
West Point Flooding Event Water Quality Summary Report

February 2018



King County

Department of Natural Resources and Parks
Water and Land Resources Division

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West Point Flooding Event Water Quality Summary Report

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King County

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EXECUTIVE SUMMARY

The West Point Treatment Plant (West Point) experienced equipment failure and flooding on February 9, 2017 that severely damaged mechanical and electrical systems needed to provide heat to the secondary system biology, which essentially crippled the plant's solids handling capabilities. From February 9 through May 9, the plant was unable to treat to secondary levels required under its state and federal permits.

To protect the plant from further damage immediately following the flooding, West Point discharged 244 million gallons of untreated stormwater and sewage through a 40-foot-deep emergency bypass outfall (EBO) during two separate events on February 9 and 15–16. Under normal operation, effluent is discharged from the 240-foot deep main outfall in the Puget Sound Central Basin. The bypasses consisted of approximately 85–90 percent stormwater and 10–15 percent wastewater.

In response to the bypasses and the temporarily limited treatment capabilities and capacity at West Point, the Wastewater Treatment Division (WTD) voluntarily increased the frequency of its water quality monitoring in Puget Sound and the number of sampling locations.

These actions included daily marine beach monitoring until bacteria levels returned to normal levels followed by weekly monitoring for bacteria. There were also weekly marine waters monitoring for a variety of parameters, additional effluent sampling for a variety of parameters, and two rounds of marine waters sampling for total and dissolved metals. The purpose of the expanded monitoring effort was to:

- Provide representative monitoring and analyses of West Point discharge conditions and the marine environment of Puget Sound.
- Document West Point treatment performance and effluent quality improvements over time as repairs to West Point were completed.
- Evaluate short-term water quality effects of wastewater discharges to Puget Sound while repairs to West Point occurred including any correlations with observed changes in marine water quality based upon historical data.

Additional monitoring included sediment sampling near the outfall to assess solids deposition and organic enrichment, metals and organic compounds, and benthic infauna community structure. Metals in intertidal sediments and clams were monitored as well as zooplankton and crab tissues for metals and organic compounds. Sediment and tissue monitoring results will be reported separately in 2018. Monitoring plans and water quality observations were regularly posted on the King County WTD website during the plant restoration period.

Repair of all critical equipment needed to operate West Point took three months to complete, and the plant resumed full compliance with its National Pollutant Discharge Elimination System (NPDES) permit on May 10, 2017. During the restoration, West Point

provided reduced treatment that included screening and full disinfection. With the exception of the two emergency discharges of untreated stormwater mixed with sewage in February, all effluent discharged was disinfected and met bacterial permit limits. The effluent did not always meet permit limits for total suspended solids (TSS), carbonaceous biochemical oxygen demand (CBOD), and residual chlorine parameters during the period of reduced treatment.

Strong winter storms and above-normal spring rains resulted in higher than normal stormwater flows to West Point in February, March, and April. To cope with high volumes of stormwater at West Point and reduce water quality impacts, inflows to the plant during storm events were shed to combined sewer overflow (CSO) facilities or diverted to King County's other regional wastewater treatment plants. This flow diversion resulted in an increased volume treated at three of King County's wet weather treatment facilities. Untreated overflows from the combined system were exacerbated as well, particularly during storm events that required management of peak inflows to West Point. Daily average inflows to West Point varied from about 100 million gallons per day to over 300 million gallons per day during winter and spring of 2017. To enable the recovery of the secondary system biology at the plant and progressively improve effluent quality during the restoration, a substantial volume of solids that could not be treated at West Point were trucked to South Plant in Renton.

Immediate Effects from Emergency Discharge of Untreated Effluent

Discharge of untreated stormwater and sanitary sewage from the EBO on February 9 and 15–16 resulted in short-term water quality impacts along the adjacent shorelines. Several Seattle-area beaches were closed to public recreation starting on February 9 to protect public health. King County conducted daily fecal bacteria monitoring, which showed that bacteria levels on February 9 and 16 along the beach on the north side of West Point near the EBO were orders of magnitude higher than regulatory levels established for the protection of public health. Fecal bacteria levels were also elevated, though not to the same degree as the north side of West Point, at several other nearby beaches following the untreated discharge events. Fecal bacteria concentrations returned to safe levels at all beaches after three days following each event. Seattle area beaches were re-opened for public recreation on February 21 after bacteria concentrations returned to safe levels, and have remained open since. King County Wastewater Treatment Division received no reports of problems from any of the public health agencies during the beach closures.

Effluent Quality During the Period of Reduced Treatment

King County increased the frequency of West Point effluent quality monitoring between February and June, 2017, during the reduced level of treatment. As King County was in emergency response mode, no effluent monitoring occurred during the emergency discharges of untreated effluent through the EBO on February 9 and 15–16. West Point effluent was monitored during the period of reduced treatment for bacteria, solids, nutrients, organic matter, metals, and organic compounds. Treated effluent from February 9 through May 9 did not meet NPDES permit limits for TSS and CBOD. During

March and April, the effluent also occasionally exceeded permit limits for residual chlorine (the disinfectant added to eliminate potentially harmful pathogens). All other constituents in West Point effluent met permit limits throughout the period of reduced treatment. The Elliott West wet weather treatment facility, which handled some of the additional flows during storm events, did not meet its monthly bacteria effluent permit limit in March. All other wet weather treatment plants and King County's other wastewater treatment plants met effluent permit limits during this time period.

During the period of reduced treatment, higher concentrations of bacteria, solids, organic matter, most metals, and some organic chemicals were found in the effluent relative to normal conditions. The increased concentration of these constituents resulted in increased loadings to Puget Sound from West Point relative to normal conditions.

Effluent concentrations of most nutrients were lower or comparable to historical conditions. Ammonia concentrations, while lower in West Point effluent, were slightly elevated in South Plant effluent as a result of processing additional solids from West Point. All constituents returned to normal levels in effluent once secondary processes were restored.

An analysis at the edge of the main outfall's effluent mixing zone indicated that at no time during the period of reduced treatment did effluent ammonia or metals concentrations rise to the level that would exceed any applicable criterion in Puget Sound receiving waters. Acute and chronic toxicity tests conducted on effluent samples collected during the period of reduced treatment verified that the effluent met permit performance standards for toxicity and were comparable to past results. State water quality criteria were developed to be protective of aquatic life. Therefore, no short-term toxicity impacts to biota were expected due to the quality of effluent discharged to Puget Sound receiving waters during the period of reduced treatment.

Receiving Water Quality During the Period of Reduced Treatment

King County substantially expanded its routine monitoring of Central Puget Sound receiving waters from February through June 2017 to assess potential changes and impacts to marine water quality during the period of reduced treatment. In offshore waters, weekly monitoring occurred at a subset of 5 stations near West Point and biweekly at 10 stations for bacteria, physical parameters, nutrients, dissolved oxygen, chlorophyll, and phytoplankton. Metals in the water column were collected twice during the three month period. All water column observations at offshore locations met the state marine water quality standards during the period of reduced treatment, with the exception of dissolved oxygen in June.

Beach bacteria monitoring was also increased to weekly at a subset of stations during this time period. Aside from bacteria standards being exceeded at beaches near the plant in early February following the discharges from the EBO, standards were intermittently exceeded at a few beaches away from West Point during the sampling period. Occasional bacteria exceedances are not uncommon at these beaches.

Dissolved oxygen concentrations observed in offshore waters were at healthy levels to support marine life for all Central Basin sites throughout the monitoring period. All concentrations were above the numeric state water quality standard with the exception in late June. Late June oxygen levels in bottom waters at most sampling sites throughout the Central Basin fell slightly below the numeric state standard but were within normal historical ranges for each site and above the threshold in terms of potential for biological stress. Oxygen levels observed at West Point did not fall below the state standard.

Levels of TSS in mid-water depths were slightly elevated at some sites compared to typical conditions but did not exceed historical background levels. These TSS levels are likely attributed to a combination of inputs. Nutrients at the West Point outfall and other sites were generally similar to or below typical conditions. No changes in the timing or composition of the spring phytoplankton bloom were observed. Concentrations of several metals measured in receiving waters in 2017 were slightly elevated compared to previously measured conditions, likely due to a combination of factors, such as field contamination and surface runoff.

Conclusions

The February 9 flooding of West Point resulted in changes to effluent characteristics from February 9 through May 9. The largest impact observed was the increase in bacteria levels in waters at Seattle area beaches following the two untreated emergency discharge events in February. No other significant water quality impacts were observed near the West Point outfall. Increased loadings to Puget Sound of some constituents in the effluent during the period of reduced treatment did not appear to measurably affect concentrations in the water column. All measurements of marine water quality met applicable water quality standards with the exceptions of beach bacteria levels in February and dissolved oxygen in bottom waters in late June. As stated above, oxygen levels in late June at most sampling sites throughout the Central Basin fell slightly below the numeric standard but were within normal historical ranges. Additionally, with the exception of TSS, CBOD, and residual chlorine, treatment plant effluent also met applicable permit limits.

Given these monitoring results and observations, effluent discharged during the period of reduced treatment did not directly result in exceedances in marine water quality standards in receiving waters, which are intended to be protective of aquatic life. Therefore, no short-term impacts to biota were expected due to the quality of effluent discharged to Puget Sound receiving waters during the period of reduced treatment. Additional monitoring and analysis to identify potential adverse effects to fish, crabs, clams, and other organisms that live in the sediments and the water column are on-going. Potential impacts to sediments and organism tissues around the West Point outfall will be assessed in future reports, expected to be completed in 2018.

1.0 INTRODUCTION

1.1 West Point Treatment Plant Characteristics and the Flooding Event

King County's West Point Wastewater Treatment Plant (West Point) is located near the west side of Magnolia Bluff, adjacent to Seattle's Discovery Park (Figure 1). This regional treatment plant serves a combined system that receives both wastewater and stormwater. The plant began providing primary wastewater treatment in 1966 and was upgraded to secondary treatment in late 1995. The average annual secondary treatment volume of the plant is 95 million gallons per day (MGD), with an average wet-weather flow of 133 MGD and a peak wet-weather capacity of 440 MGD. Secondary treatment at West Point consists of screening, grit removal, primary sedimentation, air-activated sludge, secondary sedimentation, disinfection by chlorination, and anaerobic digestion of solids. Secondary treated effluent is dechlorinated prior to discharge.

The receiving waters of treated effluent from West Point are in the Central Basin of Puget Sound. Effluent is discharged through a marine outfall at a discharge point approximately 3,600 feet (914 m) offshore to the west of West Point at the bottom depth of -240 feet (-73 m) referenced to mean lower low water (MLLW). This effluent exits the outfall through a multi-port diffuser located at the end of the pipe and is approximately 610 feet (186 m) in length. The diffuser produces rapid mixing of the effluent with seawater. In addition to the main outfall, the plant has an emergency bypass outfall (EBO) which is located about 525 feet offshore on the north side of West Point (see Figure 1). The discharge point is at the bottom at an approximate water depth of -40 feet (-12 m) MLLW.

Early in the morning on February 9, 2017, an emergency bypass event occurred due to equipment failure and subsequent flooding of the West Point Treatment Plant during peak inflows. This bypass resulted in the release of 186 MG of untreated stormwater and wastewater into Puget Sound through the EBO. A smaller bypass event occurred over the course of February 15 and 16 resulting in 58 MG of untreated discharge through the EBO. In total, about 244 MG of untreated flows were discharged via the EBO. Over the course of the initial period of the restoration activities at West Point, maximum wastewater inflows to West Point during storm events had to be managed carefully to prevent additional bypasses. To control flows conveyed to West Point, three of the County's combined sewer overflow (CSO) treatment facilities that provide solids removal and disinfection (Alki, Carkeek, and Elliott West) were used to treat excess flows during storm events. Additionally, untreated overflows from the combined system were exacerbated due to reduced West Point operation, particularly during the emergency bypass events, as well as during storm events that required management of peak inflows to West Point.

To put in context the volume of untreated flow bypassed from the EBO, the 244 MG was substantial relative to the historic February untreated CSO discharges. The average February CSO discharge from all of the CSOs in the King County system is 52 MG in the

previous 10-year period of 2007-2016. Over the last ten years, the February CSO discharges have ranged from no discharges in several years to a maximum of 214 MG (in 2014). The total untreated CSO discharge in February 2017 was 749 MG as a result of record rainfall and the West Point incident. The total EBO bypass flow of 244 MG was relatively small compared to the total annual untreated CSO discharge that was 1.7 billion gallons in 2017, as well as the average annual volume of 918 MG for the last ten years.

Following the February 9 flooding event, the plant operated using reduced treatment while efforts were underway to restore secondary treatment processes. This included some settling of solids, screening, disinfection, and dechlorination. The event severely damaged mechanical and electrical systems needed to provide heat to the secondary system biology, which essentially crippled the plant's solids handling capabilities. During the restoration process, the inflows to West Point during storm events were managed carefully to protect recovery of the biological treatment processes and prevent further damage to the plant. This resulted in the need to rely on three King County combined sewer overflow (CSO) treatment facilities (Alki, Carkeek, and Elliott West CSO treatment facilities) to reduce the flows conveyed to the West Point plant. To a lesser degree, additional flows during storm events were routed to King County's Brightwater and the City of Edmonds wastewater treatment plants. Considerably higher-than-normal rainfall occurred in the service area during the months of February through April (details provided in Section 1.4) while the West Point restoration was underway, which contributed to elevated stormwater flows in the combined system. CSO flows depend on many site-specific characteristics such as background flow in the system, rainfall intensity, and other facility operations. Thus, it is not possible to estimate the additional quantities of CSO discharges during the period of West Point repairs compared to discharges that would have occurred had the plant been fully operational.

Restoration of West Point's primary and secondary treatment processes was completed by the end of April 2017, and after April 27 all wastewater was receiving full secondary treatment. However, the recovery of solids handling processes was still ongoing which resulted in discharge of higher suspended solids than normal. This affected the ability of the plant to consistently meet its National Pollutant Discharge Elimination System (NPDES) permit limits for total suspended solids (TSS), carbonaceous biochemical oxygen demand (CBOD), and residual chlorine through May 9. In addition, from late March through mid-June, the recovery of the solids handling processes was partially managed by conveyance of a portion of the solids produced at West Point to the South Plant for additional treatment. The additional treatment of solids at the South Plant did not affect the ability of the plant to meet its NPDES permit requirements, but did result in an increase (approximately 10%) in South Plant effluent ammonia levels compared to normal. West Point began meeting all NPDES permit limits on May 10, 2017, and has continued to meet permit limits through the writing of this report. The current NPDES permit can be accessed at <http://www.kingcounty.gov/depts/dnrp/wtd/system/npdes.aspx>.

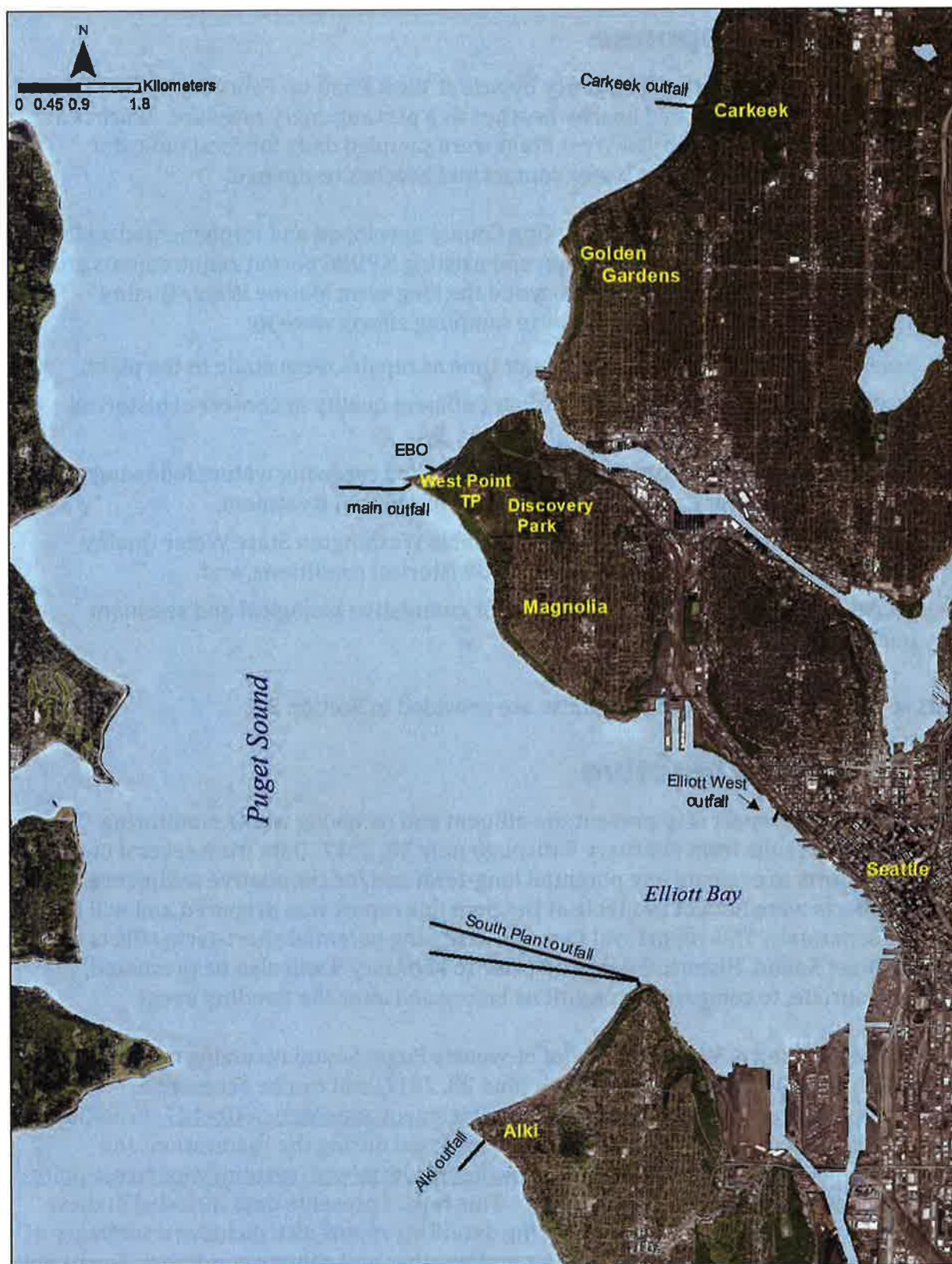


Figure 1. Location of the West Point Wastewater Treatment Plant and other outfalls.

1.2 Initial Response

Less than eight hours after the emergency bypass at West Point on February 9, King County posted warning signs and closed nearby beaches as a precautionary measure. Beaches at multiple locations in the vicinity of West Point were sampled daily for fecal indicator bacteria until levels were safe for water contact and beaches re-opened.

Following the initial sampling response, King County developed and implemented a plan to conduct additional effluent monitoring beyond existing NPDES permit requirements and additional receiving waters monitoring beyond the long-term Marine Water Quality Monitoring Program. The objectives of these sampling efforts were to:

- assess West Point effluent quality over time as repairs were made to the plant,
- evaluate observed changes in West Point effluent quality in context of historical conditions,
- assess potential short-term effects to Puget Sound receiving waters following the untreated discharges and during the period of reduced treatment,
- compare receiving water results to applicable Washington State Water Quality Standards for Marine Surface Waters and historical conditions, and
- assess potential for any long-term and/or cumulative biological and sediment quality effects.

Details regarding the monitoring response are provided in Section 2.0.

1.3 Report Objective

The purpose of this report is to present the effluent and receiving water monitoring approaches and results from February 9 through June 30, 2017. Data from several of the monitoring efforts to evaluate any potential long-term and/or cumulative sediment and biological effects were not yet available at the time this report was prepared and will be presented separately. This report will focus on assessing potential short-term effects in the waters of Puget Sound. Historical data and prior to February 9 will also be presented, where appropriate, to compare to conditions before and after the flooding event.

During the restoration of West Point, brief bi-weekly Puget Sound receiving waters monitoring reports were provided through June 23, 2017, and can be accessed at <http://green2.kingcounty.gov/ScienceLibrary/Document.aspx?ArticleID=427>. In addition, effluent quality and discharge effects were also assessed during the restoration, and updates were posted at <http://kingcounty.gov/depts/dnrp/wtd/system/west/west-point-restoration/environmental-monitoring.aspx>. This report presents data included in these short reports as well as additional monitoring data. This report also includes a summary of Puget Sound receiving water characteristics and weather and climate conditions due to the influence on monitoring results.

1.4 Receiving Water Characteristics

King County's marine sampling area is located within Central Puget Sound, extending south to Dumas Bay and north to Edwards Point. This section describes the general geographic characteristics, circulation patterns, and water residence time for this region. Prior results from tidal current characterization at the West Point outfall are also provided.

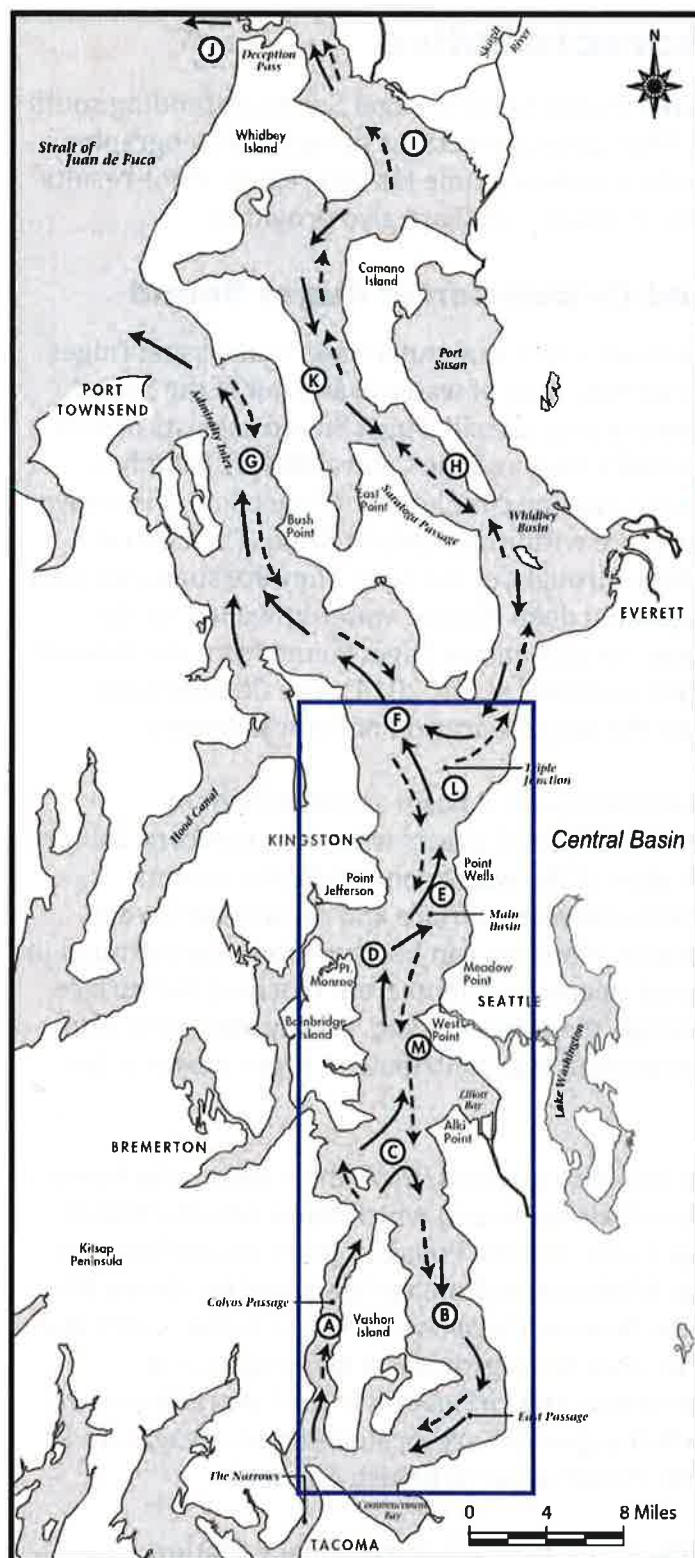
1.4.1 Geographic Features and Circulation of Puget Sound

Puget Sound is a fjord-like estuary that consists of a series of underwater valleys and ridges (basins) and submerged hills (sills). Sills impede the flow of water in and out of the Sound and also generate vertical mixing as water moves over the sill. Puget Sound consists of four major interconnected basins: the Main (Admiralty Inlet and the Central Basin), Whidbey, Southern, and Hood Canal Basins. The general estuarine circulation in Puget Sound is shown in Figure 2. All of King County's marine waters are within the Central Basin. The Central Basin bottom waters have near-oceanic salinity throughout the year. They are supplemented with cold, dense, nutrient-rich and low-oxygenated deep oceanic water upwelled off the Washington coast during the late summer months that enters Puget Sound from the Strait of Juan de Fuca (Geyer and Cannon, 1982; Alford and MacCready, 2014). The Central Basin contains water depths up to 284 meters, with the deepest area off of Point Jefferson.

Freshwater flows influence water circulation in the Central Basin as the amount of freshwater input varies seasonally and interannually, and affects water temperature, salinity, and density, which then determines stratification of the water column. Water column stratification, or strengthening of the separation between surface and deep water layers based on density, impacts biological populations. Plankton can become more concentrated in the surface layer, and stratification can prevent deeper nutrients from reaching the surface and/or limit vertical plankton migration through the water column. Freshwater input into rivers is mainly through rainfall; however, snowmelt also contributes a large source in late spring and early summer.

Main freshwater inputs to the Central Basin include the Green/Duwamish River which enters Elliott Bay, the Cedar River (Lake Washington drainage basin) which flows into the Sound primarily through the Lake Washington Ship Canal, and the Puyallup River which flows into Commencement Bay. Since flows in the Lake Washington drainage basin and the Green River are regulated, snowmelt does not increase the flows in these river systems to the extent that it does in other systems. Additionally, the Puyallup River provides a major source of freshwater into the Central Basin. Water conditions and circulation in the Central Basin are also influenced by rivers with much larger discharges that are located further away, such as the Skagit River in the Whidbey Basin and the Fraser River in British Columbia.

Water circulation is impacted by density differences, river discharge, tidal variation, sustained winds, and bathymetry. Estuarine circulation generally consists of a two-layered flow, with incoming, saltier oceanic water flowing along the bottom and a fresher, less dense water layer flowing out at the surface (Figure 2).



Inflow and Outflow in Puget Sound

Major flow features of the estuarine circulation in the Central Basin of Puget Sound are A) top to bottom northward flow in Colvos, B) top to bottom southward flow in East Passage, C) outflow from Colvos, D) outflow continues north around Bainbridge, D-E) near (D) Point Jefferson shoals deflect outflow eastward (E) where most continues northward passing Point Wells and some moves south, F) upper outflow heads to Admiralty Inlet joined by outflow from Possession Sound, and L) net inflow from Admiralty Inlet diverges with most flowing southward in the Central Basin and a secondary fraction flowing northward through Puget Sound. (Ebbesmeyer and Cannon, 2001).

---> Inflow
—> Outflow

Creation and Production of this
Illustration was a combined effort of
the Wastewater Treatment Division and
the WLR GIS & Visual Communications Unit
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Figure 2. General schematic of Puget Sound circulation (with tides averaged out). The Central Basin is outlined, and shallow (solid arrows) and deep (dashed arrows) flows are shown and described in the figure (Source: Ebbesmeyer and Cannon, 2001).

Salty, cold, and dense waters enter Puget Sound at depth through Admiralty Inlet. A portion flows south in the Central Basin while the other portion flows northeast through Possession Sound to the Whidbey Basin at the triple junction. Water tends to flow faster on the eastern side of the Central Basin near Alki Point and Point Wells and along the western side near Point Monroe and north of Kingston, where major topographic features affect the currents (Ebbesmeyer and Cannon, 2001).

The residence time of water in the Central Basin, or average amount of time a parcel of water spends in the basin, can vary between 9–55 days depending on the depth and time of year, with an estimated annual average of roughly 50 days for deep waters (Babson et. al, 2006; Sutherland et. al, 2011). Spring and early summer stratification can result in longer seasonal residence times, while residence time in the late summer or fall could decrease due to increased exchange flow at the Admiralty Inlet sill, and spatial variability and local mixing processes can strongly influence residence time (Ahmed et. al, 2017). Year to year variability, such as differences in climate oscillations and the timing and volume of freshwater flows, can also impact circulation and thus the residence time.

1.4.2 Tidal Currents at the West Point Outfall

Amplitudes of tidal currents in the Central Basin are about 50 centimeters per second (cm/s) on average. Typical tidal dispersion of the West Point effluent from the main outfall is depicted Figure 3. Estuarine circulation is important for transporting water masses and is typically up to about 10 cm/s but can be higher during storms and bottom saltwater intrusion from Admiralty Inlet (King County, 2009).

Currents were assessed in the vicinity of the West Point outfall for a five-week period beginning in February 2003. The objective was to gather data on water movement in the vicinity of the outfall to determine how the movement of these waters may affect physical properties of sediment around the outfall, as well as effluent transport. Four Acoustic Doppler Current Profilers (ADCPs) were deployed between February and March 2003. ADCPs lie on the seafloor and measure currents throughout the water column using acoustic pulses that bounce off particles suspended in the seawater. The current meters were deployed at multiple depths and locations were chosen to measure both nearshore and deep water currents that may affect effluent transport. Three of the current meters were placed along a transect parallel to the outfall at shallow, moderate, and deep depths (-70, -260, and -760 ft MLLW, respectively). The fourth current meter was placed north of the outfall, in the general direction of the net current flow, at a moderate depth of -295 ft. A five-week deployment period was chosen in order to collect sufficient data to account for tidal variability. Results showed that tidal currents along the parallel transect aligned with the outfall flowed predominantly in the southwest/northeast directions, corresponding to the semi-diurnal tides. In addition, a clockwise eddy can form to the north of West Point during ebb tides, recirculating some water masses (Lincoln, 1976; King County, 2005). Tidal currents at the offshore station west of the outfall flowed in a more north/south direction. Currents at depths of 100-m and greater had a wider distribution of direction and aligned more towards the southwest/northeast than the currents at shallower depths. The 90th percentile current speeds ranged between 30 and 50 centimeters/second (cm/s),

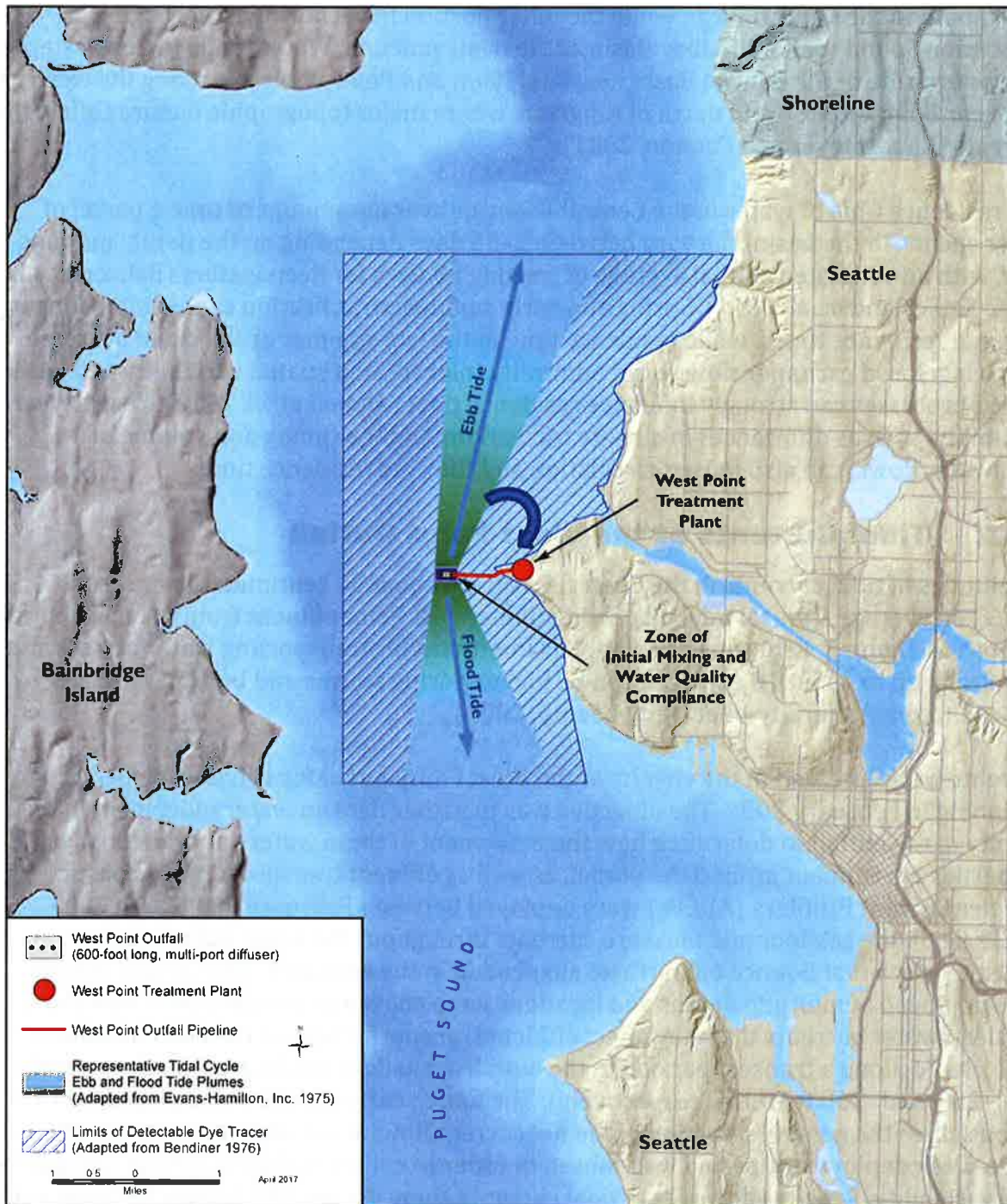


Figure 3. Typical dispersion in the winter and spring of the West Point treatment plant effluent over a tidal cycle. The blue box shows the extent of detectable dye tracer released from the main outfall in prior tracing studies (Bendliner, 1976). A clockwise eddy forming to the north of West Point has been observed in current data during ebb tides as well (Lincoln, 1976; King County, 2005). (Source: King County Dept. of Natural Resources, Wastewater Treatment Division)

including at depths greater than 100-m. Current direction is influenced by the topography of West Point as the shoreline is approached. A detailed description of the methods and results are provided in West Point Treatment Plant Marine Outfall Current Meter Analysis (King County, 2005).

1.5 Weather and Climate Conditions

Weather and climate impact freshwater inputs and marine water column conditions. Weather data are provided in context of historical conditions for better interpretation of water quality monitoring results. Precipitation, air temperature, and river discharge are reported for the first half of 2017.

Overall conditions in the Puget Sound region are summarized below:

- Record-breaking high precipitation occurred in the first half of 2017.
- Cooler than average conditions occurred in the winter of 2016-17, followed by slightly warmer than average conditions in the spring and early summer of 2017.
- Higher than normal river discharge increased the freshwater input into Puget Sound for the first half of 2017, compared to historical conditions.

Monthly precipitation and air temperature data from the Sea-Tac International Airport (station# 24233) were obtained from the National Climatic Data Center (<https://www.ncdc.noaa.gov/cdo-web/>). The historical record dates back to 1948 and are used to represent regional conditions, with an understanding that local patterns can vary on a smaller scale between locations. Daily river discharge charts were obtained from the US Geological Survey that compare 2017 to the historical period of record for two sites: the Green River near Auburn and the Skagit River near Mt. Vernon (<https://waterdata.usgs.gov/wa/nwis/current/?type=flow>).

1.5.1 Precipitation

February 2017 had the second highest total precipitation on record at Sea-Tac International Airport since 1948. Total monthly precipitation is shown compared to the 30-year baseline for the Sea-Tac station (Figure 4). Cumulative precipitation was 28.4" from January through June 2017. This 6-month total exceeded the historical 30-year average by 9 inches for the same period.

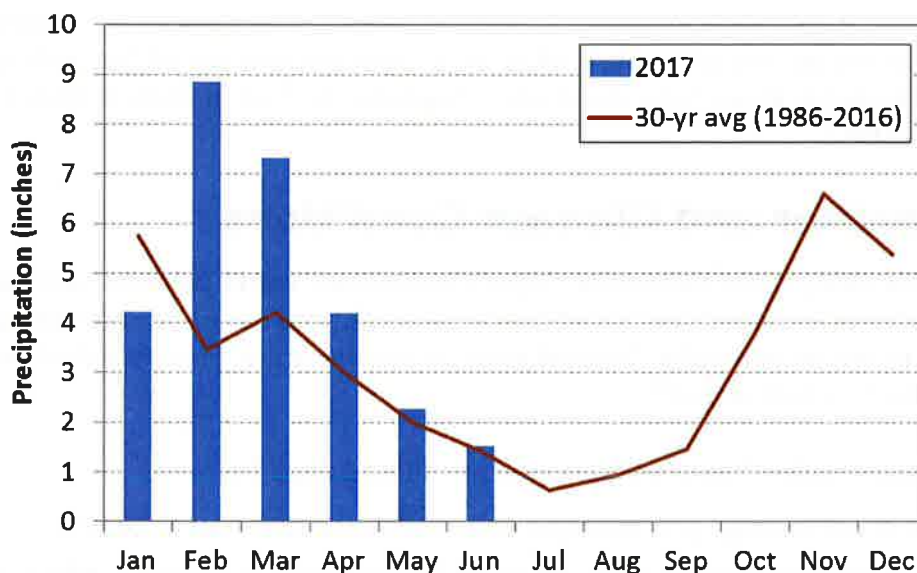


Figure 4. Total monthly precipitation in 2017 compared to 30-year monthly averages at Sea-Tac.

In addition to the heavy precipitation in February, late winter and early spring 2017 were wetter than normal compared to the 30-year baseline (Figure 5). Similar wetter-than-normal conditions occurred in the winter of 2015-16, though the total precipitation was higher in 2017 compared to the same time period. Beginning in mid-summer 2017, conditions became drier than normal with no measurable precipitation in July at the Sea-Tac station.

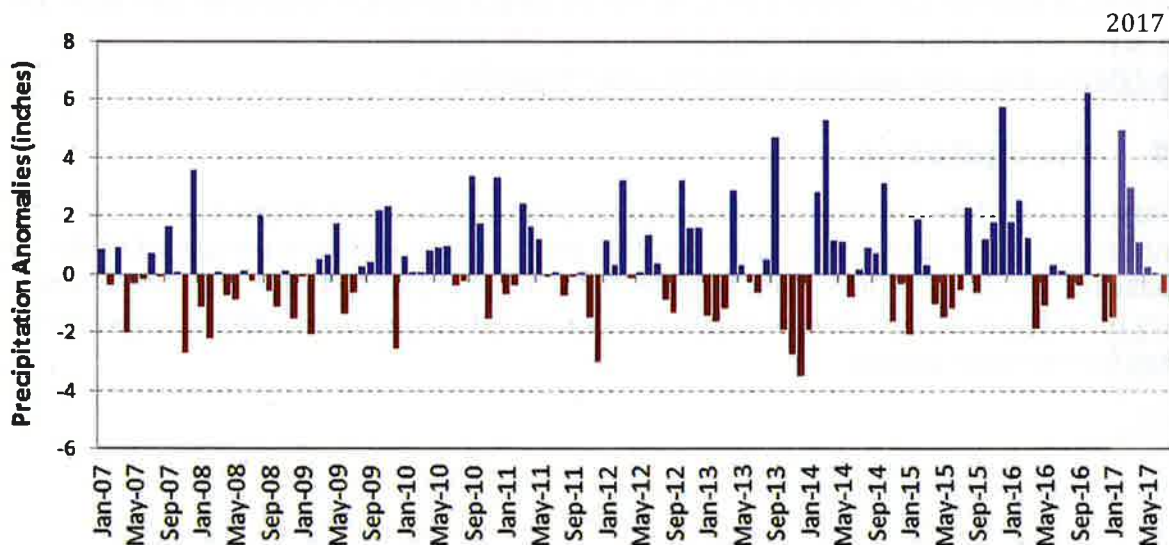


Figure 5. Monthly precipitation anomalies (departure from normal based on 30-year mean) from 2007–early 2017 at Sea-Tac.

1.5.2 Air Temperature

Average monthly air temperatures followed a typical seasonal pattern in 2017. However, the differences between seasons were greater than normal conditions, in terms of the 30-year mean baseline. In early 2017, winter conditions were cooler than normal, followed by a warmer than normal spring and early summer at the Sea-Tac station (Figure 6).

Warmer than normal conditions occurred consistently in recent years, particularly from 2013 through 2016 (Figure 7). Though conditions in spring/summer 2017 were warmer than the 30-year baseline mean, in general, conditions in 2017 were not as high above normal compared to the most recent several years. This pattern follows climate oscillations, such as the El Nino Southern Oscillation (ENSO), where warming and strong stratification of the surface waters in the equatorial Pacific Ocean generally indicate a positive El Nino event. In the winter of 2016-17, conditions were neutral to slightly cooler tending towards a La Nina phase, and developed to slightly warmer ENSO-neutral conditions in the spring of 2017. Atmospheric air temperature patterns in the Puget Sound region often follow a similar pattern to this coupled ocean-atmospheric oscillation. Though other global and local processes impact conditions as well, such as warming due to climate change.

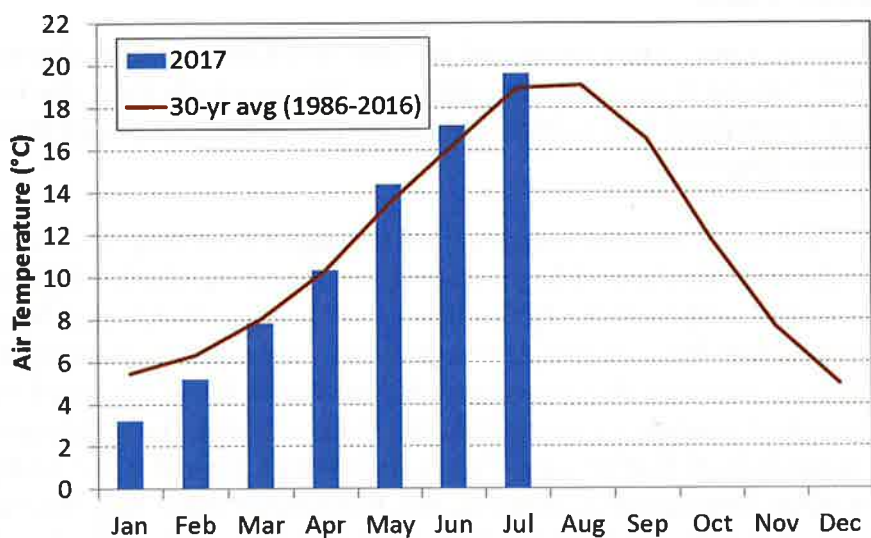


Figure 6. Average monthly air temperature in 2017 compared to 30-year monthly averages at Sea-Tac.

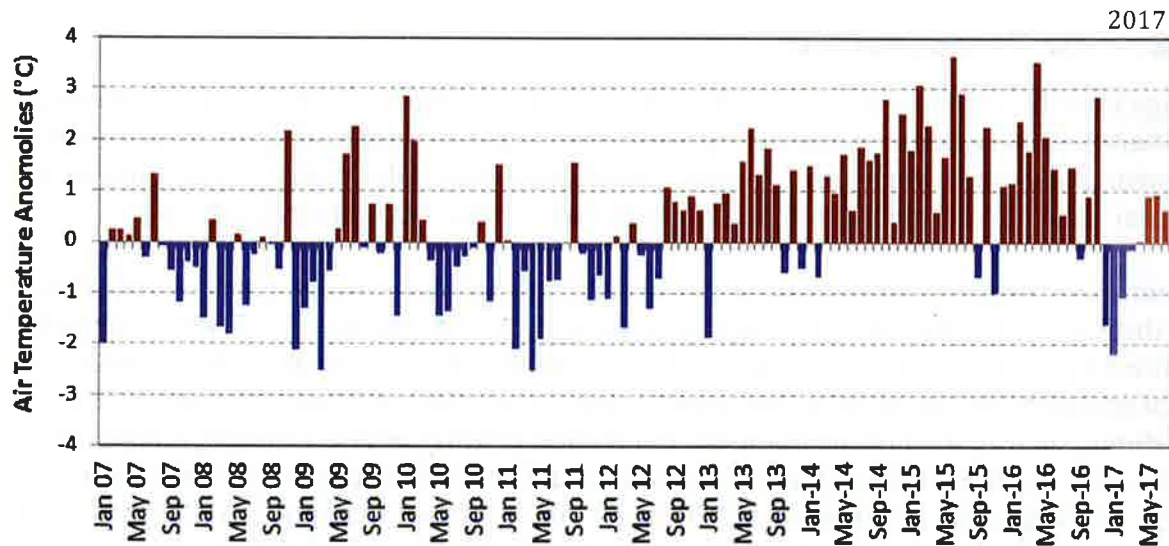


Figure 7. Monthly average air temperature anomalies (departure from normal based on 30-year mean) from 2007–early 2017 at Sea-Tac.

1.5.3 Stream Flow

In general, freshwater inputs from rivers and streams into Central Puget Sound were also high for early 2017, linking to precipitation patterns. Average daily river discharge rates are shown for 2017 compared to historical values for the Green and Skagit Rivers from the US Geological Survey (Figure 8).

The Green/Duwamish River system, which enters through Elliott Bay, is an important source of freshwater into the Central Basin marine waters. In particular, higher than normal flows were observed from the Green River in February, March, and May of 2017. However, due to regulated flows in this drainage basin, natural flow conditions may not be fully reflected, such as increases due to snowmelt. The Skagit River has much larger discharge, and can affect marine waters within the Central Basin. Daily discharges from the Skagit were particularly high beginning in February through June in 2017, compared to the historical daily median flow values. Generally, this freshwater input may increase estuarine exchange and vertical mixing at Admiralty Inlet (Babson et. al, 2006), which will impact Central Puget Sound marine conditions.

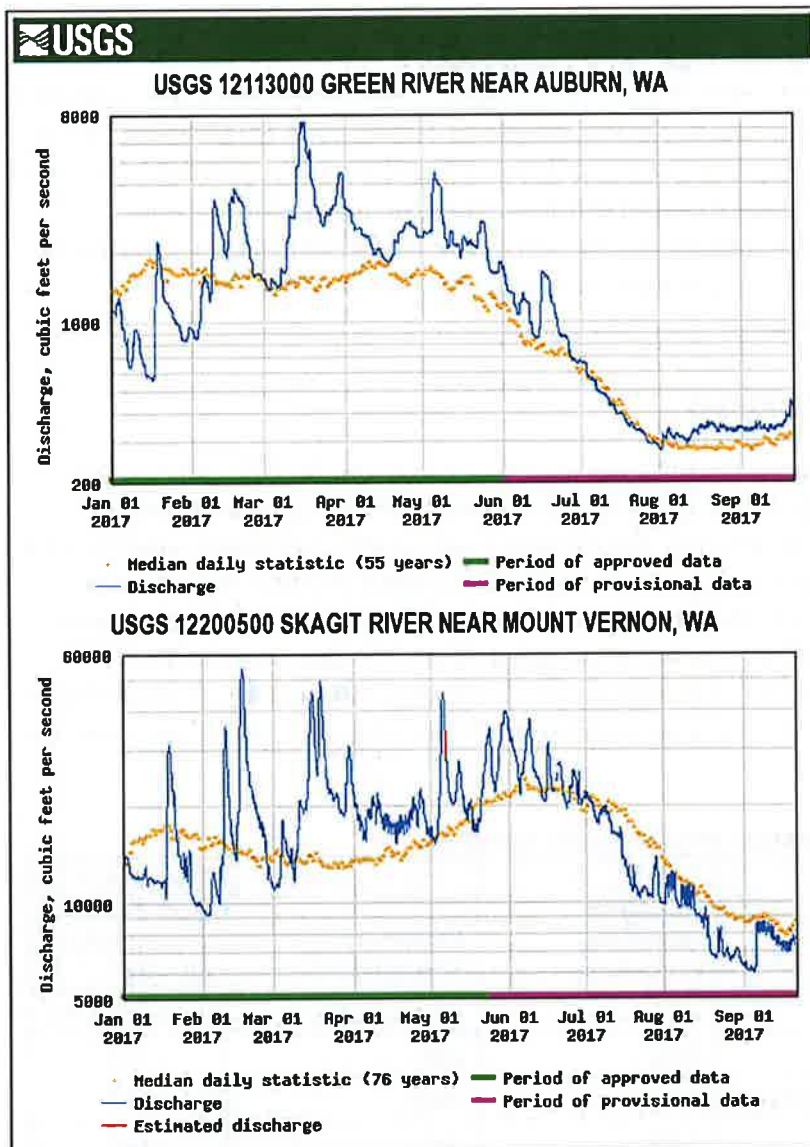


Figure 8. Daily river discharge compared to historical values from the Green/Duwamish (top) and Skagit (bottom) river systems (Source: USGS, 2017).

2.0 MONITORING APPROACH

After the initial discharge event from the West Point EBO on February 9, 2017, King County increased routine monitoring efforts to protect public health and assess potential impacts of discharges of untreated and partially-treated effluent. Monitoring of effluent and receiving waters was conducted throughout the period of the treatment plant's restoration. This section provides a description of the matrices sampled, sampling locations and frequency, and parameters analyzed.

2.1 Effluent Monitoring

King County conducts routine effluent monitoring as required by the NPDES permit for each wastewater treatment facility. For West Point, Table 1 shows the parameters and frequency of monitoring required by permit. King County conducted additional analyses for priority pollutant metals and organic compounds beyond required effluent monitoring while West Point was being restored. Monitoring of priority pollutant metals and organic compounds is required twice per year, but were sampled 12 and 7 times, respectively, between February 9 and June 30, 2017. A summary of all effluent monitoring at West Point is also shown in Table 1. Method references and detection limits for each parameter can be found in Appendix B.

Table 1. West Point effluent parameters and frequency sampled.

Parameter	Required Sampling Frequency	Frequency Sampled	Samples from Feb. 9 through Jun. 30, 2017
Flow	continuous	continuous	not applicable
Total suspended solids	daily	daily	142
Carbonaceous biochemical oxygen demand	daily	daily	142
Residual chlorine	daily	daily	142
pH	daily	daily	142
Fecal coliform bacteria	daily	daily	142
Ammonia	monthly	weekly	18
Nitrate/nitrite	monthly	weekly	18
Total Kjeldahl nitrogen	monthly	weekly	18
Total phosphorus	monthly	weekly	18
Soluble reactive phosphorus	monthly	weekly	18
Priority pollutant metals	2/year	2/year	12*
Priority pollutant organics	2/year	2/year	7*
Acute toxicity tests	2/permit cycle	2/permit cycle	1
Chronic toxicity tests	2/permit cycle	2/permit cycle	1

*Additional samples were analyzed until all permit limits were met.

2.2 Initial Beach Monitoring Following Event

King County monitored high-use public beaches for fecal indicator bacteria (both fecal coliforms and *Enterococcus*) at four beaches in the vicinity of the EBO within hours after the February 9 flooding and overflow event (Figure 9). Three locations at each beach were sampled at Carkeek Park, Golden Gardens, and each of the two West Point beaches. At West Point, three sites were sampled on the north side of the point and three on the south side. All four beaches are typically monitored monthly as part of King County's routine water quality monitoring program. Samples were collected from the four beaches for 13 consecutive days, with the exception of February 14 at Carkeek Park and Golden Gardens. Sampling ended on February 21 because bacteria levels demonstrated a return to typical values after several days.

Bacteria concentrations in the water column are important indicators of potential human health risks. Although not typically harmful on their own, indicator bacteria such as fecal coliforms and *Enterococcus* are frequently sampled because they are relatively easy to monitor, and can be associated with viruses and other harmful pathogens that often occur in lower concentrations and are more difficult to detect. Both fecal coliforms and *Enterococcus* are found in the intestinal tracts and feces of warm blooded animals and humans. They can enter the aquatic environment directly from humans, and animals, from agricultural and stormwater runoff, and from wastewater. High concentrations of fecal indicator bacteria can indicate a greater potential for the presence of harmful pathogens.

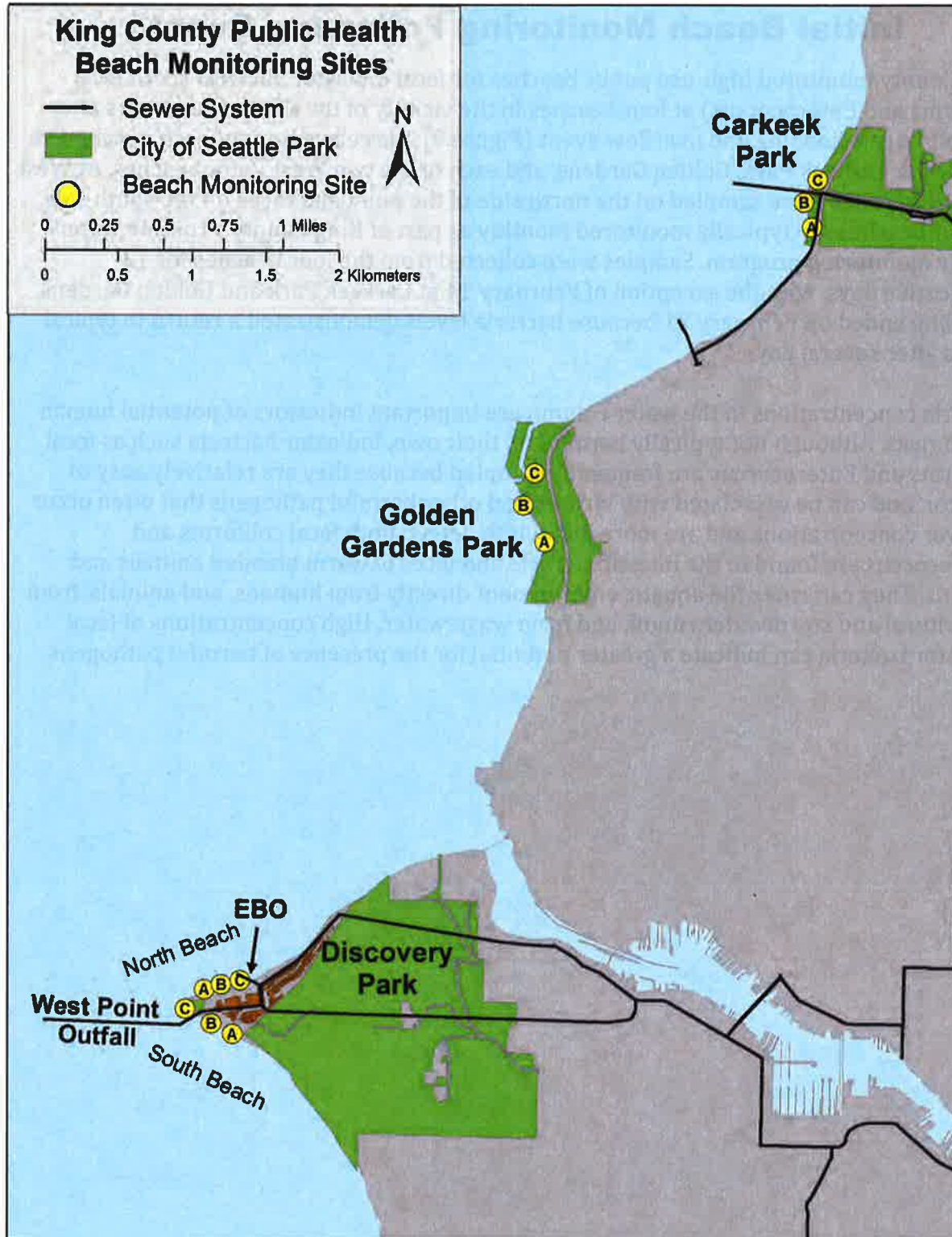


Figure 9. Location of bacteria sampling stations immediately following the flooding event.

2.3 Receiving Water Monitoring

King County monitors marine water quality at a total of 38 routine stations in the Central Basin of Puget Sound. The routine monitoring program includes 12 offshore sites (an additional two shoreline stations in Quartermaster Harbor and four in the Duwamish River estuary) and 20 beach locations (Figure 11, see 2017 annual work plan [[King County 2016a](#)]). This monitoring is part of a long-term program that helps provide an understanding of water quality within the Puget Sound Central Basin. Eight of the offshore locations are at or near treatment plant or combined sewer overflow (CSO) outfall discharge points and 10 of the beach stations are shoreward of a treatment plant or CSO outfall.

Offshore locations are typically sampled every two weeks (bi-monthly). During these monitoring events, temperature, salinity, density (calculated), dissolved oxygen, fluorescence (chlorophyll), photosynthetically active radiation (PAR) and light transmission are measured throughout the water column from surface to bottom and reported at 0.5-m intervals. These data are collected in real-time using a CTD (Conductivity, Temperature, and Depth) profiling instrument (King County, 2014). Additionally, water samples are collected at specific depths for each station and analyzed in the laboratory for nutrients (ammonia, nitrate + nitrite, silica, and orthophosphate), fecal indicator bacteria (fecal coliform and *Enterococcus*), total suspended solids, chlorophyll-a, and phytoplankton and zooplankton composition. Method references and detection limits for each parameter can be found in Appendix B. Dependent upon the depth of the station, water is collected from up to seven depths for these parameters.

At beach locations, water temperature, salinity, nutrients (ammonia, nitrate + nitrite, and orthophosphate), fecal indicator bacteria (fecal coliform and *Enterococcus*) are measured in waters approximately knee depth on a monthly basis.

During the West Point restoration period, monitoring of Puget Sound waters was expanded beyond the existing efforts described above to assess changes in water quality as described in the study's objectives (Section 1.2). Additional monitoring included:

- increasing the sampling frequency to weekly at a subset of four offshore long-term monitoring stations based upon their proximity to the West Point outfall and availability of historical data,
- adding a new offshore monitoring location near the emergency bypass outfall (EBO) and conducting weekly monitoring,
- increasing the bacteria sampling frequency to weekly at a subset of six beach locations based upon their proximity to the West Point outfall and availability of historical data,
- expanding nitrate sampling throughout the water column at all offshore stations using a Submersible Ultraviolet Nitrate Analyzer (SUNA), and
- measuring trace metals concentrations in the water column at four locations (see Section 4.4).

Weekly sampling of the five offshore stations (including the EBO) began on March 6, 2017 and continued through June 9, 2017 (Figure 12). After June 9 the sampling frequency at all the long-term stations returned to a bimonthly basis and sampling at the EBO ended. Weekly bacteria sampling at the subset of six beach stations began on April 10 and continued through June 9 (see Figure 12), after which time the sampling frequency returned to a monthly basis. Nitrate sampling throughout the water column at offshore stations began on April 11 using a Submersible Ultraviolet Nitrate Analyzer (SUNA) on loan from the Department of Ecology. Nitrate water column profiling is continuing as a new component of King County's Marine Monitoring Program as a SUNA was obtained as part of this monitoring effort. Trace metals were sampled at four locations with historical data to compare recent conditions: KSSK02 (West Point outfall), LSEP01 (South Plant outfall), KSBP01 (Pt. Jefferson), and LSNT01 (off Pt. Williams). Metals samples were collected at multiple depths at each location on April 27 at the end of the period of reduced effluent treatment and again on June 6 when effluent was receiving full secondary treatment. Summary tables of parameters sampled, sampling frequency, and location coordinates for each station are detailed in Appendix A. Figure 12 shows the station locations where monitoring frequency was increased for this effort. A timeline for the various sampling activities for effluent and receiving waters from the time of the flooding event until the end of June is provided in Figure 10. The monitoring activities shown in green are provided in context with the restoration timeframe of the plant (shown in light orange).

This monitoring program and dataset form the basis from which water quality conditions are assessed in this report.

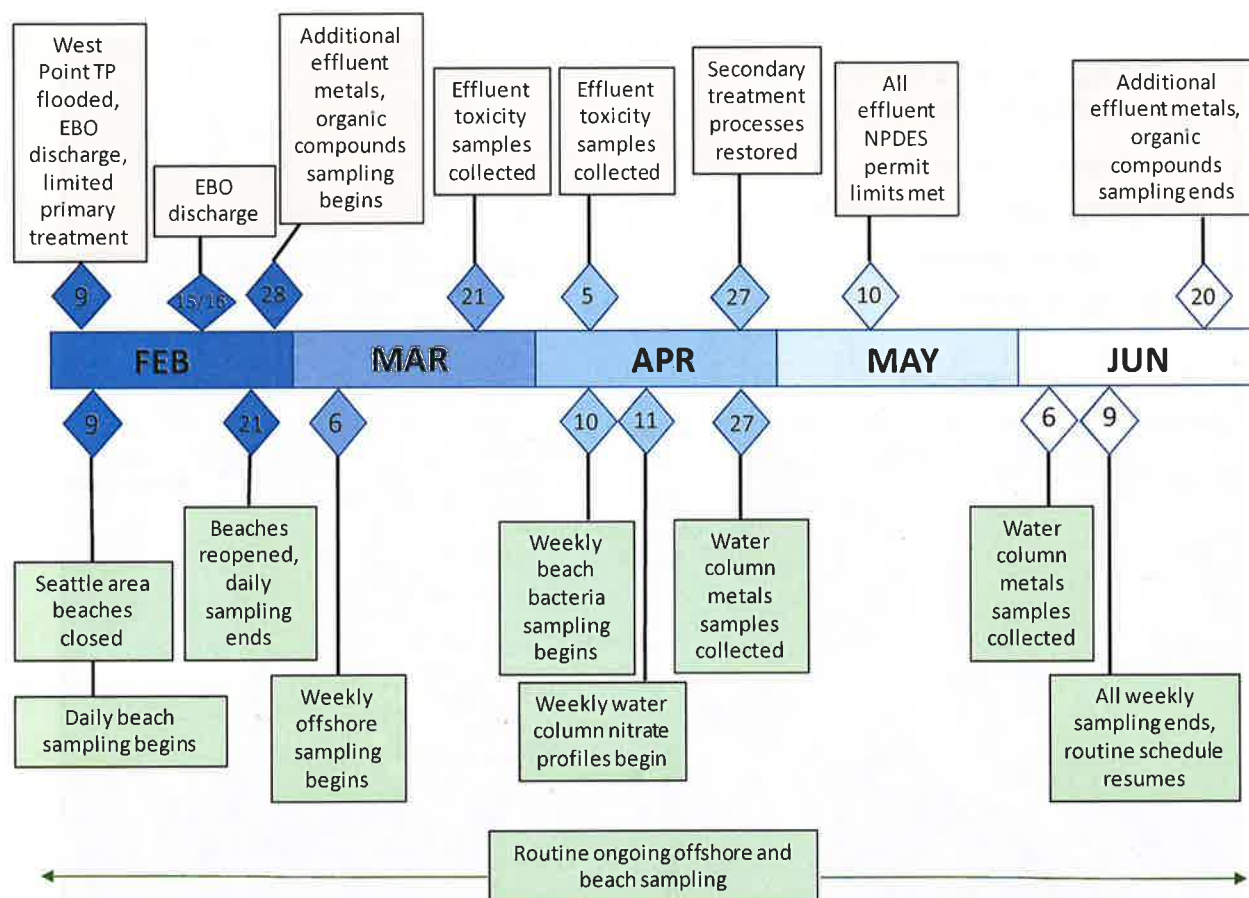


Figure 10. Generalized timeline of West Point events (light orange) and monitoring activities in receiving waters (green). The number in the diamond shape indicates the day of the month.

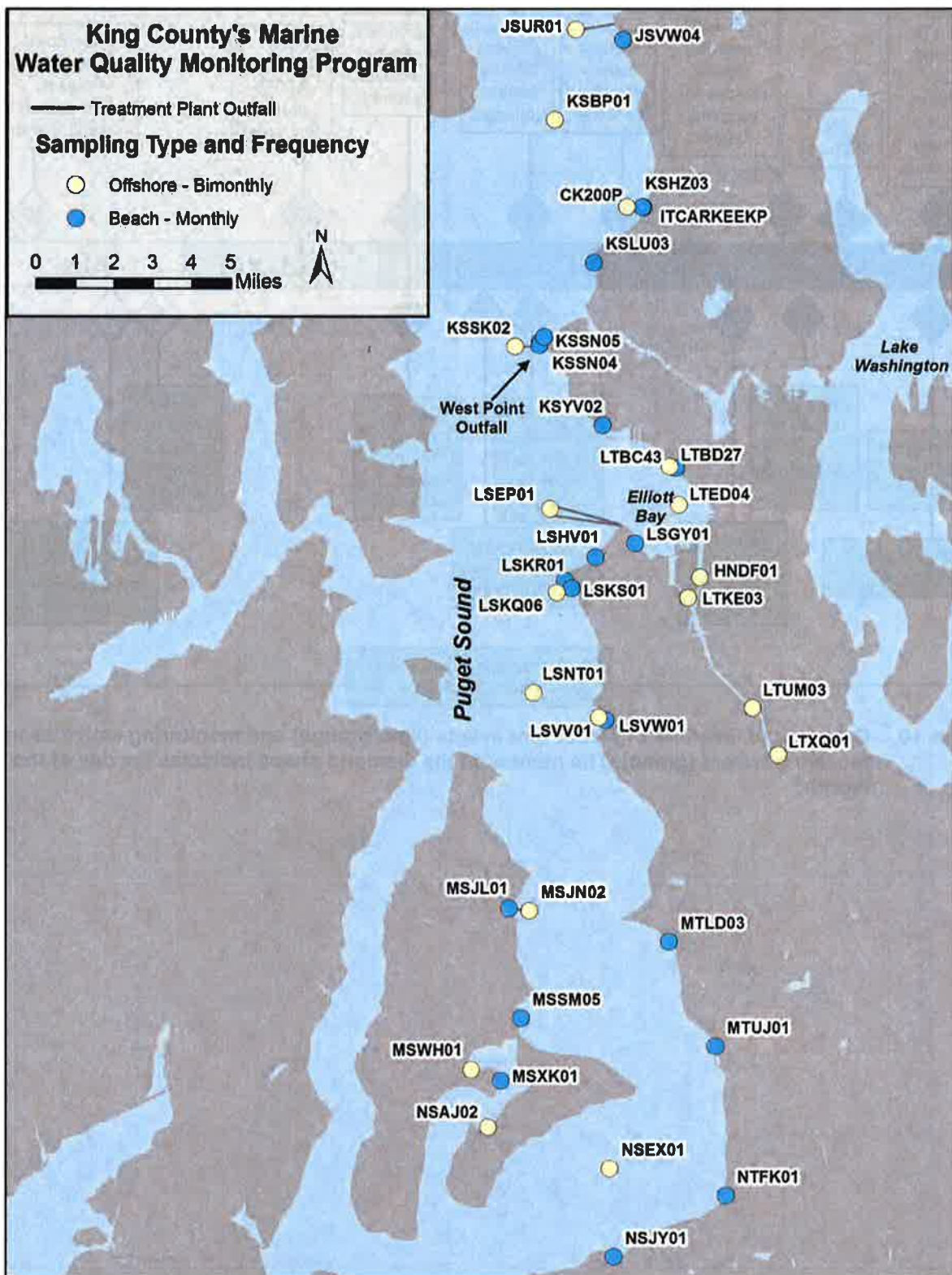


Figure 11. Location of routinely-monitored offshore and beach sampling stations.

