Water Quality Status Report For Marine Waters, 2005--2007

King County

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WATER QUALITY STATUS REPORT FOR MARINE WATERS, 2005—2007

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Executive Summary

This report provides a summary of water quality data collected between 2005 and 2007 as part of King County's ambient and outfall marine monitoring program. The monitoring program contains elements of baseline sampling to assess background conditions (ambient monitoring) and also sampling to assess conditions around the County's marine outfalls (point source monitoring). Data are assessed at three secondary wastewater treatment plant (TP) marine outfalls (West Point TP, South TP, and Vashon TP), three combined sewer overflow (CSO) treatment facilities (Alki TP, Carkeek TP, and Elliott West TP), and selected CSO outfalls as part of the point source monitoring program. The County's marine monitoring program is part of an inter-governmental Puget Sound monitoring effort, the Puget Sound Assessment and Monitoring Program (PSAMP).

In 2005, 12 outfall stations (6 offshore and 6 beach) and 20 ambient stations (5 offshore and 15 beach/creek) were sampled. In 2006, 32 outfall stations (26 offshore and 6 beach) and 18 ambient stations (7 offshore and 11 beach/creek) were sampled. In 2007, 12 outfall stations (6 offshore and 6 beach) and 40 ambient stations (18 offshore and 22 beach/creek) were sampled.

Offshore water samples were collected monthly and analyzed for fecal indicator bacteria, nutrients, temperature, salinity, dissolved oxygen, turbidity/light transmission, water clarity, suspended solids, photosynthetically active radiation (PAR), and chlorophyll. Beach waters were collected monthly and analyzed for fecal indicator bacteria, nutrients, temperature, and salinity.

Beach sediments were collected only in 2005 as this program is now conducted on a five-year monitoring cycle. Sediment conventionals, organic compounds, and metals were analyzed in the beach sediments. Nineteen sediment samples were collected at the West Point TP outfall in 2006 and analyzed for sediment conventionals, organic compounds, and metals. In addition, benthic community structure and abundance was assessed at 11 of the 19 West Point TP outfall sites. Fourteen subtidal sediment samples were collected in 2007 at ambient sites, of which eight were located in Elliott Bay, and analyzed for sediment conventionals, organic compounds, and metals.

Butter clam tissues were collected at seven sites in 2005 and at eight sites in 2006 and 2007. In 2005, butter clams were collected in August and starting in 2006, clams were also collected in March to assess seasonal differences. Macroalgae samples, consisting of the green alga *Ulva sp*. were collected in 2005 and analyzed for metals. Macroalgae sampling was subsequently discontinued due to limited data usage.

Climate Data

In terms of precipitation, 2005 and 2007 were typical years when compared to the 30-year(yr) average. However, a total of 48.42 inches of rain fell in 2006 which is more than 15 inches above the 30-yr average and the second highest on record since 1969. Average monthly air temperatures in 2005 and mid-2007 were typical when compared to the 30-yr average. Warmer

than normal air temperatures were seen from May to September in 2006. In September 2006, a mild El Niño event developed in the Pacific Ocean, which dissipated in early 2007. Warmer air temperatures preceding this El Niño event were apparent in June and July of 2006.

Monitoring Results

Water

In general, water quality monitoring results were consistent with past findings and indicated the following:

- Fecal coliform bacteria in offshore waters were consistently low and all samples collected between 2005 and 2007 met the State standards, with the majority of samples having either no detectable levels or 1 colony forming unit (CFU)/100 ml.
- Fecal coliform counts in Elliott Bay and Quartermaster Harbor were higher more frequently than other offshore stations, with 58% of the Elliott Bay and 33% of the Quartermaster Harbor samples having values of 2 CFU/100 ml or higher compared to 11% for other offshore sites.
- There was no difference between fecal coliform levels at outfall stations as compared to ambient stations.
- Fecal coliform levels at beach stations varied between stations and year and no spatial or seasonal pattern was detected.
- The beach stations that most frequently exceeded the State standards were at Redondo, Des Moines Creek Park, and Dumas Bay.
- In all three years, a seasonal thermocline developed at offshore stations between April and June. The thermoclines were much more pronounced in 2006 due to El Niño conditions in mid-2006.
- During the winter months at beach stations, the coldest water temperatures were seen at sites with the most freshwater input, Shilshole Bay, Piper's Creek, and the Seattle waterfront. However, in January 2007 ice was observed floating in Quartermaster Harbor near Burton Acres where a temperature of 4.1^{o}C was observed.
- The cycle of coastal upwelling along the outer Pacific coast is seen as a deep, salty signal in late summer and fall of each year in the Central Basin.
- Maximums in dissolved oxygen correspond with maximums in chlorophyll-*a* concentration, temporally and spatially, in the upper 25 meters of the water column.
- Seasonal variations throughout the water column indicate the entrance of low-oxygenated Pacific Ocean water and consumption of oxygen by bacterial respiration in the deep basin over late summer and fall.
- For all three years at all stations, most dissolved oxygen concentrations were above 5.0 mg/L. In 2005, all values were above 5.0 mg/L, including the Elliott Bay stations which typically had values less than 5.0 mg/L in the late summer and early fall months in previous years.
- Low dissolved oxygen values were seen in 2006 and 2007 at the Quartermaster Harbor stations, including a value of 3.6 mg/L in September 2007. This low oxygen level is of concern as biological stress may be induced.

- All ammonia concentrations were well below the Washington State chronic criterion. The highest concentrations in offshore waters in 2005 and 2006 were detected at the West Point and South Plant outfalls, respectively, at the trapping depth of each effluent plume. In 2007, the highest value was detected in Quartermaster Harbor following a large phytoplankton bloom.
- Ammonia values at beach stations were usually higher during the summer months, particularly during times when large amounts of decaying seaweed along the shoreline occur. This was particularly evident in July 2006 due to warm air temperatures causing optimal seaweed growth.
- Seasonal variations in nitrate+nitrite concentrations in the photic zone correspond to phytoplankton production in the water column.
- Nitrate+nitrite concentrations in beach waters were slightly higher than those at offshore stations and showed seasonal fluctuations corresponding to marine vegetation growth cycles.
- In 2005 and 2006, silica was below detectable levels at several stations which is an unusual occurrence. In both years, the undetectable levels occurred during the second large phytoplankton bloom of the year indicating that silica likely became the limiting growth factor rather than nitrogen.
- The spring phytoplankton bloom occurred in April during all three years. Phytoplankton blooms in the southern portion of the Central Basin occurred both earlier and later in the year than in other areas.

Sediment

The beach (intertidal) sediment program, as an annual event, was sampled for the final time in 2005. Subsequent to 2005, the beach sediment program will be sampled once every five years. Results from the 2005 beach sediment sampling event indicate that:

- Sediments collected from all eight stations (four outfall and four ambient) were comprised mainly of sand and gravel.
- Four of the 14 metals analyzed – arsenic, cadmium, selenium, and silver – were not detected in any of the samples. All other metals were detected at concentrations indicative of natural background concentrations. All concentrations of those metals regulated under the Washington State Sediment Management Standards (SMS) were well below their respective chemical criteria.
- Out of the 99 organic chemicals analyzed, only 19 were detected. Pesticides and PCBs were not detected in any of the samples. All detected concentrations of organic chemicals were well below their respective SMS chemical criteria and/or sediment quality values (Lowest Apparent Effects Thresholds or LAET).

Sediment samples were collected from 19 stations at the West Point TP in 2006 to meet requirements of the County's NPDES permit. Results from chemical and biological analysis of these sediments indicate that:

- There were no exceedences of SMS or LAET sediment quality criteria/values for those compounds regulated under SMS.

- Polybrominated flame retardants (PBDEs) were detected in all nine samples analyzed. PBDE concentrations detected at West Point were similar in range to concentrations detected at ambient monitoring stations in Puget Sound.
- The benthic infaunal community near the West Point outfall is robust, with a diverse and abundant population.

Fourteen stations in Elliott Bay, the Central Basin, and selected embayments were sampled in 2007 as part of the ambient subtidal sediment monitoring program. Results from the 2007 ambient subtidal sediment sampling event indicate that:

- Mercury concentrations at two stations, located in Quartermaster Harbor and offshore of Harbor Island in Elliott Bay, exceeded the SMS chemical criterion. Concentrations of mercury at the other 12 stations, as well as concentrations of the other 7 regulated metals, were all below their respective chemical criteria.
- Concentrations of arsenic, cadmium, and lead were elevated in Quartermaster Harbor compared to other stations, but did not exceed SMS criteria. Stack emissions from the former Asarco Smelter in Tacoma may have lead to the elevated concentrations of arsenic, cadmium, lead, and mercury in Quartermaster Harbor.
- The concentration of benzyl butyl phthalate detected at the Harbor Island station exceeded the SQS. The concentration of bis(2-ethylhexyl) phthalate detected at the station located in East Passage exceeded the cleanup screening level (CSL) chemical criterion. Concentrations of all other organic compounds were below their respective chemical criteria.
- PCBs were detected at 13 of 14 stations and, at stations removed from direct anthropogenic inputs, correlated well with the percent of fine material in the sediment. The highest PCB concentrations were detected in Elliott Bay.
- One or more PAH compounds were detected at all 14 stations and, again, correlated well with the percent of fine material in the sediment at those stations removed from direct anthropogenic inputs. The highest total PAH concentrations were detected along the Seattle waterfront and at the station located in outer Salmon Bay, just outside of the Hiram Chittenden locks.
- Tributyltin was detected at 3 of 14 stations, all located in areas with heavy commercial vessel traffic and/or vessel maintenance drydocks; outer Salmon Bay, the Seattle waterfront, and Harbor Island.
- Polybrominated flame retardants (PBDEs) were detected in all 14 samples, with the highest concentration detected at the station in outer Salmon Bay.

Shellfish

Shellfish (butter clam) tissues were collected in August of all three years. Beginning in 2006, samples were also collected in March to assess seasonal differences. A minimum of five clams were collected at each site and composited into one sample. Results indicate the following:

- Metal concentrations in butter clams showed little variation for most metals, both spatially and temporally.

- Metal concentrations found in butter clams between 2005 and 2007 were low when compared to regulatory limits and in previous years.
- For most metal concentrations, there does not appear to be a seasonal difference between samples collected in March and August. Arsenic tended to be higher in samples in August.
- Organic compound were analyzed in 2005 and only 5 of the 97 compounds analyzed were detected. As so few organic compounds are detected in clam tissues, these analyses were discontinued after 2005.
- A PCB Aroclor, Aroclor 1254® was detected in one sample from the north side of Discovery Park (West Point) at a low concentration. PCBs had not been previously been detected in any shellfish tissues or sediment from this station.
- Beta-BHC, a chlorinated pesticide, was detected in four of seven samples. This compound was one of the three organics compounds previously detected in shellfish tissues. Although beta-BHC was a constituent in pesticide mixtures, it is now banned in the United States. However, beta-BHC is also a breakdown product of gamma-BHC (Lindane) which is still in use as an insecticide.

Macroalgae

Macroalgae samples consisting entirely of the green alga, *Ulva spp*. (also known as sea lettuce), were collected in August 2005 and analyzed for 14 metals. Results were consistent with past findings and indicated the following:

- Arsenic, cadmium, chromium, copper, lead, nickel, and zinc were detected in all samples but showed no spatial or temporal pattern.
- Selenium, beryllium, and silver were not detected in any samples, nor in past years.
- Mercury was detected in all three ambient samples but not in any of the outfall samples.
- Due to limited use of the data, the macroalgae sampling program was discontinued in 2006.

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SECTION 1
Introduction

1.1 Overview

The King County Department of Natural Resources and Parks and its predecessor agency Municipality of Metropolitan Seattle (Metro) have a long history of water quality improvements and monitoring water quality in Puget Sound. As part of an ongoing effort to maintain and improve Puget Sound's water quality, the King County Wastewater Treatment Division oversees regional sewerage collection, treatment processes, and disposal systems that discharge wastewater to the Central Puget Sound Basin and waters flowing into the Sound. King County's Marine and Sediment Assessment Group supports a comprehensive long-term marine monitoring program that assesses water quality in the Central Puget Sound Basin on behalf of and in coordination with the Wastewater Treatment Division.

King County's marine monitoring program is part of an intergovernmental monitoring effort, the Puget Sound Assessment and Monitoring Program (PSAMP), with the County's program focusing primarily on water quality within King County's borders. Other agencies involved in PSAMP that monitor water quality and/or the environmental health of Puget Sound include the Washington State Department of Ecology (water and sediment quality), Washington Department of Fish & Wildlife (contaminants in fish tissues, herring and rockfish populations), Washington Department of Natural Resources (nearshore vegetation and habitat), Washington Department of Health (shellfish growing areas and contaminants), National Oceanic and Atmospheric Administration (contaminants in fish), and U.S. Department of Fish & Wildlife (contaminants in birds and fish). These agencies have monitoring stations throughout the Sound, including sites within King County. The main distinction between these programs and King County's monitoring program is that the County has a larger number of stations within a concentrated area which are targeted near wastewater treatment plant discharges. Although other agencies have monitoring stations within King County, the stations do not overlap with the County's stations which allows a broader area of Puget Sound marine waters to be monitored.

The objectives of the marine monitoring program are to provide an understanding of water quality within King County and to assess water quality near the County's wastewater plant outfalls to identify if discharges are affecting water quality. The County maintains a long-term dataset, consisting of over 40 years of data collected at some stations. These data provide insight into natural variations and a basis from which recent water quality conditions near outfalls and throughout the entire Puget Sound Central Basin can be assessed.

This report summarizes results of King County's outfall and ambient marine monitoring programs between 2005 and 2007. The report provides an overview of the sites monitored, matrices (e.g., water and sediment) sampled, parameters measured, and a summary of analytical results.

1.2 Wastewater Collection and Treatment

Wastewater from homes, businesses, and industries within King County and southern Snohomish County is transported through pipelines belonging to local sewer agencies to King County's system of larger pipelines (interceptors), which conveys the wastewater to the County's treatment plants. At the plants, solids are separated from liquids, which are then treated, disinfected, and discharged into Puget Sound marine waters. The separated solids are digested and the resulting rich organic material, known as biosolids, is used to enrich agricultural and forest soils and is also turned into compost.

The County's Wastewater Treatment Division provides wastewater treatment and disposal services to 17 cities, 16 local sewer and/or water districts, and the Muckelshoot Indian Tribe. The system serves about 1.4 million people in King County, southern Snohomish County, and northern Pierce County, transporting and treating over 200 million gallons of wastewater each day. To accomplish this, King County currently operates and maintains four wastewater treatment plants, four combined sewer overflow (CSO) treatment plants (Figure 1-1), 42 pump stations, and approximately 335 miles of sewer lines. The West Point Treatment Plant (TP), South TP (formerly known as the Renton and East Division Reclamation TP), Vashon Island TP, and a new, small TP in the City of Carnation provide secondary wastewater treatment. The Carnation TP provides advanced secondary treatment that discharges to the Snoqualmie River or a beneficial use wetland (the Chinook Bend Natural Area). As the Carnation TP does not discharge to marine waters, it will not be discussed further in this report.

The average wet-weather flows (based upon average wet season flows from November through April, excluding large storms) for the West Point and South TPs are 133 and 115 million gallons per day (MGD), respectively. The maximum capacity (maximum flows that can be handled by the plants for short periods with a portion of the flows receiving minimal treatment) of the West Point, South, and Vashon TPs are 440, 325, and 1.0 MGD, respectively. The Alki, Carkeek, Denny/Elliott West, and Henderson/Martin Luther King (MLK) CSO Treatment Plants store combined wastewater and stormwater flow and later pump it to the West Point TP or provide the equivalent of primary treatment and disinfection before discharging to Puget Sound or the Duwamish River (Henderson/MLK). The South TP outfall discharges at a water depth of 640 feet (ft), the West Point TP at 230 ft, the Vashon TP at 200 ft, the Alki CSO TP at 143 ft, the Carkeek CSO TP at 200 ft, the Elliott West CSO TP at 63 ft, and the Henderson/MLK CSO TP at the surface.

The West Point TP discharges the largest volume of effluent of the four secondary facilities. Between 2005-2007, the average daily discharge rate for the West Point TP was 96.7, 117.6, and 98.0 MGD, respectively. The average daily discharge rate for the South TP from 2005-2007 was 73.5, 80.0, and 79.6 MGD, respectively. The Vashon TP has the least discharge volume with average daily discharge rates of 0.1, 0.14, and 0.11 MGD from 2005-2007, respectively. Average daily wastewater discharge volumes from the two largest TPs are shown for the last five years in Figure 1-2, along with monthly total rainfall measured at SeaTac Airport. The higher discharge volumes in 2006 correspond to the high amount of rainfall, particularly for both January and November 2006. The rainfall total for January 2006 was over twice the 30-year

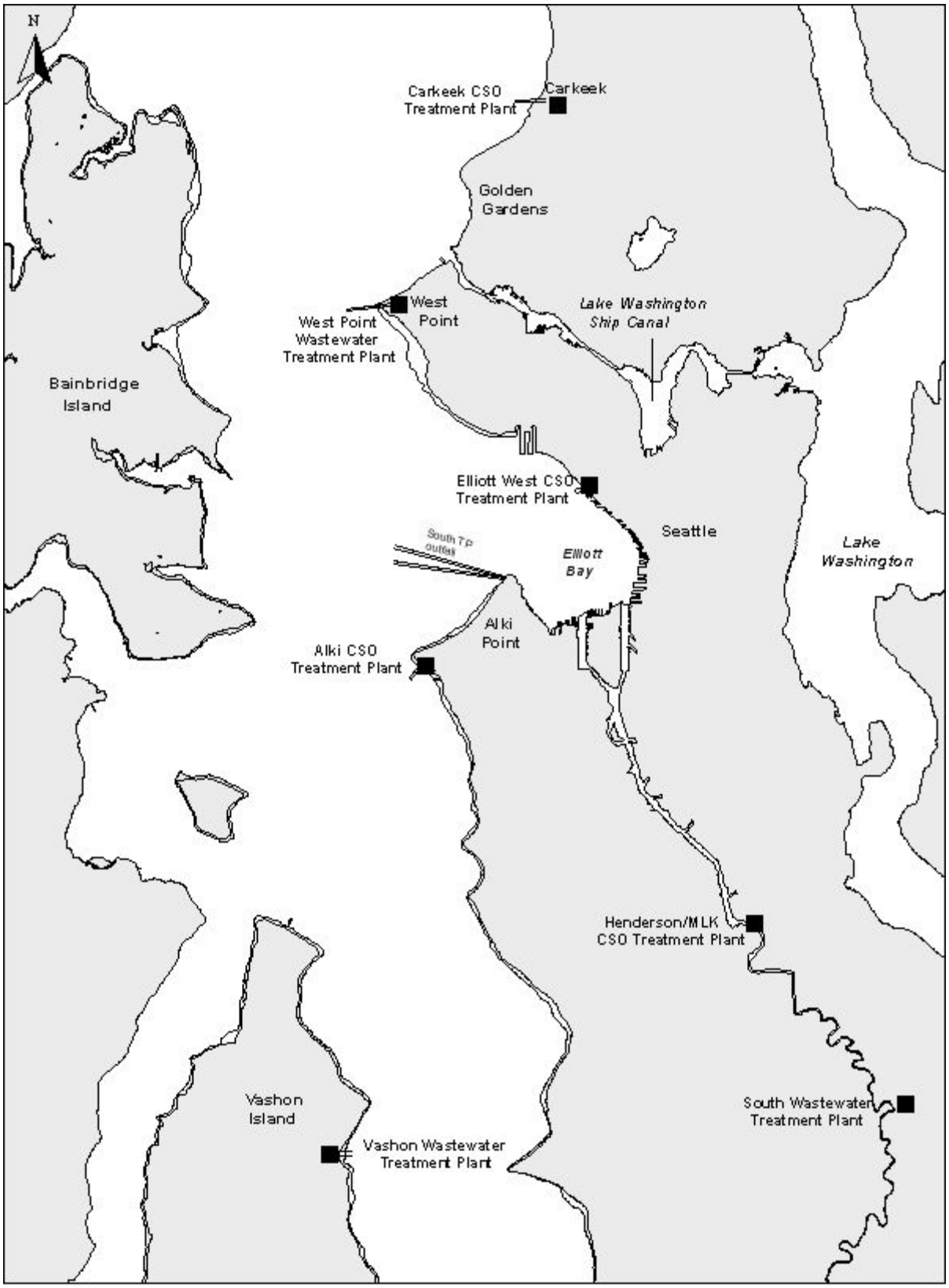

Figure 1-1. King County Wastewater & CSO Treatment Plant & Outfall Locations
(excludes Carnation TP)

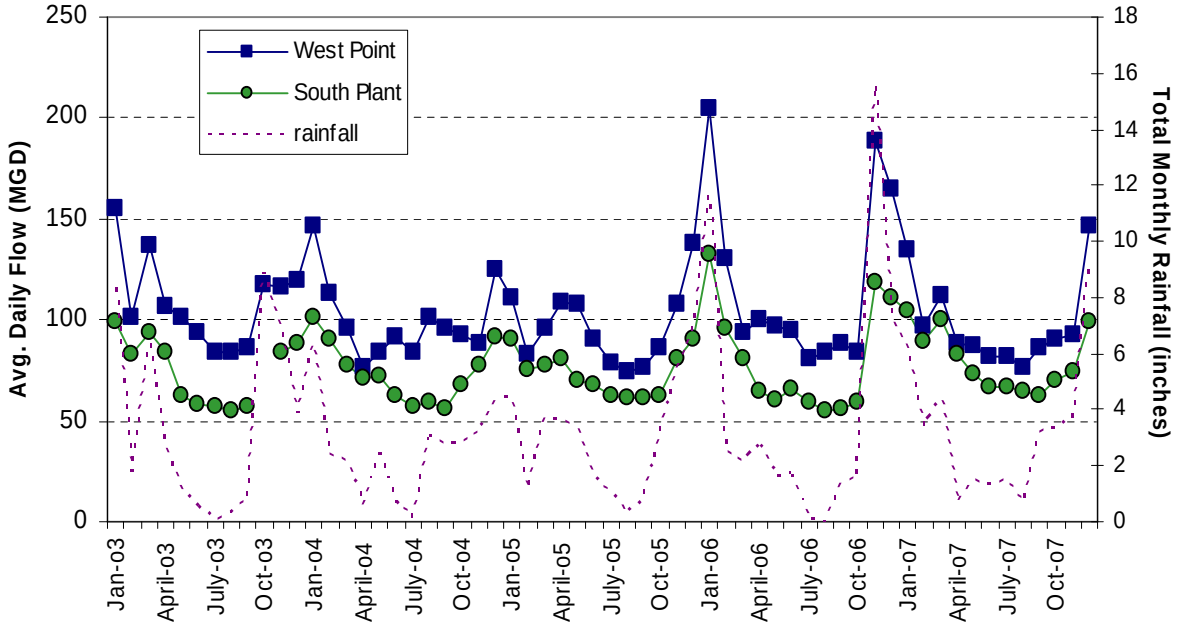

Figure 1-2. Average Daily Flow from South Plant and West Point TPs and Total Monthly Rainfall (at SeaTac) Between 2003 and 2007

average for that month and the total in November 2006 was almost 2.5 times the 30-year average. The rainfall total in 2005 was slightly under the 30-year annual average while 2007 was slightly over. The average discharge volumes shown in Figure 1-2 reflect annual rainfall patterns as effluent discharges peak during times of high rainfall, with January and February typically having the highest average discharge rates (see Section 3.1 for detailed rainfall patterns). Average daily wastewater discharge volumes from the Vashon TP are shown for the last five years in Figure 1-3 along with total rainfall amounts measured at the treatment plant. Vashon Island receives more rainfall than in other parts of King County. Therefore, when comparing discharge volumes with rainfall, using rainfall measured on Vashon Island is more applicable than SeaTac totals.

