporal trend in iron concentrations over the period of record. In mid-2001, the detection limit for dissolved iron was lowered, allowing for improved characterization of the low dissolved iron concentrations seen in the Willamette River. Prior to mid-2001, all dissolved iron concentrations were below the detection limit (Figure 69).

Figure 68. Total iron concentrations at the three Willamette River sites from 2000 to 2010.

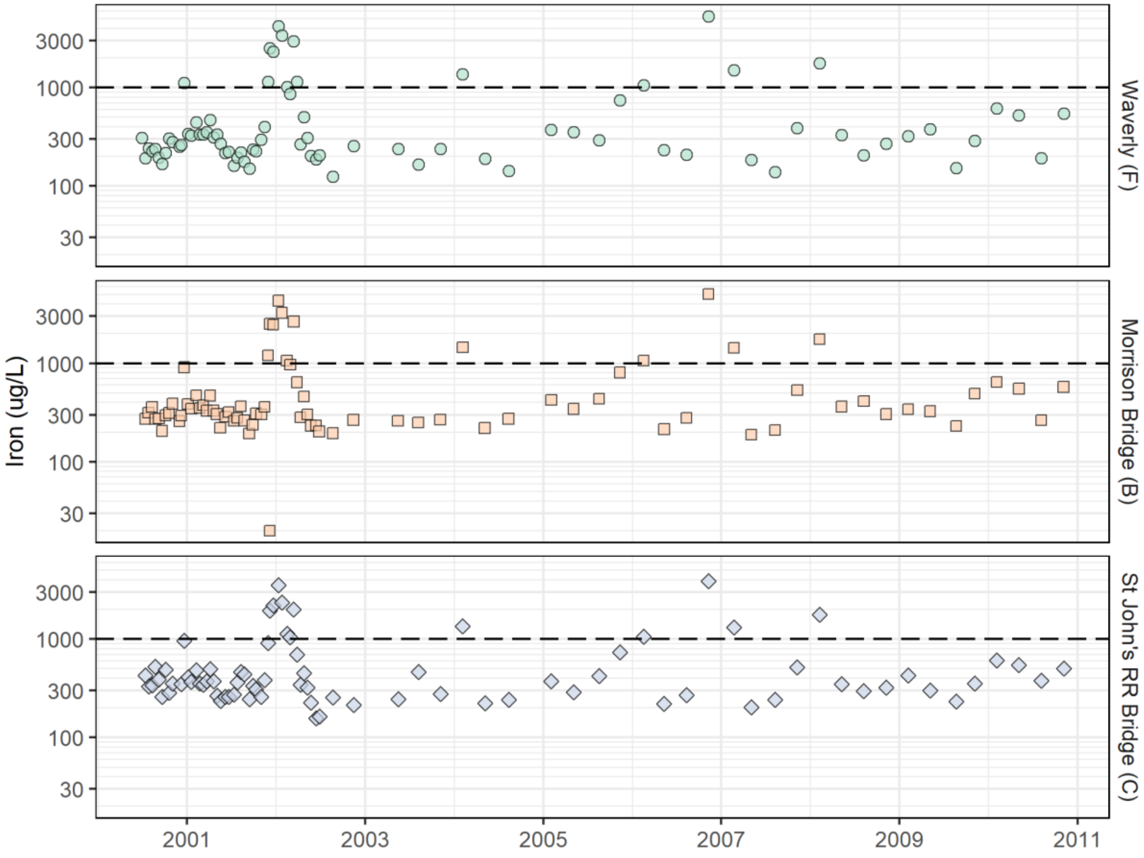
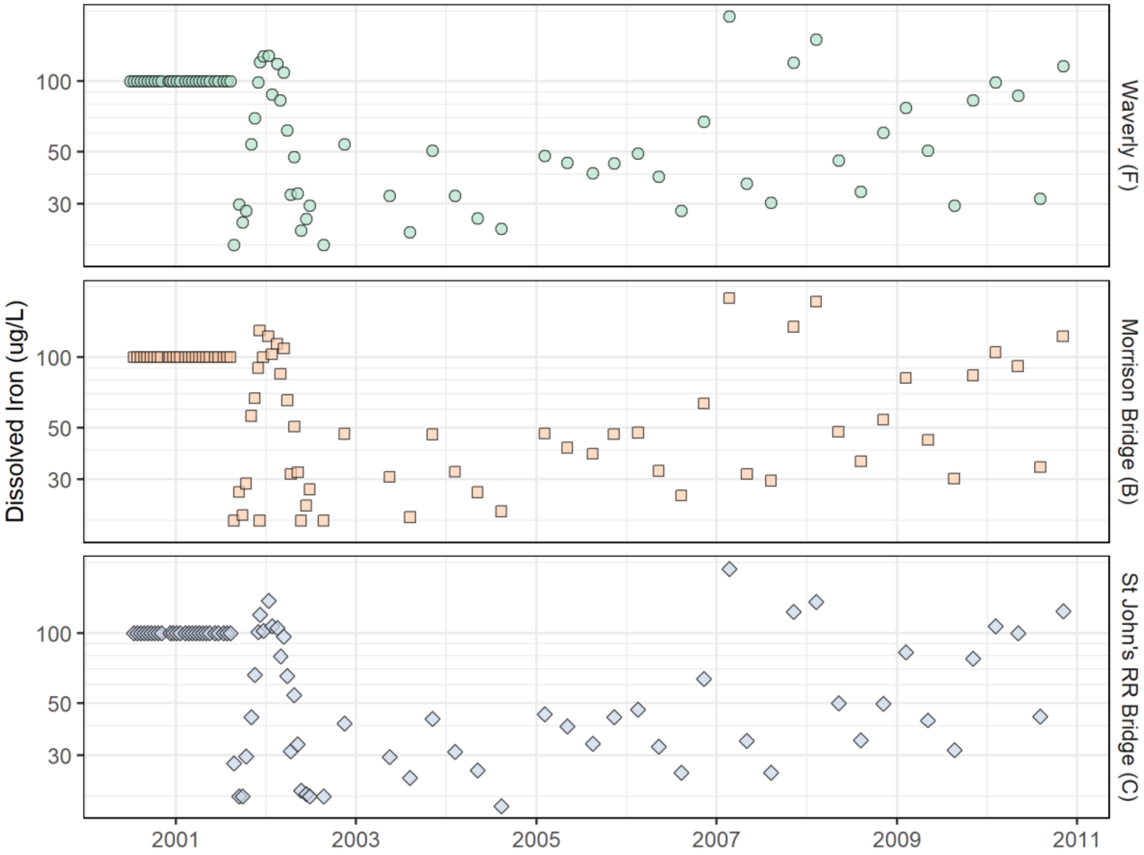


Figure 69. Dissolved iron concentrations at the three Willamette River sites from 2000 to 2010.



4.3.3.6 Lead

Lead is a dense, malleable heavy metal that was widely used until the late 19th century. Lead is currently still used in ammunition and lead-acid car batteries. Past uses of lead have included weights, solder, paint, plumbing, and leaded gasoline. Lead was added to gasoline (in the form of tetraethyl lead) in the 1920s to reduce engine knocking and improve fuel performance. Efforts to phase out leaded gasoline began in the 1970s and by the end of the 20th century, the sale of leaded fuel was banned for use in on-road vehicles in the United States.

Lead is a neurotoxin and can accumulate in bones and soft tissue. The human health impacts associated with lead were first recognized in the late 19th century. With the increased understanding of the harmful human health impacts, the use of lead has been phased out since the late 19th century. The water quality criteria for lead are expressed in terms of the dissolved concentration in the water column. The acute and chronic criteria for dissolved lead are expressed as a function of hardness in the water column.

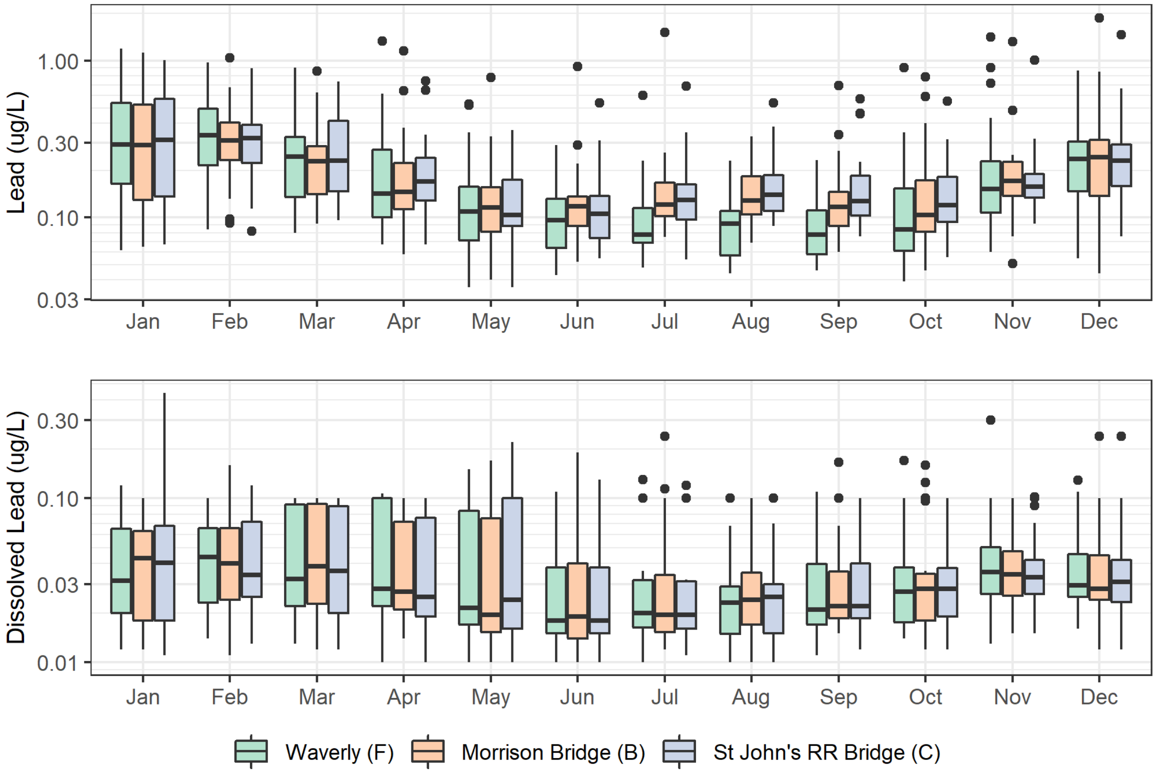
The analytical laboratory method used to analyze the Willamette River mainstem samples for lead was changed in mid-2001. The new method has a lower detection limit. BES uses the low-level analytical method for Willamette River samples as total and dissolved lead concentrations are consistently lower and below the detection limit of the standard procedures.

Table 17. Summary statistics for total and dissolved lead samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Lead (µg/L)								
F	290	0.22	0.04	0.06	0.13	0.53	1.41	*NA*
B	291	0.24	0.04	0.08	0.15	0.51	1.88	*NA*
C	289	0.23	0.04	0.08	0.16	0.47	1.46	*NA*
Dissolved Lead (µg/L)								
F	290	0.04	0.01	0.01	0.03	0.10	0.30	0.0
B	291	0.04	0.01	0.01	0.03	0.10	0.24	0.0
C	289	0.04	0.01	0.01	0.03	0.10	0.44	0.0

The calculated acute dissolved lead criteria ranged from 9.6 to 58.7 µg/L and the chronic criteria ranged from 0.4 to 2.3 µg/L. No exceedances of the acute or chronic dissolved lead criteria were observed during the sampling period, in fact, dissolved lead concentrations were observed far below any of the calculated criteria.

Figure 70. Seasonal pattern in total and dissolved lead concentrations from the three Willamette River sites since 2000. In mid-2001 the dissolved lead detection limit was lowered to better capture the low levels of lead seen in the Willamette River. The 75th percentile value on the dissolved lead boxplots reflect the higher detection limit.



There is little difference in both total and dissolved lead concentrations between the three sites. Generally, higher total lead concentrations are observed during the winter months. In contrast, dissolved lead concentrations vary little across the year.

In addition to the seasonal total lead pattern, there is also evidence that total lead concentrations have been decreasing at all three of the Willamette River stations (Figure 71). There is no indication that dissolved lead concentrations have changed over the sampling period. A more detailed analysis of the observed trend is described in Section 4.4.

Figure 71. Total lead concentrations at the three Willamette River sites since 2000.

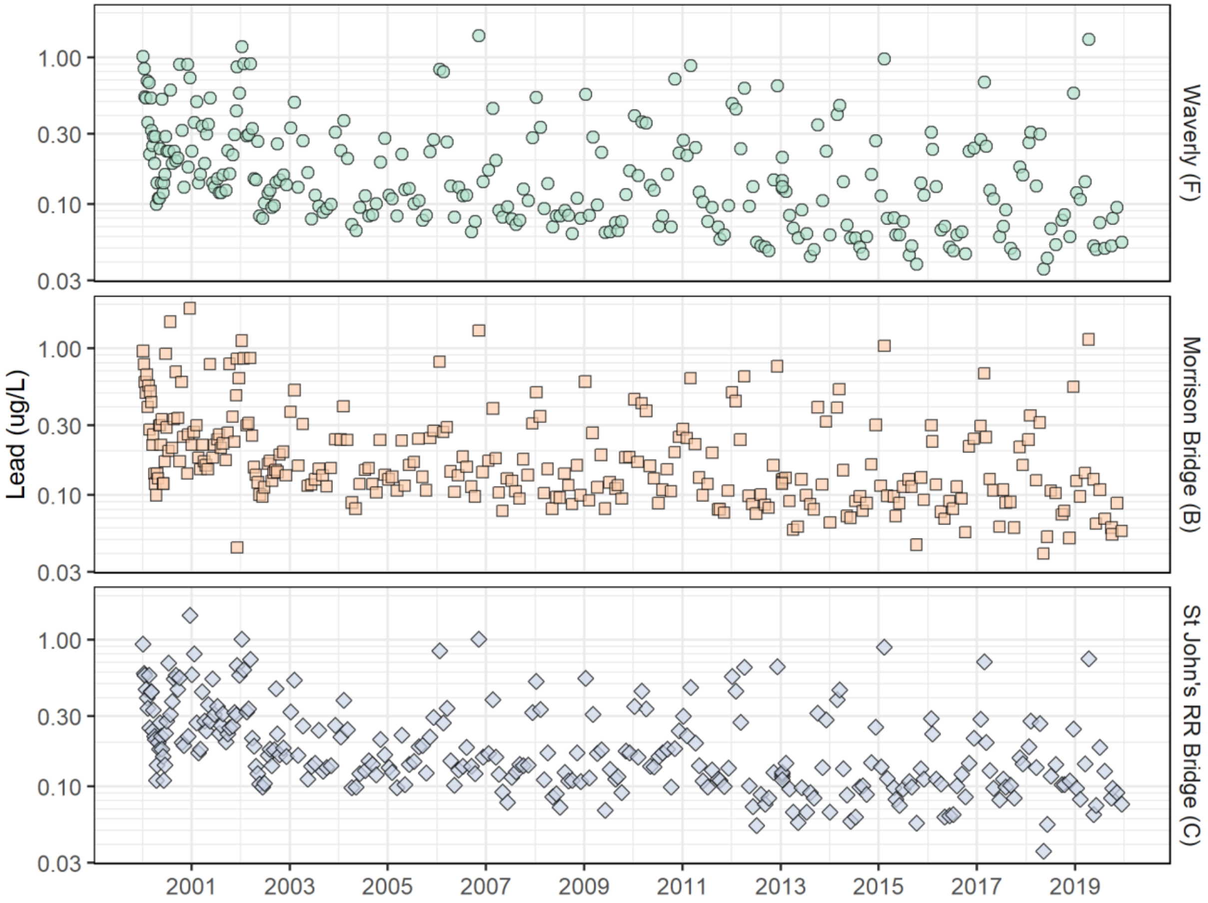
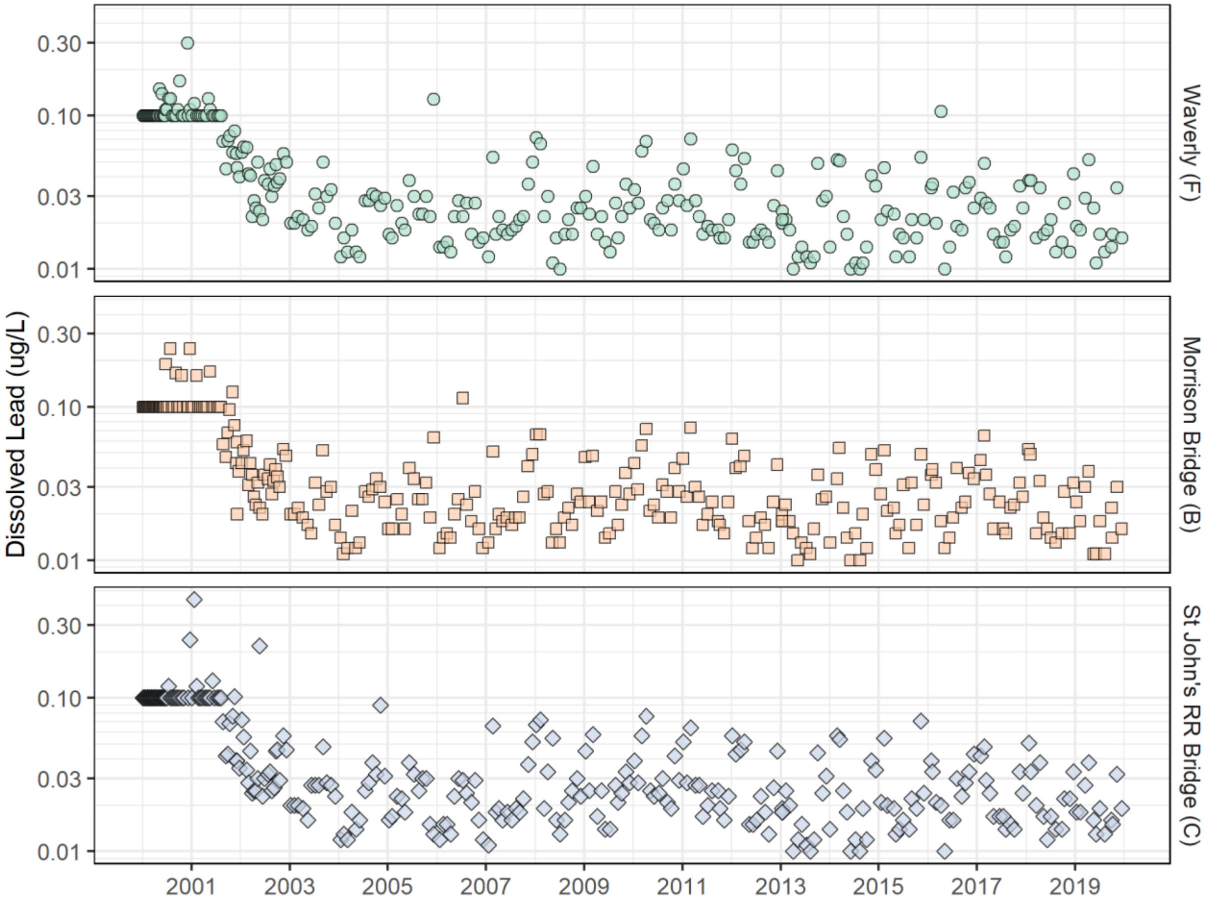


Figure 72. Dissolved lead concentrations at the three Willamette River stations since 2000. The detection limit for dissolved lead changed in 2001 from 0.1 µg/L to 0.01 µg/L when the laboratory began using a low-level analytical method for Willamette River lead samples.



4.3.3.7 Mercury

Mercury is a dense metal that is liquid at room temperature. Due to its unique properties, mercury has been used in many applications, including barometers, thermometers, fluorescent lamps, and hydraulic gold mining. Natural atmospheric mercury emissions include volcanic eruptions, while anthropogenic sources result from coal combustion. Pollutants in the atmosphere (including mercury) can enter stormwater through two mechanisms: dry and wet deposition. Dry deposition occurs when particles in the air settle directly on the land, trees, buildings, or other surfaces. When it rains, these pollutants are washed off the surfaces and are transported by stormwater runoff. Wet deposition occurs when particles in the atmosphere are incorporated into water vapor that subsequently falls as precipitation. In the Willamette basin, the atmosphere represents the primary source of mercury pollution (DEQ, 2019).

Mercury and many mercury compounds are toxic. In humans and other vertebrates, mercury is a potent neurotoxin and can cause damage to the brain, kidneys and lungs. The organic mercury compounds, including methylmercury, are the most toxic forms of mercury. In aquatic systems, mercury accumulation (typically in the form of methylmercury) is observed in fish and other aquatic organisms. To protect human health, DEQ has established a methylmercury fish tissue criterion of 0.040 mg/kg (OAR 340-041-8033 - Table 40). The aquatic life criteria for mercury include an acute criterion for total mercury of 2.4 µg/L and a chronic criterion of 0.012 µg/L (OAR 340-041-8033 - Table 30). An update to the Willamette basin mercury TMDL was released in November 2019. To meet the methylmercury fish tissue criterion of 0.040 mg/kg, DEQ calculated a water column target of 0.14 ng/L of total mercury for the TMDL based on the modeled bioaccumulation of methylmercury in Willamette River fish. At this time, it is not possible to fully assess attainment of the instream total mercury concentration target identified in the 2019 TMDL. The target instream concentration of 0.14 ng/L is below the current total mercury detection limit of 1 ng/L.

Table 18. Summary statistics for mercury samples from the three Willamette River sites.

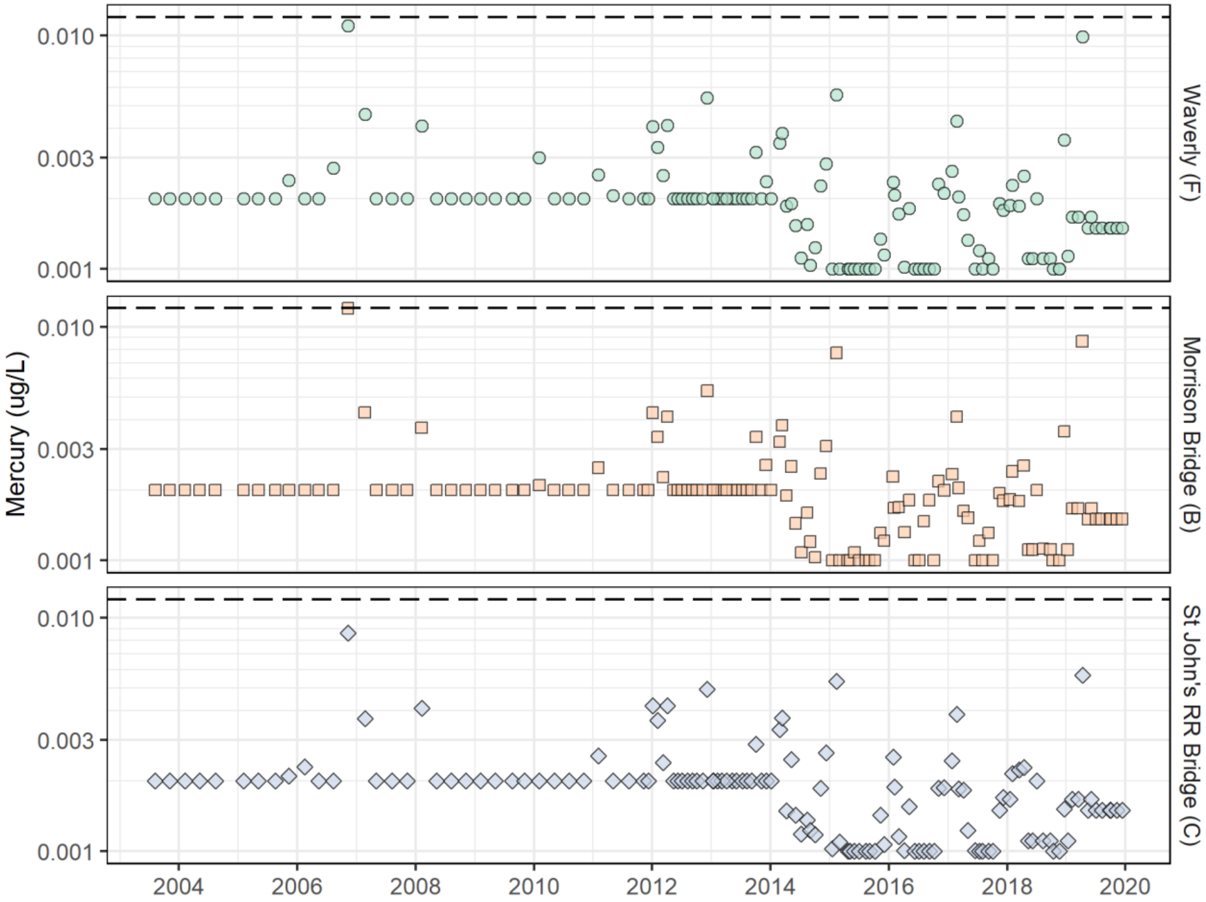
Mercury (ng/L)

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
F	134	2.1	1.0	1.0	2.0	3.1	11.0	0.0
B	133	2.1	1.0	1.0	2.0	3.2	12.0	0.0
C	133	2.0	1.0	1.0	2.0	2.6	8.6	0.0

No meaningful differences in mercury concentrations was observed between the three sites (Table 18) and concentrations were frequency measured below the detection limit throughout the sampling period. No exceedances of the acute (2.4 µg/L) or chronic total mercury criteria (0.012 µg/L) were observed at any of the stations.