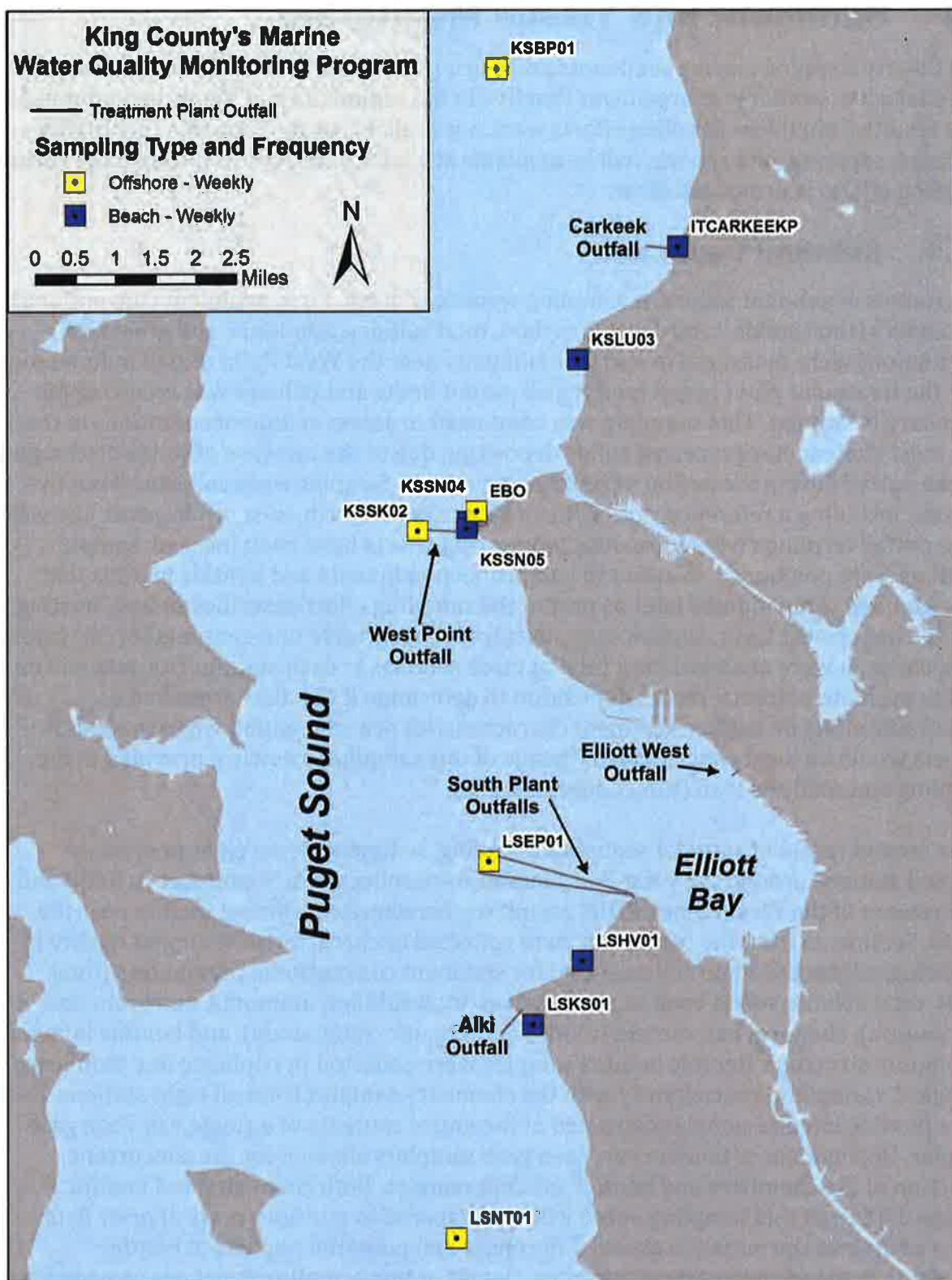


Figure 12. Location of offshore and beach sampling stations sampled weekly during West Point restoration.

2.4 Sediment and Tissue Monitoring

King County sampled marine sediments and organism tissues near West Point to identify potential adverse effects to organisms that live in the sediments and the water column. As most results from these sampling efforts were not available at the time this report was prepared, separate data reports will be available at a later date. A description of the various sampling efforts is provided below.

2.4.1 Subtidal Sediment

Two rounds of subtidal sediment sampling were conducted. First, sediment conventional parameters (total solids, total organic carbon, total sulfides, ammonia, and grain size distribution) were measured in surface sediments near the West Point outfall in June, soon after the treatment plant began meeting all permit limits and effluent was receiving full secondary treatment. This sampling was conducted to assess sediment conditions in the area most likely to have received solids deposition due to the increase of solids discharged out the outfall during the period of reduced treatment. Samples were collected from five stations, including a reference station, in an approximate north-to-south transect just west of the outfall terminus where previous monitoring efforts have been focused. Sample locations were positioned so as not to compromise sediments and benthic infauna that were sampled three months later as part of the sampling effort described below. Starting with the uppermost layer, surface sediments from consecutive one-centimeter (cm) layers, three-cm deep were analyzed for a total of three samples at each station. The data will be used to evaluate potential recent deposition to determine if the discharges had a measurable effect on surface sediment characteristics near the outfall where potential impacts would be most concentrated. Details of this sampling event are provided in the Sampling and Analysis Plan (King County, 2017a).

In the second round of subtidal sediment sampling, sediments from eight previously sampled stations around the West Point outfall were collected in September to fulfill one requirement of the West Point NPDES permit to characterize sediment quality near the outfall. Sediments from the top 10-cm were collected to characterize sediment quality in the biologically active zone and analyzed for sediment conventional parameters (total solids, total volatile solids, total organic carbon, total sulfides, ammonia, and grain size distribution), chemical parameters (metals and organic compounds), and benthic infauna community structure. Benthic infauna samples were collected in triplicate due to inherent biological variability, concurrently with the chemistry samples from all eight stations. Each of the benthic infauna samples consisted of the entire contents of a single van Veen grab sampler. Deployment of tandem van Veen grab samplers allowed for the concurrent collection of the chemistry and benthic infauna samples. Both chemistry and benthic infauna data from this sampling event will be compared to multiple years of prior data collected around the outfall to assess differences and potential impacts to benthic organisms in the vicinity of the discharges. Details of this sampling event are provided in the Sampling and Analysis Plan (King County, 2017b).

2.4.2 Intertidal Sediment

Intertidal (beach) sediments were sampled at six beaches in late August 2017. Samples were collected at sites with historical data collected in August in order to compare results. Intertidal sediment quality data have been collected since 1988 and sites are currently sampled every five years with the most recent data having been collected in August of 2015 (King County, 2015). For this sampling effort, intertidal sediments were collected from six locations with historical data: the north (KSSN04) and south (KSSN05) side of the West Point, Carkeek Park (KSHZ03), Golden Gardens (KSLU03), Magnolia (KSYV02), and Alki (LSKS01). Intertidal sediment samples were analyzed for conventional parameters (total solids and grain size distribution), and metals. Intertidal sediment samples were collected from the top five-cm to evaluate chemical concentrations in the most recently deposited material of the biologically active zone. Samples were collected from the +6.5 foot mean lower low water tide height. Details of this sampling event are provided in the Sampling and Analysis Plan (King County, 2017c).

2.4.3 Butter Clams

Butter clam (*Saxidomus gigantea*) tissues were sampled concurrently with the intertidal sediment samples at five of the six locations. King County previously measured chemical concentrations in butter clam tissues at these locations between 1996 and 2010. Metals and organic compounds (semivolatiles, pesticides, and polychlorinated biphenyls) in butter clams were analyzed from 1996 until 2006, after which time the organic chemicals were discontinued due to lack of detection. In 2008, PBDEs were added to the program and analyzed along with metals until the program ended in late 2010. Butter clams were collected annually in August until 2006, after which time clams were collected in both March and August to assess variability between wet and dry seasons. For the 2017 sampling effort, butter clams were collected from five locations with historical data: the north (KSSN04) and south (KSSN05) side of the West Point, Carkeek Park (KSHZ03), Golden Gardens (KSLU03), and Alki (LSKS01). Clams were not collected at the Magnolia site along with intertidal sediments as few clams are present at this location due to lack of suitable substrate. Five to 10 butter clams with a shell length between 60 to 120 millimeters were collected at each station and composited into a single sample for analysis of total solids, total lipids, and metals. Details of this sampling event are provided in the Sampling and Analysis Plan (King County, 2017c).

2.4.4 Dungeness Crab

Dungeness crab (*Metacarcinus magister*) were collected to assess if there were substantive increases in tissue concentrations of metals and organic compounds when compared to crab tissue data collected by Washington Department of Fish and Wildlife (WDFW) (Carey et al., 2014) and King County (King County, 2016a) in 2014 and 2016, respectively. This sampling is a collaborative effort between King County and WDFW. Historical Dungeness crab tissue data are not available in the immediate vicinity of West Point; therefore, King County sampled two locations north and south of the Shilshole Marina where crabs were previously sampled in 2014. Crabs were collected using pots in May and September 2017 from water depths of approximately 15-18-m. Fifteen male Dungeness crabs of legal

harvest size were collected from each location in May and composited into five muscle tissues samples (three crabs per sample) and three hepatopancreas tissue composite samples (five crabs per sample). All samples were analyzed for polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs), metals, and well as conventional parameters (total solids and lipids). Crab muscle tissue was also analyzed for nitrogen and carbon stable isotopes. Stable nitrogen isotopic signatures supply information about the trophic position and diet of consumers (Peterson and Fry 1987; Fry 1988; Peterson et al. 1985). Stable carbon isotopic signatures are useful for distinguishing among food webs based on different types of primary producers or the location in which consumers feed along a salinity gradient (e.g., Stewart et al. 2004; France 1995). Details of this sampling event are provided in the Sampling and Analysis Plan (King County, 2017d). Dungeness crabs were also collected by WDFW near Myrtle Edwards Park in Elliott Bay and by King County on behalf of WDFW in Smith Cove in Elliott Bay. Two crab tissue composite samples, consisting of three crabs per sample, from Myrtle Edwards and one composite sample, also consisting of three crabs, from Smith Cove were analyzed for the same parameters listed above.

2.4.5 Zooplankton

Zooplankton were sampled for chemical analyses as they are relatively short-lived organisms with many having life cycles or planktonic stages that are typically on the order of several weeks to months. Because they are short lived, zooplankton are more likely to reflect contaminant exposure on relevant time-scales to the West Point flooding event relative to higher trophic organisms such as fish. Zooplankton tissues were collected in May and again in August 2017 after full secondary treatment processes were restored to assess chemical concentrations. Zooplankton were collected by oblique tows in the upper 30-m of the water column with two 60 cm diameter nets mounted side-by-side on a frame (a “bongo” net). The nets have a mesh size of 335 µm and the most common taxonomic groups represented in this size range include: crustaceans, euphausiids, cnidarians, ctenophores, mollusks, amphipods, and fish. Zooplankton from two locations in the Central Basin, Pt. Jefferson (KSBP01) and off Pt. Williams (LSNT01) were collected as these two sites are also routinely sampled for quantitative taxonomic analysis of zooplankton. Samples were analyzed for PCBs, PBDEs, metals, total solids, total lipids, and carbon and nitrogen stable isotopes. There are no existing comparable zooplankton contaminant data; therefore, general comparisons to WDFW krill (type of crustacean) data will be made where appropriate. WDFW sampled krill at two locations in the Central Basin (Port Madison and Elliott Bay) in 2009 (West et al. 2011). Details of this sampling event are provided in the Sampling and Analysis Plan (King County, 2017e).

2.4.6 English Sole

King County is collaborating with WDFW on the analysis of English sole tissues. English sole were collected by WDFW using bottom trawl nets from two sampling locations (north and south) of the West Point outfall and from one sampling location off Myrtle Edwards Park in Elliott Bay. Historical chemistry data are available for comparison to the Myrtle Edwards Park location but not the West Point locations. The West Point data will be

compared to data collected from other Puget Sound locations as part of WDFW's biannual marine toxics monitoring conducted for the Puget Sound Ecosystem Monitoring Program. English sole tissues were collected in May 2017. From each location, six composite samples of English sole fillet tissue will be analyzed by King County for PCBs, PBDEs, organochlorine pesticides, metals, lipids and carbon and nitrogen stable isotopes. English sole bile tissue samples will be analyzed for the biomarkers vitellogenin, steroidal hormones, and PAH metabolites (bile analysis will be conducted by NOAA).

3.0 EFFLUENT MONITORING RESULTS

This section presents the results of West Point effluent monitoring. In addition to the discharge flow rate, samples were analyzed for total suspended solids (TSS), bacteria, nutrients, carbonaceous biochemical oxygen demand (CBOD), pH, residual chlorine, metals, and organic pollutants. The effluent toxicity was also evaluated with acute and chronic Whole Effluent Toxicity (WET) tests. The West Point NPDES permit has effluent limits for the maximum concentration of TSS, CBOD, fecal coliform bacteria, pH, and total residual chlorine.

The mass loading rate is presented for TSS, CBOD, nutrients, and metals. Organic compounds were detected too infrequently to calculate an estimate of the mass loading rate. The change in loading rates during the period of reduced treatment capacity is relative to historic loading rates and total loading estimates to Puget Sound. In addition, the NPDES permit specifies maximum weekly and monthly loading rates for TSS and CBOD. The relative increase in the loading rates provides context for the magnitude of change expected to be observed in Puget Sound.

3.1 Effluent Discharge

The total daily average West Point effluent discharge during January through June 2017, which includes the emergency bypass flows that occurred on February 9 and 15/16, is shown in Figure 13. Average daily effluent discharge fluctuated considerably during the extremely wet period from mid-January through mid-April. The daily discharge is shown for three distinct time intervals: prior to the flooding event, during the flooding event and period of reduced treatment and restoration (February 9 to May 9), and after the plant fully met effluent limitations (May 10). Prior to the flooding event early on February 9, instantaneous incoming flows to the system were at the maximum wet-weather design capacity of the plant (440 MGD) when the equipment failure occurred.

The monthly average West Point effluent discharge rates from the main outfall for the period while the restoration process was underway is shown in Figure 14. Average and maximum monthly flows from 2007 through 2016 are also shown for comparison. Even with limiting peak inflows to West Point and conveyance of excess storm event flows to other locations in the system, the amount of West Point effluent discharged remained consistently higher during February through April compared to average flows over the last decade.

During the initial period of reduced treatment at West Point, some of the excess system wastewater flow was diverted to three CSO treatment facilities: Alki, Carkeek, and Elliott West. Figure 15 shows the cumulative monthly volume of flow treated at these CSO treatment facilities during the first half of 2017. Average cumulative monthly discharge for the previous six years at these facilities is also shown for comparison. The Elliott West CSO facility treated the most flow compared to other CSO facilities and treated substantially higher flows than prior years. The Alki and Carkeek facilities also treated and discharged

considerably more flow than typical. During the restoration period, the CSO treatment facilities operated similarly to prior years with most discharges occurring in February and March. No discharge events occurred after April for the Alki and Carkeek facilities and after May at the Elliott West facility.

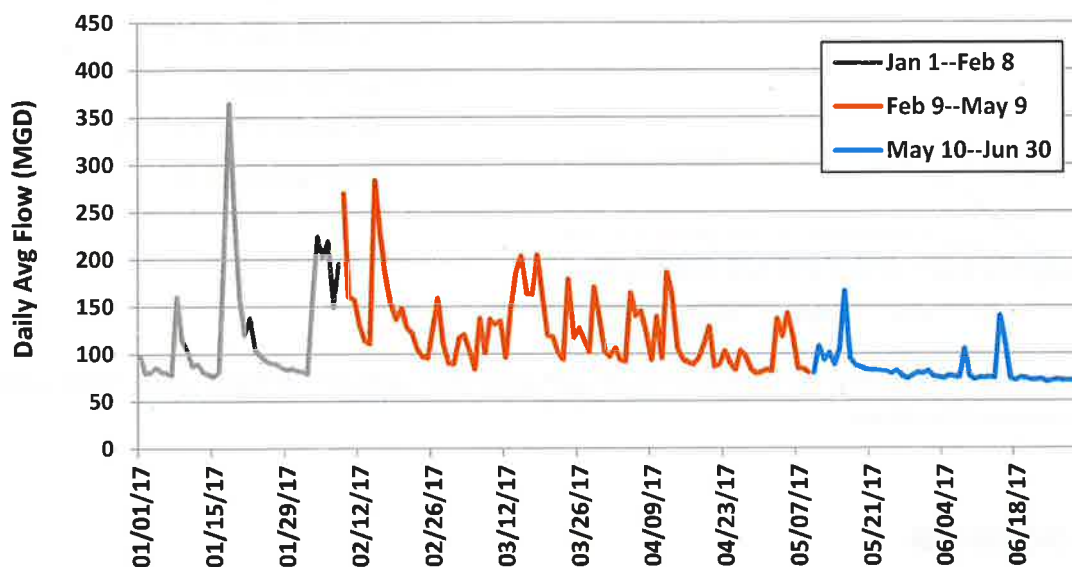


Figure 13. Daily average West Point effluent discharge (includes EBO discharge).

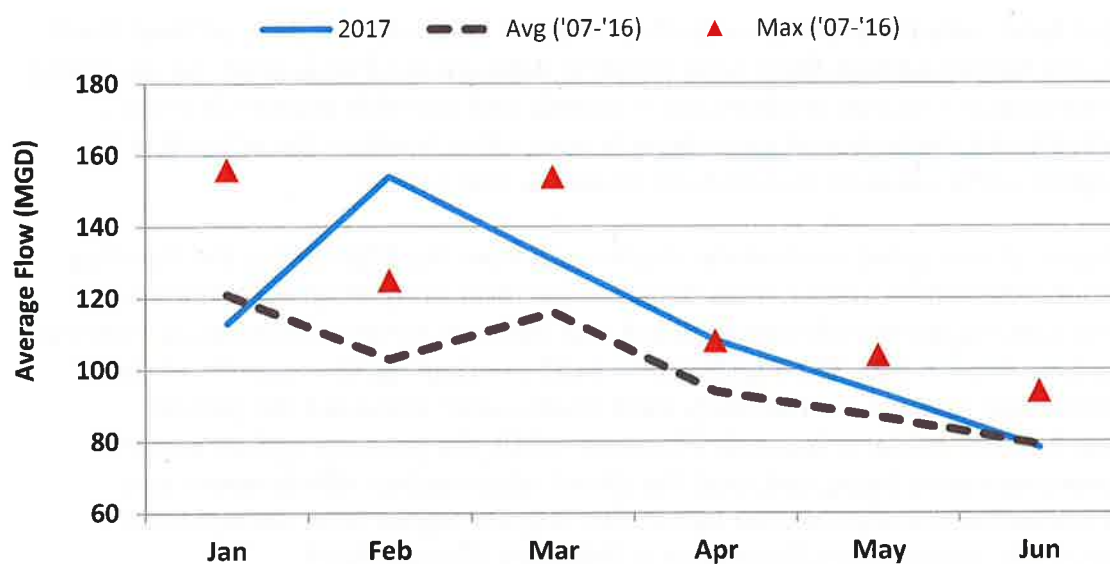


Figure 14. Average monthly West Point effluent discharge.

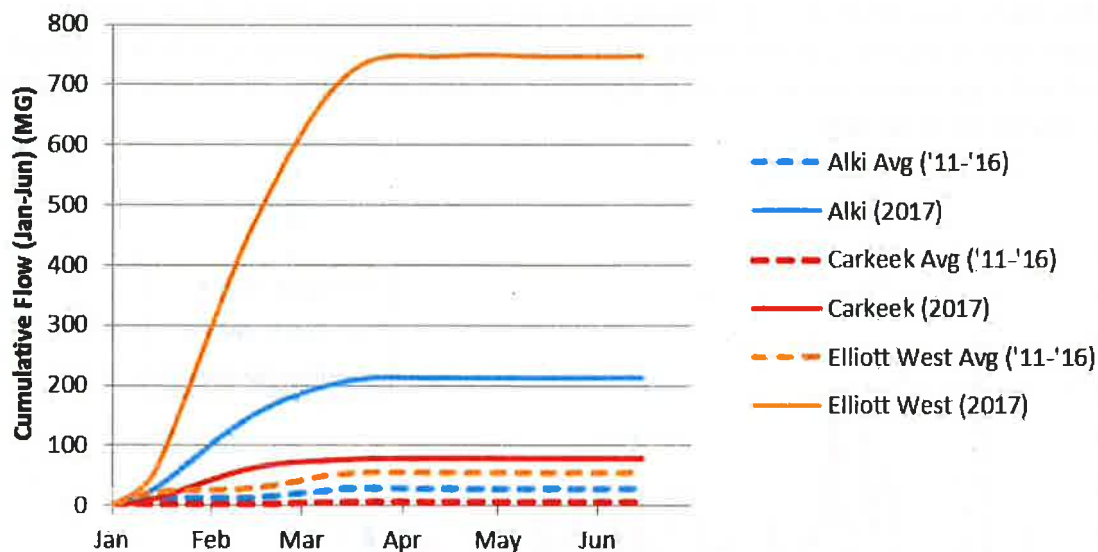


Figure 15. Cumulative monthly discharge (million gallons) from January through June from CSO treatment facilities.

3.2 Bacteria

Untreated municipal wastewater (and stormwater that contributes to elevated flows during wet weather events) is known to contain a variety of potential human pathogens (e.g., viruses, bacteria, and protozoa). These pathogens are primarily a concern with activities such as shellfish consumption and swimming in water bodies where the wastewater is discharged.

Monitoring of fecal coliform bacteria in the final effluent is conducted daily at West Point according to the NPDES permit. Daily fecal coliform data are used by Ecology for assessing regulatory compliance through comparison to weekly and monthly geometric mean effluent permit limits. Reduction of pathogens to acceptable levels in the effluent is the primary purpose of the chlorine disinfection system at West Point.

Effluent samples of untreated wastewater discharged from the EBO during the flooding event were not collected. However, fecal indicator bacteria samples (fecal coliform and *Enterococcus* bacteria) were collected in beach and offshore waters immediately following these events (see Section 2.2). The flooding event did not damage the capacity of the chlorine disinfection process to effectively treat wastewater and meet the permit requirements for fecal coliform bacteria. However, while the primary and secondary treatment processes were being restored, the disinfection system effectiveness was variable. As a result of this disinfection variability, slightly higher than normal fecal coliform bacteria levels occurred in effluent in February through April.

The time series of daily fecal coliform concentrations measured in West Point effluent in 2017 is shown in Figure 16 and indicates that the range of values was considerably higher

than normal following the flooding event. Figure 17 shows that in March, in particular, the geometric mean fecal coliform concentration of >100 most probable number (MPN)/100 milliliters (mL) was considerably elevated compared to typical values of 1-4 MPN/100 mL (2011–2016). At no time during the period of repairs did West Point effluent exceed the applicable permit limits which consist of a weekly geometric mean limit of 400 MPN/100 mL and monthly geometric mean of 200 MPN/100 mL. Fecal coliform bacteria concentrations returned to normal in May and June once treatment processes were restored.

The additional flows treated at the Elliott West, Alki, and Carkeek CSO treatment facilities were disinfected, and with the exception of a disinfection failure at Elliott West that occurred over an approximate five-hour period on March 4, operated normally while repairs to West Point were ongoing. The EBO bypass and additional untreated CSO flows that occurred at outfalls most likely contributed to significantly higher than normal bacterial concentrations in the Duwamish estuary and Elliott Bay.

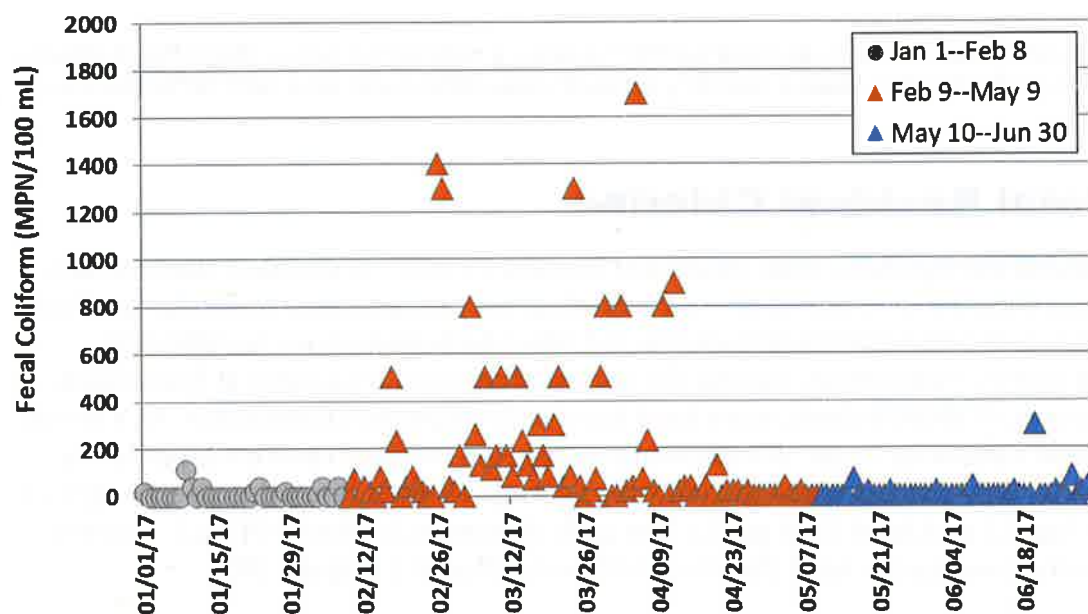


Figure 16. 2017 Daily fecal coliform bacteria values in West Point effluent.

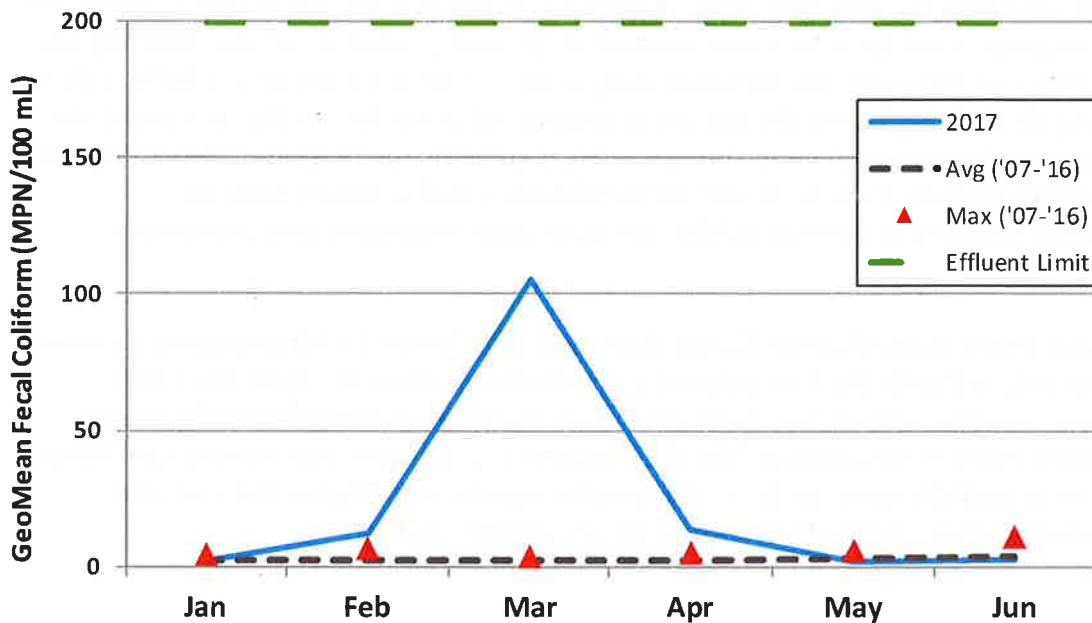


Figure 17. Monthly geometric mean fecal coliform bacteria concentrations in West Point effluent. Green dashed line shows monthly effluent geometric mean limit (200 MPN/100 mL).

3.3 Total Residual Chlorine

Chlorine is added during the normal treatment process in order to disinfect wastewater, and any excess chlorine is removed in the dechlorination process prior to discharge. These final steps ensure the elimination of bacteria and other pathogens prior to releasing effluent back to the environment. During the period of reduced treatment at West Point, higher than normal chlorine doses were used to provide adequate disinfection. As a result of the increased variability in the disinfection process, the residual chlorine levels were occasionally elevated and exceeded the monthly average effluent limitation of 139 $\mu\text{g/L}$ in March (139.3 $\mu\text{g/L}$) and April (148 $\mu\text{g/L}$). The daily maximum limit of 364 $\mu\text{g/L}$ was also exceeded during two days in April (levels of 630 and 420 $\mu\text{g/L}$) (Figure 18).

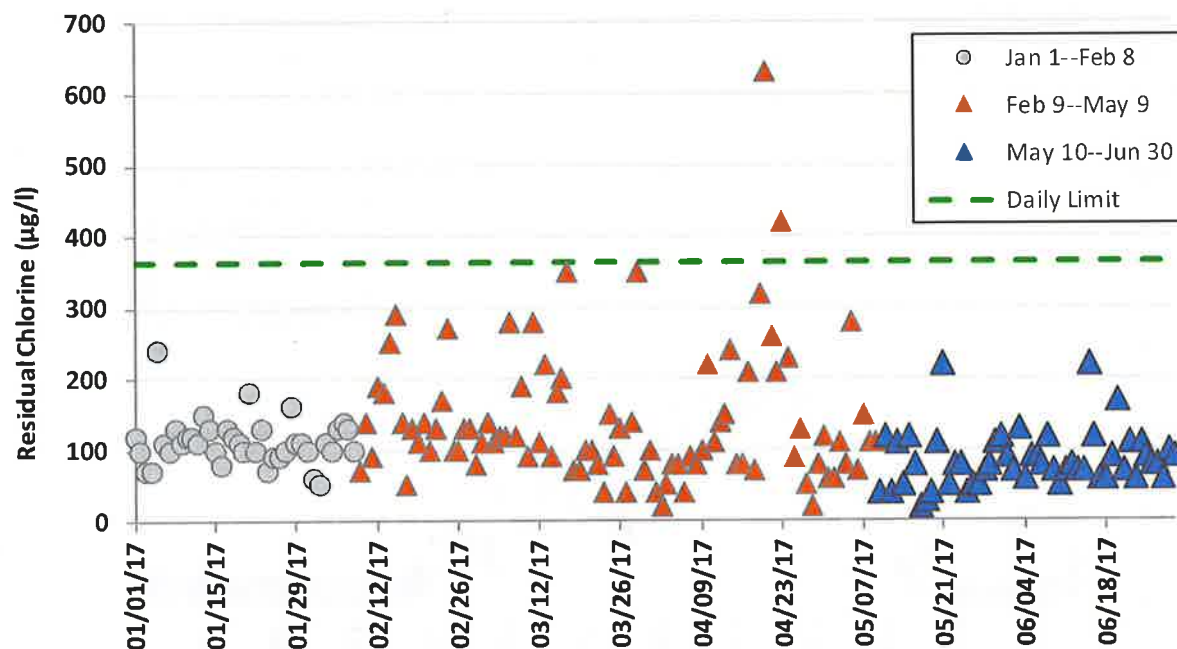


Figure 18. 2017 Daily average residual chlorine concentration in West Point effluent. Green dashed line shows daily average effluent limit (364 µg/L).

3.4 Total Suspended Solids

Total suspended solids (TSS) is an important physical parameter used to monitor the performance of the West Point wastewater treatment processes in degrading organic matter and settling (removing) solids (i.e., sediment, particulate matter). The average concentration of TSS in the effluent is measured from a 24-hour composite sample, and the total mass (loading) is calculated from the product of discharge rate and TSS concentration. The daily TSS data are used to calculate the percent TSS removed by treatment and used by Ecology for assessing regulatory compliance through comparison to average weekly and monthly effluent permit limits.

As a result of the initial damage to the treatment processes from the flooding, the capacity of the plant to remove TSS was reduced. Effluent TSS concentrations during the restoration period were considerably higher than normal, with a maximum level of 227 mg/L (Figure 19). Note that these concentration data do not include the settleable solids and TSS that were discharged through the EBO outfall during the bypass events on February 9 and 15/16, which contributed additional solids to the nearshore zone. The average monthly TSS concentrations of 61, 110, and 70 mg/L in February, March, and April, respectively, were considerably elevated compared to the monthly effluent permit limitation of 30 mg/L. TSS values during this timeframe were also well above the normal range of monthly average effluent concentrations of about 6-19 mg/L (Figure 20). For context, the elevated average monthly TSS concentrations in February through April were comparable to TSS levels in West Point effluent in 1995 of about 63 mg/L when it was a primary treatment facility prior to being upgraded to secondary treatment (i.e., addition of oxidation and clarifiers for

improved removal of solids). The data show that with the restoration of treatment processes by the end of April, TSS removal performance returned to normal, and the effluent was able to meet the permit limits for TSS by May 10.

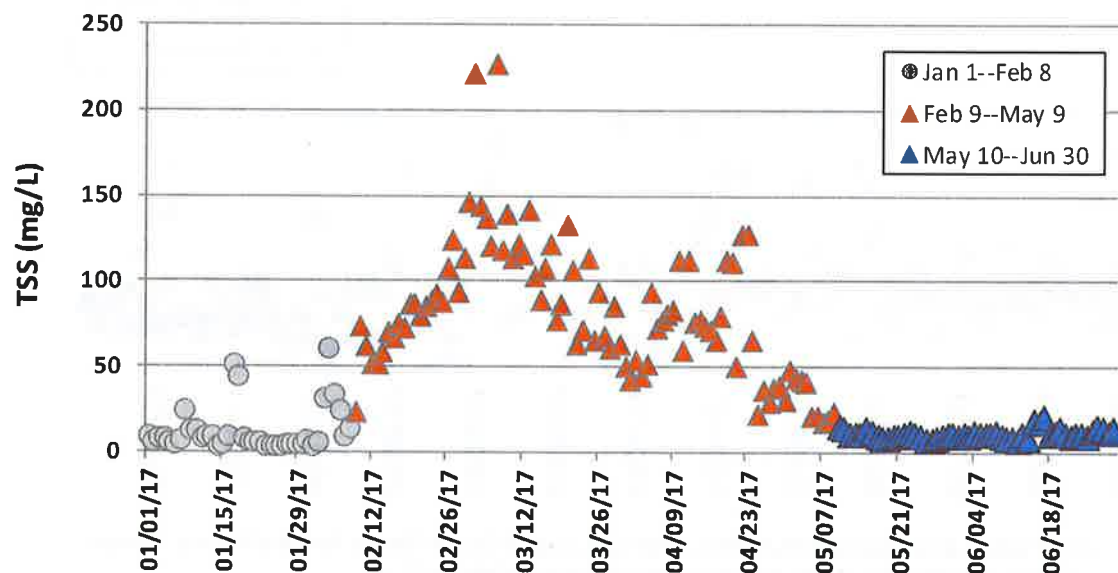


Figure 19. 2017 Daily TSS concentration in West Point effluent.

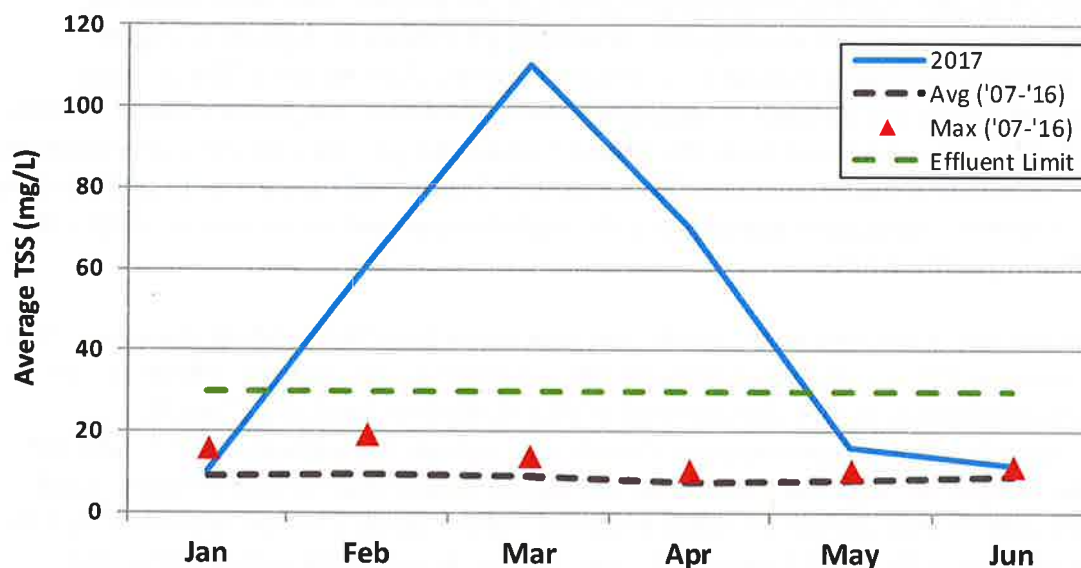


Figure 20. Average monthly TSS concentration in West Point effluent. Green dashed line shows monthly average effluent limit (30 mg/L).

The average monthly TSS loading, which includes both West Point and EBO discharges, compared to the historical conditions and the permit limit is shown in Figure 21. Daily TSS

loading compared to the historical average is shown in Figure 22 along with the weekly permit limit for comparison. Both the weekly and monthly average effluent discharge limits were exceeded in February through April while the restoration was in progress.

The TSS loading from West Point, including EBO bypass events, between February 9 and May 9 was more than ten times the normal amount, contributing an additional 7.2 million pounds of solids to Puget Sound. For context, this is about equal to the annual sediment load carried by the Lake Washington Ship Canal, or about two percent of the annual sediment load carried by the Duwamish River (USGS, 2011).

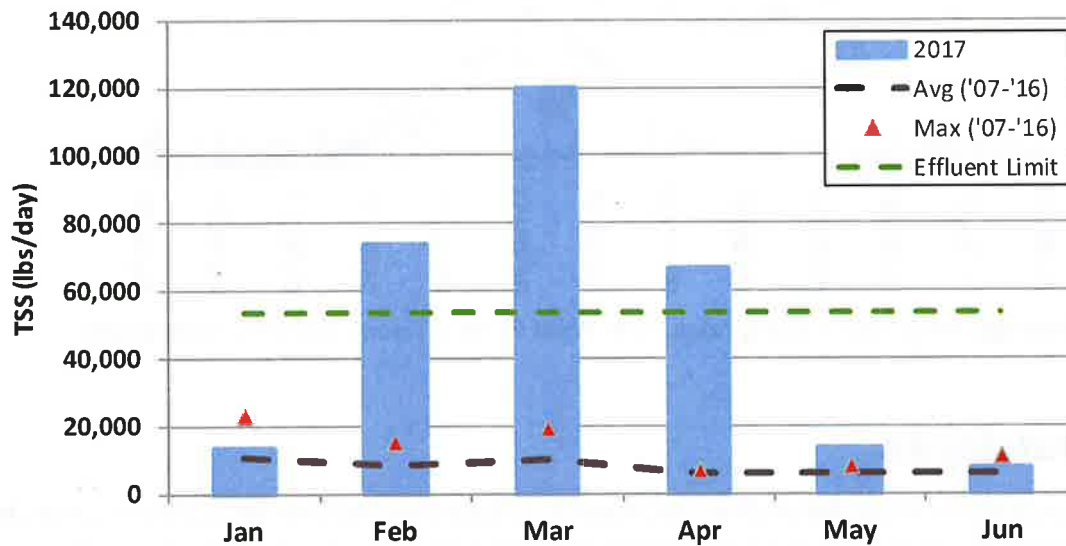


Figure 21. Average monthly TSS loading rates from West Point effluent and EBO discharges. Green dashed line shows monthly average effluent limit (53,800 lbs/day).

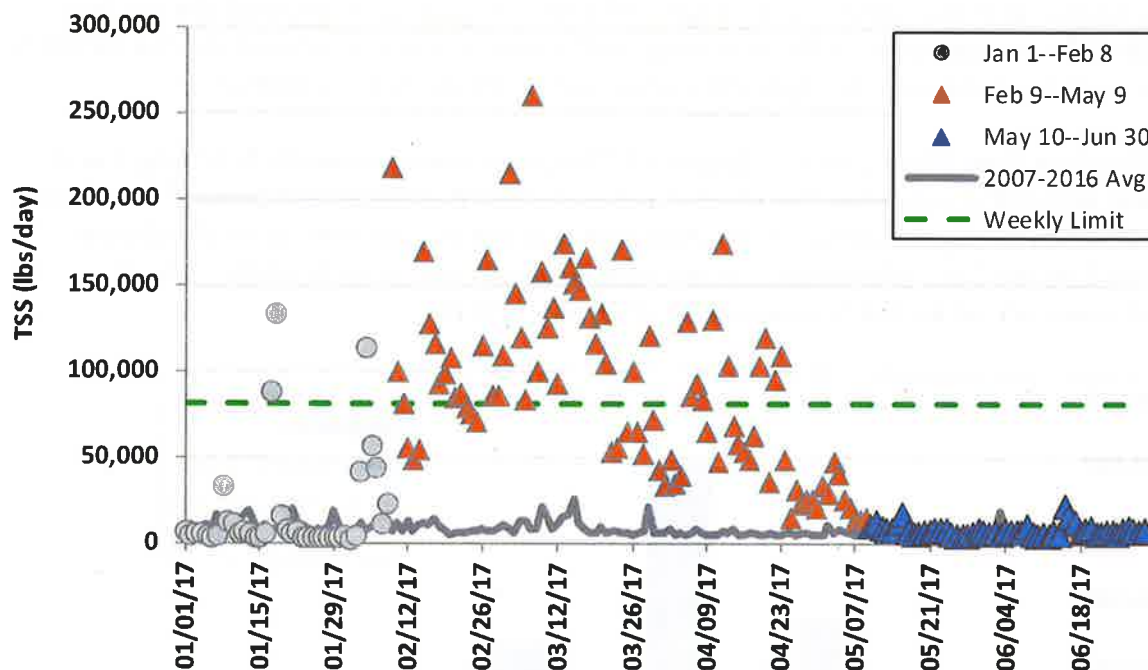


Figure 22. Average daily TSS loading rates from West Point effluent and EBO discharges.

3.5 Nutrients

The NPDES permit for West Point does not specify effluent limitations for nutrients, which refer to constituents that have the potential to stimulate biological growth in primary producing organisms such as algae and bacteria. The principal nutrients that are monitored in the effluent include inorganic forms of nitrogen (ammonia, nitrite, and nitrate), organic nitrogen, and inorganic forms of phosphorus (soluble reactive phosphorus and total phosphorus). While the treatment process at West Point is not designed for nutrient removal, about 25 percent of the nitrogen and 50 percent of the total phosphorus is typically removed along with the solids.

3.5.1 Nitrogen

Influent wastewater to West Point contains nitrogen primarily in the forms of ammonia and organic nitrogen compounds. The biological secondary process converts a portion of the organic nitrogen compounds to inorganic forms of nitrogen. The resulting effluent contains primarily dissolved inorganic nitrogen as ammonia, nitrate, and nitrite. With the secondary process offline following the flooding event, the lack of biological conversion of organic nitrogen is reflected in lower ammonia (Figure 23) and nitrate + nitrite concentrations (Figure 24).

During May and June, the higher than normal nitrate/nitrite concentrations and lower than normal ammonia concentrations reflect an intentional modification to create strongly nitrifying conditions for performance testing purposes. The nitrifying conditions were not related to the plant restoration process, but rather resulted from intentional testing

completed in advance of an aerator mixing system maintenance project planned for 2018. Typically, as seasonal rainfall and elevated wastewater flows taper off in the spring, the plant will adjust for lower flows by aerator process units being taken out of service. However, in 2017, all the aeration units were left in service for the collection of baseline data for the mixer replacement project. This resulted in the strongly nitrifying conditions observed. After the testing was completed, aeration units were taken out of service and effluent nitrate concentrations returned to normal levels. The sum of dissolved inorganic nitrogen (DIN) concentrations (ammonia and nitrate + nitrite) was typical compared to historical conditions, indicating that the conversion of organic nitrogen to inorganic forms was typical.

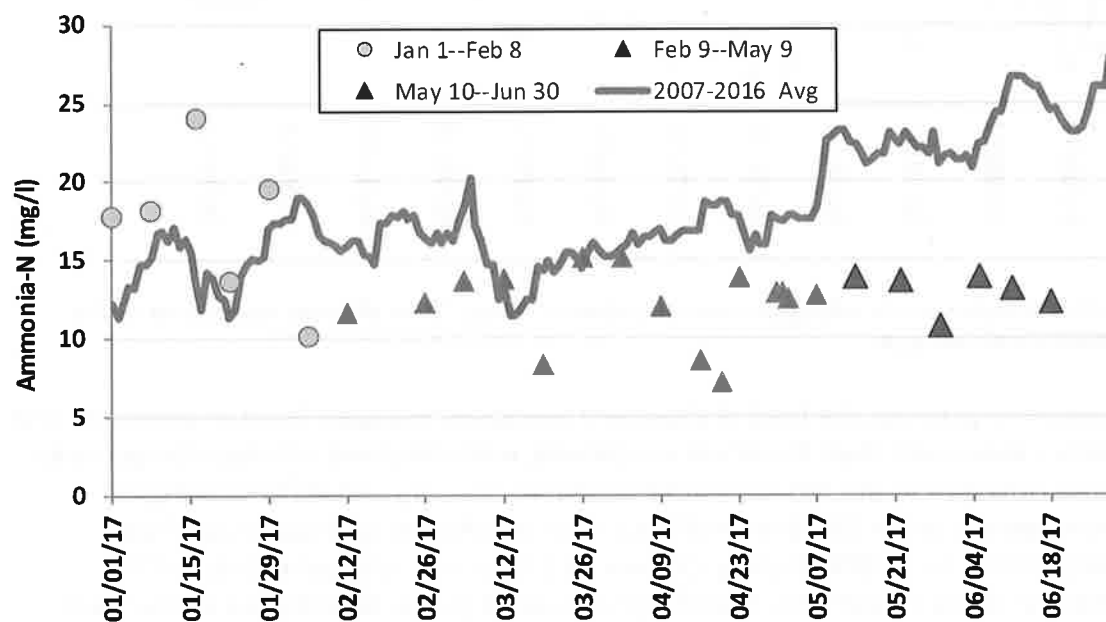


Figure 23. 2017 Ammonia nitrogen concentration in West Point effluent compared to the historical average.

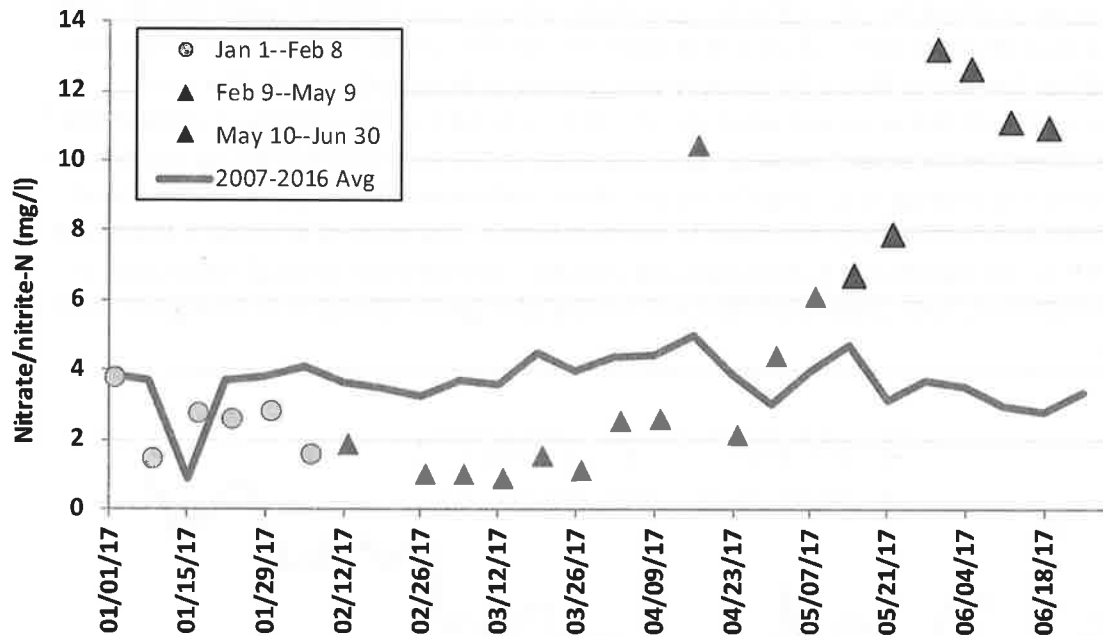


Figure 24. 2017 Nitrate+nitrite nitrogen concentration in West Point effluent compared to the historical average.

During the recovery process, the load of dissolved inorganic nitrogen (sum of ammonia and nitrate + nitrite) was lower than historical conditions, while the load of total nitrogen was greater than normal due to the reduced solids removal capacity and lack of biological treatment processes (Figure 25). The total mass load of nitrogen to Puget Sound was approximately 20,000 to 25,000 lbs/day (Figure 25). This was approximately 2,800 lbs/day higher, or about 15 percent, than the previous 10 years. An estimate of the total nitrogen loading rate from all sources to Puget Sound was not available. The increase in the total nitrogen loading rate during the period of reduced treatment represents a two percent increase above the annual average DIN loading rate to Puget Sound of 120,000 lbs/day from all watershed and wastewater treatment plant sources (Mohamedali et al., 2011a).

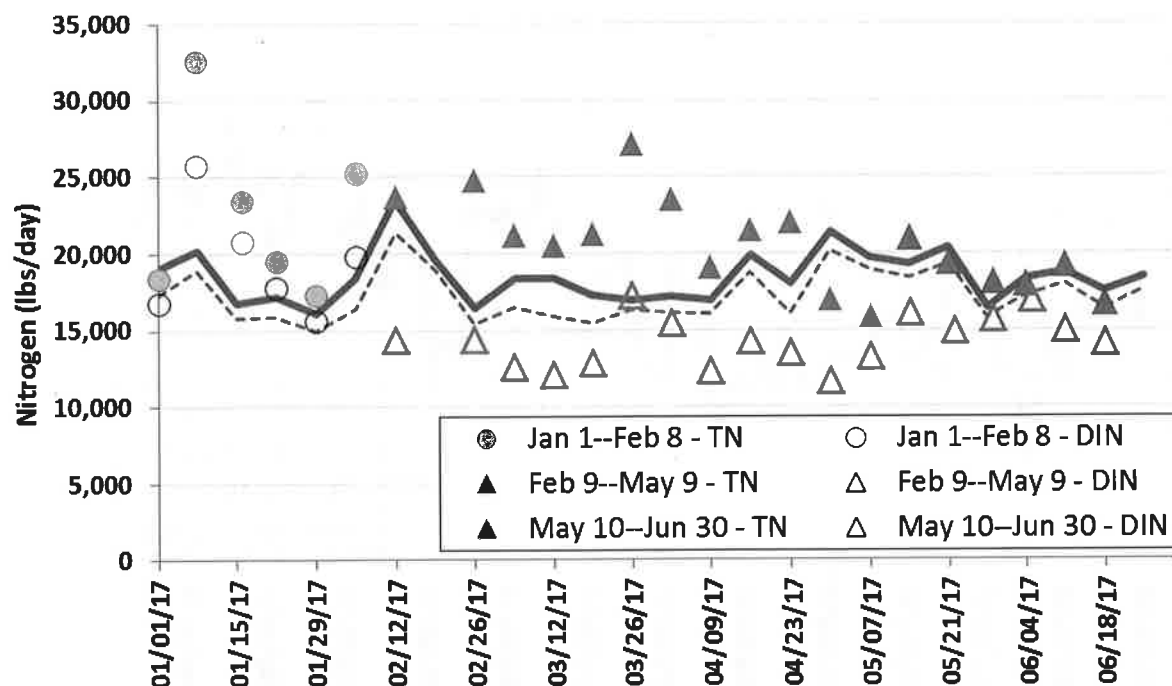


Figure 25. 2017 Dissolved inorganic nitrogen (DIN) and total nitrogen (TN) loading rates from West Point effluent compared to the historical averages for each (dotted and solid lines, respectively).

3.5.2 Phosphorus

Phosphorus can be present in wastewater and the aquatic environment as dissolved phosphates, which are readily available for uptake by aquatic algae and plants and less biologically available forms of phosphorus. The analytical test for total phosphorus measures inorganic and organic phosphorus in organic and mineral matter, along with dissolved forms. West Point effluent is monitored weekly for total phosphorus but dissolved orthophosphate has only been monitored since 2013. Total phosphorus results are presented below as they are most representative of the effects of the reduced level of solids removal that occurred during the restoration period. West Point was not designed to specifically remove phosphorus beyond the extent it is removed as part of the solids removal.

During the period of reduced treatment, higher effluent TSS concentrations resulted in higher effluent total phosphorus concentrations (Figure 26). A similar pattern is apparent in the total phosphorus mass loading rate (Figure 27). The total mass loading rate of phosphorus was approximately 900 lbs/day above the historic average of 1,700 lbs/day, or about a 50 percent increase during the period of reduced treatment. This represents a five percent increase to the estimated annual average total phosphorus loading rate of 17,000 lbs/day (Mohamedali et al., 2011a,b). The data show that total phosphorus concentrations and loadings returned to normal in May and June.

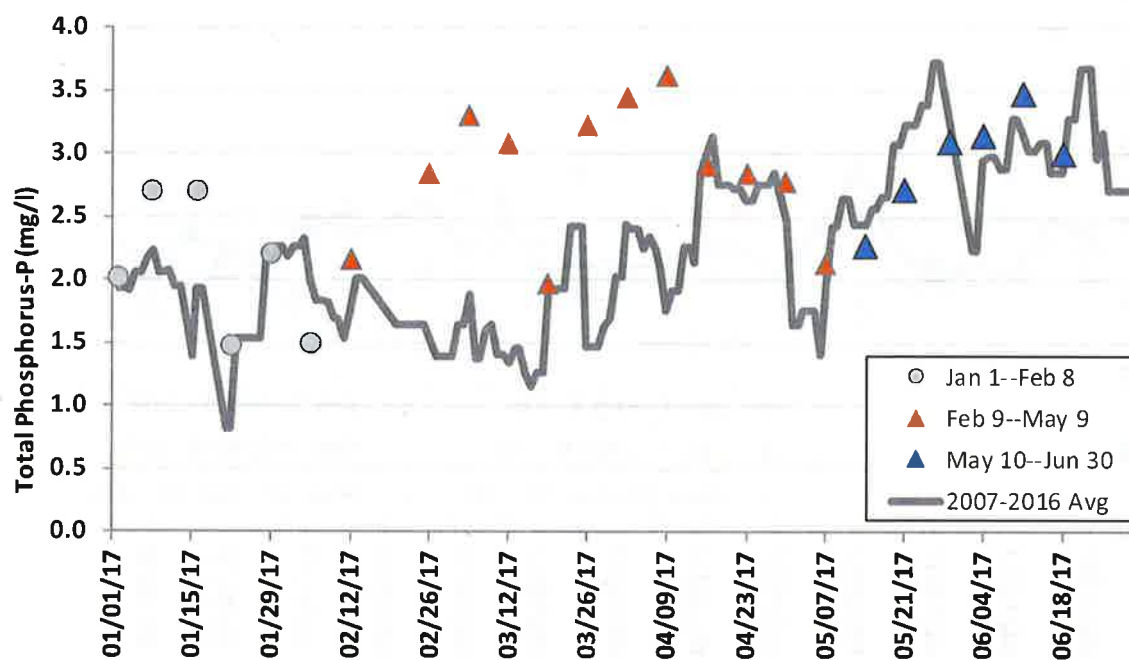


Figure 26. 2017 Daily total phosphorus concentration in West Point effluent.

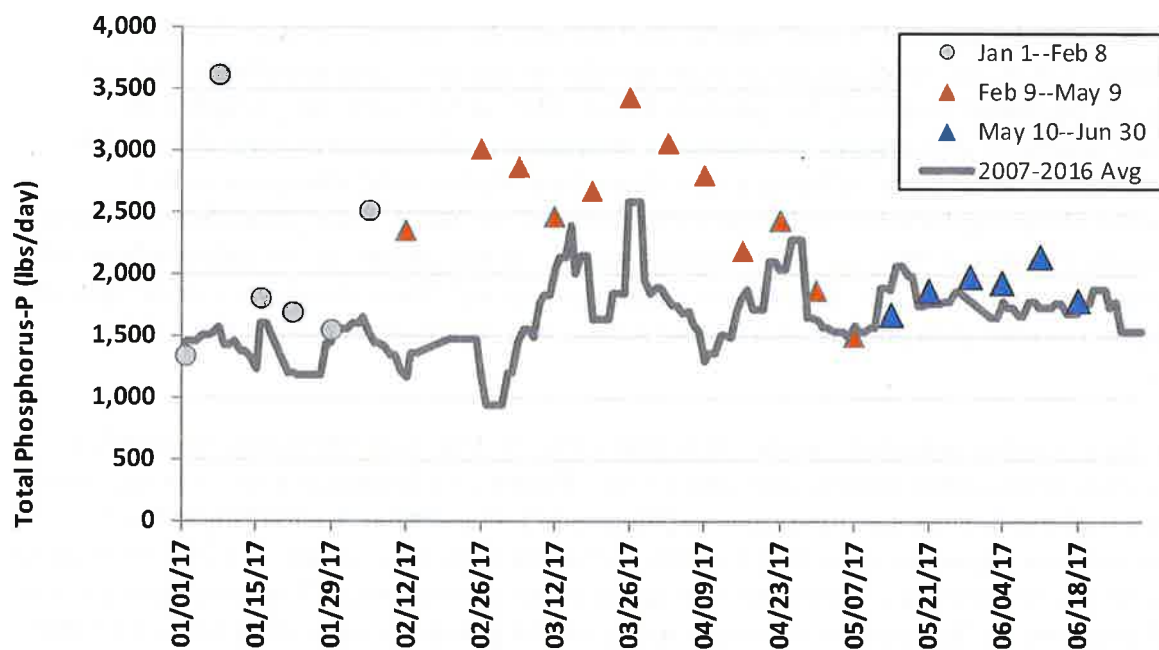


Figure 27. Total phosphorus loading rate from West Point effluent in 2017 compared to the historical average.

3.6 Carbonaceous Biochemical Oxygen Demand

Carbonaceous biochemical oxygen demand (CBOD), similar to TSS, is a parameter used to evaluate performance of the treatment processes in degrading and removing organic matter. CBOD is a measure of the oxygen demand that aerobic organisms would exert to degrade the remaining organic matter in the wastewater in which the contribution from nitrogenous bacteria has been suppressed. Nitrogenous bacteria also utilize oxygen for the oxidation of nitrogen compounds, primarily ammonia. The concentration of effluent CBOD is monitored daily and the percent removal of CBOD in the influent is calculated. The CBOD concentration data are used by Ecology for regulatory compliance assessment in comparison to average weekly and monthly effluent limits.

While the primary and secondary treatment processes were being restored, the capacity of the plant to remove CBOD was reduced. The range of CBOD concentrations in West Point effluent (up to about 160 mg/L) was considerably higher than normal (Figure 28). CBOD concentrations in final effluent ranged from about 60-160 mg/L, considerably elevated compared to the monthly effluent limitation (25 mg/L) and normal range of 6-10 mg/L (as measured by the previous 10-year period of 2007-2016). The data show that with the restoration of treatment processes by the end of April, CBOD removal performance returned to normal, and the effluent met the effluent limits for CBOD by May 10.

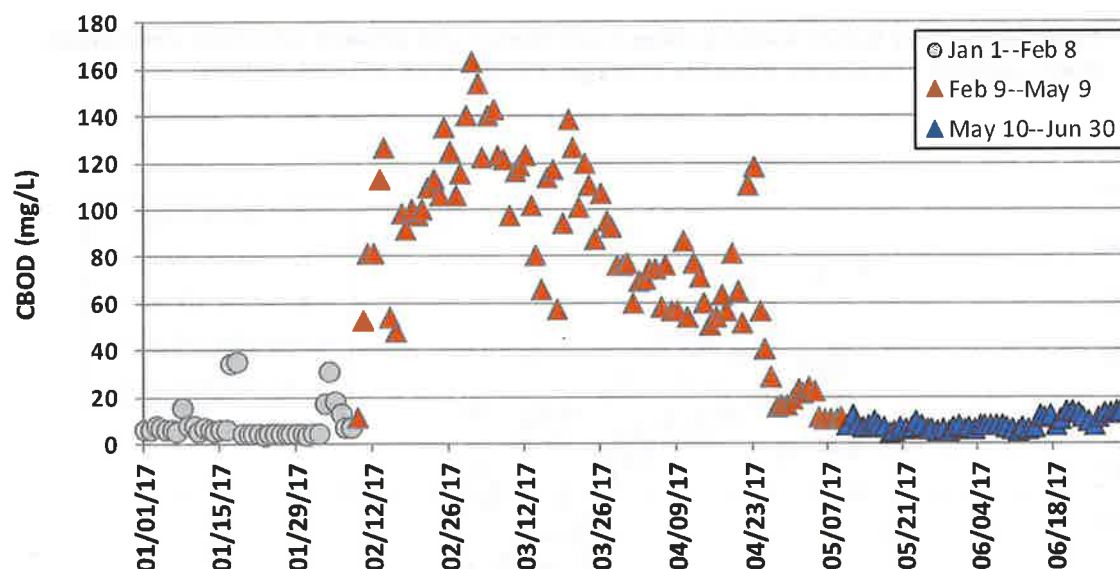


Figure 28. 2017 Daily carbonaceous biochemical oxygen demand (CBOD) concentration in West Point effluent.

The average monthly CBOD loading compared to the historical average and monthly permit limit is shown in Figure 29. Daily CBOD loading from West Point is compared to the historical average and the weekly permit limit in Figure 30. Both the weekly and monthly average effluent discharge limits were exceeded in February through April while the restoration was in progress.

The CBOD loading between February 9 and May 9 was approximately fourteen times the normal amount, contributing on average, an additional 80,000 lbs/day. For context, the increased CBOD loading is about equal to twice the CBOD loading rate from all major point sources to Puget Sound combined (Mohamedali et al., 2011a,b). This loading rate was similar to the loading rate prior to the West Point upgrade to secondary treatment in 1996.

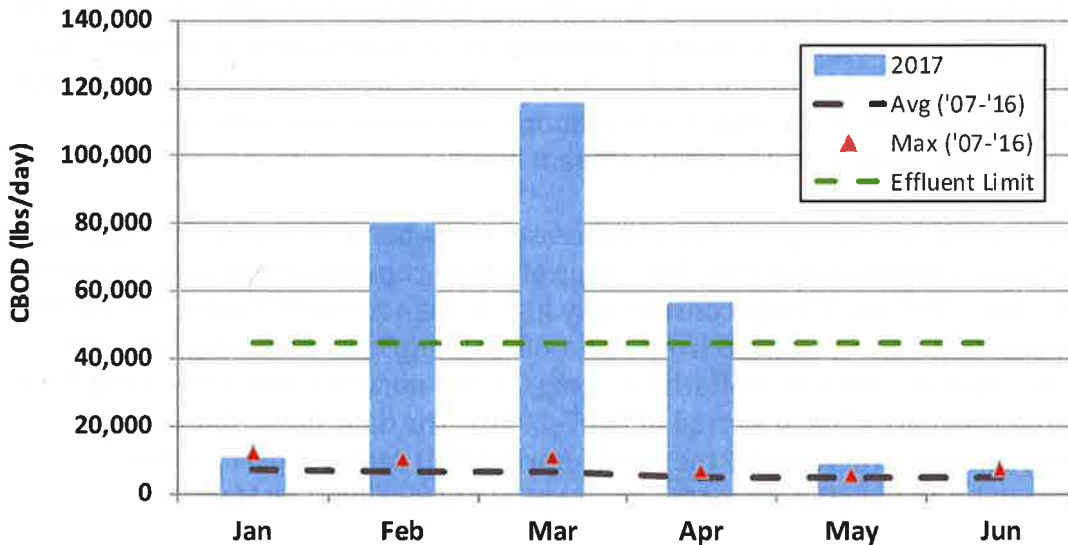


Figure 29. Average monthly CBOD loading rates from West Point effluent and EBO discharges. Green dashed line shows monthly average effluent limit (44,800 lbs/day).

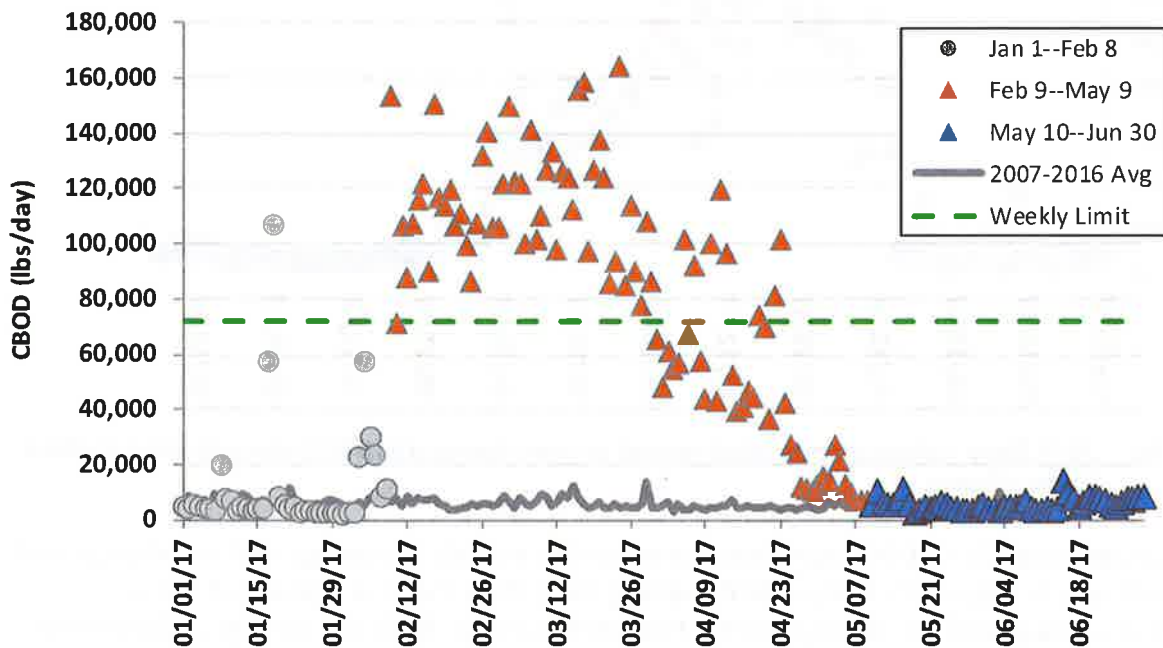


Figure 30. Daily CBOD loading rates from West Point effluent and EBO discharges. Green dashed line shows weekly average effluent limit (71,700 lbs/day).

3.7 pH

The standard measurement of pH refers to the hydrogen ion activity in a solution, and can impact chemical and biological processes. Low alkalinity in stormwater can be a source of reduced pH levels (Ecology, 2014). The West Point effluent is monitored continually for pH. The NPDES permit has instantaneous limits for pH to remain between 6 and 9 units. The effluent remained within this pH range during the period of reduced treatment (Figure 31).