A summary of the discharge events and volumes for the Alki, Carkeek, and Elliott West CSO treatment facilities may be found on the Wastewater Treatment Division's CSO website at http://www.kingcounty.gov/environment/wastewater/CSO/Library/AnnualReports.aspx.

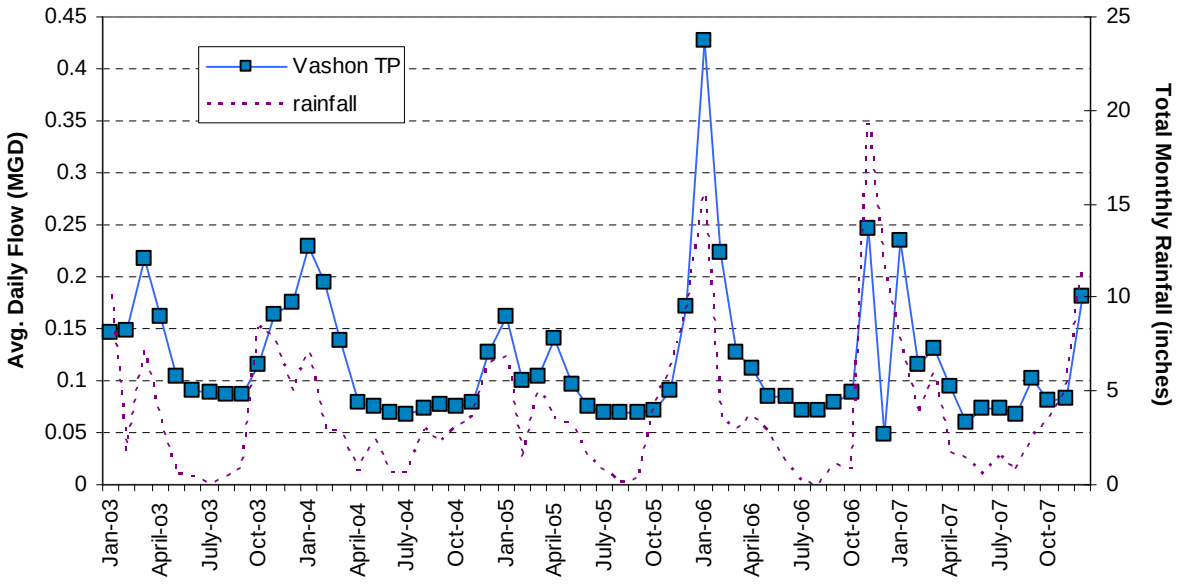

Figure 1-3. Vashon TP Average Daily Flows and Total Monthly Rainfall (measured on northern Vashon Island) Between 2003 and 2007

1.2.1 Permit and Sampling Requirements

The Federal Clean Water Act states that all sewage treatment plants that discharge effluent from a point source into surface waters must have a National Pollutant Discharge Elimination System (NPDES) permit. The permit delineates conditions and quantities that a municipality can discharge to a receiving waterbody. In Washington, the Washington State Department of Ecology (Ecology) administers the NPDES permit program by delegation from the U.S. Environmental Protection Agency (EPA).

King County has four NPDES permits to discharge treated wastewater. The West Point permit (permit # WA-002918-1) includes the West Point TP, Alki and Carkeek CSO TPs, the County's CSOs, and the Elliott West and Henderson/Martin Luther King (MLK) CSO Storage and Treatment Facilities. The Elliott West and Henderson/MLK CSO Facilities were added as an addendum to the West Point permit in 2005. King County also has separate permits for the South TP (permit # WA-002958-1), the Vashon TP (permit # WA-002252-7), and the Carnation TP (permit #WA-003218-2). All treatment plant NPDES permits can be downloaded at the following website http://www.kingcounty.gov/environment/wtd/About/System/NPDES.aspx.

In addition to wastewater treatment NPDES permits, the County also has permits for the production and distribution of reclaimed water, operation of the Beulah Park/Cove Community wastewater system on Vashon Island, and a municipal stormwater permit. More information on

these permits can be accessed at the Wastewater Treatment Division's website at http://www.kingcounty.gov/environment/wtd.aspx.

1.2.2 King County Treatment Plant Descriptions

West Point Wastewater Treatment Plant

The West Point TP service area includes the City of Seattle and areas north and west of Lake Washington. Most of the neighborhoods in the north Lake Washington area were constructed with separate sanitary and storm sewers but within the city of Seattle, approximately 75% was constructed with combined sewers that carry both sanitary sewage and stormwater. Sanitary and combined flows from Seattle are merged prior to arriving at the West Point TP. In addition to domestic sewage, almost all of Seattle's industrial areas discharge to the West Point TP.

The plant is designed to provide secondary treatment of wastewater flows up to 300 MGD. The maximum monthly average design criteria flow is 215 MGD. The secondary treatment process includes screening through bar screens to remove rags and plastics, which are then flushed down a trough to grinder pumps. The ground screenings (grit) are cleaned and dewatered. From 2005 to 2007, the grit was recycled in a composting facility. Liquid wastewater treatment includes primary sedimentation, biological treatment using activated sludge and oxygen, secondary clarification, chlorine disinfection, and dechlorination. The primary treatment process for flows above 300 MGD and up to 440 MGD (the maximum instantaneous capacity) consists of screening, degritting, primary sedimentation, chlorine disinfection, and dechlorination. Treated wastewater (effluent) is discharged to Puget Sound through an eight-foot diameter concrete outfall with a 600-ft long diffuser, located approximately 3,400 ft offshore at a depth of 240 ft MLLW. A detailed description of the West Point TP can be accessed at the following website http://www.kingcounty.gov/environment/wtd/About/System/West.aspx.

South Wastewater Treatment Plant

The South TP service area includes the areas and cities east of Lake Washington and Lake Sammamish and the Muckleshoot Tribe and the cities of Renton, Tukwila, Kent, Black Diamond, and Auburn. The service area includes 32 jurisdictions and utility districts. All flows to the South TP are from separated sanitary systems with the exception of a small portion (approximately 4%) of the Seattle system that is a combined system. The plant's design criteria for maximum monthly average flow is 144 MGD but the plant can handle flows of up to 325 MGD.

The secondary treatment process consists of screening, degritting, primary sedimentation, grease removal, biological treatment using activated sludge and oxygen, secondary clarification, and sodium hypochlorite disinfection. Pumps transport the treated wastewater from the plant to the Puget Sound outfall located almost two miles off a point of land north of Alki. The outfall

includes a 500-ft long diffuser and terminates about 10,000 ft offshore at a depth of approximately 600 ft MLLW. The facility produces Class A water for reuse from a small portion of the plant's flow. The chlorinated effluent is treated using coagulation and filtration. The water then flows through sand filters and is disinfected with hypochlorite. The treated solids are used to create a biosolids product that is used in eastern Washington for agriculture applications and in western Washington for forest applications and commercial composting. A description of the South Plant treatment process is available at the following website http://www.kingcounty.gov/environment/wtd/About/System/South.aspx

Vashon Wastewater Treatment Plant

The Vashon TP serves the Vashon Sewer District and treats wastewater from about 425 residential and commercial customers in and around the Island's main business area, located near the northeastern portion of Vashon Island. Major upgrades to the plant began in 2004 and were completed in 2006. The plant has an instantaneous maximum capacity to treat 1.0 MGD and a design criteria maximum monthly average of 0.5 MGD.

The secondary treatment process first consists of screening out large debris through a bar screen. Secondary treatment is accomplished in an oxidation ditch with clarification occurring in a secondary clarifier. Solids are removed from the secondary clarifier and dewatered in a belt filter press before being transported to the South Plant. Effluent is disinfected using ultraviolet radiation prior to discharge through the Puget Sound outfall. The outfall discharges at a depth of approximately 200 ft MLLW and 2,800 ft offshore. The outfall is an eight-inch pipe with no diffuser. A detailed description of the Vashon Treatment Plant can be accessed at the following website http://www.kingcounty.gov/environment/wtd/About/System/Vashon.aspx.

Alki CSO Treatment Plant

The Alki CSO TP is located in West Seattle near Alki Point and was constructed in 1958 as a primary treatment plant to serve an area of 4,095 acres. The service area is primarily residential with some commercial activity mainly along portions of California Avenue and SW Alaska Street. There are no significant industrial users discharging to the Alki plant. The plant was overhauled in 1987 to enclose the facilities and retrofit the mechanical and electrical systems. In 1998, the plant was remodeled to operate as a near-fully automated CSO treatment plant and was phased out of operation as a sewage treatment plant.

The Alki TP operates intermittently, only when flows in the Alki service area exceed 18.9 MGD and the West Seattle storage tunnel is full. For flows less than 18.9 MGD, the flow is transferred directly to the West Point TP for secondary treatment without entering the Alki plant. Wet weather flows in excess of 18.9 MGD and the 7.1 million gallon storage capacity of the West Seattle tunnel are diverted to the Alki CSO TP for treatment. Treatment consists of screening, and primary sedimentation followed by chlorine disinfection and dechlorination. Treated flows are discharged to Puget Sound via a 42-inch outfall that is about 1,136 ft offshore at a water depth of 143 ft MLLW. Flows in excess of 65 MGD can be discharged via the 63rd Avenue pump station outfall, which is a permitted CSO located south of the Alki TP.

Carkeek CSO Treatment Plant

The Carkeek CSO TP was constructed in 1962 as a primary treatment plant to serve the Carkeek Basin. It is located in north Seattle within Carkeek Park. In 1994, the plant was converted to a pumping station/CSO treatment facility. During dry weather and normal flows, the facility operates as a pump station only; pumping wastewater to the West Point Treatment Plant. The Carkeek TP operates intermittently, only when the combined sanitary/storm water flow during a storm exceeds the pump capacity of the Carkeek Pump Station (9.2 MGD). The excess flow is stored and treated in the plant and then returned to the pump station at the end of the storm. From the pump station, the flow is pumped to the West Point TP. If flows exceed the storage capacity of the treatment plant, the treated flows are then discharged to Puget Sound via a 4,200-ft long outfall at a water depth of approximately 200 ft MLLW. After the storm, any stored flow remaining in the plant is pumped to the West Point TP.

The treatment process at the Carkeek TP consists of screening, degritting, primary sedimentation, disinfection with sodium hypochlorite, and dechlorination. Dechlorination was added to the plant in 2005. In the grit tank, the flow is aerated and grit is pumped to the storage tanks. From the grit tanks, the flow moves into two primary sedimentation tanks. Any settled solids in these tanks are pumped to the storage tanks. When both sedimentation tanks are full, the flow moves to the chlorine tank for disinfection and is dechlorinated before being discharged out the outfall.

Elliott West CSO Facility

The Elliott West CSO Storage and Treatment Facility became operational in May 2005 and was a joint effort between King County and the City of Seattle Public Utilities to control CSO overflows into Lake Union and Elliott Bay. This new facility is the largest CSO control facility in the County's wastewater conveyance system.

The facility has two modes of operation. During rainstorms, the facility will direct combined stormwater and sanitary sewer flows into the Mercer Street wastewater storage tunnel. This scenario is expected to occur about 50 times a year. Following each storm, the CSO control facility will pump the stored flows from the tunnel to the Elliott Bay interceptor, which will then direct the flows to the West Point TP. During larger rainstorms, expected about 10 to 20 times a year, the Mercer Street tunnel will be filled to capacity. When this happens, the facility will begin to treat the stored flows and then pump them to a newly constructed marine outfall in Elliott Bay. The Elliott West outfall is 490-ft in length and discharges at a depth of about -63 ft MLLW. Treatment includes screening out floatable materials, disinfection, and dechlorination.

During very large storms, expected to occur once per year on average, flows may exceed the facility's storage and pumping capacity of 250 MGD. When this occurs, untreated flows will be discharged through the new shorter marine outfall at Myrtle Edwards Park. The outfall is 100-ft in length and discharges at a depth of approximately -20 ft MLLW.

Henderson/Martin Luther King CSO Facility

The Henderson/Martin Luther King (MLK) CSO Storage and Treatment Facility became operational in July 2005. The project was initiated to decrease CSO overflows into Lake Washington and the Duwamish River. Prior to facility construction, CSO overflows from the Rainier Beach area flowed into Lake Washington. The new facilities consists of a 3.2 MG storage tunnel with treatment capabilities and conveyance lines that will store flows during rainstorms and then route the flow to either the South or West Point TPs for treatment. The Henderson Pump Station was also upgraded to add capacity to the system and further reduce the potential for overflow events.

The tunnel was designed to provide wastewater storage during rainfall events. When the storm event subsides, the stored flows will be conveyed primarily to the South TP but can also be conveyed to the West Point TP for secondary treatment. In the event the storage tunnel is filled to capacity during extreme storms and water continues to flow into the tunnel, the flow will be treated and then pumped and discharged through the Norfolk outfall into the Duwamish River. The flows will be disinfected prior to discharge through the Norfolk outfall. The Norfolk outfall is located on the north bank of the Duwamish River at approximately river mile 6.5.

1.3 Other Puget Sound Discharges

There are several types of anthropogenic inputs that enter Puget Sound marine waters. A brief description of the major inputs is provided below. Figure 1-4 shows wastewater treatment plant discharge locations within Puget Sound. CSO and stormwater discharge locations within western King County are shown in Figure 1-5.

1.3.1 Other Wastewater Treatment Plant Discharges

There are municipal wastewater treatment plant discharges into Puget Sound originating from city, county, tribal, federal, and privately operated wastewater treatment facilities. Besides King County's facilities, there are 50 other permitted wastewater facilities with marine discharges to Puget Sound, excluding facilities on the outer coast and north of Admiralty Inlet. Figure 1-4 shows the locations of wastewater treatment plant that have discharges to Puget Sound marine waters. Discharge volumes and discharge distance offshore vary dependent upon the capacity of the facility. Most treatment plant outfalls are located close to shore, with the exception of the Kimberly-Clark marine outfall in Port Gardner, which is located 2,700 ft offshore.