While mercury is frequently measured below the detection limit of 1 ng/L, samples above the detection limit are not uncommon. These samples exceed the TMDL mercury target by an order of magnitude. Given that the current detection limit is higher than the TMDL mercury target, it is not possible to fully assess the extent to which the Willamette River is exceeding the 0.14 ng/L target.

Figure 73. Mercury concentrations at the three Willamette River sites since 2003. The dashed line represents the chronic water quality criterion of 0.012 µg/L. The detection limit was lowered in 2014.



4.3.3.8 Nickel

Nickel is a hard, malleable metal. Today, nickel is often used in alloys, including stainless steel, as well as in batteries, pigments, and metal surface treatments due to its corrosion-resistant properties. Nickel is also used around the world in coins. Environmental sources of nickel include the natural weathering of rocks, but also anthropogenic sources from coal combustion and industrial discharges.

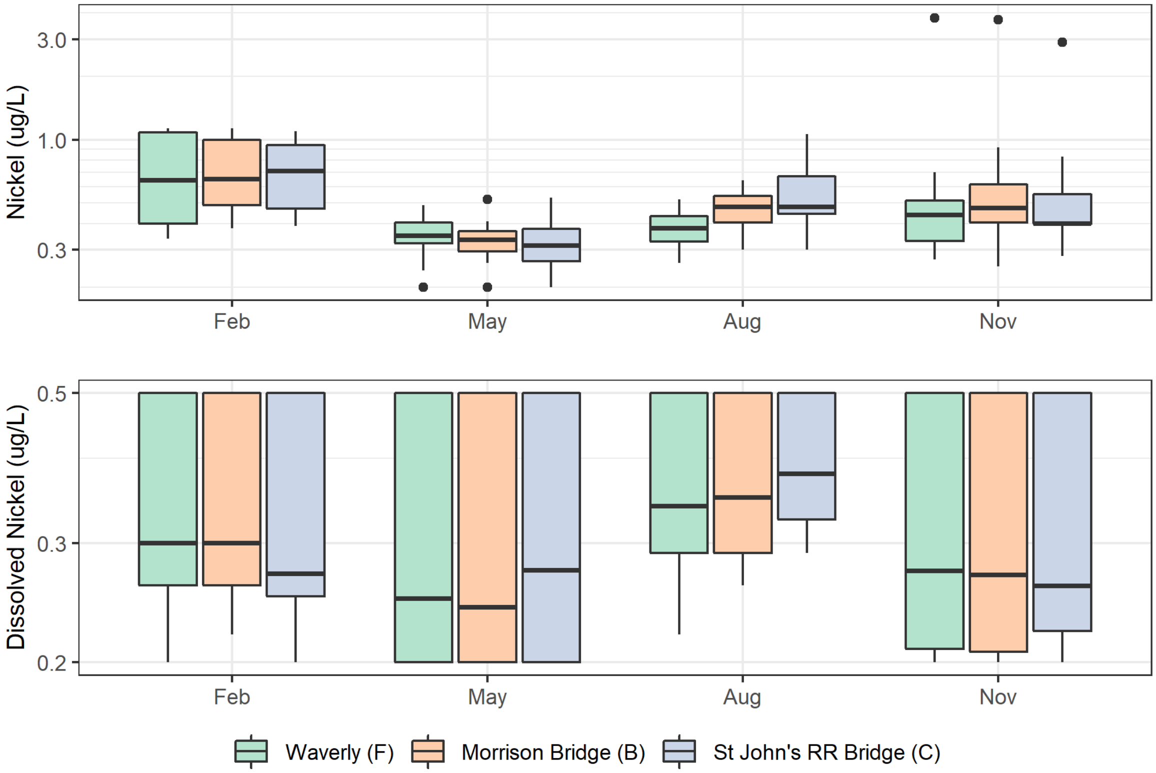
In higher concentrations, nickel can be toxic to aquatic life. The water quality criteria for nickel are expressed in terms of dissolved concentrations in the water column. The acute and chronic criteria for dissolved nickel are expressed as a function of hardness in the water column. The human health criterion for nickel is 140 µg/L.

Table 19. Summary statistics for total and dissolved Nickel samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Nickel (µg/L)								
F	40	0.55	0.20	0.27	0.40	0.94	3.79	*NA*
B	40	0.59	0.20	0.30	0.48	0.95	3.70	*NA*
C	40	0.58	0.20	0.28	0.45	0.95	2.90	*NA*
Dissolved Nickel (µg/L)								
F	40	0.35	0.20	0.20	0.30	0.50	0.50	0.0
B	40	0.35	0.20	0.20	0.30	0.50	0.50	0.0
C	40	0.36	0.20	0.20	0.32	0.50	0.50	0.0

No exceedances of the dissolved nickel criteria were observed during the sampling period and the dissolved nickel concentrations at the three Willamette sites were consistently far lower than the applicable criteria. The calculated acute dissolved nickel criteria ranged from 115.9 to 200.1 µg/L and the chronic criteria ranged from 12.9 to 22.2 µg/L.

Figure 74. Seasonal pattern in total and dissolved nickel concentrations at the three Willamette River sites since 2000. The detection limit for dissolved nickel was increased to 0.5 µg/L in 2007, resulting in more non-detects.



Total and dissolved nickel concentrations did not vary substantially between the three stations and the seasonal variability was also small. Generally, higher nickel concentrations were observed during periods with higher instream flows. There is no evidence of a temporal trend in nickel concentrations at any of the three sites.

Figure 75. Total Nickel concentrations at the three Willamette River sites since 2000.

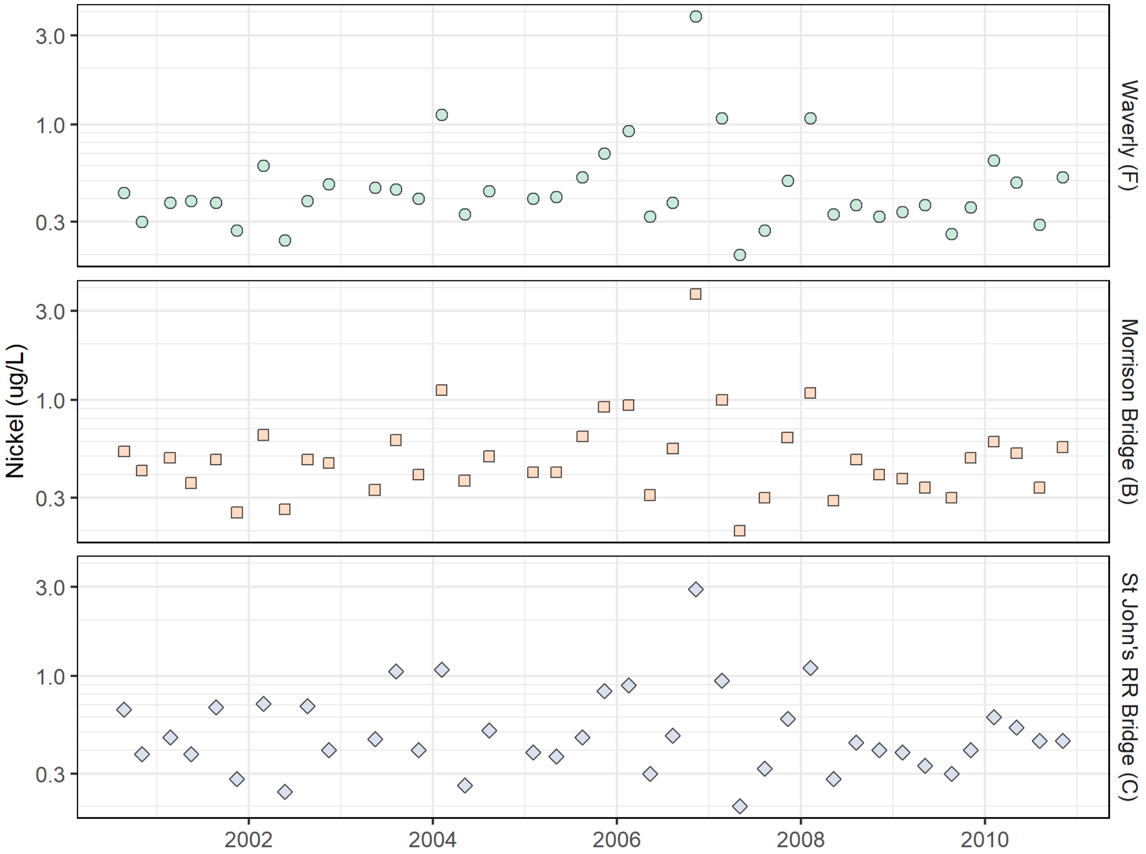
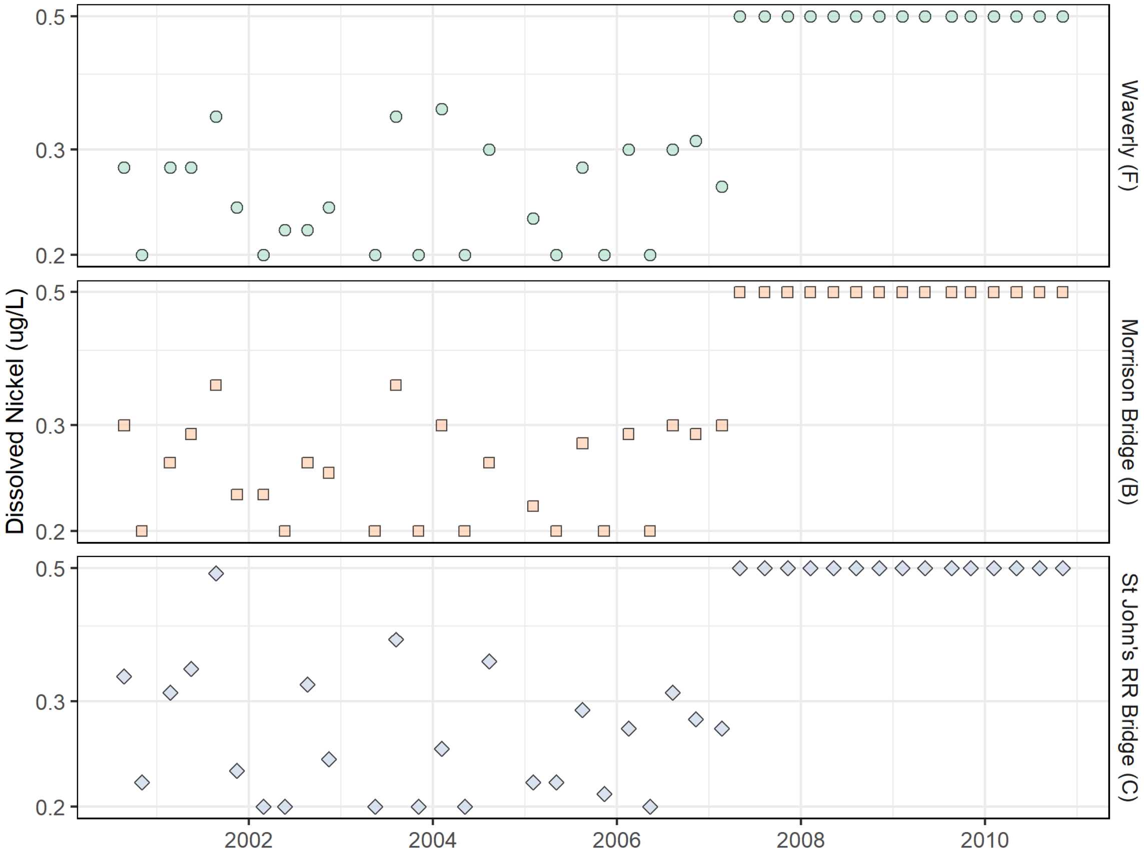


Figure 76. Dissolved nickel concentrations at the three Willamette River sites since 2000. The detection limit was increased to 0.5 µg/L in 2007.



4.3.3.9 Selenium

Selenium is a nonmetal often found in metal sulfide ores. Refining these ores produces selenium as a byproduct. Today, selenium's main commercial use is in pigments and glassmaking. In the past, selenium has also been used in electronics as part of semiconductor devices, however, most of these uses have now been replaces silicon devices.

In higher concentrations, selenium can be toxic to aquatic life. The water quality criteria for selenium are expressed in terms of dissolved concentrations in the water column. The acute criterion for dissolved selenium is calculated based on fractions of total selenium that are treated as selenite and selenite. A single chronic criterion of 4.6 µg/L applies to dissolved selenium.

No total and dissolved selenium samples were measured above the detection limit for the entire period of record. No exceedances of the dissolved selenium criteria were observed during the sampling period and applicable criteria are substantially higher than the detection limit.

Table 20. Summary statistics for total and dissolved Selenium samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Selenium (µg/L)								
F	40	0.62	0.50	0.50	0.50	1.00	1.00	*NA*
B	40	0.62	0.50	0.50	0.50	1.00	1.00	*NA*
C	40	0.62	0.50	0.50	0.50	1.00	1.00	*NA*
Dissolved Selenium (µg/L)								
F	40	0.62	0.50	0.50	0.50	1.00	1.00	0.0
B	40	0.62	0.50	0.50	0.50	1.00	1.00	0.0
C	40	0.62	0.50	0.50	0.50	1.00	1.00	0.0

4.3.3.10 Zinc

Zinc is a commonly used metal. The earliest known used of zinc by humans was the use of brass (a zinc–copper alloy). Today, zinc is widely used for its corrosion-resistant properties as a plating for iron or steel (galvanization) to prevent rusting. Zinc is also used in electrical batteries, pigments, and as a wood preservative and fungicide.

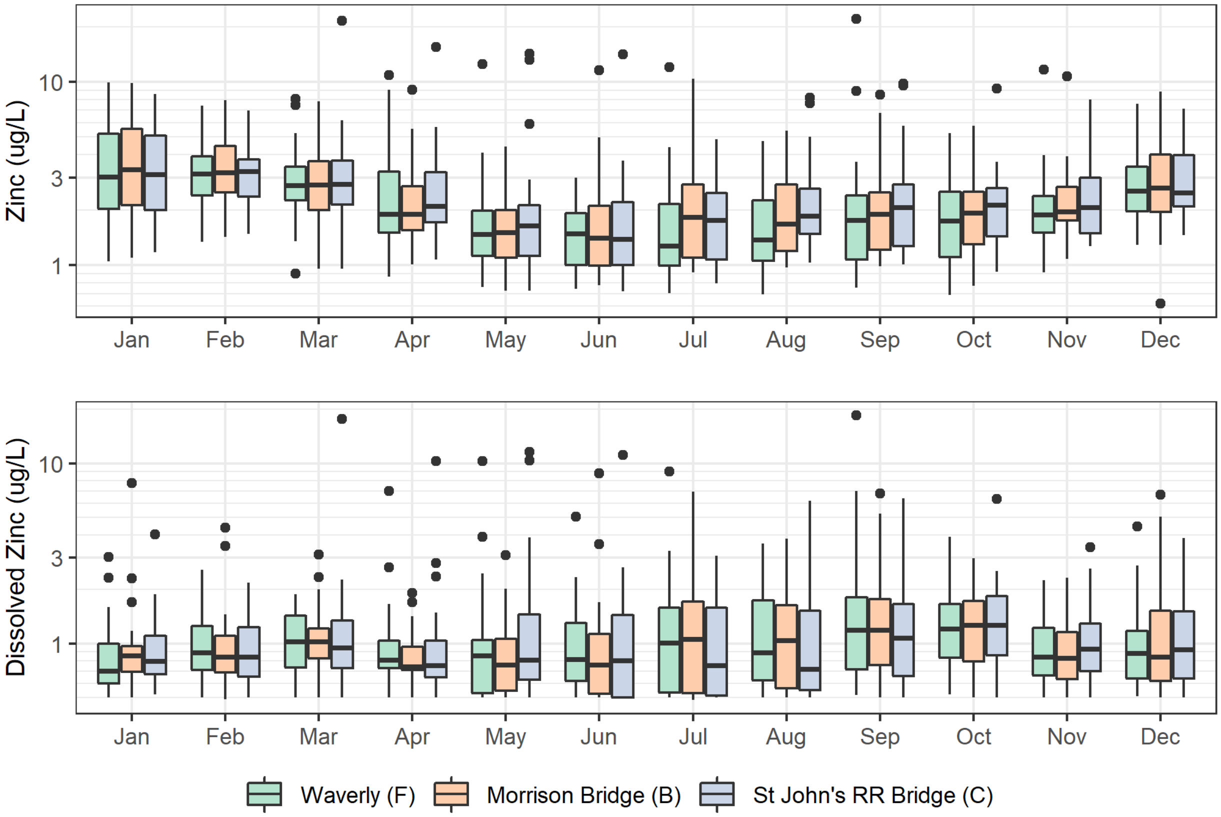
In higher concentrations, zinc can be toxic to aquatic life. The water quality criteria for zinc are expressed in terms of dissolved concentrations in the water column. The acute and chronic criteria for dissolved zinc are expressed as a function of hardness in the water column. The human health criterion for zinc is 2,100 µg/L.

Table 21. Summary statistics for total and dissolved zinc samples from the three Willamette River sites.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Zinc (µg/L)								
F	290	2.6	0.7	0.9	2.0	4.9	22.1	*NA*
B	291	2.7	0.6	1.1	2.1	5.2	11.6	*NA*
C	289	2.9	0.7	1.1	2.2	5.1	21.6	*NA*
Dissolved Zinc (µg/L)								
F	290	1.3	0.5	0.5	0.9	2.1	18.5	0.0
B	291	1.2	0.5	0.5	0.9	2.0	8.8	0.0
C	289	1.4	0.5	0.5	0.9	2.4	17.6	0.0

No exceedances of the dissolved zinc criteria were observed during the sampling period (Table 21). The calculated acute dissolved zinc criteria ranged from 27.5 to 108.8 µg/L and the chronic criteria ranged from 27.7 to 109.7 µg/L. There was little difference in zinc concentrations between the three stations. Generally, the total zinc concentrations were highest during the winter months. Conversely, dissolved zinc concentrations were lower during the winter months and more variability in concentrations seen during periods of low flow (Figure 77).

Figure 77. Seasonal pattern in total and dissolved zinc concentrations at the three Willamette River sites since 2000.



There is evidence that both total and dissolved zinc concentrations have decreased over the period of record. The higher concentrations of zinc seen during times of high flow are seen throughout the period, but the lower zinc concentrations appear to be declining. This is evident in the dissolved zinc concentrations where a larger number of non-detects were observed the latter half of the of the period. A more detailed analysis of zinc trends is included in Section 4.4.4.

Figure 78. Total zinc concentrations at the three Willamette River sites since 2000.

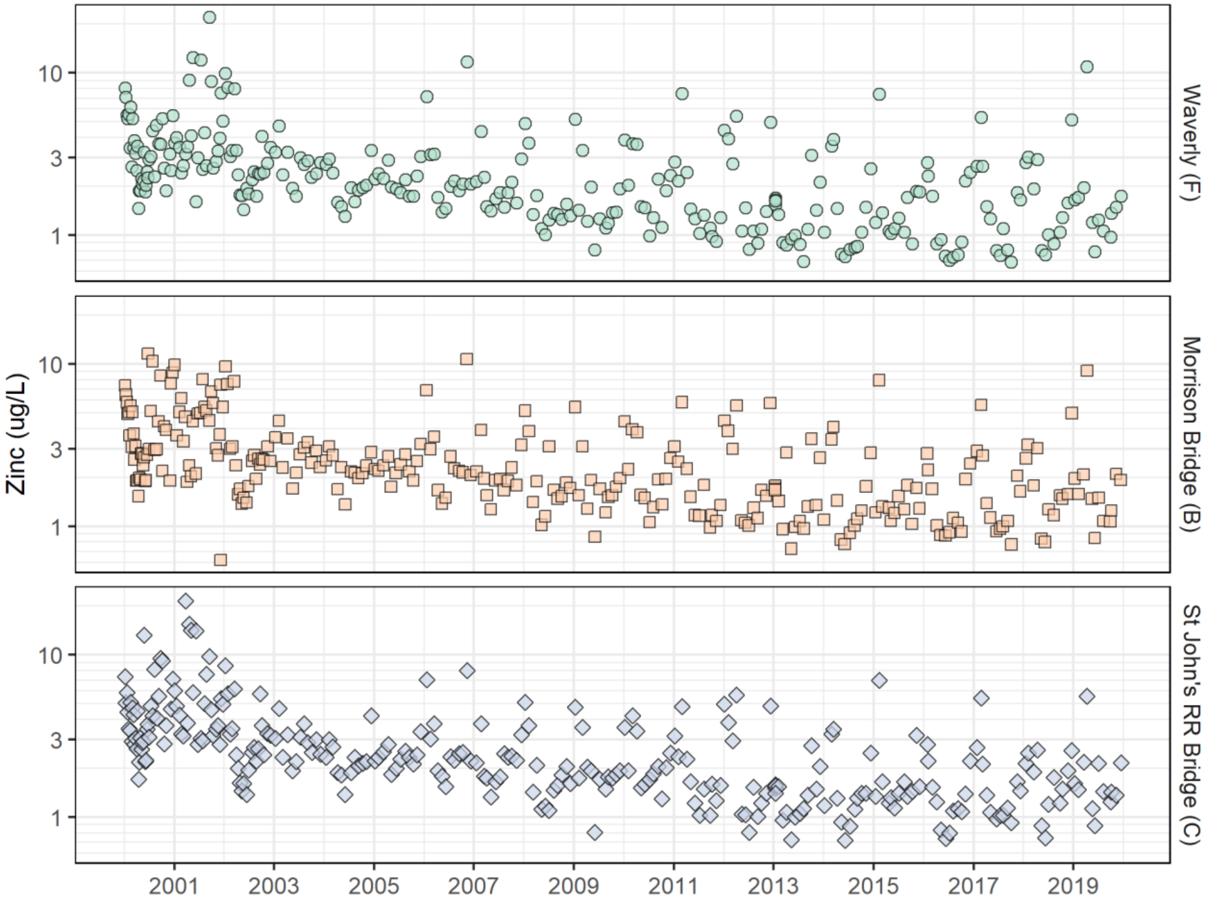
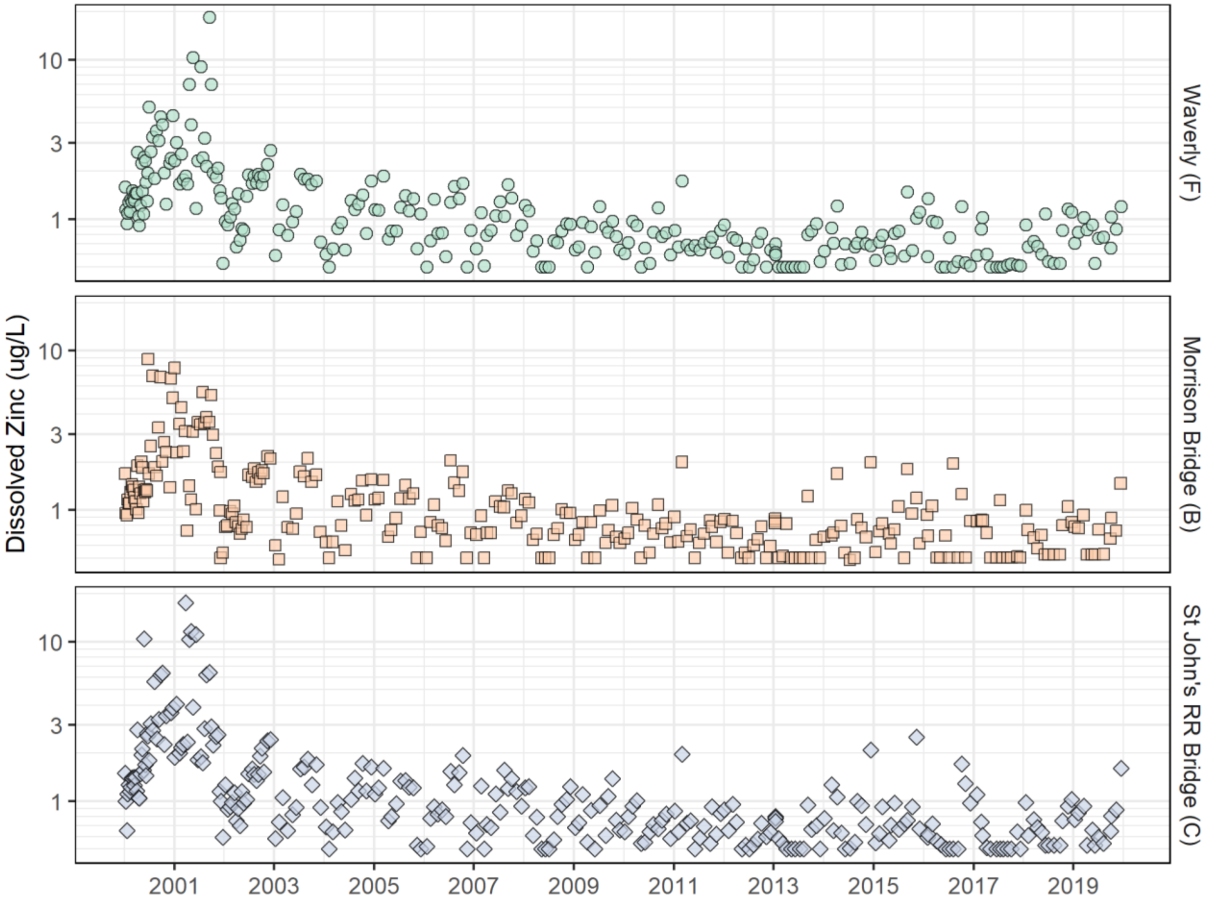