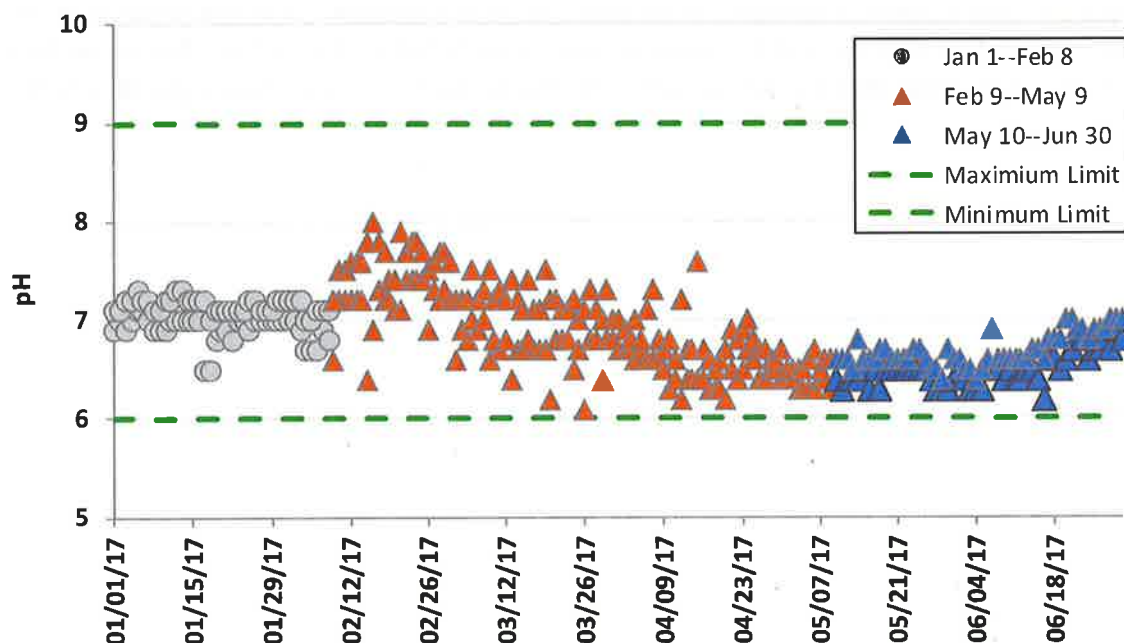


Figure 31. West Point effluent pH in 2017 compared to permit limits. Effluent remained within the pH limit (between 6 to 9 units) for the duration of sampling.

3.8 Trace Metals

Total concentrations of 14 trace metals (metals) were analyzed in each of 12 effluent samples collected between February 28 and June 20, 2017: antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Eight samples were analyzed during the period of reduced treatment (collected February 28–April 24) and four were analyzed after secondary treatment processes were restored (collected May 10–June 20). Total metals concentrations in effluent were also evaluated to determine if any were present at levels that could cause exceedances of water quality criteria in receiving waters following effluent dilution at the edge of the mixing zone. The concentrations and loads of metals measured in effluent are presented below. Results of the mixing zone analysis are presented in Section 3.11. When data are available, changes in loading rates of metals during reduced treatment are compared to total Puget Sound loads. The total loadings study was conducted previously for selected toxic chemicals by the Dept. of Ecology and King County, and includes specific metals assessments for arsenic, cadmium, copper, lead, mercury, and zinc only (Ecology, 2011). Although the period of reduced treatment occurred over a three-month period, average

loading rates are also reported in units of tonnes per year in order to match units given in the prior loadings study.

Table 2 shows the average, median, and maximum total metals concentrations detected during both reduced and secondary treatment. Historical values are also given for effluent samples analyzed during that same timeframe for comparability. Due to seasonal differences in the amount of flow and proportion of stormwater that can affect metal concentrations, only historical samples analyzed between February and June were included for comparison with recent data. All historical results included in Table 2 are for secondary treated effluent; the West Point was upgraded from a primary to a secondary plant in late 1995.

Table 2. Average, median, and maximum concentrations of commonly detected trace metals in effluent during reduced treatment (Feb-Apr) and secondary treatment (May-Jun) in 2017 compared to historical values.

	Historical				2017			
	Average (µg/L)	Median (µg/L)	Maximum (µg/L)	# of samples	Average (µg/L)	Median (µg/L)	Maximum (µg/L)	# of samples
Antimony *	2004-2016							
Feb-Apr	0.41	0.33	0.95	16	0.52	0.46	0.84	8
May-Jun	0.49	0.30	0.59	8	0.31	0.32	0.32	4
Arsenic	2004-2016							
Feb-Apr	1.48	1.60	2.0	16	1.76	1.72	2.03	8
May-Jun	1.61	1.64	1.91	8	1.45	1.44	1.49	4
Barium	1996-2016							
Feb-Apr	7.90	7.64	13.70	38	18.7	19.60	22.90	8
May-Jun	7.17	7.00	8.92	14	9.48	9.40	10.30	4
Cadmium *	2004-2016							
Feb-Apr	0.05	0.05	0.10	16	0.145	0.14	0.29	8
May-Jun	0.069	0.05	0.24	8	0.035	0.03	0.07	4
Chromium	2004-2016							
Feb-Apr	0.68	0.64	1.10	16	1.97	1.82	3.41	8
May-Jun	0.74	0.65	1.10	8	0.66	0.67	0.81	4
Copper	1996-2016							
Feb-Apr	15.2	14	47.9	115	25.8	27.3	32.9	8
May-Jun	15.1	12.7	130	74	11.1	11.4	12.9	4
Lead	2004-2016							
Feb-Apr	0.81	0.60	1.82	16	3.52	3.02	6.69	8
May-Jun	0.74	0.63	1.08	8	0.51	0.48	0.74	4
Mercury	2007, 2010-2016							
Feb-Apr	0.0097	0.0039	0.0616	11	0.0129	0.0140	0.0164	8
May-Jun	0.0052	0.0048	0.0061	3	0.0041	0.0040	0.0048	3
Nickel	2004-2016							
Feb-Apr	2.96	2.58	6.11	16	3.69	3.74	4.20	8
May-Jun	2.84	2.67	3.81	8	2.60	2.61	2.66	4
Silver *	2004-2016							
Feb-Apr	0.16	0.08	0.50	16	0.14	0.16	0.18	8
May-Jun	0.28	0.13	0.91	8	0.05	0.05	0.07	4
Zinc	1996-2016							
Feb-Apr	42.4	41.2	96.6	118	65.4	66.2	81.0	8
May-Jun	39.1	37.8	91.7	74	38.6	39.0	41.7	4

* For results below the method detection limit (MDL), half the MDL was used to calculate the average.

As is typical for these metals in effluent, beryllium and thallium were below the method detection limit (the minimum concentration a substance can be detected) in all 12 samples. Antimony and silver concentrations were either below the method detection or reporting limit in all samples. For both historical and recent samples, cadmium was only detected above either the method detection or reporting limits in two samples analyzed during the period of reduced treatment. Selenium concentrations were below the reporting limit of 1.0 micrograms/liter ($\mu\text{g/L}$) in all samples with the exception of the sample analyzed on April 4, 2017, which had a detectable value (1.05 $\mu\text{g/L}$) just above the reporting limit. Selenium has only been detected in 6 of 51 previous effluent samples analyzed between 2004 and 2016 at low concentrations ranging from 0.51 to 1.3 $\mu\text{g/L}$. These six metals are not discussed further due to very low concentrations throughout the sampling period.

Arsenic

Arsenic is a naturally occurring metal in soils and along with its compounds may be used in a variety of products including semi-conductors, insecticides, and exterior paints and finishes as a wood preservative. Arsenic was detected in all samples ranging from 1.41 to 2.03 $\mu\text{g/L}$. The median concentration during the period of reduced treatment was 1.72 $\mu\text{g/L}$ and 1.44 $\mu\text{g/L}$ once secondary processes were restored (see Table 2). Although arsenic concentrations were higher during the period of reduced treatment, the average and median values during this time period were only slightly higher than the historical secondary treatment values. Once secondary processes were restored, arsenic values in 2017 were lower than historical values. Figure 32 shows arsenic values following the flooding event compared to values between 2004 and 2016. Only data from 2004 to present are included as a significant method change occurred in 2004 which resulted in the lowering of detection limits from 25 to 0.5 $\mu\text{g/L}$. Prior to 2004, most values were below the higher detection limit. Similar to concentration, the mass loading rate of arsenic was comparable to historical values. The average loading rate during the three-month period of reduced treatment was 1.8 lbs/day, or equivalent to a rate of 0.3 tonnes/yr, less than two percent of the estimated 14–25 tonnes/yr total discharge rate from all sources to Puget Sound (Ecology, 2011).

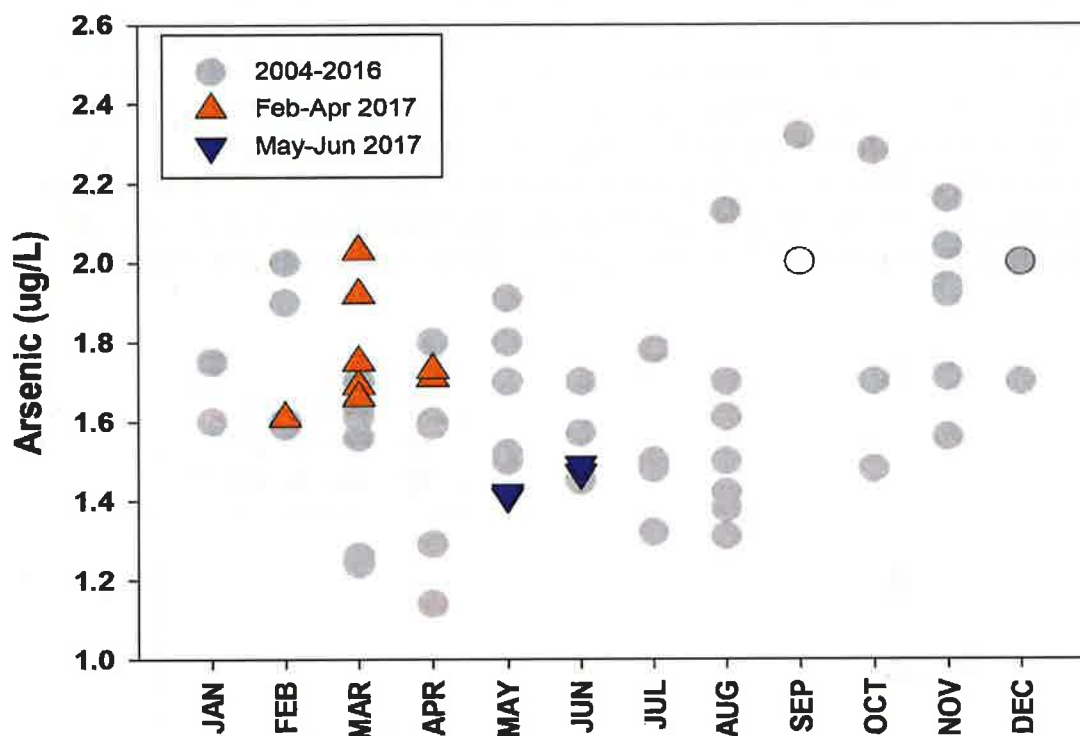


Figure 32. Arsenic values during reduced treatment (orange) and secondary (blue) treatment compared to historical values (gray) for all months. Open gray circles indicate concentration was below the method detection limit.

Barium

Barium is an earth metal and is used, along with its compounds, in a variety of industrial products including lubricants, cosmetics, cement, and paints. Barium may also be used in the manufacturing process for soap, rubber, and linoleum (Choudhury and Cary, 2011) and is also used in the medical industry for diagnostics. Barium was detected in all samples ranging from 8.79 to 22.9 $\mu\text{g/L}$. The median concentration during the period of reduced treatment was 19.6 $\mu\text{g/L}$ and subsequently declined to 9.4 $\mu\text{g/L}$ once secondary processes were restored. The highest concentration (22.9 $\mu\text{g/L}$) was detected in the March 13, 2017 sample during the period of reduced treatment. An estimate of the total barium load from all sources to Puget Sound was not available.

Chromium

Chromium is a naturally occurring metal in soils and rocks and along with its compounds, is widely used for a variety of industrial purposes including electroplating and cement manufacturing. Automotive emissions are a significant source to the atmosphere. Chromium was detected in all samples ranging from 0.5 to 3.41 $\mu\text{g/L}$. The median concentration during the period of reduced treatment was 1.82 $\mu\text{g/L}$ which then dropped to 0.67 $\mu\text{g/L}$ once secondary processes were restored in early May. Concentrations in May and June, 2017, were similar to past results. Average, median, and maximum concentrations detected during both reduced and secondary treatment as well as historical

values for comparison are provided in Table 2. Only data since 2004 are included as a significant method change occurred in 2004 which resulted in the lowering of detection limits from 5 to 0.4 µg/L. The chromium detection limit was lowered in 2008 to the current 0.2 µg/L. Prior to 2004, the majority of values were below the higher detection limit. Figure 33 shows chromium values following the flooding event compared to historical values. Similar to concentration, the mass loading rate of chromium during the period of reduced treatment was about double the normal rate, at an average loading rate of 2 lbs/day. An estimate of the total chromium load from all sources to Puget Sound was not available.

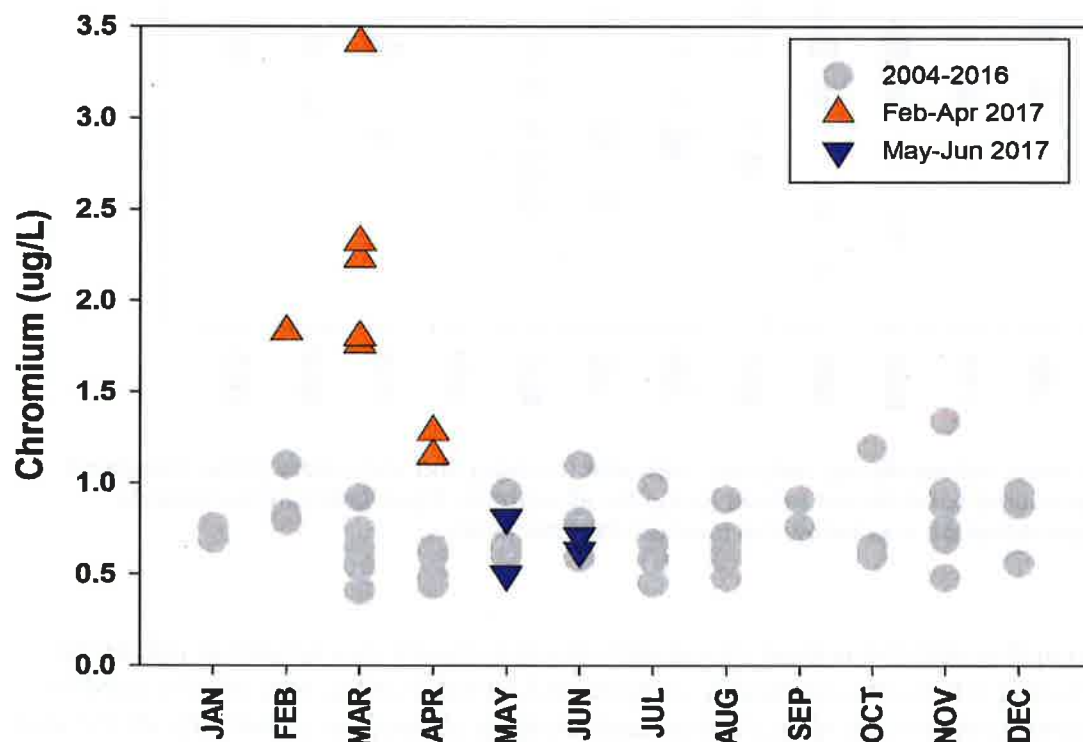


Figure 33. Chromium values during reduced treatment (orange) and secondary (blue) treatment compared to historical values (gray) for all months.

Copper

Copper is contained in a variety of products including fungicides and pesticides, automotive brake pads, pigments, wood preservatives, and antifouling paints. A main source into wastewater treatment plants is from corrosion and leaching of both household and municipal water distribution infrastructure. Copper was detected in all samples ranging from 10.1 to 32.9 µg/L. The median concentration during the period of reduced treatment was 27.3 µg/L compared to 11.4 µg/L once secondary processes were restored (see Table 2). For comparative purposes, only historical data after the plant was upgraded to secondary (1996) are included in the table.

Copper values were higher than historical concentrations between February and April but were lower than historical values in May and June after secondary processes were

restored. The lower than historical values in May and June may be a reflection of the difference in sample size. Figure 34 shows the higher concentrations during the period of reduced treatment compared to recent results and Figure 35 shows historical data from 1971 to present. Three distinct time intervals are evident in Figure 35: 1971 to 1983, 1984 to 1996, and 1996 to present. A large decrease in effluent concentrations of copper occurred after the City of Seattle implemented the Corrosion Control Project in 1982/1983 which raised the pH of drinking water to a target of 8.2 (SPU, 2016). This project was implemented to reduce corrosion of pipes and leaching of copper and lead, but also reduced other metals associated with water distribution systems such as zinc and nickel. The federal Lead and Copper Rule was implemented in 1991 (40 CFR Part 141, Subpart 1) and further reduced copper inputs into the treatment plant which then reduced effluent concentrations. Another large decrease occurred in 1996 after the plant was upgraded to secondary treatment in late 1995 and concentrations have remained low since that time.

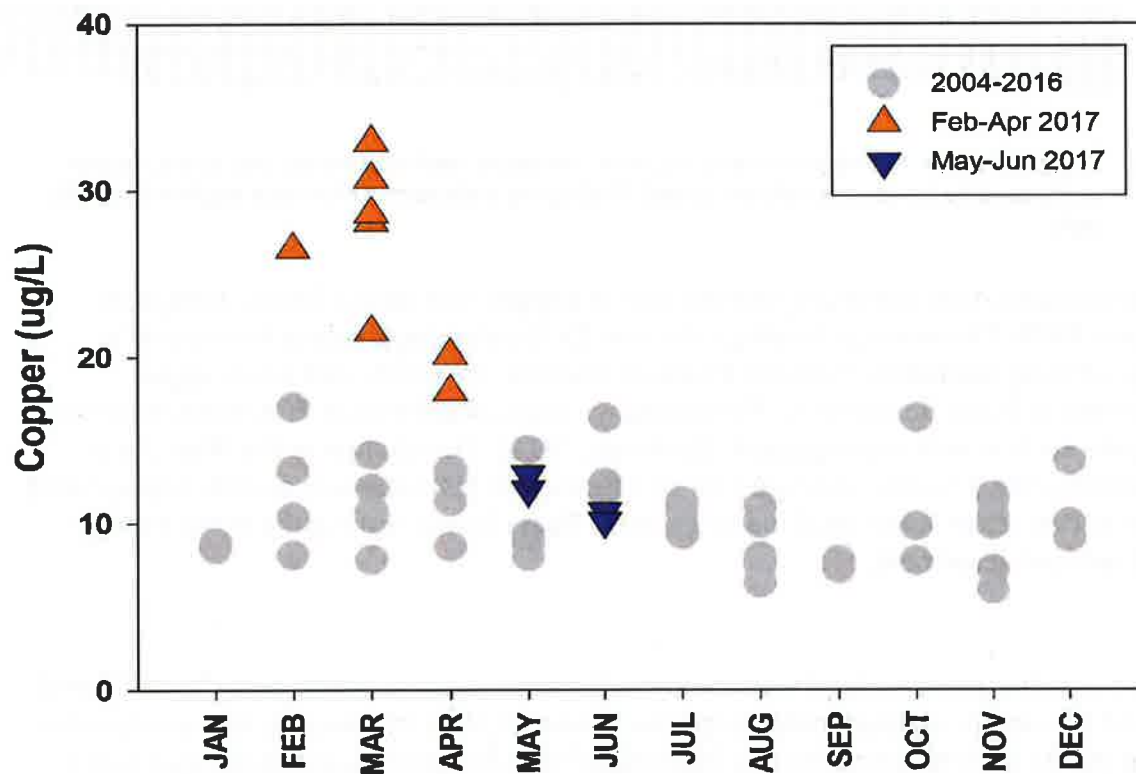


Figure 34. Copper values during reduced treatment (orange) and secondary (blue) treatment compared to recent historical values (gray) for all months.

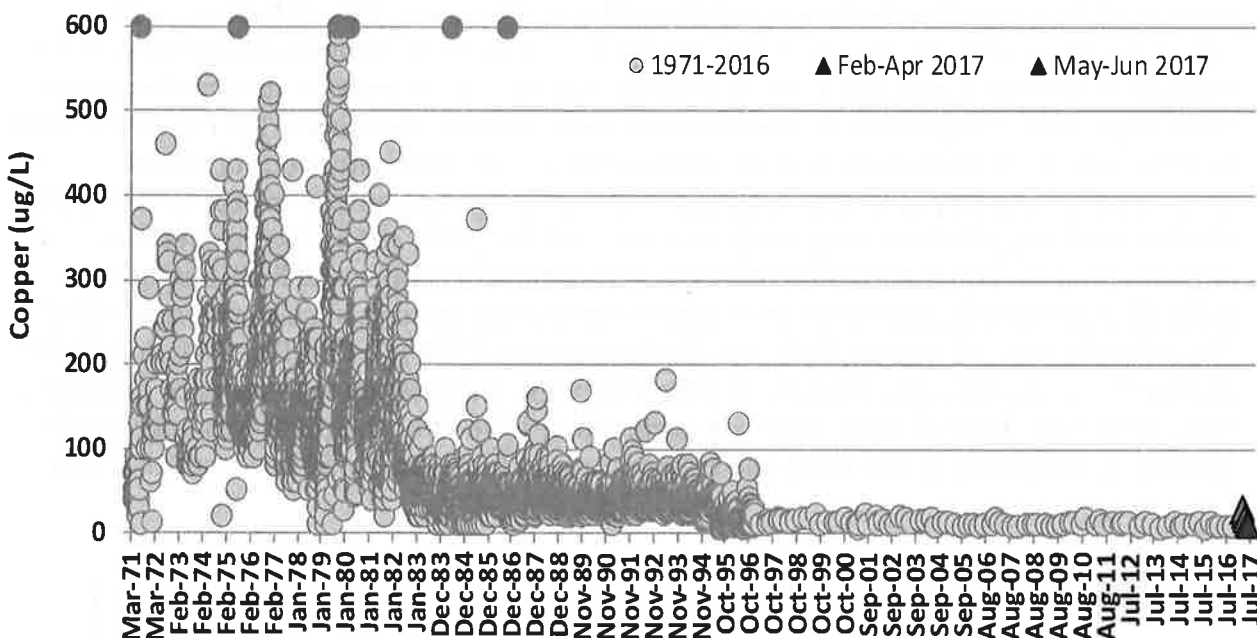


Figure 35. Copper values during reduced treatment (orange) and secondary (blue) treatment compared to historical values (gray). Dark gray indicates value was higher than 600 µg/L.

Similar to concentration, the mass loading rate of copper was about double historical values since 1996. The average loading rate was 25 lbs/day (equivalent to a rate of 4 tonnes/yr) during reduced treatment. From all sources, the estimated total copper discharge rate to Puget Sound is 33–80 tonnes/yr, plus an additional 26 tonnes/yr from direct inputs such as anti-fouling paints (Ecology, 2011). The change in the West Point copper loading rate from the average rate of 2 tonnes/yr from the last decade represented a 2–5 percent increase in the total loading rate to Puget Sound during the three-month period of reduced treatment.

Lead

In addition to other sources, lead was contained in paint used in homes prior to 1976 and solder used for electrical/electronic purposes. However, the main source into wastewater treatment plants is from corrosion and leaching of both household and municipal water distribution infrastructure. Lead was detected in all samples ranging from 0.35 to 6.69 µg/L. The median concentration during the period of reduced treatment was 3.02 µg/L compared to 0.48 µg/L once secondary processes were restored (see Table 2). For comparative purposes, only data since 2004 are included as a significant method change occurred in 2004 which resulted in the lowering of detection limits from 30 to 0.2 µg/L and subsequently to 0.1 µg/L.

Lead values were higher than historical concentrations between February and April but were lower than historical values in May and June after secondary processes were restored. Figure 36 shows the higher concentrations during the period of reduced

treatment compared to recent results and Figure 37 shows historical data from 1971 to present. As seen with copper, a large decrease in lead effluent concentrations occurred after the City of Seattle implemented the Corrosion Control Project in 1982/1983 to specifically reduce corrosion of pipes and leaching of copper and lead (SPU 2016). The phase out of leaded gasoline between 1975 and 1995 and the implementation of the federal Lead and Copper Rule in 1991 further reduced effluent concentrations. Lead was rarely detected past 1995 until a method change lowered detection limits in 2004.

Similar to concentration, the mass loading rate of lead was more than double the normal rate. The average loading rate was 4 lbs/day (equivalent to a rate of 0.6 tonnes/yr) during the period of reduced treatment. The estimated total lead discharge rate to Puget Sound from all sources is 3.6–12 tonnes/yr (Ecology, 2011). The change in the West Point lead loading rate from the average rate of 0.2 tonnes/yr from the last decade represented a 4–13 percent increase in the total loading rate to Puget Sound during the three-month period of reduced treatment.

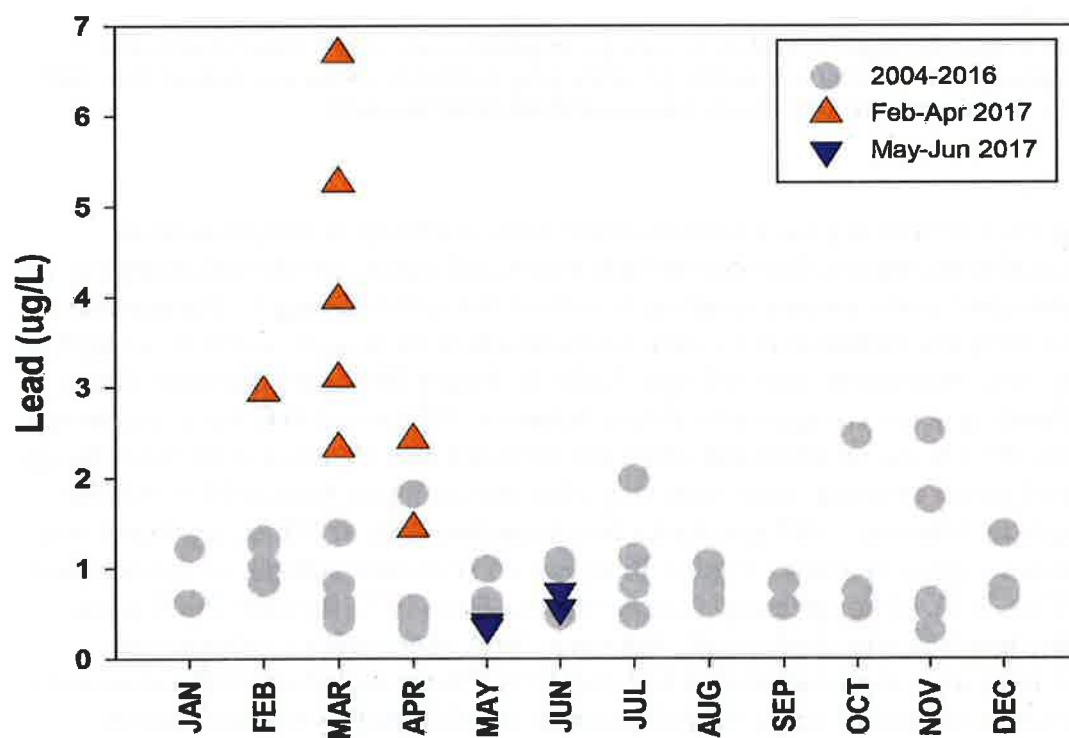


Figure 36. Lead values during reduced treatment (orange) and secondary (blue) treatment compared to recent historical values (gray) for all months.

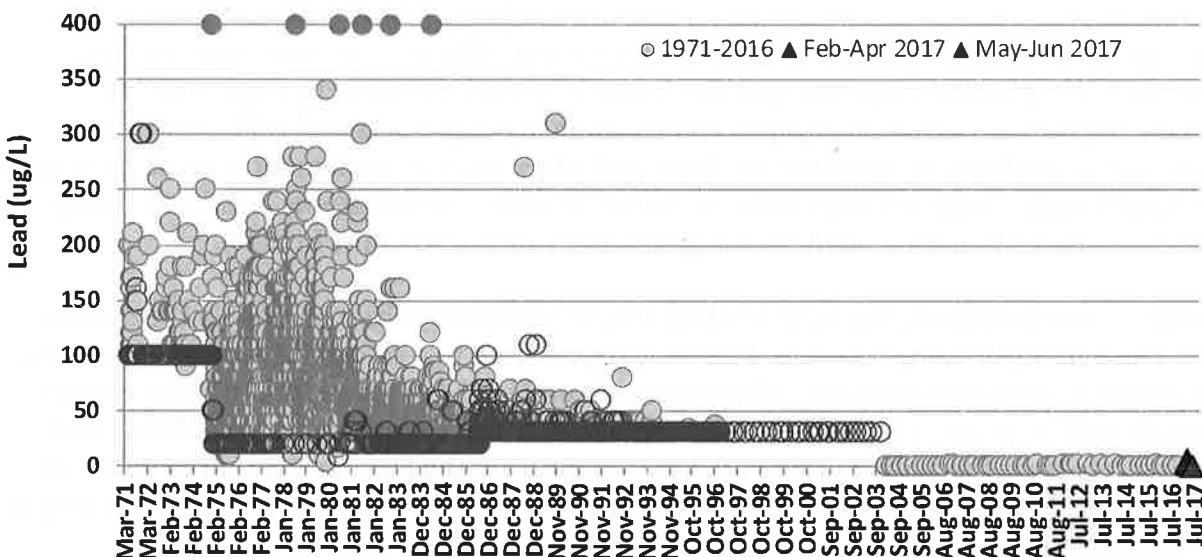


Figure 37. Lead values during reduced treatment (orange) and secondary (blue) treatment compared to historical values (gray). Dark gray indicates value was higher than 400 µg/L. Open gray circles indicate below method detection limit.

Mercury

Although many uses of mercury have been banned, some mercury is still present in products such as thermometers, fluorescent light bulbs and tubes, and dental amalgam. Mercury was detected in all samples ranging from 0.00348 to 0.0164 µg/L. The median concentration during the period of reduced treatment was 0.0140 µg/L and 0.0040 µg/L once secondary processes were restored (see Table 2). Figure 38 shows mercury values following the flooding event compared to values between 2010 and 2016. For comparison to recent results, data between 2010 and 2016 are included as a significant method change occurred in 2010 which resulted in the lowering of detection limits from 0.05 to 0.0002 µg/L. One sample in February 2007 also had a low detection limit of 0.0002 µg/L and was included in the descriptive statistics. Figure 39 shows 2017 results compared to historical data from 1972 to 2016. Although many concentrations from 1972 through 2009 were below detectable levels due to the 0.2 µg/L detection limit, there were a substantial number of high mercury values between 1972 and 1991. These high historical values were prior to the County's industrial waste dental program which significantly reduced the amount of mercury input into the plant. Mercury concentrations were reduced further after the upgrade to secondary treatment in late 1995.

Similar to concentration, the mass loading rate of mercury was more than double the normal rate. The average loading rate was 0.01 lbs/day (0.002 tonnes/yr) during the period of reduced treatment. The estimated total mercury discharge rate to Puget Sound from all sources is 0.11–0.37 tonnes/yr (Ecology, 2011). The change in the West Point mercury loading rate from the average rate of the last decade represented a one percent increase in the total mercury loading rate to Puget Sound during the three-month period of reduced treatment.

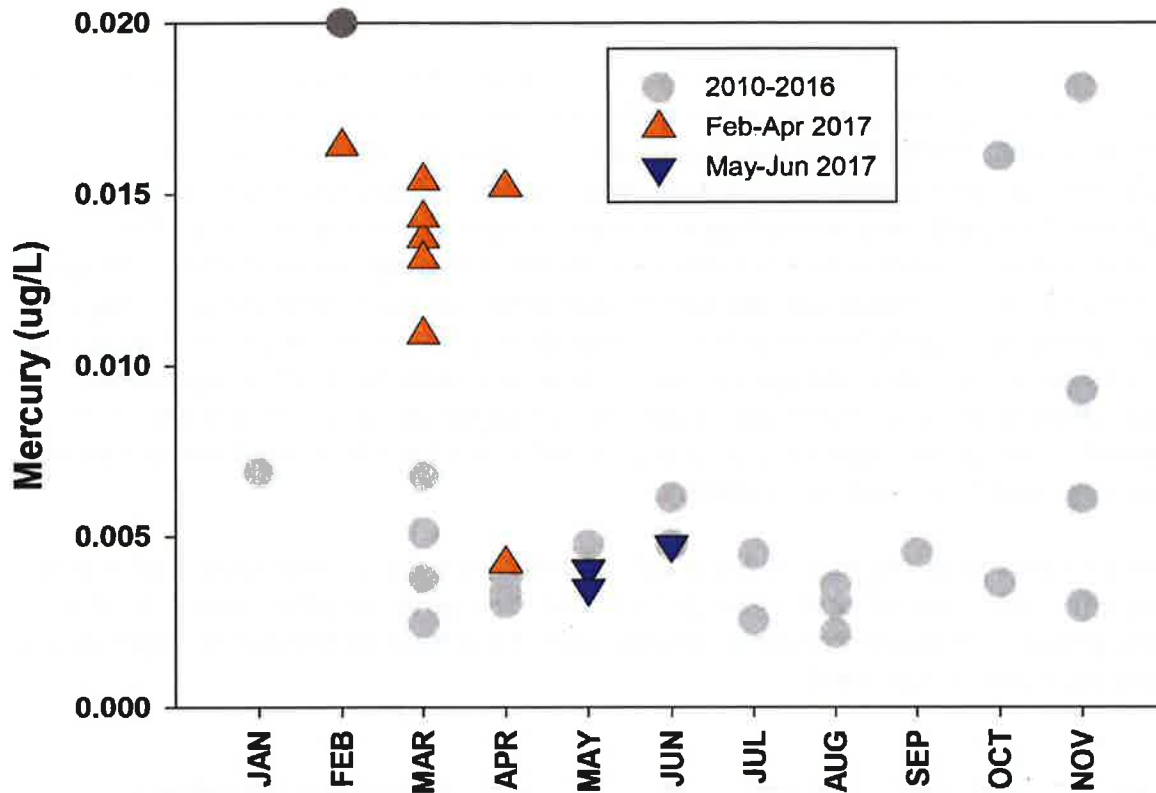


Figure 38. Mercury values during reduced treatment (orange) and secondary (blue) treatment compared to recent historical values (gray) for all months. Dark gray indicates value was higher than 0.02 $\mu\text{g/L}$.

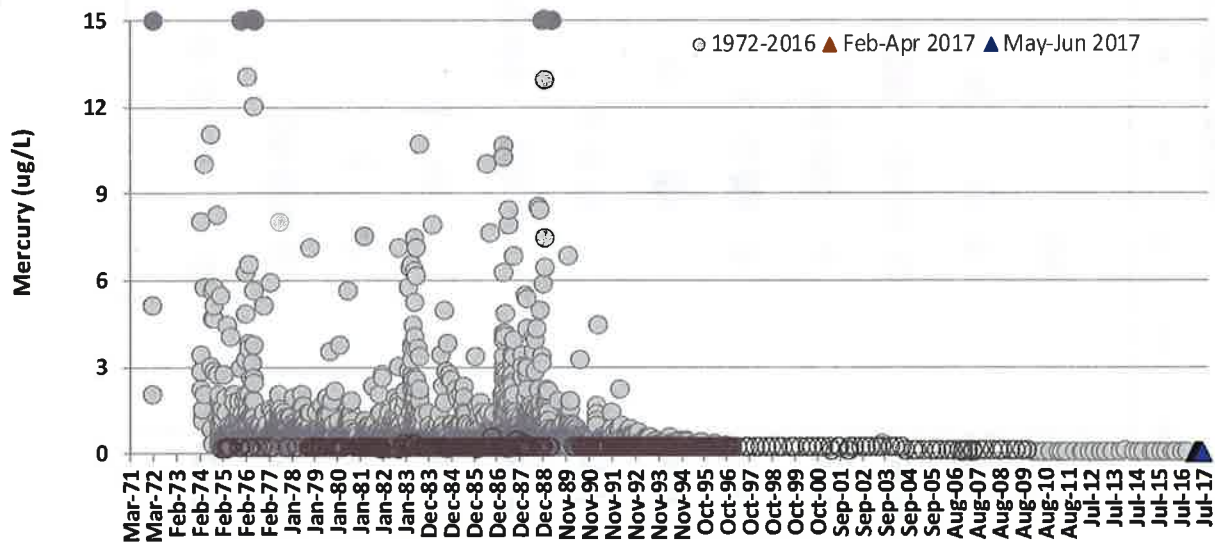


Figure 39. Mercury values during reduced treatment (orange) and secondary (blue) treatment compared to historical values (gray) back to 1972. Dark gray indicates value was higher than 15 $\mu\text{g/L}$. Open gray circles indicate below method detection limit.

Nickel

Nickel is an earth metal that is used in many alloys and also food processing (stainless steel and nickel alloy equipment), rechargeable batteries, and protective coatings (US Department Health, 2005). Nickel was detected in all samples ranging from 2.53 to 4.20 µg/L. The median concentration during the period of reduced treatment was 3.74 µg/L and 2.61 µg/L once secondary processes were restored (see Table 2). For comparative purposes, only data since 2004 are included as a significant method change occurred in 2004 which resulted in the lowering of detection limits from 20 to 0.3 µg/L. Figure 40 shows the slightly higher concentrations during the period of reduced treatment compared to recent results and Figure 41 shows historical data from 1971 to present. Similar to mercury, nickel concentrations were much higher in the 1970s and 1980s and then showed a precipitous drop in approximately 1991 and have remained low since the plant was upgraded to secondary treatment.

Similar to concentration, the mass loading rate of nickel was about 50 percent higher than the average from the preceding ten-year period. The average loading rate was 4 lbs/day during the period of reduced treatment. An estimate of the total nickel load to Puget Sound from all sources was not available.

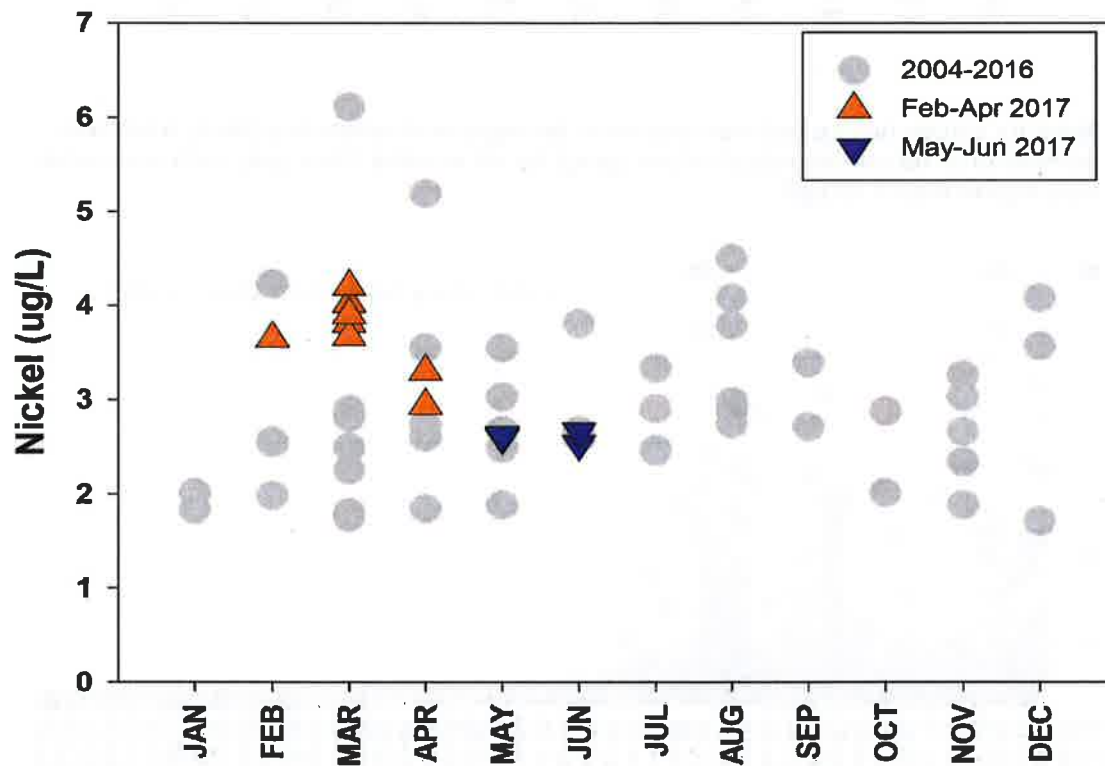


Figure 40. Nickel values during reduced treatment (orange) and secondary (blue) treatment compared to recent historical values (gray) for all months.

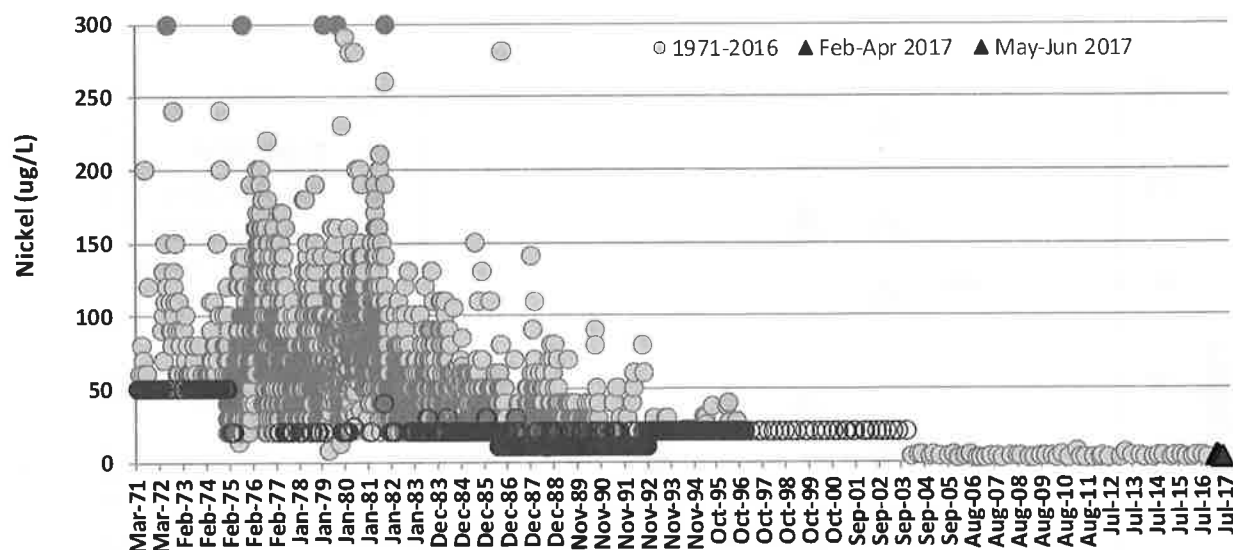


Figure 41. Nickel values during reduced treatment (orange) and secondary (blue) treatment compared to historical values (gray) back to 1971. Dark gray indicates value was higher than 300 $\mu\text{g/L}$. Open gray circles indicate below method detection limit.

Zinc

Zinc is contained in a variety of products including pesticides, algae and fungicides, cosmetics, medicines, paints, and water proofing products. Similar to copper and lead, a main source into wastewater treatment plants is from corrosion and leaching of both household and municipal water distribution infrastructure. Zinc was detected in all samples ranging from 34.7 to 81.0 $\mu\text{g/L}$. The median concentration during the period of reduced treatment was 66.2 $\mu\text{g/L}$ compared to 39.0 $\mu\text{g/L}$ once secondary processes were restored (see Table 2). For comparative purposes, only historical data after the plant was upgraded to secondary treatment in late 1995 are included.

Zinc values were higher than historical concentrations between February and April but similar to historical values in May and June after secondary processes were restored. Figure 42 shows the higher concentrations during the period of reduced treatment compared to recent results and Figure 43 shows historical data from 1971 to present. A similar pattern to copper, three distinct time intervals are evident in zinc concentrations: 1971 to 1983, 1984 to 1996, and 1996 to present. The large decrease in zinc effluent concentrations occurred after the City of Seattle implemented the Corrosion Control Project in 1982/1983 (SPU, 2016). Another large decrease occurred in 1996 after the plant was upgraded to secondary treatment.

Similar to concentration, the mass loading rate of zinc was about double the normal rate. The average loading rate was 65 lbs/day (equivalent to a rate of 11 tonnes/yr) during the period of reduced treatment. The estimated total zinc discharge rate to Puget Sound from all sources is 140–200 tonnes/yr (Ecology, 2011). The change in the West Point zinc loading rate from the average rate of 6 tonnes/yr from the last decade represented a 2–3

percent increase in the total loading rate to Puget Sound during the three-month period of reduced treatment.

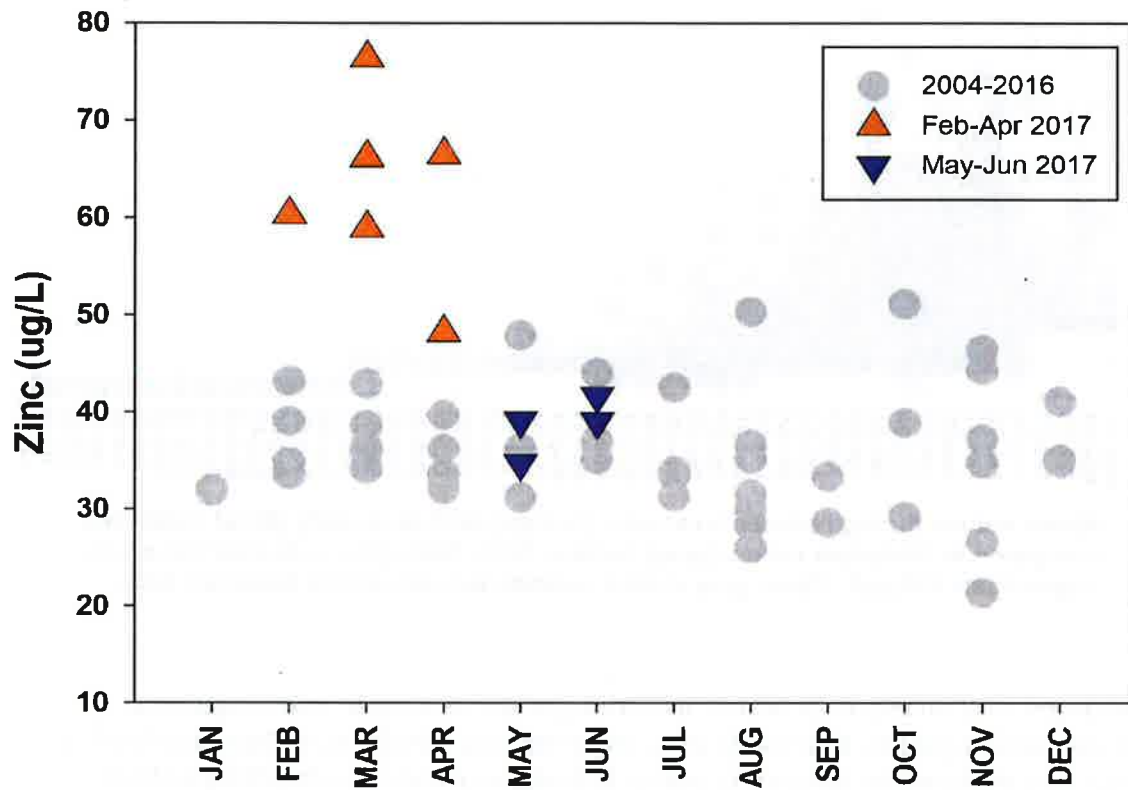


Figure 42. Zinc values during reduced treatment (orange) and secondary (blue) treatment compared to recent historical values (gray) for all months.

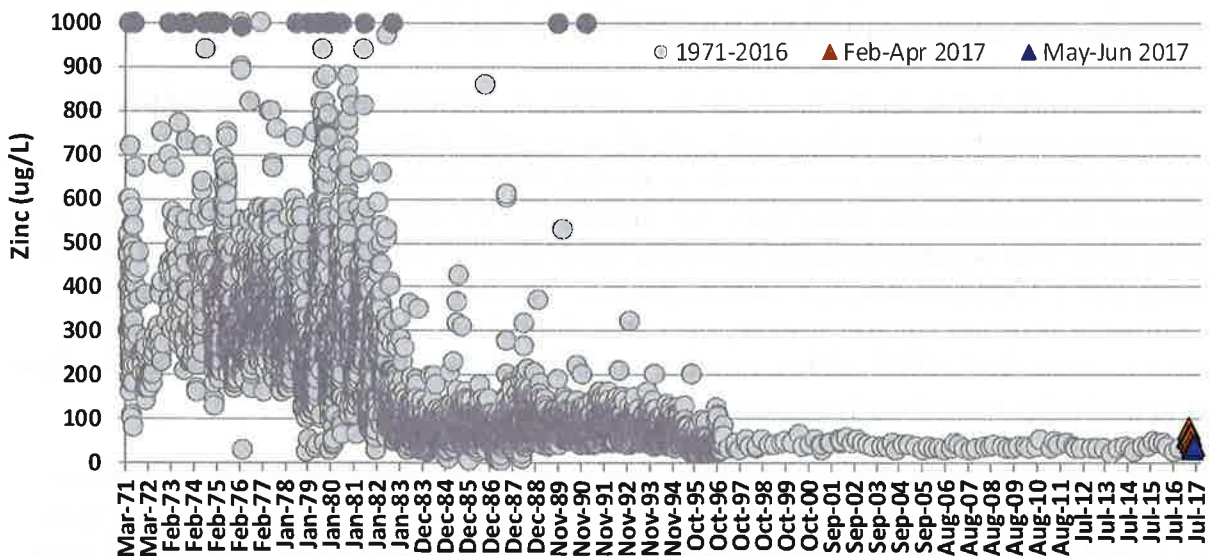


Figure 43. Zinc values during reduced treatment (orange) and secondary (blue) treatment compared to historical values (gray). Dark gray indicates value was higher than 1000 $\mu\text{g/L}$.

In summary, of the 14 metals analyzed, antimony, beryllium, cadmium, selenium, silver, and thallium, were either below detectable levels or infrequently detected at low concentrations, which is typical for these metals. All other metals were elevated to some degree during the period of reduced treatment and then declined to historical levels once secondary processes were restored.

Effluent arsenic concentrations were slightly higher during the period of reduced treatment compared to historical data as well as slightly higher than concentrations once secondary treatment processes were restored. Barium, nickel, and zinc concentrations were about one to two times higher during the period of reduced treatment compared to historical data, and were also around one to two times higher than concentrations once secondary treatment processes were restored. Although mercury values during the period of reduced treatment were just about one times higher than historical values, concentrations during this time were almost three times higher than the values once secondary treatment processes were restored. Other metals, such as chromium, copper, and lead, were substantially higher during the period of reduced treatment compared to historical data (about three to four times higher), and were also substantially higher (up to almost seven times higher) than concentrations once secondary treatment processes were restored. Similar to concentrations, total mass loads were higher during reduced treatment, and typically about or more than double the normal rates for several detected metals. The differences in metal concentrations and loads between the period of reduced treatment and full secondary treatment show that West Point treatment processes under normal conditions are effective at removing metals. Compared to the longer historical record available for some metals, values during the period of reduced treatment were significantly below levels prior to 1996 due to changes in influent quality and the upgrade to secondary treatment.

3.9 Organic Compounds

Seven effluent samples were analyzed for organic compounds between February 28 and June 5, 2017. Four samples were collected between February 28 and April 24, 2017 when effluent was receiving reduced treatment. Three samples were collected between May 10 and June 5, 2017 after secondary treatment processes had been restored. A total of 141 compounds were analyzed, which included polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides, polychlorinated biphenyls (PCBs), other semivolatile organics, and volatile organics (Table 3). For methods, see Appendix B. Of the 141 compounds, 12 were detected in the samples analyzed during the period of reduced treatment and 6 were detected in the samples analyzed once secondary treatment was restored. No PAHs, pesticides, or PCBs were detected in any sample. A list of all compounds, summary statistics of detected compounds, and detection limits, see Appendix C. Due to the lack of available data and few samples above detection limits, changes in loading rates of organic compounds were not estimated. Sampling results are summarized below.

Table 4 shows concentrations of the detected compounds in recent samples and the average and range of values detected in historical samples after the plant was upgraded to secondary treatment for comparison. The historical data for each compound includes a

summary of all sample results, regardless of the month analyzed. Past NPDES permits required effluent testing during specific months during wet (e.g., January and December) and dry seasons (e.g., July and August), resulting in no data available between 1996 and 2016 in April, May and June for the majority of the compounds listed in Table 4. Therefore, all available data since 1996 were included to allow comparisons. One-half the detection limit value was used to calculate summary statistics when a compound was not detected. Details on detected organic compounds can be found below.

Table 3. List of organic compounds analyzed in effluent samples during 2017. Bolded compounds were detected.

Polycyclic aromatic hydrocarbons	Pesticides & polychlorinated biphenyls	Other semivolatile organics	Volatile organics
2-Methylnaphthalene	4,4'-DDD	1,2-Diphenylhydrazine	1,1,1-Trichloroethane
Acenaphthene	4,4'-DDE	2,4,6-Trichlorophenol	1,1,2,2-Tetrachloroethane
Acenaphthylene	4,4'-DDT	2,4-Dichlorophenol	1,1,2-Trichloroethane
Anthracene	Aldrin	2,4-Dimethylphenol	1,1,2-Trichloroethylene
Benzo(a)anthracene	Alpha-BHC	2,4-Dinitrophenol	1,1-Dichloroethane
Benzo(a)pyrene	Alpha-Chlordane	2-Chloronaphthalene	1,1-Dichloroethylene
Benzo(b,j,k)fluoranthene	Aroclor 1016	2-Chlorophenol	1,2,4-Trichlorobenzene
Benzo(g,h,i)perylene	Aroclor 1221	2-Methylphenol	1,2-Dibromoethane
Benzo(r,s,t)pentaphene	Aroclor 1232	2-Nitrophenol	1,2-Dichlorobenzene
Chrysene	Aroclor 1242	3,3'-Dichlorobenzidine	1,2-Dichloroethane
Dibenzo(a,e)pyrene	Aroclor 1248	3,4-Methylphenol**	1,2-Dichloropropane
Dibenzo(a,h)acridine	Aroclor 1254	3-Methylcholanthrene	1,3-Dichlorobenzene
Dibenzo(a,h)anthracene	Aroclor 1260	4,6-Dinitro-O-Cresol	1,4-Dichlorobenzene
Dibenzo(a,h)pyrene	Beta-BHC	4-Chloro-3-Methylphenol	2,4-Dinitrotoluene
Dibenzo(a,i)acridine	Delta-BHC	4-Nitrophenol	2,6-Dinitrotoluene
Dibenzofuran	Dieldrin	Acrolein	2-Butanone (MEK)*
Fluoranthene	Endosulfan I	Acrylonitrile	2-Chloroethylvinyl ether
Fluorene	Endosulfan II	Benzidine	2-Hexanone
Indeno(1,2,3-Cd)Pyrene	Endosulfan Sulfate	Benzoic Acid*	4-Bromophenyl Phenyl Ether
Naphthalene	Endrin	Benzyl Alcohol*	4-Chlorophenyl Phenyl Ether
Perylene	Endrin Aldehyde	Benzyl Butyl Phthalate	4-Methyl-2-Pentanone (MIBK)
Phenanthrene	Gamma-BHC (Lindane)	Bis(2-Ethylhexyl)Phthalate**	Acetone**
Pyrene	Heptachlor	Carbazole	Benzene
	Heptachlor Epoxide	Diethyl Phthalate**	Bis(2-Chloroethoxy)Methane
	Methoxychlor	Dimethyl Phthalate	Bis(2-Chloroethyl)Ether
	Total Aroclors	Di-N-Butyl Phthalate	Bis(2-Chloroisopropyl)Ether
	Toxaphene	Di-N-Octyl Phthalate*	Bromodichloromethane
	trans-Chlordane	Hexachlorobenzene	Bromoform
		Hexachlorobutadiene	Bromomethane
		Hexachlorocyclopentadiene	Carbon Disulfide
		Isophorone	Carbon Tetrachloride
		n-Decane	Chlorobenzene
		Nitrobenzene	Chlorodibromomethane
		N-Nitrosodimethylamine	Chloroethane
		N-Nitrosodi-N-Propylamine	Chloroform**
		N-Nitrosodiphenylamine	Chloromethane
		n-Octadecane*	Cis-1,3-Dichloropropene
		Pentachlorophenol	Ethylbenzene
		Phenol*	Hexachloroethane

Polycyclic aromatic hydrocarbons	Pesticides & polychlorinated biphenyls	Other semivolatile organics	Volatile organics
			Methylene Chloride
			Methyl-t-butyl Ether (MTBE)
			O-Xylene
			Styrene
			Tetrachloroethylene
			Toluene**
			Total Xylenes
			Trans-1,2-Dichloroethylene
			Trans-1,3-Dichloropropene
			Trichlorofluoromethane
			Vinyl Acetate
			Vinyl Chloride

Bolded = detected in one or more sample

* = detected during the period of reduced treatment

** = detected during reduced primary and secondary treatment

Table 4. List of organic compounds detected in 2017 and comparison with historical data. All concentrations are in µg/L. Values in parentheses are detection limits and provided when compounds were not detected.

Compound	Reduce Treatment				Secondary Treatment			1996-2016		
	Feb 28	Mar 8	Apr 4	Apr 24	May 10	May 22	Jun 5	FOD	Mean	Range
2-Butanone (MEK)	<(5.0)	7.4	<(5.0)	<(5.0)	<(5.0)	<(5.0)	<(5.0)	0/86	--	--
3-,4-Methylphenol	34.8	33	20.1	16.5	1.42	1.33	0.717	8/12	0.452	<0.12-0.91
Acetone	177	143	53	66.7	3.3	8.9	2.6	54/86	17.5	<2.5-168
Benzoic Acid	103	88.5	54.5	20.3	<(2.0)	<(2.0)	<(2.0)	19/56	5.42	1.83-20.8
Benzyl Alcohol	24.1	37.7 ^B	14.6	5.61 ^B	<(0.13)	<(0.13)	<(0.13)	2/56	1.28	<0.13-2.3
Bis(2-Ethylhexyl) Phthalate	1.8	1.1	0.64	0.77	0.45	0.626	<(0.13)	53/56	2.41	0.21-13.2
Chloroform	2.1	2.01	1.6	2.0	1.5	1.4	1.4	80/86	4.05	<1.0-8.52
Diethyl Phthalate	1.43	1.56 ^B	0.72	0.63	0.378	1.05 ^B	<(0.13)	7/56	0.664	<0.13-1.6
Di-N-Octyl Phthalate	0.68	<(0.38)	<(0.38)	<(0.38)	<(0.075)	<(0.075)	<(0.075)	2/56	1.28	<0.071-2.2
n-Octadecane	1.19	0.67	<(0.38)	<(0.38)	<(0.075)	<(0.075)	<(0.075)	1/32	0.88	--
Phenol	7.85	6.56	3.6	3.87	<(0.50)	<(0.50)	<(0.50)	1/56	3.8	--
Toluene	1.3	<(1.0)	1.6	1.5	<(1.0)	<(1.0)	1.1	10/86	1.56	<1.0-2.52

FOD = frequency of detection

B= blank contamination detected. Benzyl alcohol values are expected to be true values.

Volatile Organics

Volatile organic compounds easily become vapors or gasses from solid or liquid forms, therefore not persisting long in the liquid form. Four volatile organic compounds were detected in effluent samples between February and June, 2017.

2-butanone (MEK), an industrial solvent, was detected in a single sample at a concentration of 7.4 µg/L on March 8, 2017 during the period of reduced treatment. The detected concentration was slightly above the detection limit of 5.0 µg/L. This compound was not detected in subsequent samples and has not been detected previously in secondary treated effluent.

Acetone is a compound frequently used in paint coatings, varnishes, cleaners, and also contained in automobile exhaust and wood and plastic combustion emissions. While it volatilizes readily, it is also soluble in water. Acetone was detected in all samples. The average concentrations of acetone during the period of reduced treatment was 109.9 µg/L, and was 4.9 µg/L once secondary treatment processes were restored. This sharp decline in concentrations is shown in Figure 44. Acetone is a compound that is typically detected in primary treated effluent. The average acetone concentration in the months of February through April between 1990 and early 1996 (prior to the secondary treatment upgrade at the West Point TP) was 103.0 µg/L. This historical value, when West Point was a primary plant, is similar to the concentration seen during the period of reduced treatment in 2017. After the plant upgrade to secondary treatment, the historical average acetone concentration between February and April was 8.2 µg/L, similar to the observed value once secondary processes were restored in 2017.

Chloroform was detected in all the samples and concentrations were not substantially different between the periods of reduced and secondary treatment (see Table 4). Chloroform is typically detected in West Point effluent samples as low levels are generated in the final effluent during the chlorination process used for disinfection.

Toluene was detected in three of the samples during the period of reduced treatment and one after secondary processes were restored. Detected values ranged from 1.1 to 1.6 µg/L, which is similar to the historical range. Toluene is one of the most commonly detected volatile compounds in wastewater treatment plant effluent (Jelic et al., 2015). Toluene is an aromatic hydrocarbon and used as a cleaning solvent and in the manufacturing process for several products, including paints, coatings, adhesives, and resins. It is also used in blending gasoline to increase the octane content and contained in vehicle emissions (EPA, 1994). As with other volatile organic compounds, it volatilizes rapidly into the atmosphere.

Phthalates

Phthalates are semi-volatile organic compounds that are widely used as additives in a variety of plastics and other materials to make them soft and flexible. They are ubiquitous in the environment as they are not chemically bound to plastics and can be leached out of products. Three phthalates were detected in effluent. As with the other compounds, concentrations of phthalates declined once secondary processes were restored.

Bis(2-ethylhexyl)phthalate was detected in all the samples, with the exception of the sample collected on June 5. The average concentration was 1.1 µg/L during the period of reduced treatment and was only detected in two of three samples, with an average concentration of 0.54 µg/L, once secondary treatment was restored. Concentrations throughout the sampling period were lower than the historical average observed since 1996, and at the low end of the range compared to historical values.

Diethyl phthalate was detected in all samples, with the exception of the sample collected on June 5. Diethyl phthalate is a common laboratory contaminant and two of the samples (one during the period of reduced treatment and one during the period of secondary treatment) did contain blank contamination. Excluding the two values with blank contamination, the average concentration of diethyl phthalate was 0.93 µg/L during the period of reduced treatment and 0.22 µg/L, once secondary treatment was restored.

Di-n-octyl phthalate was detected in one sample collected on February 28, 2017, during the period of reduced treatment and was not detected in subsequent samples. Based on past data, this compound is rarely detected in secondary treated effluent; however, when it is detected, it is observed at a similar concentration.

Other semi-volatile organic compounds

Benzoic acid was detected in all samples during the period of reduced treatment, but was not detected in any samples once secondary treatment processes were fully restored. The average concentration of benzoic acid during the period of reduced treatment was 66.5 µg/L. Benzoic acid is one of several compounds (including benzyl alcohol and phenol) that serve as a food source for the microbes used in the secondary treatment process and are efficiently removed.

Benzyl alcohol was detected in all samples during the period of reduced treatment, but was not detected in any samples once secondary treatment processes were fully restored. Two of the benzyl alcohol samples during the period of reduced treatment did contain blank contamination, but the compound is a common laboratory contaminant and the contamination was expected to be limited to water samples used for the method blank analysis. Therefore, the samples themselves were not expected to be affected by this contamination. The average concentration of benzyl alcohol from the four samples collected during the period of reduced treatment was 20.5 µg/L. Benzyl alcohol is one of several compounds (including benzoic acid and phenol) that serve as a food source for the microbes used in the secondary treatment process and are efficiently removed.

3-,4-methylphenol was detected in all samples. The average concentration was 26.1 µg/L during the period of reduced treatment and 1.2 µg/L once secondary treatment processes were restored. This decline in concentrations is shown in Figure 44. In this case, levels during reduced treatment were elevated compared to historical data collected since 1996.

Phenol was detected in all samples during the period of reduced treatment, but was not detected in any samples once secondary treatment processes were fully restored. The average concentration of phenol during the period of reduced treatment was 5.47 µg/L. Phenol is one of several compounds (including benzoic acid and benzyl alcohol) that serve as a food source for the microbes used in the secondary treatment process and are efficiently removed.

N-octadecane was detected in two samples between February 28 and March 8, 2017, and was not detected in subsequent samples. Based on past data, this compound is rarely detected in secondary treated effluent.

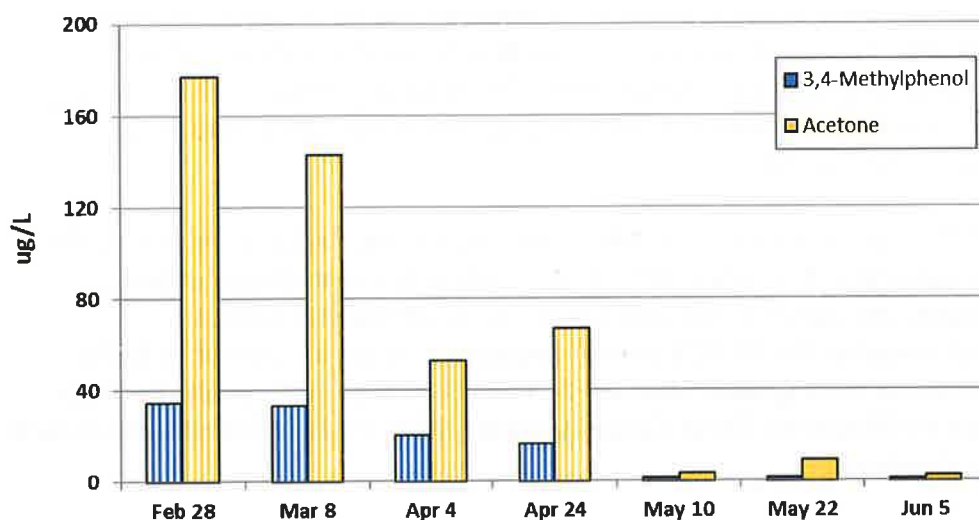


Figure 44. Concentrations of acetone and 3,4-methylphenol during reduced (February 28-April 24, 2017) and secondary (May 10-June 5, 2017) treatment.

In summary, most of the 141 organic compounds analyzed from effluent samples collected between February and June of 2017 were not detected, as is common in effluent samples. Concentrations of volatile and semi-volatile organic compounds detected in effluent during the period of reduced treatment were at their highest concentration early in the restoration process and subsequently decreased. Semi-volatile organics that were only detected during reduced treatment are compounds that serve as a food source for microbes in secondary treatment. Of the few compounds that were detected both during reduced treatment and after secondary treatment processes were restored, all were detected at higher concentrations during the period of reduced treatment. These same compounds were within historical ranges from May to June of 2017 after secondary treatment processes were restored, with the exception of 3,4-methylphenol, whose concentration was outside of the historic range until the last sampling event on June 5. These data suggest that by June, 2017 the concentration of organic compounds in West Point's effluent had returned to expected levels for secondary treatment.

3.10 Whole Effluent Toxicity

During the period while repairs to West Point were underway, King County analyzed the effluent for the permit-required quarterly acute and chronic Whole Effluent Toxicity (WET) tests. The WET tests were conducted on a series of effluent concentrations ranging from the calculated dilution ratio that occurs in the initial zone of mixing at the main outfall diffuser. As specified in the NPDES permit, the Acute Critical Effluent Concentration (ACEC) is 3.6% effluent, and the Chronic Critical Effluent Concentration (CCEC) is 0.53% effluent. WET testing is conducted on a dilution series: 0% (control), 0.53% (chronic only), 3.6% (ACEC), 12.5%, 25%, 50%, and 100% effluent. The ACEC and CCEC test concentrations are evaluated to reflect the maximum anticipated concentration of effluent that organisms would be expected to encounter in the marine environment outside of the initial zone of effluent mixing. Acute WET test data are evaluated to determine if undiluted effluent (100% effluent) exhibits acute toxicity relative to the 0% control. Similarly, the chronic WET test data are evaluated to determine if there is evidence of toxicity at the ACEC concentration relative to the control.