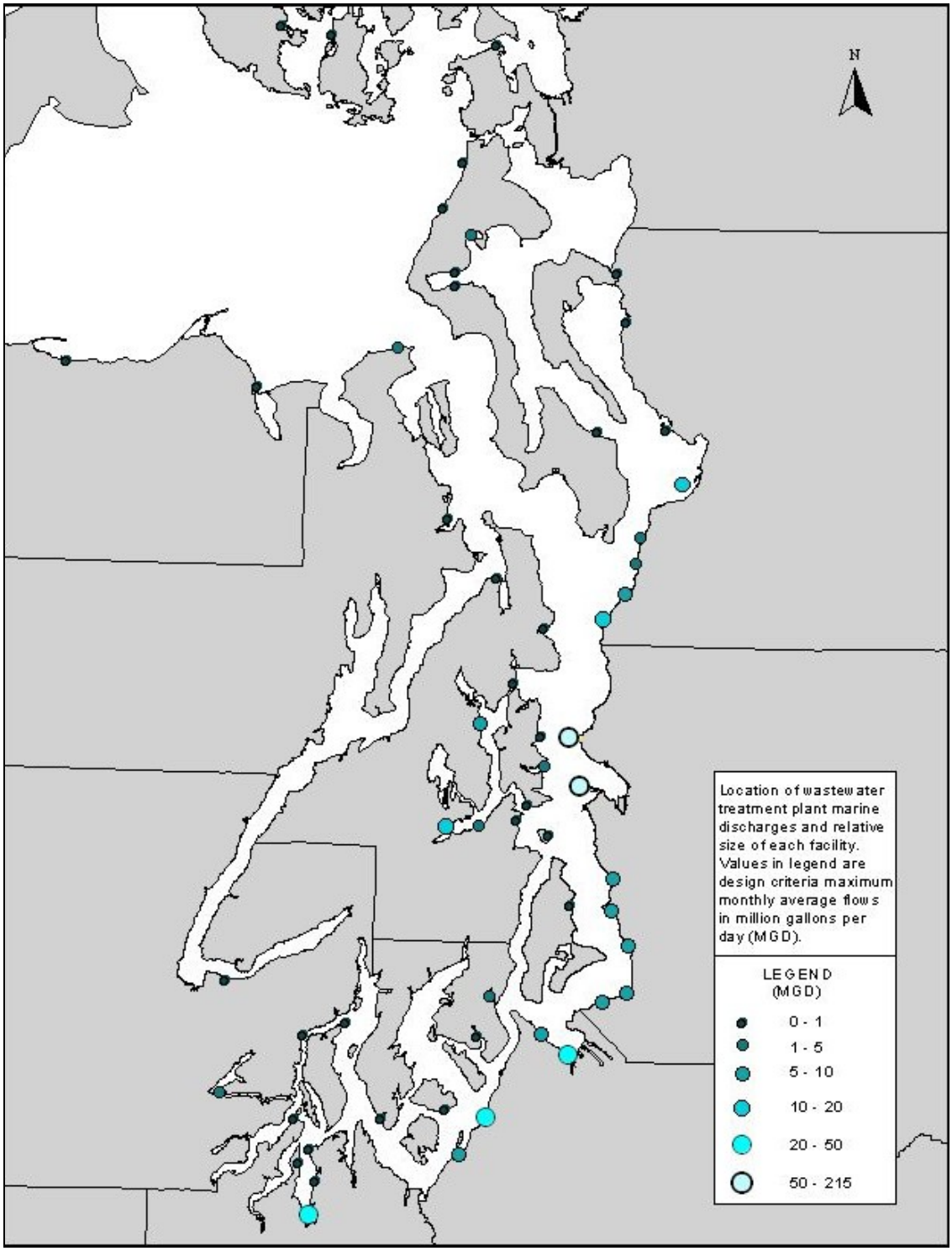

Figure 1-4. Puget Sound Wastewater Treatment Plant Marine Discharge Locations

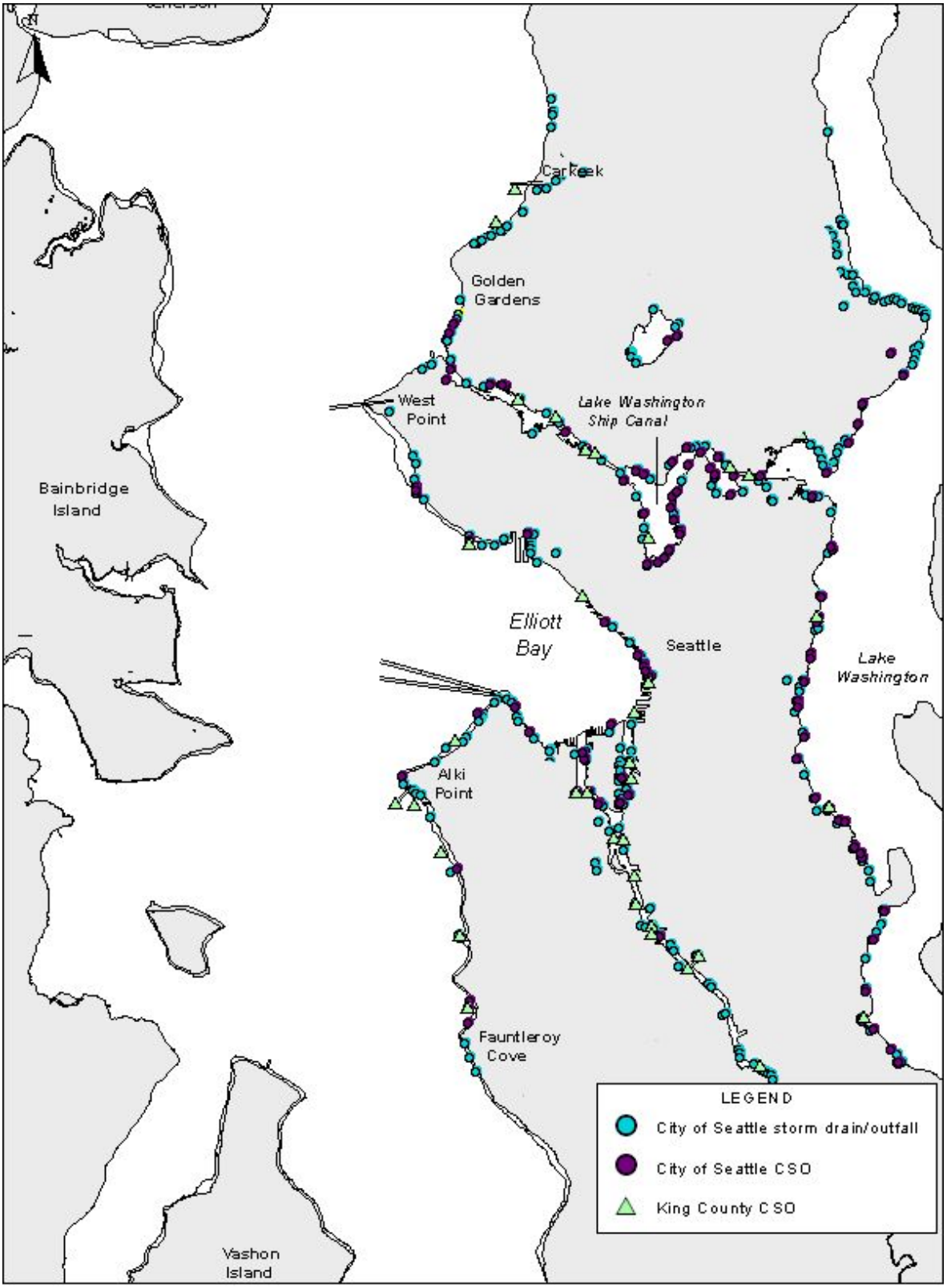

Figure 1-5. Location of CSO and Stormwater Discharges in Western King County

1.3.2 Combined Sewer Overflow Discharges

CSO discharges consist of untreated sewage and stormwater that occur when sewers have reached their capacity during heavy rainfall events. Between the late 1800s and 1940s in the City of Seattle, engineers designed combined sewer systems to convey both sanitary sewage and stormwater runoff in a single pipe to the nearest receiving body of water. In the early 1950s, most sewer systems were built as separated systems which conveyed sewage in one pipe and stormwater runoff in another pipe. In the late 1950s, treatment plants were built to treat wastewater. Combined sewer systems still exist in portions of older cities, including Seattle. Figure 1-5 shows locations of King County and City of Seattle CSOs in western King County. All the CSOs within King County are in Seattle, as this is the oldest part of the sewer system that is not separated. Wastewater and stormwater from other parts of King County are separated, with the wastewater conveyed to treatment plants for treatment before being discharged. There are long-term control plans for reducing the frequency and volume of all CSOs in Washington State to the required limit of no more than one untreated overflow event per year.

1.3.3 Stormwater Discharges

Stormwater runoff is water that flows off surfaces such as paved streets, rooftops, parking lots, and lawns. Stormwater can contain a variety of pollutants, dependent upon the runoff source. For example, runoff from parking lots and streets can contain hydrocarbons from combustible fuel, while runoff from lawns and grassy areas can contain pesticides and herbicides. In urban areas, stormwater is collected through storm drains and can then be conveyed in different ways. Stormwater can be conveyed to treatment systems for various types of treatment before being discharged to a receiving water body or be directly discharged through a stormwater outfall without receiving treatment. Figure 1-5 shows the location of storm drains and CSOs (which contain some portion of stormwater) within the western portion of King County.

In 1987, the Clean Water Act was amended to require certain industries and municipalities to have a NPDES permit for stormwater discharges. The EPA stormwater regulations for Washington State established two phases for the stormwater permitting process. Phase I permits promulgated in 1990 cover stormwater discharges from certain industries, construction sites over five acres, and municipalities with a population over 100,000 people. King, Snohomish, and Pierce Counties, the City of Seattle, and the City of Tacoma are all covered under the Phase I municipal stormwater NPDES permit. The municipal stormwater permit requires the implementation of a Stormwater Management Program, which includes a plan to reduce the discharge of pollutants through discharge of stormwater, reduce impacts to receiving water, and eliminate illegal discharges. The Phase II regulations promulgated in 1999 expanded the requirements for stormwater permits to all municipalities located in urbanized areas and construction sites between one to five acres.

1.4 Sampling Area

King County's sampling area is located within the Puget Sound Central Basin, extending south to Dumas Bay and north to Edwards Point. Elliott Bay, a large urban embayment which includes the City of Seattle waterfront, is also located within the County's monitoring area. All but four sites sampled between 2005 and 2007 as part of the marine monitoring program were located in marine waters. One brackish site was located in the Lake Washington Ship Canal directly west of the Ballard Locks, two sites were located in the lower Duwamish Waterway, and a freshwater site was located in Piper's Creek. All data, with the exception of the two Duwamish Waterway sites, are reported in this document.

1.4.1 Sampling Area Characteristics

Puget Sound is a fjord-like estuary that extends approximately 230 kilometers (km) in a north-south direction and is bordered by the Olympic mountains to the west and the Cascade mountain range to the east. Puget Sound consists of a series of underwater valleys and ridges (called basins) and submerged hills (called sills). Sills impede the flow of water in and out of the Sound and also induce vertical mixing as water moves over the sill. The Sound consists of four major interconnected basins, including the Main (Admiralty Inlet and the Central Basin), Whidbey, Southern, and Hood Canal Basins. The Whidbey Basin is not a basin in the geological sense; its southern boundary is an arbitrarily chosen line running from Possession Point on Whidbey Island across the channel to Picnic Point in southern Snohomish County.

Water from the Pacific Ocean enters the Sound primarily through Admiralty Inlet and secondarily through Deception Pass. The area where Possession Sound and Admiralty Inlet join with the Central Basin is referred to as the Triple Junction. The Main Basin, with depths greater than 280 m, is shielded at the northern entrance to the Sound by the Admiralty Inlet Sill which impedes the exchange of deep waters. However, the Sound has near-oceanic salinity throughout the year and is supplemented with cold, nutrient-rich, low-oxygenated, deep oceanic water upwelled off the Washington coast during the late summer months.

Puget Sound has an average depth of 106 meters (m) and contains approximately 168 billion cubic meters of water. The average tidal range is 3.7 to 4.3 m and an average water volume exchange of 8 billion cubic meters occurs with each tidal cycle (King County, 1994). A mixed semi-diurnal tide, which is characterized by two unequal high tides and two unequal low tides occurring each day, dominates the tidal pattern within Puget Sound. These relatively high water exchange rates are conducive to maintaining overall favorable water quality conditions in Puget Sound.

Many complex factors influence water quality in Puget Sound, including water currents, physical, biological, and chemical processes, and human activities. Offshore water samples consistently indicate good water quality. However, nearshore waters and sediments tend to exhibit more water quality problems due to proximity to pollutants from industrial and urban

sources. Bacteria levels in nearshore waters are consistently higher than in offshore waters due to proximity to sources such as storm drains, freshwater input (creeks and streams), and urban wildlife. Sediment carried in runoff from land plays a much greater role in Puget Sound's water quality than in most marine areas. Being surrounded by hills, lakes, and rivers in an urbanized area with substantial rainfall gives the Sound a multitude of complex sediment sources. The predominant sediment sources are from river transport and bluff erosion. The twelve largest rivers entering Puget Sound contribute approximately 1.8 million cubic meters of sediment annually. Their suspended sediment load is highest during winter and early spring when heavy seasonal precipitation from storms erodes soil from the surrounding lowlands. Sediment sampling generally shows the highest levels of organic chemicals are found in nearshore areas of Elliott Bay, where urban runoff from storm drains, industrial sources, and nonpoint sources is the greatest.

Around September 2006, a mild El Niño event (a warming episode of Pacific Ocean waters) developed in the Pacific Ocean and dissipated in early 2007. This El Niño event was milder than the very strong 1997/1998 event. La Niña conditions (a cooling phase of Pacific Ocean waters) were observed in late summer of 2007 and persisted until early spring of 2008.

1.4.2 Freshwater Input

In an estuarine environment such as Puget Sound, freshwater flows from rivers and streams are important as they affect both physical and biological processes. Freshwater flows influence Puget Sound water circulation as the amount of freshwater input varies seasonally and affects water temperature, salinity, and density, which then determines stratification of the water column. Water column stratification can affect biological populations by trapping nutrients and/or affecting vertical migration through the water column. Freshwater flow also affects the amount of nutrients and contaminants transported into marine waters. Freshwater input into rivers is mainly through rainfall, however, snowmelt also contributes a large source in later spring and early summer.

There are two main freshwater inputs into the Central Basin marine waters: the Green/Duwamish River system, which enters Elliott Bay and the Lake Washington Drainage Basin (Cedar River) which flows into the Sound primarily through the Lake Washington Ship Canal. The Skagit, Stillaguamish, Snohomish, and Puyallup Rivers all have substantial freshwater flows, particularly the Skagit River, and can affect marine waters within the Central Basin (Figure 1-6a). There are also numerous smaller streams that discharge directly into nearshore Puget Sound waters.

Freshwater flows can increase in late spring and summer from snowmelt, but are dependent upon the location and hydrology of the drainage basin. An increase in freshwater flow is evident during late May to early July in the Skagit River (Figure 1-6b) and also in May and June in the Puyallup River. However, due to regulated flows in the Lake Washington Drainage Basin and the Green River, snowmelt does not increase the flows in these river systems to the extent that it does in other systems.

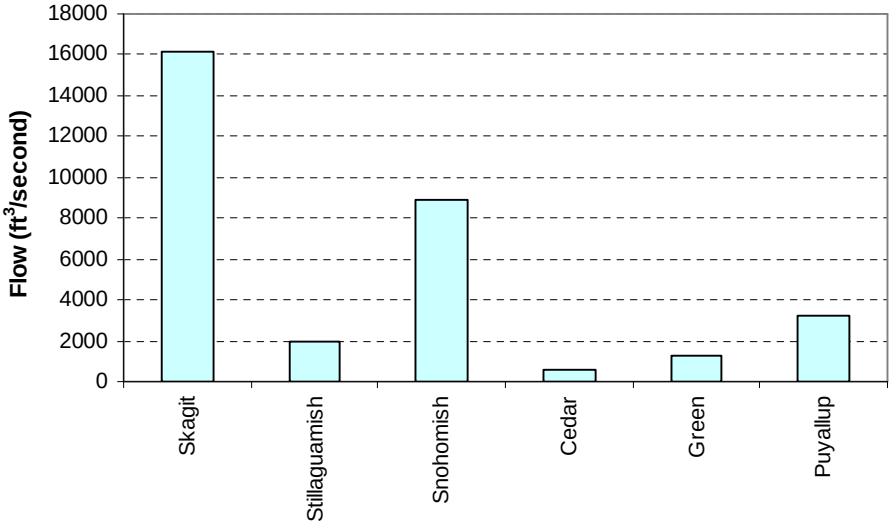

Figure 1-6a. 5-Year Average Annual Streamflow for Six Rivers (2003-2007)

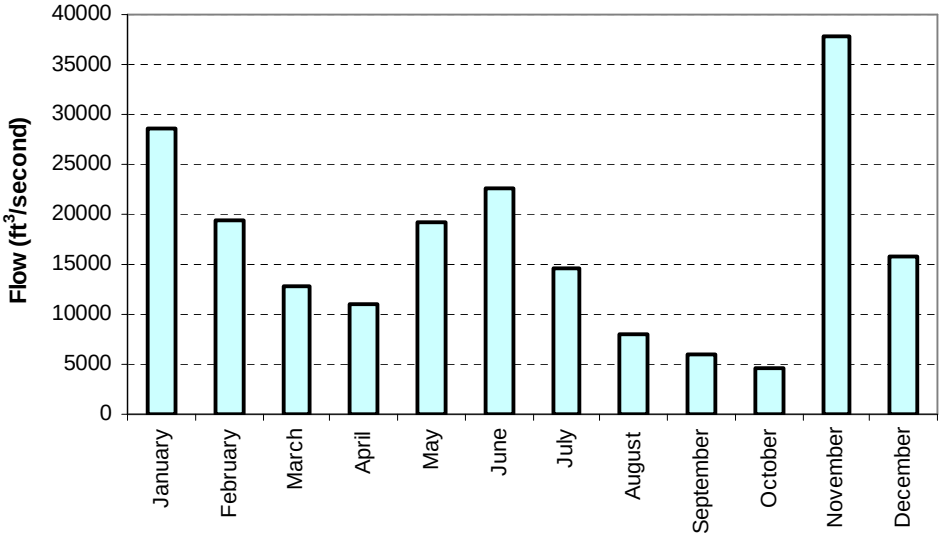

Figure 1-6b. Monthly Mean Streamflow for the Skagit River in 2006

1.4.3 Oceanographic Characteristics

General Circulation Patterns

Water circulation in Puget Sound 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. The largest single source of freshwater into Puget Sound is the Skagit River, followed by the Snohomish and Stillaguamish Rivers, all of which flow into the Whidbey Basin. The

Puyallup and Nisqually Rivers are the largest freshwater sources into southern Puget Sound. The largest sources of freshwater input into the Central Basin are the Duwamish River, which flows into Elliott Bay, and water from the Lake Washington Ship Canal. The freshwater flow is driven by freshwater runoff from rainfall and the summer snow melt. Salty, cold dense waters enter Puget Sound at depth through Admiralty Inlet and a portion flows south in the Central Basin while the other portion flows northeast through Possession Sound to the Whidbey Basin. Figure 1-7 shows the net circulation pattern in Puget Sound with the deep incoming water flowing beneath the outflowing upper layer. 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. The deeper, denser waters in the Main Basin often move 5 to 10 times faster than deeper currents in the Whidbey Basin as a result of vigorous mixing at the Narrows (Ebbesmeyer and Cannon, 2001).

The circulation of inflowing and outflowing water is affected by the sills, which provide vertical mixing of the two water layers. An exception to the two-layered flow in the Main Basin occurs in the southern portion around Vashon Island. In this area, the net flow is mainly southward through East Passage, around the southern end of Vashon Island, and then north through Colvos Passage (see Figure 1-7). This effect is caused by the location of Vashon Island relative to the outflowing water from the Narrows. The outflow from Colvos Passage has a significant effect on surface circulation in the northern portion of the Central Basin (Ebbesmeyer and Cannon, 2001). Water moving northward through Colvos passage is directed across the channel towards Alki Point, where a portion then returns south in East Passage. The other portion flows north toward the Triple Junction, the area where waters from the Central Basin, Whidbey Basin, and Admiralty Inlet converge.

Winds can cause significant variations in circulation. Southerly winds augment the surface outflowing water and northerly winds can impede and sometimes reverse the surface flow. Bottom water intrusions can also cause significant variations in circulation. Intrusions occur when dense saltwater crosses the Admiralty Inlet sill and replaces deep water in the Main Basin. Bottom water intrusions circulate down Puget Sound at speeds of about 20 centimeters per second (cm/s) near the Admiralty Inlet sill and 10 cm/s along the Central Basin (Ebbesmeyer and Cannon, 2001).

The residence time of water in the Main Basin is about 48 days, depending upon the time of year (Babson, 2004).

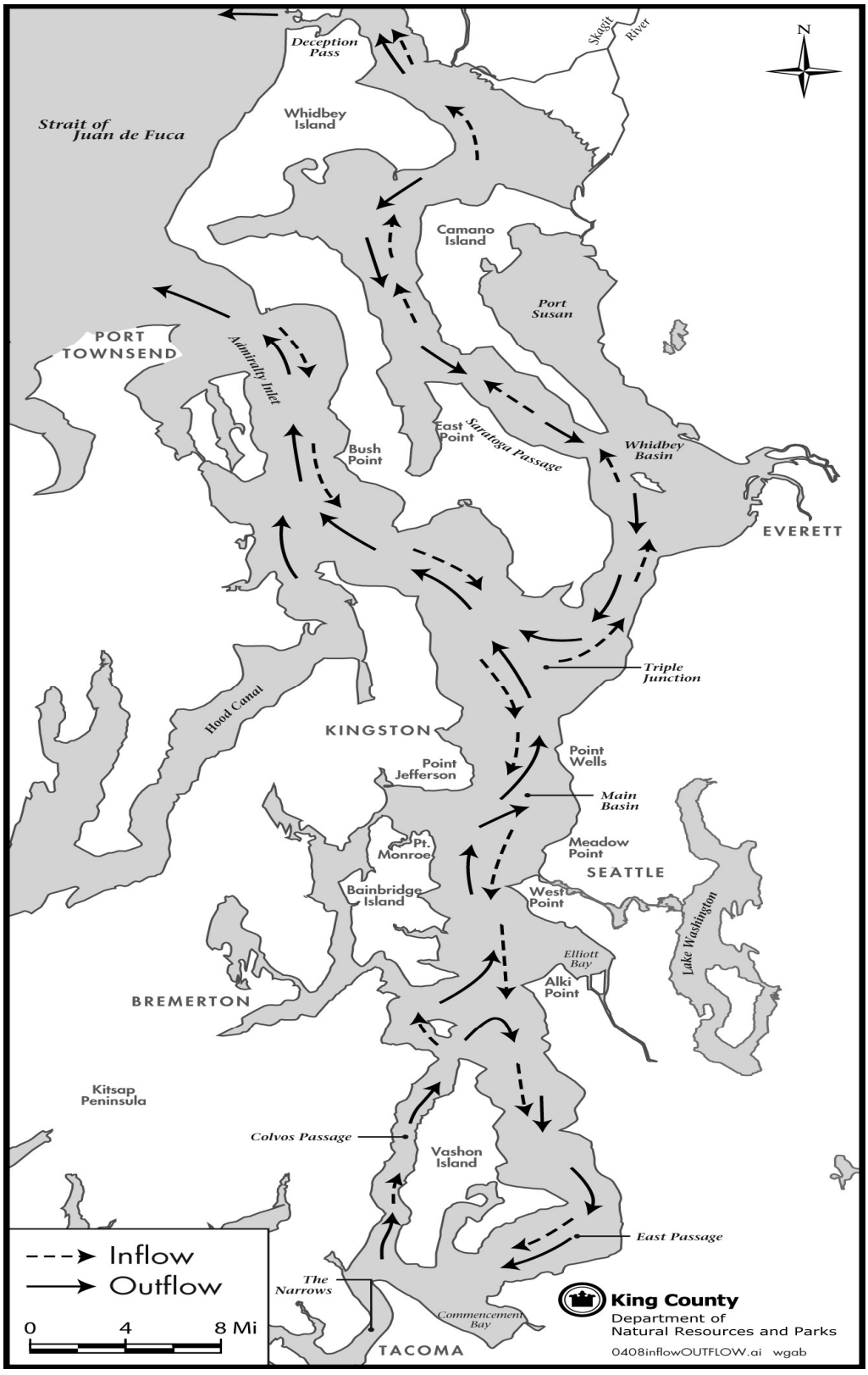

Figure 1-7. Generalized Puget Sound Circulation (from Ebbesmeyer et. al, 2002)

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SECTION 2
Water Quality Monitoring Programs

King County has conducted an extensive marine monitoring program for almost 40 years to assess water quality in Puget Sound. The monitoring program contains elements of baseline sampling to assess background conditions (ambient monitoring) and also sampling to assess conditions around King County's marine outfalls (point source monitoring).