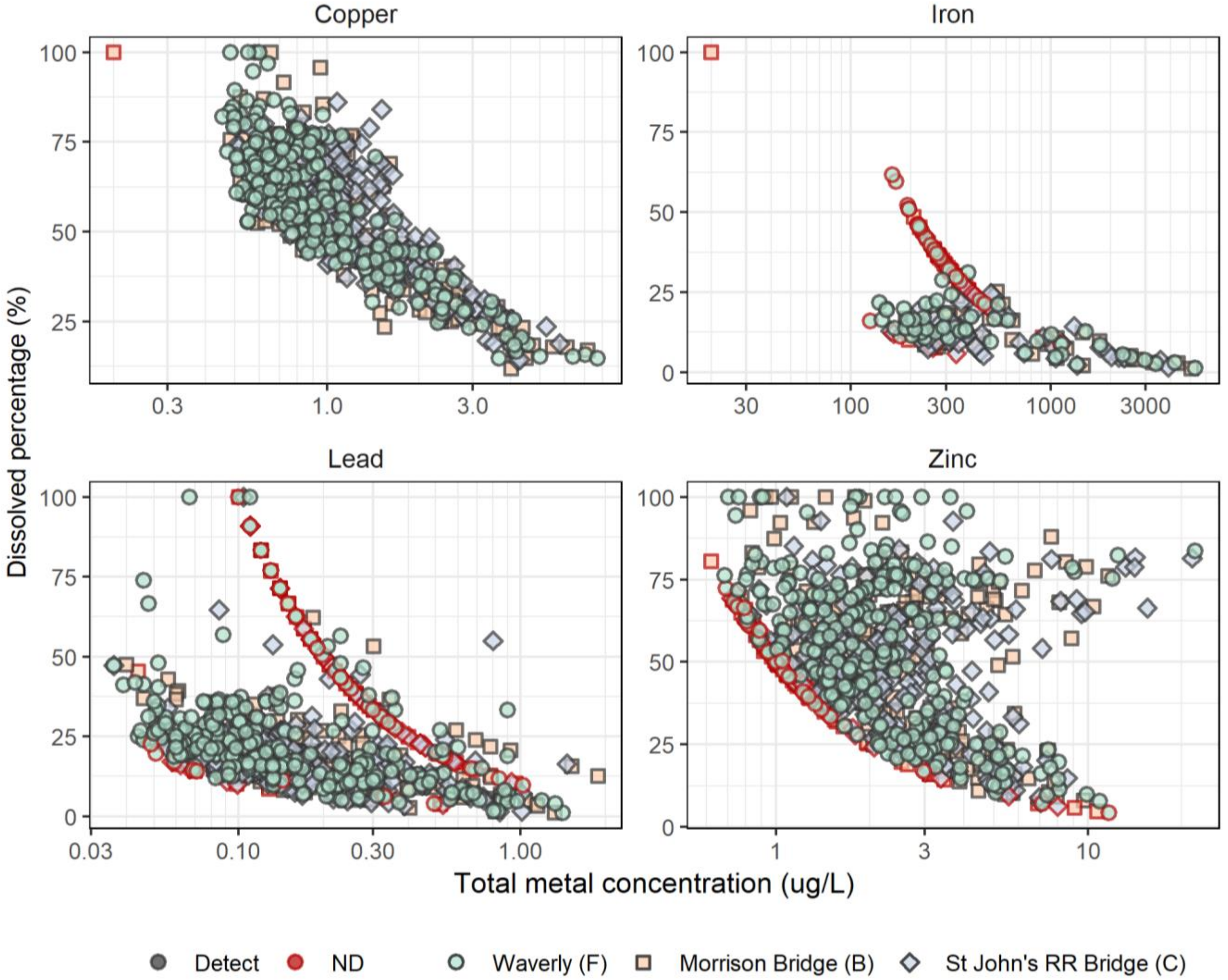
Figure 79. Dissolved zinc concentrations at the three Willamette River sites since 2000.



4.3.3.11 Dissolved Metals Fractions

The Willamette River ambient monitoring program analyzes both total dissolved metals (with the exception of mercury). Dissolved metals are the portion that passes through a 0.45 µm filter. In the case of most metals, the toxicity of dissolved metals to aquatic organisms is substantially higher than the particulate form. Since the primary mechanisms for toxicity for aquatic organisms is through adsorption to or uptake across the gills, the dissolved fraction of a metal is small enough to interact with or inhibit physiological processes.

Figure 80. Dissolved fraction of each metal analyzed at the three Willamette River sites since 2000. The points outlined in red represent non-detects for the dissolved metal.



At the three Willamette sites, dissolved copper concentrations were found to decrease as total copper concentrations increased (Figure 80). As described above, these higher total copper concentrations were consistently seen during periods of higher flows, while the lower total copper concentrations were observed when flows were lower. Under these low flow conditions, a greater proportion of the copper in the Willamette is found in its dissolved form.

Unlike copper, a very small proportion of the iron in the Willamette was observed in a dissolved form Figure 80). As noted above, the dissolved iron detection limit decreased substantially in 2001. With the change in the dissolved iron detection limit, almost none of the samples were found to be composed of more than 25% dissolved iron. That is, most of the iron in the Willamette is seen in particulate form.

The proportion of dissolved lead in the Willamette decreases as total lead concentrations increase (Figure 80). As described above, there was a change in the laboratory method used to analyze lead samples. As a result, the lead detection limit decreased. While the dissolved lead percentage does decrease with increasing total lead concentrations, less than half of the measured lead is dissolved. As with iron, most of the lead measured in the Willamette is seen in particulate form.

As with copper, iron, and lead, the proportion of dissolved zinc tends to decrease as total zinc concentrations increase, however, the relationship is more variable than with the other three metals (Figure 80). Unlike the other metals, at higher total zinc concentrations, more than 50% may be dissolved. In contrast to the other metals, zinc is more frequently observed in a dissolved form.

4.3.4Nutrients

4.3.4.1 Nitrogen

In rivers and streams, nitrogen is typically observed in the form of nitrate (NO_3), which is highly water soluble. High concentrations of nitrogen can promote primary production, potentially leading to eutrophication.

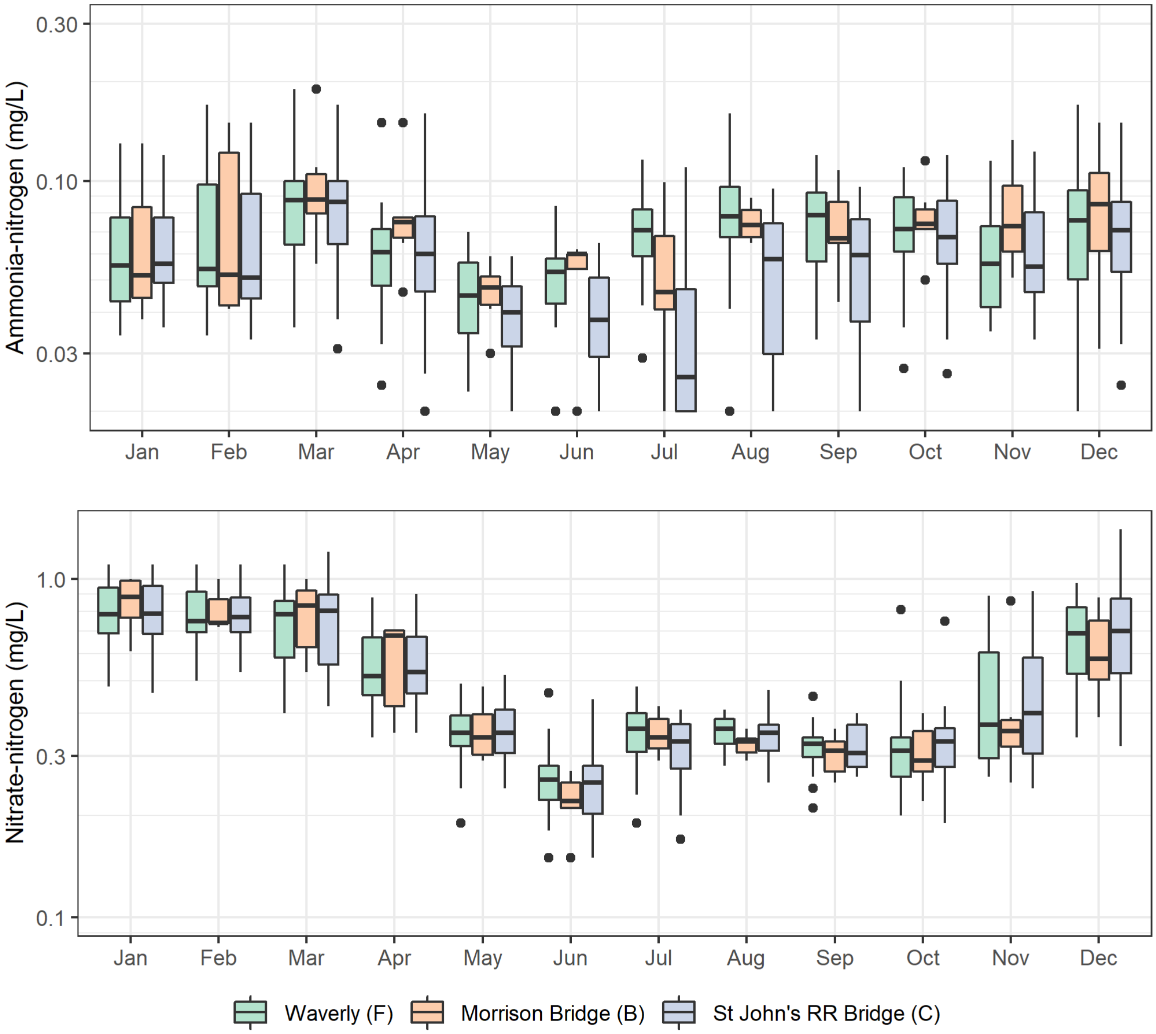
Under certain water quality conditions and concentrations, ammonia can be toxic to aquatic life. Additionally, the metabolic oxidation of ammonia (nitrification) results in an oxygen demand which can reduce concentrations of dissolved oxygen in the water column. The toxicity of ammonia to aquatic organisms and the corresponding water quality criteria are dependent on the pH and temperature of the water body, as well as the life stage of the organism (OAR 340-041-8033 Table 30). The chronic ammonia criterion is expressed as a 30-day rolling average. No water quality criteria for nitrate apply to the Willamette River.

Table 22. Summary statistics for ammonia and nitrate samples from the three Willamette River sites. Note: ammonia and nitrate were not sampled at the Morrison Bridge site (B) between 2005 and 2017.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
Ammonia-Nitrogen (mg/L)								
F	227	0.07	0.02	0.04	0.06	0.10	0.19	0.0
B	76	0.07	0.02	0.04	0.07	0.12	0.19	0.0
C	227	0.06	0.02	0.02	0.05	0.10	0.17	0.0
Nitrate-Nitrogen (mg/L)								
F	227	0.50	0.15	0.26	0.40	0.86	1.10	*NA*
B	76	0.50	0.15	0.26	0.38	0.88	1.00	*NA*
C	227	0.50	0.15	0.26	0.39	0.88	1.40	*NA*

No exceedances of the ammonia criteria were observed at any of the sites throughout the entire sampling period. Nitrogen samples were not collected at the Morrison Bridge station (B) between 2005 and 2017.

Figure 81. Seasonal pattern in ammonia and nitrate concentrations at the three Willamette River sites since 2000. Note: ammonia and nitrate were not sampled at the Morrison Bridge site (B) between 2005 and 2017.



There is little difference in ammonia and nitrate concentrations between the three stations. Ammonia concentrations do not vary substantially across the year, while nitrate concentrations during the wet season are substantially higher than those measured in the summer and early fall. There is no evidence of a temporal trend in nitrogen concentrations.

Figure 82. Ammonia concentrations at the three Willamette River sites since 2000. Note: ammonia was not sampled at the Morrison Bridge site (B) between 2005 and 2017.

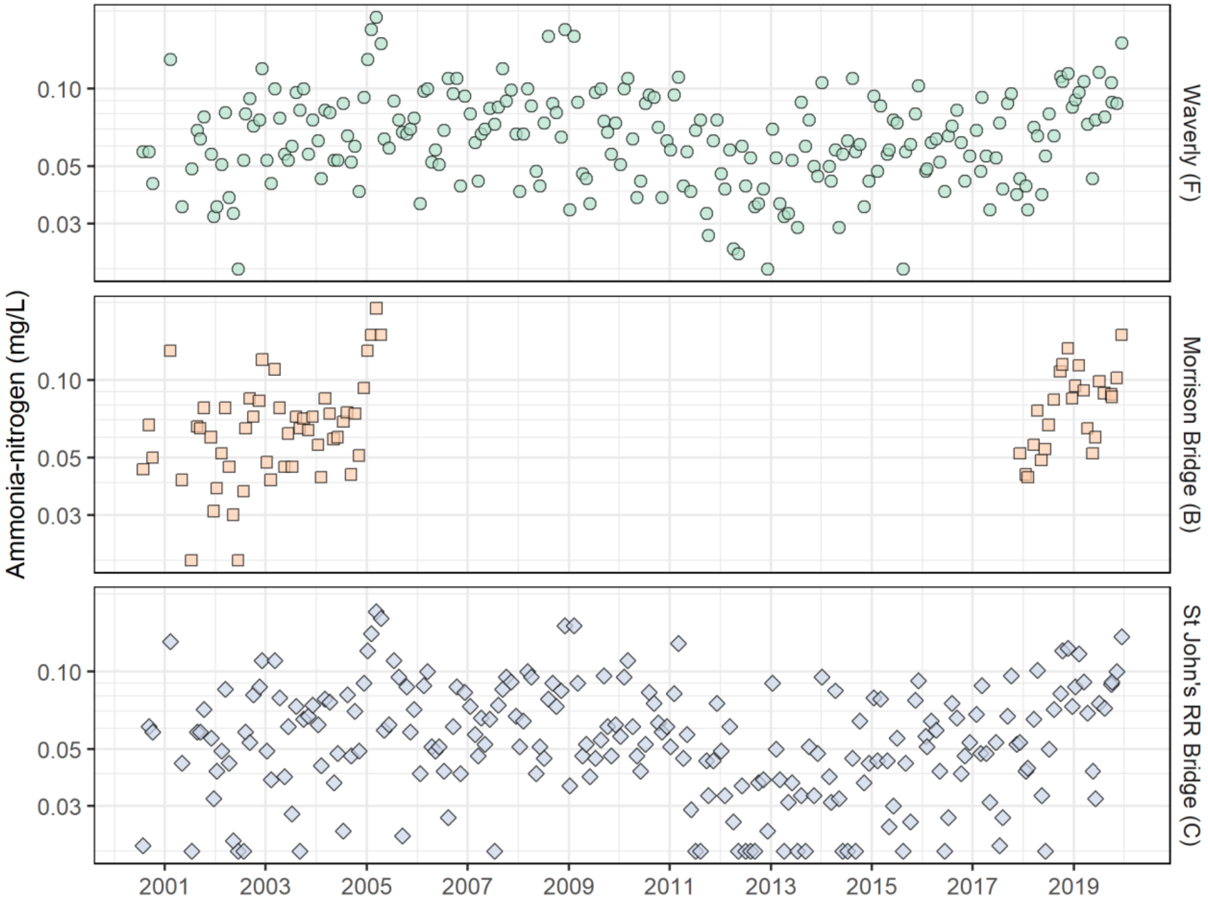
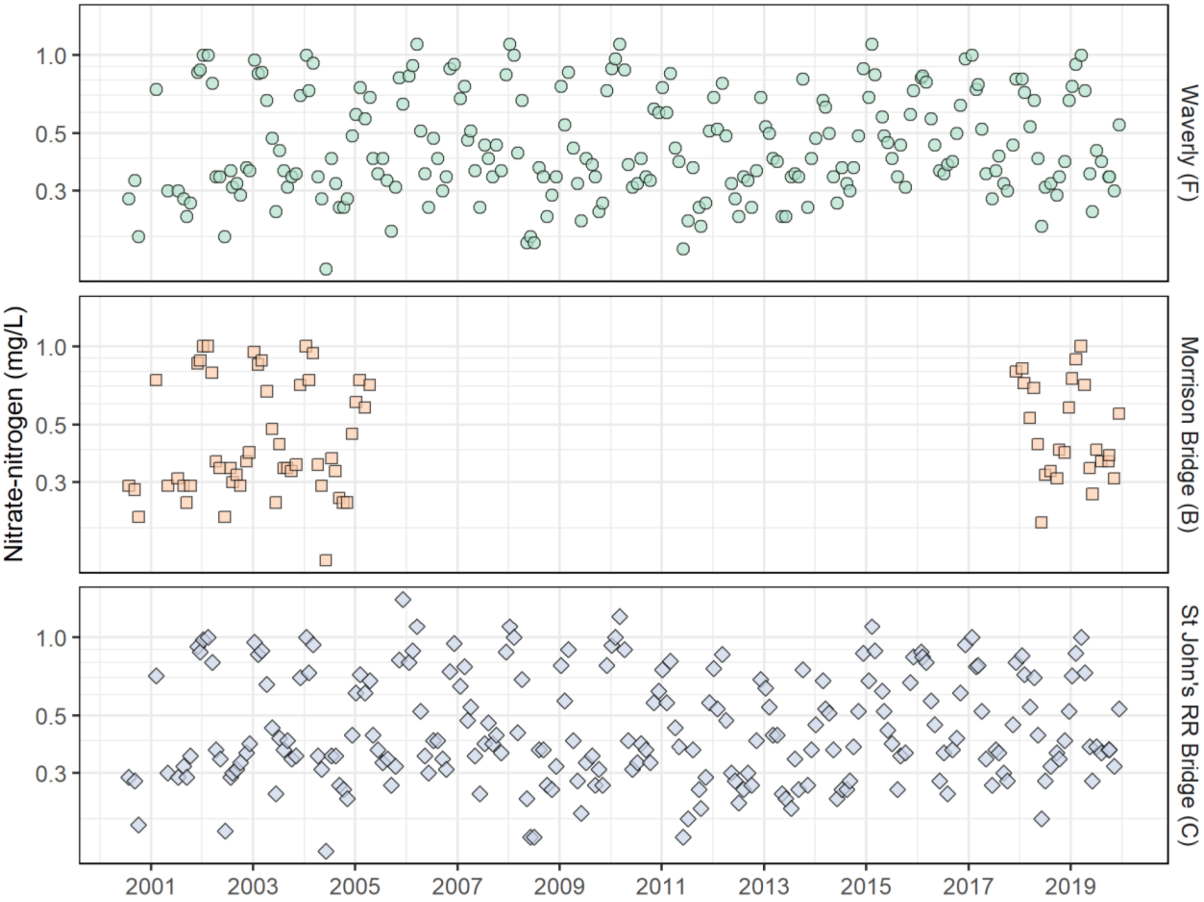


Figure 83. Nitrate concentrations at the three Willamette River sites since 2000. Note: nitrate was not sampled at the Morrison Bridge site (B) between 2005 and 2017.



4.3.4.2 Phosphorus

Like nitrogen, phosphorus is an essential nutrient for plant growth. In many water bodies phosphorus is important as it is often the limiting nutrient for the growth of algae in freshwater systems. Algal blooms can result in exceedances of the state water quality standards for aesthetics, pH, and dissolved oxygen. Soluble orthophosphate represents the fraction of phosphorus that can be filtered through a 0.45-micron filter. The concentration of soluble orthophosphate is generally used as a measure of the readily available phosphorus present in natural waters for utilization by biota.