A summary of the WET tests are shown in Table 5 and a more detailed description of the test results are provided below. The acute WET test is conducted to evaluate effluent toxicity to two organisms: an invertebrate and a fish. For acute toxicity tests, the performance standard stated in the NPDES permit requires a median survival in 100% effluent to be at levels equal to or greater than 80%. The acute WET test results for both organisms showed the No Observed Effect Concentration (NOEC) was 100% effluent which met the performance standard.

The chronic WET test is also conducted using an invertebrate and a fish. The chronic toxicity test performance standard requires that no chronic toxicity test shows a statistically significant difference in response between the control and test concentration equal to the ACEC. The chronic WET test results showed fish survival was 92% at the CCEC and ACEC concentrations and invertebrate survival was 93% at the ACEC, in addition to no significant difference in growth between the control and effluent samples.

Based upon the WET test results, both the acute and chronic toxicity tests performance standards outlined in the NPDES permit continued to be met during the plant restoration. Results from the March and April 2017 toxicity tests conducted using effluent during the period of reduced treatment were comparable to past results conducted using fully treated secondary effluent. Details regarding the methods and test results are provided in the toxicity test reports (King County, 2017f,g).

Acute Toxicity

Acute WET tests are conducted in the first and third quarter of the year for West Point. Acute WET testing effluent samples were collected on March 21, 2017. The acute WET test is conducted using the invertebrate *Daphnia pulex* (water flea) in a 48-hour test period, and the fathead minnow (*Pimephales promelas*) in a 96-hour test period.

The fathead minnow acute toxicity test survival was 100% in the control, 3.6% (ACEC) effluent, and 12.5% effluent. Survival was 95% in the 25% and 50% effluent and 93% in 100% effluent. The NOEC was 100% effluent. An LC50 (lethal concentration to 50 % of the test organisms) could not be calculated due to lack of mortality.

The *Daphnia pulex* acute toxicity test survival was 100% in the control and all effluent concentrations. The NOEC was 100% effluent and a LC50 could not be calculated due to lack of mortality.

There was no statistically significant difference in survival at the ACEC for either *Daphnia pulex* or the fathead minnow.

Chronic Toxicity

Chronic WET tests are conducted in the second and fourth quarter of the year for West Point and effluent samples were collected on April 5, 2017. The chronic WET test evaluates potential aquatic toxicity by observation of significant differences in mortality and growth (weight) of organisms incubated in the effluent concentration series samples relative to organisms in the laboratory control water sample. Topsmelt fish (*Atherinops affinis*) and mysid shrimp (*Mysidopsis bahia*) are both evaluated in a 7-day test period for the chronic WET test.

The topsmelt test 7-day survival was 80% in the control and 25% effluent concentration. Survival was 92% in the CCEC (0.55% effluent) and ACEC (3.6% effluent). Survival was 72% in 25% effluent and 76% in 50% effluent. There were no survivors in 100% effluent. Growth in the ACEC was not reduced relative to the control. The IC25 (effluent concentration inhibiting growth by 25%) for growth was 55.7% effluent.

In the mysid test, survival was 95% in the control and 25% effluent. Survival was 98% in 0.55% (CCEC) effluent and 93% in 3.6% (ACEC) effluent. Survival was 90% in 12.5% effluent and 83% in 50% effluent. There were no survivors in 100% effluent. Growth in the ACEC concentration was not significantly reduced relative to the control ($p > 0.05$; 1-tailed t-Test). The IC25 for growth was 24.6% effluent.

There was no statistically significant difference in growth at either CCEC or ACEC for the chronic WET tests.

Table 5. Acute and chronic whole effluent toxicity (WET) test results in 2017.

Acute Toxicity Test Results

Test Organism	LC50 % Effluent	NOEC % Effluent	Percent Survival in 100% Effluent
Fathead Minnow (<i>Pimephales promelas</i>)	>100	100	93
Water Flea (<i>Daphnia pulex</i>)	>100	100	100

Chronic Toxicity Test Results

Test Organism	Growth IC25 ^a % Effluent	Difference in Growth from Control (Control vs ACEC ^b)
<i>Atherinops affinis</i>	55.7	Not Significantly Different
<i>Mysidopsis bahia</i>	24.6	Not Significantly Different

^a Concentration of effluent inhibiting growth by 25%^b Acute Critical Effluent Concentration (3.6% effluent)

3.11 Mixing Zone Analysis

The West Point NPDES permit allows for a mixing zone where effluent mixes with Puget Sound receiving waters. Mixing occurs near the outfall due to a combination of density differences, tides, currents, and the momentum of the discharge. The permit requires that Washington State's marine water quality standards are met at the edge of the mixing zone. Effluent ammonia and metals concentrations from February through June were combined with two mixing zone dilution estimates to evaluate compliance with water quality standards at the edge of the mixing zone. This section summarizes assessments that were conducted for data collected during the plant's restoration period using methods and contextual data for West Point included in its NPDES permit. This assessment, using maximum effluent concentrations recorded during the restoration process, was conducted to determine if receiving waters were likely to exceed water quality criteria due to West Point effluent discharges.

Mixing characteristics and modeling of the effluent discharged to Puget Sound receiving waters have been previously assessed as part of the NPDES permit renewal process (Ecology, 2014). For protection of aquatic life from harm due to chronic exposures (i.e., long-term) to contaminants, modeling of the effluent mixing zone (included as part of the NPDES permit renewal process) was based on typical tidal flow and maximum monthly effluent discharge rates. The dilution factor of 188:1 was established in the NPDES permit for the modeled worst-case scenario based on minimum dilution at the edge of the allowed mixing zone, 860 feet from the outfall. This scenario occurs in July when stratification in receiving waters is typically strongest and mixing is less. While effluent flows are higher in winter months, more dilution occurs due to less stratification. While overall flows were higher in February than typical, they were not unusually high for West Point during winter months, and therefore the dilution factor from the permit is still a conservative estimate for the period of reduced treatment. Similarly, for protection of aquatic life from harm due to acute exposure (short-term), the dilution is assessed for conditions of peak daily effluent discharge into minimal tidal flow conditions at the edge of the acute mixing zone, 86 feet from the outfall. Mixing under the acute flow conditions results in a 28:1 dilution factor of seawater to effluent.

As part of the NPDES permit renewal process's reasonable potential analysis, contaminant concentrations at the edge of the zone of initial mixing were calculated with the dilution factors above for acute and chronic exposure scenarios. The analysis used estimated 95th percentile effluent concentration and 90th percentile receiving water concentration. The

constituents analyzed included those for which Washington State has adopted marine water quality criteria for the protection of aquatic life. The initial study determined that under normal operation of the West Point TP, discharges have no potential to cause or contribute to exceedances of any receiving water criteria (Ecology, 2014). Consequently, the West Point NPDES permit does not include operational requirements (i.e., effluent limitations) for any of the trace metals or ammonia. The values used for these calculations (historic 95th percentile effluent and 90th percentile ambient concentrations) were used in the calculations detailed below to provide context to effluent values measured during the treatment plant's restoration process.

A mixing calculation was used to assess whether Washington State water quality standards for ammonia and metals were exceeded between February and June, 2017 at the edge of the acute and chronic mixing zones. The dilution factors and ambient concentrations determined during the most recent characterization study (King County, 2013) were used to calculate edge of the mixing zone concentrations based off of the following mass balance approach:

$$MC = [EC + (AC \times DF)] / (1 + DF)$$

Where:

EC = Effluent concentration (*Maximum concentration for time period*)

AC = Ambient concentration (*90th percentile as detailed in NPDES permit*)

DF = Dilution factor (*acute = 28; chronic = 188*)

The maximum effluent concentration for each contaminant recorded during the sampling period was used in calculations. Maximum effluent concentrations were determined from: the period of reduced treatment (collected between February 28 and April 24) and the period of secondary treatment (collected May 10–June 20).

Effluent concentrations of trace metals are measured as total metals, but the ambient Puget Sound conditions and the water quality standards are reported as only the dissolved fraction. As such, prior to executing mixing zone calculations, total metals concentrations were adjusted using total to dissolved metals ratios (translator values) specific to the West Point TP's NPDES permit (available in Appendix B).

The results are presented in Table 6 for the acute mixing zone estimates and comparison to acute water quality criteria, and Table 7 for the chronic mixing zone estimates and comparison to chronic water quality criteria. The results of these assessments illustrate the worst-case scenario of concentrations of contaminants (ammonia and trace metals) at the edge of the zone of initial mixing from effluent observations. These calculated concentrations were then compared to estimates based on historical data. Additionally, concentrations were compared to water quality standards to determine if the effluent could have led to exceedances of water quality standards at the edge of the mixing zone.

This analysis indicates that concentrations at the edge of the mixing zone were highest during the period of reduced treatment for all parameters measured (Table 6 and Table 7).

Ammonia concentrations were estimated to be lower than historical estimates throughout the restoration process. Of the metals evaluated, lead had the highest concentration increase at the edge of the mixing zone relative to typical concentrations (161% acute; 122% chronic) during the period of reduced treatment. The concentration of all other analyzed constituents during the period of reduced treatment differed from historic values at a range of -10% (nickel, acute) to 57% (copper, acute). The concentrations of ammonia and trace metals at the edge of the mixing zone were lower than historic estimates during the period of secondary treatment from May 10 through June.

The results of this assessment indicate that at no time during the period of reduced treatment did effluent ammonia or metals concentrations rise to the level that would exceed any applicable criterion in Puget Sound receiving waters. State water quality criteria were developed to be protective of aquatic life. Therefore, no short-term impacts to biota were expected due to the quality of effluent discharged to Puget Sound receiving waters during the period of reduced treatment.

Table 6. Acute mixing zone analysis based on 28:1 dilution. All metals are reported as the dissolved fraction.

Concentrations During Reduced Treatment (collected Feb. 28–Apr. 24)										Concentrations During Secondary Treatment (collected May 10–Jun. 20)				
Parameter	90% Ambient Puget Sound (µg/L)	Acute Criteria (µg/L)	Historic 95% Acute Mixing Zone (µg/L)	n	Effluent Max (µg/L) ^a	Est. Acute Mixing Zone (µg/L)	% Change (2017 vs historic)	Above Acute Criteria?	n	Effluent Max (µg/L) ^a	Est. Acute Mixing Zone (µg/L)	% Change (2017 vs historic)	Above Acute Criteria?	
Ammonia	85	8923	1151	11	15200	606	-47%	NO	10	13900	561	-51%	NO	
Arsenic	1.39	69.0	1.42	8	2.03	1.41	0%	NO	4	1.49	1.39	-2%	NO	
Cadmium	0.073	42.0	0.075	8	0.279	0.080	7%	NO	4	0.065	0.073	-3%	NO	
Chromium	0.148	1000.0	0.18	8	3.27	0.26	39%	NO	4	0.78	0.17	-8%	NO	
Copper	0.363	4.8	0.79	8	25.99	1.25	57%	NO	4	10.2	0.70	-12%	NO	
Lead	0.005	210.0	0.09	8	6.36	0.22	161%	NO	4	0.70	0.03	-66%	NO	
Mercury	0.00020	1.8	0.0006	8	0.0139	0.0007	4%	NO	3	0.0041	0.0003	-48%	NO	
Nickel	0.424	74.0	0.616	8	4.20	0.554	-10%	NO	4	2.66	0.501	-19%	NO	
Silver	0.027	1.9	0.030	8	0.153	0.031	4%	NO	4	0.060	0.028	-7%	NO	
Zinc	0.643	90.0	2.28	8	76.6	3.26	43%	NO	4	39.4	1.98	-13%	NO	

^aNPDES designated translator values were used to convert effluent total metals concentrations to expected dissolved fractions for comparison to water quality criteria. Translator values are provided in Appendix B.

Table 7. Chronic mixing zone analysis based on 188:1 dilution. All metals are reported as the dissolved fraction, except for the chronic criterion for mercury, which is total.

Parameter	90% Ambient Puget Sound (µg/L)	Chronic Criteria (µg/L)	Historic 95% Chronic Mixing Zone (µg/L)	Concentrations During Reduced Treatment (collected Feb. 28–Apr. 24)					Concentrations During Secondary Treatment (collected May 10–Jun. 20)				
				n	Effluent Max (µg/L) ^a	Est. Chronic Mixing Zone (µg/L)	% Change (2017 vs historic)	Above Chronic Criteria?	n	Effluent Max (µg/L) ^a	Est. Chronic Mixing Zone (µg/L)	% Change (2017 vs historic)	Above Chronic Criteria?
Ammonia	85	1340	249	11	15200	165	-34%	NO	10	13900	158	-36%	NO
Arsenic	1.39	36	1.39	8	2.03	1.39	0%	NO	4	1.49	1.39	0%	NO
Cadmium	0.073	9.3	0.073	8	0.279	0.074	1%	NO	4	0.065	0.073	0%	NO
Chromium	0.148	50	0.153	8	3.27	0.165	7%	NO	4	0.78	0.151	-1%	NO
Copper	0.363	3.1	0.429	8	26.0	0.499	16%	NO	4	10.2	0.415	-3%	NO
Lead	0.005	8.1	0.017	8	6.36	0.039	122%	NO	4	0.70	0.009	-50%	NO
Mercury ^b	0.00048	0.025	0.00056	8	0.01640	0.00056	1%	NO	3	0.0048	0.00050	-10%	NO
Nickel	0.424	8.2	0.453	8	4.2	0.444	-2%	NO	4	2.66	0.436	-4%	NO
Silver	0.027	n/a	0.028	8	0.15	0.028	1%	n/a	4	0.060	0.027	-1%	n/a
Zinc	0.643	81	0.89	8	76.626	1.05	17%	NO	4	39.4	0.85	-5%	NO

^aNPDES designated translator values were used to convert effluent total metals concentrations (with the exception of Mercury) to expected dissolved fractions for comparison to water quality criteria. Translator values are provided in Appendix B.

^bThe chronic criterion for mercury is based on total mercury.

4.0 RECEIVING WATERS MONITORING RESULTS

4.1 Bacteria

King County routinely monitors both fecal coliforms and *Enterococcus* at beach and offshore sites. In the event of a large untreated sewage discharge by a King County facility, King County will monitor bacteria at nearby beaches and King County's Department of Public Health will close beaches as necessary based on the concentrations reported.

Immediately following the discharge of untreated wastewater out the EBO, King County Public Health closed beaches from Alki to Carkeek Park and daily monitoring of bacteria concentrations began at the public beaches nearest to the West Point Treatment Plant: Discovery Park (north and south beaches), Golden Gardens, and Carkeek Park. These are the public beaches that effluent was most likely to impact due to circulation patterns near West Point (see Figure 3). During the time when treatment systems were being restored, the routine marine monitoring programs continued to monitor bacteria in the Puget Sound Central Basin at increased frequencies at a subset of sites.

A summary of the results of immediate response monitoring as well as enhanced long-term monitoring efforts related to this event are summarized below, following a description of marine bacteria criteria that are applicable to the discussion of results.

4.1.1 Fecal Indicator Bacteria Criteria

To protect humans in contact with marine waters, the EPA and Ecology developed marine water quality criteria for fecal indicator bacteria. The Washington State primary contact criteria for surface waters are for fecal coliforms. However, Ecology's BEACH monitoring program and King County Public Health use the *Enterococcus* criteria based on the EPA's *Ambient Water Quality Criteria for Bacteria* (1986) to determine beach warnings and closures.

The *Enterococcus* criteria based on EPA recommendations includes two parts and if either of the following criteria are exceeded the beach is closed to swimming:

- The geometric mean shall not exceed 35 *Enterococcus*/100 mL; based on the results from a minimum of five weekly samples.
- The *Enterococcus* maximum should not exceed 276 *Enterococcus*/100 mL.

Additionally, a Beach Action Value is used and an advisory is issued if mean *Enterococcus* concentrations exceed 104 colony forming units (CFU)/100 mL.

The geometric mean criteria is used to determine chronic or seasonal problems, while the maximum and beach action values are used to determine if closures or beach advisories, respectively, are necessary after a beach sampling event.

To be protective of primary contact recreation, the State of Washington uses a two part criteria for fecal coliform bacteria:

- Fecal coliform organism levels must not exceed a geometric mean value of 14 colonies/100 mL.
- No more than 10% of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 43 colonies/100 mL.

Similar to *Enterococcus*, the geometric mean criterion is best used for identifying chronic issues at beaches, while the peak criterion is more applicable when the number of samples is limited. For both the *Enterococcus* and fecal coliform criteria, multiple samples collected in a single day are averaged prior to comparison to criteria.

4.1.1.1 Initial Beach Monitoring Results

Three samples were collected at each of the four beaches immediately following the first discharge event at the West Point EBO on February 9. Concentrations of *Enterococcus* were orders of magnitude above the EPA guidelines on February 9, with the highest bacteria concentrations occurring at the north beach of Discovery Park, nearest the location of the EBO (Figure 45). There, the highest concentration was 22,000 CFU/100 mL and the mean of three samples was 15,333 CFU/100 mL. Because samples are indicative of a single event, and not a chronic problem, the Beach Action Value (104 CFU/100 mL) and the maximum criterion (276 CFU/100 mL) are most applicable to the data collected. At all four beaches, all individual samples and the mean of all three samples were below the lower Beach Action Value within three days or less of the two discharge events (Figure 46 and Table 8).

Table 8 shows concentrations of *Enterococcus* between February 9 and 21 at the four beaches with exceedances of the Beach Action Value and maximum criterion highlighted.

While not used to close or open beaches, the concentration of fecal coliforms is also important for understanding potential risks to swimmers at beaches. Similar to *Enterococcus*, fecal coliform concentrations were well above Washington's marine water quality criteria on February 9, with the highest bacteria concentrations occurring at the north beach of Discovery Park, nearest the location of the EBO (Figure 47). There, the fecal coliform concentrations were as high as 20,000 CFU per 100 mL in a single sample and the mean of three samples was 17,333 CFU/100 mL. While individual samples may have exceeded the peak water quality criterion for fecal coliforms (43 CFU/100 mL), mean concentrations at each site decreased to below the State's peak water quality criterion within three days or less following each discharge event (Figure 46 and Table 9).

Table 9 details concentrations of fecal coliforms between February 9 and 21 at the four beaches with exceedances of the peak criterion highlighted.

Both *Enterococcus* and fecal coliforms were high immediately following the two discharge events, but rapidly declined. In addition to dilution/dispersion, these types of fecal bacteria typically do not survive well in the marine environment. The survival rate of indicator bacteria in aquatic environments is dependent on a number of factors, which include salinity, temperature, solar irradiance, nutrient availability, presence of organic matter, and predation by protozoans (Gameson and Gould, 1975; McCambridge and McMeekin, 1981; Davies-Colley et al., 1994; Alkan et al., 1995; Rozen and Belkin, 2001; and Noble et al., 2004). Past monitoring following untreated discharge events suggest that fecal indicator bacteria typically decline to background levels three days following the discharge. Therefore, the rapid decrease in concentration was expected.

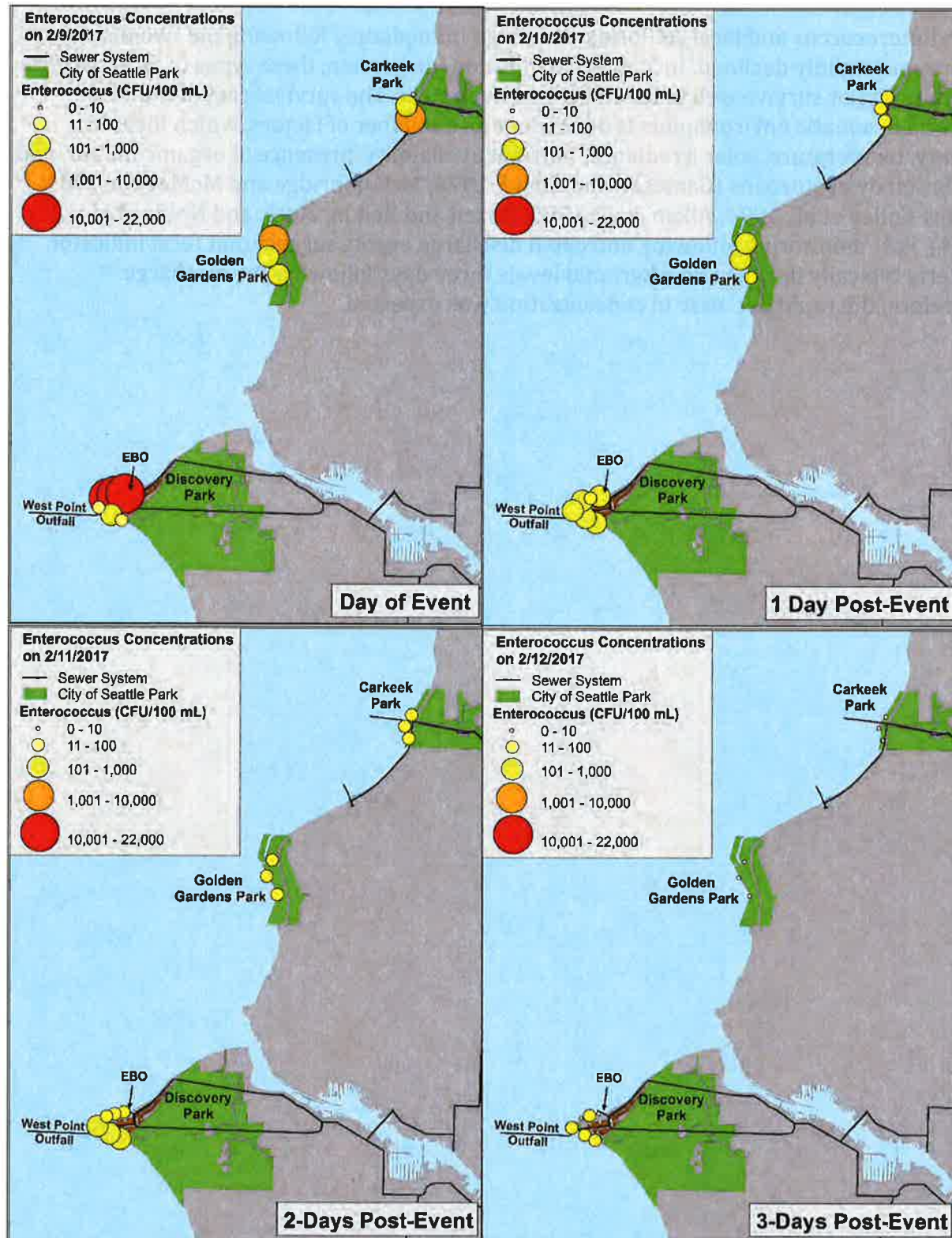


Figure 45. Enterococcus concentrations at beaches near the West Point Wastewater Treatment Plant for consecutive days following the initial plant flooding and discharge event.

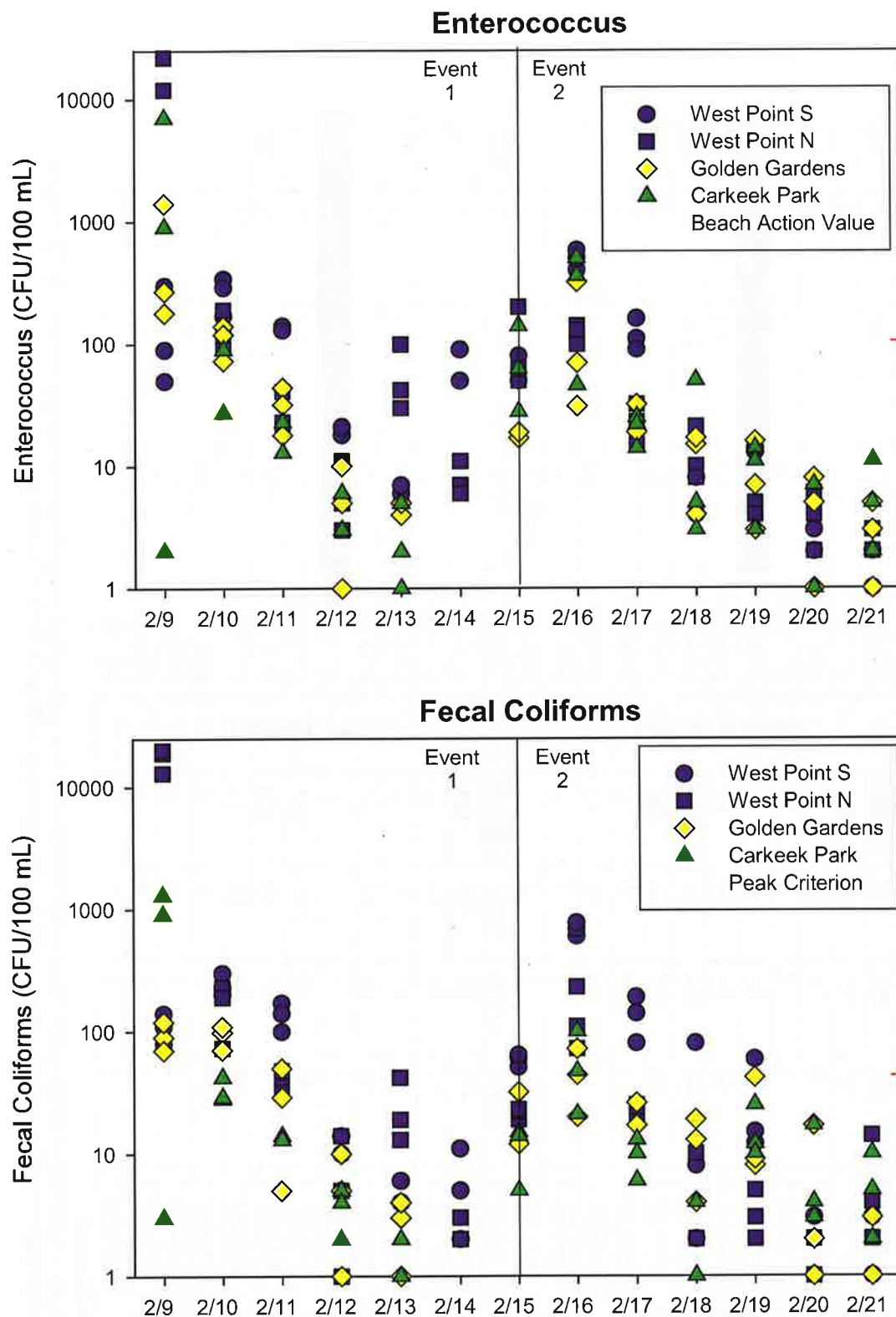


Figure 46. Enterococcus and fecal coliform concentrations at beaches following overflow events on February 9, 2017 (Event 1) and February 15/16, 2017 (Event 2). Note log-scale.

Table 8. Results of Enterococcus monitoring at beach sites following the three West Point EBO discharge events. Three samples (A, B, and C) were analyzed at each site.

Event	Site	Date	Enterococcus (CFU/100 mL)				Site	Date	Enterococcus (CFU/100 mL)			
			A	B	C	Mean			A	B	C	Mean
1	West Point South	2/9/2017	50	300	90	147	Golden Gardens	2/9/2017	270	180	1400	617
		2/10/2017	340	290	170	267		2/10/2017	73	140	120	111
		2/11/2017	140	140	130	137		2/11/2017	44	32	18	31
		2/12/2017	18	21	21	20		2/12/2017	10	1	5	5
		2/13/2017	5	6	7	6		2/13/2017	5	4	5	5
		2/14/2017	90	50	50	63		2/14/2017				
		2/15/2017	80	50	50	60		2/15/2017	17	17	19	18
		2/16/2017	400	500	580	493		2/16/2017	70	320	31	140
2	West Point North	2/17/2017	160	110	90	120	Carkeek Park	2/17/2017	32	19	19	23
		2/18/2017	4	4	8	5		2/18/2017	15	17	4	12
		2/19/2017	13	14	14	14		2/19/2017	16	7	3	9
		2/20/2017	2	5	3	3		2/20/2017	8	5	<MDL(1)	7
		2/21/2017	<MDL(1)	2	2	1		2/21/2017	<MDL(1)	3	5	3
		2/9/2017	22000	12000	12000	15333		2/9/2017	7000	<MDL (900)	2	2634
		2/10/2017	190	99	120	136		2/10/2017	90	27	27	48
		2/11/2017	21	23	41	28		2/11/2017	23	23	13	20
1	West Point North	2/12/2017	3	11	5	6	Carkeek Park	2/12/2017	6	3	3	4
		2/13/2017	99	30	42	57		2/13/2017	5	1	2	3
		2/14/2017	11	7	6	8		2/14/2017				
		2/15/2017	50	63	200	104		2/15/2017	140	63	28	77
		2/16/2017	140	130	99	123		2/16/2017	500	360	46	302
		2/17/2017	15	23	32	23		2/17/2017	25	22	14	20
		2/18/2017	21	10	8	13		2/18/2017	50	3	5	19
		2/19/2017	5	4	4	4		2/19/2017	14	11	3	9
2	West Point North	2/20/2017	2	6	4	4		2/20/2017	7	<MDL(1)	1	3
		2/21/2017	3	2	3	3		2/21/2017	11	5	2	6

CFU = Colony forming unit

Yellow cells indicate exceedance of Beach Action Value (104 CFU/100 mL). Pink cells indicate exceedance of maximum criteria (276 CFU/100 mL).

Event 1 – EBO discharge 3:05 am to 8:50 pm 2/9/17; Event 2 – EBO discharge 3:50 am on 2/15/17 to 6:05 am 2/16/17

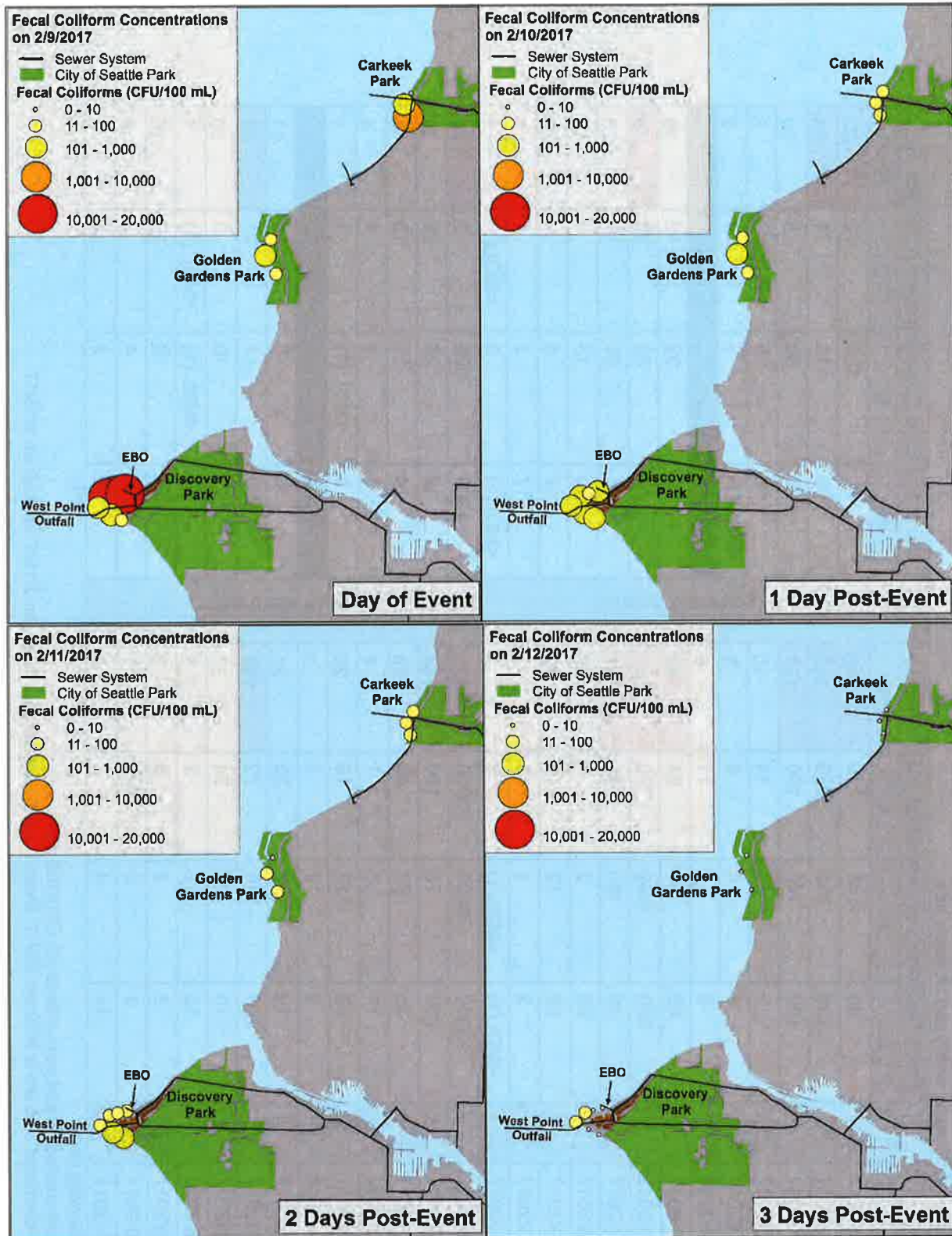


Figure 47. Fecal coliform concentrations at beaches near the West Point Wastewater Treatment Plant for consecutive days following the initial plant flooding and discharge event.

Table 9. Results of fecal coliform monitoring at beach sites following the three West Point EBO discharge events. Three samples (A, B, and C) were analyzed at each site.

Event	Date	Site	Fecal Coliform Concentration (CFU/100 mL)				Site	Fecal Coliform Concentration (CFU/100 mL)			
			A	B	C	Mean		A	B	C	Mean
1	2/9/2017	West Point South	80	140	110	110	Golden Gardens	90	120	70	93
	2/10/2017		230	300	200	243		99	110	71	93
	2/11/2017		170	140	100	137		29	50	5	28
	2/12/2017		5	10	14	10		10	5	<MDL (1)	5
	2/13/2017		4	4	6	5		<MDL (1)	3	4	2
	2/14/2017		5	2	11	6					
	2/15/2017		60	51	64	58		32	32	12	25
2	2/16/2017	West Point South	600	690	770	687		44	72	20	45
	2/17/2017		80	190	140	137		26	26	17	23
	2/18/2017		80	2	8	30		19	13	4	12
	2/19/2017		59	12	15	29		42	8	9	20
	2/20/2017		2	1	3	2		17	2	1	7
	2/21/2017		<MDL(1)	<MDL(1)	3	1		<MDL(1)	3	<MDL(1)	1
	2/9/2017	West Point North	19000	20000	13000	17333	Carkeek Park	1300	900	3	734
1	2/10/2017		230	73	190	164		42	28	29	33
	2/11/2017		36	32	48	39		14	14	13	14
	2/12/2017		14	5	1	7		5	2	4	4
	2/13/2017		42	13	19	25		2	<MDL (1)	1	1
	2/14/2017		3	2	3	3					
	2/15/2017		19	22	23	21		15	5	14	11
	2/16/2017		230	110	72	137		100	47	21	56
2	2/17/2017	West Point North	19	25	24	23	Carkeek Park	13	10	6	10
	2/18/2017		10	2	2	5		4	<MDL (1)	<MDL (1)	1
	2/19/2017		3	2	5	3		25	12	10	16
	2/20/2017		2	2	<MDL	1		17	4	3	8
	2/21/2017		14	4	2	7		10	2	5	6

CFU = Colony forming unit

Pink cells indicate exceedance of peak criteria (43 CFU/100 mL).

Event 1 – EBO discharge 3:05 am to 8:50 pm 2/9/17; Event 2 – EBO discharge 3:50 am on 2/15/17 to 6:05 am 2/16/17

4.1.2 Enhanced Offshore and Beach Routine Monitoring

Offshore and beach water quality samples were collected as part of the County's routine marine monitoring program after the flooding event were collected on February 21–22. Supplemental weekly bacteria sampling at a subset of stations began on March 6 and continued through June 9. Weekly beach bacteria monitoring was added later, from April 10 through June 9. The results of these sampling events are described below.

4.1.2.1 Offshore

Bacteria concentrations in the marine environment are typically low for reasons described in Section 4.1.1.1 (e.g., high salinity, dilution, solar irradiation, etc.). The same was generally true in offshore monitoring results through June 2017. When bacteria are present, they are typically highest near the surface when freshwater inputs are high and salinity is lower. Fecal coliform and *Enterococcus* concentrations were occasionally elevated above historical values, but State water quality fecal coliform criteria were not exceeded at any site during the sampling period of February 21 through the end of June.

As with all other sites, no fecal coliform samples in offshore waters near the West Point treatment plant exceeded State water quality criteria (Figure 48). *Enterococcus* values near the surface were similarly low (see Figure 48) with the exception of a single high concentration of *Enterococcus* (310 CFU/100 mL) near the EBO on May 1.

While within range of historical values, fecal coliform concentrations near the West Point (main and EBO) and South Plant outfalls from February 21 through June were also generally highest near the surface. This is the typical condition as less dense (fresher) water sits on the surface and freshwater/terrestrial inputs tend to be a major source of most bacteria.

This pattern of higher bacteria concentrations near the surface was not always true for *Enterococcus* concentrations. There were a few occasions, particularly in May, where *Enterococcus* concentrations were abnormally high both near the surface and in deep waters during the time when fecal coliform concentrations were low (Figure 49). The cause of these elevated values is unknown; however it is important to note that *Enterococcus* can occur in the environment, including salt water, in the absence of fecal sources due to their greater salt tolerance than other indicator bacteria like fecal coliforms (Byappanahalli et. al, 2012; Ferguson et. al, 2016). Wastewater effluent is not expected to be the source of these elevated concentrations of *Enterococcus* as the plants' disinfection processes were running as expected and effluent bacteria values (only fecal coliforms are measured) were greatly reduced compared to the previous months. There were also no untreated discharges after February 16 from West Point, and no discharges from CSO treatment facilities after April 12.

At all other stations, surface concentrations of both fecal coliforms and *Enterococcus* were generally within the historic ranges (Figure 50 and Figure 51). Higher than typical bacteria

concentrations were most common in April and early May and no spatial pattern is obvious. Despite the occasional elevated sample, there were no exceedances of the peak fecal coliform criterion (43 CFU/100 mL) at these offshore stations.

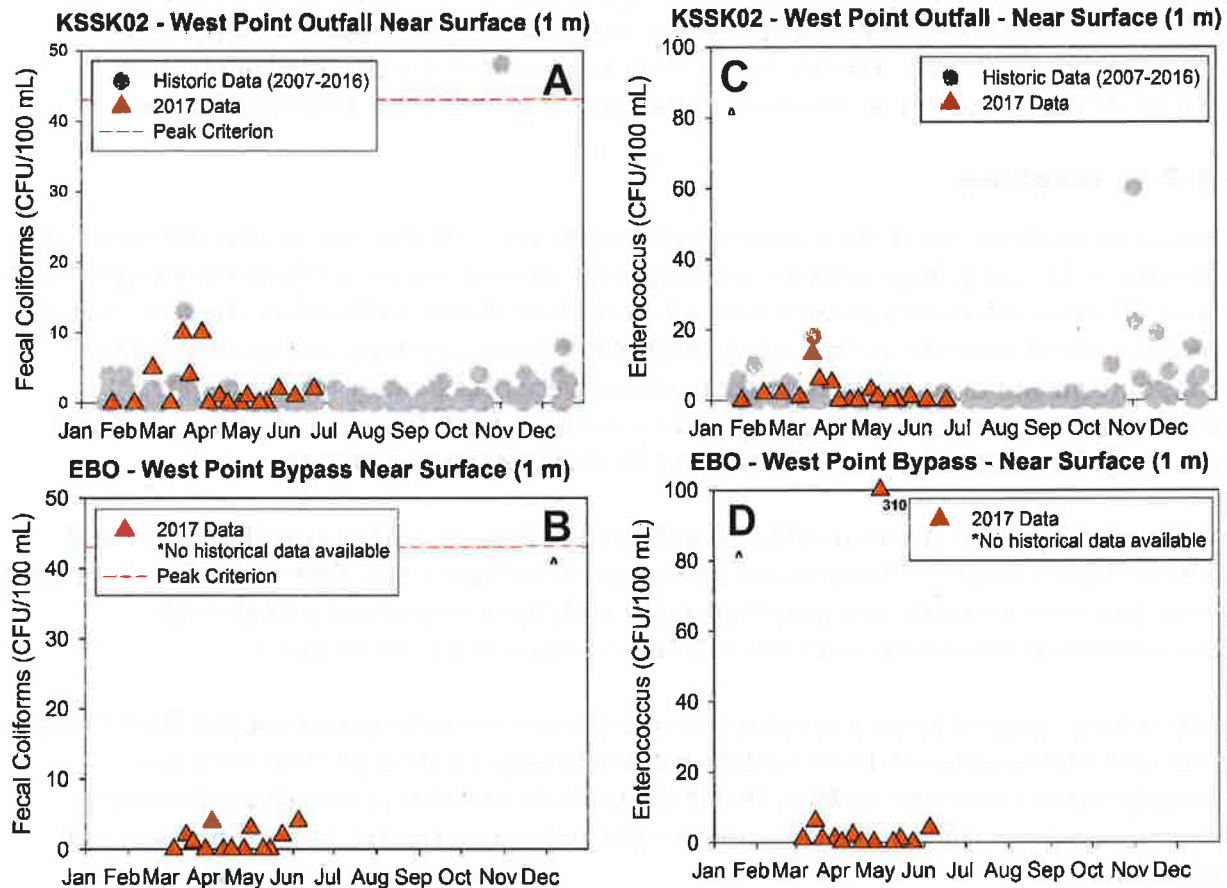


Figure 48. Bacteria concentrations offshore near the West Point outfalls through June 2017 compared to historical baseline. A) Fecal coliform at KSSK02; B) Fecal coliform at EBO; C) Enterococcus at KSSK02; D) Enterococcus at EBO.

Concentrations in receiving waters near the West Point outfalls were higher during the period of reduced treatment (February 9 through April 27) than between April 28 and June 9 (Figure 48). The same pattern was not seen at other offshore stations including those near CSO treatment plants (Carkeek and Elliott Bay). Generally, at all other stations bacteria concentrations were low, with the few peaks (mainly of Enterococcus) occurring in April or May (Figure 50 and Figure 51). These were not associated with any discharges from CSO treatment plants.

All offshore bacteria measurements are available by month compared to historical data in Appendix D. It is important to note that for both offshore and beach data (summarized in the following section) historical data include a maximum of 13 samples, so 95th percentiles presented are calculated based on those data.

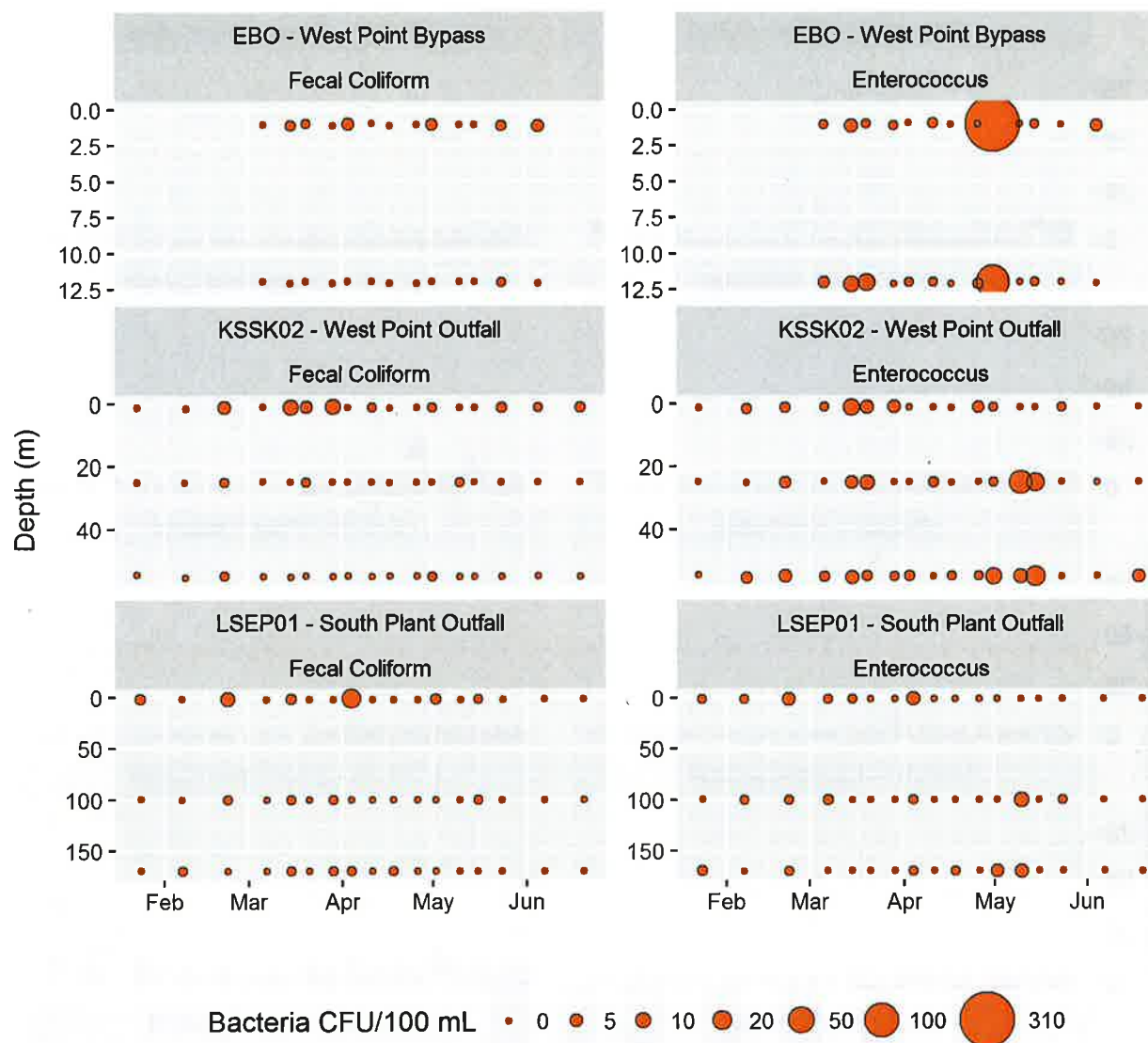


Figure 49. Bacteria concentrations offshore near the West Point and South Plant outfalls through June 2017 at all depths.

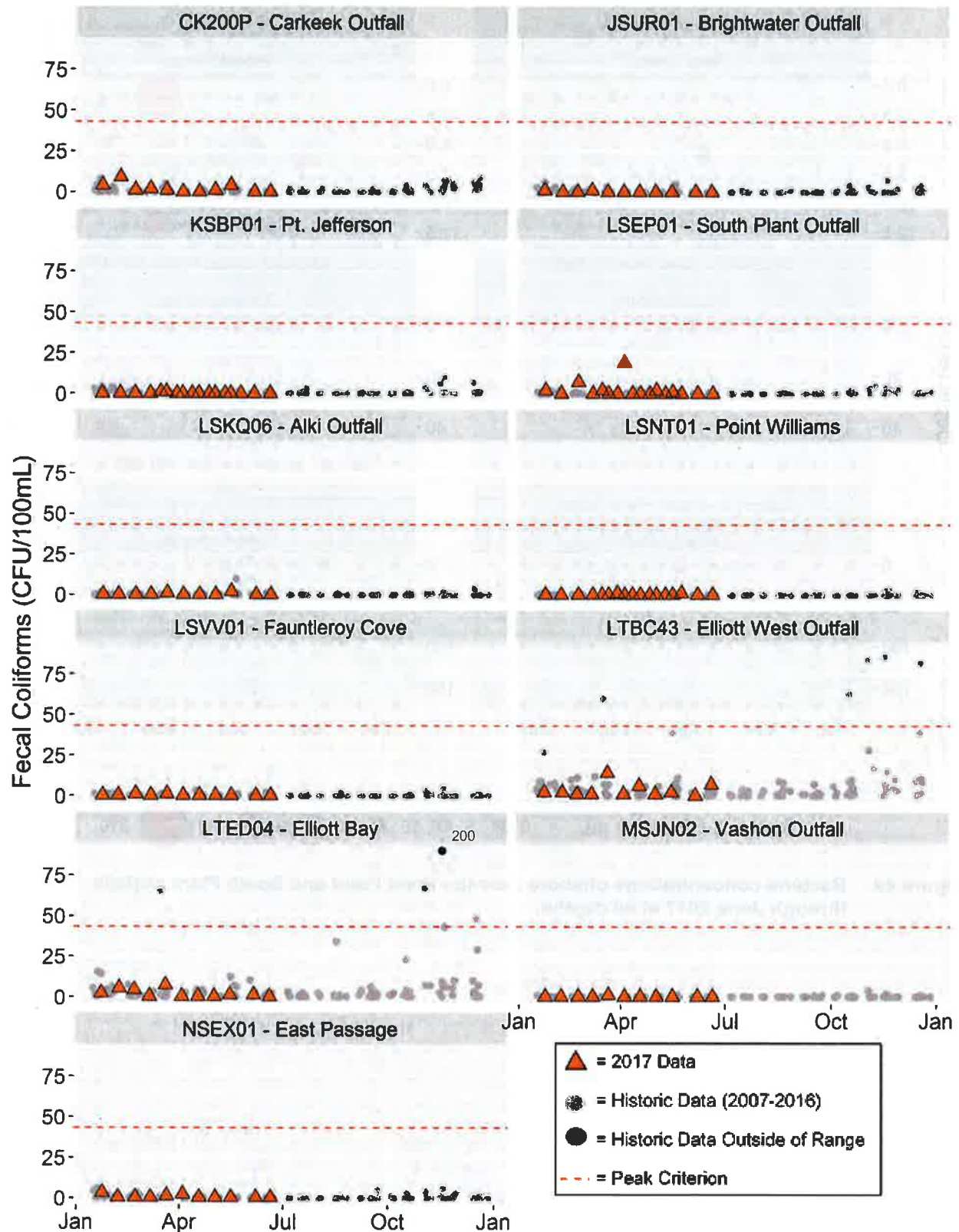


Figure 50. Fecal coliform concentrations at offshore stations in the Central Basin of Puget Sound from January through June 2017 compared to historic concentrations.

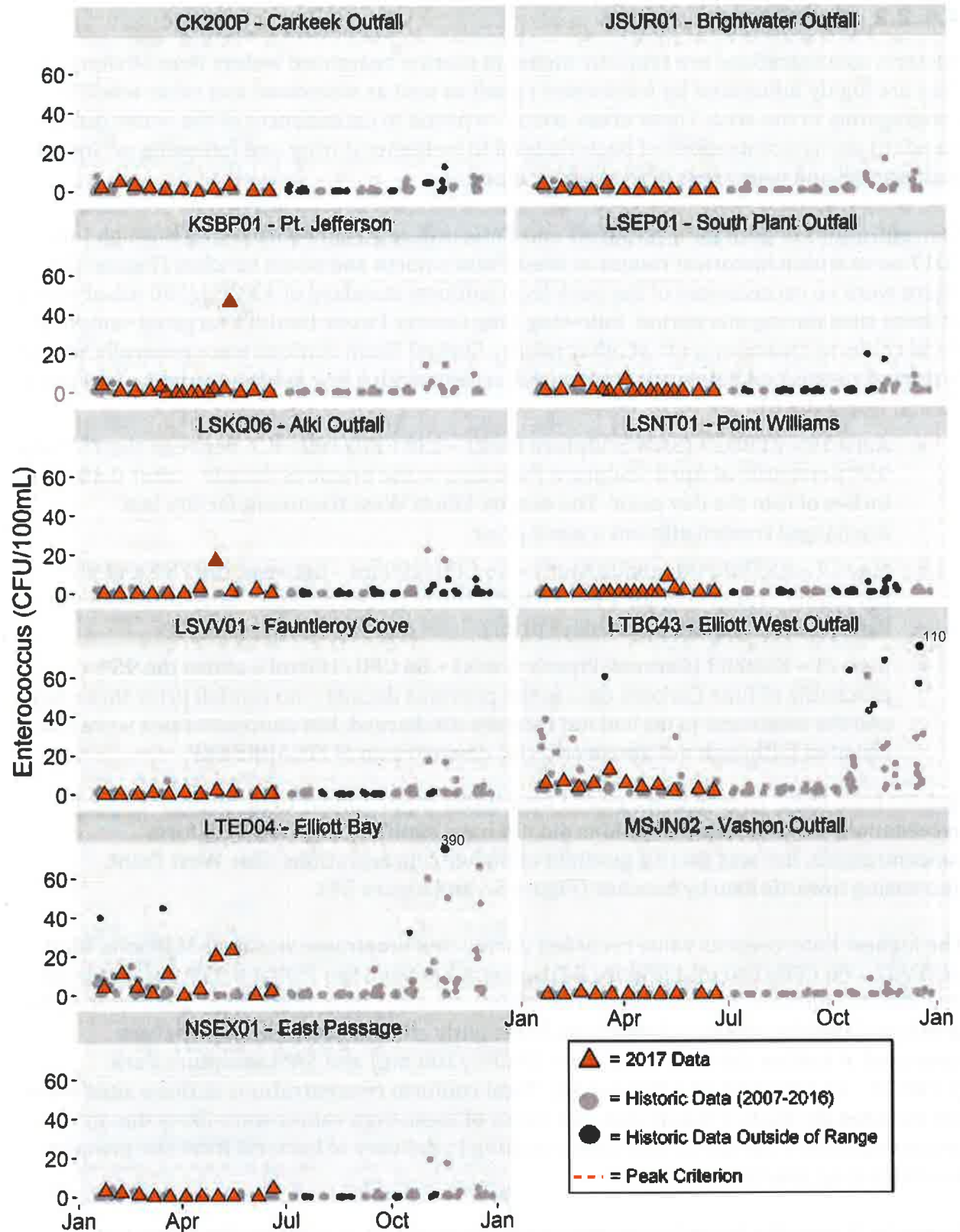


Figure 51. Enterococcus concentrations at offshore stations in the Central Basin of Puget Sound from January through June 2017 compared to historic concentrations.

4.1.2.2 Beaches

Bacteria concentrations are typically higher in marine nearshore waters than offshore as they are highly influenced by freshwater runoff as well as waterfowl and other wildlife congregating in the area. These areas are more prone to exceedances of the water quality standard and concentrations of bacteria tend to be higher during and following periods of high rainfall and near areas of freshwater input.

Concentrations of both fecal coliforms and *Enterococcus* from February 21 through June, 2017 were within historical ranges at West Point's north and south beaches (Figure 52). There were no exceedances of the peak fecal coliform standard of 43 CFU/100 mL at either of these sites during this period, following King County Public Health's targeted sampling. Fecal coliform measurements at other nearby Central Basin stations were generally within historical ranges and below the State's peak criteria with a few exceptions (also see Figure 53 and Appendix E):

- April 19 – LTBD27 (SAM Sculpture Park) – 230 CFU/100 mL – between the 75th and 95th percentile of April Sculpture Park data in the previous decade – after 0.48 inches of rain the day prior. The nearby Elliott West treatment facility last discharged treated effluent a week prior.
- May 17 – KSYV02 (Magnolia Bluff) – 46 CFU/100 mL – between the 75th and 95th percentile in May Magnolia Bluff data in the previous decade – after three days of light rain (0.52 inches three days prior).
- June 21 – KSHZ03 (Carkeek Piper's Creek) – 86 CFU/100 mL – above the 95th percentile of June Carkeek data in the previous decade – no rainfall prior three days, and the treatment plant had not recently discharged, but concentrations were also elevated (although not above criteria) downstream at ITCARKEEKP.

Results from these sites that are near a freshwater input appear to be highly localized exceedances as other nearby stations did not have similarly high fecal coliform concentrations, nor was there a gradient of higher concentrations near West Point, decreasing towards nearby beaches (Figure 53 and Figure 54).

The highest *Enterococcus* value recorded during this timeframe was near Magnolia Bluff (KSYV02 – 66 CFU/100 mL) (Figure 54) and was between the 75th and 95th percentile for that site on February 22. Concentrations of *Enterococcus* near West Point were lower than at Magnolia during this sampling event, but slightly elevated concentrations were measured at Golden Gardens (KSLU03 – 18 CFU/100 mL) and SAM Sculpture Park (LTBD27 – 22 CFU/100 mL) (Figure 54). Fecal coliform concentrations at these sites were not elevated during this timeframe. The cause of these high values were likely due to the continuous heavy rainfall in February, resulting in delivery of bacteria from stormwater and terrestrial sources.

Appendix E provides bacteria concentrations measured at marine beaches from late February through June 2017 in context of historical values.

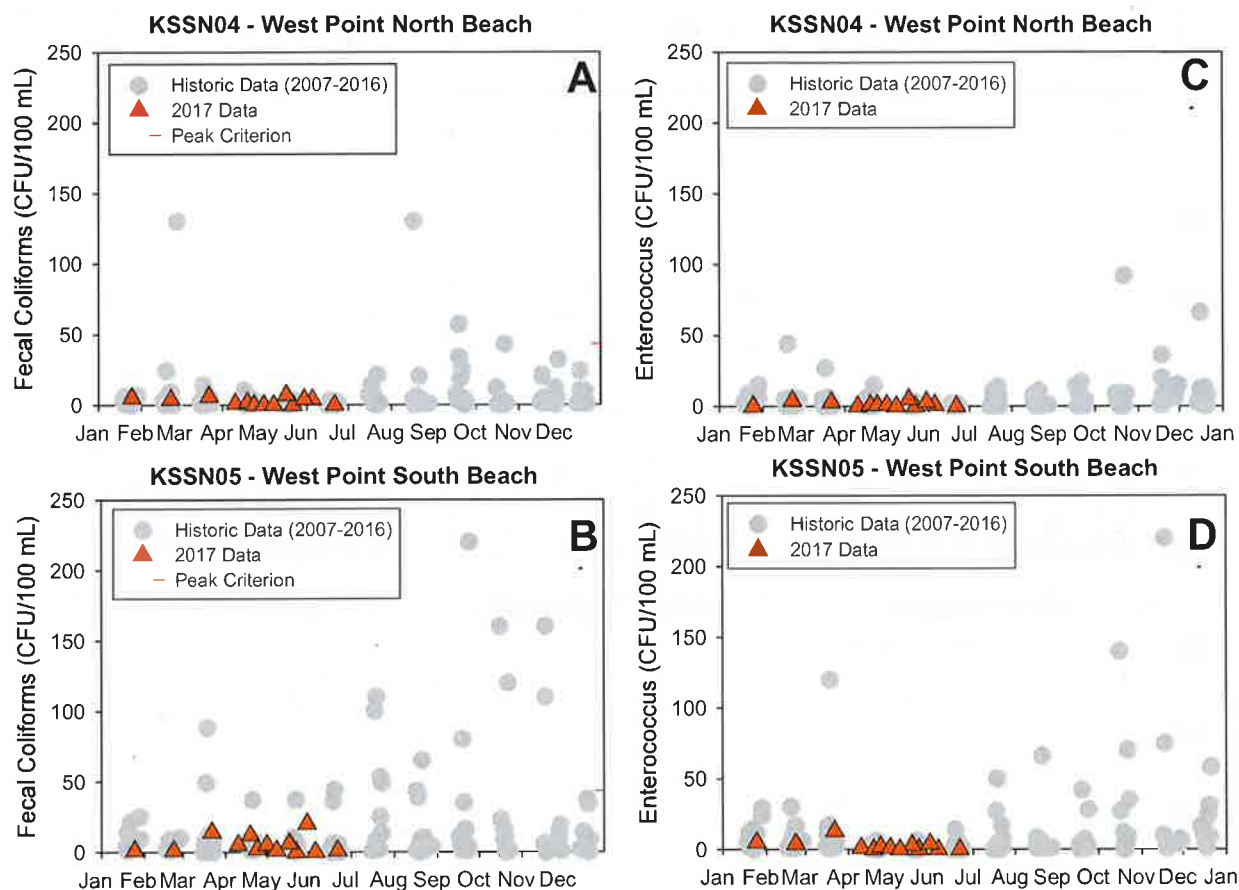


Figure 52. Bacteria concentrations offshore near the West Point outfalls through June 2017 compared to historical baseline. A) Fecal coliform at KSSN04; B) Fecal coliform at KSSN05; C) Enterococcus at KSSN04; D) Enterococcus at KSSN05.

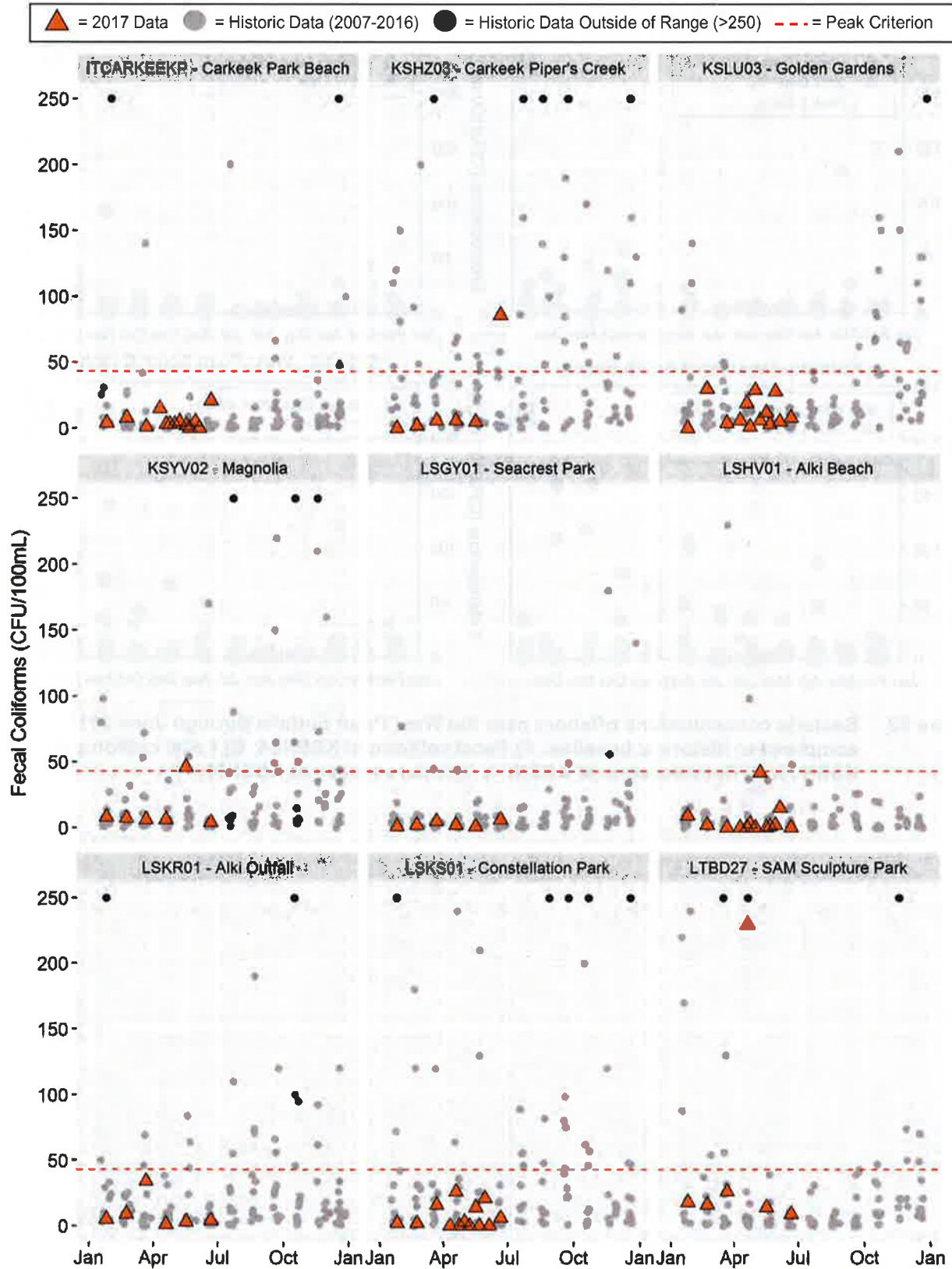


Figure 53. Fecal coliform concentrations at beach stations (excluding West Point) through June 2017 compared to historical data.

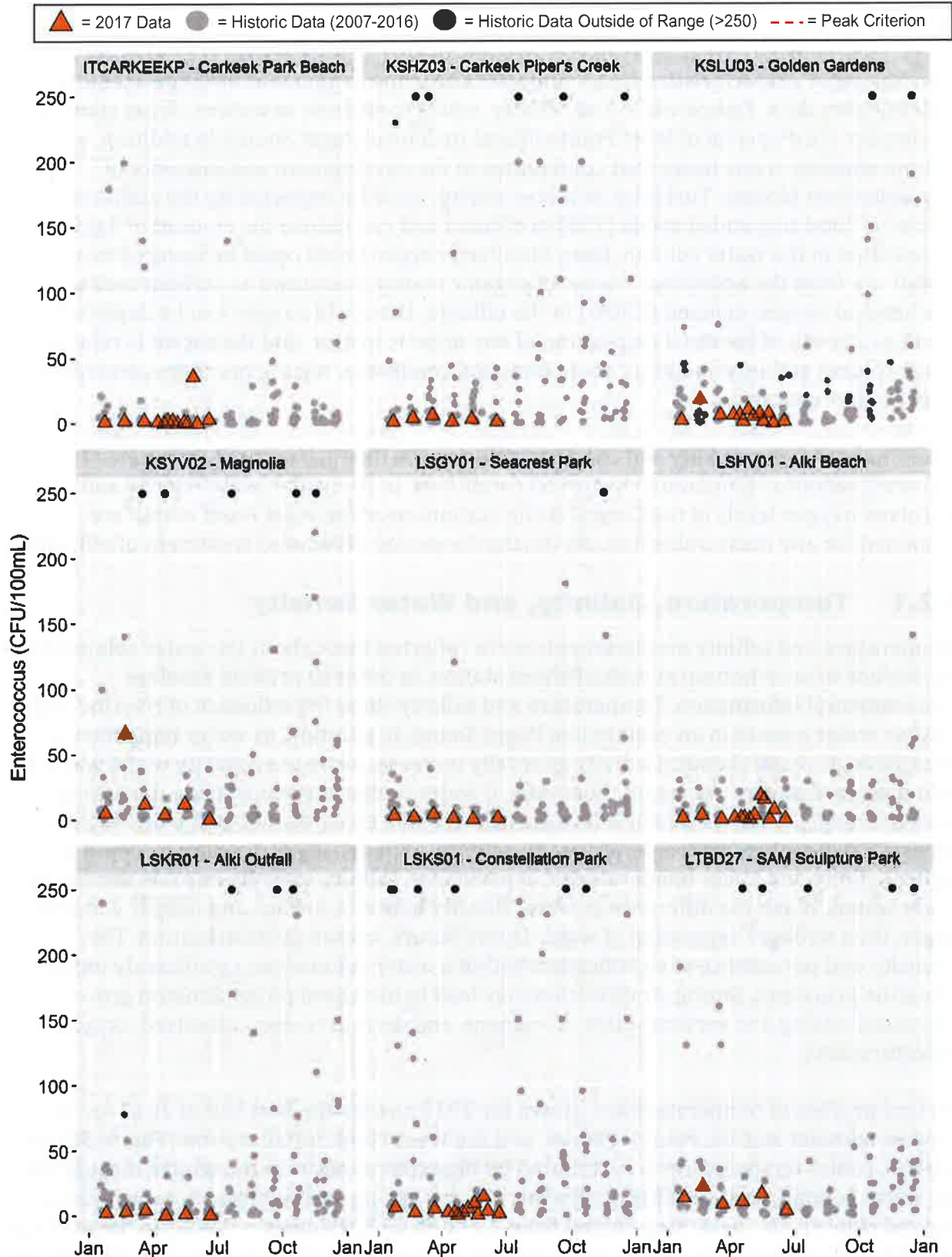


Figure 54. Enterococcus concentrations at beach stations (excluding West Point) through June 2017 compared to historical data.