The goal of the marine monitoring program is to identify sources of water pollution, provide water quality information for management decisions, and evaluate status and trends of marine waters within King County.

In order to meet that goal, the marine monitoring program works within a framework of the following objectives:

- implement a long-term monitoring program to characterize water quality in King County;
- evaluate data results in regard to applicable State water and sediment quality guidelines;
- comply with NPDES sediment monitoring requirements;
- gather sufficient data to determine both short and long-term water quality conditions;
- determine physical and chemical dynamics that influence water quality;
- support coordinated regional monitoring efforts; and
- collect scientific data of high quality to inform water quality management decisions.

Water quality may be affected by natural processes as well as by two types of pollution: point source and nonpoint source. Point source pollution is defined by its entry into the aquatic environment from a specific conveyance, such as an outfall pipe. Point source pollution can be generated by a variety of industrial and municipal facilities, such as sewage treatment plants and manufacturing facilities. Nonpoint source pollution comes from any source that is not a point source and includes runoff or infiltration from streams, groundwater, stormwater, atmospheric deposition, etc. Land use, such as agricultural and urban usage, affects the quality of the runoff. King County's marine monitoring program assesses both nonpoint and point source pollution in nearshore and offshore environments, as well as assessing ambient (background) conditions. The stations monitored by the marine program fall into one of two categories; ambient or outfall (point source). Within these categories, stations are classified as either beach (+3 to -3 meter mean lower low water) or offshore (bottom depth greater than -3 m mean lower low water).

Obtaining background data from areas in receiving waters that are not influenced by point sources is important in order to accurately evaluate the overall condition of receiving waters. King County has established an ambient monitoring program in the Central Puget Sound Basin to better understand regional water quality and provide data needed to identify trends that might indicate impacts from long-term cumulative pollution.

2.1 Outfall and Ambient Monitoring Programs

The outfall and ambient monitoring programs focus on both marine water and the underlying sediments. Many marine pollutants are associated with particulates in the water. As these contaminated particles settle out of the water column, pollutant concentrations in the underlying sediments tend to increase. Most pollutant sources are found in shallow nearshore areas where pollutants tend to accumulate in sediments close to these sources. Benthic organisms that live on or in contaminated sediments tend to accumulate these contaminants through contact or ingestion (bioaccumulation). Pollutants also tend to concentrate as they move from one trophic level to the next (biomagnification), as contaminated organisms become prey to animals higher up in the food web. Contaminated sediments can have an impact on both human and marine environmental health, especially in nearshore areas which are generally high contact areas for marine organisms and people.

Water monitoring for physical, chemical, and biological parameters is an important component of the County's monitoring programs. In offshore and beach waters, excess nutrients and pathogens can cause water quality related problems for both animals and humans. While excess nutrients do not cause immediate harm to organisms living in the water column, they can increase the growth of phytoplankton and algae. The decay of phytoplankton and algae populations can subsequently deplete oxygen to levels incapable of sustaining aquatic organisms. Physical parameters, such as salinity and temperature, are important as these properties affect water column stratification. The intensity and persistence of density stratification within a water column is significant with respect to vertical water movement, phytoplankton growth, and dissolved oxygen concentrations.

2.1.1 Marine Outfall Monitoring Program

King County collected offshore water column samples at wastewater and CSO treatment plant outfall discharge locations in 2005, 2006, and 2007 as part of the outfall monitoring program. Beach water and shellfish tissue were also collected from areas in the vicinity of treatment plant outfalls during all three years. Macroalgae tissues were collected from areas in the vicinity of treatment plant outfalls in 2005, however, the macroalgae sampling program was discontinued in 2006. Beach sediments were collected in 2005 but not 2006 or 2007. Beginning in 2005, beach sediments in the vicinity of outfall sites and at ambient sites are collected on a five-year cycle. Water samples were collected from multiple depths at the offshore stations and from a single depth at the beach stations. Offshore sediments at the West Point TP outfall were collected in 2006 in support of the NPDES permit. Station locations are shown in Figures 2-1 through 2-3 and station coordinates are provided in Appendix E.

Outfall stations that were sampled between 2005 and 2007 were also sampled in previous years with the following exceptions described below. In 2006 and 2007, a station was sampled at the mid-diffuser point for each of the South TP twin outfall pipes in an effort to determine if there were discernible water quality differences between the two locations. A beach site in the vicinity of the Alki CSO TP outfall was added in 2006, however, this site was subsequently removed from the sampling program in 2007 as it was deemed to be unrepresentative of the outfall area.

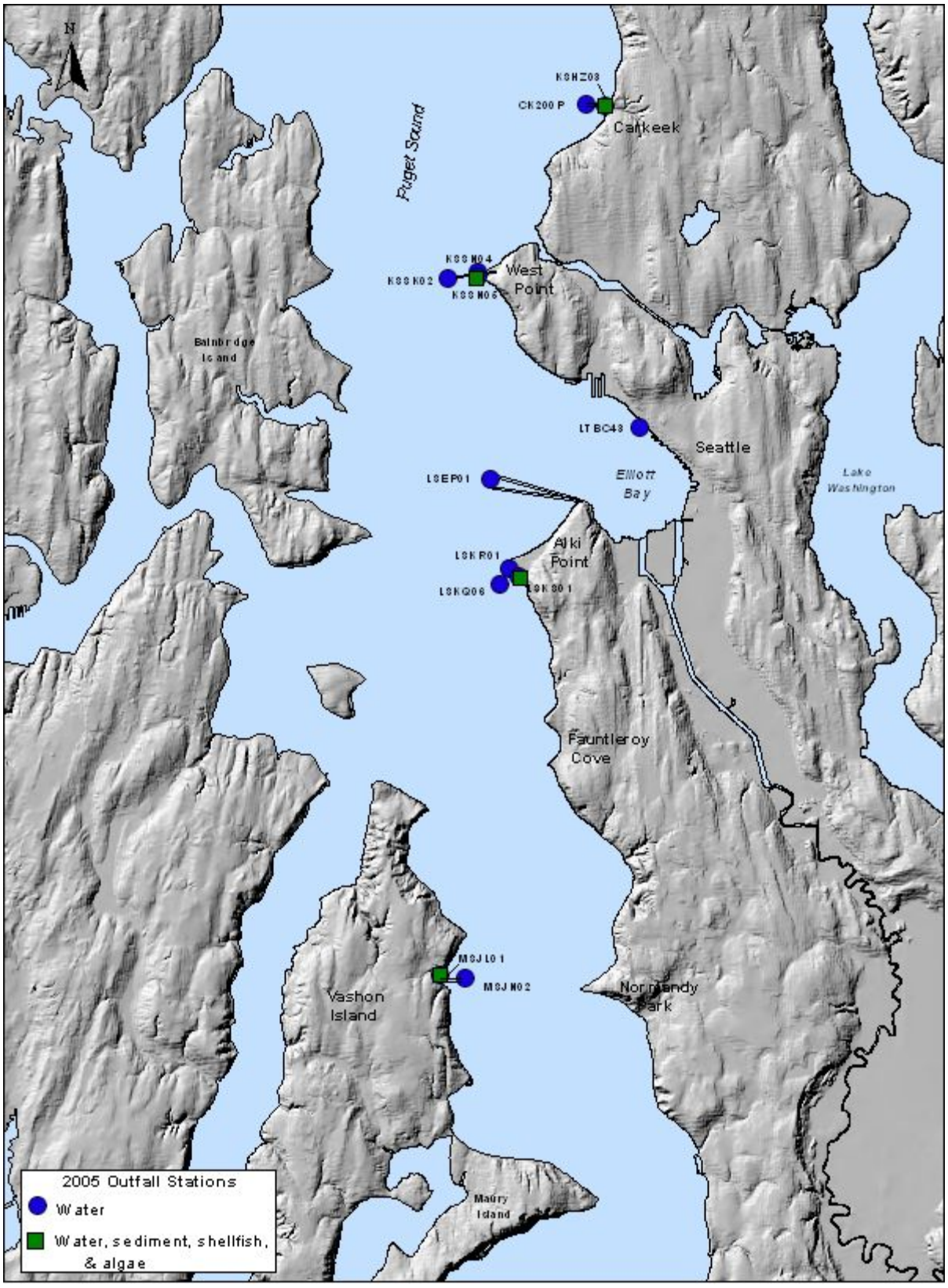

Figure 2-1. 2005 Outfall Monitoring Station Locations

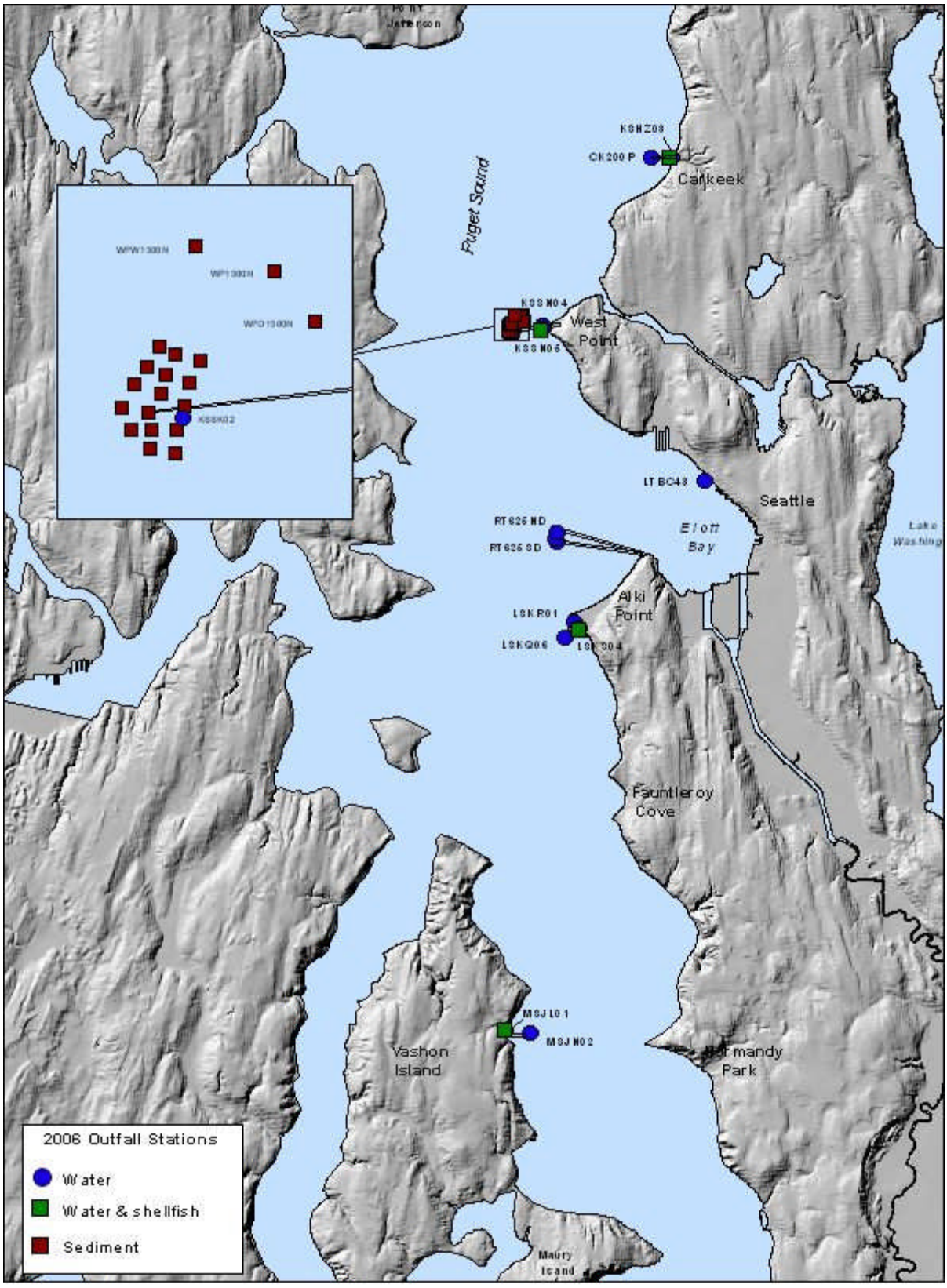

Figure 2-2. 2006 Outfall Monitoring Station Locations (see Table 2-1 for West Point locators)

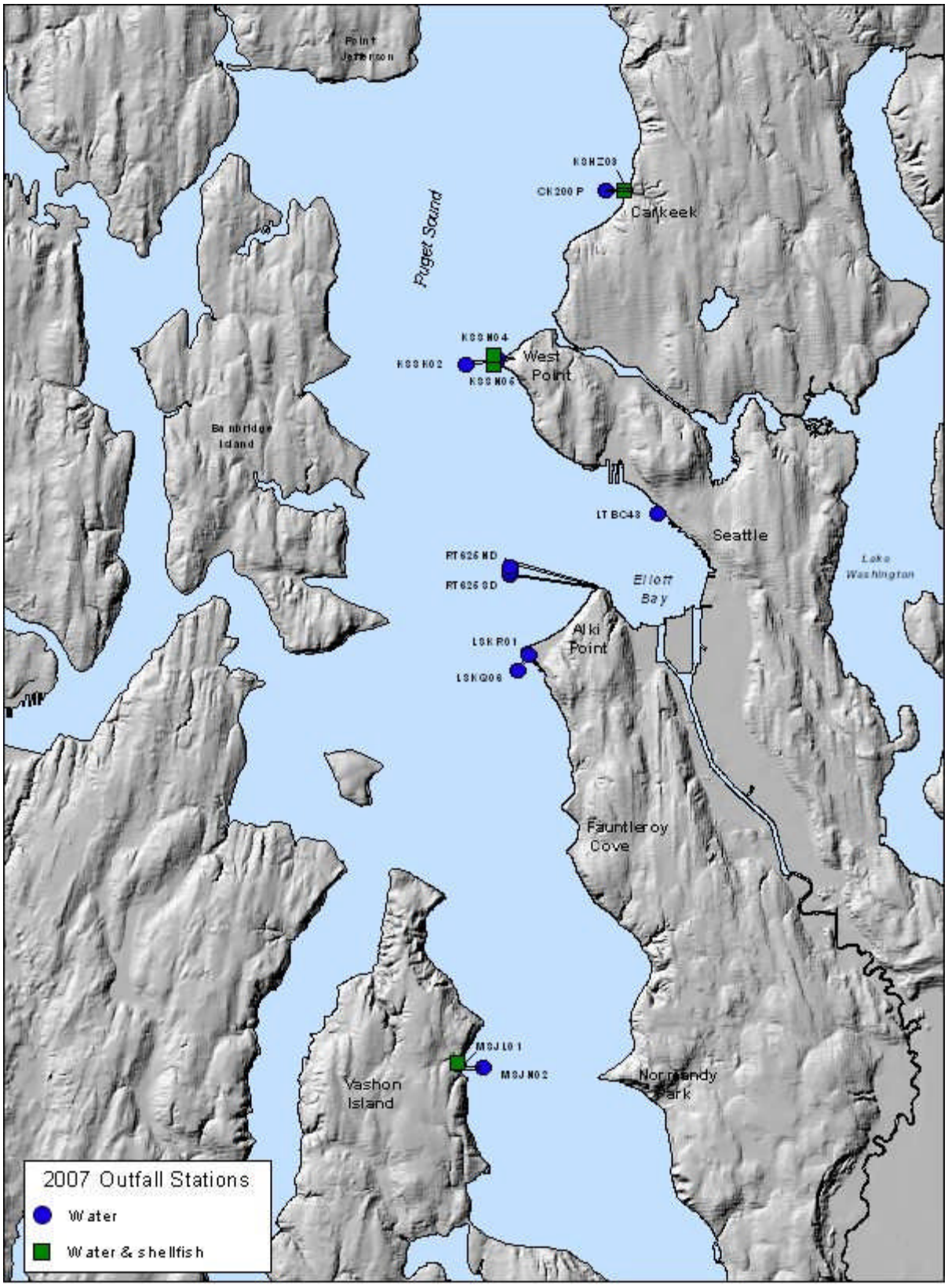

Figure 2-3. 2007 Outfall Monitoring Station Locations

A new sampling station (MSJN02) was established in 2005 at the end of the newly constructed Vashon TP outfall and the previous station (VO50E) discontinued.

Locations for outfall water stations were based upon the following: stations KSSK02, LSEP01, MSJN02, LTBC43, CK200P, and LSKQ06 were established in the water column at the end of outfall pipes. Station KSSK02 is located at the end of the West Point TP outfall diffuser, LSEP01 is located at the end of the South Plant's north diffuser, MSJN02 is at the end of the Vashon TP outfall, LTBC43 is at the end of the Denny Way/Elliott West CSO long outfall pipe, CK200P is at the end of the Carkeek CSO TP outfall, and LSKQ06 is located at the end of the Alki CSO TP outfall. Stations RT625ND and RT625SD were established at the mid-diffuser point for the north and south South TP outfall pipes, respectively. Stations were placed at these locations in order to characterize water quality at the point where effluent is discharged into the marine environment.

The three West Point TP sediment transects were based upon the following: one transect was placed at the mid-diffuser point (approximately 200 ft east of the end of the outfall), one at the end of the outfall, and another 200 ft west of the end of the outfall. All three transects were placed in a north-to-south alignment as the currents in this area are in a net north direction. The farthest northern sampling point along each transect was placed 645 ft north of the center of the outfall and the farthest south was placed 430 ft south of the center of the outfall. Other sampling points along each transect were placed at the outfall, 215 ft both north and south of the outfall, and 430 ft north of the outfall. Three stations placed approximately 1500 ft north of the outfall were sampled to provide baseline reference conditions in the vicinity of the outfall but outside the immediate influence of the effluent plume.

Beach station locations were established along the shoreline in the vicinity of treatment plant outfalls. Stations were placed at these locations in order to evaluate water and sediment quality at beach sites in the vicinity of effluent discharges. Two stations, KSSN04 and KSSN05, are located on the north and south side of West Point, respectively. Station LSKR01 is located north of the location where the Alki CSO TP outfall exits the shoreline. Station MSJL01 is located on the beach directly west of the Vashon TP outfall and KSHZ03 is located directly east of the Carkeek CSO TP outfall. A beach station is not located near the South TP outfall as the outfall is over 10,000 feet offshore.

A summary of parameters measured and the frequency sampled for each station is provided in Tables 2-1 through 2-3. Offshore water samples were collected monthly to assess seasonal trends for the following parameters: temperature, salinity, turbidity, water clarity, dissolved oxygen, nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica), chlorophyll-*a*, pheophytin-*a*, total suspended solids, photosynthetically active radiation, and fecal indicator bacteria (fecal coliforms and enterococci). Beach waters were analyzed monthly for fecal indicator bacteria, temperature, salinity, and nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica) in order to evaluate seasonal trends for these parameters.

Beach sediments were collected in August of 2005 and analyzed for organic compounds, metals, and conventional parameters (total organic carbon, total solids, total volatile solids, and grain size). In 2005, shellfish tissues were analyzed in August for organic compounds, metals, and conventional parameters (total solids and percent lipids). Beginning in 2006, shellfish tissues

were collected in March as well as August to assess seasonal differences. Prior to discontinuing the sampling program for macroalgae in 2006, samples were collected and analyzed for metals in 2005.

Table 2-1. 2005 Outfall Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH			ALGAE
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Bacteria	GWQP *	Organics	Metals	Conventionals	Metals
KSHZ03	Carkeek	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
CK200P	Carkeek	Offshore				◆ 12	◆ 12				
KSSN04	West Point	Beach				◆ 12					◆ 1
KSSN05	West Point	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
KSSK02	West Point outfall	Offshore				◆ 12	◆ 12				
LTBC43	Denny Way outfall	Offshore				◆ 12	◆ 12				
LSEP01	South Plant outfall	Offshore				◆ 12	◆ 12				
LSKR01	Alki Point	Beach				◆ 12					
LSKS01	Alki	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
LSKQ06	Alki outfall	Offshore				◆ 12	◆ 12				
MSJN02	Vashon I. Outfall	Offshore				◆ 12	◆ 12				
MSJL01	Vashon Island	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1

* GWQP = general water quality parameters. Includes nutrients, salinity, temperature, chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters; nutrients, salinity, temperature for beach waters.
Shellfish conventionals include total solids and percent lipids.
Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.
Numbers indicate frequency sampled per year on a monthly basis.

2.1.2 Marine Ambient Monitoring Program

The ambient program provides background information for comparison to data obtained from the King County outfall monitoring program and contributes to a long-term dataset which enables overall Puget Sound water quality trends to be evaluated.

Offshore water column samples were collected during 2005, 2006, and 2007 for the ambient monitoring program. Beach water and shellfish tissue were also collected all three years. Macroalgae tissues were collected in 2005, however, the macroalgae sampling program was discontinued in 2006. Beach sediments were also collected in 2005 but not in 2006 or 2007. Beginning in 2005, beach sediments at both ambient and outfall sites are collected on a five-year cycle. Water samples were collected from multiple depths at the offshore stations and from a single depth at the beach stations. In 2007, offshore sediments were collected in Puget Sound and Elliott Bay as part of the ambient sediment monitoring program. Station locations are shown in Figures 2-4 through 2-6 and station coordinates are provided in Appendix E.