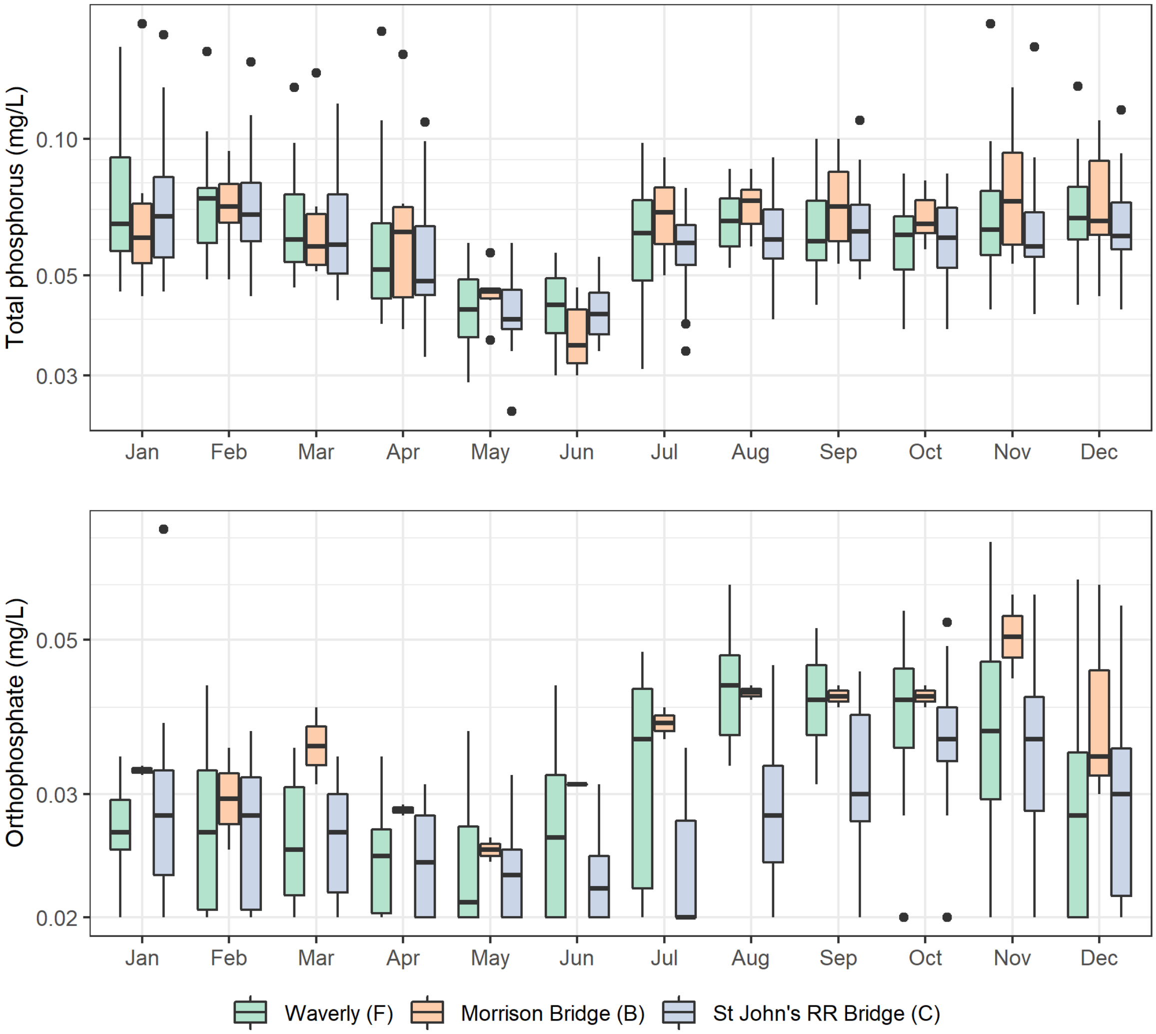
No state-wide water quality criteria have been established for phosphorus, however, DEQ has established TMDLs for total phosphorus in the Columbia Slough (0.155 mg/L) and Tualatin (0.13 mg/L for Fanno Creek) basins.

Table 23. Summary statistics for total phosphorus and orthophosphate samples from the three Willamette River sites. Note: total phosphorus and orthophosphate were not sampled at the Morrison Bridge site (B) between 2005 and 2017.

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Exceedance
Orthophosphate (mg/L)								
F	176	0.032	0.020	0.020	0.030	0.047	0.069	*NA*
B	25	0.037	0.024	0.027	0.035	0.044	0.060	*NA*
C	176	0.029	0.020	0.020	0.027	0.039	0.072	*NA*
Total Phosphorus (mg/L)								
F	227	0.064	0.029	0.042	0.059	0.089	0.180	*NA*
B	76	0.069	0.030	0.044	0.064	0.096	0.180	*NA*
C	227	0.061	0.025	0.040	0.058	0.084	0.170	*NA*

Little variability in total phosphorus and orthophosphate concentrations was observed between the three sites. As with nitrogen, total phosphorus samples were not collected at the Morrison Bridge station (B) between 2005 and 2017. Orthophosphate samples were first collected at the Morrison Bridge station in 2018.

Figure 84. Seasonal pattern in total phosphorus and orthophosphate concentrations at the three Willamette River sites since 2000. Note: total phosphorus was not sampled at the Morrison Bridge site (B) between 2005 and 2017, and orthophosphate was first sampled at the Morrison Bridge site in 2018.



Total phosphorus concentrations varied over the course of the year, with the lowest concentrations observed in the spring. Orthophosphate concentrations did not vary substantially over time or from month to month. There is no evidence of a temporal trend in either total phosphorus or orthophosphate concentrations.

Figure 85. Total phosphorus concentrations at the three Willamette River sites since 2000. Note: total phosphorus was not sampled at the Morrison Bridge site (B) between 2005 and 2017.

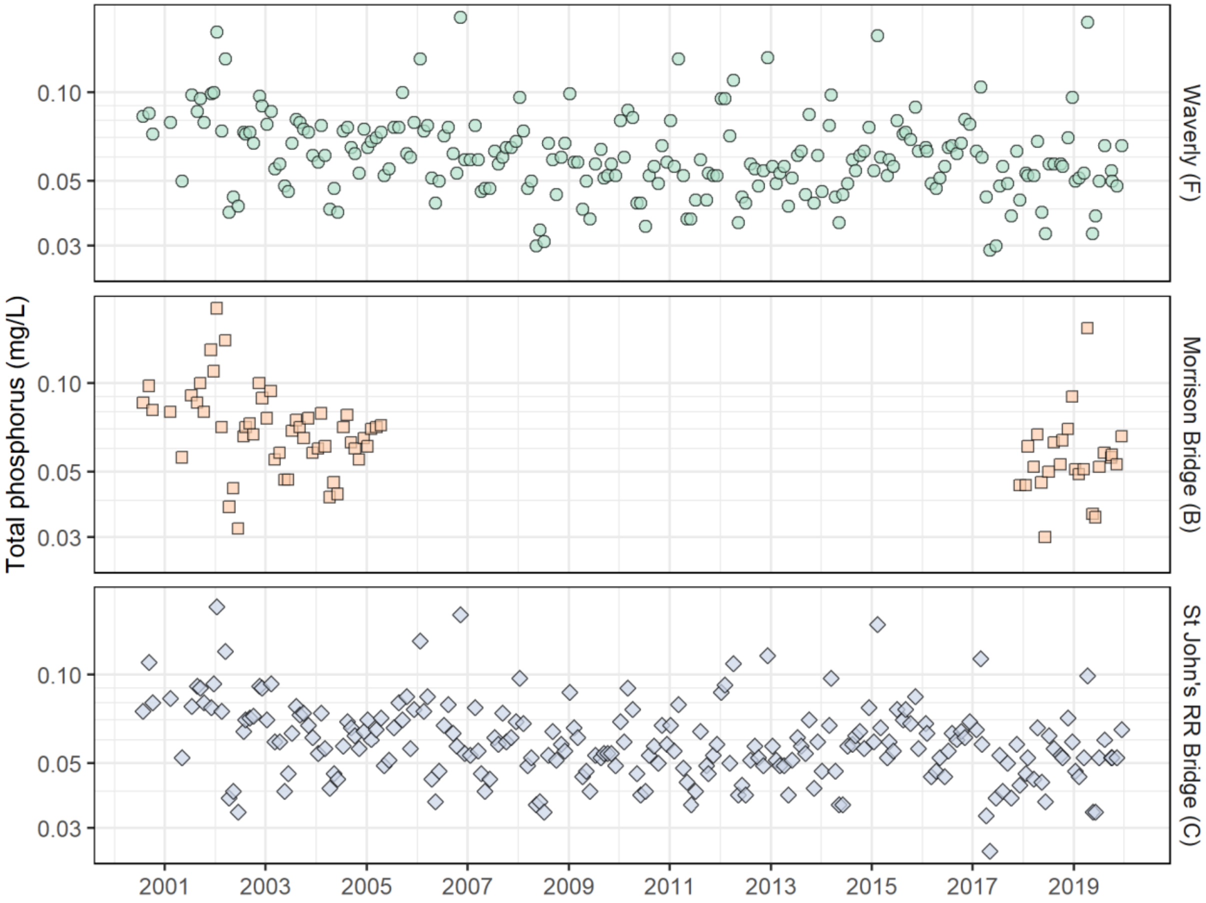
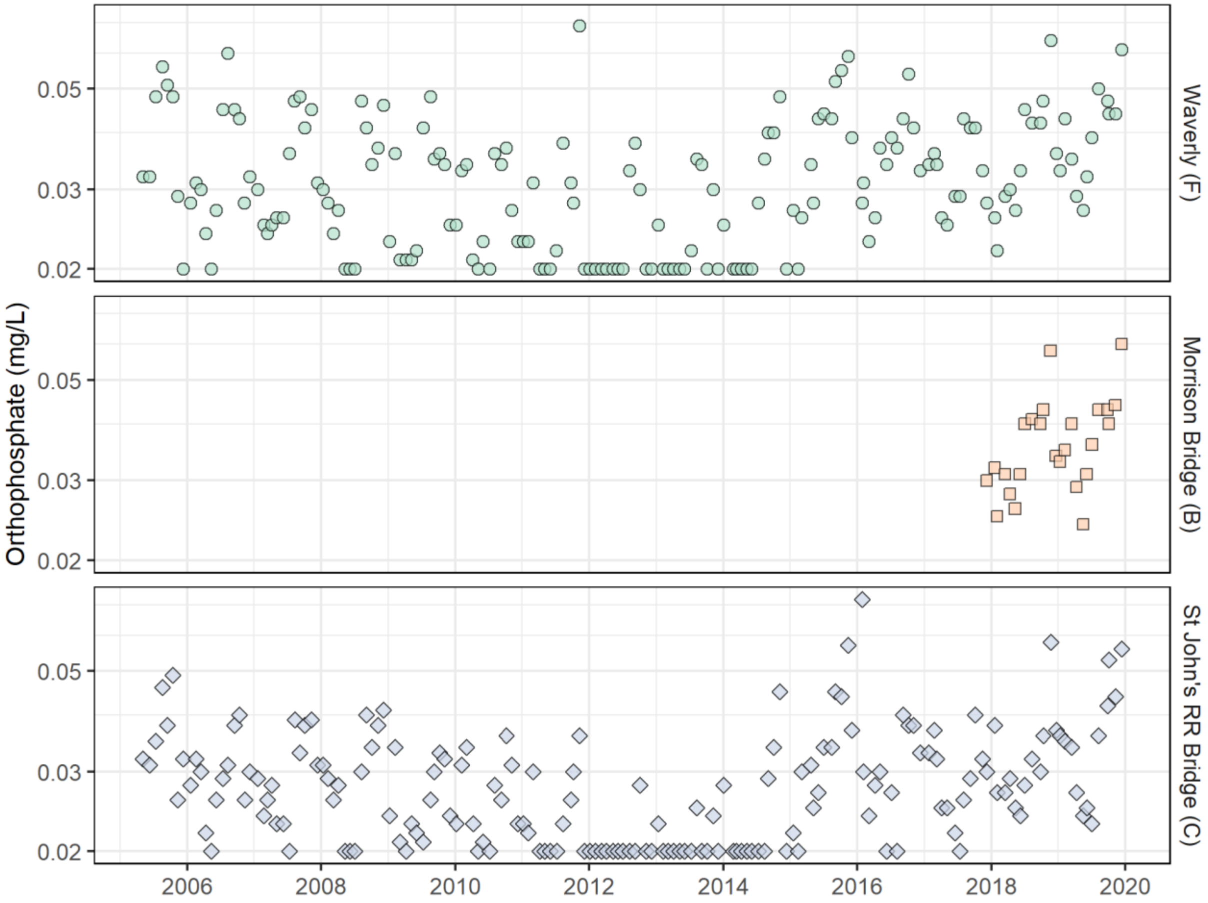


Figure 86. Orthophosphate concentrations at the three Willamette River sites since 2000. Note: orthophosphate was not sampled at the Morrison Bridge site (B) between 2005 and 2017.



4.3.4.3 Chlorophyll-*a*

Chlorophyll is a green pigment found in algae and plants that is essential for photosynthesis. Chlorophyll-*a* is the dominant pigment found in algae and is often used to estimate algal biomass. DEQ uses chlorophyll-*a* concentrations to determine whether a waterbody's beneficial use is impaired by nuisance phytoplankton growth (OAR 340-041-0019(1)(b)). Chlorophyll-*a* concentrations may not exceed 15 µg/L in rivers.

Chlorophyll-*a* samples are collected during the summer months (July, August, and September) at the three Willamette River sites. As with nitrogen and phosphorus samples, no chlorophyll-*a* samples were collected at the Morrison Bridge site (B) from 2003 to 2017. Sampling resumed in July 2018 at the Morrison Bridge site.

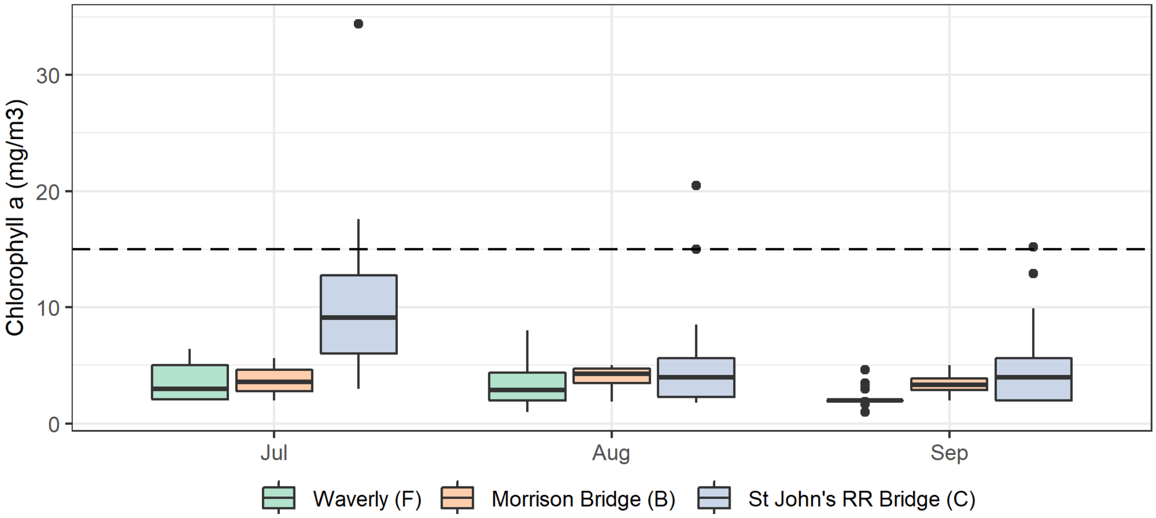
Table 24. Summary statistics for chlorophyll-a samples from the three Willamette River sites. No samples were collected at the Morrison Bridge site (B) from 2003 to 2017.

Chlorophyll-*a* (µg/L)

Site	Number of Samples	Mean	Min	10th Percentile	50th Percentile	90th Percentile	Max	% Chronic Exceedance
F	60	3.0	1.0	2.0	2.5	5.0	8.0	0.0
B	11	3.7	1.9	2.0	3.6	5.0	5.6	0.0
C	60	6.7	1.8	2.0	4.8	14.0	34.4	6.7

Exceedances of the chlorophyll-*a* criterion were only observed at the St. John's RR Bridge site—the most downstream site. Generally, more variability in chlorophyll-*a* concentrations were observed at the St. John's RR Bridge site, with higher concentration typically seen in the early summer. There is no evidence of a temporal trend in chlorophyll-*a* concentrations at any of the sites.

Figure 87. Seasonal pattern in chlorophyll-*a* concentrations at the three Willamette River sites since 2001. The dashed line represents the water quality criterion for rivers and streams. Note: chlorophyll-*a* samples were not collected at the Morrison Bridge site (B) between 2003 and 2017.



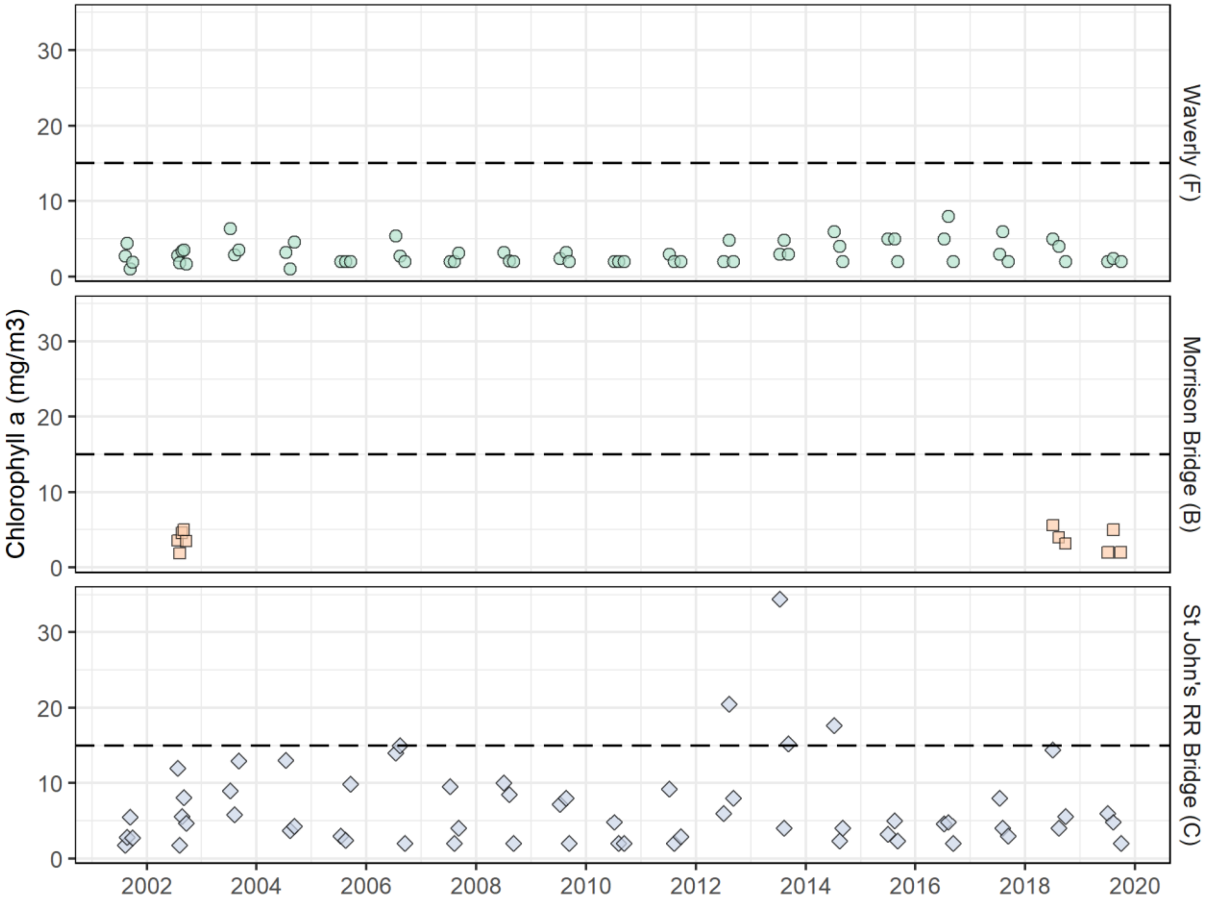
Abundant phytoplankton growth (measured as the concentration of chlorophyll-*a*) can reduce water clarity and degrade water quality. In aquatic systems where abundant algal growth is dominated by the growth of cyanobacteria, it is possible for the excess algal growth to be more than an unattractive nuisance and may pose a public health risk. Certain cyanobacteria species are known to produce cyanotoxins. When consumed, cyanotoxins can cause illness or death in livestock, pets, and wildlife. Human exposure to cyanotoxins is typically due to recreational water exposure which can result in illness and skin rash.

Since 2014, harmful algal blooms (HABs) have frequently been observed on the Willamette River. The blooms seen in Portland originate from the Ross Island lagoon at river mile 15. HABs are typically observed during the late summer but can persist until early October (Table 25). When HABs are detected, the Oregon Health Authority (OHA) will issue a recreational use health advisory for the duration of the bloom.

Table 25. Harmful algal bloom recreational use health advisories from the Oregon Health Authority for the Willamette River in Portland and the Ross Island lagoon (OHA, 2020).

Year	Advisory Period
2019	None
2018	Aug 3 – Aug 24
2017	None
2016	Aug 16 – Sep 1
2015	Jul 9 – Oct 1
2014	Sep 16 – Oct 2

Figure 88. chlorophyll-a concentrations at the three Willamette River sites since 2001. The dashed lines represent the water quality criterion of 0.15 µg/L for rivers and streams. Note: chlorophyll-a samples were not collected at the Morrison Bridge site (B) between 2003 and 2017.



4.4 Analysis of Water Quality Trends

The long-term monitoring of the three Willamette River stations provides a unique opportunity to evaluate possible trends in water quality and to evaluate whether there have been changes over time. As described above, the three stations have been sampled since the mid-1990s, however, not all of the analytes have been monitored continuously at the stations. Consequently, the analysis of possible trends is focused on analytes with long-term records and only those with a statistically significant temporal trend are presented here.

4.4.1Analysis Approach

Instream concentrations of different water quality parameters are highly variable and are typically dependent on instream flows, weather conditions, and also the time of year. As such, only looking at how the concentration of a pollutant has changed over time does not account for the expected variability in concentration based on the time of the year, nor does it account for the ambient conditions present at the time each sample was collected. The analysis approach employed in this report to assess the Willamette River samples for temporal trends fits a generalized additive model to the water quality data. This method allows for an additive modeling approach in which the predictive variables can be incorporated using smoothing functions. These smoothing functions match the underlying pattern of the data and do not have to be linear.

Models were fit for each water quality parameters at each of the three sampling stations using the R Statistical Software (version 3.5.1; R Core Team, 2018) to assess for changes over time. The mgcv package (Wood, 2011) was used to fit the models where the independent variable is a function of smooth functions of predictor variables.

In the Willamette River, the distribution of analyte concentrations is consistently skewed—there are typically more low concentration samples than high concentration samples—as such, all of the models were fit using the log of the analyte concentration, with the except of Secchi depth. All of the models include a temporal trend term (included as a decimal date) to assess whether concentrations are changing over time. A seasonal term is included in each model to reflect the time of year (represented as decimal value to reflect the day of the year). The mean daily discharge recorded at the USGS Morrison Bridge stream gauge and the concentration of TSS are included in the models using a tensor interaction term.