4.2 Physical Characteristics

Physical water characteristics are an important baseline component for understanding water quality data. Temperature and salinity, which contribute to water column stability, can impact the dispersal of West Point effluent in Central Puget Sound. In addition, water column stability is one factor that contributes to the development and intensity of phytoplankton blooms. Turbidity, or water clarity, could be impacted by the additional release of total suspended solids (TSS) in effluent and can reduce the amount of light penetration in the water column. Deep dissolved oxygen levels could be lowered near the outfall site from the additional release of organic matter, measured as carbonaceous biochemical oxygen demand (CBOD) in the effluent. Dissolved oxygen can be depleted at depth as a result of bacterial respiration of any organic matter, and the extent is related to water column stability and other environmental conditions, mixing processes, and inputs from oceanic sources.

A summary of water quality and conditions during the first half of 2017 is included in the following sections compared to historical conditions. In particular, water clarity and dissolved oxygen levels at the Central Basin stations near the West Point outfall are examined for any measurable impacts during the period of reduced treatment of effluent.

4.2.1 Temperature, Salinity, and Water Density

Temperature and salinity measurements were collected throughout the water column from the surface to near-bottom at each offshore station, in order to provide baseline environmental information. Temperature and salinity show the influence of riverine and oceanic water masses in an estuary like Puget Sound. In addition, as water temperature rises, biological and chemical activity generally increase, while the capacity of the water to hold dissolved oxygen decreases. Generally, if water temperature is outside the normal seasonal range, it may adversely affect the health of the estuary and marine life. Water density is determined by temperature and salinity, with density increasing by depth and at higher salinity and lower temperatures. In particular, salinity strongly impacts density in Puget Sound. When the difference in water density between surface and deeper water is larger, then stronger separation of water layers occurs, known as stratification. The intensity and persistence of stratification within a water column can significantly impact estuarine processes. Strong stratification may lead to increased phytoplankton growth, decreased mixing and vertical water movement, and decreased deep dissolved oxygen concentrations.

Vertical profiles of temperature are shown for 2016 and for the first half of 2017 for the deepest ambient station, Point Jefferson, and the West Point outfall station (Figure 55). In general, cooler temperatures (represented by blue colors) occur in the winter throughout the water column, and warming occurs through the spring and summer months (orange and red colors). Temperatures ranged from 7.7 °C to 13.3 °C (mean = 8.9 °C) in the first half of 2017 at all offshore sites in the Central Basin. Compared to the prior decade, the first half of 2017 was generally cooler than average, and reflected the end of the influence of the marine heat wave that occurred in late 2014 through 2016.

Vertical profiles of salinity are shown for 2016 and the first half of 2017 for the same stations, Point Jefferson and the West Point outfall site (Figure 56). In general, the lowest salinities (blue colors) are observed near the surface in the spring due to high river flows and run-off, and the highest salinities (deep red) are observed throughout the water column due to mixing and inputs of upwelled deep Pacific oceanic water that enters Puget Sound during the late summer and fall. Salinities ranged from 20.6 PSU to 30.2 PSU (mean = 28.5 PSU) in the first half of 2017 at all offshore sites in the Central Basin. In the first half of 2017, the highest salinities were observed at deep depths in January and early February likely due to influence of saltier oceanic water masses. Starting in early March, the entire water column became less salty through the spring due to high river inputs and precipitation. Compared to the prior decade, salinity from March through June was generally less salty than average. Salinity at the surface was quite variable related to fluctuations in freshwater input and circulation.

Vertical profiles of density (in units of sigma-t) are shown for 2016 and the first half of 2017 for the same stations, Point Jefferson and the West Point outfall site (Figure 57). In general, density follows the same seasonal pattern as salinity, with more uniform density throughout the water column in the winter, followed by lower densities (blue colors) near the surface in the spring/summer due to freshwater input and increased solar heating. Then, higher densities at deep depths (deep red) occur in the late summer/fall due to inputs of oceanic water masses. Larger differences in density between surface and deep water layers indicate stronger stratification. In January/early February 2017, the upper 100-m of the water column was well-mixed with moderately high densities. In late February, some stratification occurred briefly in the upper 10-m at most Central Basin sites, followed by well-mixed conditions at the next sampling event. Beginning in late March, the upper 10–25-m of the water column exhibited strong stratification that persisted through June, with some exceptions such as early May. Generally, observations of density in the spring and early summer of 2017 showed strong and more persistent stratification than typically observed across Central Basin stations. This can impede vertical mixing and affect the concentrations of substances and materials found at different depths in the water column. In addition, phytoplankton can become more concentrated in the surface layers where light penetrates. They then take up available nutrients, while nutrients at deeper depths are unable to reach the surface. See Section 4.3.4 for more details on phytoplankton dynamics in 2017.

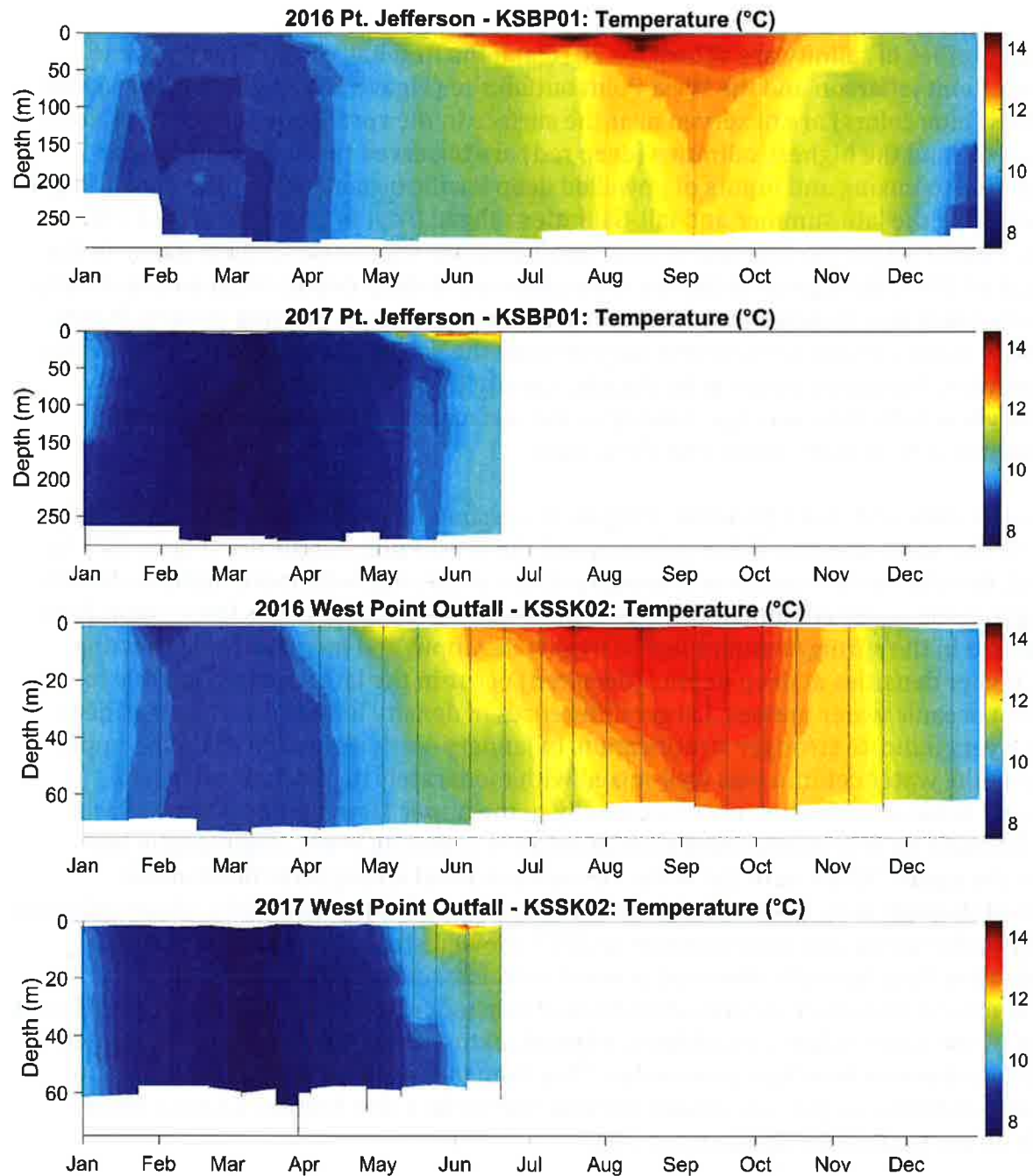


Figure 55. Vertical water column profiles of temperature for Pt. Jefferson for 2016 and for the first half of 2017, and for the West Point outfall site for 2016 and 2017.

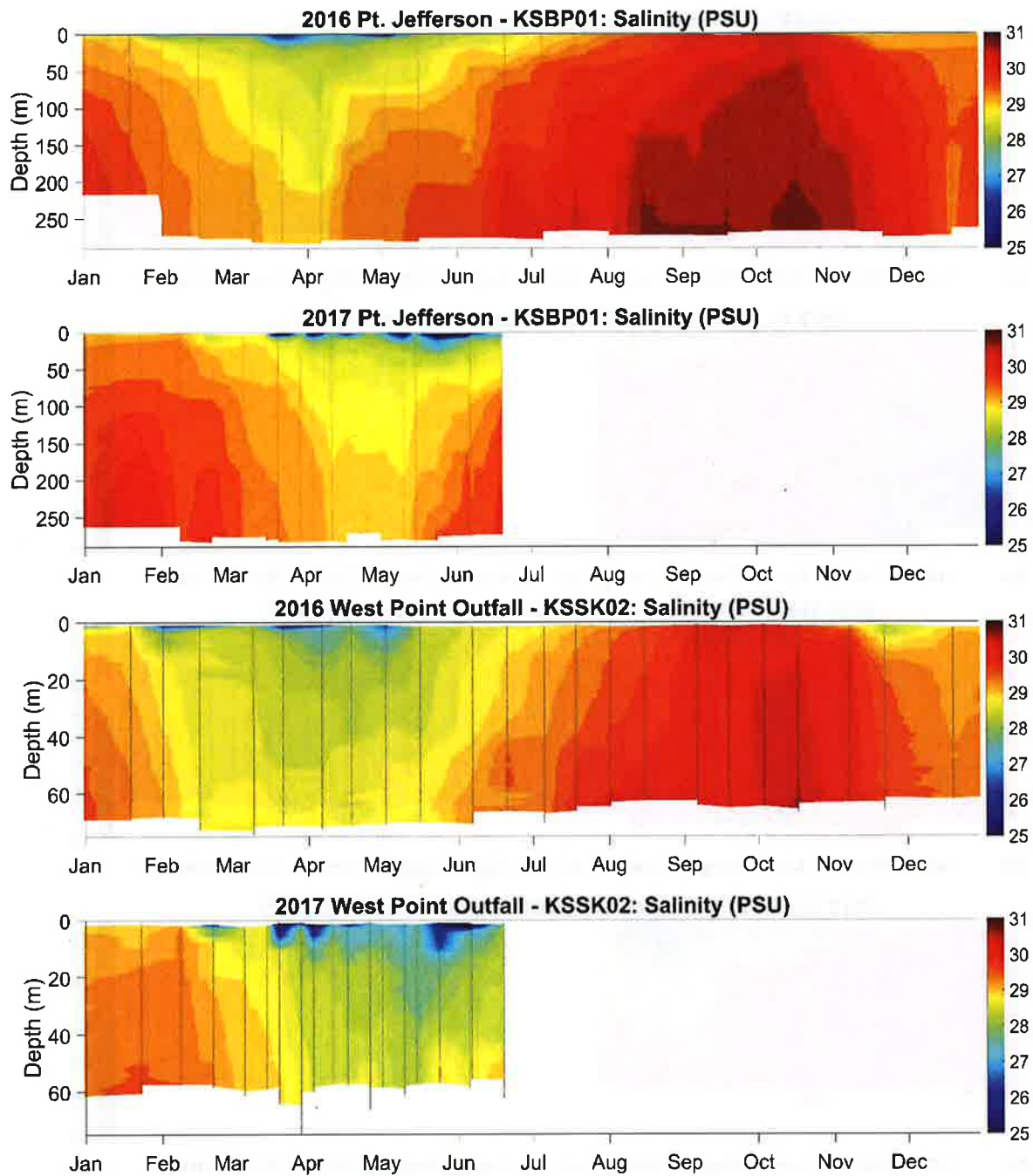


Figure 56. Vertical water column profiles of salinity for Pt. Jefferson for 2016 and for the first half of 2017, and for the West Point outfall site for 2016 and 2017.

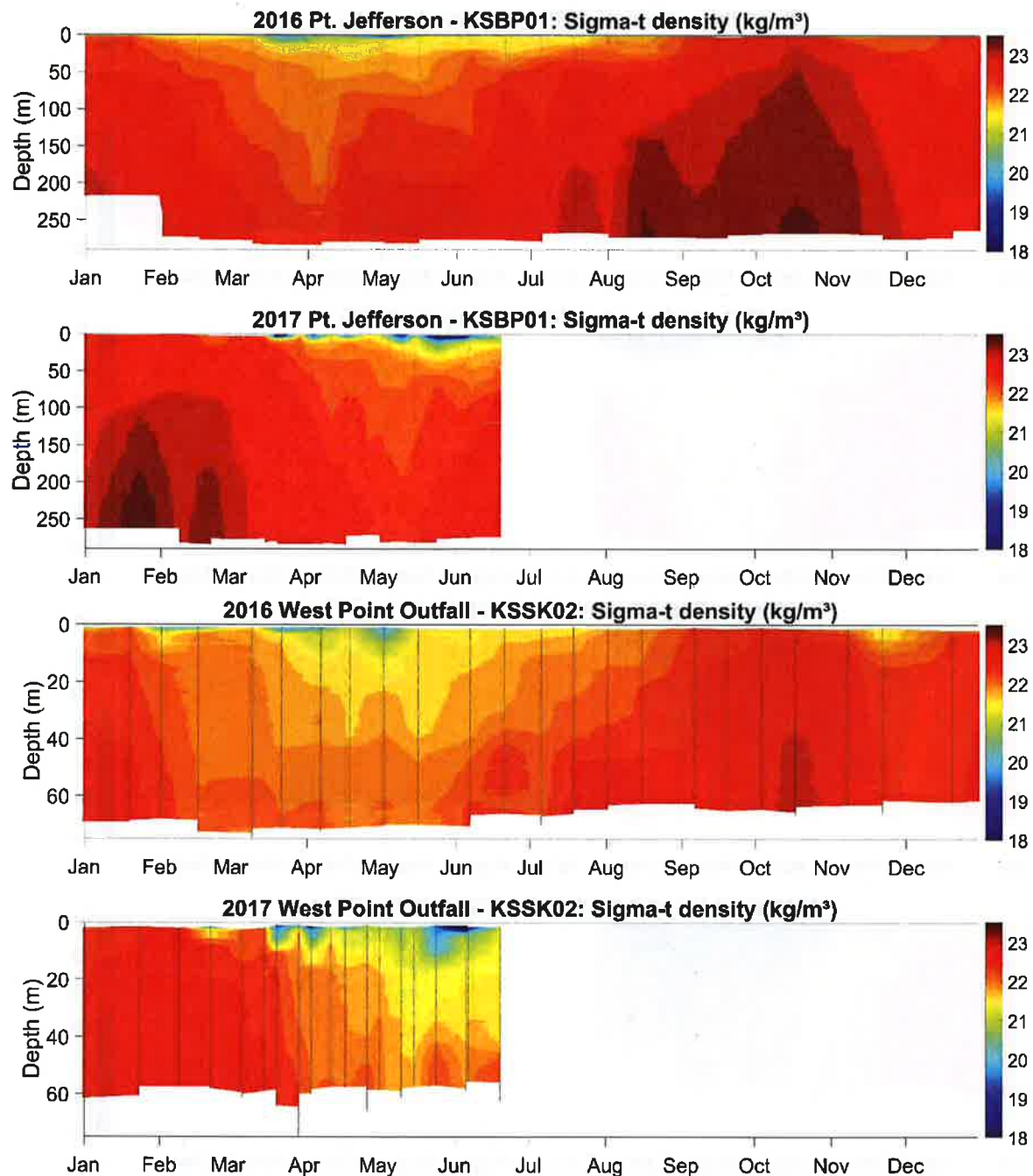


Figure 57. Vertical water column profiles of water density for Pt. Jefferson for 2016 and for the first half of 2017, and for the West Point outfall site for 2016 and 2017.

4.2.2 Water Clarity and TSS

Water clarity or transparency can be an indicator of water quality. Several factors impact water clarity, including amounts of suspended silt and soil particles, plankton biomass, and other particulate organic materials in the water column. Sediments and detrital material can originate from rivers, streams, and erosion run-off, especially after storms and flooding events. Suspended solids can also come from human sources such as stormwater and wastewater treatment plant effluent. Sediments may also become resuspended from the bottom due to wave action or currents, or submarine landslides at deep depths. In addition, sediment can be trapped at a particular depth due to water density differences, resulting in plumes in deep layers. Low water clarity conditions that persist over an extended period of time can degrade the health of a waterbody. Particularly, if this occurs in the photic zone, this may reduce the area in which aquatic plants and phytoplankton can grow and thrive. In addition, many benthic marine organisms feed by filtering water and large amounts of suspended matter may obstruct their filter-feeding systems.

Transmissivity is a measurement of water clarity at a given point in the water column, measured through a fixed sensor path-length (25-cm). If the water is completely transparent, then 100% of the light is transmitted and water clarity is high. Losses of light can result from scattering and absorption from particles. Greater concentrations of suspended materials will result in lower percentage of light transmission and lower water clarity. Vertical profiles of transmissivity are shown for 2016 and for the first half of 2017 for the deepest ambient station, Point Jefferson, and the West Point outfall station (Figure 58). In general, the lowest values of light transmission (yellow colors) are found near the surface and bottom, and the highest light transmission (blue) is found in the mid-water column. In 2017, light transmission typically ranged from 50–90%, with the lowest values generally in the top 15-m of the water column in May and June when large phytoplankton blooms occurred across all Central Basin offshore stations. One exception is the Point Jefferson station, where the lowest light transmission occurs at deep depths greater than 200-m (Figure 58 top panels), with a minimum value of 28% at 275-m in early June 2017. This pattern also occurs in the historical record at this site, related to bathymetry and hydrodynamics that transport silt and organic matter. In deep depths of the Central Basin, high concentrations of suspended sediments typically occur near the bottom and are maintained by local resuspension, also known as a nepheloid layer (Baker, 1984). At the West Point outfall site, deep depths (>35-m) outside of the photic zone showed a minimum of 83.4% light transmission in the first half of 2017, comparable to patterns observed in 2016 with a minimum value of 83% in the same season (Figure 58 lower panels).

Another measurement of the amount of material in the water column comes from discrete samples for total suspended solids (TSS). TSS concentrations can vary based on inputs from sources mentioned earlier, as well as change due to water mass differences. Near-bottom data from Central Basin offshore sites near West Point are shown for the first half of 2017 with monthly historical data from the last decade (Figure 59). In general, all sites showed near-bottom TSS levels within the expected ranges of prior observations, and maximum

levels did not exceed 7 mg/L, the ambient background maximum identified in the West Point NPDES permit for receiving waters (Ecology, 2014).

The ranges of TSS observations at each Central Basin site during reduced treatment at West Point are shown by depth. Median and percentiles (5th, 25th, 75th, and 95th) are shown for weekly observations collected during February 9 through May 10, 2017, compared to the last decade of historical data for each discrete depth (Figure 60). At the West Point outfall, the median and 75th percentile TSS values were higher than historical at deeper depths (35 and 55-m) in particular. However, the 95th percentiles were within historical ranges. This indicates that observed TSS concentrations overall were elevated compared to historical conditions, but within the spread of historical ranges. In addition, TSS concentrations at mid-depths were elevated in 2017 at the ambient stations Point Jefferson and Point Williams. This suggests similar water mass characteristics between sites, particularly at the 35-m depth. At the South Plant outfall site, TSS concentrations in 2017 were comparable or lower than the historical record, with the exception of slightly elevated TSS levels at the typical trapping depth for the South Plant effluent (100-m). Overall, TSS levels at the West Point outfall site and across the Central Basin were variable and generally within expected ranges based on the historical record.

During the period of reduced treatment at West Point, additional inputs of total solids to receiving waters occurred from February through late April (see 3.4). The highest observed daily TSS effluent concentrations ranged from 128 mg/L in February and April to 227 mg/L in March. Assuming a range of dilution factors from dilution modeling for the West Point outfall, the potential increase in TSS at the edge of the chronic mixing zone can be estimated. Using the highest TSS effluent concentrations and winter/spring dilution factors from 100:1 to 300:1, the TSS increase in receiving waters during reduced treatment can be conservatively estimated from 0.4 to 2.3 mg/L. At typical TSS effluent concentrations (6 to 19 mg/L), the potential TSS increase in receiving waters can be estimated at 0.02 – 0.2 mg/L, which would be difficult to detect and is within the natural variability of observations.

Effluent from West Point typically initially mixes at a depth range from 15 to 55-m, depending on receiving water density differences, tidal currents, and effluent discharge rates. Weekly TSS observations at the West Point outfall site are shown for deeper depths (> 25-m) from January through June 2017 (Figure 61). Peak TSS concentration occurred at 35-m in mid-March, but otherwise no discernable pattern in concentrations of TSS in receiving waters related to effluent treatment level is present.

Near-bottom concentrations of total suspended solids were within historical ranges near West Point as well as other Central Basin stations, while TSS concentrations were elevated at mid-water depths for the first half of 2017. While elevated TSS levels in West Point effluent contributed additional solids near the outfall site, TSS concentrations across sites in the Central Basin were similar, so it is difficult to definitively identify sources. Other possible mechanisms include inputs of TSS from silt, plankton, or other organic matter. TSS levels at all sites during the first half of 2017 were below the ambient background maximum (7 mg/L) identified in the West Point NPDES permit for receiving waters.

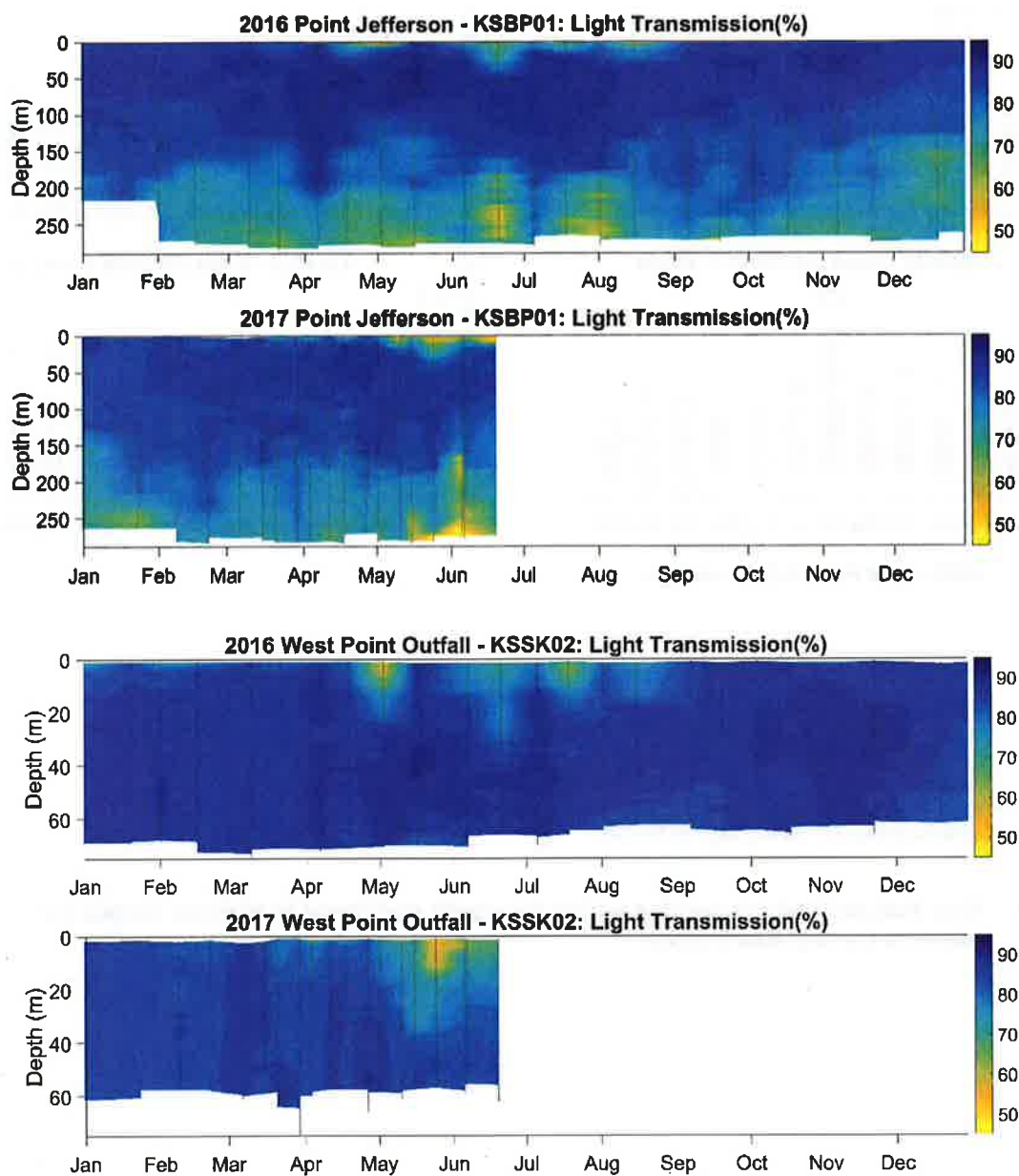


Figure 58. Vertical water column profiles of % light transmission for Pt. Jefferson for 2016 and for the first half of 2017, and for the West Point outfall site for 2016 and 2017.

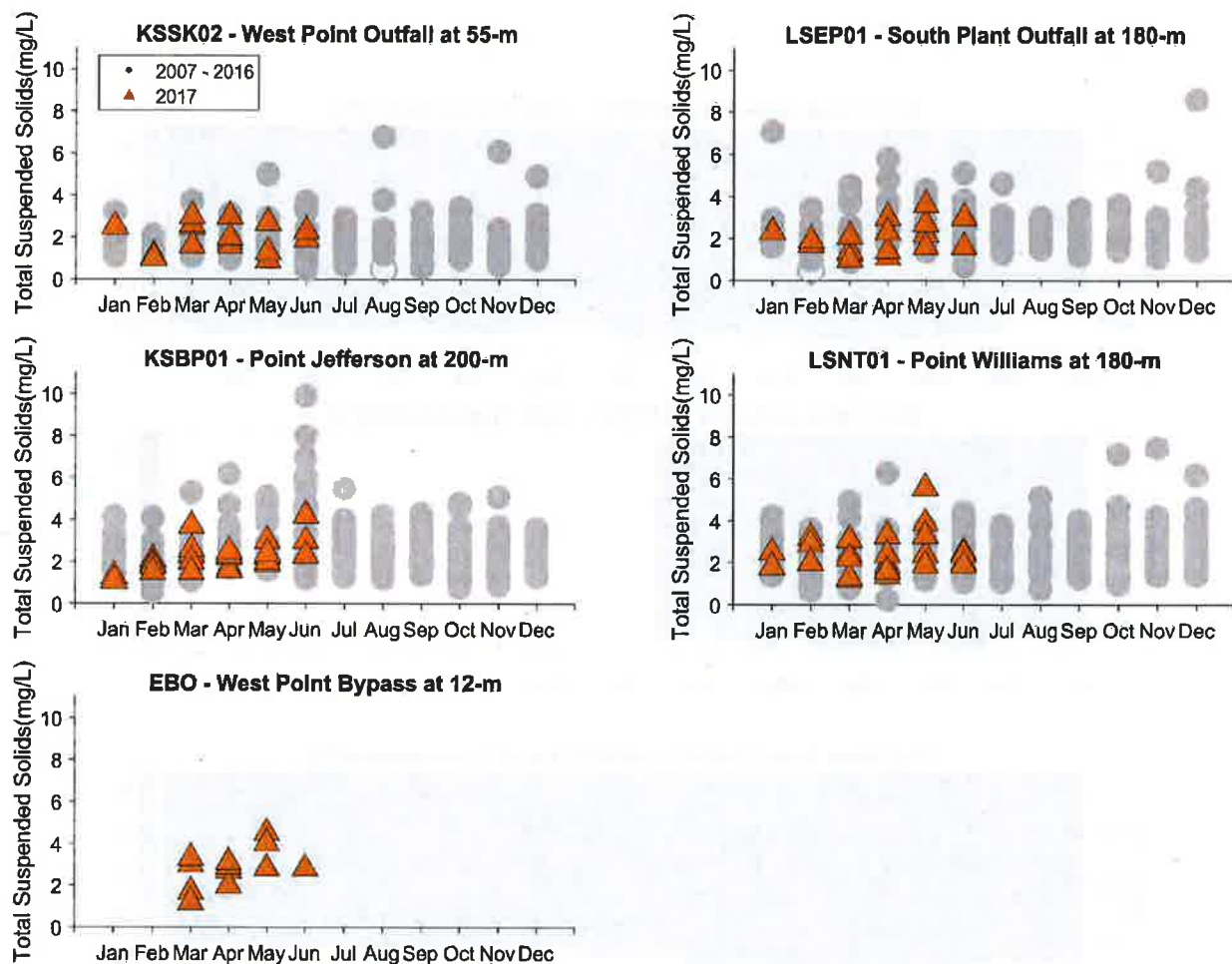


Figure 59. Near bottom total suspended solids by month compared to historic ranges for offshore Central Basin sites.

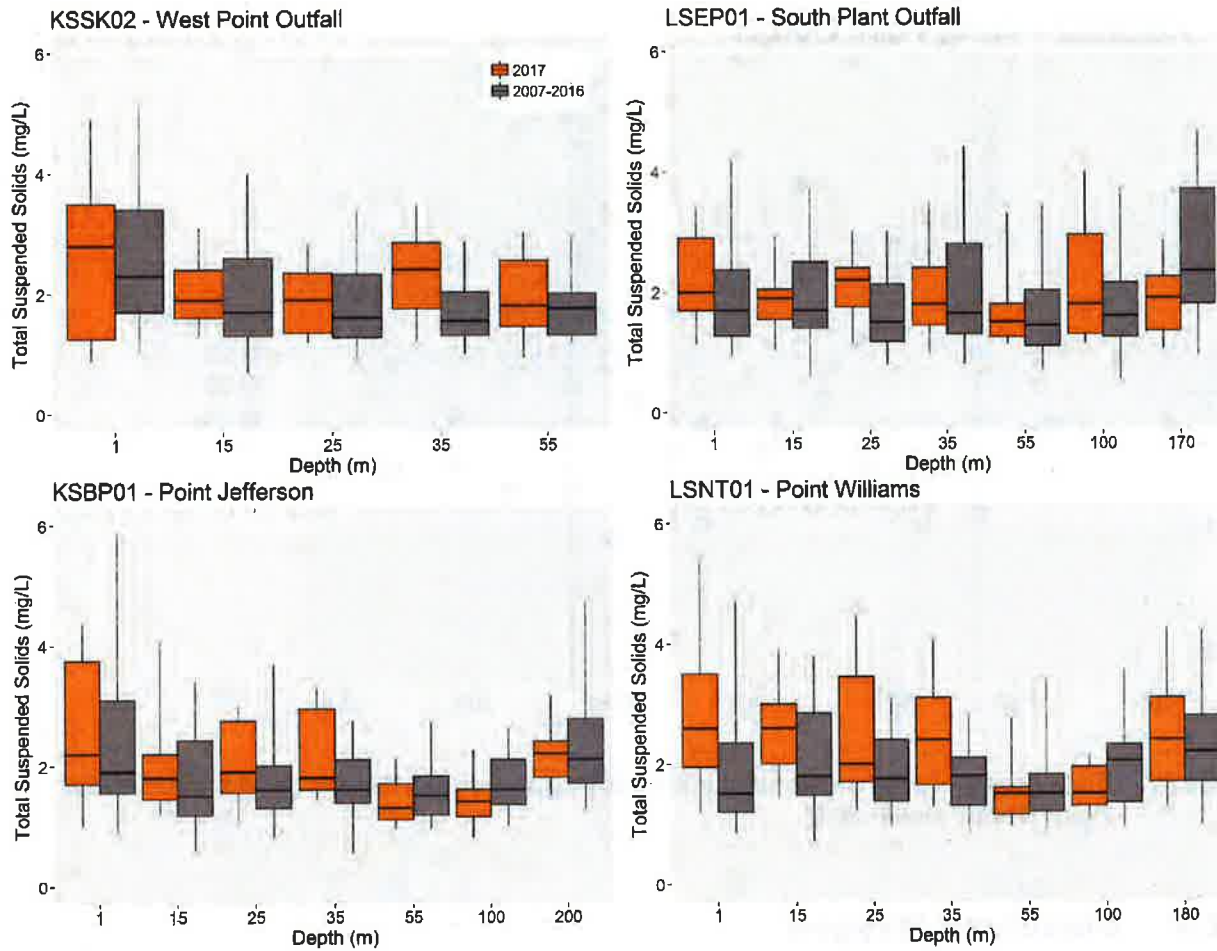


Figure 60. Total suspended solids percentiles from Feb. 9 to May 10, 2017 combined by depth compared to the historical record for the same months for Central Basin sites. Bars show medians, boxes show 25th and 75th percentiles, and vertical lines show 5th and 95th percentiles.

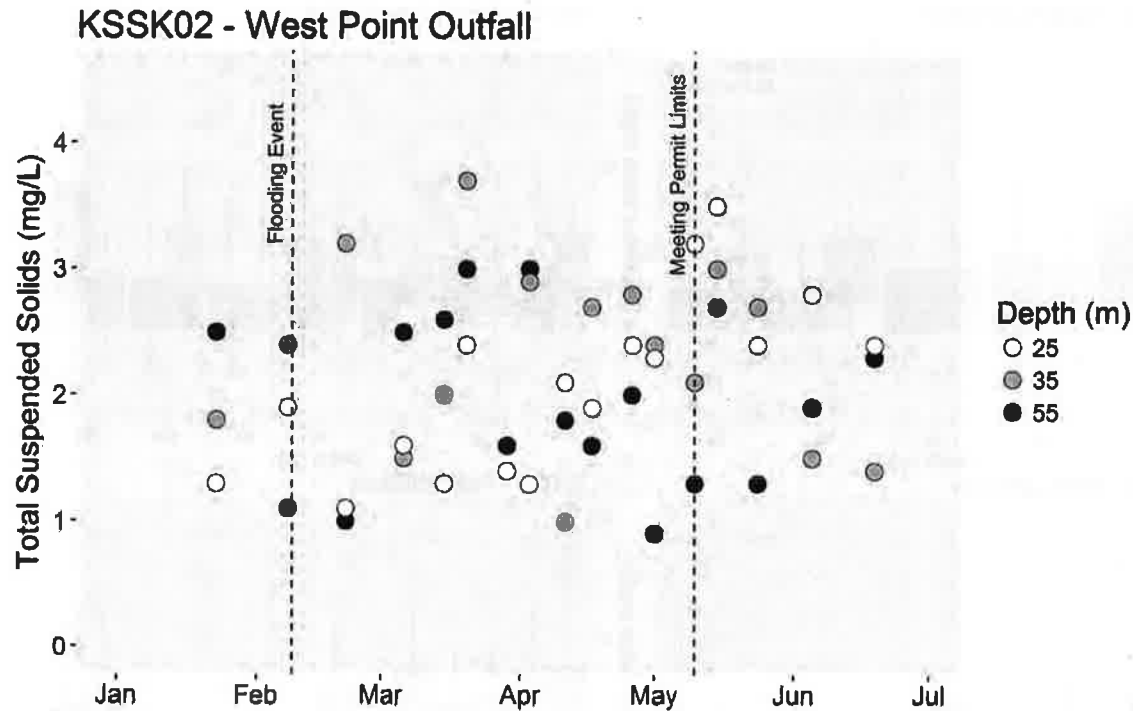


Figure 61. Time series of total suspended solids concentrations in deeper depths at the West Point Outfall site in 2017.

4.2.3 Dissolved Oxygen

Dissolved oxygen levels are an important component of marine water quality, and can control the presence or absence of marine species in some ecosystems. Aquatic life requires a certain amount of oxygen dissolved in the water, and different species have different tolerances for how little oxygen they can survive on. Waters with high concentrations of dissolved oxygen are considered healthy for sustaining many species. In general, the Central Basin of Puget Sound is well-oxygenated compared to other areas, such as southern Hood Canal.

Sources of oxygen to marine waters include photosynthesis from plants and algae during the daytime and gas exchange with atmospheric oxygen at the water surface. Decomposition of organic matter by bacteria can be a sink of oxygen, such as due to decay of sinking plankton. In addition, terrestrial organic materials from rivers and human inputs from wastewater discharges and runoff can be a source to fuel bacterial respiration, which decreases dissolved oxygen. Another important contributing factor in Puget Sound is the concentration of dissolved oxygen from oceanic sources. Deep, dense, low-oxygenated waters that originate from coastal upwelling in the Pacific Ocean enter Puget Sound particularly in the late summer/fall months. This can result in naturally occurring lower oxygen levels at deep depths in the Central Basin. In deep waters, it can be too dark for plant growth and is separated from surface mixing with air. Thus, higher inputs of organic matter at depth may further decrease oxygen levels.

The State of Washington dissolved oxygen standard to protect aquatic life depends on the designated waterbody use. The Central Basin of Puget Sound is classified in the category of waters of extraordinary quality, and the one-day minimum dissolved oxygen numeric standard is 7.0 mg/L (WAC 173-201A-210, 2011). In addition, the standard states that when dissolved oxygen levels fall below 7.0 mg/L due to natural conditions, then human actions may not decrease levels more than 0.2 mg/L. Hypoxia, or low dissolved oxygen in the water, occurs when oxygen levels become too depleted to support aquatic species (Diaz and Rosenberg, 2008). At the dissolved oxygen level of 5 mg/L, biological stress can be induced in sensitive marine life such as some fish species (CENR, 2011). If dissolved oxygen levels fall below 2 to 3 mg/L, this can displace marine species or potentially result in death (Rabalais et al., 2001).

In Puget Sound, the lowest dissolved oxygen concentrations are typically found near the bottom of the water column, and vary on a seasonal basis. Vertical profiles of dissolved oxygen are shown for 2016 and the first half of 2017 for the deepest ambient station, Point Jefferson, and for the West Point outfall station (Figure 62). The highest concentrations (represented by red and orange colors) occur in the surface layers during the period of phytoplankton growth in the spring and summer. The lowest concentrations (deep blue) occur in the late summer and fall due to processes such as phytoplankton decay and intrusions of deep, low-oxygenated oceanic waters. In the first half of 2017, the lowest dissolved oxygen concentrations were observed at the deepest depths, following typical conditions. Since low oxygen levels are of concern, the focus of the discussion is on near-bottom dissolved oxygen levels.

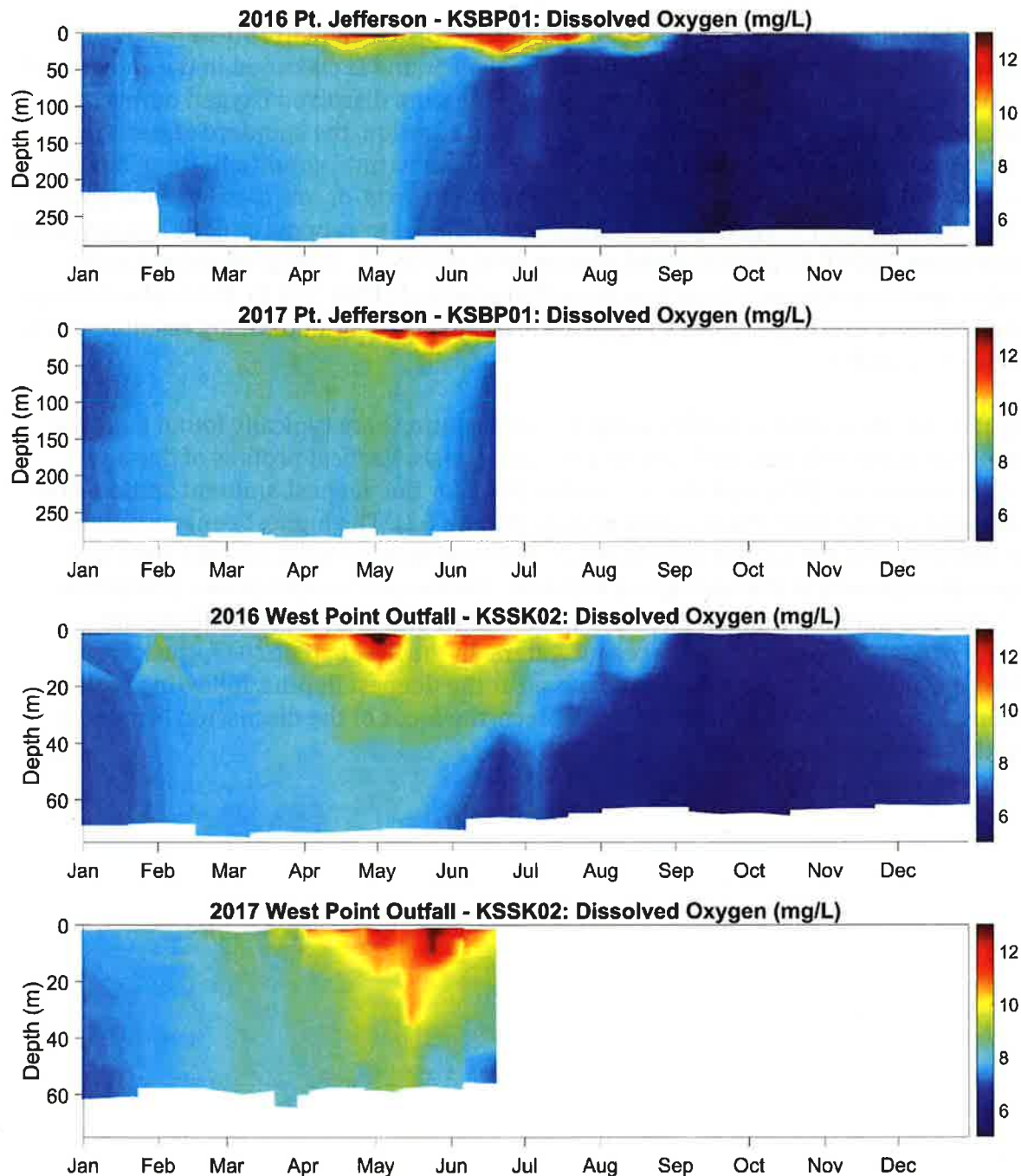


Figure 62. Vertical water column profiles of dissolved oxygen at Point Jefferson and the West Point outfall site for 2016 and the first half of 2017.

In addition to seasonal variability, oxygen levels can vary over shorter time periods and between years, so it is important to compare recent data in context of historical ranges. Near-bottom dissolved oxygen levels in 2017 are shown for the West Point and South Plant outfalls next to monthly ranges observed over the last decade (Figure 63). For both sites, deep dissolved oxygen concentrations were within healthy levels and historical ranges for all months, and above the state numeric water quality standard with one exception. In late

June 2017, the bottom water oxygen value at the South Plant outfall was 6.8 mg/L. However, the lower value in late June falls within the 25th to 75th percentile range, indicating oxygen levels within the normal ranges. In addition, this June value was within 0.2 mg/L of the state numeric standard (7.0 mg/L).

During the period of reduced treatment at West Point, additional inputs of organic matter, measured as carbonaceous biochemical oxygen demand (CBOD), to receiving waters occurred from February through late April (see Section 3.6). Oxygen demand is measured in the lab over a 5-day period; therefore, detecting CBOD impacts in the water column in Puget Sound can be problematic due to time lags and differences in biological processes and mixing. The potential dissolved oxygen decrease in receiving waters depends on effluent travel time, oxidation rates, water temperature, as well as effluent concentrations and flows (Ecology, 2014).

Despite increased loads of organic matter from the West Point effluent during reduced treatment, deep dissolved oxygen concentrations were within historical ranges. In addition, oxygen depletion was not observed at the West Point outfall site below the numeric water quality standard. Tidal currents, high effluent flows, and weak stratification can all contribute to mixing and dispersal of effluent (King County, 2005; Turner and Gregg, 1994). From February through mid-March, when effluent CBOD concentrations were highest, density observations showed a well-mixed water column (Figure 57), and precipitation and flows were high. In addition, bacterial respiration of organic matter from the effluent is a biological process that is not instantaneous. These factors likely contributed to increase effluent dilution and made any dissolved oxygen changes in receiving waters difficult to detect within the natural variability of observations.

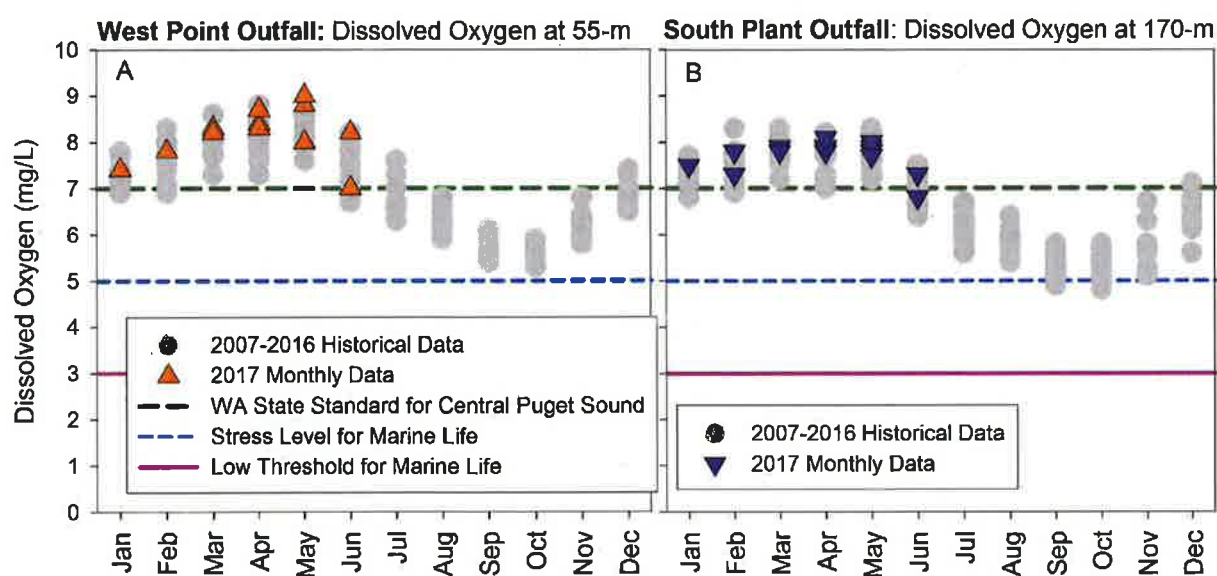


Figure 63. Near-bottom dissolved oxygen levels by month for 2017 on top of historical ranges for the West Point (A) and South Plant (B) outfalls. For Central Puget Sound, the one-day minimum dissolved oxygen numeric standard is 7.0 mg/L (green dashed line).

Dissolved oxygen concentrations may vary spatially across sites over time. Near-bottom levels are shown for all monitoring sites in the Central Basin of Puget Sound for the first half of 2017 (Figure 64). In general, deep northern sites such as the West Point outfall, Point Jefferson (KSBP01) and Carkeek (CK200P) tended to show slightly higher oxygen concentrations, while central and southern sites, such as the South Plant outfall, Point Williams (LSNT01), and East Passage (NSEX01) tended to have slightly lower concentrations (Figure 64A). These patterns are typical of prior years' observations, and are related to circulation and the intensity and duration of phytoplankton blooms at a particular location. Shallow sites (with water depth less than 35-m) are shown separately, since the bottom depths fall within the photic (sunlight) zone for phytoplankton growth and oxygen production. Dissolved oxygen steadily increases in April through June due to the typical spring phytoplankton bloom, particularly at the most shallow sites at the Emergency Bypass Outfall (EBO) and Fauntleroy Cove (LSVV01) (Figure 64B).

2017 Offshore Near-Bottom Dissolved Oxygen Levels

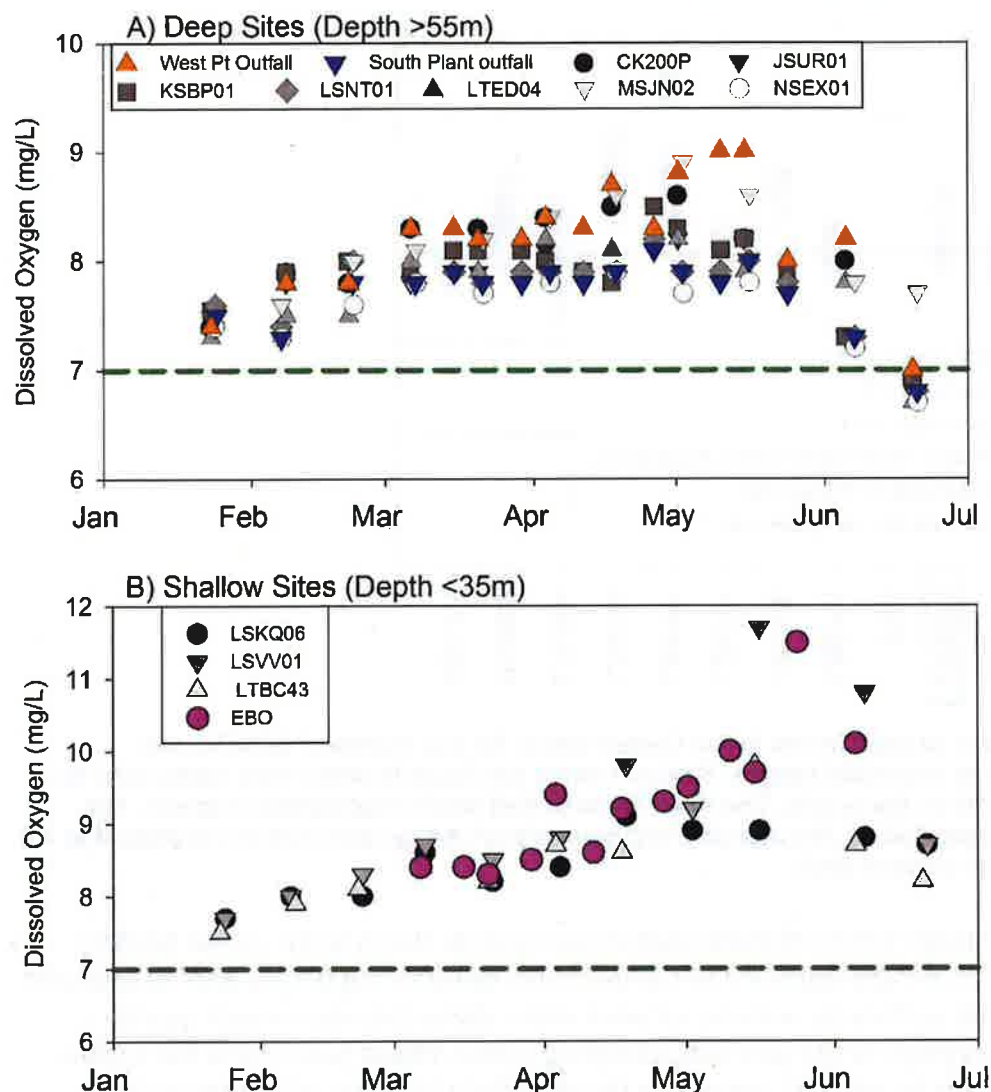


Figure 64. Time series of near-bottom oxygen levels by site for the first half of 2017 for the Central Basin for both deep (A) and shallow (B) locations. The green dotted line represents the state water quality standard for Central Puget Sound. For Central Puget Sound, the one-day minimum dissolved oxygen numeric standard is 7.0 mg/L (green dashed line).

In late June, near-bottom dissolved oxygen observations were at or below the state standard (7.0 mg/L) for all deep sites, with the exception of the Vashon TP outfall site (MSJN02). In order to compare the lower dissolved oxygen levels in late June across sites in the Central Basin, near-bottom data from all sites are shown for June only in context of historical ranges over the last decade (Figure 65). All dissolved oxygen levels fall within the historical range by site for both sampling events in June, and are typical of early summer conditions for this region.

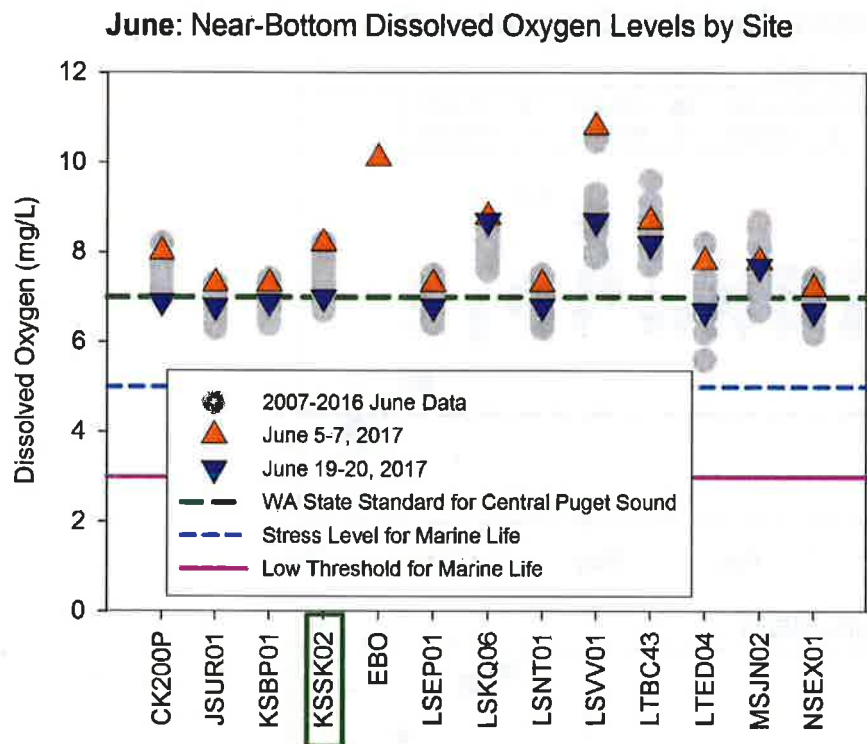


Figure 65. Near-bottom oxygen levels in the Central Basin for the month of June by site compared to historical ranges. Station names are listed in order from north (left) to south (right) on the x-axis. The West Point outfall site is highlighted in green. For Central Puget Sound, the one-day minimum dissolved oxygen numeric standard is 7.0 mg/L (green dashed line).

In general, all observations from offshore sites in the Central Basin were within healthy dissolved oxygen levels for the duration of the intensive monitoring period and throughout the water column from surface to bottom. All sites were above the state water quality standard with the exception of the late June sampling event. These June levels fell within normal historical ranges by site and are above the threshold in terms of potential for biological stress. Dissolved oxygen levels showed typical seasonal conditions for the Central Basin of Puget Sound. Based on the levels of dissolved oxygen observed throughout the monitoring period and the comparison to historical conditions, no negative impacts to biota from these concentrations were expected over the short three month duration of reduced treatment.

4.3 Nutrients and Chlorophyll

Nutrients, such as nitrogen compounds (ammonia, nitrate, and nitrite) and orthophosphate, are essential elements for the growth of aquatic plants, algae, and phytoplankton. Silica is a micronutrient needed by some algae, such as diatoms, and other organisms for skeletal growth. Excess nutrients can have an impact on water quality, and may cause a sudden increase in aquatic plants (bloom) that can lead to unfavorable conditions such as low dissolved oxygen once the bloom decays. The dissolved inorganic

forms are of greatest concern to water quality since these provide a ready source of nutrients for plant growth.

Dissolved inorganic nitrogen and phosphorus compounds may enter Puget Sound waters from oceanic sources, wastewater discharges, stormwater runoff, and riverine and stream sources. Other minor sources include aquaculture operations, groundwater inputs, and atmospheric deposition. Silica may enter marine waters from similar natural sources such as rivers, run-off, and oceanic inputs, and remineralization of organic matter, but does not originate from human sources. Sinks of nutrients include uptake by plants and phytoplankton, burial in the sediments, advection out of Puget Sound, and denitrification processes. Nutrients may be recycled in the water column through remineralization of organic matter as well as through the sediment-water interface.

High ammonia concentrations can be toxic to aquatic organisms, including fish, and the susceptibility depends on temperature, salinity, and pH conditions. Ammonia is a nutrient that has both un-ionized (NH_3) and ionized (NH_4^+) forms. Total ammonia is the sum of both the un-ionized and ionized forms and what is typically measured in waters. Washington State ammonia criteria for marine surface waters are based upon un-ionized ammonia. However, for total ammonia which is measured by King County, Washington State uses U.S. EPA's criteria concentrations based upon total ammonia. These total ammonia criteria are based on water temperature, salinity, and pH (EPA, 1989). For offshore water conditions monitored weekly near the West Point outfall (includes KSSK02, LSEP01, LSNT01, KSBP01, and the EBO) between February through June 2017, the maximum observed temperature of 14.2 °C, minimum observed salinity of 20.7 PSU, and an estimated maximum pH of 8 from prior characterizations (King County, 2013) were used to calculate the lowest (chronic) and most conservative water quality criterion of 1.28 mg/L of total ammonia.

Chlorophyll is a green pigment used by algae and plants during the process of photosynthesis. There are several different forms of chlorophyll but chlorophyll-a is the primary pigment responsible for photosynthesis. The additional chlorophyll forms are accessory pigments and are associated with different groups of algae and phytoplankton. Chlorophyll-a concentrations are an indicator of phytoplankton biomass as all marine planktonic algae contain this pigment, but it is not an exact measurement of phytoplankton abundance. The ratio of phytoplankton biomass to chlorophyll varies with species and environmental conditions. In Central Puget Sound, phytoplankton are limited by light and water column stability during much of the year, and can be seasonally limited by nutrients in the summer.

Determining phytoplankton biomass and the timing of blooms (when a large population increase occurs) is important as phytoplankton form the base of the marine food web and influence water chemistry and nutrient dynamics. Major groups of phytoplankton in marine waters include diatoms, dinoflagellates, and nanoflagellates. Diatoms, which are relatively large and adapted to high-nutrient environments, can multiply rapidly at certain times of the year, such as in early spring in Puget Sound. Diatoms are a major food source for a wide variety of zooplankton, including larger species that are important prey for fish. Dinoflagellates, in contrast, generally flourish under lower nutrient conditions and do not

require silica for growth, unlike diatoms. Nanoflagellates can typically be too small to be a good food source for the larger zooplankton. The progression from diatom-dominated communities in the spring to more diverse communities of smaller, motile (flagellated) types of phytoplankton in the summer is a general pattern that is frequently observed in coastal marine waters. In the Central Puget Sound Basin, although dinoflagellates typically increase in abundance and diversity in the summer and fall, diatoms make up a large proportion of the phytoplankton biomass during most of the spring through fall growing season.

4.3.1 Offshore Nutrients

Nutrients (ammonia, nitrate + nitrite, orthophosphate, and silica) were analyzed at multiple depths at all offshore stations, and total nitrogen (includes particulate and dissolved forms) were analyzed at the surface at a subset of offshore stations. Offshore nutrient concentrations in the Central Basin are affected by several factors, including oceanic and river inputs, proximity to outfalls, biological uptake, and water depth. At shallow depths in the photic zone, nutrient concentrations can reach low levels due to phytoplankton uptake. Data are presented for the Central Basin locations with a focus on the five sites nearest to West Point, as well as an additional site at the West Point emergency bypass (EBO).

4.3.1.1 Ammonia

Ammonia levels are generally low and frequently below detection limits particularly in the winter months. Beginning in late spring through the fall, ammonia levels may increase due to decay of organic materials such as from phytoplankton blooms. This seasonal pattern is often observed at ambient sites in Puget Sound under natural conditions. At the West Point and South Plant outfall sites, sampling locations are inside the discharge mixing zone as defined by the NPDES permit, and elevated ammonia concentrations are often observed due to the effluent plume. Generally, effluent from these treatment plants contains higher levels of ammonia than other forms of dissolved inorganic nitrogen and other nutrients (See Section 3.5 for details). However, the historical peak ammonia concentrations at West Point (max = 0.363 mg/L in June 2014) are more than 3 times lower than the lowest (chronic) and water quality standard (1.28 mg/L).

Near surface ammonia levels are shown by month to compare 2017 to historical conditions of the prior decade for the five Central Basin offshore sites that were sampled weekly (Figure 66). In general, ammonia concentrations at the surface in the first half of 2017 were well below historical ranges at all sites throughout the sampling period. One exception was the February 8 sampling event at West Point, prior to when the plant flooding occurred. This sample was likely attributed to high flows and a well-mixed water column, where the effluent plume may reach near the surface. This can be a normal discharge pattern, particularly in the winter, and its occurrence depends on weather conditions and stormwater input flows.

Near bottom ammonia levels are shown by month for the same sites and time period (Figure 67). Ammonia levels at West Point between February and June 2017 were below historical ranges, and other ambient sites show expected conditions. West Point effluent during reduced treatment contained lower ammonia concentrations than average as well (See Section 3.5). Overall, concentrations at the bottom and mid-water column depths at the outfall, with the exception of February 8 (prior to the flooding event), were lower than expected values based upon historical ranges. Near bottom concentrations at the South Plant outfall were on the higher range of historical values during some sampling events.

In order to compare ranges in 2017 relative to the historical record, ammonia medians and percentiles (5th, 25th, 75th, and 95th) are shown for January–June 2017 compared to historical data from the last decade for each discrete depth (Figure 68). All sites show ammonia ranges similar to or below historical conditions across depths for 2017. Cumulatively, the deepest depths at the South Plant outfall site showed ammonia ranges similar to historical levels. Overall, this indicates that ammonia levels were normal or lower than historical conditions in the Central Basin offshore sites throughout the February–June 2017 period, and at healthy levels well below the chronic water quality standard. As the water quality criterion was developed to be protective of aquatic life, no short-term impacts to biota were expected due to ammonia concentrations discharged to Puget Sound receiving waters during the period of reduced treatment.

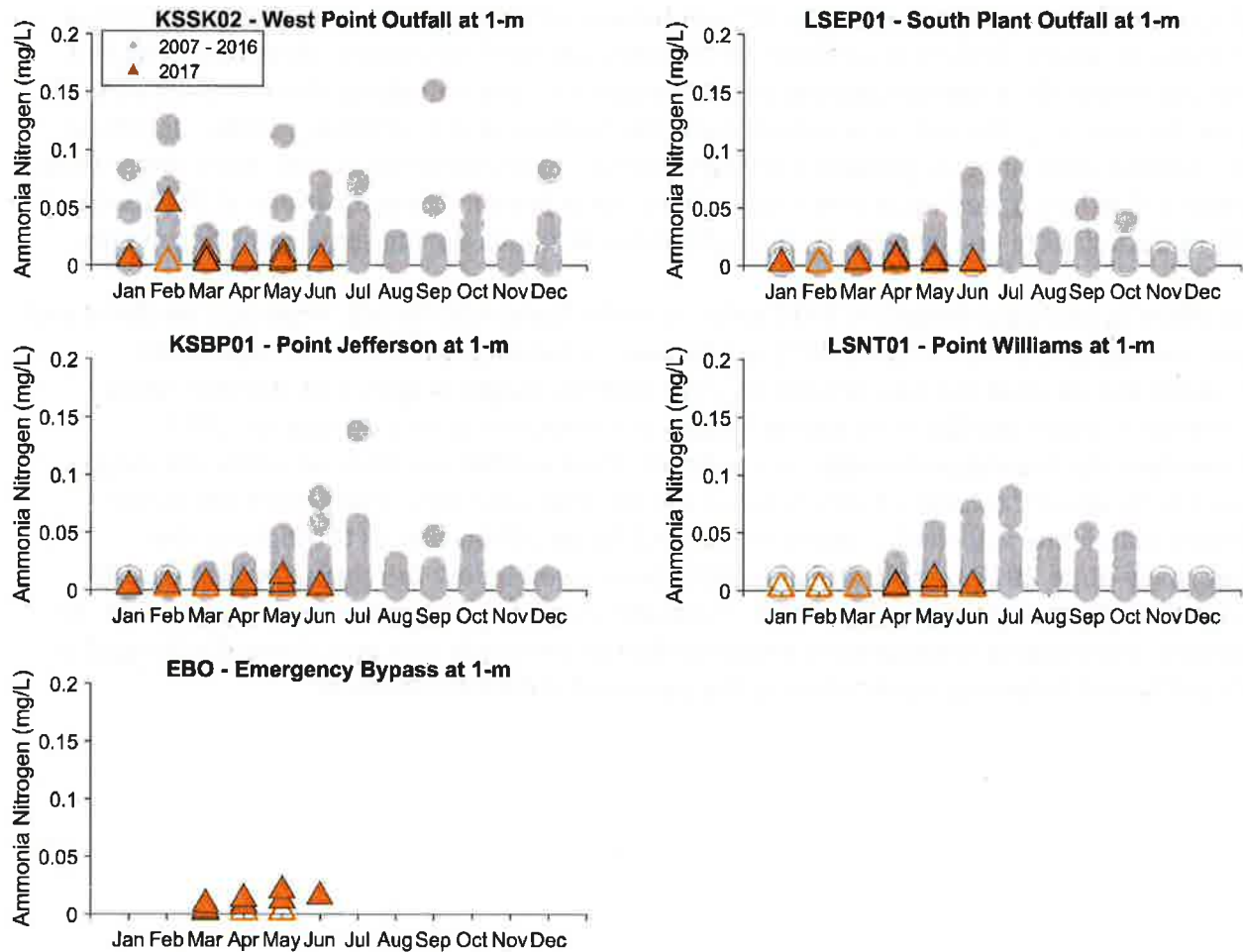


Figure 66. Near surface ammonia levels by month compared to historic ranges for offshore Central Basin sites. Open symbols indicate concentrations below the detection limit. The lowest (chronic) and most conservative water quality criterion is 1.28 mg/L (not shown), based on observed temperature, salinity, and pH.