Table 2-2. 2006 Outfall Stations, Parameters, and Frequency Measured

			SEDIMENT				WATER		SHELLFISH	
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Benthic infauna	Bacteria	GWQP *	Metals	Conventionals
KSHZ03	Carkeek	Beach					◆ 12	◆ 12	◆ 2	◆ 2
CK200P	Carkeek	Offshore					◆ 12	◆ 12		
KSSN04	West Point	Beach					◆ 12	◆ 12		
KSSN05	West Point	Beach					◆ 12	◆ 12	◆ 2	◆ 2
KSSK02	West Point outfall	Offshore					◆ 12	◆ 12		
WP230P	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP215N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP215S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP430N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP430S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP645N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WP1500N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WP230D	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPD215N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPD215S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPD430N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPD430S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPD1500N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WP280W	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPW215N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPW215S	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	◆ 1				
WPW430N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPW645N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
WPW1500N	West Point outfall	Offshore	◆ 1	◆ 1	◆ 1	1				
LTBC43	Denny Way outfall	Offshore					◆ 12	◆ 12		
RT625ND	South Plant north outfall	Offshore					◆ 12	◆ 12		
RT625SD	South Plant south outfall	Offshore					◆ 12	◆ 12		
LSKR01	Alki north	Beach					◆ 12	◆ 12		
LSKS04	Alki south	Beach					◆ 12	◆ 12	◆ 2	◆ 2
LSKQ06	Alki outfall	Offshore					◆ 12	◆ 12		
MSJN02	Vashon I. Outfall	Offshore					◆ 12	◆ 12		
MSJL01	Vashon Island	Beach					◆ 12	◆ 12	◆ 2	◆ 2

* GWQP = general water quality parms. Includes nutrients, salinity, temperature, chlorophyll, dissolved oxygen, solid transparency, photosynthetically active radiation for offshore waters; nutrients, salinity, temp. for beach waters.

Shellfish conventionals include total solids and percent lipids.

Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.

Numbers indicate frequency sampled per year on a monthly basis.

Table 2-3. 2007 Outfall Stations, Parameters, and Frequency Measured

STATION	LOCATION	OFFSHORE/ BEACH	SEDIMENT			WATER		SHELLFISH	
			Organics	Metals	Conventionals	Bacteria	GWQP *	Metals	Conventionals
KSHZ03	Carkeek	Beach				◆ 12	◆ 12	◆ 2	◆ 2
CK200P	Carkeek	Offshore				◆ 12	◆ 12		
KSSN04	West Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSSN05	West Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSSK02	West Point outfall	Offshore				◆ 12	◆ 12		
KSYV02	Magnolia CSO	Beach				◆ 12	◆ 12		
LTBC43	Denny Way outfall	Offshore				◆ 12	◆ 12		
LSEP01	South Plant outfall	Offshore				◆ 12	◆ 12		
LSKR01	Alki north	Beach				◆ 12	◆ 12		
LSKQ06	Alki outfall	Offshore				◆ 12	◆ 12		
MSJN02	Vashon I. Outfall	Offshore				◆ 12	◆ 12		
MSJL01	Vashon Island	Beach				◆ 12	◆ 12	◆ 2	◆ 2

* GWQP = general water quality parameters. Includes nutrients, salinity, temp., chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters; nutrients, salinity, temp. for beach waters.
Shellfish conventionals include total solids and percent lipids.
Numbers indicate frequency sampled per year on a monthly basis.

The majority of the ambient stations sampled in 2005 were also sampled in 2006 and 2007. Three beach stations sampled in 2005 were discontinued after an assessment of previous sample results and/or an unnecessary high sample resolution in a particular area. Ten beach stations were added to the ambient program in 2007 to increase spatial coverage within King County waters. Other ambient beach locations were sampled for various reasons, such as a high-use public beach, potential to have water quality problems, and continuation of a long-term dataset. Locations for offshore water samples were chosen based on continuation of a long-term dataset (stations KSBP01 and LSNT01) and spatial coverage to assess water conditions within the Central Basin.

King County's previous ambient subtidal sediment monitoring program evaluated sediment quality at four stations in Elliott Bay, two stations in the Puget Sound Central Basin, and one station in Shilshole Bay. Samples were collected from these stations biennially between 1996 and 2004 and annually at several of the stations, as well as others, prior to 1996.

The former subtidal sediment monitoring program was temporarily discontinued after 2004 to allow King County staff scientists to evaluate data generated from the program as well as other data collection efforts within the region. Following this review period, King County expanded its marine ambient subtidal sediment monitoring program to focus on sediment quality in Elliott Bay, while still monitoring truly ambient sediment quality in the Central Basin of Puget Sound as well as three smaller embayments of interest.

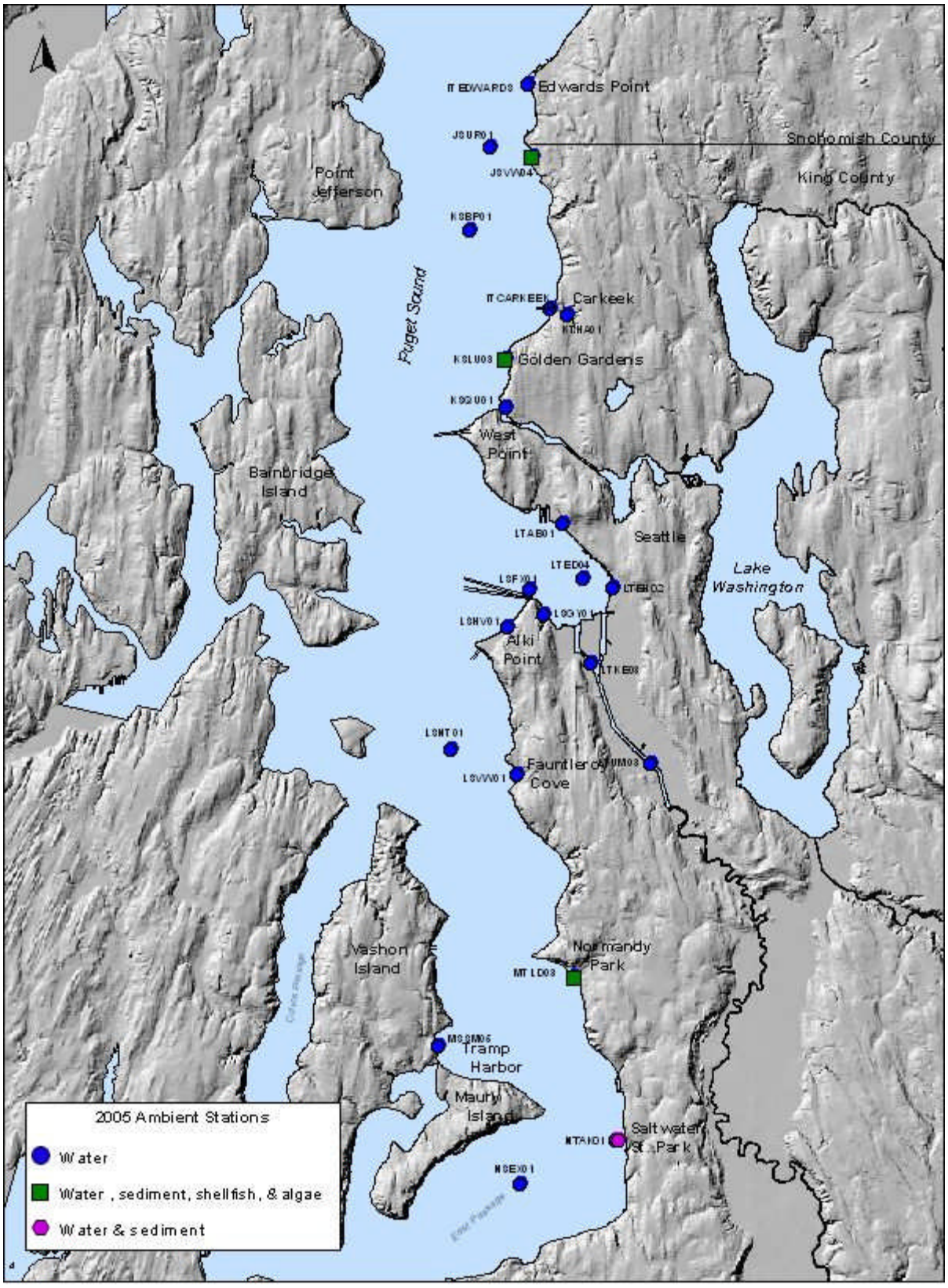

Figure 2-4. 2005 Ambient Monitoring Station Locations

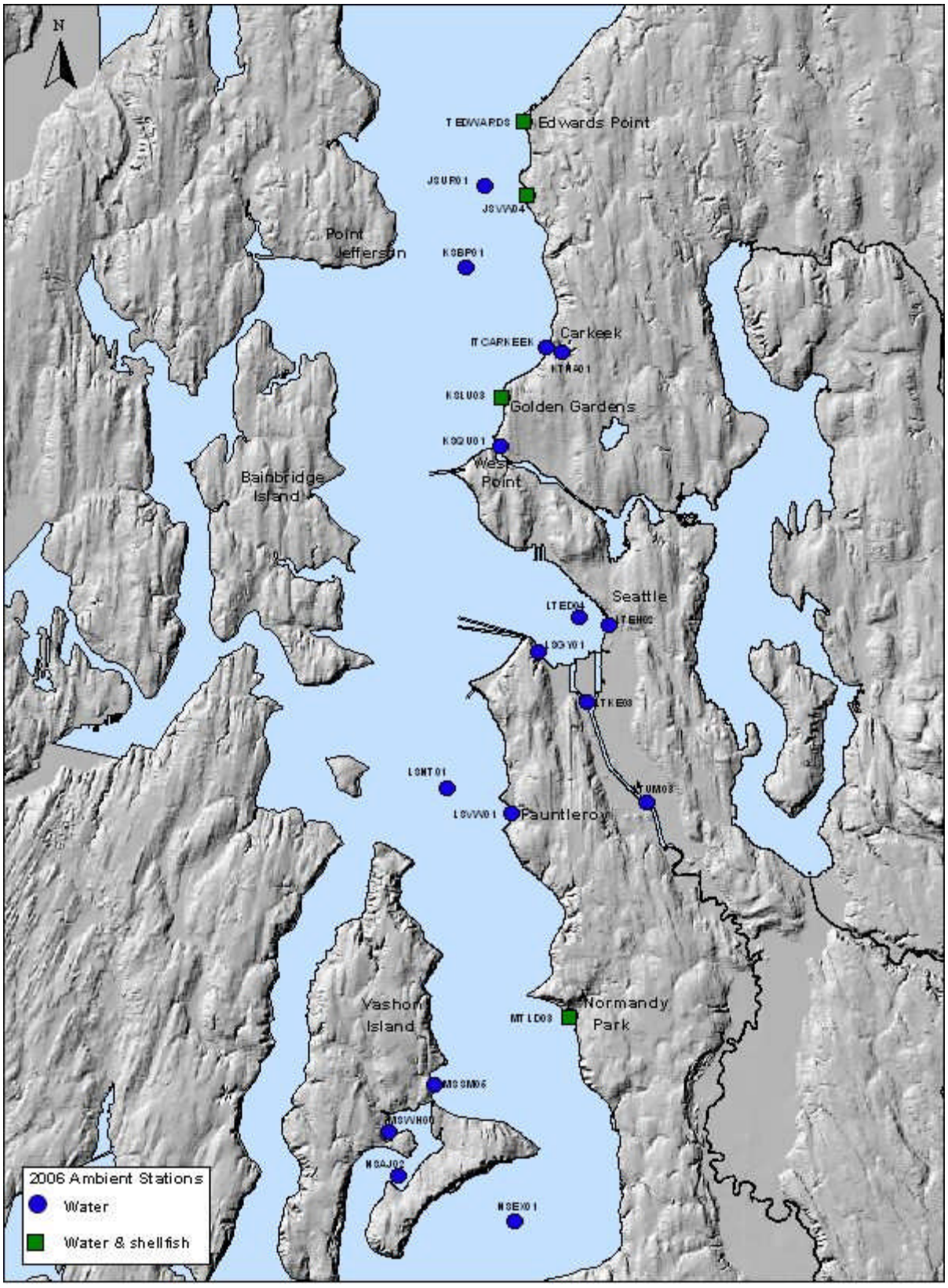

Figure 2-5. 2006 Ambient Monitoring Station Locations

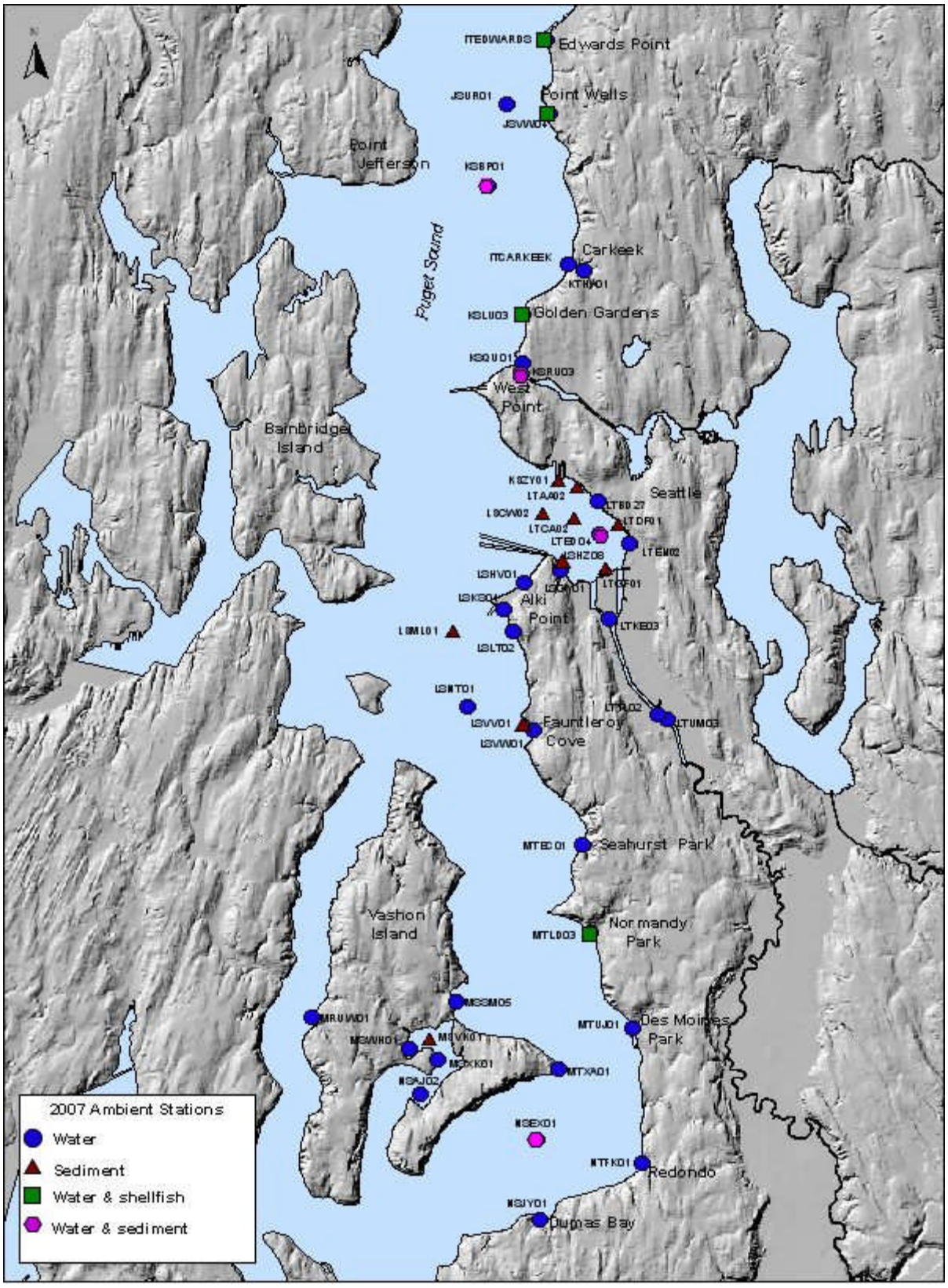

Figure 2-6. 2007 Ambient Monitoring Station Locations

The Central Basin and associated smaller embayments sediment program will include six sites sampled every five years. The frequency of sampling for these six stations should be sufficient to monitor long-term trends in sediment quality. The three stations in the Central Basin which represent ambient sediment conditions in the deep, depositional areas of Puget Sound include:

- Station KSBP01 located off of Point Jefferson. This station represents conditions in the northern area of the Central Basin and is one of King County's long-term water column monitoring stations.
- Station LSML01 located off of West Seattle. This station represents conditions in the middle of the Central Basin and is one of King County's long-term sediment monitoring stations.
- Station NSEX01 located in East Passage. This station represents conditions in the southern area of the Central Basin and is another of King County's long-term water column monitoring stations.

The three stations located in the small embayments which represent specific areas of interest due to potential anthropogenic impacts include:

- Station LSRU03 located in outer Salmon Bay, just downstream from the Hiram Chittenden locks. This area receives a high level of small and large vessel traffic entering and exiting the locks.
- Station LSVV01 located in Fauntleroy Cove. This area has a history of water quality issues, receives a large amount of freshwater input, and is impacted by ferry traffic at the Fauntleroy ferry dock.
- Station MSVK01 located in inner Quartermaster Harbor. This area is of importance as habitat for a variety of species, including wintering birds and Pacific herring. This shallow, quiescent embayment receives a moderate amount of seasonal small vessel traffic.

The Elliott Bay sediment monitoring program includes eight stations with sampling occurring every two years. This more-frequent sampling will allow King County and other decision-makers to better evaluate temporal changes in sediment quality and help assess the potential positive impacts to the marine environment from various sediment cleanup projects and other improvements in Elliott Bay. Four Elliott Bay stations have long-term sediment quality data sets that will continue with the new sampling program and form a rough east-west transect away from areas of potential point-source impacts. These stations are:

- LSCW02 located at the hypothetical boundary-line between Elliott Bay and the Central Basin of Puget Sound;
- LTCA02 located in the center of Elliott Bay;
- LTED04 located in the center of Elliott Bay, inshore of LTCA02; and
- LTDF01 located along the central Seattle waterfront, near Pier 66.

Four new Elliott Bay stations have been added to the monitoring program to assess specific areas of the bay. These stations are:

- KSZY01 located just offshore of Piers 90/91. This area has historically received high heavy-vessel traffic and will continue to receive large ships when cruise liners begin using these docking facilities.
- LTAA02 located just offshore of the grain terminal. This area has also historically received high heavy-vessel traffic and docking.

- LTGF01 located just offshore of the northern end of Harbor Island. This location is in an area of heavy industry, including fuel storage and transfer, shipbuilding and repair, and the transportation industry.
- LSHZ08 located just offshore of Cove 2 at Seacrest Park. This area has high usage by recreational SCUBA divers, including diving classes, which includes a high incidence of primary contact with bottom sediments, especially by student divers.

Ambient offshore water samples were collected monthly to assess seasonal trends for the following parameters: temperature, salinity, turbidity, water clarity, dissolved oxygen, nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica), chlorophyll-*a*, pheophytin-*a*, total suspended solids, photosynthetically active radiation, and fecal indicator bacteria (fecal coliforms and enterococci). In 2005, water samples collected from all beach sites were analyzed monthly for fecal indicator bacteria and temperature. Samples from five beach sites were also analyzed monthly for salinity, and nutrients (ammonia-nitrogen, nitrate+nitrite, total phosphorus, and silica) in order to evaluate seasonal trends for these parameters. Beginning in 2006, all beach waters were analyzed for the full suite of parameters listed above.

Beach sediments were collected at four locations in August 2005 and analyzed for organic compounds, metals, and conventional parameters (total organic carbon, total solids, total volatile solids, and grain size). Shellfish tissues from three sites in 2005 were analyzed for organic compounds, metals, and conventional parameters (total solids and percent lipids). In 2006 and 2007, shellfish tissues from four sites were analyzed for metals and conventional parameters. Organic compounds were not analyzed in shellfish tissues in 2006 and 2007 as they were rarely detected. Macroalgae samples were analyzed for metals in 2005 only. Shellfish and algae samples were collected in August and beginning in 2006, shellfish were also collected in March. A summary of parameters measured and the frequency sampled for each station is provided in Tables 2-4 through 2-6.

Near the end of November 2007, a high-frequency water quality data acquisition system was installed at the Seattle Aquarium along the Seattle waterfront in Elliott Bay (station SEAQYSI). This site was chosen to be representative of inner Elliott Bay. Salinity, temperature, dissolved oxygen, turbidity, chlorophyll, and depth data are collected every 15 minutes at two depths and telemetered to a website. The top depth is approximately one meter below the water surface and the bottom depth is approximately 10 meters below the water surface. In addition, meteorological parameters (wind speed and direction, air temperature, precipitation, solar radiation, and relative percent humidity) are also collected every 15 minutes. Data are available at the following website: http://green.kingcounty.gov/marine/HiFrequency.htm. As only about a month of data were collected during 2007 at this site, results from station SEAQYSI will be discussed in the 2008 Water Quality Status Report for Marine Waters.