Smoothing splines are incorporated into the model for both the temporal and seasonal variables to reflect the underlying pattern of the data. With the temporal trend term, there is a lack of independence between the observations. To address this, a time covariate was added to the temporal smoothing function to account for the lack of independence in observations over the time series. The smoothing function for the seasonal term was set so that the function would connect at the end points (January 1 and December 31). Mean daily discharge and TSS concentrations are combined in the models using as tensor product smooths to capture the interaction between these two related variables. The models were constructed as follows:

$$\log(\text{analyte}) \sim s(\text{temporal}) + s(\text{seasonal}) + te(\text{discharge, TSS})$$

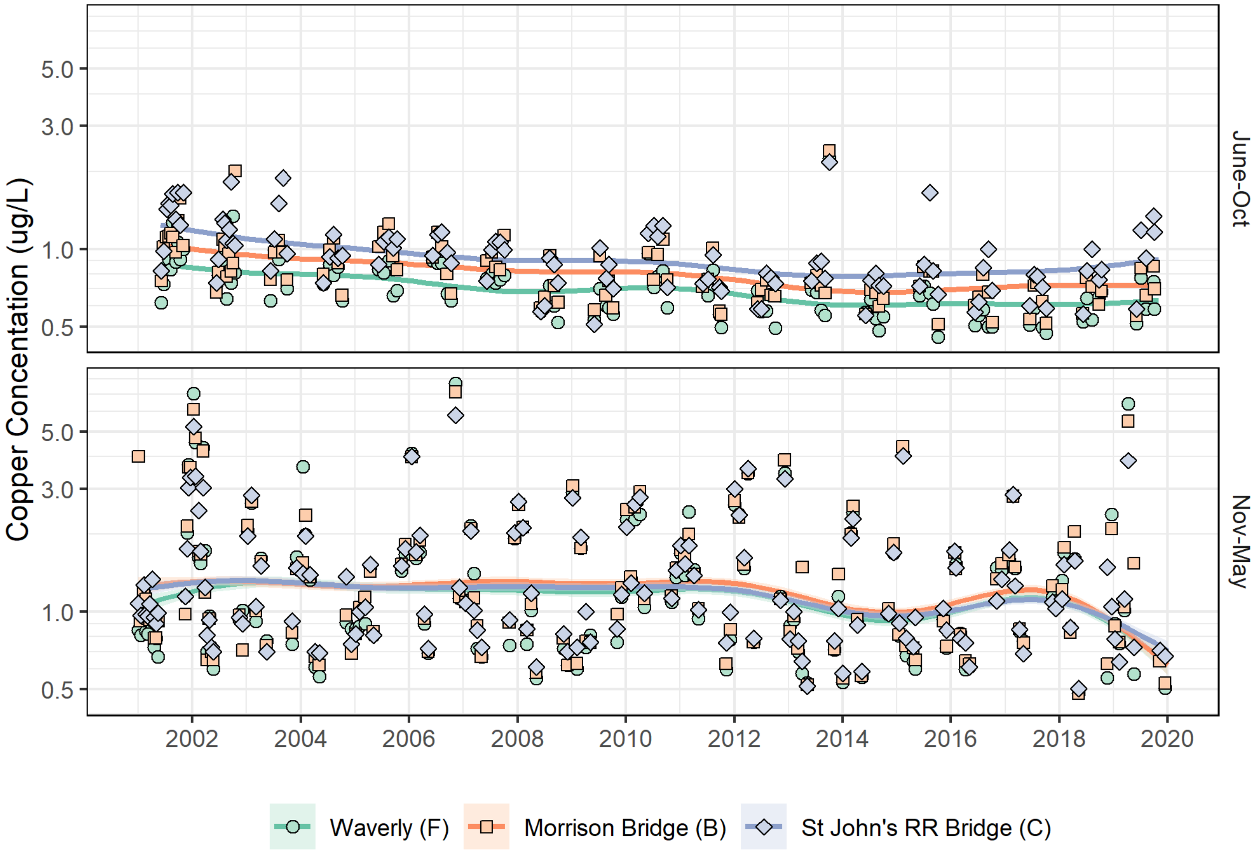
Where $s()$ represents a smoothing spline function for each variable and $te()$ represent a smoothing tensor product function of the two variables.

Separate models were developed for each analyte at each sampling station, however, only the models with an observed temporal trend are presented in the following sections. Where possible, the historic flow data have been combined with the water quality model to estimate annual pollutant loads over the period of record.

4.4.2 Copper Trends

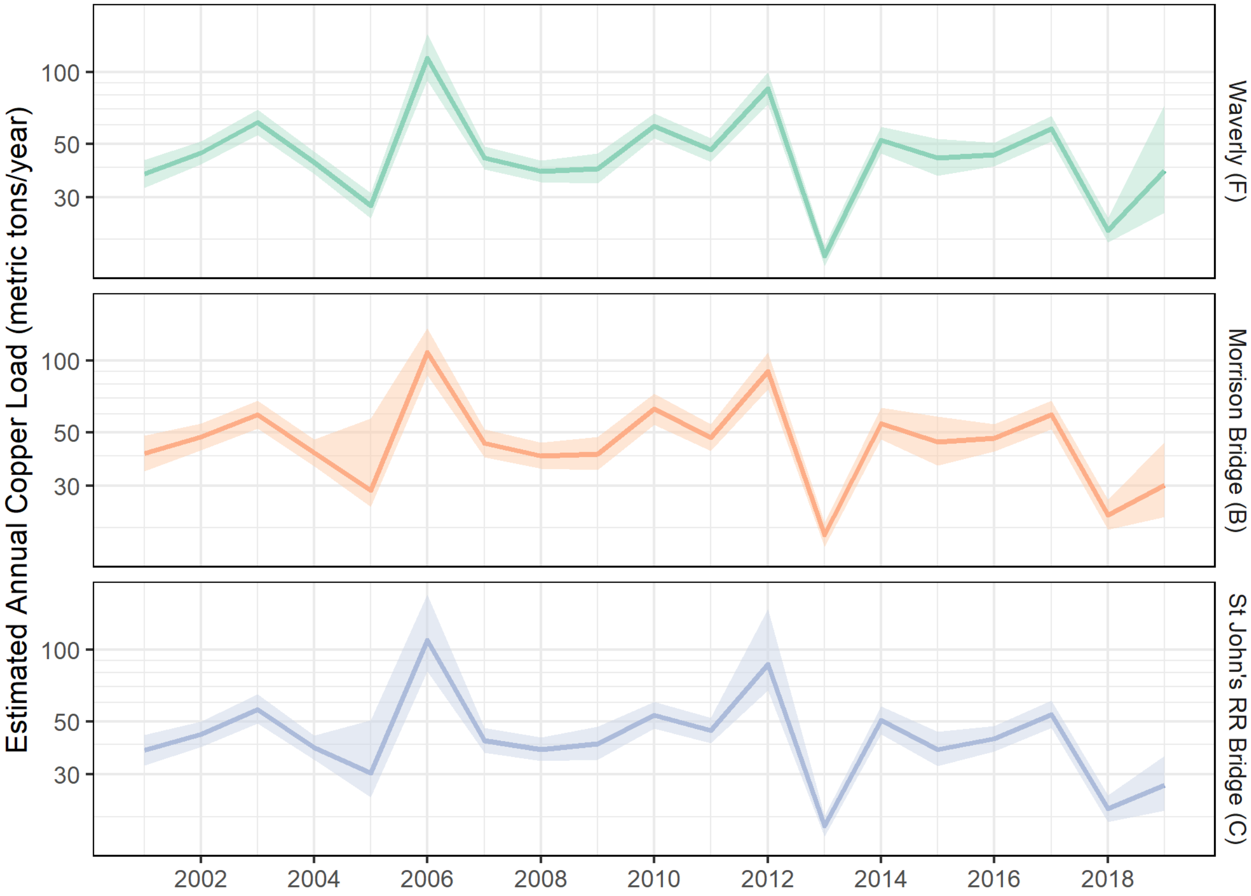
Since 2000, total copper concentrations at all three sites have decreased over time (Figure 89). The decreasing trend in copper concentrations is not seen across all river conditions, rather it is more pronounced during periods of low flow (June-October; Figure 89). As noted above, TSS was used in the model to predict copper concentrations; however, there was no evidence of a decrease in TSS concentrations during this same period that would explain the trend in copper concentrations.

Figure 89. Temporal trends in copper concentrations over the period of record split into low-flow (June-October; first panel) and high-flow (November-May; second panel) periods. The points represent the observed copper concentrations.



While the changes in copper concentrations reflect improvements in water quality, the improvements are primarily limited to improved ambient conditions during the summer and early fall. Reduced copper concentrations during low flow periods does not necessarily translate into a substantial reduction in the annual copper loads (Figure 90). The majority of the annual Willamette copper load is transported during periods of high flow. Consequently, since copper concentrations have changed little during periods of higher flows, the decreases observed in summer and fall concentrations do not result in notable decreases in annual copper loads. While the concentration changes do not result in a substantial load reduction, the reduction in low flow copper concentrations does improve conditions for the organisms in the river at those times.

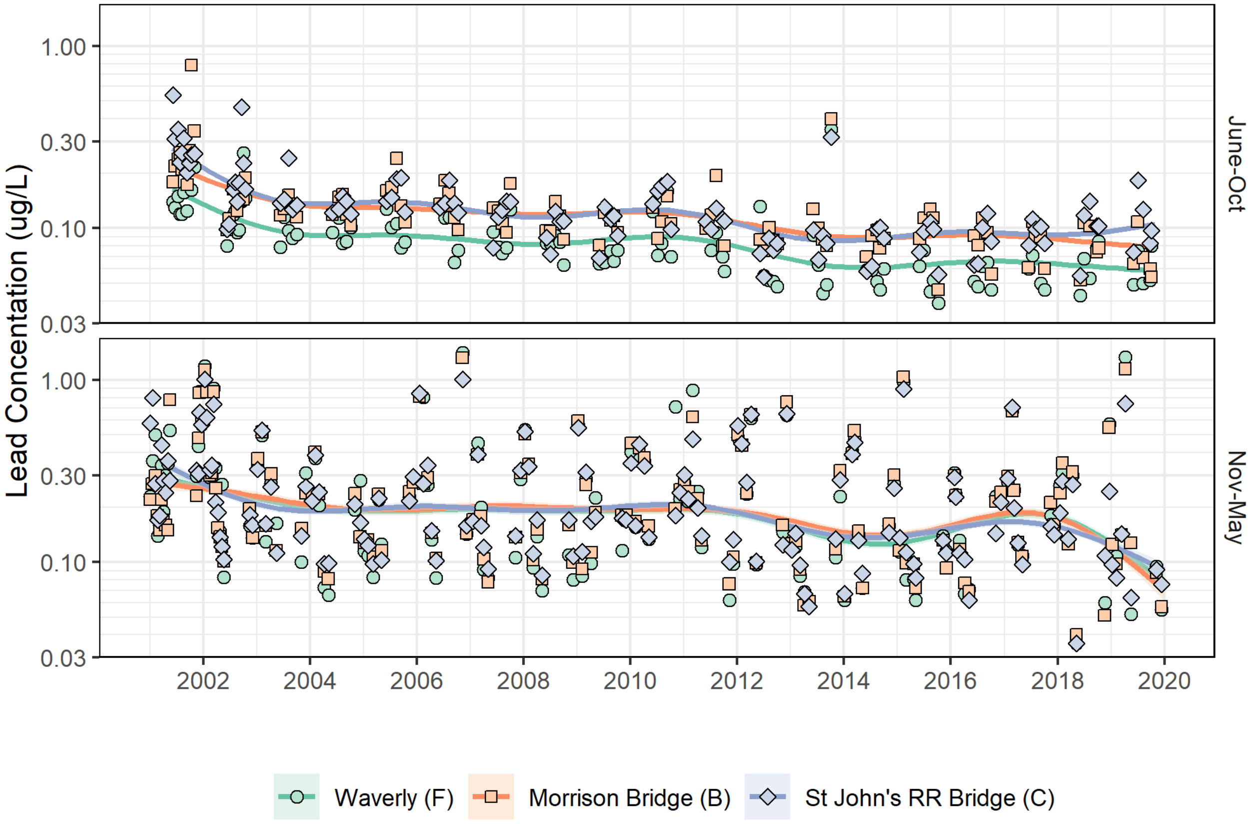
Figure 90. Estimated annual copper load at the three Willamette River stations. The shaded area represents the 95% confidence interval.



4.4.3Lead Trends

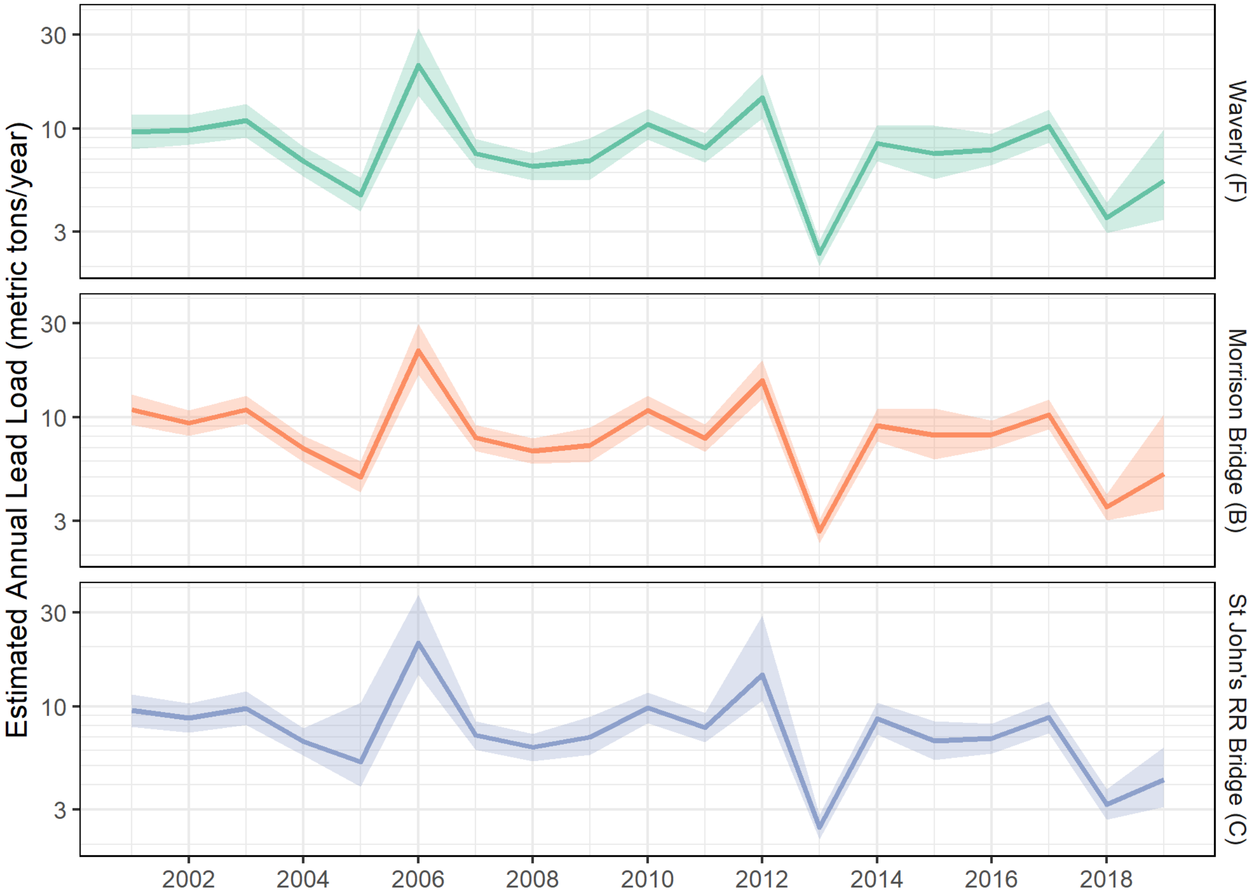
Lead concentrations at all three sites have decreased over time (Figure 91). The decreasing trend in lead is most evident during periods of low river flows (June-October), with some evidence of decreasing concentrations during high flow. While lead concentrations are driven in part by TSS concentrations, the reduction in lead concentrations cannot be fully explained by changes in TSS, nor is there a corresponding trend in TSS concentrations during this same period. As such, the decrease in lead concentrations cannot simply be attributed to a reduction of particulates in the water column, but rather a reduction in lead inputs from the watershed.

Figure 91. Temporal trend in lead concentrations over the period of record split into low-flow (June-October; first panel) and high-flow (November-May; second panel) periods. The points represent the observed lead concentrations.



The changes in lead concentrations are reflective of improvements in water quality. These improvements are mostly seen during period of low flow, but there is evidence that lead concentrations have decreased somewhat during high flow periods as well. The reduction in lead concentrations has resulted in small reductions in annual Willamette lead loads (Figure 92). Since less of the improvement has been observed during periods of high flow when the majority of the lead load is transported, the reduction in concentrations has not resulted in a substantially large reduction in annual lead loads. As with copper, the reduction in low flow lead concentrations does improve conditions for the organisms in the river at those times.

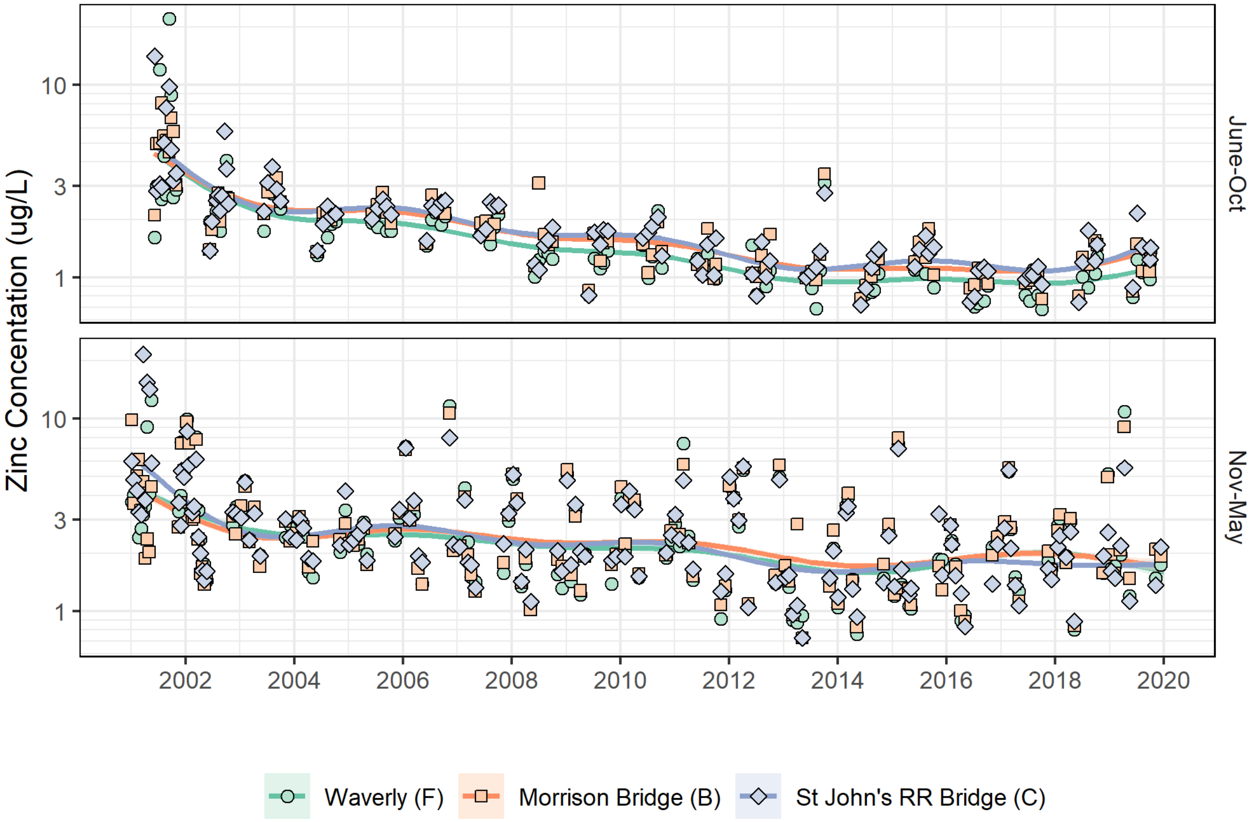
Figure 92. Estimated annual lead load at the three Willamette River stations. The shaded area represents the 95% confidence interval.



4.4.4Zinc Trends

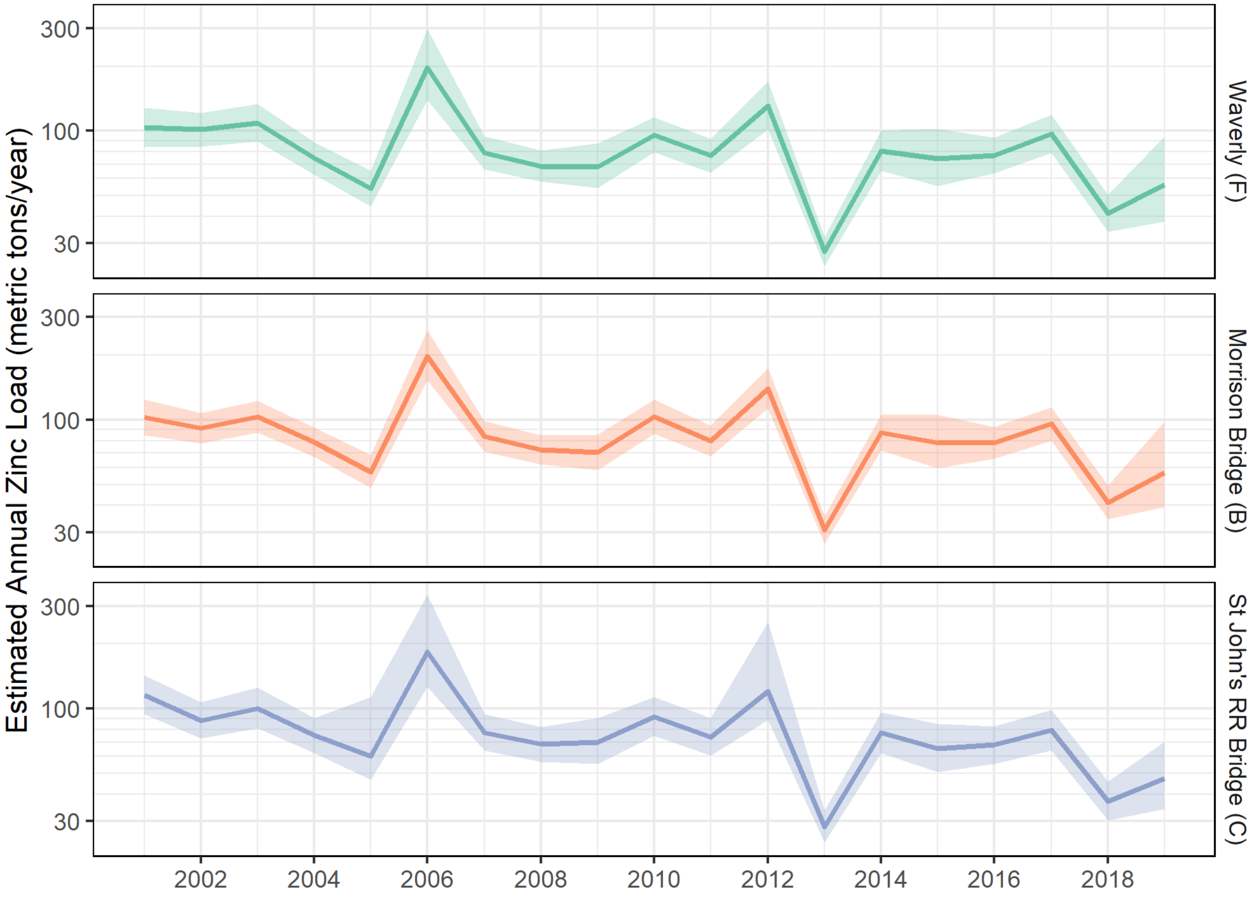
As noted above, there is evidence of a temporal trend in zinc concentrations at all three stations, with zinc decreasing over the 20-year period. Zinc concentrations have decreased consistently over the entire period; however, the greatest change can be seen during periods of low river flows (June-October). As with other metals, zinc concentrations are driven in part by the concentration of TSS in the water column, but no corresponding change in TSS was observed over the same time period to explain the change in zinc.

Figure 93. Temporal trend in zinc concentrations over the period of record split into low-flow (June-October; first panel) and high-flow (November-May; second panel) periods. The points represent the observed zinc concentrations.



The changes in zinc concentrations over time reflect improvements in water quality and a corresponding reduction in annual loading (Figure 94). Over the 20-year period, a greater frequency of lower zinc concentrations during both low and high flow periods has been observed. While lower concentrations during periods of low flow do contribute to lower annual loads, it is the reduced zinc concentrations during the periods of high flow that have had a greater impact on reducing annual zinc loads. As with copper and lead, lower water column concentrations are beneficial to aquatic organisms.

Figure 94. Estimated annual zinc load at the three Willamette River stations. The shaded area represents the 95% confidence interval.