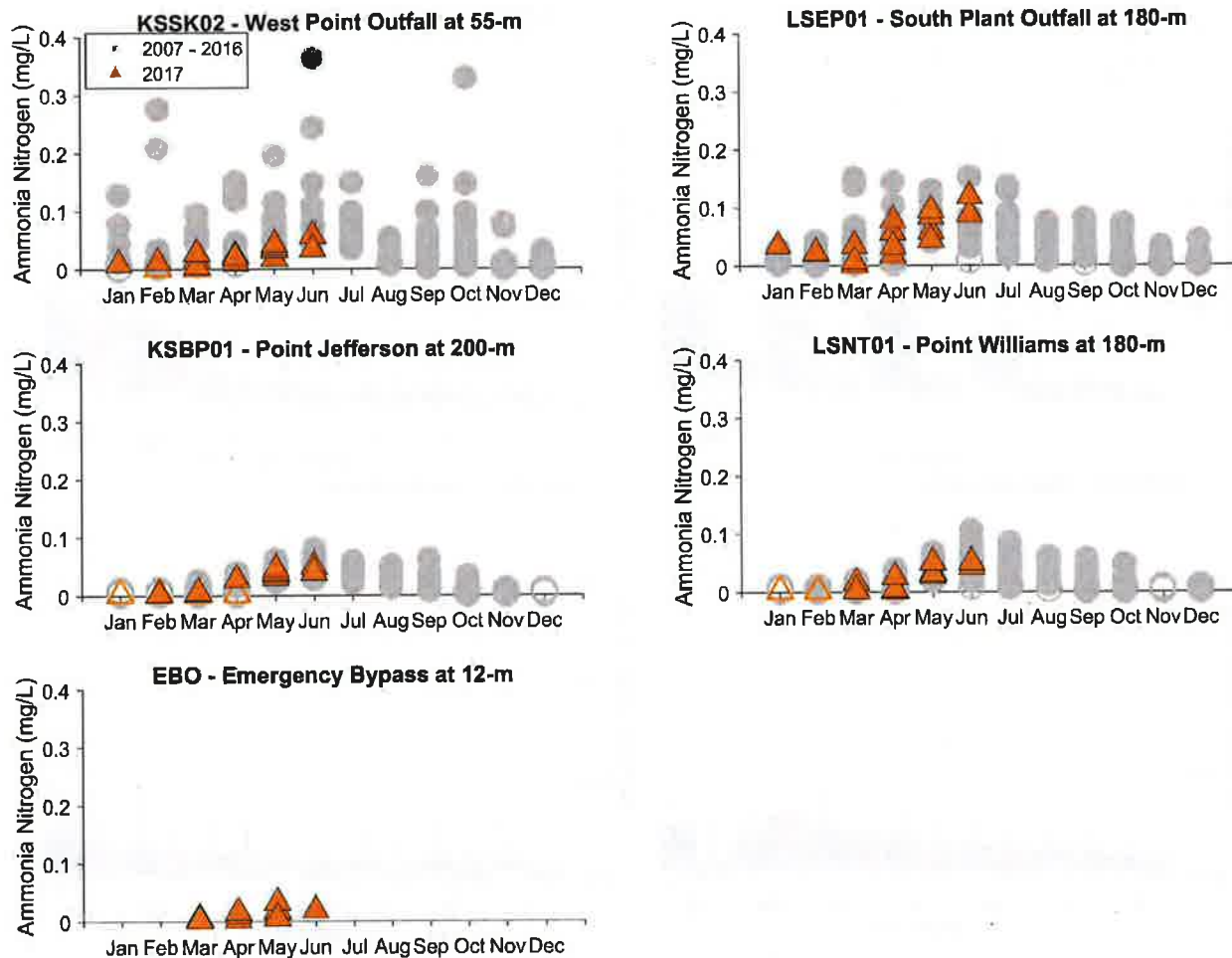


Figure 67. Near bottom ammonia levels by month compared to historic ranges for offshore Central Basin sites. Open symbols indicate concentrations below the detection limit. The lowest (chronic) and most conservative water quality criterion is 1.28 mg/L (not shown), based on observed temperature, salinity, and pH.

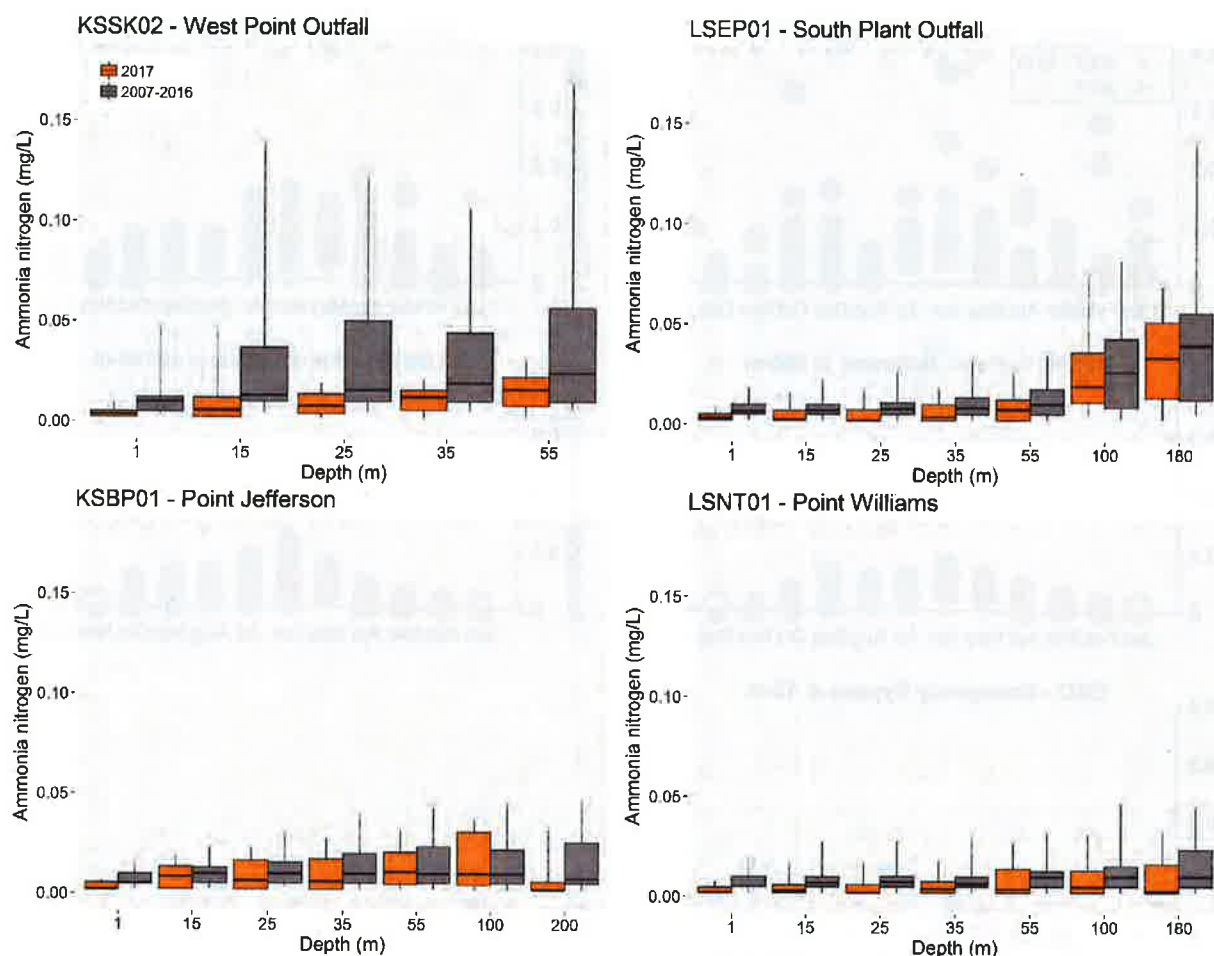


Figure 68. Ammonia concentration percentiles from Feb. 9 to May 10, 2017 combined by depth compared to the historical record for the same months for Central Basin sites. Bars show median, boxes show 25th and 75th percentiles, and vertical lines show 5th and 95th percentiles. The lowest (chronic) and most conservative water quality criterion is 1.28 mg/L (not shown), based on observed temperature, salinity, and pH.

4.3.1.2 Nitrate + nitrite and orthophosphate

Generally, nitrate + nitrite and orthophosphate show an opposite seasonal pattern compared to ammonia, and are frequently above detection limits year-round in the Central Basin, with some exceptions during intense phytoplankton blooms. Beginning in the spring, nutrient concentrations typically decline over time in the surface layers where light penetrates due to phytoplankton uptake. Concentrations continue to decrease through the summer, with some replenishment due to mixing. In the late fall, nutrients tend to increase along with a reduction in stratification, mixing from winds and storms, and increased freshwater nutrient inputs. Typically, nutrient concentrations are highest in the winter outside of the growing season, and this seasonal pattern is often observed at ambient sites in Puget Sound under natural conditions.

Near surface nitrate + nitrite (referred to as nitrate) levels are shown by month to compare 2017 to conditions of the prior decade for the five Central Basin offshore sites that were sampled weekly (Figure 66). In general, nitrate concentrations at the surface were within historical conditions. During May and June, near-surface nitrate concentrations were low across sites and below detection limits at some sites. This can be attributed to concentrated phytoplankton growth due to physical conditions such as persistent stratification (See discussion in Section 4.3.3 for details). In addition, this same pattern and depletion of nutrients in the surface layer was observed in silica concentrations (Figure 72) and orthophosphate concentrations (Figure 73), indicating all macronutrients were being taken up by phytoplankton blooms.

Near-bottom nutrient concentrations of nitrate + nitrite (Figure 70) and orthophosphate (Figure 74) are shown by month for the same sites and time period. All sites, including at the West Point and South Plant outfall locations, show deep nutrient concentrations and ratios from the first half of 2017 within the expected historical record and seasonal pattern.

In addition, vertical profiles of nitrate throughout the water column are shown for the four deep sites from April through June 2017, using a Submersible Ultraviolet Nitrate Analyzer (SUNA) on loan from the Dept. of Ecology during this time period (Figure 71). These data more precisely show the vertical extent of the nitrate depletion near the surface due to phytoplankton uptake, and the signal closely follows the depth of the pycnocline (gradient of sharp density difference). Nitrate concentrations over time also show a seasonal pattern due to the influence of both oceanic and freshwater inputs, and resulting estuarine exchange circulation. For example, less salty water layers throughout the water column are observed starting in late April, likely due to increased mixing at the sills. This lower salinity water also contains lower nitrate. At the mid-depths (75–125-m) of the deep stations, slightly elevated nitrate concentrations were seen in conjunction with a cooler water mass at the same depth. Similar nitrate patterns are observed across the Central Basin sites.

Overall, nutrient concentrations between February and June 2017 were similar to or lower than historical observations. As in previous years, physical and biological dynamics greatly contributed to the patterns seen in 2017.

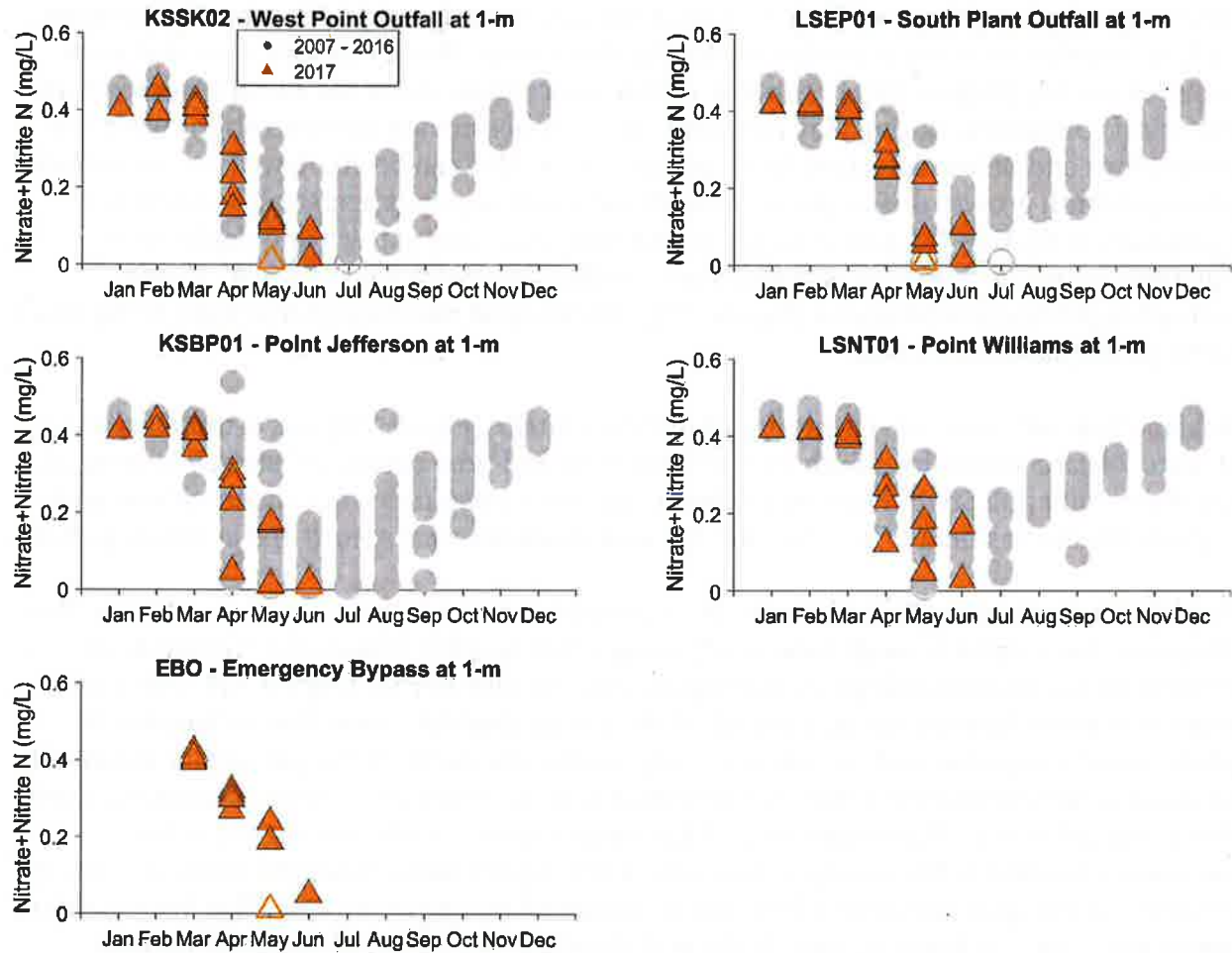


Figure 69. Near surface nitrate + nitrite nitrogen levels by month compared to historic ranges for offshore Central Basin sites. Open symbols indicate concentrations below the detection limit.

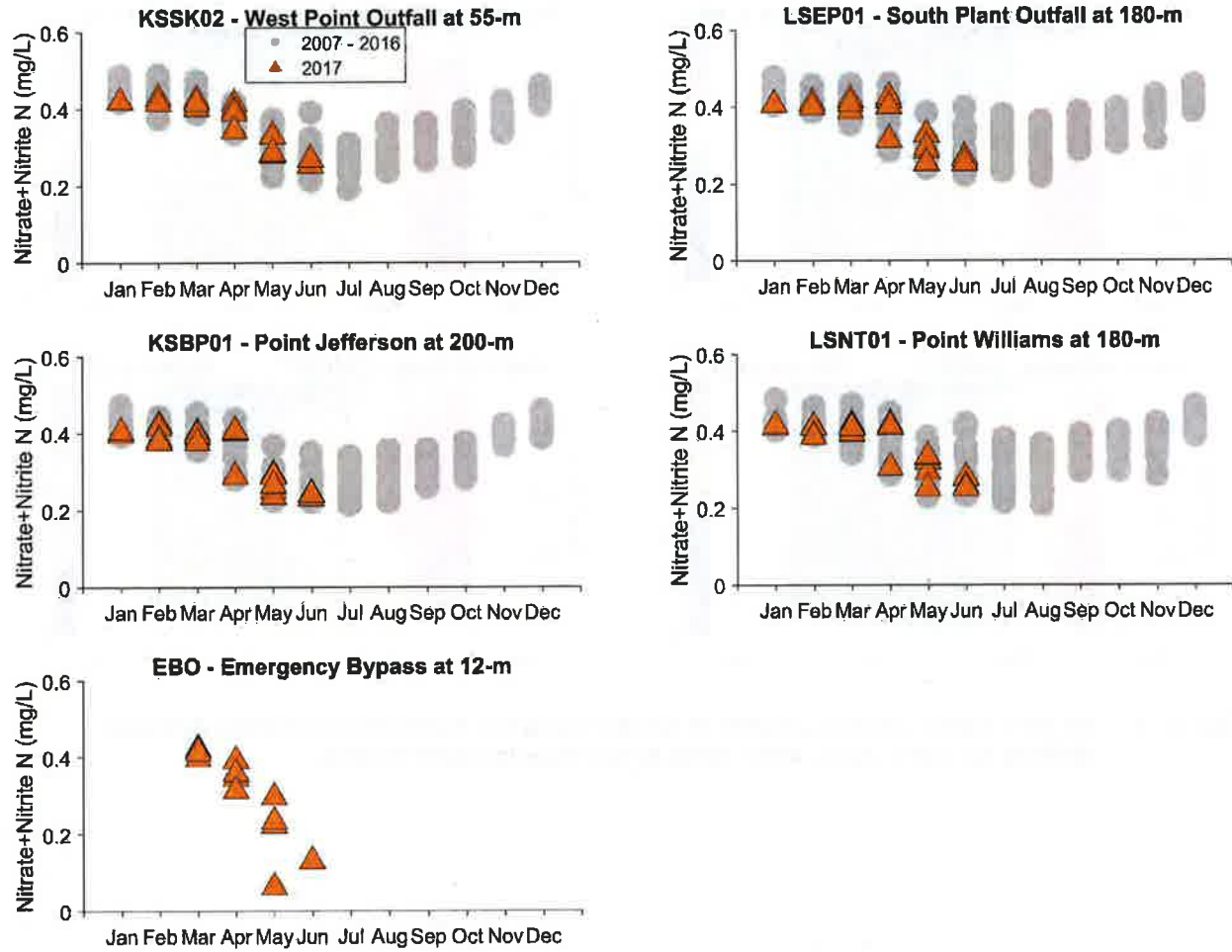


Figure 70. Near bottom nitrate + nitrite nitrogen levels by month compared to historic ranges for offshore Central Basin sites.

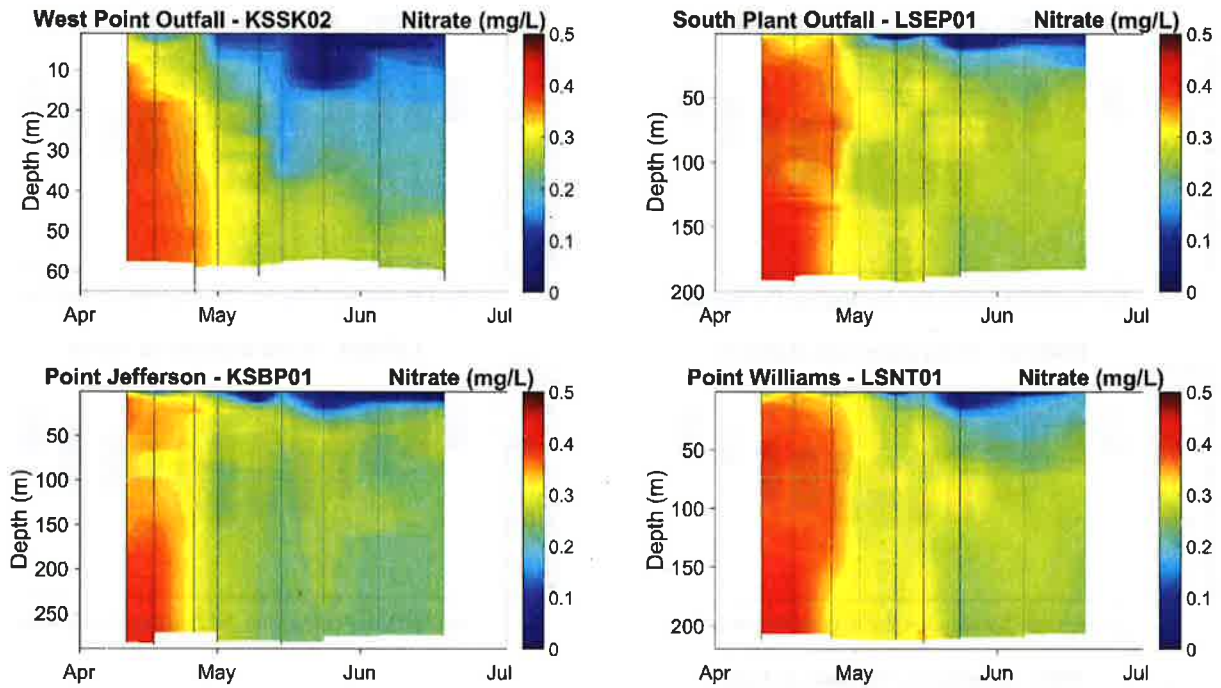


Figure 71. Vertical water column profiles of nitrate using the Submersible Nitrate Analyzer (SUNA) for April–June, 2017. Note differences in depth scales.

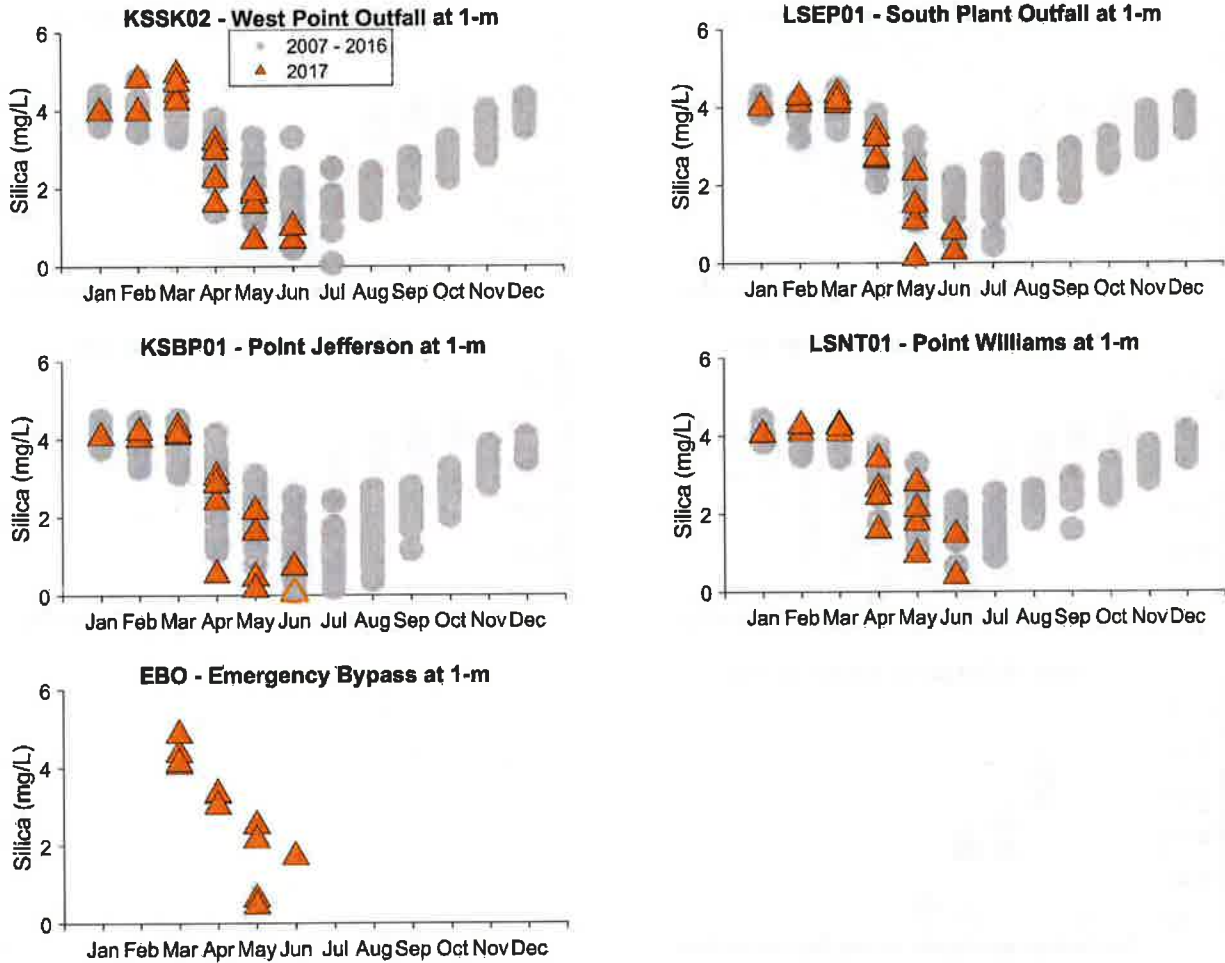


Figure 72. Near surface silica levels by month compared to historic ranges for offshore Central Basin sites. Open symbols indicate concentrations below the detection limit.

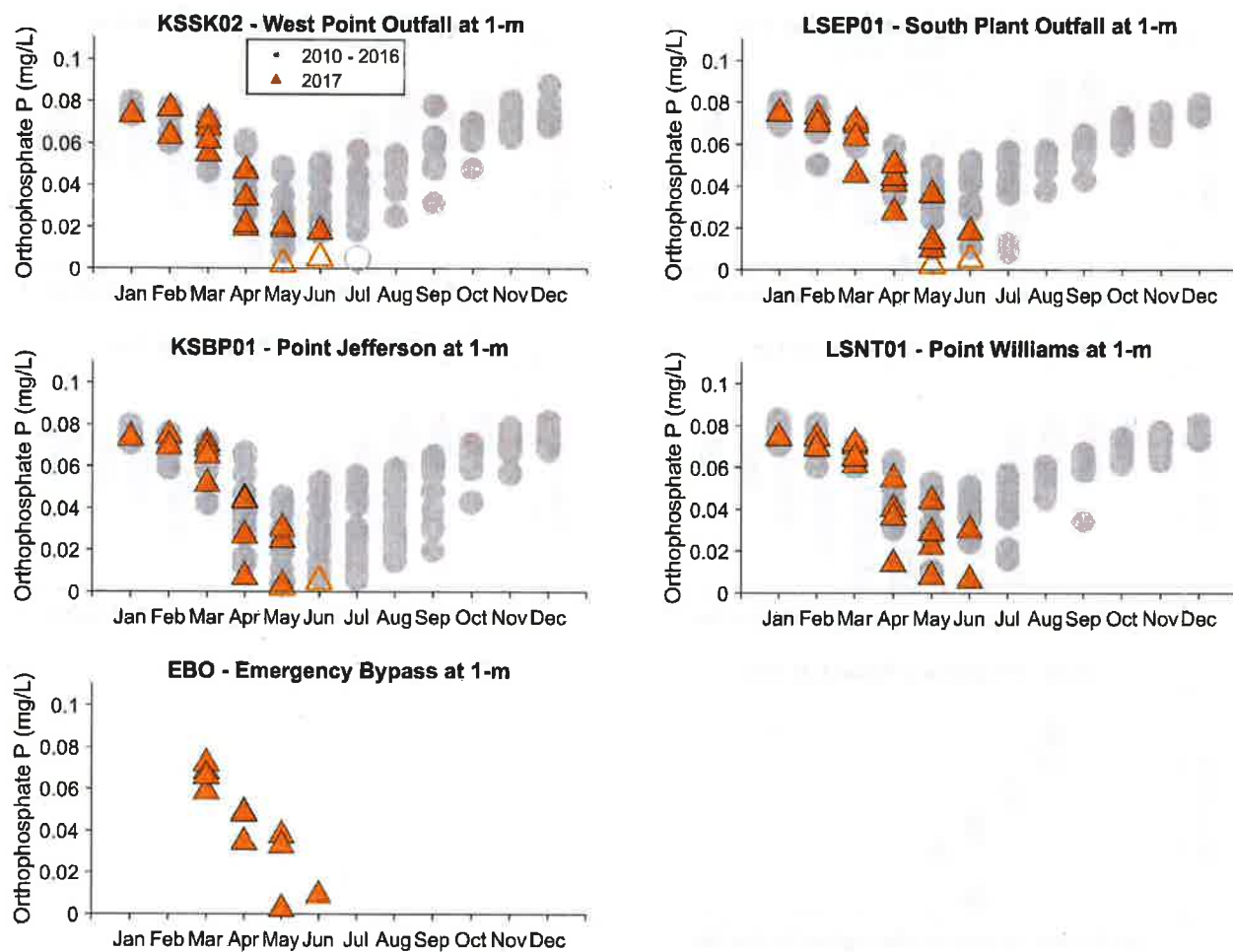


Figure 73. Near surface orthophosphate levels by month compared to historic ranges for offshore Central Basin sites. Open symbols indicate concentrations below the detection limit.

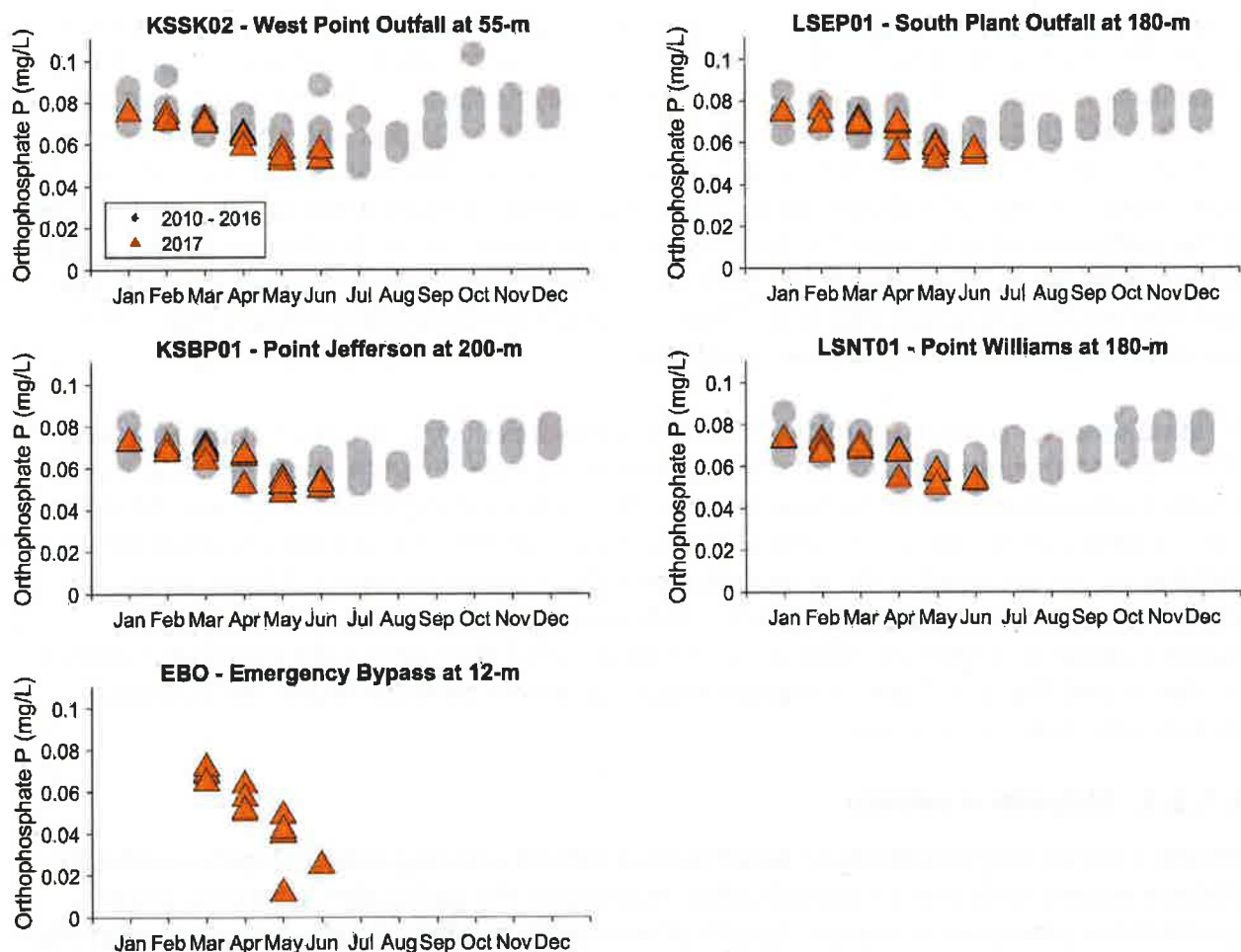


Figure 74. Near bottom orthophosphate levels by month compared to historic ranges for offshore Central Basin sites.

4.3.2 Nearshore Nutrients

Ammonia, nitrate + nitrite, and orthophosphate were analyzed monthly in nearshore (beach) waters at all King County routine monitoring stations. Only data from 11 of the 20 beach sites (see Figure 11) will be discussed below in order to focus on the sites nearest to the West Point outfall and to account for location differences. Beach nutrient concentrations vary considerably by station and are influenced by proximity to freshwater sources, such as streams or stormwater outfalls, and if located in open water or an embayment/cove. The 11 stations discussed are landward of a treatment facility outfall and located from Point Wells south to West Seattle. Areal coverage of these sites encompass the beaches at Carkeek Park, the north and south side of West Point, Elliott Bay, and the north and south side of Alki.

4.3.2.1 Ammonia

Similar to the pattern seen in offshore waters, ammonia concentrations in beach waters exhibit a seasonal cycle, with low concentrations in the winter months and increasing

values in late spring to early summer before steadily declining the remainder of the year. Figure 75 and Figure 76 show 2017 results through June for the 11 stations compared to historical data from 2007 to 2016. Overall, the highest value (0.053 mg/L) was seen in May at station KSLU03 (Golden Gardens). This site tends to have higher values at various times throughout the year and is influenced by nutrients from the freshwater outflow of Lake Washington via the Lake Washington Ship Canal, as well as the outflow of the small stream at the southern end of Golden Gardens beach. There were no CSO discharges in May at any of the treatment facilities that might have contributed to the higher value at this site. The two sites in Elliott Bay, KSYV02 and LTBD27, also tend to have higher values due to the influence of the outflow of the Duwamish River.

Ammonia concentrations at the two West Point beaches in 2017 were all at the low range of historical values and similar to or lower than other sites. In addition to the West Point beaches, ammonia levels at the beaches near the Carkeek Park, Elliott West, and Alki CSO outfalls were low or similar to historical values during February and March, when more CSO discharges occurred at these facilities from the increase in diverted flows. Ammonia levels at most sites were higher April through June, which is consistent with typical seasonal patterns. Concentrations at all 11 sites in 2017 throughout the period of reduced treatment and May and June during secondary treatment were far below the 1.28 mg/L chronic criterion for ammonia.

4.3.2.2 Nitrate + nitrite

Nitrate + nitrite concentrations in beach waters exhibit a strong seasonal cycle similar to offshore waters, with lower concentrations starting in the spring due to aquatic plant uptake during the growth season. Aquatic plants in the marine nearshore include eelgrass, microalgae, and macroalgae (seaweed). Figures Figure 77 and Figure 78 show 2017 results through June for the 11 stations compared to historical data from 2007 to 2016. The lowest values in 2017 were seen in June at most stations, as is typical when macroalgal growth is high. Nitrate + nitrite were below detectable levels in June at both of the West Point sites and also Carkeek Park. The two sites in Elliott Bay had noticeably higher nitrate + nitrite values in June than the other sites; historically these sites have the least amount of macroalgae growth compared to the other nine locations and less uptake. With the exception of the low June values, all other nitrate + nitrite values were within historical ranges for each site, including the two West Point beaches during the period of reduced treatment. The June 2017 levels were either at the low end or lower than historical values at all but the Elliott Bay sites. Nitrate + nitrite values in February and March were within historical levels at all stations, including those near the Alki, Carkeek, and Elliott West CSO outfalls when more CSO discharges than normal occurred at these facilities.

The higher concentrations during the first part of the year and subsequent decrease due to algae uptake are shown.

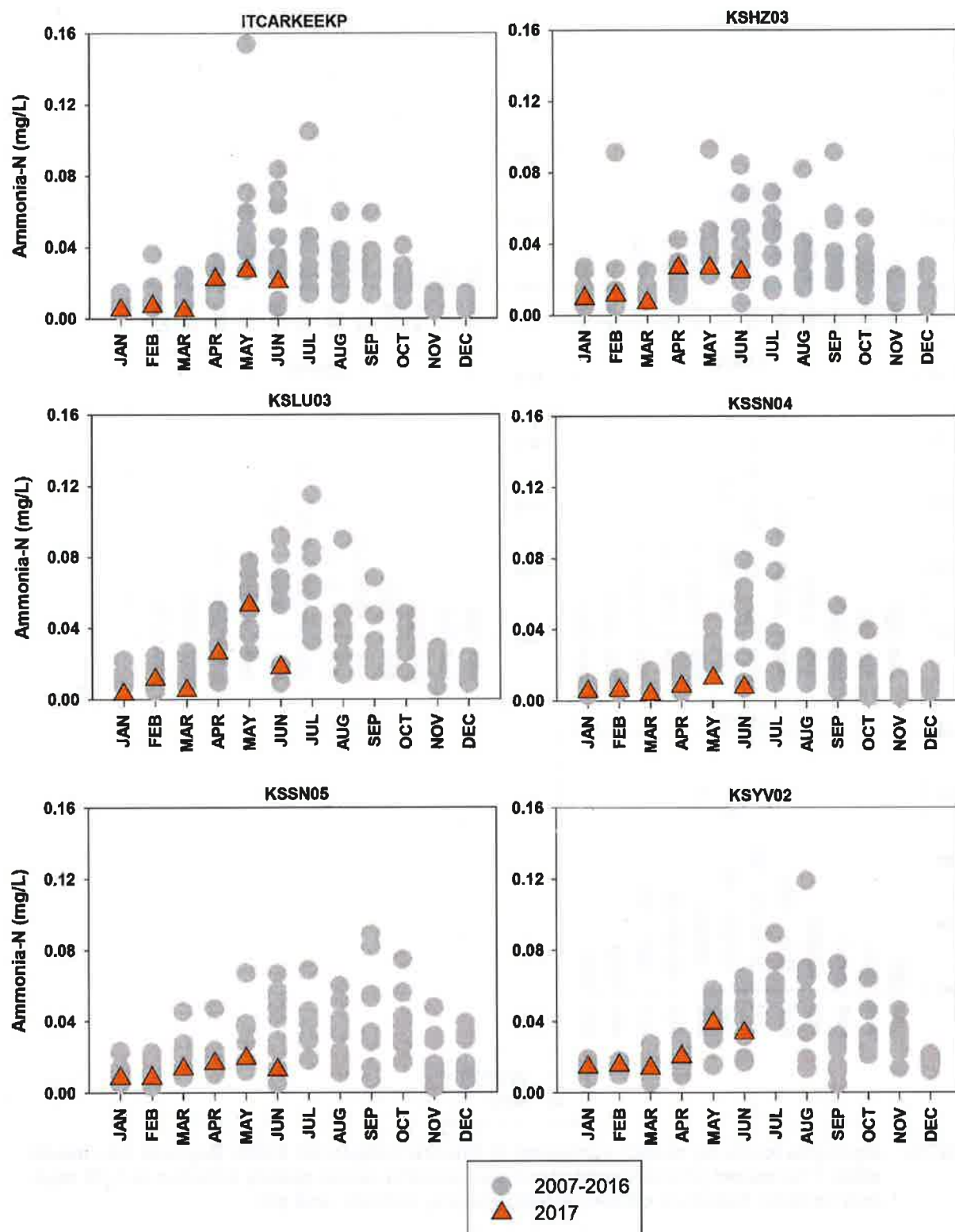


Figure 75. Ammonia levels by month compared to historic ranges for northern beach sites (Carkeek to Magnolia). The lowest (chronic) and most conservative water quality criterion is 1.28 mg/L (not shown), based on observed temperature, salinity, and pH.

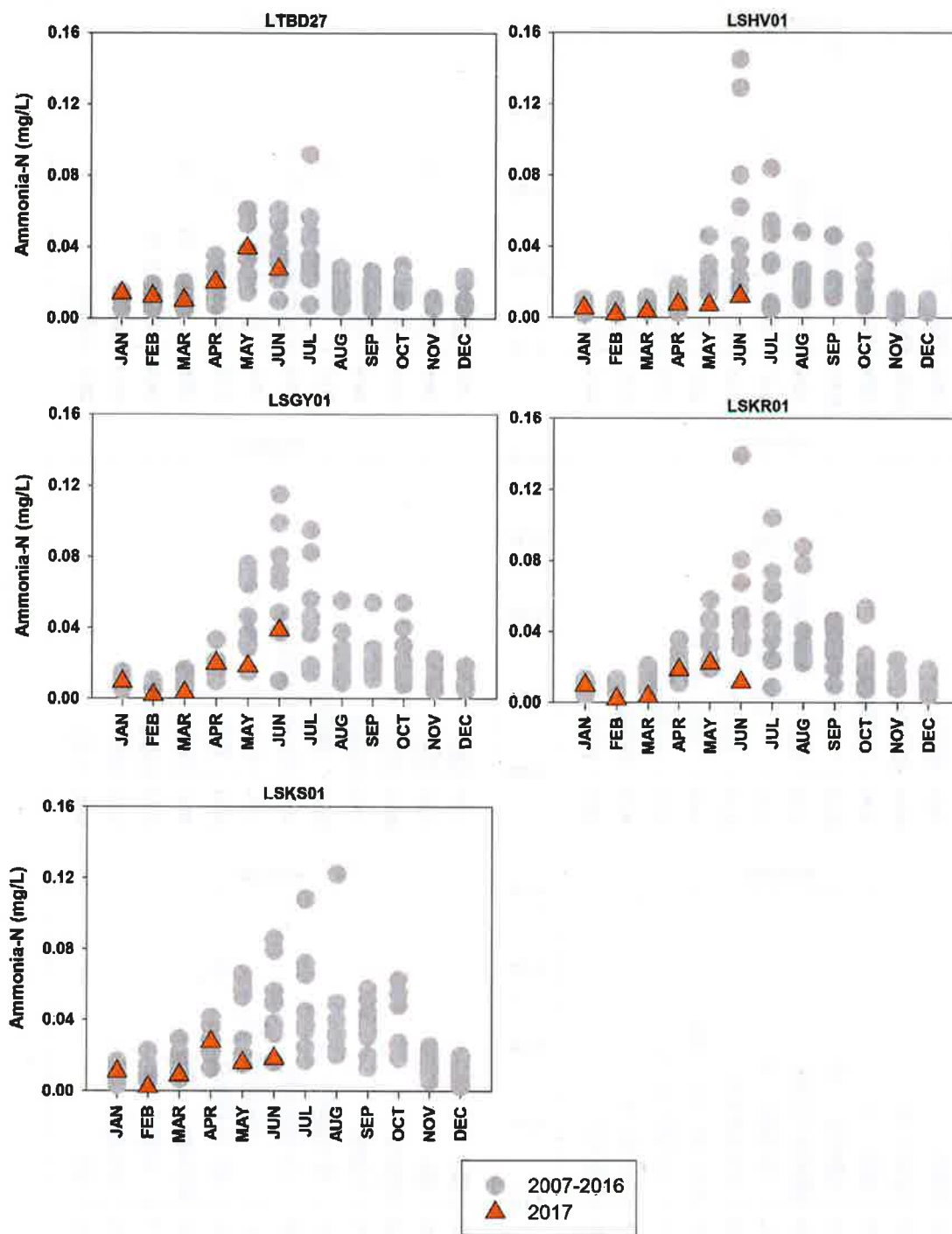


Figure 76. Ammonia levels by month compared to historic ranges for Elliott Bay and Alki beach sites. The lowest (chronic) and most conservative water quality criterion is 1.28 mg/L (not shown), based on observed temperature, salinity, and pH.

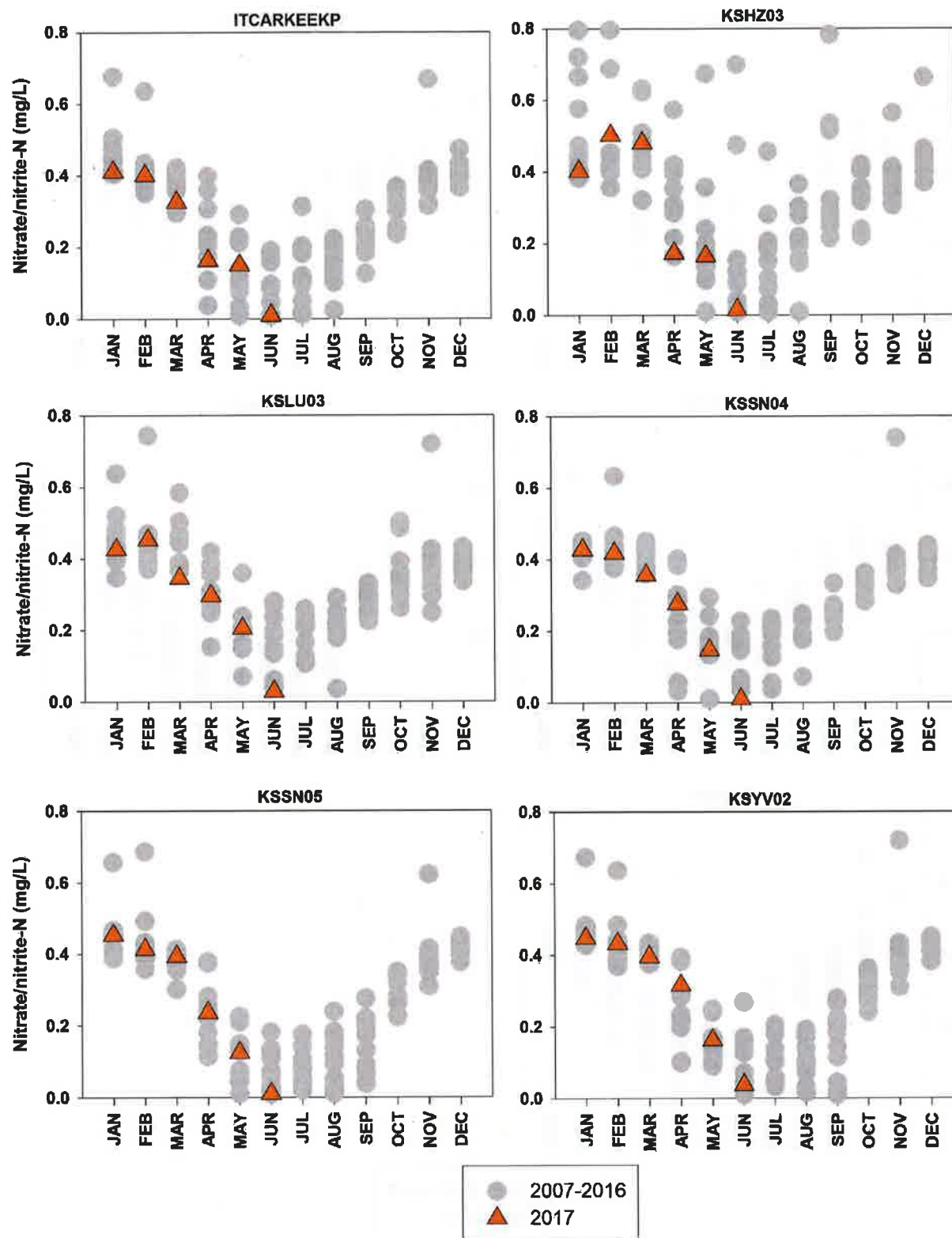


Figure 77. Nitrate+nitrite levels by month compared to historic ranges for northern beach sites (Carkeek to Magnolia).

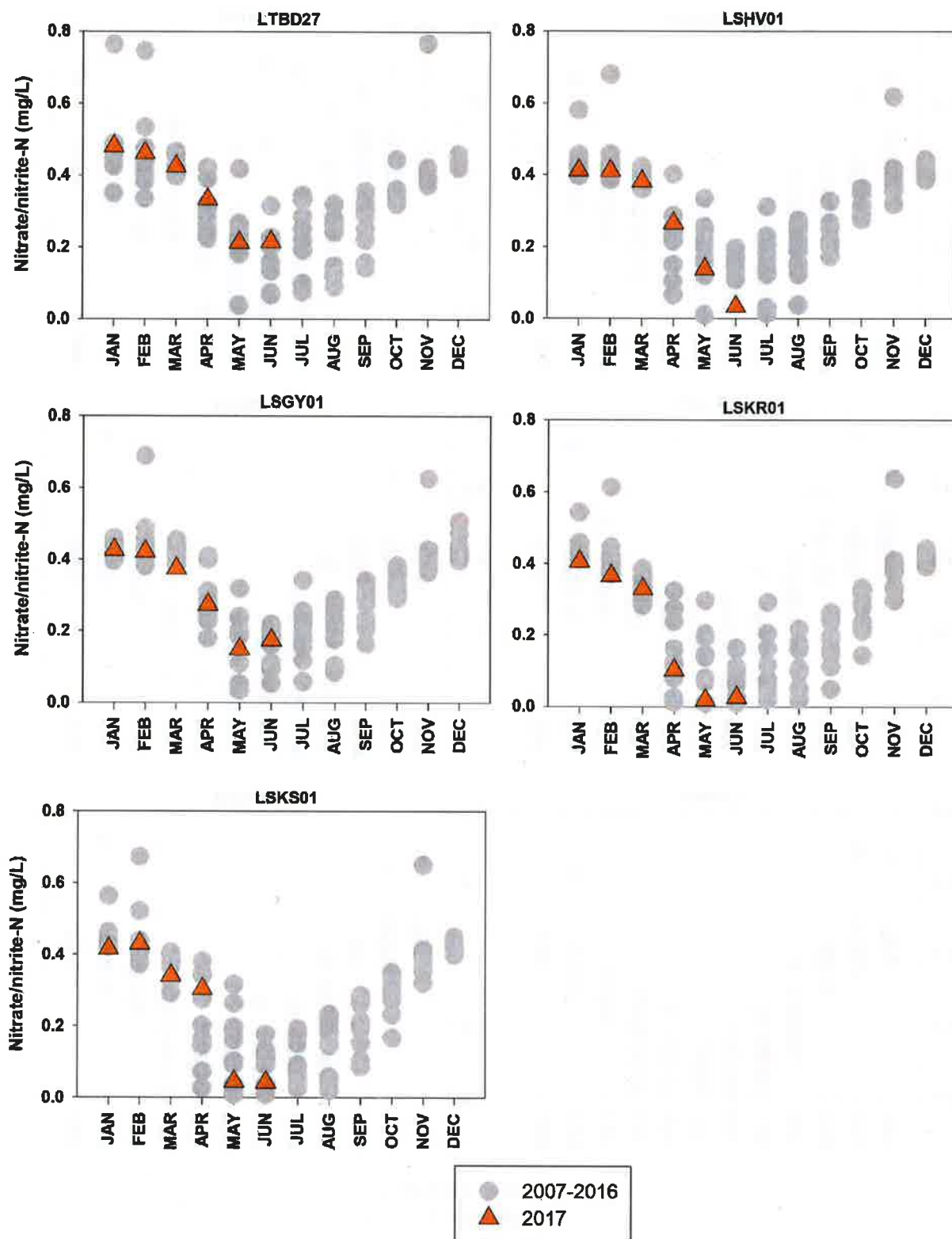


Figure 78. Nitrate+nitrite levels by month compared to historic ranges for Elliott Bay and Alki beach sites.

4.3.2.3 Orthophosphate

Orthophosphate concentrations also exhibited a typical seasonal pattern with a steady decrease at the beginning of the year until May. However, unlike nitrate + nitrite values that remained low throughout the summer, orthophosphate levels increased in June at the majority of the sites. The four sites where orthophosphate levels decreased rather than increased in June were the two West Point beaches, Golden Gardens, and the north side of Alki. The orthophosphate levels in June at these four sites were all below the historical range and these same sites also had very low levels of nitrate + nitrite. Concentrations in March at all 11 stations were below the historical range. For other months, orthophosphate levels were within or lower than the historical range at each station with the exception of a higher than typical value in June at the northern Carkeek Park site (ITCARKEEKP). Figure 79 and Figure 80 show 2017 results through June for the 11 stations compared to historical data from 2007 to 2016. Orthophosphate values at beaches near the West Point, Carkeek, Elliott West, and Alki outfalls were not elevated between February and April during the period of reduced treatment.

For the first six months of the year, orthophosphate values were generally higher January through March, with the exception at Carkeek Park noted above. The sites along the eastern shoreline in Elliott Bay (LTBD27 and KSYV02) tend to have higher values throughout the year than other sites, primarily due to the influence from the Duwamish River outflow. Although the seasonal patterns is similar between most locations, concentrations are typically highly variable.

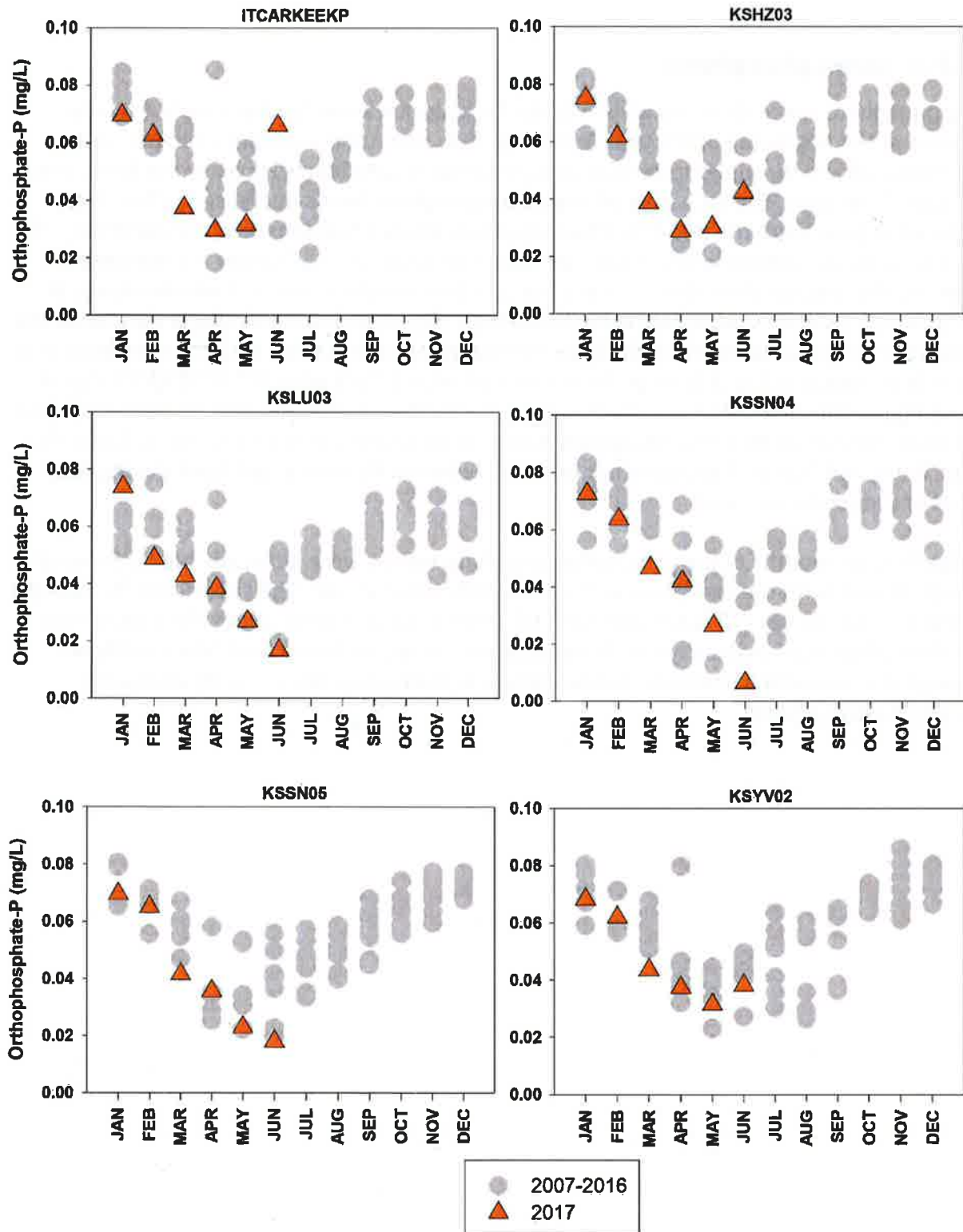


Figure 79. Orthophosphate levels by month compared to historic ranges for for northern beach sites (Carkeek to Magnolia).

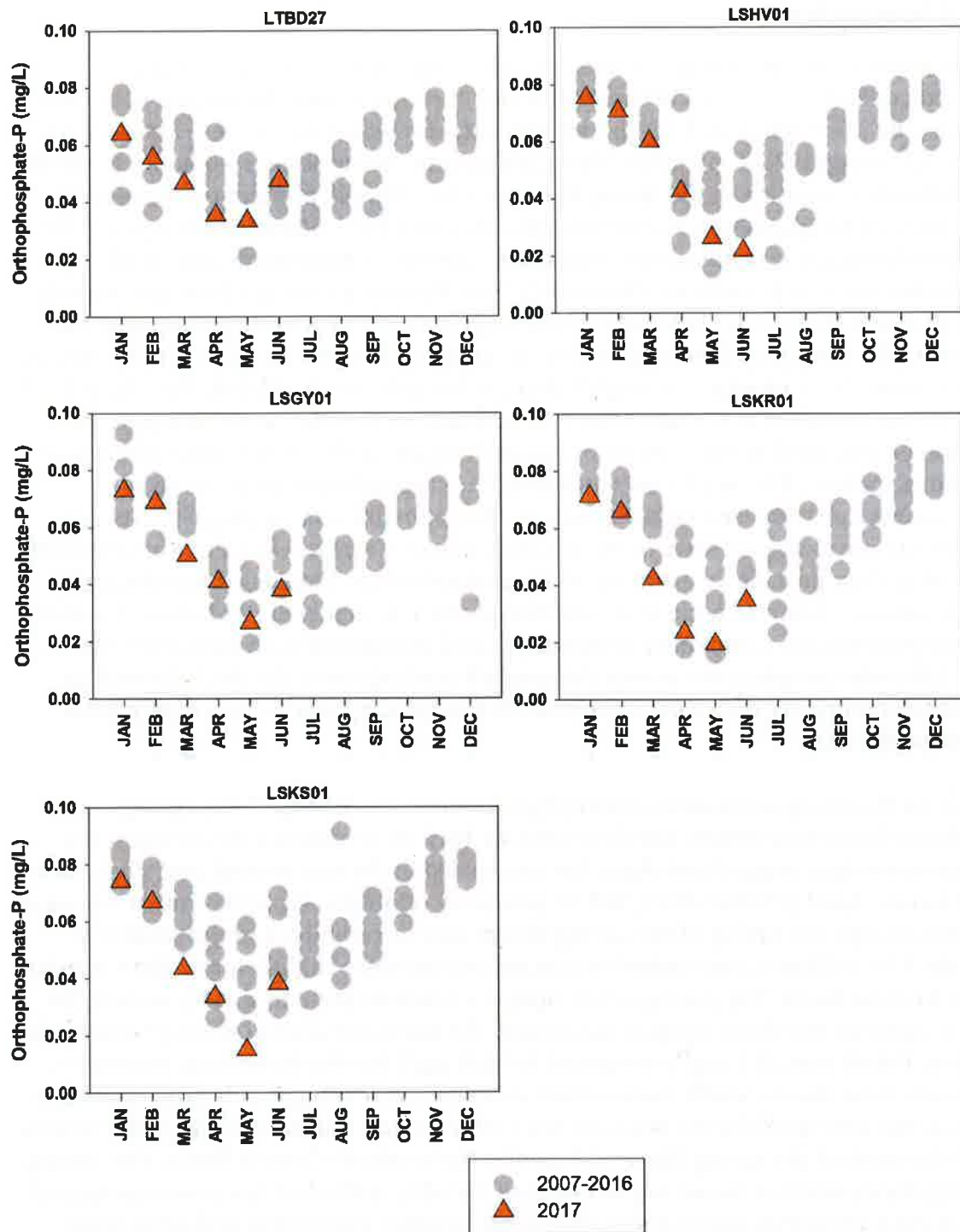


Figure 80. Orthophosphate levels by month compared to historic ranges for Elliott Bay and Alki beach sites.

4.3.3 Chlorophyll

Increased nutrients and/or changes in nutrient ratios have the potential to change phytoplankton dynamics in terms of the timing and duration of blooms and the species composition. The chlorophyll and phytoplankton data discussed below were assessed for these potential changes. Phytoplankton biomass can vary on the scale from hours to weeks, making it difficult to capture all the bloom dynamics. In addition, phytoplankton blooms are patchy and can be spatially variable between sites. In 2017, chlorophyll-a, a proxy for phytoplankton biomass, was measured in discrete samples at multiple depths at all offshore stations once in January, twice a month from February through June, and weekly at a subset of five stations from February 21 through June 9. The weekly sampling at the five stations in 2017 increased the probability of capturing blooms. Samples were collected in the photic zone, the area where enough light penetrates to allow photosynthesis, at 1, 15, 25, and 35-m and analyzed in the laboratory. In addition to the laboratory samples, an in-situ fluorometer was used to measure chlorophyll throughout the entire water column at all the offshore stations. The in-situ measurements are typically not as accurate as laboratory results due to several factors, such as chlorophyll levels varying with species composition and physiological state of the phytoplankton. However, in situ measurements are beneficial as they provide an estimate of the phytoplankton biomass throughout the entire water column. Samples were also collected at the 1-m depth at 10 offshore stations to provide phytoplankton community composition and abundance data as neither the laboratory (discrete samples) nor in-situ chlorophyll methods provide this information. Phytoplankton community data were collected once in January and twice a month from February through June.

As indicated by the sharp increase in chlorophyll-a values, the timing of the spring phytoplankton bloom was evident the first week in April at all stations. Historically, the spring bloom is evident around mid-April but has varied in the last several years between late-March to late-April (PSEMP 2015, 2016), primarily related to stratification of the water column. Even though the timing of the spring bloom was in early April in the southern portion of the Central Basin, chlorophyll-a concentrations were slightly lower than in other areas of the Central Basin. The average chlorophyll-a concentration in surface waters the first week in April for the three deepest stations in the northern Central Basin (Point Wells south to West Point) was 29.1 µg/L compared to 16.8 µg/L for the three deep stations in the southern Central Basin (South Plant outfall south to East Passage). It is typical to have differences in the timing of blooms between the northern and southern areas of the Central Basin, with the peak of the spring bloom delayed in the southern Central Basin. The timing of the spring phytoplankton bloom has been more variable in the last few years compared to long-term data, primarily due to anomalous local weather conditions and large-scale climate patterns affecting water column stratification and temperatures.

Weekly chlorophyll data show that concentrations varied following the start of the spring bloom but remained elevated throughout June, with a large peak in May at all but the Elliott Bay sites. Elliott Bay typically has lower chlorophyll values throughout the year than other sites. The timing of the May peak varied between stations, with the highest value (62.4 µg/L) detected at the East Passage station (NSEX01) on May 2. The May bloom was

higher than in 2016 but similar to 2015. Figure 81 shows chlorophyll-a values for six sites in 2017 compared to historical values. The strong and more persistent than normal water column stratification that was seen from late March through June (see Section 4.2.1) likely contributed to sustained phytoplankton and chlorophyll levels. Figure 82 shows chlorophyll concentrations in the upper 50-m of the water column for four sites in 2016 through June 2017. The East Passage station was sampled twice monthly rather than weekly like the other sites shown; therefore, some bloom dynamics may have been missed. With the exception of the high value in May at the East Passage station, chlorophyll levels at all sites, including the West Point station, were within historical values. Comparison to historical values cannot be made for the EBO station as this site was only sampled in 2017, however, chlorophyll-a levels at this site were similar to values at other shallow water stations.

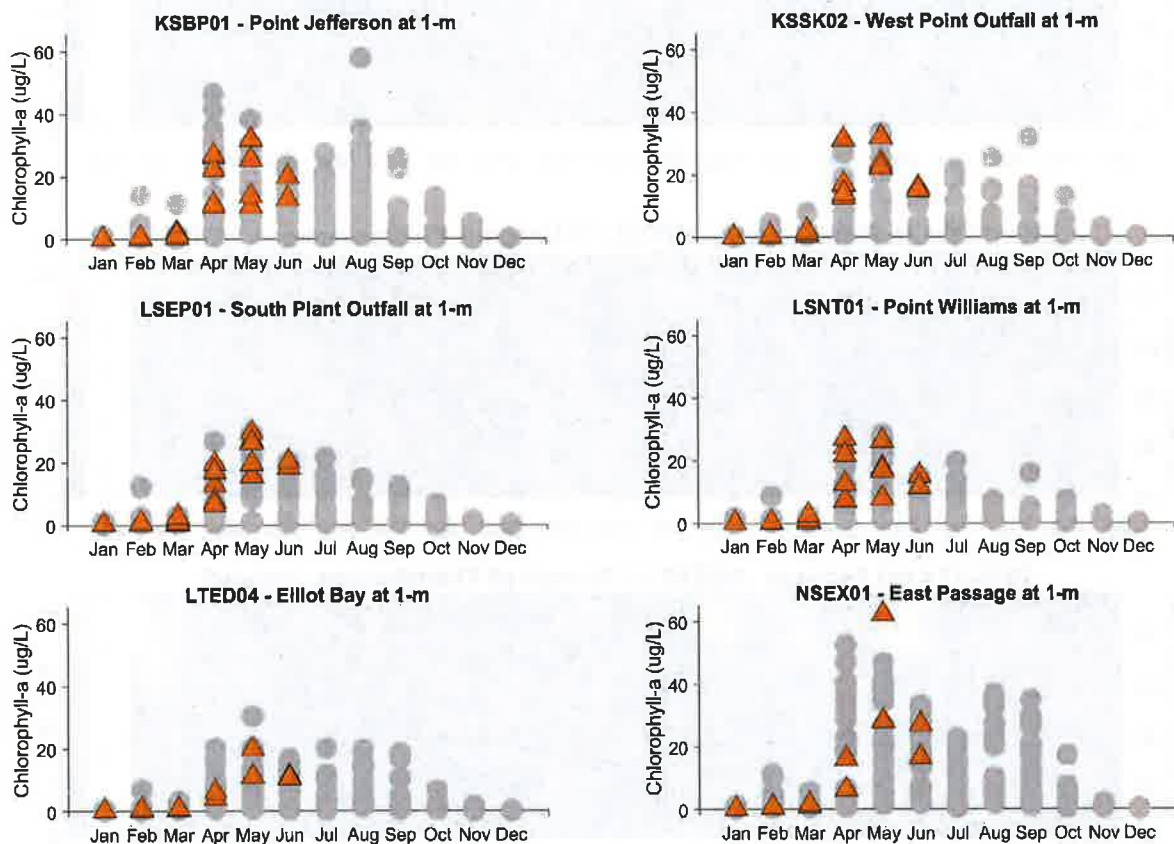


Figure 81. Near surface chlorophyll-a concentrations by month compared to historic ranges for offshore Central basin sites.

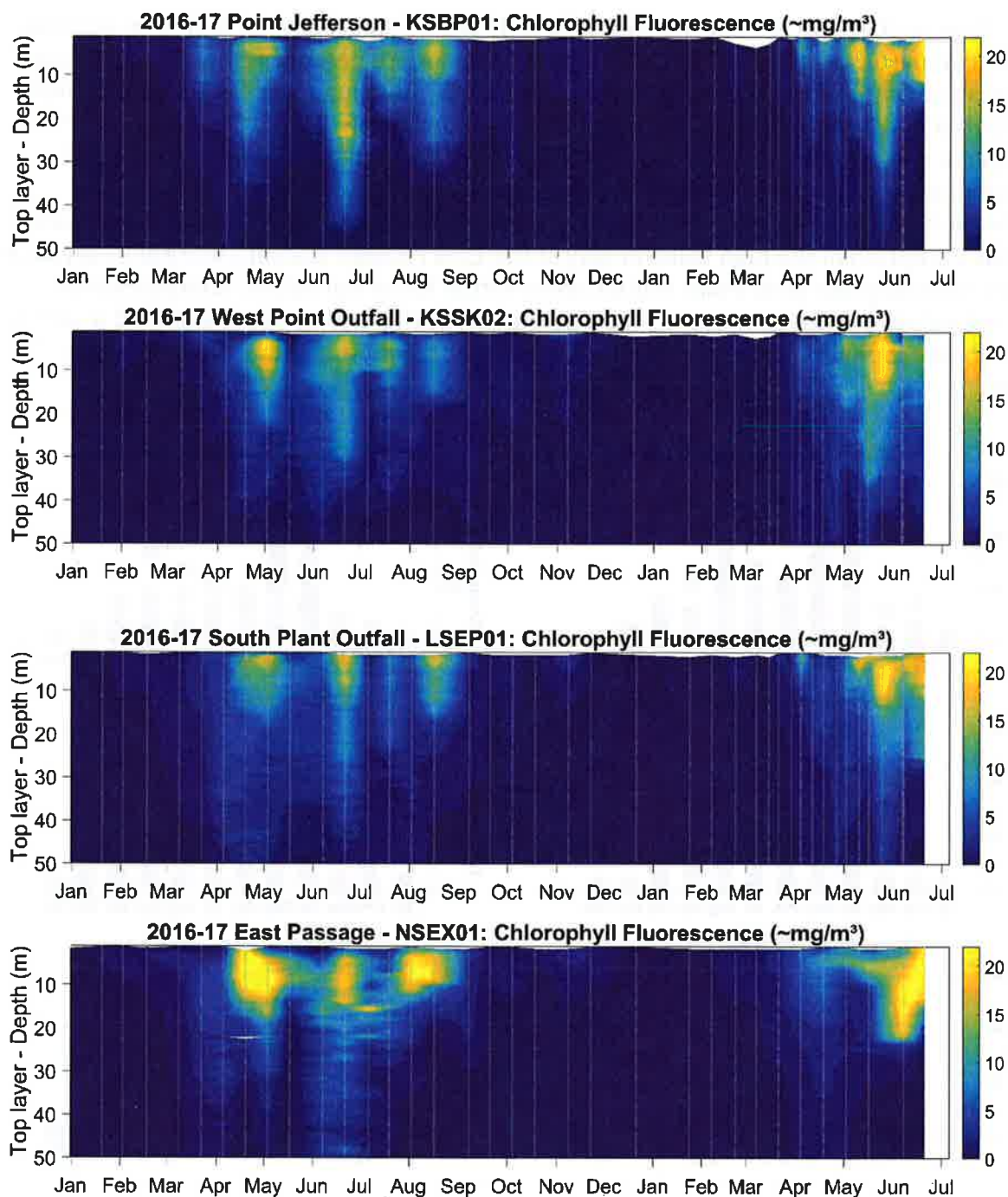


Figure 82. Upper water column chlorophyll concentrations from January 2016 through June 2017 for four sites.