Table 2-4. 2005 Ambient Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH			ALGAE
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Bacteria	GWQP *	Organics	Metals	Conventionals	Metals
ITEDWARDSPT	Edwards Point	Beach				◆ 12	◆ 12				
JSUR01	Point Wells	Offshore				◆ 12	◆ 12				
JSVW04	Point Wells	Beach	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12	◆ 1	◆ 1	◆ 1	◆ 1
KSBP01	Point Jefferson	Offshore				◆ 12	◆ 12				
ITCARKEEKP	Carkeek Park	Beach				◆ 12	◆ 12				
KTHA01	Piper's Creek	Creek				◆ 12	◆ 12				
KSLU03	Golden Gardens	Beach	◆ 1	◆ 1	◆ 1	◆ 12		◆ 1	◆ 1	◆ 1	◆ 1
KSQU01	Shilshole Bay	Beach				◆ 12					
LTAB01	inner Elliott Bay	Beach				◆ 12					
LTEH02	inner Elliott Bay	Beach				◆ 12					
LTKE03	West Waterway	River				◆ 12	◆ 12				
LTUM03	Duwamish River	River				◆ 12	◆ 12				
LSGY01	Seacrest	Beach				◆ 12					
LSFX01	Duwamish Head	Beach				◆ 12					
LTED04	Elliott Bay	Offshore				◆ 12	◆ 12				
LSHV01	West Seattle	Beach				◆ 12					
LSNT01	Dolphin Point	Offshore				◆ 12	◆ 12				
LSVW01	Fauntleroy Cove	Beach				◆ 12	◆ 12				
MTLD03	Normandy Park	Beach	◆ 1	◆ 1	◆ 1	◆ 12		◆ 1	◆ 1	◆ 1	◆ 1
MSSM05	Tramp Harbor	Beach				◆ 12					
NTAK01	Saltwater St. Park	Beach	◆ 1	◆ 1	◆ 1	◆ 12					
NSEX01	East Passage	Offshore				◆ 12	◆ 12				

* GWQP = general water quality parameters. Includes nutrients, salinity, temperature, chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters. Includes nutrients, salinity, temperature for beach waters.

Shellfish conventionals include total solids and percent lipids.

Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.

Numbers indicate frequency sampled per year on a monthly basis.

Table 2-5. 2006 Ambient Stations, Parameters, and Frequency Measured

STATION	LOCATION	OFFSHORE/ BEACH	SEDIMENT			WATER		SHELLFISH	
			Organics	Metals	Conventionals	Bacteria	GWQP *	Metals	Conventionals
ITEDWARDSPT	Edwards Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
JSUR01	Point Wells	Offshore				◆ 12	◆ 12		
JSVW04	Point Wells	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSBP01	Point Jefferson	Offshore				◆ 12	◆ 12		
ITCARKEEKP	Carkeek Park	Beach				◆ 12	◆ 12		
KTHA01	Piper's Creek	Creek				◆ 12	◆ 12		
KSLU03	Golden Gardens	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSQU01	Shilshole Bay	Beach				◆ 12	◆ 12		
LTEH02	inner Elliott Bay	Beach				◆ 12	◆ 12		
LTKE03	West Waterway	River				◆ 12	◆ 12		
LTUM03	Duwamish River	River				◆ 12	◆ 12		
LSGY01	Seacrest	Beach				◆ 12	◆ 12		
LTED04	Elliott Bay	Offshore				◆ 12	◆ 12		
LSNT01	Dolphin Point	Offshore				◆ 12	◆ 12		
LSVW01	Fauntleroy Cove	Beach				◆ 12	◆ 12		
MTLD03	Normandy Park	Beach				◆ 12	◆ 12	◆ 2	◆ 2
MSSM05	Tramp Harbor	Beach				◆ 12	◆ 12		
MSWH01	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSAJ02	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSEX01	East Passage	Offshore				◆ 12	◆ 12		

* GWQP = general water quality parameters.Includes nutrients, salinity, temp., chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters. Includes nutrients, salinity, temp. for beach waters.

Shellfish conventionals include total solids and percent lipids.

Numbers indicate frequency sampled per year on a monthly basis.

Table 2-6. 2007 Ambient Stations, Parameters, and Frequency Measured

			SEDIMENT			WATER		SHELLFISH	
STATION	LOCATION	OFFSHORE/ BEACH	Organics	Metals	Conventionals	Bacteria	GWQP *	Metals	Conventionals
ITEDWARDSPT	Edwards Point	Beach				◆ 12	◆ 12	◆ 2	◆ 2
JSUR01	Point Wells	Offshore				◆ 12	◆ 12		
JSVW04	Point Wells	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSBP01	Point Jefferson	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
ITCARKEEKP	Carkeek Park	Beach				◆ 12	◆ 12		
KTHA01	Piper's Creek	Creek				◆ 12	◆ 12		
KSRU03	Salmon Bay	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
KSLU03	Golden Gardens	Beach				◆ 12	◆ 12	◆ 2	◆ 2
KSQU01	Shilshole Bay	Beach				◆ 12	◆ 12		
LTBD27	inner Elliott Bay	Beach				◆ 12	◆ 12		
LTEH02	inner Elliott Bay	Beach				◆ 12	◆ 12		
LTAA02	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LSCW02	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LSHZ08	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTCA02	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTDF01	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
KSZY01	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTGF01	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1				
LTED04	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
LTKE03	West Waterway	River				◆ 12	◆ 12		
LTUM03	Duwamish River	River				◆ 12	◆ 12		
LTTL02	Duwamish River	River				◆ 12	◆ 12		
LSGY01	Seacrest	Beach				◆ 12	◆ 12		
LSHV01	Alki Beach	Beach				◆ 12	◆ 12		
LSKS01	Richey Viewpoint	Beach				◆ 12	◆ 12		
LSLT02	Mee-Kwa-Mooks	Beach				◆ 12	◆ 12		
LSML01	Central Basin	Offshore	◆ 1	◆ 1	◆ 1				
LSNT01	Dolphin Point	Offshore				◆ 12	◆ 12		
LSVV01	Fauntleroy Cove	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
LSVW01	Fauntleroy Cove	Beach				◆ 12	◆ 12		
MTEC01	Seahurst Park	Beach				◆ 12	◆ 12		
MTLD03	Normandy Park	Beach				◆ 12	◆ 12	◆ 2	◆ 2
MSSM05	Tramp Harbor	Beach				◆ 12	◆ 12		
MRUW01	Lisabuela Pk	Beach				◆ 12	◆ 12		
MTUJ01	Des Moines Pk	Beach				◆ 12	◆ 12		
MSXK01	Burton Acres	Beach				◆ 12	◆ 12		
MTXA01	Point Robinson	Beach				◆ 12	◆ 12		
MSVK01	Quartermaster Hbr.	Offshore	◆ 1	◆ 1	◆ 1				
MSWH01	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSAJ02	Quartermaster Hbr.	Offshore				◆ 12	◆ 12		
NSEX01	East Passage	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12		
NTFK01	Redondo Beach	Beach				◆ 12	◆ 12		
NSJY01	Dumas Bay	Beach				◆ 12	◆ 12		

* GWQP = general water quality parameters. Includes nutrients, salinity, temp., chlorophyll, dissolved oxygen, solids, transparency, photosynthetically active radiation for offshore waters.Includes nutrients, salinity, temp. for beach waters. Numbers indicate frequency sampled per year.

Shellfish conventionals include total solids and percent lipids. Sediment conventionals include total solids, organic carbon, sulfides, ammonia, and grain size distribution.

2.2 Water Column Monitoring

Water column monitoring at outfall and ambient sites is an important component of the County's water quality monitoring program and is structured to detect natural seasonal changes in the water column as well as to identify changes from anthropogenic inputs. General water quality parameters, including temperature, salinity, transparency, dissolved oxygen, chlorophyll-*a*, pheopigment, photosynthetically active radiation, ammonia, nitrate+nitrite, total phosphorus, silica, and total suspended solids, are monitored at multiple depths at each site. Fecal indicator bacteria are monitored at all water column monitoring sites.

2.2.1 Bacteria

Biologists and agencies responsible for protecting public health define water quality in terms of several variables, including the presence of certain types of bacteria. Fecal coliforms are found in the intestinal tract and feces of humans and other warm-blooded animals. These bacteria may enter the aquatic environment directly from humans and animals, agricultural and stormwater runoff, and wastewater. Although fecal coliform bacteria are usually not pathogenic, they may occur along with disease-causing bacteria and thereby serve as an indicator of the potential for pathogens to be present. Generally, a high fecal coliform count indicates a greater possibility for pathogens to be present. Fecal coliforms are typically found in higher numbers than pathogens and are easier and safer to analyze in the laboratory.

In Washington State, regulatory standards have been established for acceptable levels of fecal coliforms for various water uses, including recreation and fish and wildlife habitat. It should be noted that although fecal coliforms are commonly used as an indicator for the presence of pathogens, there are limitations to the use of these data. There is no recognized numeric association between the number of fecal coliforms and the number of pathogenic bacteria measured in a sample. In addition, the presence of viruses and naturally occurring toxic organisms (such as certain dinoflagellates) is not indicated by the presence of fecal coliforms, so these organisms must be measured independently.

Enterococci, like fecal coliforms, are also found in the intestinal tract of warm-blooded mammals and birds and are also used as an indicator for the presence of pathogens. As with fecal coliforms, there is no recognized numeric association between the amount of enterococci and the amount of pathogenic bacteria measured in a sample. The U.S. Environmental Protection Agency (EPA) recommends the use of enterococci as the indicator for potential human health risks at marine swimming beaches, however, Washington State uses fecal coliforms as the bacterial indicator organism for reasons described in Section 2.6.2. King County measures both fecal coliform and enterococci bacteria as part of the marine monitoring program.

2.2.2 Temperature and Salinity

Water temperature is an important factor in an estuary. As water temperature rises, biological and chemical activity generally increases, while the capacity of water to hold dissolved oxygen decreases. Water temperature is dependent upon various factors including depth, season, amount of tidal mixing, wind, storms, amount of freshwater input, and degree of vertical stratification.

Both temperature and salinity influence water column stratification, although salinity is more important in determining stratification in estuaries due to its effect on density. Estuaries usually exhibit changes in salinity as freshwater input increases or decreases. Salinity also fluctuates with tides, the input of high salinity water from deep Pacific oceanic water, precipitation, and degree of water column mixing from winds. Generally, salinity increases with water depth unless the estuary is well-mixed.

2.2.3 Dissolved Oxygen

Dissolved oxygen is an important factor controlling the presence or absence of marine species. Aquatic plants and animals require a certain amount of oxygen dissolved in the water for respiration and basic metabolic processes. Waters with high concentrations of dissolved oxygen are generally considered healthy ecosystems and are capable of sustaining many species of aquatic organisms.

Several factors influence dissolved oxygen concentrations. Seasonal climatic fluctuations can cause water temperature to rise in the spring and summer, reducing the capacity of water to hold dissolved oxygen. In winter, deep oceanic water from the Pacific Ocean containing naturally low levels of oxygen enters Puget Sound. Moreover, anthropogenic input of organic matter and phytoplankton decay may also decrease levels of oxygen. Most bacteria that utilize organic matter for food consume dissolved oxygen. Hypoxia results when the rate of oxygen consumption, mostly by bacteria decomposing organic material in the water column, exceeds the rate of oxygen production by photosynthesis and by replenishment at the air/water interface. When the system is overloaded with organic material, oxygen consumption by bacteria may increase to the point where conditions can no longer support marine life.

2.2.4 Transparency

Transparency, or water clarity, is measured to determine the euphotic zone, the depth at which light capable of supporting plant growth penetrates the water column. Several factors affect transparency, including the amount of suspended silt and soil particles (measured as total suspended solids) and the amount of phytoplankton and zooplankton in the water column. Silt from streams and rivers (particularly after storms) stirred up by wave action also affects transparency. Low transparency conditions that persist over an extended period of time can degrade the health of a water body as the decreased amount of light penetration reduces the area in which aquatic plants and primary producers can grow. In addition, many marine organisms

feed by filtering water and large amounts of suspended matter may obstruct their filter-feeding systems.

2.2.5 Photosynthetically Active Radiation (PAR)

Sunlight consists of a wide spectrum of wavelengths, of which only a small portion can be used for photosynthesis. This small range of light energy available for photosynthesis is in the 400 to 700 nanometer range. Photosynthetically active radiation (also referred to as light intensity) is measured at various depths throughout the water column to determine the amount of light energy available to phytoplankton, macrophytes, and some diatoms for photosynthesis. PAR is an important factor as phytoplankton and other plants can only grow in the water column where enough light penetrates to support photosynthesis. Turbidity, waves, and atmospheric conditions are factors which may affect PAR levels.

2.2.6 Nutrients

The addition of nutrients, such as nitrogen and phosphorus, into marine waters can have a considerable effect on water quality. This is particularly true in nearshore habitats where most nutrient input typically occurs. Nutrients may enter marine waters from wastewater discharges, nonpoint runoff, and riverine and oceanic sources. The greatest impact these nutrients may have is a sudden increase in aquatic plant growth.

The amount of light that penetrates the water column and the amount of nutrients in the water column affect phytoplankton growth. Nitrogen is the primary limiting nutrient that determines the growth of phytoplankton in marine waters (Valiela, 1984). Although nitrogen occurs naturally in the marine environment, increases from sources such as wastewater or fertilizers can cause increases in phytoplankton growth, particularly in areas with reduced circulation. An increase in phytoplankton biomass may cause a decline in dissolved oxygen as the phytoplankton cells respire and decay. This depression in dissolved oxygen can become critical to non-motile marine organisms. The marine waters within King County have not experienced significant eutrophication problems, mainly due to the high degree of mixing in the Central Basin of Puget Sound (PSWQAT, 2000).

Nitrogen Compounds. Nitrate, nitrite, and ammonium ion are forms of inorganic nitrogen used by phytoplankton in the aquatic environment. Nitrates and nitrites are formed through the oxidation of ammonium ion by nitrifying bacteria. As noted above, nitrogen is usually the limiting nutrient in marine waters. Therefore, an increase in nitrogen compounds could lead to phytoplankton blooms. When blooms occur, water conditions (such as reduced water clarity and dissolved oxygen) may become unfavorable for aquatic organisms. Input of nitrogen compounds may originate from sources such as wastewater from municipal discharges, stormwater runoff, septic systems, agricultural runoff, oceanic input, and atmospheric deposition.

Phosphorus. Phosphorus is an essential element for aquatic plants and a fundamental element in the metabolic process for both plants and animals. Total phosphorus includes both organic

phosphorus and inorganic phosphate. Inorganic phosphates are rapidly taken up by algae and other aquatic plants, although phosphates are usually not the limiting nutrient in marine waters. However, large inputs could cause algal blooms leading to unfavorable conditions. Potential sources of phosphorus entering the marine environment include wastewater from municipal discharges, industrial wastes, nonpoint agricultural and urban runoff, rivers and streams, and the Pacific Ocean.

Silica. Silica is a micronutrient needed by diatoms, radiolarians, some sponges, and other siliceous organisms for skeletal growth. Water column silica concentrations can be used as an indicator of plankton blooms, along with chlorophyll-*a*, as silica concentrations in the photic zone will decrease from an increase in phytoplankton uptake. Sediments act as a sink for silica, which may be regenerated by various physical and biological processes and reused by organisms on the seafloor and in overlying waters.

2.2.7 Chlorophyll and Pheopigments

Chlorophyll-*a* is a green pigment produced by algae and other green plants and used during the process of photosynthesis to convert light, carbon dioxide, and water to sugar. Chlorophyll-*a* concentration is an indicator of phytoplankton biomass since all marine planktonic algae contain this photosynthetic pigment. However, chlorophyll-*a* concentrations are not an exact measurement of phytoplankton abundance. The ratio of phytoplankton biomass to chlorophyll varies with species and environmental conditions. Pheopigments, such as pheophorbide-*a* and pheophytin-*a*, are degradation products of chlorophyll and are produced when phytoplankton cells are grazed upon by zooplankton. High concentrations of pheopigments relative to chlorophyll-*a* indicate a high level of grazing in an aquatic ecosystem. Several factors influence phytoplankton abundance including amount of solar radiation, extent of grazing, water temperature, nutrient availability, and water column stratification.

2.2.8 Water Column Sampling Methods

Field Methods. Offshore water column samples were collected by the King County Environmental Services Section in accordance with the *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissues in Puget Sound* (PSEP, 1997). The King County Laboratory also has a specific Standard Operating Procedure (SOP) for each type of field sample and data collection process that is available upon request.

Offshore water samples were collected from the *R/V Liberty*, a 42-ft research vessel equipped with a hydraulic crane on the rear deck. Water column profiles were collected using a SeaBird Electronics SBE 25 SEALOGGER conductivity-temperature-depth (CTD) profiler. Parameters measured by the CTD included temperature, salinity, light transmission, dissolved oxygen, photosynthetically active radiation (PAR), and fluorescence (an indicator of chlorophyll-*a* abundance). Density is a calculated parameter using temperature and salinity measurements. The CTD was lowered into the water using a hydraulic boom and allowed to equilibrate for five minutes at the surface before being lowered to a few meters above the seabed. Measurements were collected on the downcast. Multiple five-liter Niskin bottles were mounted onto the rosette

containing the CTD profiler for collecting discrete water samples on the upcast at predetermined depths for analysis of nutrients, total suspended solids, bacteria, and quality control samples. The rosette was electronically programmed to close individual bottles at specific depths as the system ascended through the water column. The rosette was then brought on deck and water samples were immediately drawn from the Niskin bottles and placed into appropriate sample containers. Dissolved oxygen samples were immediately preserved with liquid $MnSO_4$ (manganese sulfate) and AIA (alkali iodide azide) and stored in the dark. With the exception of dissolved oxygen bottles that were stored at ambient temperature, sample containers were stored on ice until delivered to the King County Environmental Laboratory.

The two offshore stations in Quartermaster Harbor, MSWH01 and NSAJ02, were sampled from docks rather than by boat. Dissolved oxygen and temperature at these two sites were sampled in the field using a Hydrolab. Water samples for laboratory analysis (salinity, nutrients, bacteria, chlorophyll, suspended solids) were collected using a five-liter Niskin bottle lowered by hand to the selected depth.

Transparency (water clarity) measurements were collected using a 12-inch diameter black and white Secchi disk. Secchi depths were recorded to the nearest 0.1 meter. As readings may vary depending upon environmental conditions (e.g., waves and glare), readings were taken on the shaded and downwind side of the boat to standardize results among individual field personnel and atmospheric conditions as much as possible.

Beach (intertidal) water samples were collected at approximately knee-depth by wading in the water and inverting sample containers just above the water surface, then sinking the bottle down to approximately three to six inches below the water surface. The bottles were not filled completely in order to allow room for mixing. At some sites where accessibility is difficult, such as LSGY01 located in Elliott Bay, samples were collected with a container lowered on a rope from a pier and then transferred into the sample container. Field methods and detection limits are provided in Table 2-7.

Laboratory Methods. Temperature, Secchi disk transparency, and CTD parameters were measured in the field. All other water column parameters were analyzed at the King County Environmental Laboratory. Laboratory methods and detection limits are provided in Table 2-7. Fecal coliforms and enterococci were analyzed using membrane filtration methodology according to Standard Methods 9222D and 9230C, respectively (APHA, 1998). Quality assurance/quality control procedures included the use of blanks, duplicates, and spikes when appropriate. All data were reviewed prior to entry into the LIMS (Laboratory Information Management System) database.

2.3 Sediment Monitoring

Many pollutants tend to be associated with particles that settle out onto bottom sediments. At sufficient concentrations, these compounds may be harmful to benthic organisms and may

bioaccumulate. Sediment monitoring for metals and organic pollutants is part of King County's marine monitoring program. Total solids, total volatile solids, grain size distribution, total organic carbon, ammonia, and total sulfides, referred to as conventional parameters, are also monitored as these parameters affect the bioavailability and/or toxicity of metals and organics as well as influence the concentration of pollutants accumulated. A more detailed description of why sediment conventional parameters are measured is provided below.