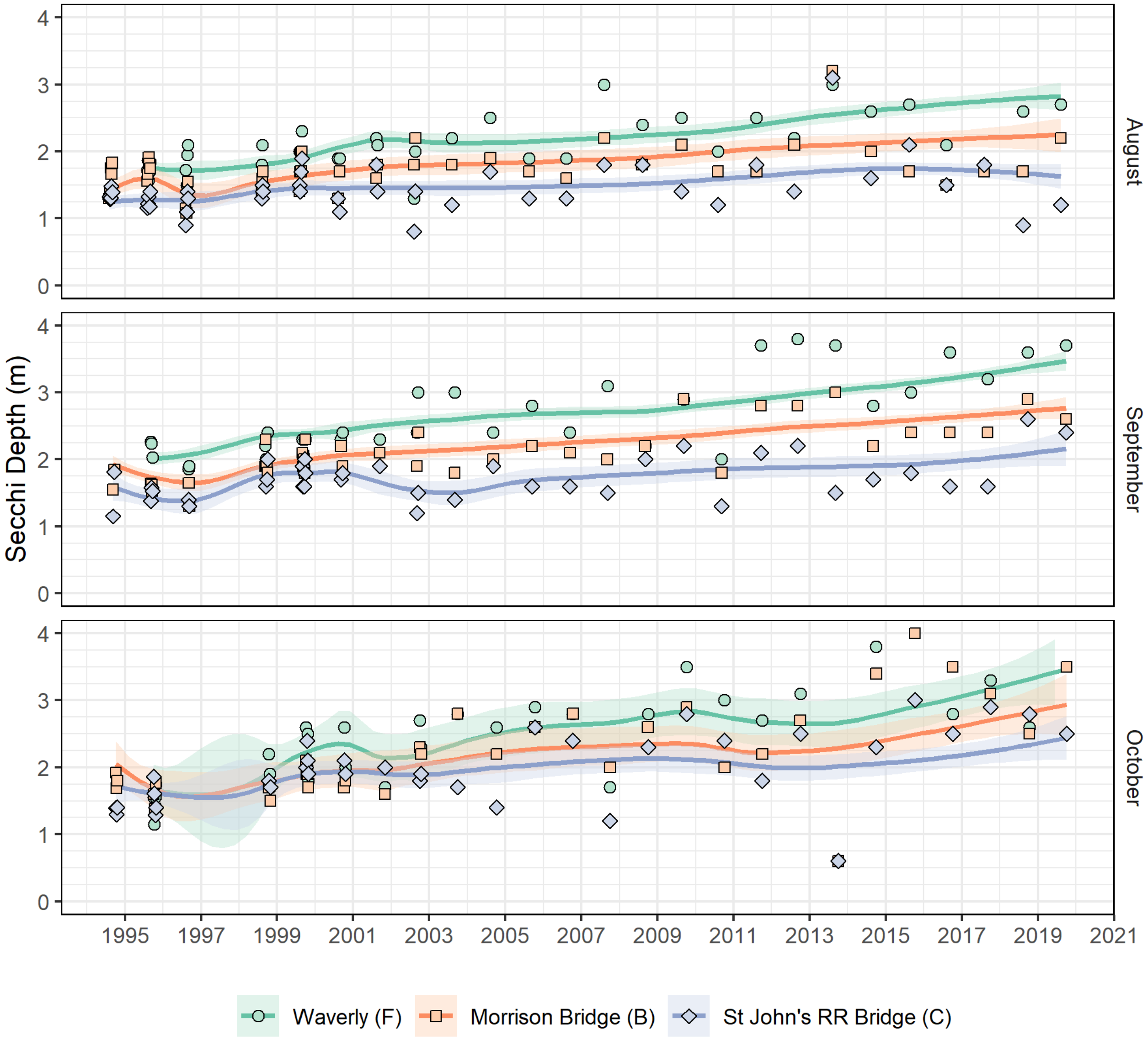
4.4.5Secchi Depth Trends

Since the mid-1990s, summer water clarity has improved at all three Willamette River sites (Figure 95). While improvements in water clarity have been observed at all three of the sites, these improvements have been most pronounced at the upstream site (Waverly; F) and become less pronounced as you progress downstream.

Across all three sites, water clarity in October show the largest change, with Secchi depths increasing by approximately 1-2 meters and only small differences seen between the three sites (Figure 95). In contrast, there was a greater difference in water clarity between the three sites during August and September. In September, Secchi depths at Waverly (F) increased from 2 meters in 1996 to 3.5 meters in 2019, while at the most downstream site (St John's RR Bridge; C) September Secchi depths increased by less than one meter (from 1.5 m to 2.25 m; Figure 95).

While the improvements in water clarity were substantial, these improvements were not observed outside of the summer and early fall. Low water clarity was consistently observed during periods of higher flows, with no detectible trend over the 25-year period of record.

Figure 95. Temporal trends in Secchi depth during the summer and fall months. The shaded area represents the 95% confidence interval around the predicted Secchi depth trend. The points represent the observed Secchi depths.



4.4.6Other Parameters

It is important to note that while the trends presented in the sections above are limited to three metals and measures of water clarity, other parameter trends were evaluated as part of this assessment. For many of the other metals (including arsenic, cadmium, chromium, iron, nickel, and selenium), an insufficient number of samples have been collected to assess for temporal trends. In the case of nutrients and the conventional parameters, the sample sizes were large enough to assess for possible trends, but no temporal trends were detected.

4.5 Willamette River Impairment Status

Section 305(b) of the Clean Water Act requires states to assess the state's waterbodies every two years to determine whether they are meeting water quality standards. Section 303(d) requires that a list of assessed waterbodies that do not meet water quality standards is submitted to Congress. This list is often referred to as the 303(d) List. Oregon DEQ compiles the water quality assessments and list of impaired waterbodies in Oregon in their Integrated Report .

In September 2019, Oregon DEQ released its draft 2018/2020 Integrated Report. This report includes a statewide of assessment of water quality data collected between January 1, 2008 through December 31, 2017. The assessment combines ambient water quality data from across multiple agencies to evaluate attainment of water quality standards. To assist DEQ with their assessment, BES submitted all of the Willamette River ambient water quality data.

Oregon DEQ's most recent assessment of the Willamette River in Portland found that the waterbody is not meeting all of the applicable water quality standards (Table 26). Many of these water quality impairments were noted in this report. Herbicides, pesticides, and toxic organic compounds are not sampled as part of BES' ambient monitoring program, but DEQ found that they exceed the state water quality standards in the Willamette River.

Table 26. Summary of the parameters from the draft 2018/2020 Integrated Report with Category 4 or 5 listings on the Willamette River (assessment unit #OR_SR_1709001202_88_104175).

Parameter Category	Parameter	Assessed in 2018	Category
General Chemistry & Biological Conditions	Aquatic weeds	Yes	Impaired (Cat 5)
	BioCriteria	No	Impaired (Cat 5)
	Chlorophyll-*a*	Yes	Impaired (Cat 5)
	Cyanide	No	Impaired (Cat 5)
	Dissolved oxygen	Yes	Impaired (Cat 5)
	E. coli	Yes	Impaired w/ TMDL (Cat 4A)
	Temperature	Yes	Impaired (Cat 5)*
Metals	Iron	Yes	Impaired (Cat 5)
Herbicides & Pesticides	Aldrin (human health)	Yes	Impaired (Cat 5)
	Chlordane (human health)	Yes	Impaired (Cat 5)
	DDD 4,4′ (human health	Yes	Impaired (Cat 5)
	DDT 4,4′ (human health)	Yes	Impaired (Cat 5)
	Dieldrin (human health)	Yes	Impaired w/ TMDL (Cat 4A)
	Dioxin (human health)	No	Impaired w/ TMDL (Cat 4A)
Toxic Organic Compounds	Ethylbenzene (human health)	Yes	Impaired (Cat 5)
	Hexachlorobenzene	Yes	Impaired (Cat 5)
	Pentachlorophenol (human health)	Yes	Impaired TMDL not needed (Cat 4B)
	Polychlorinated Biphenyls (PCBs)	Yes	Impaired (Cat 5)
	PAHs	No	Impaired (Cat 5)

* Oregon's temperature TMDLs were legally challenged and vacated by the court

Water bodies listed as ‘Category 4’ are those where the assessed data indicate that at least one designated use is not supported, but a TMDL is not needed to address the pollutant. In the case of ‘Category 4A’ waterbodies, this is because a TMDL has already been developed. For ‘Category 4B’ waterbodies, other pollution control requirements are expected to address the pollutant of concern which will result in attainment of water quality standards. Waterbodies listed as ‘Category 5’ are those where the available data indicate a designated use is not supported or a water quality standard is not attained and that a TMDL is needed.

4.6 Water Quality Summary

BES’ ambient Willamette River monitoring program provides a unique opportunity to comprehensively assess water quality conditions in Portland and whether river conditions have changed over time. Samples collected over the past 25 years highlight that river conditions vary substantially over the course of a year. Many of these changes are driven by the variability of river discharge over each year, with often the highest analyte concentrations observed under high flow conditions.

An evaluation of potential temporal trends found that the concentration of most water quality parameters has not changed over time. The temporal trends that were identified in this report all reflect improvements in water quality—decreases in metals (copper, lead, and zinc) and an increase in summer water clarity. The decrease in the concentration of metals is most pronounced in the concentrations seen under low flow river conditions. Since the majority of metal loads are transported under high flows in the Willamette, these reduced concentrations do not translate into large reductions in annual metal loading; however, they do represent an improvement in ambient river conditions that are beneficial to aquatic organisms.

Elevated water temperatures during the summer represents one of the largest exceedances of water quality standards in the Willamette. With climate change, we can expect to see increasing air temperatures and decreasing stream flows in the Willamette basin. Rupp et al. (2017) estimate that by the end of the 21st century, mean annual air temperatures in the Columbia River basin will increase by 2.8 to 5.0°C.[24] Along with increased air temperatures, the duration and intensity of droughts in the Willamette basin are expected to increase under different climate change scenarios, including a higher risk of summer droughts (Ahmadalipour et al. 2017). These changes will continue to exacerbate the temperature issues in the lower Willamette River.

The temperature issues in the lower Willamette are primarily a result of activities upstream of Portland (ODEQ 2006). While restoration efforts in the lower river cannot fully mitigate the upstream impacts, active restoration efforts can improve local conditions and provide refuges for aquatic organisms. As described in Section 3, changes to the lower river have substantially reduced the abundance of available habitat. The stressful environment encountered by fish migrating through the lower Willamette makes the restoration and management of coldwater refugia all the more important. Proactive measures to restore and protect coldwater inputs will be essential to buffer against future negative impacts of climate change and address elevated water temperatures.

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[24] The 2.8 and 5.0°C estimated increases are based on representative concentration pathways (RCP) 4.5 and 8.5 emission scenarios respectively (Rupp et al. 2017).

4.7 Portland Harbor Water Quality and Sediment Contamination

4.7.1Portland Harbor Investigations

In 2014, GSI summarized the available information on known upland and in-river sediment and water quality contamination issues for the North Reach (GSI 2014). Information sources were used to identify preliminary asset areas and watershed health problems within the context of the Portland Watershed Management Plan (PWMP; City of Portland 2005) objectives. Asset areas are those geographic locations that provide important or unique watershed health characteristics. Problems are issues that need to be resolved to a measured extent in order to achieve PWMP watershed health objectives. Watershed health problems, as summarized in this report, principally affect attainment of the Pollutants objective[25] in the PWMP. Since the completion of this summary report, several key documents have been updated and are discussed below, with some background information provided.

The lower Willamette River draft Remedial Investigation Report and draft Feasibility Study (RI/FS) findings identified watershed health problems, specifically:

- Preliminary areas of sediment contamination that pose unacceptable risk to human health and the environment
- Key sources of these pollutants (from land uses in the upland area and from within the river)
- Pathways, or mechanisms, by which pollutant sources were mobilized and deposited in the sediment (such as overwater activities or eroding soil)

The draft RI reports over one million sample results for multiple media for the time period between 1969 and 2008 (summarized in RI Report Table 2.1-1, not incorporated into this document). Indicator Chemicals (IC) were identified from the initial extensive list of Contaminants of Interest (COIs) to represent the nature and extent of the range of contaminants that potentially pose risk to human health and the environment in sediment, surface water, transition zone water/porewater, and biota. The ICs are: total PCBs, dioxins/furans (noted as PCDD/F), total DDx (i.e., the sum of DDT, DDD and DDE), and total PAHs. The Baseline Ecological Risk Assessment [BERA; Appendix G (not included in this review)] and Human Health Risk Assessment [HHRA; Appendix F (not included in this review)] were used in the FS to identify contaminants, receptors, and areas of concern to assess the protectiveness of the potential remedial alternatives.

The risk assessments found that potential risks from PAHs and DDx are largely to benthic invertebrates and other sediment-associated receptors. Potential risks from PCBs and dioxin/furan are to receptors higher in the food chain who consume fish (birds, mammals and humans). The remaining contaminants potentially posing unacceptable risks account for less than 2 percent of the cumulative cancer risk on a Study Area-wide basis. The contribution of contaminants to the cumulative cancer risks varies on a localized basis (Integral 2011, page 87). Other contaminants pose potential risk to specific areas, media, or receptors.

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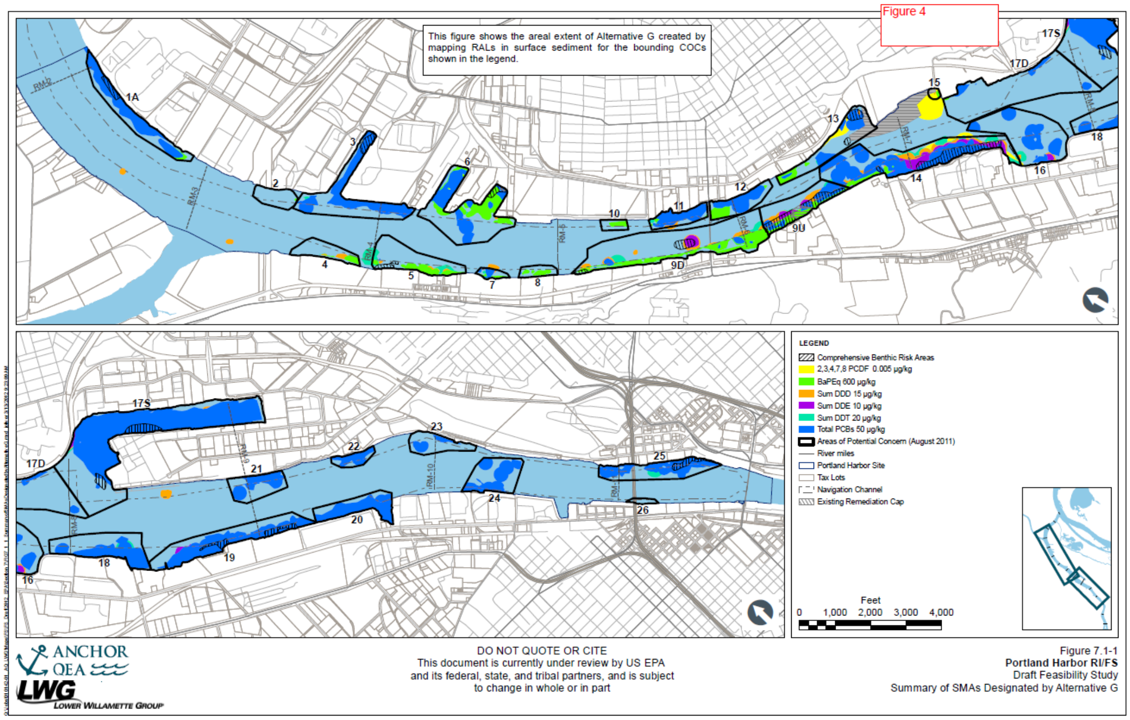
[25] The intent of this objective is to “manage the sources and transport of stormwater and industrial pollutants and nutrients to limit surface water, groundwater, soil, and sediment contamination to levels that protect ecological and human health and achieve applicable water quality standards”.

The draft FS report uses the data to develop Area of Potential Concern (AOPC) and Sediment Management Area (SMA) to describe the spatial extents where primary potentially unacceptable risks exist from exposure to all media sampled (i.e., sediment, transition zone water, etc.). These areas are the focus for developing the remedial alternatives, though some risk may be outside of these areas.[26] Twenty eight (28) AOPCs were identified [Figure 96: AOPCs and SMAs designated by Remedial Alternative F (FS Figure 7.1-1)]. SMAs are a refinement of the AOPCs, developed by looking at benthic risk areas, surface and subsurface sediment concentrations, and short term RALs for sediment cleanup. SMA boundaries and cleanup levels will be refined further in the remedial design stage (after the Record of Decision).

Figure 96: Portland Harbor Superfund site AOPCs as identified in the draft Feasibility Study



The FS also develops remedial alternatives by modeling the physical system and chemical data to project future contaminant levels in water, sediment and fish, and then these future contaminant levels are evaluated for risk reduction. As a result, the FS set forth twelve remedial alternatives, generally identified as Alternative A through Alternative G, as protective of human health and the environment over the long term. Alternatives B through F each have one variation that is "removal focused" (r) and one that integrates (i) different technologies (DAR Figure 4). The alternatives were evaluated for a number of "remedy selection criteria", including but not limited to protectiveness, effectiveness, implementability, and cost.

Since submittal of the draft RI/FS to U.S. Environmental Protection Agency (EPA), (and the preparation of the 2014 GSI summary), EPA has revised the FS and issued its draft proposed plan for remediation on June 8, 2016. EPA selected Alternative I as its preferred alternative, which will

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[26] Areas outside of the SMAs are included in the "Site-wide AOPC". The Site-Wide AOPC represents lower levels of contaminant concentrations that will not be the focus of active remedies.

involve dredging and capping approximately 290 acres of sediments (purple areas in Figure 97) and approximately 19,500 lineal feet of river bank (blue areas in Figure 97). Over time, "natural recovery" is assumed to reduce remaining concentrations to acceptable levels.

Figure 97. Sediment management areas in Alternative I from the EPA Feasibility Study.

After the 60-day public review of the plan, EPA issued the ROD identifying the final cleanup goals and the sediment management areas (SMAs) within the river. After the ROD, additional sampling will be conducted to design the remedy (i.e., a specific cleanup method, or combination of methods such as dredging and capping) for each SMA. Only after approval of the remedial design, will implementation of the cleanup begin.

Also, since preparation of the GSI 2014 summary, Oregon DEQ has released an updated *Portland Harbor Upland Source Control Summary Report* (March 25, 2016). This report provides the most recent DEQ work to identify and assess potential upland sources of contamination to Portland Harbor. This report concludes that DEQ has completed its determinations of the need for source control measures at all upland sites within the study area; and is on track to implement needed measures prior to implementation of the final in-water remedy, in order to prevent likely future adverse effects on water or sediment quality (i.e., recontamination). DEQ indicates "As of the date of this report, final actions, demonstration of effectiveness and decisions for 60% of upland sites have been completed. Controls are in place for all pathways and effectiveness demonstration is underway for 26 of the remaining 57 sites[27], with source control decisions anticipated by 2016 and 2017, which will confirm control of 75% of the sites evaluated. Plans are in place or under development to complete implementation of controls at the remaining 23% of sites evaluated by DEQ prior to or in conjunction with the in-water remedy. The three upland sites with uncontrolled

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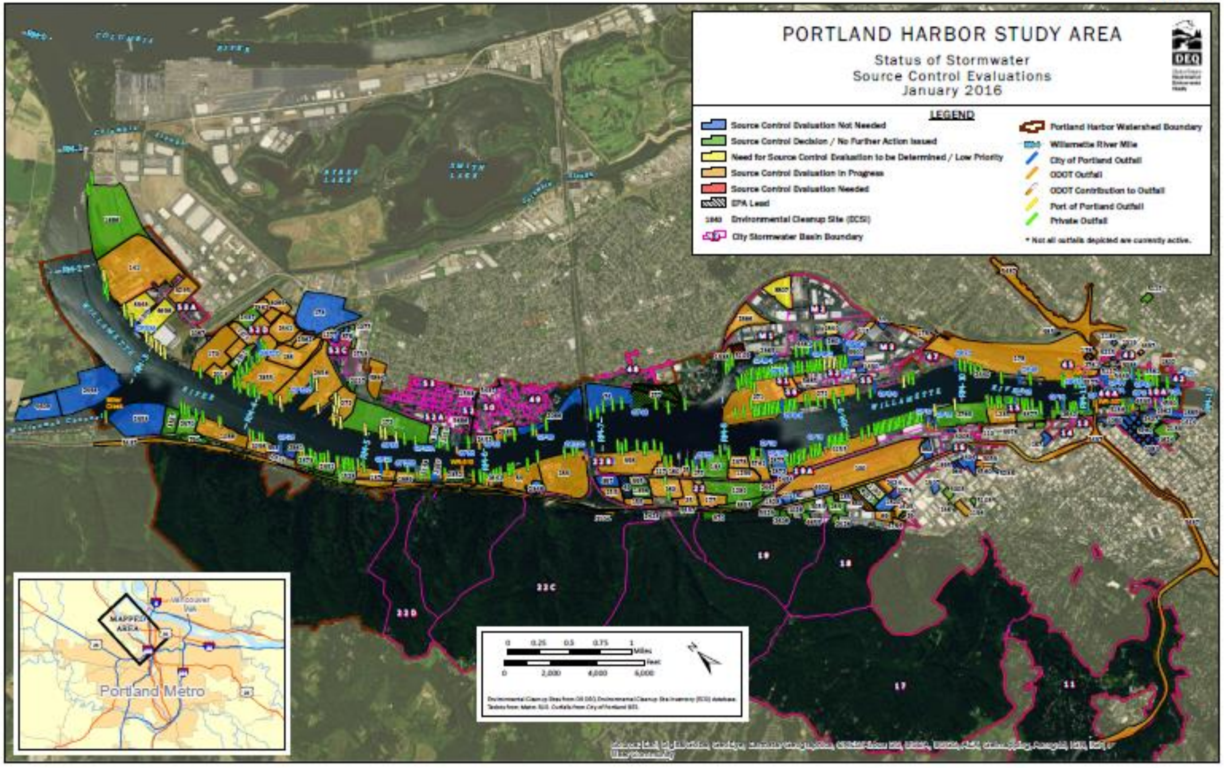
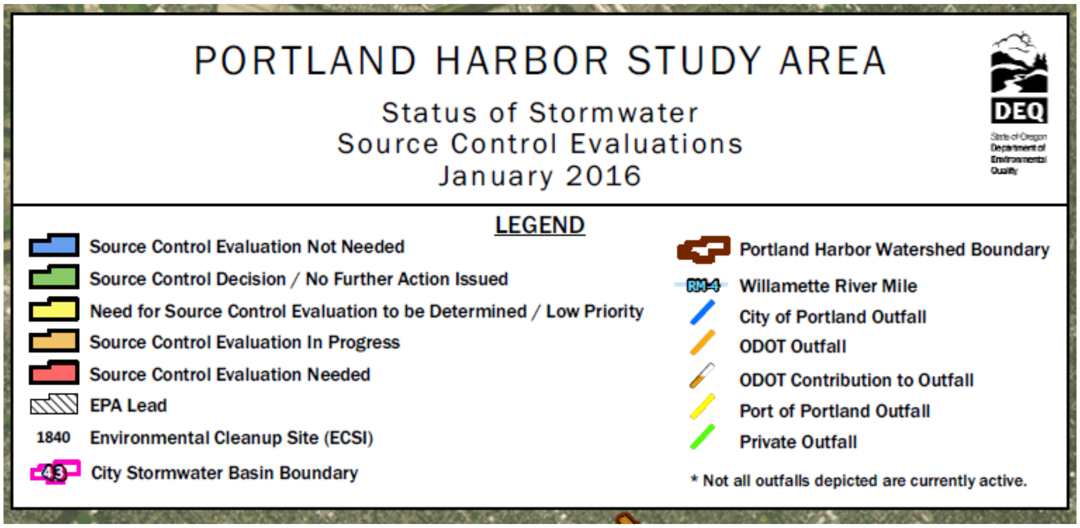
[27] More detail about each of these sites is provided in Table 5.1 of the DEQ document.

pathways that EPA is leading make up the final 2% of sites and also need completed investigation and implementation of any needed controls." Furthermore, "when viewed on a Harbor-wide basis, these conclusions strongly support a low potential for recontamination of remediated sediment and represent acceptable risk to Willamette River receptors, provided that all planned source control measures and bank remediation to be integrated with the in-water remedy are completed and demonstrated to be effective."