4.3.4 Phytoplankton

The taxonomic composition (the species present) and abundance of the phytoplankton community were also measured in addition to chlorophyll-a. Details regarding phytoplankton sampling and analytical methods are provided in the Marine Phytoplankton

Sampling and Analysis Plan (King County, 2016b). The plan is available online at <http://your.kingcounty.gov/dnrp/library/2016/kcr2077-2016/kcr2077-2016-rpt.pdf>. Figure 83 shows total biovolume (the volume of cells) and abundance (the number of particles or cells) for all phytoplankton genera combined for six stations sampled in 2017. Phytoplankton abundance followed a similar pattern to chlorophyll-a in that a sharp increase was seen at most stations the first week in April. The chain-forming diatom *Thalassiosira* spp. was the dominant taxa during the April spring bloom in 2017 as well as in prior years. Although the abundance was low relative to *Thalassiosira*, the dinoflagellate *Heterocapsa* was present at multiple sites the first week in April and in relatively high abundance at three sites (JSUR01, KSSK02, and LSNT01) for this genera. In past years, this dinoflagellate has been seen in similar numbers in May and not early April.

Following the initiation of the spring bloom, the community shifted to a more diverse mixed diatom assemblage with the chain-forming diatom *Chaetoceros* spp. dominating by late May. Figure 84 shows the seasonal progression of the 10 overall most abundant taxa in all the samples for six representative sites. The chlorophyll-a peak in May at most the sites was due to high biovolume and abundance of multiple species of *Chaetoceros*. In June, the diatom *Skeletonema* dominated along with *Chaetoceros*. The phytoplankton taxa present and seasonal progression were similar to the past several years (2014–2016).

The phytoplankton blooms affected nutrient concentrations. The large spring diatom bloom drew down nitrate + nitrite, silica, and orthophosphate in April and these nutrients were all depleted to very low levels in May and June from the large May bloom. Orthophosphate was depleted below detectable levels in May and June and nitrate + nitrite in May at KSSK02, both orthophosphate and nitrate + nitrite were depleted below detectable levels in May and June at LSEP01, and orthophosphate and silica were depleted below detectable levels in June at KSBP01. Although nitrate + nitrite is often depleted below detectable levels following large blooms, it was an unusual occurrence for this to occur for orthophosphate and silica in the Central Basin.

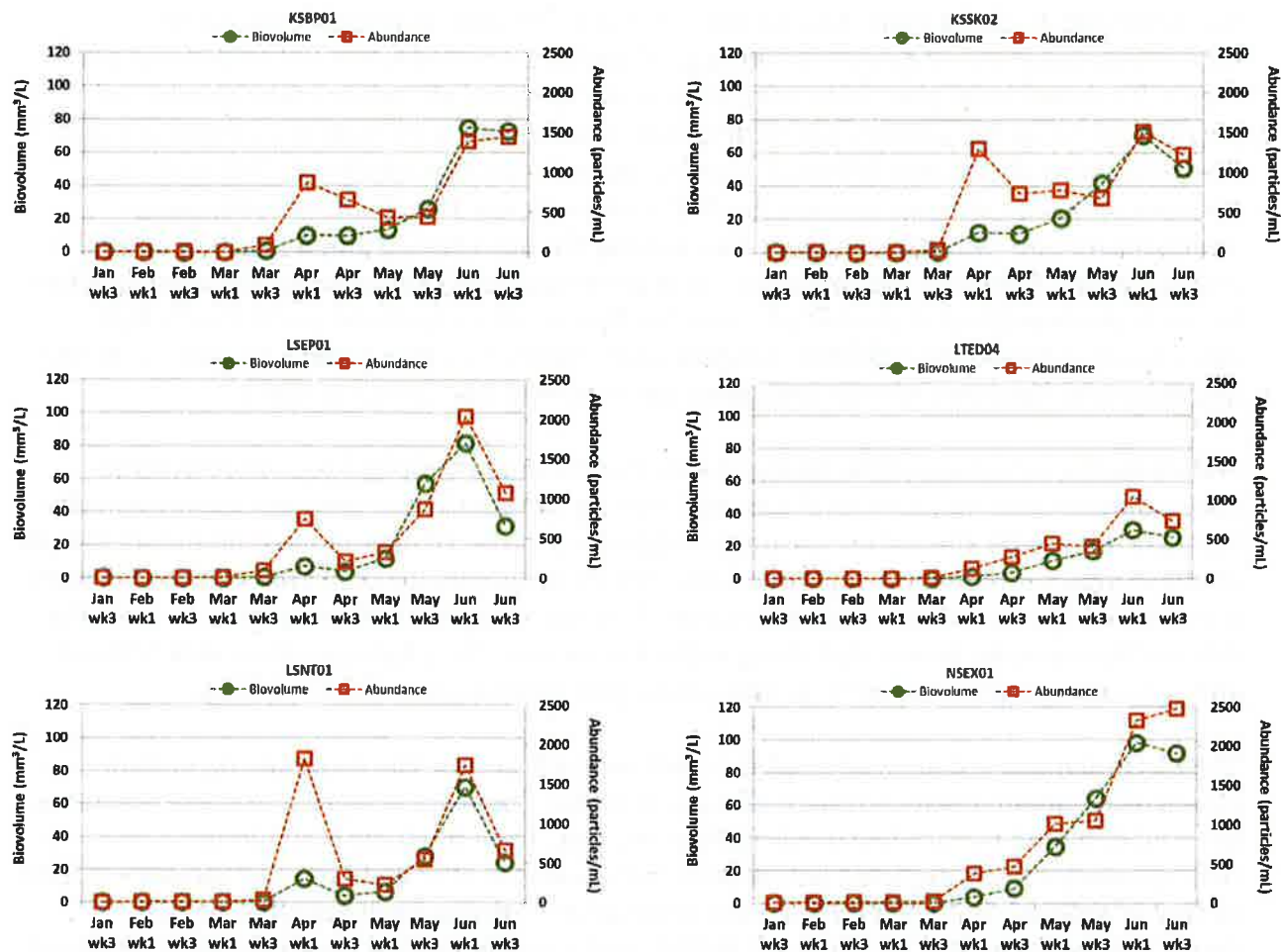


Figure 83. Phytoplankton biovolume and abundance data for each week sampled in 2017.

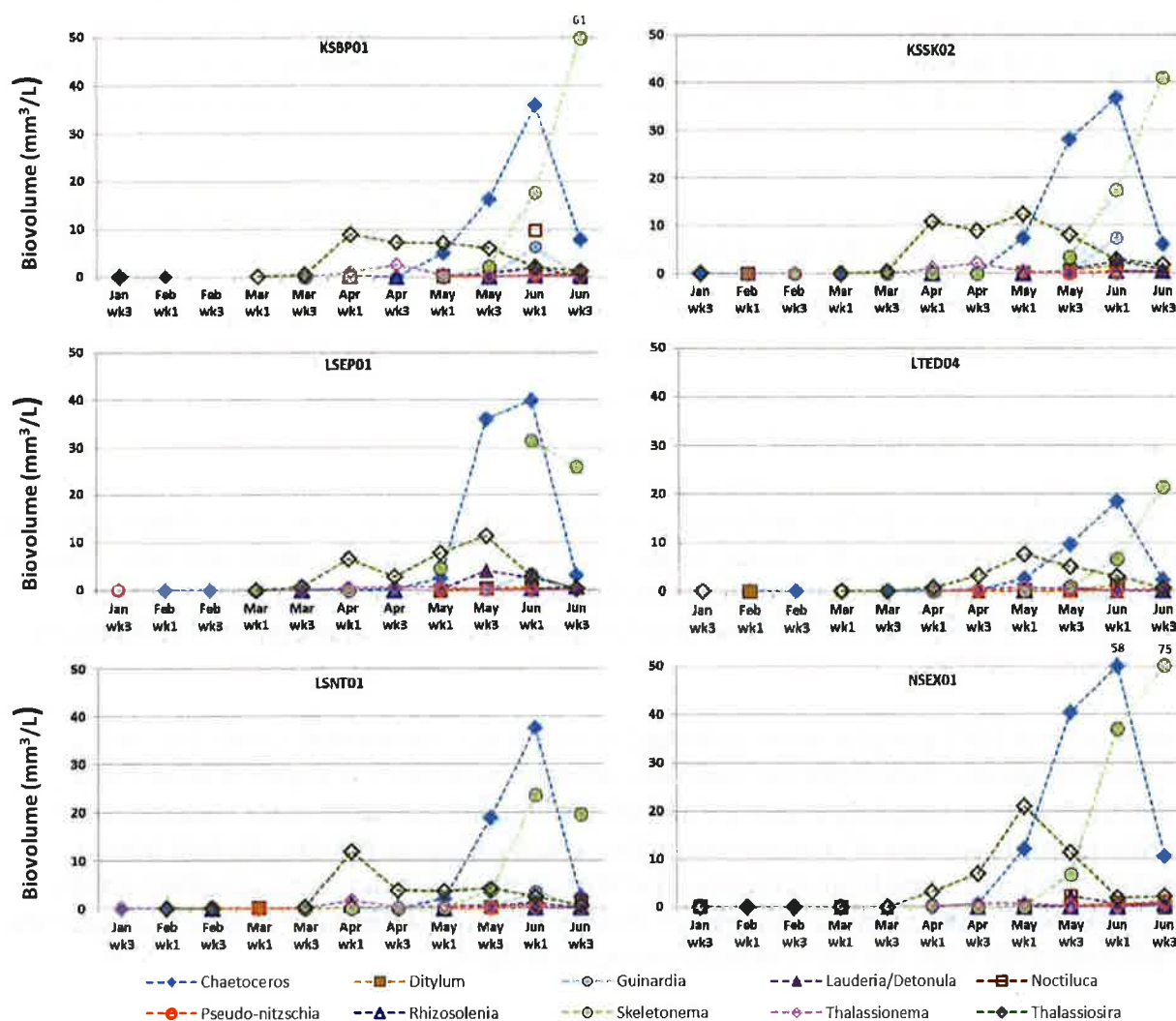


Figure 84. Seasonal biovolume progression for the 10 most abundant genera.

4.4 Trace Metals

4.4.1 Sampling and Methods

Puget Sound metals samples were collected on two dates: on April 27, 2017 and June 6, 2017. Trace metals sampling in receiving waters was added after the initial monitoring response was implemented. Increased weekly monitoring of metals in effluent was initially deemed sufficient to examine possible water quality impacts due to reduced treatment at West Point. In addition, the preparation for field sampling took several weeks as trace metals are not a routine part of the ambient monitoring program and special equipment is necessary in order to reduce potential sampling contamination.

For both sampling events, low-level metals sampling protocols were used to reduce potential contamination. Metals were collected using nonmetallic equipment (Niskin

bottles attached to a synthetic line), and employing the “clean hands/dirty hands” technique (EPA Method 1669). A specialized non-metal contaminating winch system was mounted on the deck to control the hydroline, and the boat was maneuvered to avoid engine exhaust.

Samples were collected from four stations during each of the two sampling dates. Samples were collected from three depths at each station:

- KSSK02 – West Point Outfall– 5, 30, 55 m
- LSEP01 – South Plant Outfalls – 5, 50, 130 m
- KSBP01 – Jefferson Head – 5, 50, 200 m
- LSNT01 – Point Williams – 5, 50, 160 m

Samples were analyzed for the both total and dissolved ($< 45 \mu\text{m}$) fractions of the following metals: arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. These nine metals were selected based on historical data available and current water quality criteria. See the sampling and analysis plan for a more detailed description of procedures (King County, 2017h).

Quality control (QC) samples were collected to assess environmental variability and precision of results (field replicate samples collected from the 5 m depth at West Point outfall during both sampling events). Field QC (field blank) samples were collected to identify possible sources of contamination that could influence results. All field blank samples contained some kind of metals contamination during the April sampling event, while June field blank samples were much cleaner. This indicates several potential sources of contamination from the field collection process in April.

Replicates for most metals during both sampling events had a relative percent difference (RPD) of less than 20%. April dissolved copper, lead, and zinc and total nickel and silver replicates had higher RPDs ranging from 32 to 48%. With the exception of silver, these corresponded with the metals that had the highest amount of field blank contamination. The source of these metals in field blanks remains unclear.

All laboratory QC sample results were within acceptable limits for both sampling events. This indicates acceptable precision and accuracy of metals results, with no observed laboratory contamination.

The detectable levels of field blank contamination, particularly during the April sampling event, had the potential to bias some metals results high. This is especially true for parameters like lead, which had blank contamination as high or higher in many cases than sample concentrations. In order to make large scale comparisons to historical data and water quality criteria, potentially high biased results are reported and clearly identified for each instance in the next section.

4.4.2 Results

Total arsenic, cadmium, chromium, copper, lead, nickel, silver, and zinc were detected in all samples, while total mercury was detected in 11 of 13 samples (this includes one replicate sample) in April and in 13 of 13 in June. Dissolved arsenic, cadmium, chromium, copper, nickel, silver, and zinc were detected in all samples, while dissolved lead and mercury were detected in fewer than half the samples during both events.

Two prior studies were completed on trace metals in Central Basin receiving waters. In 1999 through 2000, total and dissolved metals were sampled in offshore waters and analyzed monthly as part of the Brightwater Treatment Plant Marine Outfall Siting Study (King County, 2001). In July and December of 2011 and 2012 additional metals samples were collected at ambient monitoring stations as part of an NPDES permit-required receiving water characterization study (King County, 2010). Although depths were slightly different at some stations during each sampling event (see Table 10), both studies targeted depths similar to the present study and were deemed adequate for comparative purposes.

Table 10. Recent offshore metals data at 2017 sampling sites.

Site	Depths of 1999/2000 Samples (monthly)	Depths of 2011-2012 Samples (quarterly)	Depths of 2017 samples (2 samples)
KSBP01 – Point Jefferson	5, 50, 210 m	5, 50, 200 m	5, 50, 200 m
KSSK02 – West Point	5, 30, 55 m	NA	5, 30, 55 m
LSEP01 – South Plant	5, 50, 130 m	NA	5, 50, 130 m
LSNT01 – Point Williams	5, 50, 170 m	5, 50, 160 m	5, 50, 160 m

Method blank contamination is an indicator of probable laboratory contamination, and was an issue with several metals in the 1999/2000 dataset. Blank contamination for chromium, copper, lead, nickel, and zinc samples indicated that some samples were impacted by laboratory quality control failures. Zinc was particularly problematic with 32% of samples impacted. Additionally, a method change occurred after the 1999/2000 sampling event. After further comparisons of 1999/2000 data to 2011/2012 data, it was determined that the method change likely biased concentrations detected in the earlier dataset. As such, the 1999/2000 dataset was excluded from this comparison.

The distributions of values for each metal between April/June sampling events were compared to 2011/2012 data to determine if large-scale differences were observable. Tables of all 2017 metals data compared to summary statistics of historical datasets are available in Appendix F. For all the trace metals graphs below, the line within each box denotes the median, the box boundaries are 25th and 75th percentiles, the whiskers are the 10th and 90th percentiles, and the black dots are the outliers.

Arsenic

The dissolved fraction of arsenic ranged from 1.01 to 1.47 µg/L during the two sampling periods (Table 11 and Figure 85). While some concentrations from the April sampling event were slightly higher than the historical data range, median values were similar (i.e.,

RPD of 5% between medians). All June values were within the range of concentrations measured during the 2011/2012 sampling event.

Total arsenic concentrations collected in April were slightly higher than those collected in 2011/2012. Median and maximum values were 0.07 and 0.06 $\mu\text{g/L}$ higher than the historical values, an increase in concentration of less than 5%. The maximum concentration of total arsenic recorded in West Point effluent during the period of reduced treatment was 2.03 $\mu\text{g/L}$, versus a historical average of 1.48 $\mu\text{g/L}$ during the same season. Using maximum effluent concentrations and a conservative range of dilution factors compared to those modeled at West Point, the potential increase in receiving water metals from effluent can be conservatively estimated. Using a 100:1 and a 300:1 dilution factor, and a change of 0.55 $\mu\text{g/L}$ from the historical effluent average, the total arsenic at the edge of the mixing zone was estimated to increase between 0.002 and 0.005 $\mu\text{g/L}$ above ambient conditions. Concentrations of arsenic from effluent would be even lower further from the outfall due to tidal currents and vertical mixing. This estimate accounts for up to 8% of the average observed 0.07 $\mu\text{g/L}$ increase from historical levels in April at the West Point outfall, suggesting additional sources of arsenic. Oceanic source waters may be a factor as the concentrations of total arsenic were fairly uniform and highest at near bottom depths across sites (see data in Appendix in F).

Table 11. Frequency of detection (FOD) and summary statistics of total and dissolved arsenic in April and June samples. Concentrations are in $\mu\text{g/L}$.

Sampling Event	Dissolved Arsenic				Total Arsenic			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	13/13	1.14	1.23	1.47	13/13	1.24	1.43	1.55
June 6, 2017	13/13	1.01	1.22	1.35	13/13	1.11	1.24	1.43
2011/2012	28/28	1.15	1.38	1.46	28/28	1.11	1.36	1.49

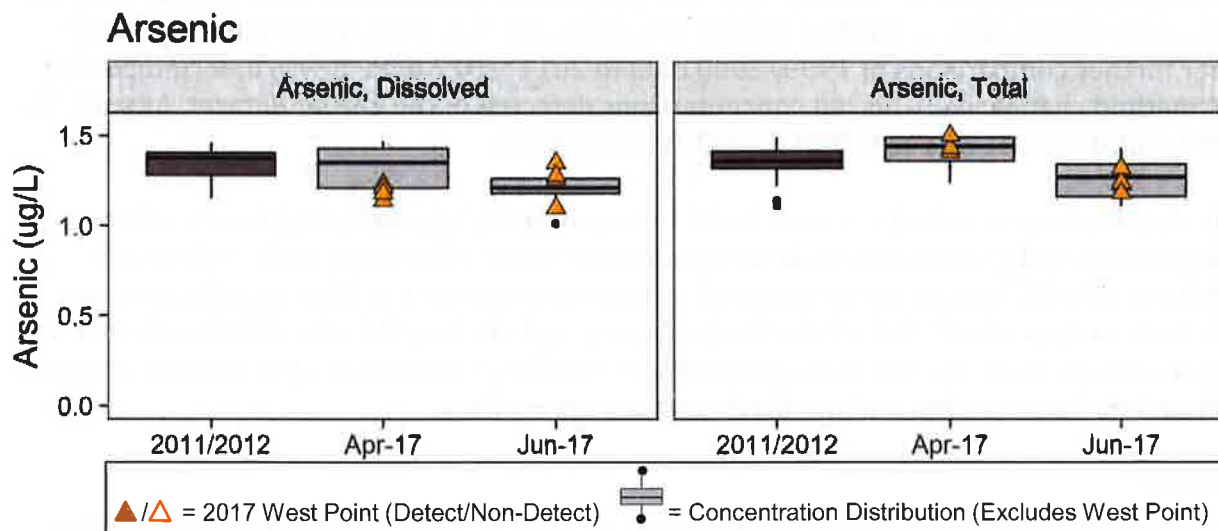


Figure 85. Concentration of dissolved and total arsenic ($\mu\text{g/L}$) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic criterion for dissolved arsenic is 36.0 $\mu\text{g/L}$.

Cadmium

The dissolved fraction of cadmium ranged from 0.0528 to 0.0724 µg/L during the two sampling events (Table 12 and Figure 86). The median and maximum values of dissolved cadmium during the April and June sampling events were lower than concentrations of cadmium collected in 2011/2012.

Total cadmium concentrations on the two sampling days ranged from 0.0569 to 0.0757 µg/L (Table 12 and Figure 86). The median and maximum values of total cadmium during the April and June sampling events were the same or lower than concentrations of cadmium collected in 2011/2012.

Table 12. Frequency of detection (FOD) and summary statistics of total and dissolved cadmium in April and June samples. Concentrations are in µg/L.

Sampling Event	Dissolved Cadmium				Total Cadmium			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	13/13	0.0661	0.0686	0.0724	13/13	0.0653	0.0725	0.0757
June 6, 2017	13/13	0.0528	0.0649	0.0706	13/13	0.0569	0.0690	0.0745
2011/2012	28/28	0.0520	0.0704	0.0749	28/28	0.0611	0.0725	0.0864

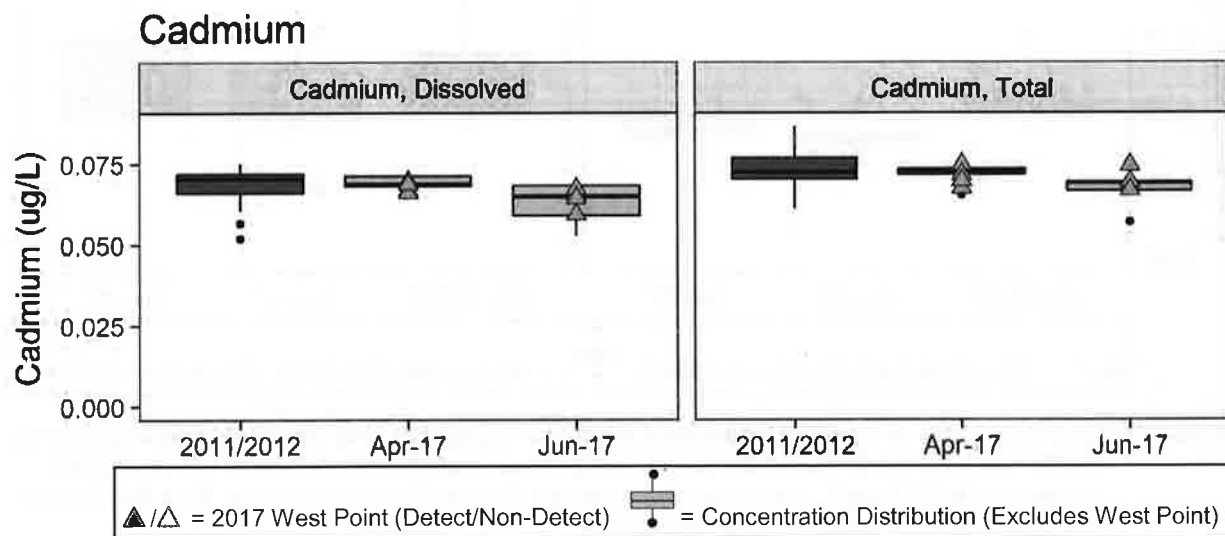


Figure 86. Concentration of dissolved and total cadmium (µg/L) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic criterion for dissolved cadmium is 9.3 µg/L.

Chromium

The dissolved fraction of chromium ranged from 0.054 to 0.12 µg/L during the two sampling events (Table 13 and Figure 87). In June, field filter blanks were contaminated with dissolved chromium (0.052 µg/L), which was detected near the minimum sample value. Because this value was just above the MDL (0.050 µg/L) and no other field contamination was detected, the potential for biased data is minimal. Additionally, the

range of values of dissolved chromium for both sampling events were similar to or lower than the 2011/2012 dataset used for comparison.

Total chromium concentrations on the two sampling days ranged from 0.086 to 0.18 $\mu\text{g/L}$ (Table 13 and Figure 87). Similar to dissolved chromium, the range of values of total chromium for both sampling events were the same or lower than the 2011/2012 dataset used for comparison.

Table 13. Frequency of detection (FOD) and summary statistics of total and dissolved chromium in April and June samples. Concentrations are in $\mu\text{g/L}$.

Sampling Event	Dissolved Chromium				Total Chromium			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	13/13	0.068	0.082	0.11	13/13	0.086	0.1	0.16
June 6, 2017	13/13	0.054	0.095	0.12	13/13	0.088	0.11	0.18
2011/2012	28/28	0.088	0.11	0.18	28/28	0.088	0.11	0.19

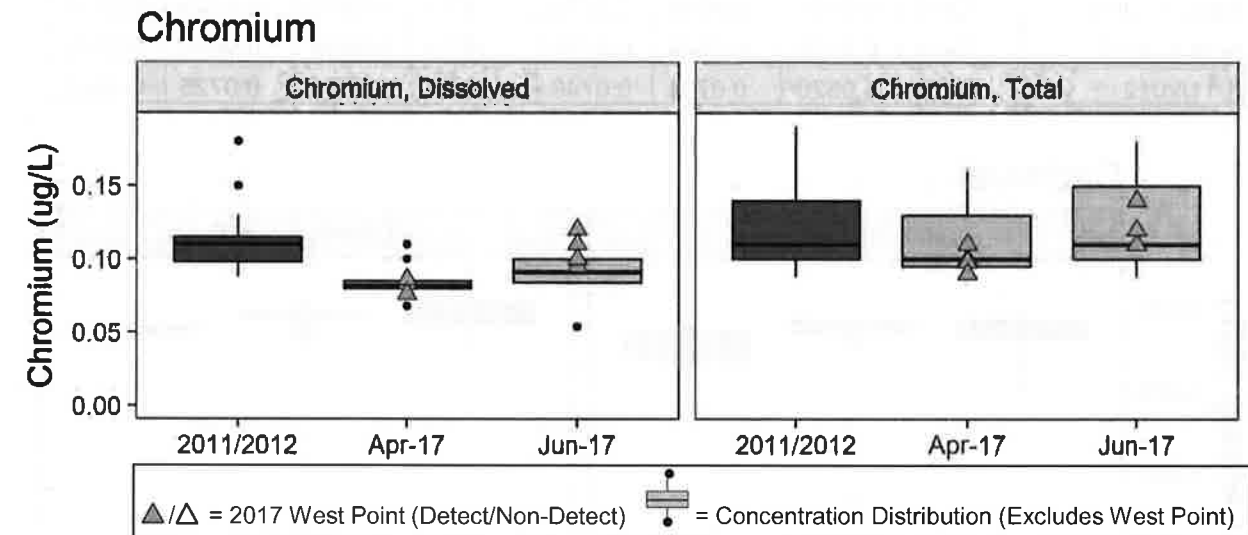


Figure 87. Concentration of dissolved and total chromium ($\mu\text{g/L}$) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic criterion for dissolved chromium is 50.0 $\mu\text{g/L}$; however, the criterion is specific to chromium VI, a fraction of chromium measured as part of this study.

Copper

The concentration of dissolved copper ranged from 0.271 to 1.15 $\mu\text{g/L}$ (Table 14 and Figure 88). The highest dissolved copper concentration was recorded in April at South Plant at 130 m (1.15 $\mu\text{g/L}$), while total copper for this sample was much lower (0.363 $\mu\text{g/L}$). This suggests that there may have been a sample handling error that led to contamination during the filtration process since the dissolved concentration should be a fraction of the total. Dissolved copper contamination was detected in field filter blanks during April and June sampling events at concentrations of 0.065 and 0.062 $\mu\text{g/L}$, respectively. Copper contamination was lower in other field blanks than in filter blanks, suggesting that the

process of filtering may have led to the dissolved copper contamination in samples. Median concentrations in receiving waters in April were higher than the 2011/2012 dataset (i.e., RPD of median values equal to 32%, while June samples were within the range of those data.

Total copper concentrations on the two sampling days ranged from 0.326 to 0.57 $\mu\text{g/L}$ (Table 14 and Figure 88). Copper contamination in field QC samples indicate potentially elevated levels due to contamination during the April sampling event. However, these values were near the MDL of 0.025 $\mu\text{g/L}$ and much lower than sample values (<10 %), therefore, bias is likely minimal. In addition, total copper concentrations were similar among all sampling events, including historical datasets.

Table 14. Frequency of detection (FOD) and summary statistics of total and dissolved copper in April and June samples. Concentrations are in $\mu\text{g/L}$.

Sampling Event	Dissolved Copper				Total Copper			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	13/13	0.343	0.397	1.15	13/13	0.332	0.374	0.47
June 6, 2017	13/13	0.271	0.339	0.581	13/13	0.326	0.402	0.57
2011/2012	28/28	0.231	0.287	0.617	28/28	0.26	0.3665	1.99

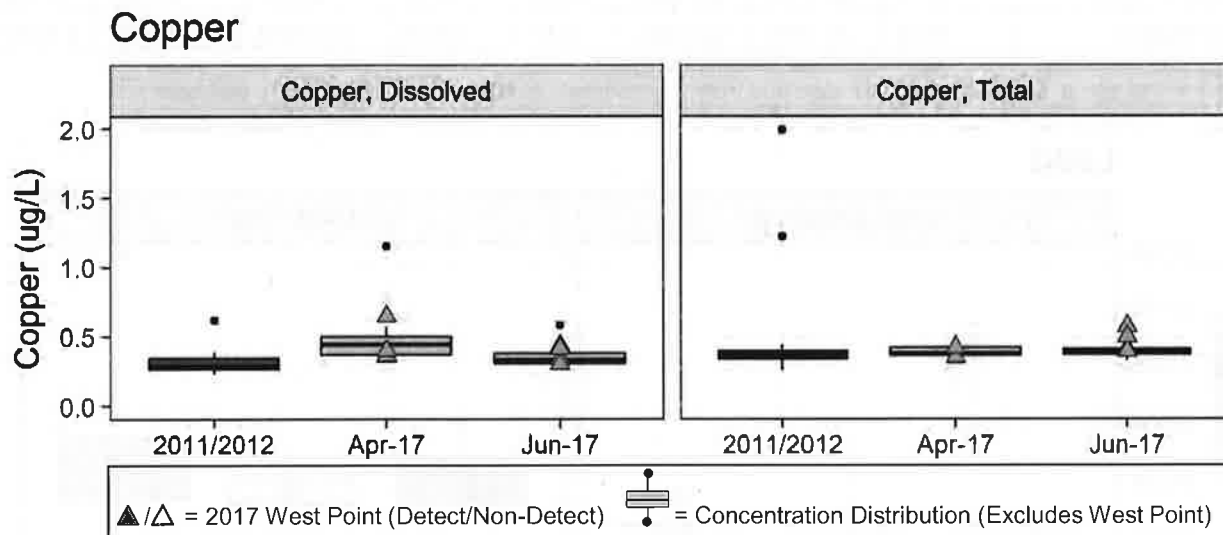


Figure 88. Concentration of dissolved and total copper ($\mu\text{g/L}$) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic criterion for dissolved copper is 3.1 $\mu\text{g/L}$.

Lead

The concentrations of dissolved lead during the two sampling events ranged from less than the detection limit (0.005) to 0.0262 $\mu\text{g/L}$ (Table 15 and Figure 89). The majority of the 2017 dissolved lead samples were below the detection limit. The replicate 5-m sample at West Point in June had the highest dissolved lead concentration. Similar to dissolved copper, elevated dissolved lead was observed near the South Plant outfall in April at 130-m.

Total lead concentrations on the two sampling days ranged from 0.0058 to 0.122 µg/L (Table 15 and Figure 89). Total lead in field blanks in April were as high as 0.025 µg/L or nearly half of the minimum detected sample value. The concentration of total lead detected in various field blank samples was higher than sample values in many cases and therefore April sample data were likely to be biased high due to contamination issues. Despite this field contamination issue, concentrations of total lead during both 2017 sampling events were within the range of historical data with one exception. There was one unexpectedly high total lead sample at the 5 m depth in June at South Plant Outfall (0.122 µg/L); this value was approximately five times the median concentration from that sampling event. Similarly high values were not seen at the deeper trapping depths of the effluent plume of the South Plant outfall, so the source is unknown.

Table 15. Frequency of detection (FOD) and summary statistics of total and dissolved lead in April and June samples. Concentrations are in µg/L. Half of the detection limit was used for calculating summary statistics, but values less than the detection limit are presented at the detection limit in parentheses.

Sampling Event	Dissolved Lead				Total Lead			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	6/13	<(0.005)	<(0.005)	0.0262	13/13	0.0058	0.014	0.0285
June 6, 2017	3/13	<(0.005)	<(0.005)	0.017	13/13	0.011	0.025	0.122
2011/2012	3/28	<(0.005)	<(0.005)	0.01	27/28	<(0.005)	0.019	0.0492

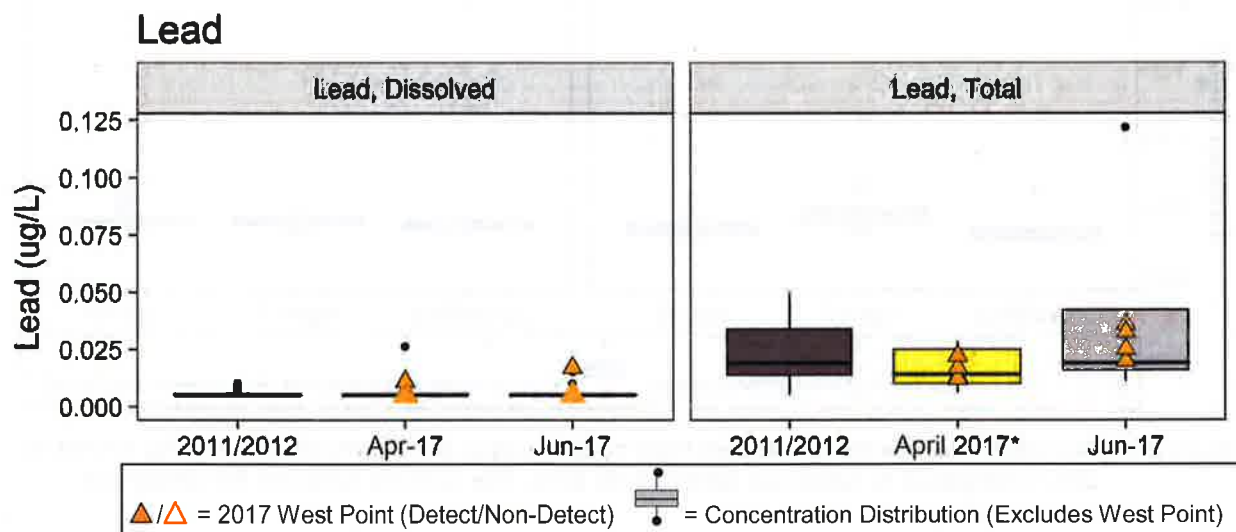


Figure 89. Concentration of dissolved and total lead (µg/L) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic criterion for dissolved lead is 8.1 µg/L. Note: A large portion of samples were non-detects, which are displayed as the method detection limit. *April 2017 (shown in yellow) total lead data are likely biased high due to field contamination.

Mercury

The concentration of the dissolved fraction of mercury during the two sampling events ranged from less than the detection limit (0.0002 µg/L) to 0.0026 µg/L (Table 16 and Figure 90). The majority of dissolved mercury samples were below detection limits, similar to historical data. In April, the deepest samples at West Point (30 and 50 m) and shallowest at Point Williams (5 m) were the only samples with detections, and were within the historical range of samples. In June, all samples of dissolved mercury were below the detection limit.

Total mercury concentrations on the two sampling days ranged from less than the detection limit (0.0002 µg/L) to 0.00046 µg/L (Table 16 and Figure 90). Total mercury concentrations from both sampling events were within the range of historical datasets.

Table 16. Frequency of detection (FOD) and summary statistics of total and dissolved mercury in April and June samples. Concentrations are in µg/L. Half of the detection limit was used for calculating summary statistics, but values less than the detection limit are presented at the detection limit in parentheses.

Sampling Event	Dissolved Mercury				Total Mercury			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	6/13	<(0.0002)	<(0.0002)	0.00026	11/13	<(0.0002)	0.00026	0.00032
June 6, 2017	0/13	<(0.0002)	<(0.0002)	<(0.0002)	13/13	0.00022	0.00026	0.00046
2011/2012	1/28	<(0.0002)	<(0.0002)	0.00023	21/28	<(0.0002)	0.00026	0.00055

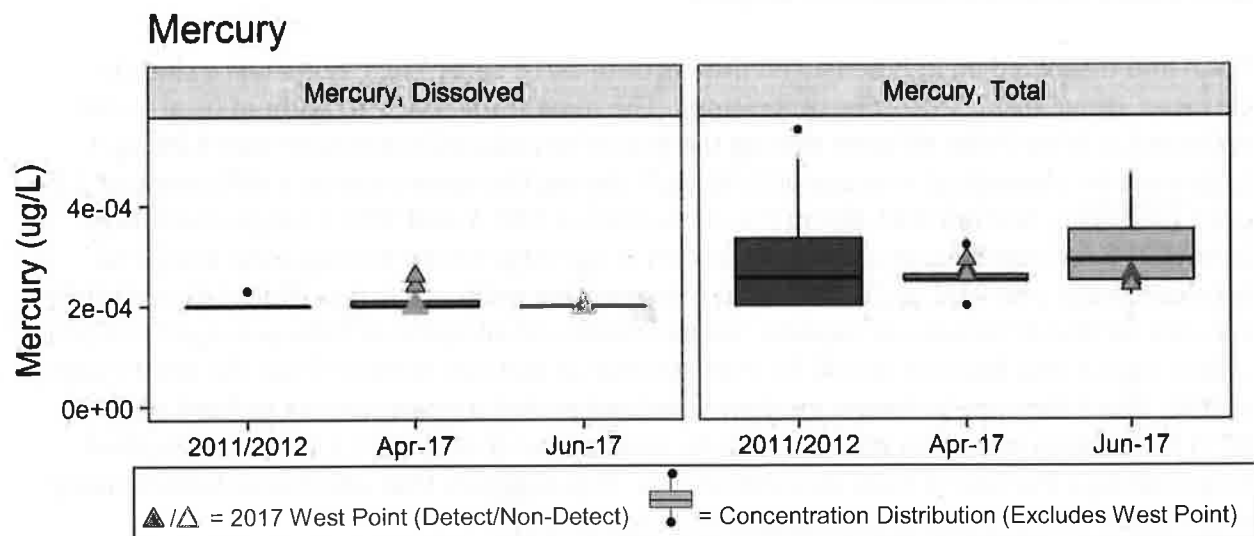


Figure 90. Concentration of dissolved and total mercury (µg/L) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic criterion for total mercury is 0.025 µg/L. Note: A large portion of samples were non-detects, which are displayed as the method detection limit.

Nickel

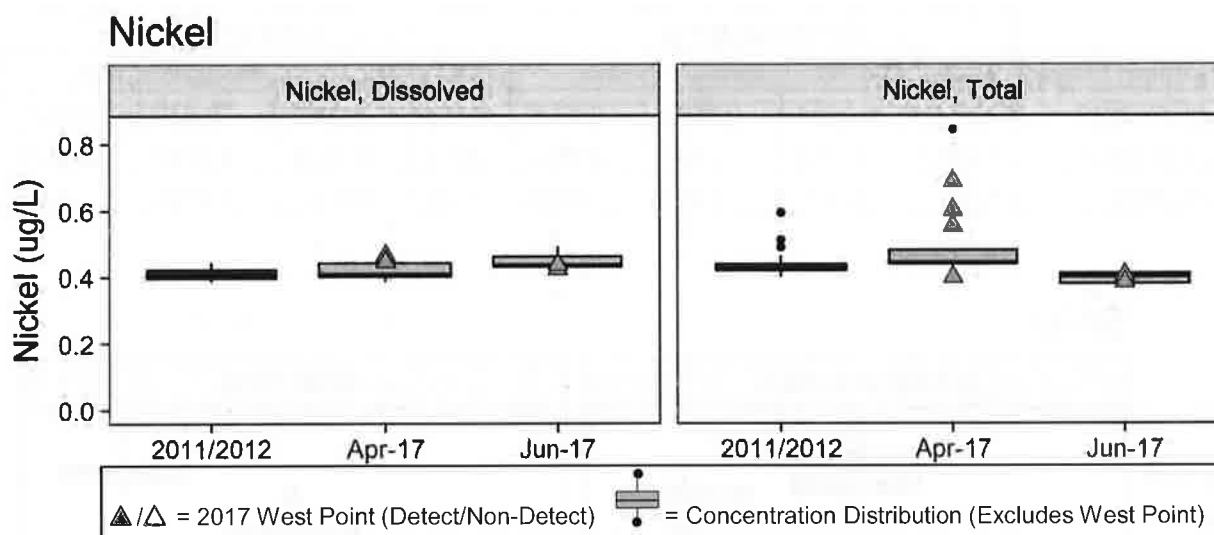
The concentration of the dissolved fraction of nickel during the two sampling events ranged from 0.387 to 0.491 $\mu\text{g/L}$ (Table 17 and Figure 91). Dissolved nickel concentrations during both sampling events were generally higher than historical data. The majority of samples from both events had slightly higher concentrations of dissolved nickel than the historical samples (the RPDs between 2017 and historical medians were 8% for April and 7% in June). Contamination in field blanks (aside from filter blanks which were the only ones to measure dissolved metals) had detectable levels of total nickel and may have biased these data high. The highest dissolved nickel concentration was recorded in June (Point Williams, 5 m, 0.491 $\mu\text{g/L}$). Other June samples collected from that site were similarly high as were nickel concentrations at the other ambient station. Treatment plant outfall station concentrations during both 2017 sampling events were above medians of all historical values, but were within historical ranges.

Total nickel concentrations on the two sampling days ranged from 0.374 to 0.844 $\mu\text{g/L}$ (Table 17 and Figure 91). Total nickel was detected in the atmospheric blank (0.028 $\mu\text{g/L}$) during the April sampling event. This concentration was only slightly above the MDL (0.025 $\mu\text{g/L}$) and less than 10% of the lowest sample concentration; therefore the potential sample bias is expected to be minimal. However, total nickel concentrations were slightly higher in April compared to the 2011/2012 dataset and median concentrations differed by 0.019 $\mu\text{g/L}$ (less than the concentration of nickel detected in the atmospheric blank). Concentrations were variable with the most elevated concentrations recorded near West Point (all depths) and near the surface at South Plant and Point Jefferson. June concentrations of total nickel were generally lower than the other sampling events and were below historical medians at all sites.

Total and dissolved nickel measured during both 2017 sampling events were slightly elevated above 2011/2012 concentrations. The maximum concentration of total nickel recorded in West Point effluent during the period of reduced treatment was 4.20 $\mu\text{g/L}$ compared to a historical average of 2.96 $\mu\text{g/L}$ during the same season, a difference of 1.24 $\mu\text{g/L}$ (details in Section 3.8). Using the conservative 100:1 and 300:1 range of dilution factors, the estimated increase in total nickel at the edge of the mixing zone would be between 0.004 and 0.01 $\mu\text{g/L}$. The most conservative estimate from effluent doesn't fully account for the difference in median concentrations at all stations between April and June (0.019 $\mu\text{g/L}$), and dilution would be even greater at stations further from the West Point outfall. The difference between median dissolved nickel concentrations in April and 2011/2012 data was even greater than for total nickel (0.036 $\mu\text{g/L}$), despite dissolved nickel being a fraction of total concentrations. This suggests that additional factors likely contributed to elevated concentrations of nickel in 2017.

Table 17. Frequency of detection (FOD) and summary statistics of total and dissolved nickel in April and June samples. Concentrations are in $\mu\text{g/L}$.

Sampling Event	Dissolved Nickel				Total Nickel			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	13/13	0.387	0.443	0.464	13/13	0.397	0.444	0.844
June 6, 2017	13/13	0.414	0.437	0.491	13/13	0.374	0.401	0.417
2011/2012	28/28	0.387	0.407	0.443	28/28	0.4	0.425	0.593

**Figure 91.** Concentration of dissolved and total nickel ($\mu\text{g/L}$) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic criterion for dissolved nickel is $8.2 \mu\text{g/L}$.

Silver

The dissolved fraction of silver ranged from 0.042 to $0.0726 \mu\text{g/L}$ during the two sampling events (Table 18 and Figure 92), while approximately half of historical samples collected in 2011/2012 were below the detection limit. It does appear that dissolved silver concentrations were elevated during both 2017 sampling events when compared to historical data.

Total silver concentrations on the two sampling days ranged from 0.031 to $0.0672 \mu\text{g/L}$ (Table 18 and Figure 92). Similar to dissolved silver, half of historical total silver samples collected in 2011/2012 were below the detection limit and 2017 samples appear to be elevated when compared to this historical data.

The source of the elevated silver concentrations is unclear. The average and maximum concentrations of total silver measured in West Point effluent were lower during 2017 than previous data collected between 2004 and 2016 (details in Section 3.8). The highest total silver effluent value measured during the period of reduced treatment was $0.18 \mu\text{g/L}$,

which is only 0.02 µg/L higher than the average historical concentration. Using the 100:1 to 300:1 range of dilution factors, the estimated increase in total silver at the edge of the mixing zone would be far below any detectable change. Observed concentration differences between 2017 and 2011/2012 datasets differed by as much as 0.032 µg/L for dissolved silver and 0.049 µg/L for total silver, likely as a result of sources other than West Point effluent, such as oceanic water mass changes or due to surface runoff.

Table 18. Frequency of detection (FOD) and summary statistics of total and dissolved silver in April and June samples. Concentrations are in µg/L. Half of the detection limit was used for calculating summary statistics, but values less than the detection limit are presented at the detection limit in parentheses.

Sampling Event	Dissolved Silver				Total Silver			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017	13/13	0.0504	0.0619	0.0726	13/13	0.031	0.042	0.0526
June 6, 2017	13/13	0.042	0.047	0.0612	13/13	0.0538	0.0597	0.0672
2011/2012	15/28	<(0.01)	0.013	0.029	14/28	<(0.01)	0.0105	0.03

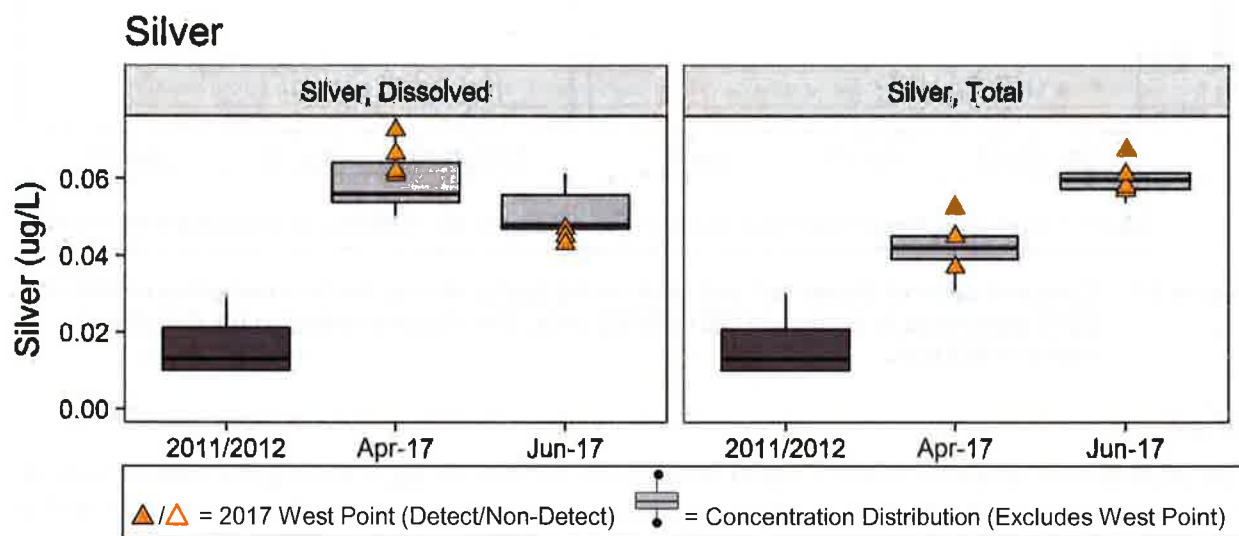


Figure 92. Concentration of dissolved and total silver (µg/L) during the two sampling events in 2017 compared to historical (2011/2012) data. The acute water quality criterion for dissolved silver is 1.9 µg/L (there is no chronic criterion for silver). Note: approximately half of 2011/2012 samples were non-detects, which are displayed as the method detection limit.

Zinc

The dissolved fraction of zinc during the two sampling events ranged from 0.26 to 1.04 µg/L (Table 19 and Figure 93). Dissolved zinc was detected in field filter blanks collected during the April sampling event at a concentration of 0.17 µg/L. This is slightly above the MDL of 0.10 µg/L and nearly 35% of the lowest concentration of dissolved zinc detected. Total zinc was detected in additional field blank samples collected during the same sampling event, suggesting that both total and dissolved zinc concentrations in April are likely biased high.

April dissolved zinc concentrations were slightly higher than those measured in 2011/2012 with median concentrations 0.192 $\mu\text{g/L}$ higher than in 2011/2012, which may be due to the field contamination. June dissolved zinc samples were within the range of historical values.

Total zinc concentrations on the two sampling days ranged from 0.36 to 0.865 $\mu\text{g/L}$ (Table 19 and Figure 93. Zinc was a common contaminant in April field blank samples and was detected in the atmospheric blank (0.12 $\mu\text{g/L}$) and field blank (0.11 $\mu\text{g/L}$) in addition to dissolved zinc detected in field filter blanks (discussed above). April data were likely biased high due to field contamination. The median concentration of total zinc in April was 0.14 $\mu\text{g/L}$ higher than historical concentrations (near the concentrations recorded in field blanks), but were within historical ranges. June concentrations were similar to and within historical data ranges.

Table 19. Frequency of detection (FOD) and summary statistics of total and dissolved zinc in April and June samples. Concentrations are in $\mu\text{g/L}$. *Dissolved and total zinc concentrations in April are likely biased high due to field contamination.

Sampling Event	Dissolved Zinc				Total Zinc			
	FOD	Min.	Median	Max.	FOD	Min.	Median	Max.
April 27, 2017*	13/13	0.49	0.587	1.04	13/13	0.501	0.61	0.668
June 6, 2017	13/13	0.26	0.42	0.584	13/13	0.36	0.501	0.865
2011/2012	28/28	0.17	0.395	0.707	28/28	0.33	0.47	0.89

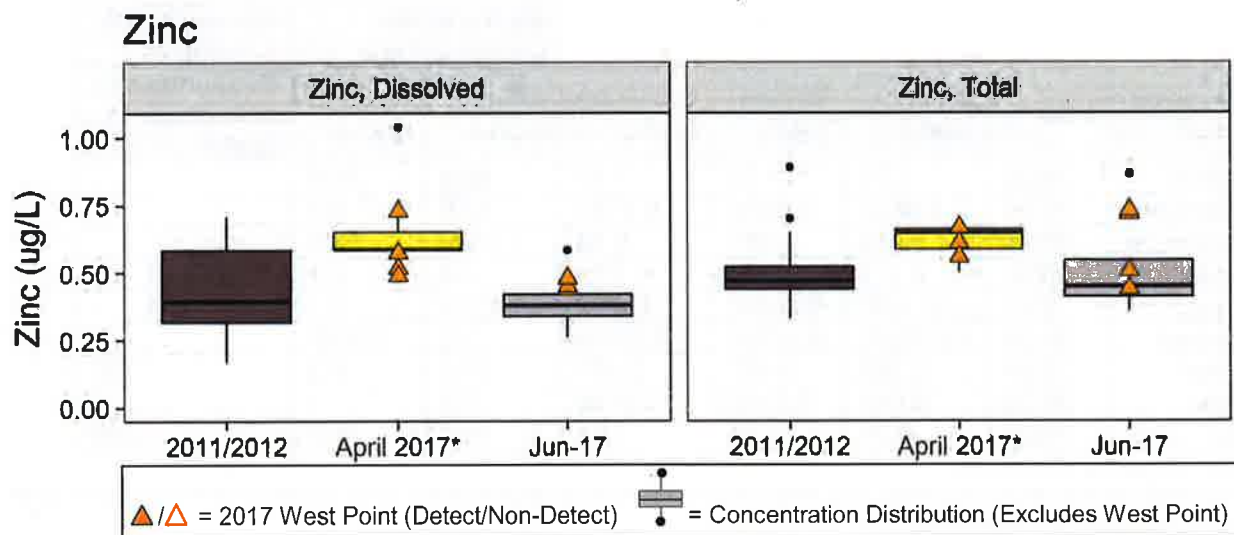


Figure 93. Concentration of dissolved and total zinc ($\mu\text{g/L}$) during the two sampling events in 2017 compared to historical (2011/2012) data. The chronic water quality criterion for dissolved zinc is 81.0 $\mu\text{g/L}$. *April 2017 dissolved and total zinc data (shown in yellow) are likely biased high due to field contamination.

Comparison to Water Quality Criteria and Summary

Washington State has promulgated water quality criteria for all nine of the metals analyzed during this sampling effort. These criteria, which include an acute and chronic level, are

designed to be protective of aquatic life. Additionally, human health criteria, meant to be protective of humans consuming aquatic organisms, are available for two of the nine metals, nickel, and zinc. The human health criterion for arsenic is for the inorganic form only and therefore not applicable for comparison. Both types of criteria are contained in the state administrative code (WAC 173-201A-240). Most criteria are for the dissolved fraction with the exception of the chronic criterion for mercury which is for total mercury.

Table 20 summarizes the results of the combined April and June sampling efforts in comparison to State water quality and human health criteria. There were no exceedances of the marine water quality criteria or the human health criteria during either sampling event. Dissolved copper was the metal detected at concentrations nearest the state's water quality criteria. Compared to state criteria, the maximum of dissolved copper during the two sampling events (1.15 µg/L) was 37% of the chronic water quality standard.

Samples in receiving waters were not collected during the time of peak effluent flows, and concentrations in Puget Sound would have been variable based on rainfall, seasonal patterns, effluent discharge, and other inputs. However, the mixing zone analysis (Section 3.11) supports the conclusion that, given observed effluent measurements, effluent metals during the period of reduced treatment were not likely to cause exceedances of water quality criteria near the zone of initial mixing, where concentrations would be highest (aside from within the mixing zone).

Table 20. 2017 metals concentrations compared to state criteria.

Dissolved Metal ^a	FOD %	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Marine Water Quality Criteria		Human Health Criteria
					Acute (µg/L)	Chronic (µg/L)	Consumption of Organisms (µg/L)
Arsenic	26/26	1.01	1.23	1.47	69.0	36.0	-
Cadmium	26/26	0.0528	0.0676	0.0724	42.0	9.3	-
Chromium ^b	26/26	0.054	0.086	0.12	1,100.0	50.0	-
Copper	26/26	0.271	0.374	1.15	4.8	3.1	-
Lead	9/26	<(0.005)	<(0.005)	0.0262	210.0	8.1	-
Mercury ^a	24/26	<(0.0002)	0.00026	0.00046	1.8	0.025 ^c	-
Nickel	26/26	0.387	0.437	0.491	74.0	8.2	100
Silver	26/26	0.042	0.0548	0.0726	1.9	-	-
Zinc	26/26	0.26	0.50	1.04	90.0	81.0	1,000

FOD – Frequency of detection

^a Dissolved concentrations reported for all metals except mercury for total mercury concentrations which are reported for comparison to marine chronic criterion.

^b Criteria for dissolved chromium VI: chromium VI is a fraction of chromium, therefore the true concentration of chromium VI for this study is expected to be lower than the value above, as all forms of dissolved chromium were measured.

In summary, concentrations of some metals were higher in April than historical data (e.g., arsenic, nickel, and silver) and cannot be fully explained by field contamination or measured increases in effluent concentrations. The elevated concentrations of these metals may be explained by the higher than typical rainfall that occurred from February through

April of 2017 (see Section 1.5.1). Rainfall increases the amount of stormwater/runoff that goes into Puget Sound, which carries contaminants from sources including roads, roofs, sidewalks, and yards. In turn, higher rates of metals deposition into Puget Sound are known to correspond to wet weather and surface runoff (Ecology, 2011). A related factor, seasonality, could have contributed to differences seen between 2017 and 2011/2012 data. Concentrations of metals can vary seasonally and the historical data used for comparison were collected over two years during the months of December and July rather than April/June.

Despite elevated concentrations of some metals, particularly in April, all metals were below state water quality standards and human health criteria during both sampling dates. As the state water quality criteria were developed to be protective of aquatic life, no short-term impacts to biota were expected due to the quality of effluent discharged to Puget Sound receiving waters during the period of reduced treatment at the West Point plant.

Due to the ability of most metals to bind with solids, some proportion of metals attached to solids in the effluent may have settled out on the seafloor. As such, the results of sediment monitoring near the West Point outfall, which occurred in June and September of 2017, will also be used to evaluate potential impacts of elevated metals in West Point effluent (King County, 2017a,b).

5.0 SUMMARY

The West Point equipment failure and flooding event on February 9, 2017 resulted in the discharge of 244 million gallons of untreated stormwater and wastewater through the emergency bypass outfall (EBO) during two separate events on February 9 and 15–16. As a result of damage to the plant, a reduced level of treatment and elevated contaminant concentrations and loads were discharged to the Central Basin of Puget Sound for a three month period from February 9 to May 9, 2017. During the West Point restoration, the inflows to the plant during storm events were managed carefully by diverting flows to combined sewer overflow (CSO) treatment facilities and other wastewater treatment plants. Considerably higher-than-normal rainfall occurred in the service area from February through April and led to elevated stormwater flows in the CSO system, with record-breaking precipitation occurring in February.

Characteristics of the West Point effluent and Central Puget Sound receiving waters were assessed for potential changes and impacts after the plant flooding event, during the period of repairs, and after secondary processes were restored. Potential short-term impacts and key results in receiving waters are summarized below:

Types of water quality impacts assessed	Effluent and water quality monitoring results from February through June 2017
Increased bacteria and pathogens that pose a risk to human health from water contact and consumption of contaminated shellfish	High levels of fecal indicator bacteria occurred on Seattle beaches during and immediately after the emergency untreated discharges on February 9 and 15/16. Beaches reopened for recreation on February 21 once values were below safe levels.
	Near the West Point outfall during the plant restoration, bacteria levels in offshore waters were variable and slightly higher than normal. Bacteria levels at all Central Basin sites monitored, including West Point, did not exceed water quality standards.
Oxygen depletion due to decay of increased organic matter inputs	Deep dissolved oxygen observations in Central Puget Sound showed normal and healthy levels during the plant restoration. All levels met (i.e., were higher than) the state water quality numeric standard, with the exception of late June, typical of early summer conditions.
Increased turbidity from total suspended solids that can reduce the amount of light penetration in the water column and carry other bound contaminants	Levels of suspended solids in the mid-water depths were slightly elevated at some sites compared to normal. While West Point is a potential source during reduced treatment, the differences are not fully explained by the excess solids loading from effluent. Other possible mechanisms include inputs from silt, plankton, or other organic matter. At all sites, solids levels did not exceed the historical background maximum level.

Types of water quality impacts assessed	Effluent and water quality monitoring results from February through June 2017
Nutrient enrichment that may increase algal blooms, algal toxicity, or alter the composition of the phytoplankton community	Dissolved inorganic nitrogen levels in West Point effluent, while variable, were generally lower than or similar to normal conditions. Concentrations and loadings of organic nitrogen were higher than normal as a result of the reduced level of treatment.
	At deep depths in Puget Sound, nutrient levels were within normal ranges. Near surface nutrient levels became depleted at times below historical levels due to algal uptake. Other environmental conditions, such as strong separation between surface and deeper water layers, contributed to vigorous spring algal bloom conditions in 2017 across Puget Sound.
Acute toxicity from chemical contaminants	In laboratory tests, aquatic organisms placed directly in West Point effluent during the period of reduced treatment met the permit performance standards for growth and mortality.
	At Puget Sound sites, ammonia levels were within or below normal ranges and well below any water quality standards.
	For metals in receiving waters, there were no exceedances of marine water quality criteria for the protection of aquatic life or the human health criteria during either sampling event.

The most obvious short-term impact to Puget Sound receiving waters was the increased bacteria in beach waters following the two untreated discharge events in February. The highest risk to human health from bacteria and pathogens occurred shortly after both untreated discharge events on February 9 and February 15/16. Fecal indicator bacteria concentrations were orders of magnitude higher than normal following these discharge events but returned to safe levels at a maximum of three days following each of the two events. The highest bacteria values were seen in the immediate vicinity of the discharge on the north side of West Point. King County Wastewater Treatment Division and Public Health posted warning signs and closed beaches for swimming and other recreational activities as a precaution from West Seattle north to Carkeek Park. Beaches remained closed until bacteria concentrations returned to safe levels. This action, combined with the permanent closure of beaches from Everett to Tacoma to recreational shellfish harvest, minimized the risk to public health.

More details and key findings from the additional monitoring in both West Point effluent and receiving waters of Central Puget Sound are summarized in the next sections.

5.1 West Point Effluent Characteristics Summary

- Daily monitoring indicated that fecal coliform levels in West Point effluent were variable and generally elevated relative to normal conditions during the period of reduced treatment, however, levels complied with the weekly and monthly effluent permit limits. The Elliott West CSO treatment facility did not meet its monthly fecal coliform effluent permit limit for March.
- TSS and CBOD concentrations were considerably elevated compared to normal conditions during February through mid-April. West Point effluent did not meet permit limits for average weekly and average monthly TSS and CBOD during this period.
- Residual chlorine levels were occasionally elevated and slightly exceeded the monthly average effluent permit limit in March and April. The daily maximum limit was exceeded two days in April. Effluent pH levels remained within the acceptable range defined by the permit during reduced treatment.
- Nutrient concentrations, particularly ammonia and nitrate, in West Point effluent were variable, but generally lower or comparable to historical conditions. Ammonia concentrations were below historical conditions at West Point and slightly elevated at South Plant as a result of the transfer of solids to South Plant. Elevated nitrate concentrations, and lower ammonia, in West Point effluent in May and June were a result of testing for an upcoming aerator mixing system improvement project. Organic nitrogen and total phosphorus loadings were generally higher than normal due to the reduced level of solids removal and biological treatment activity at West Point during February through April. Based upon a dilution factor calculation, at no time did predicted levels of ammonia exceed applicable water quality standards at the edge of the mixing zone of receiving waters at either treatment plant.
- Acute and chronic whole effluent toxicity tests conducted on samples collected during the period of reduced treatment showed that the effluent met all permit performance standards for toxicity and were comparable to previous results.
- Eight of the 14 metals analyzed were elevated to some degree during the period of reduced treatment and then declined to historical levels once secondary processes were restored. Chromium, copper, and lead were substantially higher during the period of reduced treatment compared to recent conditions during full secondary treatment. At no time did predicted levels of any metal exceed applicable water quality standards at the edge of the mixing zone in receiving waters based upon a dilution factor calculation.
- Twelve of 141 organic compounds analyzed in effluent were detected during the period of reduced treatment, and 6 were detected in samples once secondary processes were restored. Concentrations of the detected semivolatile and volatile compounds were generally highest in February and subsequently declined over time to historical levels once secondary processes were restored. The semivolatile organics that were only detected during reduced treatment are compounds that

typically serve as a food source for microbes in secondary treatment. No PAHs, pesticides, or PCBs were detected in any samples.

5.2 Receiving Water Quality Summary

Bacteria

- Fecal indicator bacteria concentrations at all four beaches sampled near West Point were high following both of the EBO discharge events. The highest concentrations of both *Enterococcus* and fecal coliform bacteria occurred on February 9 at the beach nearest the EBO. Values after each event quickly declined and daily beach monitoring ended and all beaches were reopened for swimming and other recreational activities on February 21. There were no exceedances of applicable bacteria water quality standards at beaches in the vicinity of West Point after February 21. There were three exceedances of the peak water quality standard between April and June at three beaches that are near a freshwater source and historically prone to higher bacteria levels.
- Offshore bacteria concentrations near the West Point outfall were slightly elevated above historical values during the period of reduced treatment, but returned to normal by April 28. Bacteria concentrations at other sites were highest in May when no untreated discharges occurred and secondary treatment was restored, indicating a different source. There were no exceedances of applicable water quality standards.
- Concentrations of fecal indicator bacteria at beach stations after February 21 were generally within the range of historical values and below the peak water quality criterion for fecal coliforms. In the few instances where the peak criterion was exceeded, it was only at one site per sampling event and not adjacent to West Point.

Dissolved oxygen

- Dissolved oxygen concentrations were at healthy levels and within historic ranges for all offshore Central Basin sites throughout the monitoring period from the surface to bottom.
- All sites in the Central Basin met (i.e., were higher than) the state water quality numeric standard for dissolved oxygen, with the exception of late June, where near-bottom dissolved oxygen levels were slightly below the standard at deep sites. Dissolved oxygen levels in deep waters in June were within historic ranges and typical of early summer conditions. Throughout February to June, oxygen levels observed at West Point did not fall below the state standard.
- Higher levels of organic matter, measured as CBOD, in the West Point effluent during reduced treatment did not show observable dissolved oxygen depletion below the state standard at the West Point outfall site.
- Dissolved oxygen levels in 2017 showed typical seasonal patterns, and high surface oxygen concentrations reflect the growth and oxygen production from phytoplankton during the spring bloom.

Water clarity

- Transmissivity, a measurement of water clarity, reflected seasonal phytoplankton bloom conditions and sediment dynamics at offshore sites in the Central Basin comparable to prior years.
- Total suspended solids (TSS) levels in the water column at the West Point outfall site were elevated during the period of reduced treatment particularly at mid-water depths. Concentrations were generally within expected ranges based on the historical record. At other Central Basin sites, TSS levels were also elevated compared to typical historical ranges at mid-depths, suggesting similar water mass characteristics between sites.
- In addition to elevated TSS contributions from West Point during reduced treatment, other sources include inputs of TSS from rivers, plankton blooms, and other organic matter.
- TSS concentrations at all sites and depths, including West Point, did not exceed the historical ambient background maximum concentration.

Water density

- Beginning in late March, the upper water column exhibited strong density stratification, or separation, between surface and deep water layers that generally persisted through June.
- Stratification in the spring and summer of 2017 was stronger than typically observed in the Central Basin, likely related to weather, freshwater inputs, and mixing conditions.
- Water stratification can impede vertical mixing and affect the concentrations of substances and materials found at different depths in the water column. These conditions likely led to more concentrated levels of phytoplankton in the surface layers where light penetrates.