Table 2-7. Methods and Detection Limits for Water Samples

		Lab		Field	
Parameter	**Units**	**MDL**	**Method**	**MDL**	**Method**
Salinity	PSS	2.0	SM2520-B	na	CTD:SOP 220v3
Dissolved Oxygen	mg/L	0.5	SM4500-O-C	0.5	CTD:SOP 220v3
Temperature	^{o}C	--	--	na	CTD:SOP 220v3
PAR	µmol/sm^2	--	--	na	CTD:SOP 220v3
Light Transmission	% light	--	--	0.01	CTD:SOP 220v3
Chlorophyll-*a*	mg/m^3	0.05	EPA 445.0	0.06	CTD:SOP 220v3
Pheophytin-*a*	mg/m^3	0.1	EPA 445.0	--	--
Ammonia-Nitrogen	mg/L	0.01	SM4500-NH3-H	--	--
Nitrate+Nitrite (NO_3+NO_2)	mg/L	0.02	SM4500-NO3-F	--	--
Total Phosphorous	mg/L	0.005	SM4500-P-B,E	--	--
Silica	mg/L	0.05	SM4500-SI-D	--	--
Total Suspended Solids (TSS)	mg/L	0.5	SM2540-D	--	--
Fecal coliform	CFU/100 ml	na	SM9222-D	--	--
Enterococci	CFU/100 ml	na	SM9230-C	--	--

PSS = practical salinity scale
mg/L = milligram per liter
mg/m^3 = milligram per meter cubed
na = not applicable
CFU = colony forming unit
MDL = method detection limit

2.3.1 Total Solids

Total solids are the inorganic and organic particles remaining after a sediment sample has been dried in an oven at 103 ^{o} to 105^{o} Celsius. This parameter is measured to allow the conversion of metals and organic chemical concentrations from wet weight to dry weight for reporting uniformity.

2.3.2 Grain Size Distribution

Grain size distribution is a measure of the size range of particles contained in a given sample. Grain size is usually separated into four main categories: silt, clay, sand, and gravel. The sum of percent silt and clay is referred to as percent fines. Grain size has an influence on chemical concentrations found in sediments and sediments with a large proportion of fine particles tend to

have higher chemical concentrations. Grain size also has a large influence on benthic and infaunal community structure.

2.3.3 Total Organic Carbon

Total organic carbon is a measure of the total amount of particulate and nonparticulate organic carbon in a sample. As with grain size, total organic carbon also has an influence on chemical concentrations contained in sediments. The higher the organic carbon content, the higher some chemical concentrations tend to be. This is particularly true for organic compounds.

2.3.4 Total Sulfides

Sulfides are formed by the anaerobic breakdown of organic matter. Total sulfides represent the amount of all sulfide compounds in a given sample. They are measured as they may be toxic to some benthic organisms at low concentrations and can create unaesthetic conditions for humans.

2.3.5 Total Ammonia

Ammonia in sediments can be from natural sources as well as from anthropogenic sources, such as terrestrial runoff and atmospheric deposition of nitrogen. Naturally occurring ammonia is formed by the decomposition of organic matter by bacterial as well as from excreta from organisms living in sediments. Ammonia levels at sufficiently high concentrations may be toxic to marine organisms. are formed by the anaerobic breakdown of organic matter.

2.3.6 Sediment Sampling and Analytical Methods

Field Methods. Offshore sediment samples were collected by the King County Environmental Services Section from the *R/V Liberty*. Samples were collected with two stainless steel 0.1-m^2 modified van Veen grab samplers deployed in tandem. The sampler was decontaminated between sites by scrubbing with a brush to remove excess sediment, followed by an on-board rinsing and thorough *in situ* rinsing. If sample acceptability criteria were met, the top two centimeters of sediment from a minimum of two subsamples (grabs) were composited, homogenized, and placed in the appropriate sample containers. Sediment samples were collected in accordance with the *Puget Sound Estuary Program (PSEP) Recommended Protocols* (PSEP, 1997) and the County's *Standard Protocol for Marine Sediments* (King County, 1997).

Beach (intertidal) sediment sampling locations were determined using a measuring staff, tide chart, and an optical level to sight the proper height on the measuring staff. Samples were collected at +6.5 feet above mean lower low water (MLLW) at each location. If the appropriate tidal elevation was within an area with gravel, cobbles or boulders, then sediments without gravel/cobbles or other large objects closest to the area at the same tidal elevation were sampled instead. Sediment samples were collected using hand-held 2-inch diameter stainless steel coring

tubes. Once the required sample amount was obtained, sediments were homogenized in a stainless steel bowl before being transferred to appropriate sample containers. All sampling equipment was pre-cleaned and dedicated sampling tool sets were available for use at each station. All samples were stored on ice until submitted to the laboratory.

Laboratory Methods. The King County Environmental Laboratory analyzed all chemical parameters. Methods and detection limits are provided in Table 2-8. All metals were analyzed using inductively coupled plasma (ICP) emission spectrometry with the exception of mercury, which was analyzed using cold-vapor atomic absorption spectrophotometry (CVAA). Semivolatile organics were extracted with an organic solvent and then analyzed by gas chromatography/mass spectrometry (GC/MS). Pesticides and PCBs were extracted with organic solvents and then analyzed using a gas chromatograph equipped with an electron capture detector (ECD). Butyltins and polybrominated diphenyl ethers (PBDEs) were extracted with organic solvents and analyzed using GC/ICPMS. All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and surrogates and spikes when appropriate. All data were reviewed prior to entry into the LIMS database.

Table 2-8. Laboratory Methods and Detection Limits (wet weight) for Sediment Parameters

Parameter	Units	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Organic Carbon	mg/kg	500	SM5310-G
Total Sulfide	mg/kg	10	PSEP, 1986
Total Ammonia	mg/kg	0.2	SM4500-NH3G
Metals, total, ICP	mg/kg	variable[1]	EPA 3050/6010
Mercury, total, CVAA	mg/kg	variable[1]	EPA 7471
Semivolatile (BNA[2]) Organics	µg/kg	variable[1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable[1]	SW 846 8081/8082
PBDEs[3]	µg/kg	variable[1]	SW 846/ KC 2007
Organotins	µg/kg	0.3 [1]	Krone, 1988
Grain Size Distribution	%	0.1	PSEP, 1991

[1]Detection limits vary with parameter analyzed and/or total solids content. Detection limits for individual samples and analytes are provided in Appendix B.

[2] BNA indicates base/neutral/acid compounds

[3] PBDEs indicate polybrominated diphenyl ether compounds

2.4 Shellfish and Algae

The uptake of contaminants by marine organisms occurs through ingestion of food and detrital particles, water exchange at feeding and respiratory surfaces, and adsorption of chemicals onto body surfaces. These contaminants may be stored in skeletal material, concretions, and soft tissues (Kennish, 1998). Biological monitoring has been a component of the County's ambient

and outfall monitoring programs for many years, as contaminants may be bioaccumulated by shellfish and algae.

In 2005 and in previous years, butter clam tissues were monitored for organic and metal contaminants. These measurements provide an indication of potential health risks to both shellfish and humans that consume them. However, organic compounds were rarely detected in shellfish tissues other than benzoic acid which is a metabolic byproduct, and thus were discontinued as part of the shellfish monitoring program. Metal concentrations continue to be monitored in shellfish tissues. Percent lipids in shellfish are also monitored as this parameter provides an indication as to the seasonal state of the organism.

Algae can absorb metals directly from seawater and tissues were monitored in 2005 and in previous years to assess metal concentrations in intertidal areas. However, the algae monitoring program was discontinued in 2006 due to sampling challenges and resultant data that provided limited use.

2.4.1 Shellfish and Algae Sampling Methods

Field Methods. The King County Environmental Services Section collected shellfish samples. Butter clams (*Saxidomus giganteus*) from each sampling station were collected by hand digging with shovels in the vicinity of siphon holes. A tarp was placed next to the digging site and excavated sediment was placed on the tarp to minimize disturbance to other organisms. The sediment was replaced after clams of sufficient size were removed. After the required number of clams was obtained, they were placed in four-liter glass jars and stored on ice until delivered to the laboratory. As organic compounds were no longer analyzed beginning in 2006, clams were placed into plastic bags and then stored on ice until laboratory delivery. A minimum of five butter clams with a shell length between 60 to 120 millimeters were collected at each station and composited into a single sample for analyses.

In 2005, algae samples were collected by the King County Environmental Services Section. Samples of attached, healthy *Ulva fenestrata* (sea lettuce) were collected and placed in 250 ml acid-washed plastic specimen cups. Discolored, dried, or free-floating algae were not collected. The sampling strategy was to collect only the most prevalent edible algae wherever possible and there was sufficient *Ulva fenestrata* at all the sampling stations to adhere to this strategy. After the required amount of algae was obtained, the containers were stored on ice until delivered to the laboratory.

Laboratory Methods. Shellfish samples were processed at the King County Environmental Laboratory in accordance with PSEP recommended protocols (PSEP, 1997). Before the clams were opened, the shells were rinsed with deionized water to remove sand and other adhering material. Each clam was measured and the lengths recorded. Tissue from each clam was removed with ceramic scalpels, composited with their liquor, and then homogenized in a sterilized blender equipped with stainless steel blades. Samples were frozen until analyzed.

Algae samples were processed at the King County Environmental Laboratory. Algae were rinsed with deionized water to remove sand and other material adhering to the plant blades. Samples from each station were processed in a blender equipped with titanium blades. Samples were then frozen until analyzed.

The King County Environmental Laboratory analyzed all shellfish and algae parameters. Methods and detection limits are provided in Table 2-9. With the exception of mercury, all metals were analyzed using ICP and/or ICP-MS depending upon detection limit requirements. Mercury was analyzed using cold-vapor atomic absorption spectroscopy. Semi-volatile organics were extracted with an organic solvent and analyzed by GC/MS. Pesticides and PCBs were extracted with organic solvents and then analyzed using a GC equipped with an ECD. Quality assurance/quality control procedures included the use of blanks, duplicates, surrogates, and spikes when appropriate. All data were reviewed prior to entry into the LIMS database.

Table 2-9. Laboratory Methods and Detection Limits for Shellfish and Algae

Parameter	Units	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Lipids	%	0.1	KCEL OR 07-01-001
Metals, total, ICP	mg/kg	variable[1]	PSEP (1997)
Metals, total, ICP-MS	mg/kg	variable[1]	PSEP (1997)
Mercury, total, CVAA	mg/kg	0.004	PSEP (1997)
Semivolatile Organics	µg/kg	variable[1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable[1]	SW 846 8081/8082

[1]Detection limits vary with parameter analyzed. Detection limits for individual samples and analytes are provided in Appendices C and D.

2.5 Regulatory Standards

The focus of federal water quality guidelines and state water quality standards is human health and the health of aquatic organisms. These guidelines were promulgated largely as a result of the widespread use of pesticides and other chemical compounds and the overall increase in concerns about water quality in Puget Sound. Washington State implements wildlife-based water quality standards along with human health-based standards for surface waters. When permitting point source discharges, Ecology also considers technology-based standards in the context of whether those technology-based standards will be protective of aquatic life and human health.

Current marine sediment standards are derived from the Apparent Effects Threshold (AET) method (EPA, 1988). This method compares measured chemistry values with associated biological effect data to arrive at empirically-derived chemical concentrations that predict when adverse biological effects should occur. Chemical concentrations below the standard values are

predicted to have "no adverse effect". The criteria for marine sediments were developed primarily to protect benthic invertebrates, with the assumption that such criteria would also be protective of other species.

The use of bacterial indicators and water and sediment quality criteria are used to evaluate data obtained from monitoring programs. Water quality management decisions can then be based upon these findings. In addition to their use as assessment tools, environmental quality guidelines provide a basis for the development of site-specific water quality objectives for environmental contaminants. These guidelines may also be used to identify the need for source controls to reduce the input of contaminants into marine waters.

The Clean Water Act requires the States to adopt federal water quality criteria or develop their own standards which afford equal or better protection to receiving waters. Washington State has promulgated both water and sediment quality standards.

2.5.1 Washington State Standards for Marine Surface Waters

Washington State currently has numeric marine surface water quality standards for conventional pollutants (ammonia, chlorine, and cyanide) and some toxics (metals, pesticides, and PCBs) (WAC 173-201A). These standards were derived for the protection and propagation of fish, shellfish, and other aquatic life. Water quality standards for conventional pollutants and toxics in marine surface waters are provided in Table 2-10.

Marine water quality standards were revised by Ecology in late 2003. Marine standards for conventional pollutants and toxics did not change from those previously published, however, there were changes to the water use classification system. Prior to the 2003 update, Washington State surface waters were divided into five classes: AA, A, B, C, and Lake. Currently, the letter designations are no longer used and recreational water use is divided into primary contact recreation and secondary contact recreation categories. Other use designations include aquatic life (for fish and other aquatic species), shellfish harvesting, and miscellaneous uses such as wildlife habitat, commerce and navigation, boating, and aesthetics. Aquatic life use is further categorized into extraordinary quality, excellent quality, good quality, and fair quality. EPA partially approved the revisions in early 2005, which included approval of the use designations and freshwater bacteria criteria. However, the EPA did not approve selected components and in 2006 Washington State revised those standards not previously approved. EPA formally approved the 2006 Water Quality Standards in February 2008.

2.5.2 Washington State Standards for Fecal Coliforms

Washington State has marine surface water quality bacteria standards, based upon fecal coliforms. These standards were derived for the protection of human health, including protection from primary and secondary contact recreation, as well as from consumption of shellfish. As stated above, the Washington Department of Ecology (Ecology) proposed revisions to the state water quality standards in 2003. Proposed changes to the bacterial standards included the use of

Table 2-10. Washington State Marine Surface Water Quality Standards

Contaminant	Marine Water Quality Standard		Contaminant	Marine Water Quality Standard	
Trace Metals (µg/L)	**Acute**	**Chronic**	**Semivolatile Organic Compounds (µg/L)**	**Acute**	**Chronic**
Arsenic[a]	69.0	36.0			
Cadmium [a]	42.0	9.3	Pentachlorophenol	13.0	7.9
Chromium VI[a]	1100.0	50.0	Total PCBs	10.0	0.030
Copper [a]	4.8	3.1			
Lead [a]	210.0	8.1			
Mercury	1.8[a]	0.025[b]			
Nickel [a]	74.0	8.2	**Other (µg/L)**		
Selenium[a]	290	71.0	Ammonia [c] (mg/L)	0.233	0.035
Silver [a]	1.9	---	Chlorine (residual)	13.0	7.5
Zinc [a]	90.0	81.0	Cyanide (weak dissoc.)	1.0	---
Pesticides (µg/L)					
Aldrin/Dieldrin	0.71	0.0019			
Chlordane	0.09	0.004			
Chloropyrifos	0.011	0.0056			
DDT (and metabolites)	0.13	0.001			
Endosulfan	0.034	0.0087			
Endrin	0.037	0.0023			
Heptachlor	0.053	0.0036			
Lindane	0.16	---			
Toxaphene	0.21	0.0002			

[a] Criteria are based on the dissolved fraction of the metal.
[b] Criterion is based on the total recoverable fraction of the metal.
[c] Criterion is based on un-ionized ammonia.
Source: Ecology, 2006.

enterococci as the marine indicator organism rather than fecal coliforms, and that the period of averaging for obtaining the geometric mean should not exceed a 12-month period. Following a public comment period and economic feasibility analysis, Ecology determined that fecal coliforms would continue to be the marine bacterial indicator and the numeric criteria would not change from those previously published. An additional revision to the standards was to the water use classification system. The formerly Class AA marine water standard is now the primary contact recreation standard and the formerly Class A freshwater standard is now the primary contact freshwater standard. Fecal coliform counts in samples collected from both marine water and freshwater for both the ambient and outfall monitoring programs are compared with the primary contact recreation standards.

EPA proposed changes for marine surface water bacteriological criteria as part of revisions to the Water Quality Standards for Coastal and Great Lakes Recreation Waters. These national water quality standards are applicable to states without approved state water quality standards. The proposed changes incorporated the use of enterococci as an indicator of bacterial contamination in marine waters for the protection of human health. Ecology submitted data to the EPA consisting of paired samples of fecal coliform and enterococci measurements collected in Puget Sound (including King County data), the Strait of Juan de Fuca, and Pacific Ocean embayments.

Ecology requested that EPA consider keeping the State's current fecal coliform criterion since Ecology deemed the current criterion to be as protective of human health as the proposed enterococci criteria . In November 2004, EPA reviewed the data and determined that the existing Washington State fecal coliform criterion is as protective of human health as the proposed enterococci criterion and that the State was excluded from complying with the national standards proposed by EPA.

Thus, the existing fecal coliform geometric mean standard of 14 CFU/100 ml with no more than ten percent of the samples used to calculate the geometric mean exceeding 43 CFU/100 ml is the current primary contact marine water bacteria standard. The approved use designations along with the numeric criteria are provided in Table 2-11.

One part of the State fecal coliform standards is expressed as a geometric mean value. The reason for this is the high variability in fecal coliform counts, as bacteria tend to clump and adhere to particulates in water and to multiply exponentially. Transforming the data using natural logarithms can reduce this variability. This reduces the apparent differences between very high and very low numbers and simplifies plotting the data by numerically compensating for the exponential growth rate of bacteria. Results obtained from King County's monitoring programs are expressed as a moving geometric mean to facilitate comparisons with State bacteria standards. This value is obtained by taking the geometric mean value for the 12 most recent samples. As the period of averaging cannot exceed a 12-month period and samples are collected on a monthly basis, the geometric mean is calculated with 12 values. Any value reported as zero was assigned a value of one in the geomean calculation.

As well as the moving geometric mean standard, no more than 10 percent of the samples used to obtain the moving geometric mean value may exceed a defined upper limit. For the primary contact recreation (formerly Class AA) marine water standard this value is 43 colonies/100 ml and 100 colonies/100 ml for the corresponding freshwater standard. As the revisions to the bacteria standards have been approved by the regional EPA office, geometric means will be reported using the 12 most recent monthly samples.

2.5.3 Washington State Standards for Sediment

Chemicals may occur in sediment as part of the natural environment. Sediment may also become contaminated by industrial and municipal discharges, atmospheric deposition, and other non-point sources. Sediment quality guidelines provide a means of assessing sediment quality which leads to informed management decisions regarding sediments and overlying waters.

In 1991, Ecology promulgated the Sediment Management Standards (SMS) which contain numeric criteria for specific organic compounds and metals (Table 2-12). The standards specify, based on the best available knowledge, the concentrations of sediment contaminants at which no adverse effects to marine organisms are expected. These standards are derived from the Puget Sound Apparent Effects Thresholds (AETs) for selected compounds, which are based on biological testing results (EPA, 1988). Concentrations of compounds that do not exceed the SMS values are not expected to have long-term adverse effects on marine biological resources.

Table 2-11. Fecal Coliform Standards (colonies/100 ml)

Class	Moving Geometric Mean	Peak[a]
Primary Contact Recreation:		
Freshwater	100	200
Marine	14	43
Secondary Contact Recreation:		
Freshwater	200	400
Marine[b]	70	208
Extraordinary primary contact recreation		
Freshwater	50	100

[a] Not more than 10 percent of the samples used to calculate the geometric mean may exceed this value.
[b] Standard is based upon enterococci bacteria.

Source: Ecology, 2006.

The standards for metals and ionizable organic compounds are presented on a dry weight basis (the wet weight concentration divided by the decimal fraction of the total solids value), while the nonionizable organic compounds are organic carbon normalized (the dry weight concentration in µg/Kg divided by the dry weight total organic carbon content in mg/Kg multiplied by 1000).

In general, organic compounds, which make up the largest class of chemicals of concern, are associated with the organic matter contained in sediments. The nonpolar, nonionizable organic compounds (such as chlorinated hydrocarbons, aromatic hydrocarbons, and phthalates) have a tendency to adhere to organic matter in water and sediments whereas substances that form ions (such as salts, acids, bases, phenols, and metals) are soluble and therefore dissolve in water.

Organic matter in sediment is a food source for many benthic organisms (organisms that live on or near bottom sediments). Too little organic matter will not support these organisms and too much will reduce the number and/or diversity of organisms due to natural toxic effects associated with enhanced microbial activity. The organic carbon content of sediments has been shown to be related to the bioavailability and toxicity of some organic compounds to aquatic organisms (Di Toro et al., 1991). Grain size affects the amount of organic carbon contained in sediments with predominantly silt/clay sediments usually containing higher amounts of organic carbon than sandy sediments due to fine-grained sediments having a greater amount of surface area for adsorption of organic matter.