Figure 4.1





PORTLAND HARBOR STUDY AREA

Status of Stormwater
Source Control Evaluations
January 2016

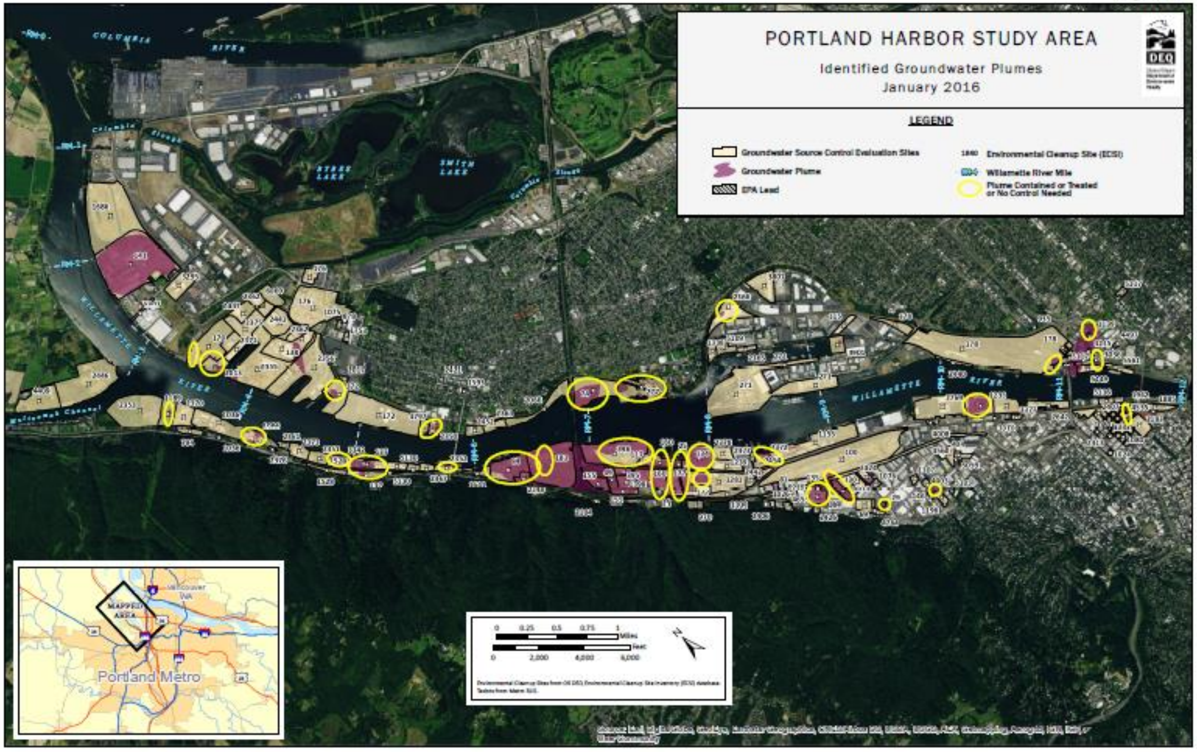
DEQ
State of Oregon
Department of Environmental Quality

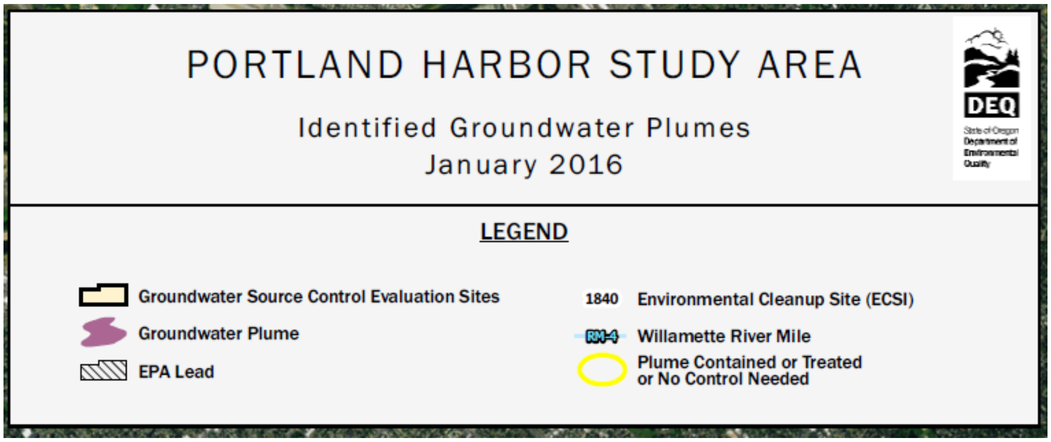
LEGEND

🟦	Source Control Evaluation Not Needed
🟩	Source Control Decision / No Further Action Issued
🟨	Need for Source Control Evaluation to be Determined / Low Priority
🟧	Source Control Evaluation In Progress
🟥	Source Control Evaluation Needed
▨	EPA Lead
1840	Environmental Cleanup Site (ECSI)
43	City Stormwater Basin Boundary
▭	Portland Harbor Watershed Boundary
RM-4	Willamette River Mile
/	City of Portland Outfall
/	ODOT Outfall
/	ODOT Contribution to Outfall
/	Port of Portland Outfall
/	Private Outfall

* Not all outfalls depicted are currently active.

Figure 4.3





4.7.2Downtown Reach Study

GSI 2014: "DEQ compared the Downtown Reach data to the Portland Harbor Superfund Project Area data, and found that, with the exception of mercury and lead, “surface sediment data shows that concentrations of contaminants of concern are significantly lower than those found in the Portland Harbor”. As a result, DEQ concluded that the Downtown Reach is unlikely to be a significant, ongoing source of contamination to the Superfund Project Area." (pg. 1-12).

5 Biological Communities

Several studies have focused on fish or wildlife communities specific to the lower Willamette River (i.e., north, central, and south reaches). Fish communities have been documented through the Willamette River Fish Study (ODFW 2001; 2002), and through a series of lower Willamette River studies over the years (e.g., EPA 2016). Aquatic communities and their habitats from the lower river through Portland are described reach-by reach in the *Willamette River Inventory* (Bureau of Planning, 2000) and in the North, Central and South Reach natural resource inventories (https://www.portland.gov/bps/river-plan). This document also provides a detailed description of wildlife communities along the lower Willamette River.

5.1 Fish Communities

Altman et al. (1997)[28] report that ODFW (1988) identified 54 species as being present within the Willamette Basin, and identified 7 additional species from other sources (see Table 3, pp. 22-23 in Altman et al. 1997). Forty-eight percent of these were introduced species. Within the lower Willamette, Farr and Ward (1993) found a total of 39 fish species from 17 families, with 19 of the species from seven families being exotic species introduced. Ward and Nigro (1991) and Farr and Ward (1993) characterized fish communities from the lower Willamette River through Portland. They found that the native northern pikeminnow was the most abundant species, followed by a number of non-native species including black crappie, white crappie, largemouth bass, smallmouth bass, and walleye.

The listings of many native populations under the Endangered Species Act (ESA), and the large numbers of exotic species present, are indicators of the poor health of fish populations in the lower Willamette River. In March 1998 and March 1999, NOAA Fisheries issued final rules to list four evolutionarily significant units (ESUs) of steelhead (*Oncorhynchus mykiss*) and Chinook salmon (*O. tshawytscha*) as threatened under the federal ESA (Table 27).

This represented one of the first listings of an aquatic species in an urban area under the ESA, and because the Willamette River flows through the heart of the downtown and industrial cores, the first application of the ESA in a densely developed and industrialized landscape. Since then, nine additional ESUs that spawn, rear or migrate through Portland streams and rivers, for a total of 13 Columbia River salmon stocks (ESUs), have been listed that use the lower Willamette River (Table 27). In addition, aquatic species such as lamprey, sturgeon and eulachon; and terrestrial species including the streak-horned lark and the yellow-billed cuckoo, have been listed as federal species of concern or threatened species.

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[28] Although not discussed at length in this document, Altman et al. provide an extensive description of aquatic communities throughout the Willamette Basin. This is an important background document for understanding regional scale patterns in Willamette River biological communities and the factors that affect them. It is a comprehensive analysis of existing studies summarizing specific information on algae, macroinvertebrates, fish, amphibians, reptiles and mammals in the basin.

Table 27: ESA-listed fish species found in Portland streams and rivers.

Portland, Oregon: ESA-Listed Species

ESU/DPS	Race	Species		Listing	Year Listed
Upper Willamette	Spring	Chinook Salmon	*Oncorhynchus tshawytscha*	FT	1999
Upper Willamette	Winter	Steelhead Trout	*Oncorhynchus mykiss*	FT	1999
Upper Columbia	Spring	Chinook Salmon	*Oncorhynchus tshawytscha*	**FE**	1999
Lower Columbia	Sp,Fa	Chinook Salmon	*Oncorhynchus tshawytscha*	FT	1999
Upper Columbia		Steelhead Trout	*Oncorhynchus mykiss*	FT	1997
Middle Columbia		Steelhead Trout	*Oncorhynchus mykiss*	FT	1999
Lower Columbia	Su,Win	Steelhead Trout	*Oncorhynchus mykiss*	FT	1998
Columbia River		Chum Salmon	*Oncorhynchus keta*	FT	1999
Lower Columbia		Coho Salmon	*Oncorhynchus kisutch*	FT	2005
Columbia River		Bull Trout	*Salvelinus confluentus*	FT	1998
Snake River		Sockeye Salmon	*Oncorhynchus nerka*	FE	1991
Snake River	Fall	Chinook Salmon	*Oncorhynchus tshawytscha*	FT	1992
Snake River	Sp-Sum	Chinook Salmon	*Oncorhynchus tshawytscha*	FT	1992
Snake River		Steelhead Trout	*Oncorhynchus mykiss*	FT	1997
Southern DPS		Pacific Eulachon	*Thaleichthys pacificus*	FT	2011
Southern DPS		Green Sturgeon	*Acipenser medirostris*	FT	2006
Northern DPS		Green Sturgeon	*Acipenser medirostris*	FSoC	2004
		White Sturgeon	*Acipenser transmontanus*	SoC	
		Pacific Lamprey	*Entosphenus tridentatus*	SoC	
		W. Brook Lamprey	*Lampetra richardsoni*	SoC	
		River Lamprey	*Lampetra ayresii*		

5.1.1ODFW Fish Study

ODFW conducted the most extensive fish study of the lower Willamette through Portland in 2000–2004. Using electrofishing, beach seines and radio telemetry, biologists documented nearshore habitat use, outmigration, timing, size structure, growth, migration rate, and residence time. Results indicated extensive use of the lower river by juveniles. Most (87%) of the juvenile salmonids captured were Chinook salmon, 13% were steelhead, and nine percent were coho salmon. Occasionally observed were mountain whitefish, sockeye salmon, and cutthroat trout.

Hatchery-produced salmon dominated the catch, composing more than half of the Chinook salmon (54%), coho salmon (66%), and steelhead (91%). Large (>100 mm fork length) hatchery Chinook salmon dominated the electrofishing catch; Small (<100 mm fork length) unclipped Chinook salmon dominated the beach seine catch.

Juvenile salmonids were present in every month sampled from May 2000 to July 2003. Outmigrating juvenile Chinook, both hatchery and unmarked, often increased in late autumn and persisted into the next summer. Coho salmon and steelhead were generally present only during winter and spring.

Fish feed and grow as they move through the lower river. ODFW found that median fork lengths and weights of hatchery and unmarked Chinook salmon were often significantly greater at downstream sampling sites than at upstream sites, suggesting that they are feeding to sustain growth as they outmigrate.

Regarding migration rate, ODFW found small juvenile salmonids move relatively quickly through the lower river. However, of 186 juveniles, the median migration rates for steelhead (12.5 km/day) and Chinook salmon (11.3 km/day) were significantly faster than for coho salmon (4.6 km/day). Median residence times in the study area were 8.7 days for coho salmon, 3.4 days for Chinook salmon, and 2.5 days for steelhead. ODFW concluded that river flow and fish size explained much of the variation in Chinook and coho migration rates. Release day and river flow explained much of the variation in coho salmon migration rates. No significant relationships were observed for steelhead.

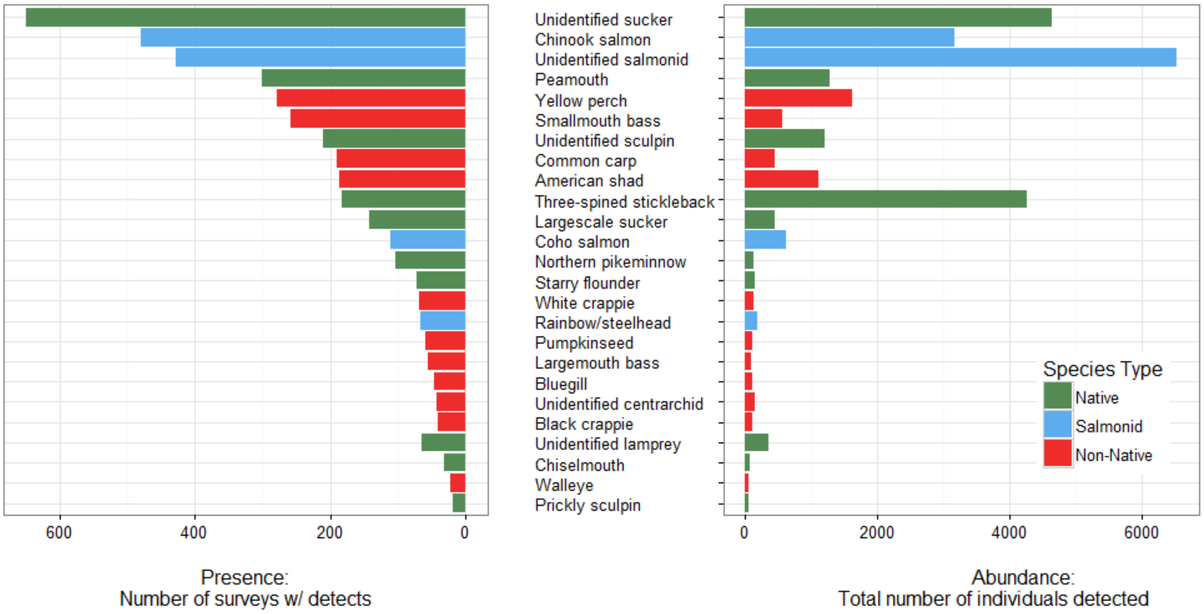
Regarding near-shore habitat use, radio-tagged juvenile Chinook salmon were not highly associated with nearshore areas; about 76% of the recoveries occurred offshore (>10% of the channel width). Steelhead were rarely (25%) associated with nearshore areas. Most fish that were recovered near shore generally did not show clear selection for (or avoidance of) particular habitats. However, coho salmon were found near shore more often (43%), appeared to prefer beaches, and avoided riprap and artificial fill.

ODFW also evaluated fish presence across generalized habitat categories (e.g., beach, riprap, rock outcrop) and into clustered groups based on similarities in physical and chemical parameters. Results for large juvenile salmonids indicated presence varied significantly among habitat types, but differences were almost always associated with low catches of fish at seawall sites (possibly due to sampling at depth only in these areas). ODFW also found no indication that yearling salmonids were associated with specific habitats or groups of habitats, with one exception. The presence of coho salmon in spring at rock outcrops was significantly higher than at other habitats, suggesting these areas have a particular value. High catches sometimes occurred more frequently in off-channel areas (alcoves, backwaters, side channels), but were not significantly different from those in the main river channel. Juvenile Chinook salmon catches were lowest at sites with low (0-10%) vegetative cover, and higher with sand substrates, shallow water, and moderate amounts of bank vegetation during winter.

Data collected to evaluate diet indicated that Chinook and coho salmon have specialized, selective feeding behaviors. Daphnia were the most important prey item for these two species, occurring in 65% of the samples and composing >80% of their diets by weight. The amphipod *Corophium* spp. and insects (both aquatic and terrestrial) were also common prey. Conversely, fish and crayfish composed nearly all (97%) of smallmouth bass diet by weight. Yellow perch, bass, and sunfish generally had more diverse diets than juvenile salmonids, and unlike salmonids, did not specialize on particular taxa. Diets of unmarked and hatchery Chinook salmon overlapped significantly, though unmarked fish exhibited a more selective feeding behavior and consumed larger amounts of prey.

For the overall species composition, ODFW found in electrofishing surveys that suckers, Chinook (and unidentified) salmonids, and peamouth were the most commonly present native species; yellow perch and smallmouth bass were the most commonly present non-native species (Figure 98). Native three-spine stickleback were not encountered in as many surveys as other species, but were present in large numbers at the sites where they occurred, and had more total number of individuals captured than all other species except unidentified suckers and salmonids.

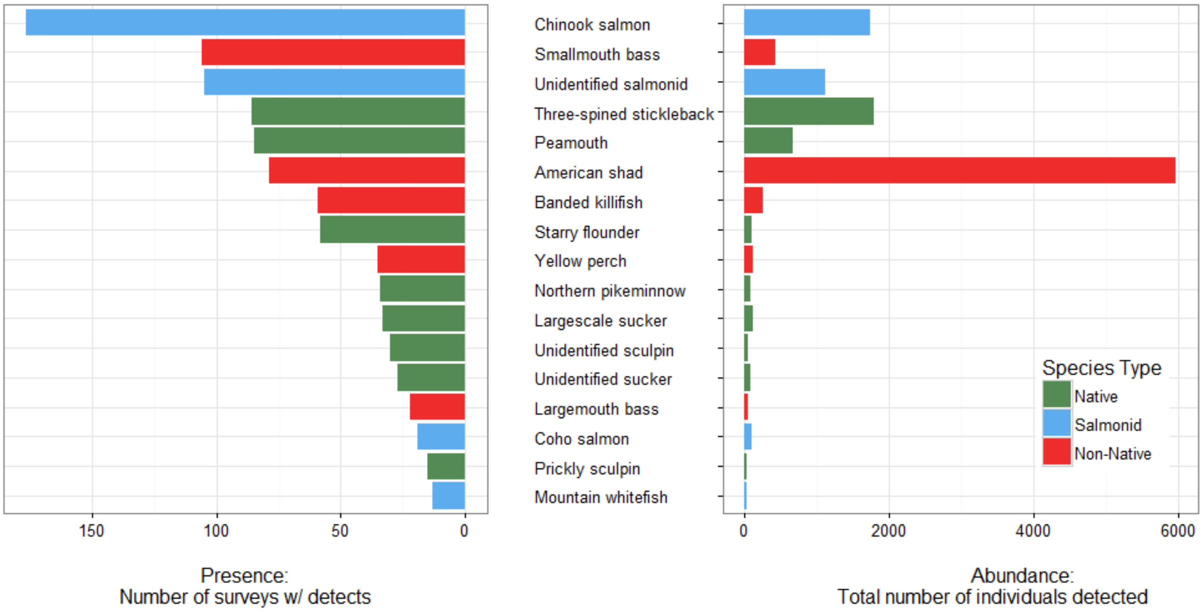
Figure 98: Species composition from the ODFW Willamette Fish Study (ODFW 2005) electrofishing surveys.



ODFW also conducted beach seine surveys (Figure 99). Beach seines can only be conducted on wadeable beach shorelines, and are ineffective in sampling habitats such as riprap, seawalls or rocky or deep shorelines. They therefore cannot be used to compare fish communities in these different habitat types, but they provide other valuable insights, such as on the value of beach habitats, and are often effective at capturing smaller fish.

In the beach seines, Chinook were by far the most commonly captured species, collected in a third more surveys than any other species. The non-native American shad was captured in fewer surveys, but was highly abundant where present (with over three times the total numbers of any other species). Smallmouth bass was the most commonly encountered non-native species, but was far less numerous than shad.

Figure 99: Species composition from the ODFW Willamette Fish Study (ODFW 2005) beach seining surveys.



ODFW found a distinct difference in the size and type of Chinook salmon captured by electrofishing and beach seining. The electrofishing typically captured larger, hatchery fish, whereas the beach seines typically captured smaller, wild fish.[29] The results also show that subyearling Chinook life stages are common in the lower Willamette through Portland. Although the extent to which they are present in other habitat types is not known, they clearly make extensive use of available beach habitats.

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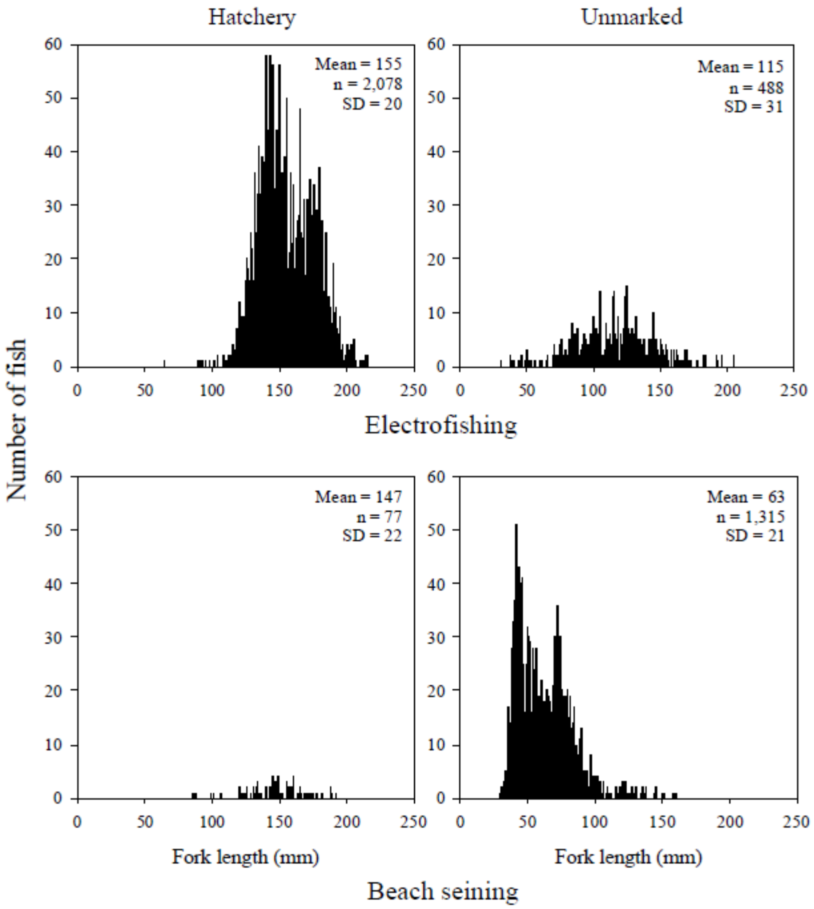
[29] Electrofishing typically caught juvenile Chinook larger than 100 mm – suggesting that they were yearling fish, and were mostly fin-clipped - indicating they were of hatchery origin. In contrast, the beach seined Chinook were predominantly less than 100 mm and unclipped suggesting that they were wild-origin subyearlings.

Figure 100: Figure 4 from Friesen and others (2005). Fork length distributions for hatchery and unmarked juvenile Chinook salmon captured by electrofishing (top panels) and beach seining (lower panels) in the lower Willamette River, 2000-2003. SD = standard deviation.