Nutrients

- Ammonia levels at the West Point outfall were similar to or below historical ranges, and other Central Basin sites generally showed typical conditions. Near-bottom ammonia levels at South Plant were slightly elevated at some sampling events, though cumulatively showed normal ranges. Ammonia levels at all sites were well below the chronic water quality standard.
- Ammonia levels at all beach sites, including beaches near West Point and CSO outfalls, were well below the chronic water quality standard.
- With the exception of surface waters, concentrations of other nutrients in early 2017 were generally within the ranges of the historical record and showed an expected seasonal pattern across Central Basin sites, including at the West Point outfall.
- Surface nutrient levels across Puget Sound were at times lower than historical ranges due to phytoplankton uptake from vigorous spring bloom conditions. As in

previous years, physical and biological dynamics greatly contributed to the nutrient patterns observed in 2017.

- Other nutrients in beach waters were within or lower than historical ranges, with the exception of orthophosphate at one site in June. Orthophosphate was high in June at Carkeek Park but lower than normal at most sites.

Chlorophyll and phytoplankton

- The spring phytoplankton bloom resulted in a sharp increase in chlorophyll-a values and was evident the first week in April at all stations. The timing was within typical seasonal ranges of the spring bloom.
- Chlorophyll-a levels at all sites, including the West Point outfall, were within historical values except for high levels in May at East Passage.
- The chain-forming diatom *Thalassiosira* spp. was dominant in April during the spring bloom in 2017, similar to prior observations of the spring bloom. The phytoplankton taxa present and the seasonal progression were similar to the past several years (2014–2016).

Metals

- Several of the metals measured in Puget Sound during 2017 sampling events were elevated above historical values, particularly in April. While West Point effluent likely contributed to small increases in some metals at the edge of the mixing zone, it did not explain all observed increases. A combination of additional factors such as field contamination, variability in oceanic inputs, and/or heavy spring rainfall increasing inputs of metals into Puget Sound from stormwater/runoff likely contributed to the differences in metals concentrations.
- All metals concentrations measured in Puget Sound were below state water quality standards and human health criteria during both sampling dates.

All Washington State marine water quality standards for receiving waters were met during the restoration of West Point from February through May, except for beach bacteria levels during untreated discharge events in February and three times between April and June at beaches near a freshwater source. Further offshore, bacteria levels were slightly elevated and variable, but did not exceed any applicable water quality standards. Dissolved oxygen levels met (i.e., were higher than) the state water quality standard, with the exception of late June at some deep sites, typical of early summer conditions. Throughout the monitoring period, oxygen levels observed at West Point did not fall below the state water quality standard.

Effluent concentrations of TSS and CBOD did not meet permit limits during the period of reduced treatment. No observable short-term impacts were seen for TSS or dissolved oxygen concentrations in the water column, except for some slightly elevated TSS levels at mid-water depths in Central Puget Sound. Elevated solids loads from West Point may have been one factor, in addition to natural sources, such as silt and organic matter inputs across

sites. Metals concentrations were elevated in West Point effluent during the period of reduced treatment. In receiving waters, observations of trace metals were normal or slightly elevated, though effluent concentrations do not account for all of the increase in concentrations. Levels were likely impacted by other factors as well, such as stormwater and runoff into Puget Sound during the wet season.

5.3 Conclusion

The flooding of West Point resulted in changes to effluent characteristics from February 9 through May 9. The largest impact observed was the increase in bacteria levels in water at beaches following the two untreated emergency discharge events in February. No other significant water quality impacts were observed near the West Point outfall. Overall, water quality observations in Puget Sound showed typical conditions compared to the last decade, with the exception of some elevated TSS and trace metals levels. Increased loadings from West Point to Puget Sound of these constituents during the period of reduced treatment does not fully explain any concentration increases observed in the water column compared to normal. Other factors, such as increased freshwater input from rivers and stormwater runoff, also likely had an effect on these constituents. Besides bacteria and deep dissolved oxygen at some sites, as indicated above, all measurements of marine water quality met applicable water quality standards throughout the monitoring period. Additionally, with the exception of TSS, CBOD, and residual chlorine, treatment plant effluent also met applicable permit limits.

Further monitoring and analysis efforts to identify potential adverse effects to organisms that live in the sediments and the water column are on-going. Potential short-term impacts to sediments around the West Point outfall and long-term impacts to sediments and organism tissues will be assessed in future reports, expected to be completed in 2018.

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Appendix A: Receiving Waters Station Coordinates and Parameter Summary Tables

Table A-1: Monitoring station coordinates. NAD83 – State Plane Coordinate System in feet

Locator	Description	Stratum	Northing	Easting
JSVW04	Richmond Beach/Point Wells	Beach	286171	1257194
ITCARKEEKP	Carkeek Park	Beach	263756	1259915
KSHZ03	Piper's Creek Mouth	Beach	263736	1259784
KSLU03	Golden Gardens	Beach	256354	1253305
KSSN04	West Point North	Beach	245729	1246032
KSSN05	West Point South	Beach	245272	1245980
KSYV02	Magnolia CSO	Beach	234547	1254488
LTBD27	SAM Sculpture Park	Beach	228851	1264297
LSGY01	Seacrest Park	Beach	218711	1258776
LSHV01	Alki Beach	Beach	216852	1253532
LSKR01	Alki North	Beach	213666	1249416
LSKS01	Richey Viewpoint	Beach	212668	1250283
LSVW01	Fauntleroy Cove	Beach	194969	1254846
MTLD03	Normandy Park	Beach	165142	1263285
MTUJ01	Des Moines Creek Park	Beach	151129	1269533
NTFK01	Redondo Beach	Beach	131067	1270899
NSJY01	Dumas Bay Park	Beach	122831	1255835
MSJL01	Vashon – Gorsuch Creek	Beach	169666	1241897
MSSM05	Vashon – Tramp Harbor	Beach	154908	1243459
MSXK01	Vashon – Burton Acres Park	Beach	146481	1240772
JSUR01	Brightwater TP outfall	Offshore	287580	1250910
KSBP01	Jefferson Head	Offshore	275439	1248062
CK200P	Carkeek CSO TP Outfall	Offshore	263819	1257728
KSSK02	West Point Outfall	Offshore	245121	1242740
EBO	West Point Emergency Bypass	Offshore	246403	1246627
LTBC43	Elliott West CSO Outfall	Offshore	228985	1263430
LTED04	Elliott Bay	Offshore	223909	1264675
HNFD01	East Waterway	Offshore	214139	1267488
LTKE03	Duwamish River	Offshore	211418	1265871
LTUM03	Duwamish River	Offshore	196629	1274591
LTXQ01	Henderson/MLK CSO Outfall	Offshore	190313	1278053
LSEP01	South Plant Outfall	Offshore	223360	1247399
LSKQ06	Alki CSO Outfall	Offshore	212065	1248334
LSNT01	Fauntleroy/Vashon	Offshore	198653	1245194
LSVV01	Barton CSO Outfall	Offshore	195347	1253935
MSJN02	Vashon Outfall	Offshore	169328	1244585
NSEX01	East Passage	Offshore	134701	1255331
MSWH01	Inner Quartermaster Harbor	Offshore	147976	1236667
NSAJ02	Quartermaster Harbor	Offshore	140223	1239011

Table A-2: Summary of offshore parameters and routine sampling frequency by station. Starred dots show the sites and parameters sampled weekly during the West Point restoration.

Station	Location	# Depths	Bacteria		Laboratory Analysis								CTD							Field	Phyto						
			Enterococcus	Fecal Coliform	Ammonia Nitrogen	Nitrite + Nitrate Nitrogen	Total Nitrogen	Orthophosphorus	Silica	Chlorophyll-a	Phaeophytin	Total Suspended Solids	Fluorescence (chlorophyll)	Density	Dissolved Oxygen	Light Intensity (PAR)	Salinity	Sample Temperature	Transmissivity			Secchi Transparency					
JSUR01	Brightwater outfall	7	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
KSBP01	Pt. Jefferson	7	☼	☼	☼	☼	☼	☼	●	●	●	●	●	●	☼	☼	☼	☼	☼	●	●	●	●	●	●	●	●
CK200P	Carkeek CSO outfall	5	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
KSSK02	West Point outfall	5	☼	☼	☼	☼	☼	☼	●	●	●	●	●	●	☼	☼	☼	☼	☼	●	●	●	●	●	●	●	●
LTBC43	Elliott West outfall	2	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
LTED04	Elliott Bay	6	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
LSEP01	South Plant outfall	7	☼	☼	☼	☼	☼	☼	●	●	●	●	●	●	☼	☼	☼	☼	☼	●	●	●	●	●	●	●	●
LSKQ06	Alki CSO outfall	4	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
LSNT01	Off Fauntleroy	7	☼	☼	☼	☼	☼	☼	●	●	●	●	●	●	☼	☼	☼	☼	☼	●	●	●	●	●	●	●	●
LSVW01	Fauntleroy	2	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
MSJN02	Vashon outfall	5	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
NSEX01	East Passage	7	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
EBO*	Emergency bypass outfall	2	☼	☼	☼	☼	☼	☼	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table A-3: Summary of beach parameters and routine sampling frequency by station. Starred dots show the sites and parameters sampled weekly during the West Point restoration.

Locator	Station Description	Bacteria		Laboratory Conventional					Field
		Enterococcus	Fecal Coliform	Ammonia Nitrogen	Nitrite + Nitrate Nitrogen	Total Nitrogen	Orthophosphorus	Salinity	Sample Temperature
JSVW04	Richmond Beach	●	●	●	●	●	●	●	●
ITCARKEEKP	Carkeek Park – North	★	★	●	●		●	●	●
KSHZ03	Carkeek Park – Piper's Creek Mouth	●	●	●	●	●	●	●	●
KTHA01	Carkeek Park – Piper's Creek Upstream	●	●	●	●		●		●
KSLU03	Golden Gardens	★	★	●	●		●	●	●
KSSN04	West Point – North	★	★	●	●		●	●	●
KSSN05	West Point – South	★	★	●	●		●	●	●
KSYV02	South Magnolia CSO	●	●	●	●		●	●	●
LTBD27	SAM Sculpture Park Beach	●	●	●	●		●	●	●
LSGY01	Seacrest Park	●	●	●	●		●	●	●
LSHV01	Alki Beach	★	★	●	●		●	●	●
LSKR01	Alki Beach – Alki Plant	●	●	●	●		●	●	●
LSKS01	Constellation Park – Richey Viewpoint	★	★	●	●		●	●	●
LSVW01	Fauntleroy Cove	●	●	●	●	●	●	●	●
MTLD03	Normandy Park	●	●	●	●		●	●	●
MTUJ01	Des Moines Creek Park	●	●	●	●		●	●	●
NTFK01	Redondo Beach	●	●	●	●	●	●	●	●
NSJY01	Dumas Bay Park	●	●	●	●	●	●	●	●
MSJL01	Vashon Island – Gorsuch Road	●	●	●	●		●	●	●
MSSM05	Vashon Island – Tramp Harbor	●	●	●	●		●	●	●
MSXK01	Vashon Island – Burton Acres Park	●	●	●	●	●	●	●	●

Appendix B: Methods and Detection Limits

Table B-1. Analytical methods used for conventional parameters for Puget Sound receiving waters.

Parameter	Units	Lab		Field	
		MDL	Method	MDL	Method
Salinity	PSU	2.0	SM2520-B	na	CTD:SOP 220v4
Dissolved Oxygen	mg/L	0.1	SM4500-O-C	0.5	CTD:SOP 220v4
Temperature	°C	--	--	na	CTD:SOP 220v4
PAR	μmol/sm ²	--	--	na	CTD:SOP 220v4
Light Transmission	% light	--	--	0.01	CTD:SOP 220v4
Chlorophyll-a	ug/L	0.05	EPA 445.0	0.06	CTD:SOP 220v4
Pheophytin-a	ug/L	0.1	EPA 445.0	--	--
Ammonia-Nitrogen	mg/L	0.01	SM4500-NH3-G	--	--
Nitrate+Nitrite (NO ₃ +NO ₂)	mg/L	0.02	SM4500-NO3-F	0.034*	CTD:SOP 220v4
Total Phosphorous	mg/L	0.005	SM4500-P-B,F,S	--	--
Orthophosphorus	mg/L	0.002	SM4500-P-F	--	--
Silica	mg/L	0.05	T. E Whittedge 1981	--	--
Fecal Coliform Bacteria	colonies/100 mL	1	SM9222-D	--	--
Enterococcus Bacteria	colonies/100 mL	1	SM9230-C	--	--
Total Suspended Solids	mg/L	0.5	SM2540D & E	--	--

PSU = practical salinity unit

mg/L = milligram per liter

ug/L = microgram per liter

MDL = method detection limit

na = not applicable

μmol = micromole

* = Nitrate only for field measurements from Submersible Ultraviolet Nitrate Analyzer (SUNA)

Conventional References:

Standard Methods for the examination of water and wastewater, 20th edition: Methods 2520B Salinity, 4500-OC Oxygen, 4500-NH3 G, 4500-NO3- F; 4500-P F, 1998.

Standard Methods for the examination of water and wastewater, 21st edition: Methods 9222-D Fecal Coliforms and 9230-C Enterococci, 2005.

Standard Methods for the examination of water and wastewater, 22nd edition: Method 2540D & E, 2012.

Automated Nutrient Analyses in Seawater (Silica only), T. E. Whittedge, S. C. Malloy, C. J. Patten, and C. D. Wirick, February 1981, Technical Report, Brookhaven National Laboratory, Upton, NY.

EPA, 1997. In Vitro Determination of Chlorophyll-a and Pheophytin-a in Marine and Freshwater Phytoplankton by Fluorescence, Method 445.0, Version 1.2.

Standard Operating Procedures for Methods from the King County Environmental Laboratory (Seattle, WA):

King County, 2006. Standard Operating Procedure for Chlorophyll-a and Pheophytin-a Fluorometric Method (SOP #314v4).

King County, 2007. Standard Operating Procedure for Total Phosphorus, Total Dissolved Phosphorus, Total Nitrogen, and Total Dissolved Nitrogen in Liquid Matrices (SOP# 331v3).

King County, 2007. Standard Operating Procedure for Ammonia-Nitrogen, Nitrate-Nitrogen, Nitrite-Nitrogen, ortho Phosphate and Silica in Liquid Matrices (SOP# 330v4).

King County, 2011. Enterococci in Environmental Water by Membrane Filtration (SOP# 512v1).

King County, 2012. Dissolved Oxygen by Winkler Titration, Azide Modification (SOP# 325v3).

King County, 2014a. Standard Operating Procedure for SBE 25Plus Sealogger CTD (SOP# 220v4).

King County, 2014b. Fecal Coliforms in Environmental Water by Membrane Filtration (SOP# 506v2).

King County, 2016. Standard Operating Procedure for Suspended Solids - Total, 0.45um, and Volatile (SOP# 309v4).

King County Environmental Lab is accredited by the WA Dept. of Ecology (Accreditation #G656-17a); listing by parameter: <https://fortress.wa.gov/ecy/laboratorysearch/SearchLabName.aspx?CompanyID=656>

Table B-2. Analytical methods and detection limits for trace metals in water.

Metal	Units	MDL	Method
Antimony	µg/L	0.01	EPA Method 200.8r5.4
Arsenic	µg/L	0.01	EPA Method 200.8r5.4
Cadmium	µg/L	0.005	EPA Method 200.8r5.4
Chromium	µg/L	0.05	EPA Method 200.8r5.4
Copper	µg/L	0.025	EPA Method 200.8r5.4
Lead	µg/L	0.025	EPA Method 200.8r5.4
Mercury	µg/L	0.0002	EPA Method 1631E
Nickel	µg/L	0.025	EPA Method 200.8r5.4
Silver	µg/L	0.005	EPA Method 200.8r5.4
Zinc	µg/L	0.1	EPA Method 200.8r5.4

MDL = method detection limit

Table B-3. Analytical methods used for organic compounds. Note: Method detection limits (MDL) by individual compounds can be found in Appendix Table C-1.

Class of Organics Compounds	Units	Method
Chlorinated Pesticides and PCB Aroclors	ug/L	EPA 608/SW846 3520C
Volatile Organics	ug/L	EPA 624/SW846 5030C*8260C (GC/MS)
Polycyclic Aromatic Hydrocarbons and Other Semivolatile Organics	ug/L	EPA 625/SW846 3520C*8270D (GC/MS)
Total Phenolics	mg/L	EPA 420.1

Standard Operating Procedures for Metals/Organics Methods from the King County Environmental Laboratory (Seattle, WA):

King County. 2003a. Standard operating procedure for preparation of aqueous samples for analysis of total and dissolved mercury by automated cold vapor atomic fluorescence spectrometry (SOP #605v0).

King County. 2003b. Standard operating procedure for instrumental analysis of environmental samples for mercury using automated cold vapor atomic fluorescence spectrometry (SOP #606v0).

King County. 2010. Standard operating procedure for determination of trace elements in water by preconcentration and inductively coupled plasma – mass spectrometry (SOP #643v1).

King County. 2012. Standard operating procedure for semivolatile compound (BNAs) analysis of water and solids by GC-MS (SOP #731v5).

King County. 2017a. Standard operating procedure for chlorinated pesticides analysis in water and solids by GC-ECD (SOP #733v5).

King County. 2017b. Standard operating procedure for volatile organic compound analysis of water and solids by GC MS (SOP #732v5).

King County. 2017c. Standard operating procedure for PCB aroclors analysis of waters and solids by GC-ECD (SOP #757v2).

Table B-4. Analytical methods used for conventional parameters by the West Point Treatment Plant process laboratory.

Parameter	Units	MDL	Method*
Total Suspended Solids	mg/L	0.61	SM2540 D97
Total Res Chlorine	mg/L	0.009	SM 4500-Cl E-00
BOD	mg/L	1.7	SM 5210 B-01
CBOD	mg/L	1.7	SM 5210 B-01
pH	SU	na	SM 4500-H+ B-00
Ammonia-Nitrogen	mg/L	0.13	SM 4500-NH3 E-97
Nitrite (NO2)	mg/L	0.0041	SM 4500-NO2 B-00
Nitrate (NO3)	mg/L	0.0606	SM 4500-NO3 E-00
Nitrogen, Total Kjeldahl	mg/L	0.21	SM 4500-Norg B-97
Total Phosphorous	mg/L	0.08	SM 4500-P E-99
Orthophosphorus	mg/L	0.023	Hach 8048 eq to SM 4500-P E-99
Fecal Coliform Bacteria	MPN/100 mL	na	SM 2340 C-97

mg/L = milligram per liter

MDL = method detection limit

na = not applicable

MPN=most probable number

*SM refers to Standard Methods for the Examination of Water and Wastewater (APHA, 2012)

Conventional References:

Standard Methods for the examination of water and wastewater, 22nd edition.

Table B-5. Metal translator values provided by West Point's NPDES permit (Ecology, 2014) for converting total metals measured in effluent to the dissolved fraction.

Metal	West Point Translator
Arsenic	1.000
Cadmium	0.980
Chromium	0.960
Copper	0.790
Lead	0.951
Mercury	0.850
Nickel	1.000
Silver	0.850
Zinc	0.946

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Appendix C: 2017 Effluent Organics Summary Data

Table C-1: Summary statistics of organic compounds sampled in effluent from February through June 2017. One half of the detection limit was used to calculate summary statistics when non-detects were present along with detected concentrations. All units in the table are in µg/L, including for method detection limit (MDL) values.

Parameter	FOD	Mean	Median	Max	Min. MDL	Max. MDL
1,1,1-Trichloroethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,1,2,2-Tetrachloroethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,1,2-Trichloroethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,1,2-Trichloroethylene	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,1-Dichloroethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,1-Dichloroethylene	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,2,4-Trichlorobenzene	0/7	<MDL	<MDL	<MDL	0.075	0.38
1,2-Dibromoethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,2-Dichlorobenzene	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,2-Dichloroethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,2-Dichloropropane	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,2-Diphenylhydrazine	0/7	<MDL	<MDL	<MDL	0.25	1.3
1,3-Dichlorobenzene	0/7	<MDL	<MDL	<MDL	1.0	1.0
1,4-Dichlorobenzene	0/7	<MDL	<MDL	<MDL	1.0	1.0
2,4,6-Trichlorophenol	0/7	<MDL	<MDL	<MDL	0.5	2.5
2,4-Dichlorophenol	0/7	<MDL	<MDL	<MDL	0.13	0.63
2,4-Dimethylphenol	0/7	<MDL	<MDL	<MDL	0.13	0.63
2,4-Dinitrophenol	0/7	<MDL	<MDL	<MDL	0.75	3.8
2,4-Dinitrotoluene	0/7	<MDL	<MDL	<MDL	0.13	0.63
2,6-Dinitrotoluene	0/7	<MDL	<MDL	<MDL	0.13	0.63
2-Butanone (MEK)	1/7	3.2	<MDL	7.4	5.0	5.0
2-Chloroethylvinyl ether	0/7	<MDL	<MDL	<MDL	1.0	1.0
2-Chloronaphthalene	0/7	<MDL	<MDL	<MDL	0.075	0.38
2-Chlorophenol	0/7	<MDL	<MDL	<MDL	0.25	1.3
2-Hexanone	0/7	<MDL	<MDL	<MDL	5.0	5.0
2-Methylnaphthalene	0/7	<MDL	<MDL	<MDL	0.2	1.0
2-Methylphenol	0/7	<MDL	<MDL	<MDL	0.13	0.63
2-Nitrophenol	0/7	<MDL	<MDL	<MDL	0.13	0.63
3,3'-Dichlorobenzidine	0/7	<MDL	<MDL	<MDL	0.5	2.5
3-,4-Methylphenol	7/7	15.4	16.5	34.8	0.13	0.63
3-Methylcholanthrene	0/7	<MDL	<MDL	<MDL	0.5	2.5
4,4'-DDD	0/7	<MDL	<MDL	<MDL	0.01	0.01
4,4'-DDE	0/7	<MDL	<MDL	<MDL	0.01	0.01
4,4'-DDT	0/7	<MDL	<MDL	<MDL	0.01	0.01
4,6-Dinitro-O-Cresol	0/7	<MDL	<MDL	<MDL	0.5	2.5
4-Bromophenyl Phenyl Ether	0/7	<MDL	<MDL	<MDL	0.05	0.25
4-Chloro-3-Methylphenol	0/7	<MDL	<MDL	<MDL	0.25	1.3

Parameter	FOD	Mean	Median	Max	Min. MDL	Max. MDL
4-Chlorophenyl Phenyl Ether	0/7	<MDL	<MDL	<MDL	0.075	0.38
4-Methyl-2-Pentanone (MIBK)	0/7	<MDL	<MDL	<MDL	5.0	5.0
4-Nitrophenol	0/7	<MDL	<MDL	<MDL	0.5	2.5
Acenaphthene	0/7	<MDL	<MDL	<MDL	0.05	0.25
Acenaphthylene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Acetone	7/7	65	53	177	2.5	2.5
Acrolein	0/7	<MDL	<MDL	<MDL	5.0	5.0
Acrylonitrile	0/7	<MDL	<MDL	<MDL	1.0	1.0
Aldrin	0/7	<MDL	<MDL	<MDL	0.01	0.01
Alpha-BHC	0/7	<MDL	<MDL	<MDL	0.01	0.01
Alpha-Chlordane	0/7	<MDL	<MDL	<MDL	0.01	0.01
Anthracene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Aroclor 1016	0/7	<MDL	<MDL	<MDL	0.05	0.05
Aroclor 1221	0/7	<MDL	<MDL	<MDL	0.05	0.2
Aroclor 1232	0/7	<MDL	<MDL	<MDL	0.05	0.2
Aroclor 1242	0/7	<MDL	<MDL	<MDL	0.05	0.05
Aroclor 1248	0/7	<MDL	<MDL	<MDL	0.05	0.05
Aroclor 1254	0/7	<MDL	<MDL	<MDL	0.05	0.05
Aroclor 1260	0/7	<MDL	<MDL	<MDL	0.05	0.05
Benzene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Benzidine	0/7	<MDL	<MDL	<MDL	7.5	37.5
Benzo(a)anthracene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Benzo(a)pyrene	0/7	<MDL	<MDL	<MDL	0.13	0.63
Benzo(b,j,k)fluoranthene	0/7	<MDL	<MDL	<MDL	0.2	1.0
Benzo(g,h,i)perylene	0/7	<MDL	<MDL	<MDL	0.13	0.63
Benzo(r,s,t)pentaphene	0/7	<MDL	<MDL	<MDL	0.63	3.1
Benzoic Acid*	4/7	38.5	20.3	103	2.0	10
Benzyl Alcohol	4/7	11.7	5.61	24.1	0.13	0.63
Benzyl Butyl Phthalate	0/7	<MDL	<MDL	<MDL	0.075	0.38
Beta-BHC	0/7	<MDL	<MDL	<MDL	0.01	0.01
Bis(2-Chloroethoxy)Methane	0/7	<MDL	<MDL	<MDL	0.13	0.63
Bis(2-Chloroethyl)Ether	0/7	<MDL	<MDL	<MDL	0.075	0.38
Bis(2-Chloroisopropyl)Ether	0/7	<MDL	<MDL	<MDL	0.25	1.3
Bis(2-Ethylhexyl)Phthalate	6/7	0.78	0.626	1.8	0.13	0.63
Bromodichloromethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
Bromoform	0/7	<MDL	<MDL	<MDL	1.0	1.0
Bromomethane	0/7	<MDL	<MDL	<MDL	5.0	5.0
Carbazole	0/7	<MDL	<MDL	<MDL	0.13	0.63
Carbon Disulfide	0/7	<MDL	<MDL	<MDL	1.0	1.0
Carbon Tetrachloride	0/7	<MDL	<MDL	<MDL	1.0	1.0

Parameter	FOD	Mean	Median	Max	Min. MDL	Max. MDL
Chlorobenzene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Chlorodibromomethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
Chloroethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
Chloroform	7/7	1.7	1.6	2.1	1.0	1.0
Chloromethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
Chrysene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Cis-1,3-Dichloropropene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Delta-BHC	0/7	<MDL	<MDL	<MDL	0.01	0.01
Dibenzo(a,e)pyrene	0/7	<MDL	<MDL	<MDL	0.63	3.1
Dibenzo(a,h)acridine	0/7	<MDL	<MDL	<MDL	0.63	3.1
Dibenzo(a,h)anthracene	0/7	<MDL	<MDL	<MDL	0.2	1.0
Dibenzo(a,h)pyrene	0/7	<MDL	<MDL	<MDL	0.63	3.1
Dibenzo(a,i)acridine	0/7	<MDL	<MDL	<MDL	0.63	3.1
Dibenzofuran	0/7	<MDL	<MDL	<MDL	0.13	0.63
Dieldrin	0/7	<MDL	<MDL	<MDL	0.01	0.01
Diethyl Phthalate	4/7	0.51	0.378	1.43	0.13	0.63
Dimethyl Phthalate	0/7	<MDL	<MDL	<MDL	0.05	0.25
Di-N-Butyl Phthalate	0/7	<MDL	<MDL	<MDL	0.13	0.63
Di-N-Octyl Phthalate	1/7	0.19	<MDL	0.68	0.075	0.38
Endosulfan I	0/7	<MDL	<MDL	<MDL	0.01	0.01
Endosulfan II	0/7	<MDL	<MDL	<MDL	0.01	0.01
Endosulfan Sulfate	0/7	<MDL	<MDL	<MDL	0.01	0.01
Endrin	0/7	<MDL	<MDL	<MDL	0.01	0.01
Endrin Aldehyde	0/7	<MDL	<MDL	<MDL	0.01	0.01
Ethylbenzene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Fluoranthene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Fluorene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Gamma-BHC (Lindane)	0/7	<MDL	<MDL	<MDL	0.01	0.01
Heptachlor	0/7	<MDL	<MDL	<MDL	0.01	0.01
Heptachlor Epoxide	0/7	<MDL	<MDL	<MDL	0.01	0.01
Hexachlorobenzene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Hexachlorobutadiene	0/7	<MDL	<MDL	<MDL	0.13	0.63
Hexachlorocyclopentadiene	0/7	<MDL	<MDL	<MDL	0.5	2.5
Hexachloroethane	0/7	<MDL	<MDL	<MDL	0.13	0.63
Indeno(1,2,3-Cd)Pyrene	0/7	<MDL	<MDL	<MDL	0.13	0.63
Isophorone	0/7	<MDL	<MDL	<MDL	0.13	0.63
Methoxychlor	0/7	<MDL	<MDL	<MDL	0.05	0.05
Methylene Chloride	0/7	<MDL	<MDL	<MDL	5.0	5.0
Methyl-t-butyl Ether (MTBE)	0/7	<MDL	<MDL	<MDL	1.0	1.0
Naphthalene	0/7	<MDL	<MDL	<MDL	0.2	1.0

Parameter	FOD	Mean	Median	Max	Min. MDL	Max. MDL
n-Decane	0/7	<MDL	<MDL	<MDL	0.075	0.38
Nitrobenzene	0/7	<MDL	<MDL	<MDL	0.13	0.63
N-Nitrosodimethylamine	0/7	<MDL	<MDL	<MDL	0.5	2.5
N-Nitrosodi-N-Propylamine	0/7	<MDL	<MDL	<MDL	0.13	0.63
N-Nitrosodiphenylamine	0/7	<MDL	<MDL	<MDL	0.25	1.3
n-Octadecane	2/7	0.34	<MDL	1.19	0.075	0.38
O-Xylene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Pentachlorophenol	0/7	<MDL	<MDL	<MDL	0.13	0.63
Perylene	0/7	<MDL	<MDL	<MDL	0.13	0.63
Phenanthrene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Phenol	4/7	3.23	3.6	7.85	0.5	2.5
Pyrene	0/7	<MDL	<MDL	<MDL	0.075	0.38
Styrene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Tetrachloroethylene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Toluene	4/7	1.0	1.1	1.6	1.0	1.0
Total Aroclors	0/7	<MDL	<MDL	<MDL	0.05	0.2
Total Xylenes	0/7	<MDL	<MDL	<MDL	1.0	1.0
Toxaphene	0/7	<MDL	<MDL	<MDL	0.2	0.2
Trans-1,2-Dichloroethylene	0/7	<MDL	<MDL	<MDL	1.0	1.0
Trans-1,3-Dichloropropene	0/7	<MDL	<MDL	<MDL	1.0	1.0
trans-Chlordane	0/7	<MDL	<MDL	<MDL	0.01	0.01
Trichlorofluoromethane	0/7	<MDL	<MDL	<MDL	1.0	1.0
Vinyl Acetate	0/7	<MDL	<MDL	<MDL	5.0	5.0
Vinyl Chloride	0/7	<MDL	<MDL	<MDL	1.0	1.0

FOD = Frequency of detection

*Blank contamination detected. Benzyl alcohol values are expected to be true values.

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Appendix D: 2017 Offshore Bacteria Data

Table D-1 Offshore fecal coliform concentrations sampled in February 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Fecal Coliforms		Feb. Values		Historic Mean & Percentiles (2007–2016)				
Site	Depth (m)	7th/8th	21st/22nd	n	Mean	50th	75th	95th
CK200P	1	9	1	12	0.58	0	1	2
CK200P	35	1	0	12	1.00	1	1	3
CK200P	55	0	0	12	0.67	0	1	3
JSUR01	1	0	0	12	0.58	0	1	2
JSUR01	100	0	0	6	0.00	0	0	0
JSUR01	170	0	0	6	0.00	0	0	0
KSBP01	1	0	0	12	0.75	0	1	3
KSSK02	1	0	5	12	0.83	0	1	3
KSSK02	25	0	1	12	0.17	0	0	1
KSSK02	55	0	1	12	0.08	0	0	0
LSEP01	1	0	7	12	0.25	0	0	1
LSEP01	100	0	1	12	0.25	0	0	1
LSEP01	170	1	0	12	0.25	0	0	1
LSKQ06	1	0	0	12	0.08	0	0	0
LSKQ06	35	0	0	12	0.00	0	0	0
LSNT01	1	0	0	12	0.08	0	0	0
LSVV01	1	0	1	12	0.08	0	0	0
LSVV01	10	1	0	12	0.08	0	0	0
LTBC43	1	2	1	12	4.50	4	7	10
LTBC43	15	1	1	12	0.58	0	1	2
LTED04	1	5	4	12	2.00	1	3	6
MSJN02	1	0	0	11	0.00	0	0	0
MSJN02	25	0	0	12	0.00	0	0	0
MSJN02	55	0	0	12	0.33	0	0	2
NSEX01	1	0	0	12	0.58	0	1	2

Table D-2 Offshore Enterococcus concentrations sampled in February 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Enterococcus		Feb. Values		Historic Mean & Percentiles (2007–2016)				
Site	Depth (m)	7th/8th	21st/22nd	n	Mean	50th	75th	95th
CK200P	1	5	3	12	1.33	0	2	5
CK200P	35	1	2	12	0.25	0	0	1
CK200P	55	4	3	12	0.25	0	0	1
JSUR01	1	1	0	12	0.67	0	0	4
JSUR01	100	1	1	6	0.00	0	0	0
JSUR01	170	0	0	6	0.00	0	0	0
KSBP01	1	1	1	12	0.83	0	0	5
KSSK02	1	2	2	12	1.75	0	2	7
KSSK02	25	0	3	12	0.58	0	1	2
KSSK02	55	3	5	12	0.50	0	1	2
LSEP01	1	1	5	12	0.17	0	0	1
LSEP01	100	1	1	12	0.75	1	1	2
LSEP01	170	0	1	12	0.17	0	0	1
LSKQ06	1	0	0	12	0.33	0	0	2
LSKQ06	35	0	0	12	0.33	0	0	1
LSNT01	1	0	0	12	0.08	0	0	0
LSVV01	1	0	0	12	0.33	0	0	1
LSVV01	10	0	1	12	0.25	0	0	1
LTBC43	1	6	3	12	6.92	4	8	24
LTBC43	15	3	3	12	2.58	1	4	8
LTED04	1	11	4	12	4.08	3	5	12
MSJN02	1	0	1	11	0.09	0	0	1
MSJN02	25	0	0	12	0.42	0	1	1
MSJN02	55	0	1	12	0.25	0	0	1
NSEX01	1	2	1	12	0.67	0	1	2

Table D-3 Offshore fecal coliform concentrations sampled in March 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Fecal Coliforms		Mar. Values				Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	6th/7th	15th	20th/21st	29th	n	Mean	50th	75th	95th
CK200P	1	2	ns	1	ns	12	0.92	0	1	4
CK200P	35	0	ns	0	ns	12	0.33	0	0	2
CK200P	55	1	ns	0	ns	12	0.08	0	0	0
EBO	1	0	2	1	0	NA	NA	NA	NA	NA
EBO	12	0	0	0	0	NA	NA	NA	NA	NA
JSUR01	1	1	ns	0	ns	11	0.36	0	0	2
JSUR01	100	0	ns	0	ns	5	0.00	0	0	0
JSUR01	170	0	ns	0	ns	5	0.00	0	0	0
KSBP01	1	0	1	1	0	10	0.20	0	0	1
KSSK02	1	0	10	4	10	11	1.91	0	2	8
KSSK02	25	0	0	1	0	11	0.18	0	0	1
KSSK02	55	0	0	0	0	11	0.09	0	0	1
LSEP01	1	0	2	0	0	11	0.45	0	1	2
LSEP01	100	0	1	0	1	11	0.09	0	0	1
LSEP01	170	0	1	0	1	11	0.82	0	0	5
LSKQ06	1	0	ns	1	ns	11	0.00	0	0	0
LSKQ06	35	0	ns	0	ns	11	0.00	0	0	0
LSNT01	1	0	0	0	1	11	0.09	0	0	1
LSVV01	1	0	ns	1	ns	11	0.36	0	1	1
LSVV01	10	0	ns	0	ns	11	0.18	0	0	1
LTBC43	1	1	ns	14	ns	11	10.00	6	10	37
LTBC43	15	0	ns	9	ns	11	0.55	0	1	2
LTED04	1	0	ns	7	ns	12	7.00	2	3	33
MSJN02	1	0	ns	1	ns	11	0.00	0	0	0
MSJN02	25	0	ns	0	ns	11	0.09	0	0	1
MSJN02	55	0	ns	0	ns	11	0.00	0	0	0
NSEX01	1	0	ns	1	ns	11	0.00	0	0	0

Table D-4 Offshore Enterococcus concentrations sampled in March 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Enterococcus		Mar. Values				Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	6th/7th	15th	20th/21st	29th	n	Mean	50th	75th	95th
CK200P	1	2	ns	1	ns	12	0.67	0	1	2
CK200P	35	3	ns	0	ns	12	0.42	0	0	2
CK200P	55	0	ns	3	ns	12	0.17	0	0	1
EBO	1	1	6	1	1	NA	NA	NA	NA	NA
EBO	12	3	11	14	0	NA	NA	NA	NA	NA
JSUR01	1	0	ns	3	ns	11	0.18	0	0	1
JSUR01	100	0	ns	0	ns	5	0.00	0	0	0
JSUR01	170	0	ns	0	ns	5	0.00	0	0	0
KSBP01	1	1	3	0	0	10	0.20	0	0	1
KSSK02	1	1	13	6	5	11	2.09	0	2	10
KSSK02	25	0	5	8	0	11	0.64	0	0	4
KSSK02	55	2	6	2	1	11	0.55	0	1	2
LSEP01	1	1	1	0	0	11	0.27	0	0	2
LSEP01	100	2	0	0	0	11	0.55	0	1	2
LSEP01	170	0	0	0	0	11	0.55	0	1	2
LSKQ06	1	0	ns	0	ns	11	0.18	0	0	1
LSKQ06	35	0	ns	0	ns	11	0.00	0	0	0
LSNT01	1	0	0	0	0	11	0.09	0	0	1
LSVV01	1	1	ns	0	ns	11	0.82	0	1	4
LSVV01	10	1	ns	1	ns	11	0.45	0	1	2
LTBC43	1	5	ns	12	ns	11	8.82	3	6	35
LTBC43	15	4	ns	26	ns	11	1.45	1	2	5
LTED04	1	1	ns	11	ns	12	5.25	2	3	22
MSJN02	1	0	ns	0	ns	11	0.27	0	0	2
MSJN02	25	1	ns	0	ns	11	0.18	0	0	1
MSJN02	55	1	ns	1	ns	11	0.09	0	0	1
NSEX01	1	0	ns	0	ns	11	0.45	0	1	2

Table D-5 Offshore fecal coliform concentrations sampled in April 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Fecal Coliforms		Apr. Values				Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	3rd/4th	11th	17th/18th	26th	n	Mean	50th	75th	95th
CK200P	1	0	ns	0	ns	12	0.08	0	0	0
CK200P	35	0	ns	0	ns	12	0.00	0	0	0
CK200P	55	0	ns	0	ns	12	0.08	0	0	0
EBO	1	4	0	0	0	NA	NA	NA	NA	NA
EBO	12	0	0	0	0	NA	NA	NA	NA	NA
JSUR01	1	0	ns	0	ns	12	0.17	0	0	1
JSUR01	100	0	ns	0	ns	6	0.00	0	0	0
JSUR01	170	0	ns	0	ns	6	0.00	0	0	0
KSBP01	1	0	0	0	0	12	0.25	0	0	1
KSSK02	1	0	1	0	0	12	0.58	0	1	2
KSSK02	25	0	0	0	0	12	0.00	0	0	0
KSSK02	55	0	0	0	0	12	0.00	0	0	0
LSEP01	1	19	0	0	0	12	0.25	0	0	1
LSEP01	100	0	0	0	0	12	0.00	0	0	0
LSEP01	170	1	0	1	0	12	0.08	0	0	0
LSKQ06	1	0	ns	0	ns	11	0.00	0	0	0
LSKQ06	35	0	ns	0	ns	11	0.18	0	0	1
LSNT01	1	0	0	0	0	11	0.00	0	0	0
LSVV01	1	0	ns	0	ns	12	0.33	0	0	2
LSVV01	10	0	ns	0	ns	12	0.00	0	0	0
LTBC43	1	1	ns	6	ns	12	1.67	1	2	5
LTBC43	15	0	ns	5	ns	12	0.17	0	0	1
LTED04	1	0	ns	0	ns	12	1.33	1	2	4
MSJN02	1	0	ns	0	ns	12	0.00	0	0	0
MSJN02	25	0	ns	0	ns	12	0.00	0	0	0
MSJN02	55	0	ns	0	ns	12	0.00	0	0	0
NSEX01	1	2	ns	0	ns	12	0.00	0	0	0

Table D-6 Offshore Enterococcus concentrations sampled in April 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Enterococcus		Apr. Values				Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	3rd/4th	11th	17th/18th	26th	n	Mean	50th	75th	95th
CK200P	1	1	ns	0	ns	12	0.42	0	0	2
CK200P	35	0	ns	0	ns	12	0.00	0	0	0
CK200P	55	0	ns	0	ns	12	0.08	0	0	0
EBO	1	0	2	0	0	NA	NA	NA	NA	NA
EBO	12	1	1	0	2	NA	NA	NA	NA	NA
JSUR01	1	0	ns	0	ns	12	0.00	0	0	0
JSUR01	100	0	ns	0	ns	6	0.00	0	0	0
JSUR01	170	0	ns	0	ns	6	0.00	0	0	0
KSBP01	1	0	0	0	0	12	0.00	0	0	0
KSSK02	1	0	0	0	3	12	0.08	0	0	0
KSSK02	25	0	2	0	0	12	0.00	0	0	0
KSSK02	55	2	0	1	1	12	0.00	0	0	0
LSEP01	1	6	0	0	0	12	0.08	0	0	0
LSEP01	100	1	0	0	0	12	0.17	0	0	1
LSEP01	170	1	0	1	0	12	0.00	0	0	0
LSKQ06	1	0	ns	3	ns	11	0.09	0	0	1
LSKQ06	35	0	ns	0	ns	11	0.00	0	0	0
LSNT01	1	0	0	0	0	11	0.00	0	0	0
LSVV01	1	1	ns	0	ns	12	0.00	0	0	0
LSVV01	10	0	ns	0	ns	12	0.08	0	0	0
LTBC43	1	5	ns	3	ns	12	0.92	0	1	4
LTBC43	15	2	ns	1	ns	12	0.50	0	1	2
LTED04	1	0	ns	3	ns	12	0.33	0	1	1
MSJN02	1	0	ns	0	ns	12	0.00	0	0	0
MSJN02	25	0	ns	0	ns	12	0.00	0	0	0
MSJN02	55	0	ns	0	ns	12	0.00	0	0	0
NSEX01	1	0	ns	0	ns	12	0.00	0	0	0

Table D-7 Offshore fecal coliform concentrations sampled in May 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Fecal Coliforms		May Values				Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	1st/2nd	10th	15th/16th	24th	n	Mean	50th	75th	95th
CK200P	1	1	ns	4	ns	13	0.31	0	1	1
CK200P	35	0	ns	0	ns	13	0.00	0	0	0
CK200P	55	0	ns	0	ns	13	0.08	0	0	0
EBO	1	3	0	0	2	NA	NA	NA	NA	NA
EBO	12	0	0	0	1	NA	NA	NA	NA	NA
JSUR01	1	0	ns	0	ns	13	0.54	0	0	3
JSUR01	100	0	ns	0	ns	7	0.00	0	0	0
JSUR01	170	0	ns	0	ns	7	0.00	0	0	0
KSBP01	1	0	0	0	0	13	0.08	0	0	0
KSSK02	1	1	0	0	2	13	0.15	0	0	1
KSSK02	25	0	1	0	0	13	0.00	0	0	0
KSSK02	55	1	0	0	0	13	0.08	0	0	0
LSEP01	1	2	0	1	0	12	0.17	0	0	1
LSEP01	100	0	0	1	0	13	0.08	0	0	0
LSEP01	170	0	0	0	0	13	0.15	0	0	1
LSKQ06	1	0	ns	2	ns	11	1.00	0	0	6
LSKQ06	35	0	ns	0	ns	12	0.00	0	0	0
LSNT01	1	0	0	0	1	12	0.08	0	0	0
LSVV01	1	0	ns	0	ns	13	0.15	0	0	1
LSVV01	10	0	ns	0	ns	12	0.42	0	0	2
LTBC43	1	1	ns	2	ns	13	5.62	1	6	22
LTBC43	15	1	ns	0	ns	12	0.25	0	0	1
LTED04	1	0	ns	1	ns	13	2.62	1	6	9
MSJN02	1	0	ns	0	ns	13	0.23	0	0	1
MSJN02	25	0	ns	0	ns	13	0.15	0	0	1
MSJN02	55	0	ns	0	ns	13	0.00	0	0	0
NSEX01	1	0	ns	0	ns	13	0.00	0	0	0

Table D-8 Offshore Enterococcus concentrations sampled in May 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Enterococcus		May Values				Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	1st/2nd	10th	15th/16th	24th	n	Mean	50th	75th	95th
CK200P	1	1	ns	3	ns	13	0.23	0	0	1
CK200P	35	0	ns	2	ns	13	0.31	0	0	2
CK200P	55	0	ns	14	ns	13	0.00	0	0	0
EBO	1	310	0	1	0	NA	NA	NA	NA	NA
EBO	12	95	0	1	0	NA	NA	NA	NA	NA
JSUR01	1	0	ns	0	ns	13	0.00	0	0	0
JSUR01	100	0	ns	12	ns	7	0.00	0	0	0
JSUR01	170	0	ns	0	ns	7	0.00	0	0	0
KSBP01	1	2	2	46	0	13	0.00	0	0	0
KSSK02	1	1	0	0	1	13	0.15	0	0	1
KSSK02	25	1	37	17	0	13	0.38	0	0	2
KSSK02	55	13	7	24	0	13	0.38	0	0	2
LSEP01	1	0	0	0	0	12	0.17	0	0	1
LSEP01	100	0	9	0	1	13	0.00	0	0	0
LSEP01	170	5	6	0	0	13	0.00	0	0	0
LSKQ06	1	17	ns	1	ns	11	0.18	0	0	1
LSKQ06	35	1	ns	0	ns	12	0.08	0	0	0
LSNT01	1	0	8	2	1	12	0.17	0	0	1
LSVV01	1	2	ns	1	ns	13	0.08	0	0	0
LSVV01	10	0	ns	2	ns	12	0.17	0	0	1
LTBC43	1	4	ns	1	ns	13	3.46	0	2	17
LTBC43	15	1	ns	1	ns	12	0.50	0	0	2
LTED04	1	20	ns	23	ns	13	2.08	0	0	11
MSJN02	1	0	ns	0	ns	13	0.08	0	0	0
MSJN02	25	0	ns	0	ns	13	0.00	0	0	0
MSJN02	55	0	ns	8	ns	13	0.00	0	0	0
NSEX01	1	0	ns	0	ns	13	0.23	0	0	1

Table D-9 Offshore fecal coliform concentrations sampled in June 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Fecal Coliforms		Jun. Values		Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	5th/7th	19th/20th	n	Mean	50th	75th	95th
CK200P	1	0	0	13	0.00	0	0	0
CK200P	35	0	0	13	0.00	0	0	0
CK200P	55	0	0	13	0.00	0	0	0
EBO	1	4	ns	NA	NA	NA	NA	NA
EBO	12	0	ns	NA	NA	NA	NA	NA
JSUR01	1	0	0	13	0.00	0	0	0
JSUR01	100	0	0	7	0.00	0	0	0
JSUR01	170	0	0	7	0.00	0	0	0
KSBP01	1	0	0	13	0.08	0	0	0
KSSK02	1	1	2	13	0.31	0	0	2
KSSK02	25	0	0	13	0.08	0	0	0
KSSK02	55	0	0	13	0.00	0	0	0
LSEP01	1	0	0	13	0.08	0	0	0
LSEP01	100	0	0	13	0.00	0	0	0
LSEP01	170	0	0	13	0.00	0	0	0
LSKQ06	1	0	0	12	0.25	0	0	1
LSKQ06	35	0	0	12	0.08	0	0	0
LSNT01	1	0	0	13	0.00	0	0	0
LSVV01	1	0	0	13	0.23	0	0	1
LSVV01	10	0	0	12	0.33	0	0	2
LTBC43	1	0	7	13	0.85	0	2	3
LTBC43	15	1	0	12	0.17	0	0	1
LTED04	1	1	0	13	1.62	1	2	6
MSJN02	1	0	0	13	0.00	0	0	0
MSJN02	25	0	0	13	0.00	0	0	0
MSJN02	55	0	0	12	0.00	0	0	0
NSEX01	1	0	0	13	0.00	0	0	0

Table D-10 Offshore Enterococcus concentrations sampled in June 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of depth and n, are in colonies per 100 mL.

Enterococcus		Jun. Values		Historic Mean & Percentiles (2007-2016)				
Site	Depth (m)	5th/7th	19th/20th	n	Mean	50th	75th	95th
CK200P	1	0	0	13	0.00	0	0	0
CK200P	35	0	0	13	0.00	0	0	0
CK200P	55	0	0	13	0.08	0	0	0
EBO	1	4	ns	NA	NA	NA	NA	NA
EBO	12	0	ns	NA	NA	NA	NA	NA
JSUR01	1	0	0	13	0.00	0	0	0
JSUR01	100	2	0	7	0.00	0	0	0
JSUR01	170	0	0	7	0.00	0	0	0
KSBP01	1	1	0	13	0.00	0	0	0
KSSK02	1	0	0	13	0.23	0	0	1
KSSK02	25	0	0	13	0.08	0	0	0
KSSK02	55	0	5	13	0.00	0	0	0
LSEP01	1	0	0	13	0.00	0	0	0
LSEP01	100	0	0	13	0.00	0	0	0
LSEP01	170	0	0	13	0.00	0	0	0
LSKQ06	1	2	0	12	0.25	0	0	1
LSKQ06	35	0	0	12	0.00	0	0	0
LSNT01	1	0	0	13	0.15	0	0	1
LSVV01	1	0	0	13	0.31	0	0	2
LSVV01	10	0	0	12	0.08	0	0	0
LTBC43	1	2	1	13	1.15	1	1	4
LTBC43	15	1	0	12	0.50	0	1	1
LTED04	1	0	2	13	0.77	0	1	4
MSJN02	1	0	0	13	0.08	0	0	0
MSJN02	25	1	0	13	0.00	0	0	0
MSJN02	55	0	0	12	0.08	0	0	0
NSEX01	1	0	4	13	0.08	0	0	0

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Appendix E: 2017 Beach Bacteria Data

Table E-1 Beaches fecal coliforms concentrations sampled in February 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Fecal Coliforms Site	Feb. Value	Historic Mean & Percentiles (2007-2016)				
	22nd	n	Mean	50th	75th	95th
ITCARKEEKP	8	10	8.10	4	10	27
KSHZ03	2	10	41.10	19	43	151
KSLU03	30	11	8.27	7	11	19
KSSN04	4	10	17.90	4	9	82
KSSN05	1	10	5.80	8	9	10
KSYV02	7	11	11.64	11	11	27
LSGY01	2	10	3.90	3	6	10
LSHV01	2	9	6.44	6	11	12
LSKR01	9	11	13.64	16	23	25
LSKS01	2	10	43.10	25	31	153
LTBD27	16	10	16.10	13	21	46

Table E-2 Beaches Enterococcus concentrations sampled in February 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Enterococcus Site	Feb. Value	Historic Mean & Percentiles (2007-2016)				
	22nd	n	Mean	50th	75th	95th
ITCARKEEKP	2	10	22.70	2	6	115
KSHZ03	4	10	31.10	7	11	147
KSLU03	18	11	11.09	8	13	36
KSSN04	4	10	6.90	4	5	27
KSSN05	4	10	7.80	6	9	24
KSYV02	66	11	28.91	14	30	102
LSGY01	2	10	3.00	2	4	9
LSHV01	3	9	7.56	6	9	18
LSKR01	3	11	18.55	8	13	68
LSKS01	2	10	69.30	29	108	217
LTBD27	22	10	12.70	8	11	39

Table E-3 Beaches fecal coliforms concentrations sampled in March 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Fecal Coliforms Site	Mar. Value	Historic Mean & Percentiles (2007-2016)				
	22nd	n	Mean	50th	75th	95th
ITCARKEEKP	1	12	17.08	1	6	86
KSHZ03	6	12	47.42	22	35	184
KSLU03	4	12	22.17	16	39	50
KSSN04	6	12	3.92	3	6	11
KSSN05	14	13	14.92	7	10	65
KSYV02	6	10	20.10	10	24	63
LSGY01	5	12	6.08	3	4	24
LSHV01	0	10	27.40	4	7	136
LSKR01	34	13	14.77	6	12	55
LSKS01	16	10	25.60	17	25	80
LTBD27	26	11	66.18	24	44	280

Table E-4 Beaches Enterococcus concentrations sampled in March 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Enterococcus Site	Mar. Value	Historic Mean & Percentiles (2007-2016)				
	22nd	n	Mean	50th	75th	95th
ITCARKEEKP	2	12	24.25	3	8	129
KSHZ03	6	12	48.42	14	23	216
KSLU03	6	12	15.33	8	19	48
KSSN04	3	12	4.25	2	5	15
KSSN05	13	13	14.54	4	10	58
KSYV02	12	10	37.30	7	34	155
LSGY01	4	12	7.33	5	7	25
LSHV01	0	10	7.80	3	12	26
LSKR01	4	13	8.23	6	8	27
LSKS01	5	10	15.40	10	14	46
LTBD27	8	11	36.45	9	29	145

Table E-5 Beaches fecal coliforms concentrations sampled in April 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Fecal Coliforms	Apr. Values			Historic Mean & Percentiles (2007-2016)				
Site	10th	19th	24th	n	Mean	50th	75th	95th
ITCARKEEKP	15	3	3	11	1.91	1	3	6
KSHZ03	ns	6	ns	11	24.82	11	44	67
KSLU03	6	19	1	12	9.50	8	15	21
KSSN04	1	2	0	11	2.45	1	4	7
KSSN05	5	12	2	13	6.69	4	7	20
KSYV02	ns	6	ns	10	7.10	4	6	26
LSGY01	ns	2	ns	12	6.92	4	6	25
LSHV01	0	0	3	10	16.00	3	10	71
LSKR01	ns	1	ns	12	11.00	8	11	34
LSKS01	0	26	0	10	43.00	22	35	161
LTBD27	ns	230	ns	10	54.90	5	15	276

Table E-6 Beaches Enterococcus concentrations sampled in April 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Enterococcus	Apr. Values			Historic Mean & Percentiles (2007-2016)				
Site	10th	19th	24th	n	Mean	50th	75th	95th
ITCARKEEKP	1	0	2	11	1.45	1	1	5
KSHZ03	ns	1	ns	11	24.91	14	28	87
KSLU03	6	6	1	12	7.75	4	6	30
KSSN04	0	1	1	11	2.55	1	2	11
KSSN05	1	0	2	13	1.62	1	2	4
KSYV02	ns	4	ns	10	63.40	2	6	338
LSGY01	ns	1	ns	12	11.83	1	4	59
LSHV01	1	1	1	10	3.90	1	3	17
LSKR01	ns	0	ns	12	4.83	2	4	19
LSKS01	2	2	0	10	42.20	2	4	225
LTBD27	ns	10	ns	10	37.50	6	9	184

Table E-7 Beaches fecal coliforms concentrations sampled in May 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Fecal Coliforms	May Values					Historic Mean & Percentiles (2007-2016)				
	1st	8th	17th	22nd	30th	n	Mean	50th	75th	95th
ITCARKEEKP	3	5	2	0	5	11	5.45	3	8	17
KSHZ03	ns	ns	5	ns	ns	11	27.45	30	40	52
KSLU03	29	6	12	3	28	11	6.91	8	10	15
KSSN04	0	0	7	0	4	11	1.18	1	2	3
KSSN05	5	1	6	0	20	11	6.27	1	6	24
KSYV02	ns	ns	46	ns	ns	11	15.27	9	18	49
LSGY01	ns	ns	1	ns	ns	12	7.42	6	9	20
LSHV01	0	42	0	1	2	10	6.40	2	7	24
LSKR01	ns	ns	3	ns	ns	11	22.27	5	34	74
LSKS01	3	0	14	0	21	10	44.70	19	26	174
LTBD27	ns	ns	14	ns	ns	10	9.40	5	13	30

Table E-8 Beaches Enterococcus concentrations sampled in May 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Enterococcus	May Values					Historic Mean & Percentiles (2007-2016)				
	1st	8th	17th	22nd	30th	n	Mean	50th	75th	95th
ITCARKEEKP	2	0	1	0	36	11	3.09	3	4	8
KSHZ03	ns	ns	3	ns	ns	11	12.27	10	21	28
KSLU03	10	5	7	1	7	11	5.18	4	6	16
KSSN04	1	0	5	0	3	11	1.09	1	2	3
KSSN05	1	0	3	0	4	11	1.27	1	1	5
KSYV02	ns	ns	12	ns	ns	11	12.18	9	16	29
LSGY01	ns	ns	0	ns	ns	12	3.00	2	4	8
LSHV01	0	3	18	15	0	10	4.20	2	5	12
LSKR01	ns	ns	1	ns	ns	11	6.00	3	8	20
LSKS01	2	5	9	0	14	10	6.60	4	11	17
LTBD27	ns	ns	16	ns	ns	10	98.00	2	9	523

Table E-9 Beaches fecal coliforms concentrations sampled in June 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Fecal Coliforms Site	Jun. Values			Historic Mean & Percentiles (2007-2016)			
	5th	21st	n	Mean	50th	75th	95th
ITCARKEEKP	0	21	11	1.82	1	3	5
KSHZ03	ns	86	11	15.45	3	25	51
KSLU03	5	8	12	6.25	6	10	15
KSSN04	4	0	11	0.91	1	2	3
KSSN05	0	1	11	10.00	3	9	40
KSYV02	ns	4	11	18.00	3	5	88
LSGY01	ns	6	11	3.09	1	5	9
LSHV01	15	0	10	9.30	4	12	34
LSKR01	ns	4	12	5.25	4	6	15
LSKS01	0	6	10	8.30	3	15	26
LTBD27	ns	9	10	3.50	1	7	11

Table E-10 Beaches Enterococcus concentrations sampled in June 2017 compared to historical values. Yellow highlighted cells indicate an exceedance of the historic 75th percentile and red indicates exceedance of the 95th percentile. All values, with the exception of n, are in colonies per 100 mL.

Enterococcus Site	Jun. Values			Historic Mean & Percentiles (2007-2016)			
	5th	21st	n	Mean	50th	75th	95th
ITCARKEEKP	0	3	11	1.00	1	2	3
KSHZ03	ns	1	11	10.09	4	11	39
KSLU03	0	1	12	10.33	4	14	35
KSSN04	1	0	11	0.45	0	1	2
KSSN05	0	0	11	3.45	1	5	12
KSYV02	ns	0	11	9.64	6	12	30
LSGY01	ns	1	11	1.45	1	2	4
LSHV01	7	0	10	7.80	1	11	27
LSKR01	ns	0	12	4.08	2	6	13
LSKS01	3	1	10	6.60	3	8	24
LTBD27	ns	3	10	3.90	2	6	12

Appendix F: 2017 Water Column Metals Data

Table F-1 Frequency of detection, median, and percentiles of dissolved and total metal concentrations in offshore waters collected in 2011/2012 used for comparison to 2017 data. All values are reported in µg/L. Half of the detection limit was used for calculating summary statistics, but values less than the detection limit are presented at the detection limit in parentheses.

	Parameter	FOD	Median	25%	50%	75%	95%
Dissolved	Arsenic	28/28	28/28	1.38	1.28	1.38	1.405
	Cadmium	28/28	28/28	0.0704	0.0660	0.0704	0.0719
	Chromium	28/28	28/28	0.11	0.098	0.11	0.115
	Copper	28/28	28/28	0.287	0.265	0.287	0.343
	Lead	3/28	3/28	<(0.005)	<(0.005)	<(0.005)	<(0.005)
	Mercury	1/28	1/28	<(0.0002)	<(0.0002)	<(0.0002)	<(0.0002)
	Nickel	28/28	28/28	0.407	0.398	0.407	0.422
	Silver	15/28	15/28	0.013	<(0.01)	0.013	0.0213
	Zinc	28/28	28/28	0.395	0.318	0.395	0.584
Total	Arsenic	28/28	1.36	1.32	1.36	1.41	1.45
	Cadmium	28/28	0.0725	0.0702	0.0725	0.0768	0.0826
	Chromium	28/28	0.11	0.10	0.11	0.14	0.16
	Copper	28/28	0.367	0.336	0.367	0.393	0.947
	Lead	27/28	0.0190	0.0138	0.0190	0.0339	0.0472
	Mercury	21/28	0.000255	<(0.0002)	0.000255	0.000333	0.000459
	Nickel	28/28	0.425	0.419	0.425	0.439	0.503
	Silver	14/28	0.0105	<(0.01)	0.0105	0.0208	0.0297
	Zinc	28/28	0.470	0.438	0.470	0.522	0.681

FOD = Frequency of detection

Table F-2 Concentration of dissolved and total metals in offshore waters in April and June 2017 compared to historical ranges. Yellow cells are above the 75th percentile of historical data (see Table F-1) and red cells are above the 95th percentile. Half of the detection limit was used for calculating summary statistics, but values less than the detection limit are presented at the detection limit in parentheses.

Metal	Site	Depth (m)	Dissolved		Total	
			April	June	April	June
Arsenic	KSBP01	5	1.33	1.01	1.39	1.11
		50	1.46	1.22	1.35	1.36
		200	1.43	1.21	1.55	1.43
	KSSK02	5	1.14	1.1	1.41	1.23
		5*	1.18	1.28	1.5	1.18
		30	1.23	1.26	1.43	1.24
		55	1.21	1.35	1.43	1.32
	LSEP01	5	1.15	1.18	1.49	1.11
		50	1.2	1.33	1.24	1.22
		130	1.21	1.34	1.53	1.3
	LSNT01	5	1.35	1.13	1.36	1.16
		50	1.4	1.21	1.49	1.27
		165	1.47	1.26	1.44	1.34
Cadmium	KSBP01	5	0.0675	0.0528	0.0653	0.0569
		50	0.0688	0.0653	0.0734	0.0666
		200	0.0712	0.0683	0.0727	0.0705
	KSSK02	5	0.0668	0.0594	0.0747	0.0679
		5*	0.0686	0.0645	0.0697	0.0668
		30	0.0661	0.0655	0.0675	0.0694
		55	0.0695	0.0673	0.0716	0.0745
	LSEP01	5	0.0685	0.0591	0.0725	0.0671
		50	0.0677	0.0683	0.0655	0.0694
		130	0.0682	0.0706	0.0716	0.071
	LSNT01	5	0.0721	0.0555	0.0757	0.0662
		50	0.0711	0.0642	0.0756	0.0693
		165	0.0724	0.0649	0.073	0.069
Chromium	KSBP01	5	0.08	0.054	0.09	0.088
		50	0.08	0.094	0.1	0.11
		200	0.084	0.084	0.16	0.17
	KSSK02	5	0.083	0.095	0.1	0.11
		5*	0.076	0.1	0.09	0.12
		30	0.076	0.12	0.098	0.12

Metal	Site	Depth (m)	Dissolved		Total	
			April	June	April	June
	LSEP01	55	0.086	0.11	0.11	0.14
		5	0.082	0.087	0.096	0.1
		50	0.068	0.1	0.095	0.1
		130	0.079	0.1	0.13	0.15
	LSNT01	5	0.1	0.091	0.091	0.11
		50	0.085	0.084	0.11	0.096
		165	0.11	0.11	0.14	0.18
Copper	KSBP01	5	0.444	0.581	0.47	0.368
		50	0.499	0.323	0.353	0.33
		200	0.37	0.271	0.419	0.326
	KSSK02	5	0.645	0.431	0.406	0.57
		5*	0.397	0.414	0.418	0.495
		30	0.356	0.339	0.344	0.406
		55	0.365	0.302	0.353	0.39
	LSEP01	5	0.5	0.402	0.391	0.451
		50	0.358	0.331	0.332	0.37
		130	1.15	0.306	0.363	0.388
	LSNT01	5	0.566	0.345	0.468	0.464
		50	0.394	0.378	0.374	0.402
		165	0.343	0.291	0.363	0.408
Lead	KSBP01	5	<(0.005)	0.015	0.012	0.011
		50	0.0051	<(0.005)	0.0058	0.015
		200	<(0.005)	<(0.005)	0.0285	0.0423
	KSSK02	5	0.007	<(0.005)	0.013	0.0359
		5*	0.011	0.017	0.022	0.0326
		30	<(0.005)	<(0.005)	0.012	0.02
		55	<(0.005)	<(0.005)	0.017	0.025
	LSEP01	5	0.0053	0.0099	0.01	0.122
		50	<(0.005)	<(0.005)	0.014	0.017
		130	0.0262	<(0.005)	0.0279	0.0397
	LSNT01	5	<(0.005)	<(0.005)	0.0076	0.019
		50	<(0.005)	<(0.005)	0.017	0.016
		165	0.0066	<(0.005)	0.025	0.0424
Mercury	KSBP01	5	<(0.0002)	<(0.0002)	0.00025	0.00046
		50	<(0.0002)	<(0.0002)	<(0.0002)	0.00025
		200	<(0.0002)	<(0.0002)	0.00032	0.00035

Metal	Site	Depth (m)	Dissolved		Total	
			April	June	April	June
	KSSK02	5	<(0.0002)	<(0.0002)	0.00029	0.00026
		5*	<(0.0002)	<(0.0002)	0.00029	0.00024
		30	0.00024	<(0.0002)	0.00027	0.00025
		55	0.00026	<(0.0002)	0.00026	0.00024
	LSEP01	5	0.00021	<(0.0002)	0.00025	0.00035
		50	0.00021	<(0.0002)	0.00025	0.00022
		130	<(0.0002)	<(0.0002)	0.00027	0.00029
	LSNT01	5	0.00026	<(0.0002)	<(0.0002)	0.00029
		50	<(0.0002)	<(0.0002)	0.00026	0.00023
		165	0.00021	<(0.0002)	0.00025	0.00033
Nickel	KSBP01	5	0.398	0.446	0.844	0.411
		50	0.411	0.435	0.439	0.374
		200	0.407	0.414	0.48	0.379
	KSSK02	5	0.464	0.439	0.555	0.403
		5*	0.446	0.437	0.399	0.384
		30	0.449	0.437	0.687	0.394
		55	0.447	0.425	0.602	0.405
	LSEP01	5	0.443	0.431	0.601	0.412
		50	0.458	0.431	0.397	0.397
		130	0.451	0.434	0.401	0.374
	LSNT01	5	0.401	0.491	0.439	0.417
		50	0.401	0.462	0.442	0.401
		165	0.387	0.476	0.444	0.403
Silver	KSBP01	5	0.056	0.0557	0.031	0.0541
		50	0.0638	0.0612	0.042	0.0591
		200	0.0515	0.0611	0.045	0.0538
	KSSK02	5	0.0665	0.047	0.0524	0.0569
		5*	0.0619	0.043	0.037	0.0611
		30	0.0726	0.045	0.045	0.058
		55	0.0609	0.043	0.0526	0.0672
	LSEP01	5	0.0641	0.042	0.048	0.0572
		50	0.0713	0.046	0.039	0.06
		130	0.0668	0.047	0.042	0.0597
	LSNT01	5	0.0504	0.049	0.039	0.0623
		50	0.0538	0.047	0.036	0.0615
		165	0.056	0.048	0.047	0.0628

Metal	Site	Depth (m)	Dissolved		Total	
			April	June	April	June
Zinc	KSBP01	5	0.585	0.584	0.648	0.37
		50	0.587	0.37	0.661	0.36
		200	0.718	0.26	0.653	0.41
	KSSK02	5	0.728	0.45	0.666	0.718
		5*	0.49	0.48	0.557	0.73
		30	0.517	0.44	0.608	0.44
		55	0.574	0.45	0.61	0.506
	LSEP01	5	0.606	0.33	0.609	0.865
		50	0.543	0.42	0.501	0.44
		130	1.04	0.44	0.519	0.552
	LSNT01	5	0.652	0.34	0.668	0.501
		50	0.588	0.38	0.66	0.45
		165	0.528	0.42	0.586	0.545

* Replicate