5.1.2PAWMAP Fish Data

The City of Portland evaluates watershed health through the Portland Area Watershed Monitoring and Assessment Program (PAWMAP), which is based on the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP)[30]. PAWMAP monitoring efforts are primarily focused on the tributaries to the Willamette River since the mainstem has been thoroughly characterized by a wide range of studies, including the Portland Harbor Remedial Investigation (EPA 2016), the Willamette Fish Study (ODFW 2005), and city water quality monitoring efforts. In order to complement but not duplicate these existing efforts and data on the mainstem, PAWMAP only samples fish communities in the Willamette. The city samples five sites along the Willamette mainstem quarterly for fish species composition. Stations are rotated – with new stations each year for four years, at which point the stations are repeated.

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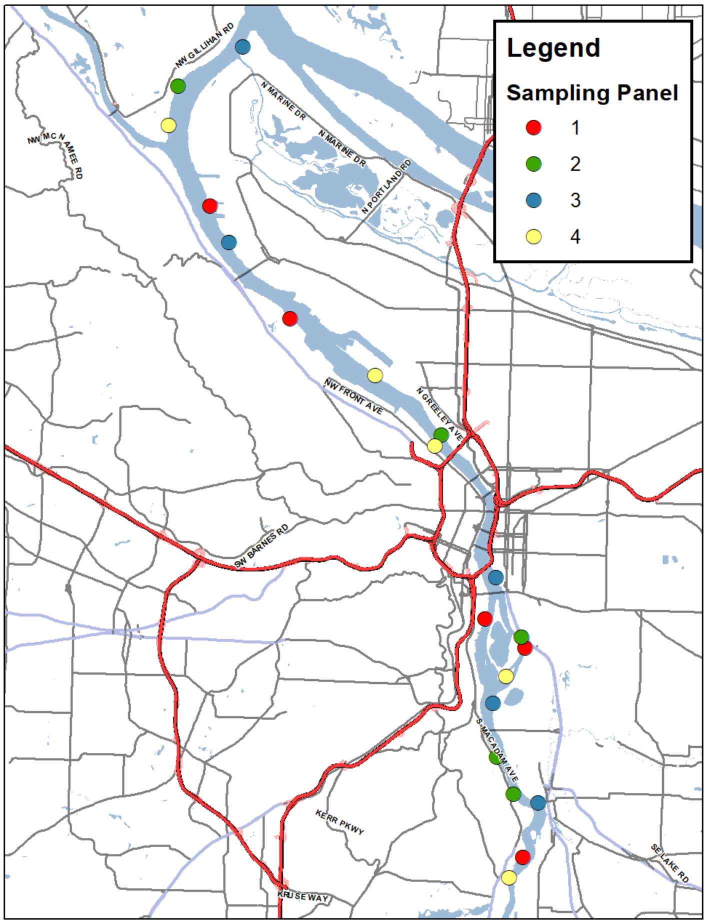
[30] PAWMAP and its design are described here: https://www.portlandoregon.gov/bes/article/489038. EMAP's Field Protocols are described here: https://www.epa.gov/sites/production/files/2013-11/documents/nrsa_field_manual_4_21_09.pdf

Figure 101: PAWMAP Stations sampled for fish communities along the lower Willamette River. PAWMAP uses a 4-year rotational sampling panel: each panel is sampled every four years. Panel 1 was sampled in 2014 & 2018, Panel 2 was sampled in 2015 & 2019, Panel 3 was sampled in 2015 & 2020, Panel 4 was sampled in 2016 and will be resampled in 2021.



Results indicated that largescale sucker and Chinook salmon were the most commonly detected species from 2014 – 2016 (Figure 102). Prickly sculpin (a native species) was more commonly found than in the ODFW surveys. Consistent with the ODFW study, smallmouth bass, yellow perch and carp were the most commonly encountered and abundant non-native species. Overall, slightly more than half of the ten most commonly encountered species are native.

The PAWMAP fish data in the lower Willamette mainstem have a higher prevalence of non-native fish than the PAWMAP tributary surveys. In the tributaries flowing to the lower Willamette (excluding the Columbia Slough), the ten most commonly captured species were all native, and two of the five most commonly encountered species were salmonids.[31]

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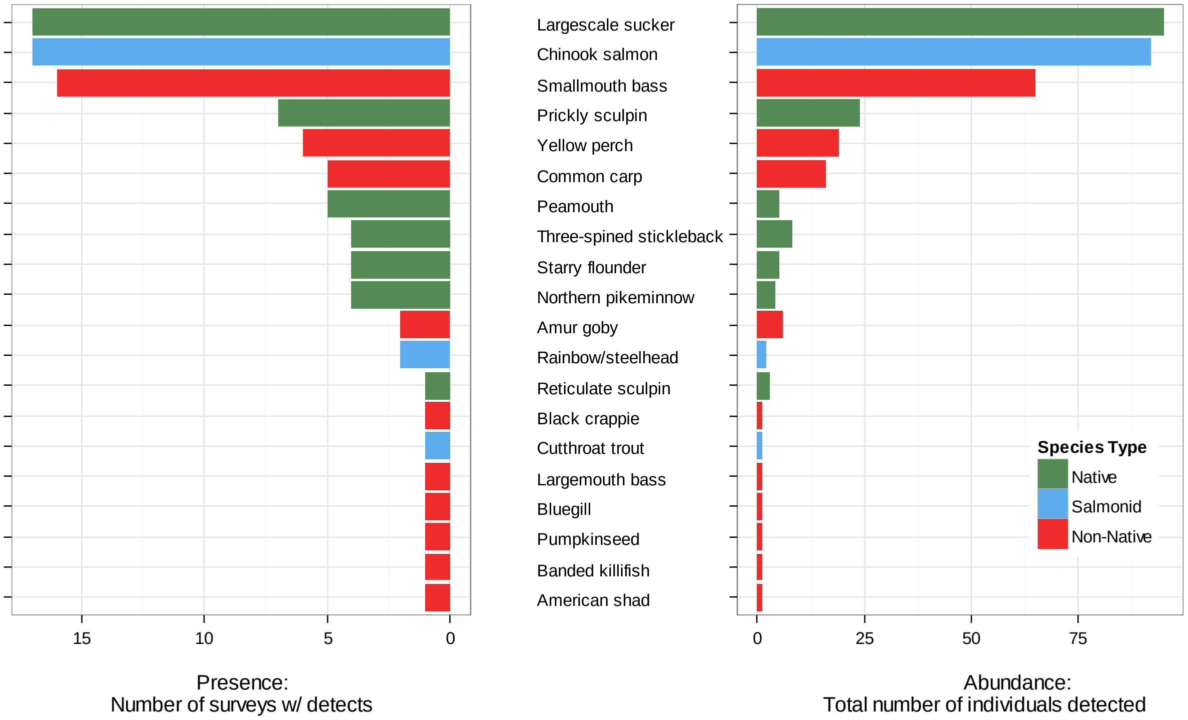
[31] Bureau of Environmental Services. Portland Area Watershed Monitoring and Assessment Program (PAWMAP): Report on the First Four Years of Data (FY 2010-11 to FY 2013-14).

Figure 102: Species composition from PAWMAP surveys from 2014–16.



5.1.3NPCC Willamette Subbasin Plan

The Northwest Power and Conservation Council (NPCC) conducts subbasin planning to support Columbia River salmon recovery efforts. Using Ecosystem Diagnosis and Treatment modeling, NPCC conducted as assessment that indicated that conditions in the Portland area of the lower Willamette are an important bottleneck for upriver populations, and that restoration of these conditions had the potential to contribute to tributary populations such as those from the Clackamas. For all six Clackamas populations combined, the Portland area was the second-ranked restoration priority. It had a moderate overall restoration ranking and relatively high rankings for Clackamas Spring Chinook (restoration rank 2 out of 13), Fall Chinook (restoration rank 3 out of 7), and upper Clackamas steelhead (restoration rank 3 out of 8).

The assessment found that salmon and steelhead currently use the area almost entirely as a migration corridor because of the lack of habitat to support rearing. (This is consistent with other studies that found that most juvenile salmonids move through the area in less than two weeks (Friesen and others, 2002). However, under a restored condition, the lower Willamette adds considerable rearing habitat that would be used by juvenile fall Chinook as they move toward the estuary (pg. 3-441). This rearing habitat would be particularly important for Clackamas fall Chinook, as well as for Clackamas spring Chinook adult and juvenile migration.

Restoration of water quality and shallow water habitat in the Portland area would greatly increase the rearing capacity for Clackamas coho and steelhead as well. However, chemicals (pollutants), and lack of habitat diversity and quantity continue to limit production of upper river coho. (3-445).

Restoration of the lower Willamette would add considerable capacity to all Clackamas populations (3-448, 9).

Overall, the NPPC found that "Conditions in the lower Willamette River affect the performance of all six populations in the Clackamas River. This assessment showed that conditions in the lower Willamette can contribute significantly to the potential biological performance of fish in the Clackamas River. In fact, it is apparent that the Clackamas River and the lower Willamette River form a contiguous habitat unit. This expanded view of the Clackamas can form a useful focus for restoration and management of coho, Chinook, and steelhead in the Clackamas River." (3-454 – 455):

Current habitat conditions in the Portland (lower Willamette) area are highly degraded, so the area had almost no protection value for the six Clackamas populations. Limiting conditions included: chemical pollutants, loss of habitat diversity, pathogens, predation (the result of large numbers of introduced fish species), and loss of key habitat.

5.1.4Teel et al. (2009) study

Teel et al (2009) conducted genetic analyses of 280 subyearling fish collected in winter and spring 2005–2006 from wetland and main-stem lower Willamette River sites. One site (Ramsey Refugia) was a City of Portland restoration project that restored new off-channel habitat.

The study found that fish from throughout the Columbia Basin were using lower Willamette habitats. Genetic stock identification analysis indicated that Willamette River spring Chinook made up a substantial proportion of the samples overall but that Lower Columbia fall Chinook, Lower Columbia spring Chinook, and subyearlings from the middle and upper Columbia River summer–fall-run populations were present in river and wetland samples over the study. "The results suggest that floodplain restoration projects intended to improve fish habitats during winter and spring periods in the lower Willamette River may benefit Chinook salmon populations from the upper Willamette River, lower Columbia River, and upper Columbia River summer–fall evolutionarily significant units." (pg. 211)

5.2 Wildlife

Lewis and Clark noted the abundant wildlife in the lower Willamette area:

> "I [s]lept but verry little last night for the noise Kept [up] during the whole of the night by the Swans, Geese, white & Grey Brant Ducks &c… they were emensely noumerous, and their noise horid." (*The Journals of Lewis and Clark* p. 277).

The *Willamette River Inventory* (Adolfson 2003) provides a comprehensive assessment of wildlife across the lower Willamette. It inventories existing resources and sites and characterizes habitat types and their use by wildlife. Since then, the city's 2011 Oregon Terrestrial Ecology Enhancement Strategy (TEES) completed a more updated assessment of special status wildlife, plants, and habitats.

The bottomland forests of the river offer wintering and/or breeding habitat for waterfowl, shorebirds, and Neotropical avian migrants and are part of a large lower Columbia River lowland ecosystem. Wetlands associated with bottomland forest (cottonwood riparian forest) are preserved on Sauvie Island and in the Smith and Bybee Lakes area. Kelley Point Park and Smith and Bybee Lakes provide critical breeding and nesting habitat for declining populations of neotropical birds. Fish and amphibians are also strongly associated with aquatic, wetland, and riparian habitats. At least seven native amphibian species inhabit Forest Park, including five salamanders and two frog species. Bald eagle, blue heron, osprey, and other raptor species depend on the upland forest, bottomland riparian forest, and emergent wetlands. The Harborton wetland area presents viable habitat for amphibians, reptiles, birds, and mammals, and off-channel fish habitat during high water conditions. Miller Creek provides a partial passageway between these wetlands and the upland forest for salmonids, amphibians, reptiles, and small mammals.

The travel corridors along Columbia Slough are important for dispersion of mammalian species such as deer, coyote, fox, and beaver, as well as reptilian (e.g., turtles, snakes) species. Bobcat, coyote, deer, and occasional bear are known to make use of the proximity of shelter in the upland forests and forage along the river. Between the Linnton area and the St. Johns Bridge, the dominant large-scale habitat context is the looming presence of the Tualatin Mountains (Forest Park section) immediately adjacent to the river. The linkage for terrestrial species is largely blocked by Hwy 30, a four- to five-lane roadway. There are few broadscale terrestrial habitat linkages on the eastern river shore in this reach.

In-water habitat is used by salmonids primarily for passage (upstream and downstream) and rearing, although the Columbia Slough channel and other embayments provides refuge areas. In the Linnton area, the Multnomah Channel provides an important linkage and resting area for salmonid species. Miller Creek, the Tualatin Mountains, Harborton wetlands, Burlington Bottoms, and Sauvie Island are part of a diverse habitat complex linked to the Channel. The open water habitat also provides feeding areas for birds such as ducks, cormorants, gulls, herons; and mammals such as river otter and mink. Kelley Point Park and the Harborton wetlands increase the importance of the reach as a corridor for terrestrial species migrating from wildlife refuges in Southern Washington and Sauvie Island. Insectivores such as swallows and bats also forage over the water.

At the north end of the lower river, water birds include double-crested cormorant, great blue heron, herring gull, mallard, hooded and common mergansers, and gadwall. Raptors detected include northern harrier, merlin, red-tailed hawk, osprey, bald eagle, and peregrine falcon. A wide variety of song birds use the reach, including black-capped chickadee, bushtit, Bewick's and winter wrens, American robin, starling, Hutton’s vireo, song sparrow, dark-eyed junco, purple finch, golden-crowned kinglet, and various other sparrows (i.e., house, white-crowned, golden-crowned, and fox sparrows). Other birds identified are downy woodpecker, northern flicker, mourning dove and rock dove (domestic pigeon), western scrub-jay, and American crow. Painted turtle, northwestern garter snake, common garter snake, long toed salamander, western red-backed salamander, red-legged frogs, Pacific chorus (tree) frog, and bull frog are present. Mammal species noted include mink, deer, beaver, river otter, and raccoon (Adolfson 2003).

The Tualatin Mountains form a topographic constraint that defines the western limit of the lower Willamette floodplain. The Tualatin Mountains are a different level III ecoregion from the rest of the lower river (Figure 1). The *Forest Park Wildlife Report* (Deshler 2012) provides a comprehensive inventory of wildlife use of this area, and documents habitat characteristics, threats and information gaps important to managing its unique resources.

In the Central Reach, a number of raptor species (red-tailed hawks, peregrine falcons, etc.) have adapted to the urban setting and limited habitat, such as are provided by riverside park/promenade. Habitat diversifies again in the South Reach. Complexes around River View Cemetery, Ross Island and Oaks Bottom are frequent stopover and forage sites for many wildlife species. In this area, numerous large and small holes at or above the ordinary high-water mark indicate the presence of river otter, bank swallows, and/or kingfishers. Barn swallows and violet-green swallows feed and collect nesting materials, and kingfishers were observed foraging. Other river bird species detected include cormorant, widgeon, bufflehead, Canada goose, and numerous pairs of mallards. Passerine and other bird species observed include golden crowned kinglet, song sparrow, winter wren, American goldfinch, bushtit, black-capped chickadee, and American crow. Purple martins are seasonal visitors.

To identify plant and animal species and terrestrial habitats needing protection, conservation, and/or restoration, TEES listed Special Status Species[32] to help land managers and planners identify actions for implementation. As of 2011, TEES has identified 76 wildlife Special Status Species in Portland: 2 amphibians, 2 reptiles, 58 birds, and 14 mammals (https://www.portlandoregon.gov/bes/article/354986, pages 4-6) (Table 28).

Table 28. Wildlife Special Status Species in Portland

	Federal Status	**State Status**	**NWPCC Focal Spp.**[33]
Amphibians			
Northern red-legged frog	Species of Concern	Sensitive-Vulnerable	X
Clouded salamander		Sensitive-Vulnerable	
Reptiles			
Northwestern pond turtle	Species of Concern	Sensitive-Critical	X
Western painted turtle		Sensitive-Critical	
Birds			
American bittern			
American kestrel			X
American white pelican		Sensitive-Vulnerable	
Bald eagle	Delisted[34]	Delisted[35]	X
Band tailed pigeon	Species of Concern		
Black throated gray warbler			

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[32] Special Status Species were identified as those wildlife species whose range includes Portland and that are officially listed or identified by various named entities.

[33] Identified in the Northwest Power and Conservation Council Willamette Basin Subbasin Plan as Focal Species. These include species that are: listed or that are current candidates for listing as threatened or endangered by federal agencies; listed as threatened, endangered, sensitive—critical, or sensitive—vulnerable by ODFW; declining in the basin or region as indicated by Breeding Bird Survey (BBS) data; endemic to the Willamette Basin; or perform ecological functions quite different from those performed by other species that regularly occur in the same habitat type.

[34] http://www.fws.gov/pacific/ecoservices/BaldEagleDelisting.htm

[35] http://www.dfw.state.or.us/conservationstrategy/news/2012/2012_may.asp

	Federal Status	State Status	NWPCC Focal Spp.[33]
Brown creeper			
Bufflehead			
Bullock's oriole			
Bushtit			
Chipping sparrow		Strategy Species	X
Common nighthawk		Sensitive-Critical	
Common yellowthroat			X
Downy woodpecker			
Dunlin			X
Great blue heron			
Green heron			X
Hammond's flycatcher			
Hermit warbler			
Hooded merganser			
House wren			
Hutton's vireo			
Loggerhead shrike		Sensitive-Vulnerable	
Long-billed curlew		Sensitive-Vulnerable	
Merlin			
Nashville warbler			
Northern harrier			X
Olive-sided flycatcher	Species of Concern	Sensitive-Vulnerable	X
Orange crowned warbler			
Pacific slope flycatcher			
Peregrine falcon	Delisted[27]	Delisted[36]	
Pileated woodpecker		Sensitive-Vulnerable	X
Purple finch			
Purple martin	Species of Concern	Sensitive-Critical	X
Red crossbill			
Red-eyed vireo			X
Red-necked grebe		Sensitive-Critical	
Rufous hummingbird			
Short-eared owl		Strategy Species	
Sora			X
Streaked horned lark	Candidate	Sensitive-Critical	X
Swainson's thrush			
Swainson's hawk		Sensitive-Vulnerable	
Thayer's gull			
Varied thrush			
Vaux's swift			X
Vesper sparrow	Species of Concern	Sensitive-Critical	X
Western meadowlark		Sensitive-Critical	X
Western sandpiper			

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[36] http://www.dfw.state.or.us/conservationstrategy/news/2010/2010_april.asp

	Federal Status	State Status	NWPCC Focal Spp.[33]
Western wood pewee			X
White-breasted nuthatch		Sensitive-Vulnerable	X
White-tailed kite			
Willow flycatcher - Little	Species of Concern	Sensitive-Vulnerable	X
Wilson’s warbler			
Winter wren			
Wood duck			X
Yellow warbler			X
Yellow-breasted Chat	Species of Concern	Sensitive-Critical	
Mammals			
American Beaver			X
California myotis		Sensitive-Vulnerable	
Camas pocket gopher	Species of Concern		
Fringed myotis	Species of Concern	Sensitive-Vulnerable	
Hoary bat		Sensitive-Vulnerable	
Long-eared myotis	Species of Concern		
Long-legged myotis	Species of Concern	Sensitive-Vulnerable	
Northern river otter			X
Red tree vole	Species of Concern	Sensitive-Vulnerable	X
Silver-haired bat	Species of Concern	Sensitive-Vulnerable	
Townshend’s big eared bat	Species of Concern	Sensitive-Critical	X
Western gray squirrel		Sensitive-Vulnerable	X
White-footed vole	Species of Concern		
Yuma myotis	Species of Concern		

Other criteria used to identify Special Status Species (and not included in the table) include: Oregon Natural Heritage Information Center (ORNHIC) data, the *Conservation Strategy for Landbirds in Lowlands and Valleys of Western Oregon and Washington* (2000) or *Conservation Strategy for Landbirds in Coniferous Forests of Western Oregon and Washington* (1999), Oregon Watershed Enhancement Board priorities, and the Audubon watchlist.

A searchable TEES database provides information about their habitats, life histories, and limiting factors, where known. The database also lists 32 Special Status plant species (page 7). Habitat types considered as having special significance were identified as Special Status Habitats, and were discussed in Section B.5 of the TEES document.

Environmental elements that limit the growth, abundance, or distribution of a population are known as limiting factors. For example, the absence of old, hollow trees is a limiting factor for some bat species. TEES developed a list of limiting factors, grouped by major categories and numbered (Attachment G of the TEES document), that are linked to species and habitat tables, matrices, and databases. The main categories of limiting factors are:

- Biological Stressors
- Climate Change

- Disruption of Natural Disturbance Regimes
- Habitat Change
- Degradation and Loss
- Habitat Fragmentation and Access
- Human Disturbance
- Pollution

Each factor has a list of more detailed factors. For example, biological stressors include 13 subfactors, such as competition for nesting cavities, and invasive aquatic animal species.[37]

5.3 Macroinvertebrates

There has been very limited evaluation of benthic macroinvertebrates in the lower Willamette River. Tetra Tech (1994) found no families of Ephemeroptera, Plecoptera, Trichoptera (EPT)[38] present in the lower reaches of the river. However, this is true for most of the middle and upper river also, and the lack of these families may not be unusual in large low gradient rivers dominated by fine-grained substrate. Altman et al. (1997) concurs, finding that macro-invertebrate assemblages in the lower mainstem are dominated by pollution tolerant organisms and those adapted to low dissolved oxygen levels. Typical invertebrates in the lower river are oligochaetes (segmented worms), cladocerans (water fleas), amphipods (scuds), odonates (dragonflies and damselflies), and chironomid midges (Ward and others, 1988)." (pp. 18-19).

Windward Environmental (2003) collected some initial baseline information on benthic invertebrates settling on artificial substrates as part of the Portland Harbor study. They found that chironomids (midges) were the most abundant and diverse taxa. Oligochaete worms were the second most diverse taxa, while amphipods were the second most abundant taxa. Other taxa included isopods, ostracods, caddisflies, mites, and flatworms. Interestingly, they found the highest abundance of organisms in a backwater section of the Swan Island Lagoon, while the least abundant site was nearby at the mouth of the lagoon. These data fill an important data gap and will be helpful in evaluating changes in the community through the lower river.

However, the challenge with evaluating the health of macroinvertebrate communities in the lower Willamette River is the lack of information on reference conditions for which to compare unimpacted macroinvertebrate populations in large low-gradient rivers. For example, it will be hard to utilize the Windward data to define the health of the impacted lower Willamette until information is obtained for invertebrate communities on artificial substrates in comparatively unimpacted reference reaches.

5.3.1ODFW Macroinvertebrate study

ODFW also sampled macroinvertebrates in the lower Willamette as part of the Willamette Fish Study (ODFW 2005). They sampled macroinvertebrates and zooplankton at 26 different habitat sites during spring 2003 using drift nets, Hester-Dendy multiple-plate samplers, and ponar dredges. ODFW "… identified approximately 38,000 organisms from 44 taxa. Cladocerans

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[37] All of the limiting factors (Attachment G) are here: http://www.portlandoregon.gov/bes/article/354993.

[38] Aquatic insects that are sensitive to degraded water quality and habitat. They are typically found in healthy tributary watersheds.

(bosminids and daphnia), copepods, and aquatic insects dominated the water column "drifting" taxa." Daphnia and chironomids dominated the taxa that attach to substrates (95% of all organisms); and oligochaetes and chironomids dominated the sediment dwelling taxa.

ODFW noted few differences in the distribution of major taxa groups among habitats, suggesting a generally homogenous macroinvertebrate community structure: "Density and community metrics varied among gear and habitat types. Beaches tended to have relatively high species diversity, taxa richness, and sensitive taxa richness; seawalls had comparatively low densities and taxa richness. Rock outcrops and floating structures appeared to be preferred habitats for adult aquatic insects. Riprapped sites had very high densities of aquatic organisms and, except for multiple-plate samples, relatively high taxa richness."

6 References

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