The presence of contaminants in sediment does not necessarily indicate that the sediment is toxic to marine organisms. An important factor in determining toxicity is how much of a compound is available for uptake directly into an organism or accumulated through the food chain. The toxicity of organic compounds in sediments appears to be more closely correlated to the concentration of organic carbon in the sediments rather than the dry weight concentration. Thus, a more accurate measure of contaminant toxicity is obtained if the data are "normalized" for the

Table 2-12. Washington State Sediment Standards

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Metals	**mg/kg dry weight**	
Arsenic	57	
Cadmium	5.1	
Chromium	260	
Copper	390	
Lead	450	
Mercury	0.41	
Silver	6.1	
Zinc	410	
Nonionizable Organic Compounds	**mg/kg organic carbon**	**µg/kg dry weight**
Total LPAHs [a]	370	5200
Naphthalene	99	2100
Acenapthylene	66	1300
Acenapthene	16	500
Fluorene	23	540
Phenanthrene	100	1500
Anthracene	220	960
2-Methylnaphthalene	38	670
Total HPAHs [b]	960	12000
Fluoranthene	160	1700
Pyrene	1000	2600
Benzo(*a*)anthracene	110	1300
Chrysene	110	1400
Total Benzofluoranthenes	230	3200
Benzo(*a*) pyrene	99	1600
Indeno(1,2,3-*c*,*d*)pyrene	34	600
Dibenzo(*a*,*h*)anthracene	12	230
Benzo(*g*,*h*,*i*)perylene	31	670

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Nonionizable Organic Compounds	**mg/kg organic carbon**	**µg/kg dry weight**
1,2-Dichlorobenzene	2.3	35
1,4-Dichlorobenzene	3.1	110
1,2,4-Trichlorobenzene	0.81	31
Hexachlorobenzene	0.38	22
Dimethyl phthalate	53	71
Diethyl phthalate	61	200
Di-n-butyl phthalate	220	1400
Butyl benzyl phthalate	4.9	63
Bis (2-ethylhexyl) phthalate	47	1300
Di-n-octyl phthalate	58	6200
Dibenzofuran	15	540
Hexachlorobutadiene	3.9	11
N-Nitrosodiphenylamine	11	28
Total PCBs	12	130
Ionizable Organic Compounds	**mg/kg dry weight**	
Phenol	0.42	
2-Methylphenol	0.063	
4-Methylphenol	0.67	
2,4-Dimethylphenol	0.029	
Pentachlorophenol	0.36	
Benzyl alcohol	0.057	
Benzoic acid	0.65	

[a] Represents the sum of the following low molecular weight PAHs: Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, and Anthracene.

[b] Represents the sum of the following high molecular weight PAHs: Fluoranthene, Pyrene, Chrysene, Benz(*a*)anthracene, Benzo(*a*)pyrene, total Benzofluoranthenes, Indeno(1,2,3-*c*,*d*)pyrene, Dibenzo(*a*,*h*)anthracene, and Benzo(*g*,*h*,*i*)perylene.

Source: Ecology, 1995

total organic carbon (TOC) content. For this reason, the State standards for nonionizable organics are based upon concentrations that have been TOC normalized (Michelson, 1992). However, when TOC values are very low (e.g. <0.2 %) it is not appropriate to normalize contaminant values as even background levels may exceed regulatory standards. When the TOC content is less than 0.5%, dry weight values are more appropriate to use than organic carbon normalized values (Michelson, 1992). These dry weight sediment concentrations are then compared to Puget Sound *Lowest Apparent Effects Thresholds* (LAETs), which are effects-based values, deemed to be protective of benthic infauna (EPA, 1988).

2.5.4 Standards for Biota

In addition to contaminants found in water and sediment, several contaminants have the potential to accumulate in the tissues of aquatic biota, such as fish and shellfish. Bioaccumulation in biota may affect not only the species directly accumulating the contaminants, but humans and other species that consume the affected organisms. Numerical tissue-residue guidelines provide a basis for assessing the hazards that tissue-laden contaminants pose to human health and wildlife, and therefore, a basis for regulating contaminant inputs into the environment. Ecology does not currently have tissue-residue standards, however, heavy metal concentrations in shellfish samples were compared with the Food and Drug Administration (FDA) guidelines listed in Table 2-13 that were established for the protection of human health.

Table 2-13. FDA Levels of Concern in Shellfish Tissues

	mg/Kg wet weight
	Level of Concern
Arsenic	55
Cadmium	3
Chromium	11
Lead	0.8
Nickel	80
	Action Level
Mercury	1.0

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SECTION 3
Summary of Water Monitoring Data

This section summarizes water data collected between 2005 and 2007 from the ambient and outfall monitoring programs.

Data for individual stations and by parameter are provided in Appendix A. Station locator maps are provided in Section 2 along with specific information such as matrix, parameters, and frequency measured. Station coordinates are presented in Appendix F.

A summary of results for specific parameters (e.g., salinity, bacteria) are provided in this section. Also included in this section is a summary of climate data as precipitation and air temperature can affect water column results and fecal indicator bacteria levels.

3.1 2005-2007 Climate Data

Precipitation data measured at the Sea-Tac International Airport station (station #24233) were obtained from the National Climatic Data Center. Precipitation data measured at Vashon Island were obtained from the Vashon Island Treatment Plant on the eastern side of the island and Boeing Creek (station # 43U) data were obtained from the King County hydrologic data website at http://green.kingcounty.gov/WLR/Waterres/hydrology/GaugeTextSearch.aspx. Precipitation data at three separate sites located in King County are presented as rainfall patterns can vary dependent upon location. The three sites are representative of location-dependent rainfall patterns. Vashon Island, particularly the northern end, tends to receive higher amounts of precipitation than other areas within King County. The Boeing Creek station is located near the eastern Puget Sound shoreline, just south of Richmond Beach.

In terms of precipitation, 2005 was a typical year when compared to the 30-year average with a total annual rainfall of 35.44 inches at the Sea-Tac station. The total amount of rainfall in 2007 (38.95 inches) was also typical and just above the 30-year average. However, in 2006 there was a total of 48.42 inches of rain which was more than 15 inches above the 30-year average (Figure 3-1). The amount of rainfall that fell in 2006 was the second highest on record since 1969. In 2006, over 11 and 15 inches of rain fell in January and November, respectively. For 2005 and 2006, the total annual rainfall was 31.21 inches and 44.68 inches at the Boeing Creek respectively. The gage malfunctioned towards the end of 2007, therefore, the annual total is not available for this site. Between 2005 and 2007, the total annual rainfall at the Vashon Island TP station was 42.32 inches, 62.83 inches, and 45.48 inches, respectively. As stated above, Vashon Island receives more rainfall than other areas within King County and received, on average, more than 6.7 inches of rain than Sea-Tac in 2005 and 2007 and received over 14 inches more than Sea-Tac in 2006. Monthly rainfall totals for all three sites is provided in Figure 3-2.

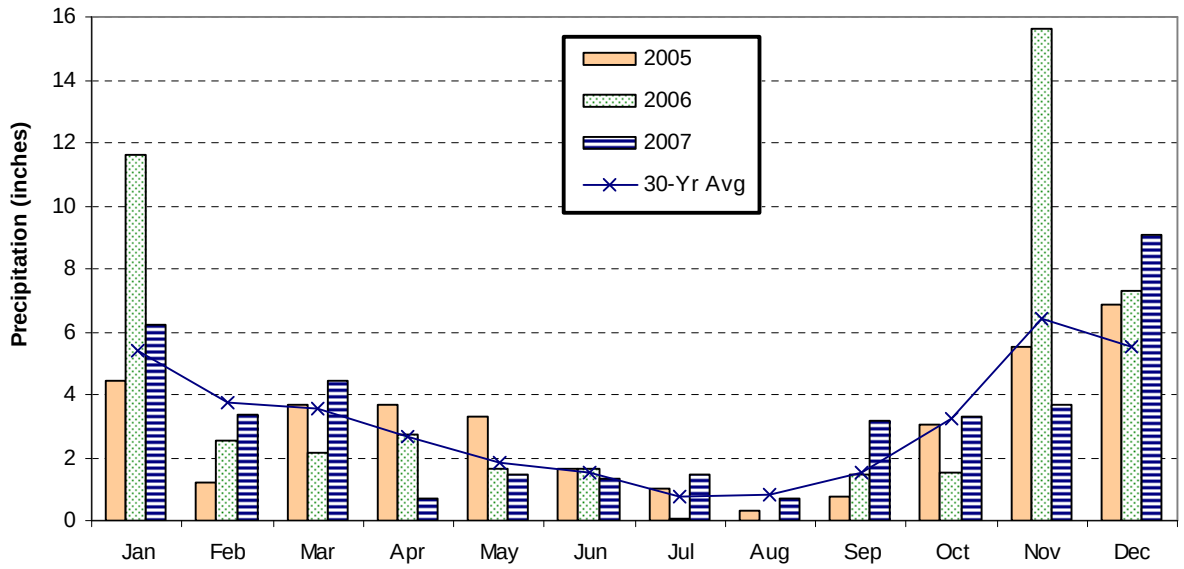

Figure 3-1. Total Monthly Precipitation at Sea-Tac Airport

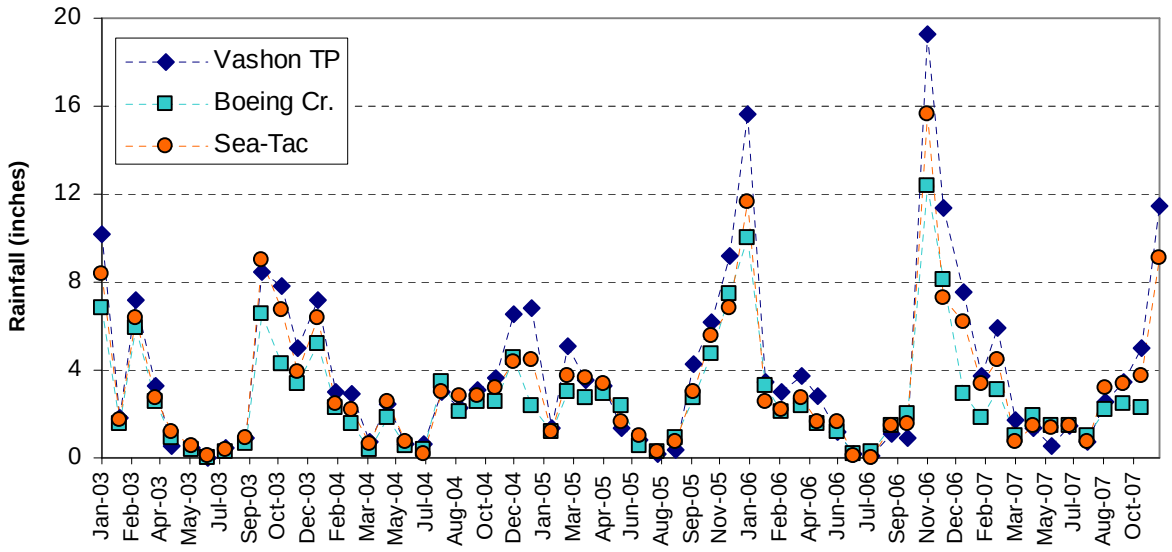

Figure 3-2. Monthly Precipitation at Three Locations in King County

Air temperature is also recorded at the Sea-Tac Airport. Average monthly air temperatures in 2005 were fairly typical when compared to the 30-year (yr) average, with slightly warmer spring temperatures. Although 2006 had a much warmer January and warmer May through September than the 30-yr average, February through April were slightly cooler than the 30-yr average as was October through December. Cooler air temperatures near the end of 2006 carried over into January 2007. The middle of 2007 was typical when compared to the 30-yr average, with cooler temperatures from June through the end of the year.

Around September 2006, a mild El Niño event (a warming episode of Pacific Ocean waters) developed in the Pacific Ocean and dissipated in early 2007. Warmer air temperatures preceding this El Niño event were apparent in June and July 2006. Although there were no days in 2005 with air temperatures above 90 ^{o}F, there were five days in 2006 with temperatures above 90^{o}F, four of which occurred in July and one in June. One day in 2007 (July) had an air temperature above 90 ^{o}F. Figure 3-3 shows average daily air temperatures for July between 2005 and 2007 and Figure 3-4 shows the departure from normal air temperatures for June.

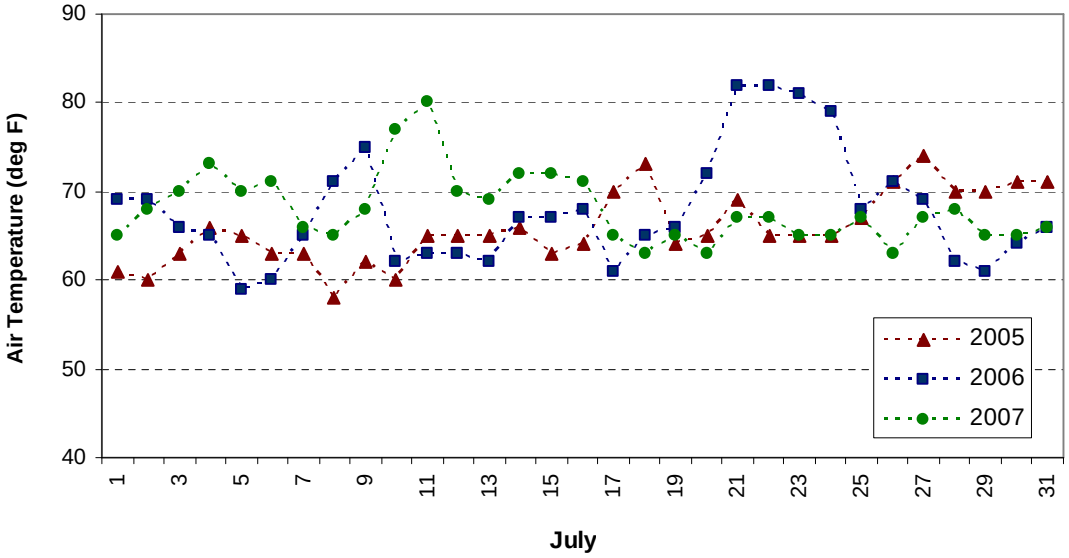

Figure 3-3. Average Daily Air Temperatures at Sea-Tac for July

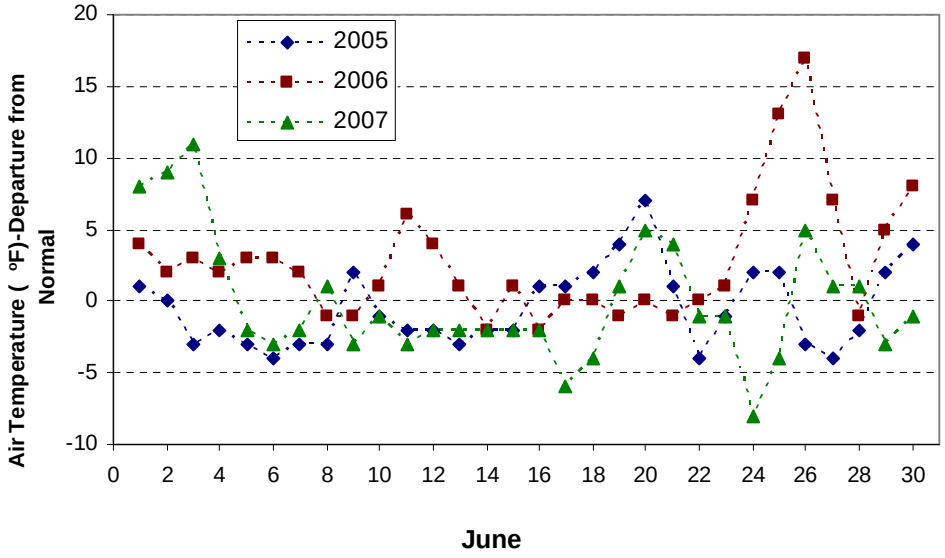

Figure 3-4. Departure from Normal Air Temperatures at Sea-Tac for June

3.2 Water Column Data Results

Water column sampling is a major component of the County's water quality monitoring program and includes offshore and beach sites (see sample locations in Section 2). The monitoring program is structured to detect natural seasonal changes in the water column and to identify anthropogenic inputs and influences.

Water quality parameters, including temperature, salinity, dissolved oxygen, total suspended solids, Secchi disk transparency, fluorescence (indicator of chlorophyll-*a*), pheophytin, photosynthetically active radiation, and nutrients (ammonia, nitrate+nitrite, and total phosphorus) were measured at all offshore stations in between 2005 and 2007 (see matrix tables in Section 2). Turbidity was measured at offshore stations in 2005 and transmissivity measured in 2006 and 2007 due to a method change. Temperature, salinity and nutrients were measured monthly at beach stations.

Fecal indicator bacteria (fecal coliforms and enterococci) were monitored monthly at all stations between 2005 and 2007.

3.2.1 Bacteria

Fecal coliforms and enterococci were monitored at all water stations. Washington State primary contact recreation fecal coliform standards for surface marine waters (formerly Class AA designation) state that organism counts shall not exceed a geometric mean value of 14 colonies/100 mL, and not more than 10 percent of the samples used to calculate the geometric mean may exceed 43 colonies/100 mL. Freshwater standards for primary contact recreation (formerly Class A designation) state that organism counts shall not exceed a geometric mean value of 100 colonies/100 mL, and not more than 10 percent of the samples used to calculate the geometric mean may exceed 200 colonies/100 mL. Freshwater standards for secondary contact recreation (formerly Class B designation) state that organism counts shall not exceed a geometric mean value of 200 colonies/100 mL, and not more than 10 percent of the samples used to calculate the geometric mean may exceed 400 colonies/100 mL. Marine fecal coliform standards are used in the evaluation of all stations except for the freshwater station located in Piper's Creek, which is compared to the secondary contact freshwater fecal coliform standards.

Geometric mean values are calculated from the 12 most recent surface (1 meter) samples. Revisions to Ecology's water quality standards recommend that the period of averaging not exceed 12 months. The monitoring program collects samples on a monthly basis, so the data are averaged over a 12-month period and geometric mean values should be interpreted accordingly.

Offshore Waters. As in previous years, all offshore outfall and ambient sites met both the geometric mean and peak standards for fecal coliforms between 2005 and 2007 (Tables 3-1 to 3-3). Most values for offshore waters were either 1 colony forming unit (CFU)/100 ml or not detected (Figure 3-5). Fecal coliform counts at the South TP and West Point TP outfalls were similar to the counts at the ambient stations.

Table 3-1. Summary of 2005 Offshore Station Compliance with Fecal Coliform Standards—Surface Waters at 1 M

Station	Meets Primary Contact Recreation Marine Surface Water Standards												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
CK200P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSK02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTBC43	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LSEP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKQ06	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJN02	--	--	--	--	--	--	--	--	--	--	--	Y	YES
Ambient													
JSUR01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
KSBP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTED04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSNT01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NSEX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

Table 3-2. Summary of 2006 Offshore Station Compliance with Fecal Coliform Standards—Surface Waters at 1 M

Station	Meets Primary Contact Recreation Marine Surface Water Standards												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
CK200P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSK02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTBC43	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
RT625NP	--	--	--	--	--	--	--	--	--	--	--	Y	YES
RT625SP	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LSKQ06	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJN02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
Ambient													
JSUR01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSBP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTED04	--	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSNT01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSWH01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	Y	YES
NSEX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

Table 3-3. Summary of 2007 Offshore Station Compliance with Fecal Coliform Standards—Surface Waters at 1 M

Station	Meets Primary Contact Recreation Marine Surface Water Standards												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
CK200P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSK02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTBC43	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSEP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKQ06	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJN02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
Ambient													
JSUR01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSBP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSRU03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTED04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSNT01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSWH01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NSAJ02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NSEX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

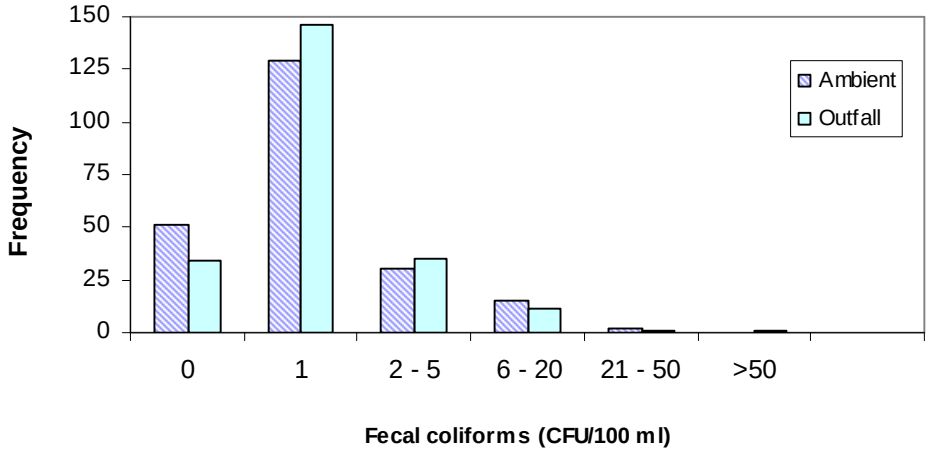

Figure 3-5. 2005-2007 Offshore Water Fecal Coliform Counts at 1 M

Fecal coliform counts at the Elliott Bay and Quartermaster Harbor stations tended to be higher more frequently than the other stations located in the Central Basin. The Elliott Bay stations had a higher proportion of values in the 6 to 50 CFU/100 ml range than the other stations. Table 3-4 shows the percentage of samples with various fecal coliform counts.

Enterococcus counts were similarly low with most surface samples (61%) having either no detectable levels or a value of 1 CFU/100 mL (17%). The highest enterococcus counts occurred in November 2006 at the West Point outfall station and December 2007 at the two Elliott Bay stations. Figure 3-6 shows enterococcus results for all offshore stations between 2005 and 2007 and Figure 3-7 shows enterococcus results plotted against concurrent fecal coliform values.

Table 3-4. Percentage of 2005-2007 Offshore Station Fecal Coliform Values in Various Categories

	Value (CFU/100 ml)						Total # of
Station Location	**0**	**1**	**2 - 5**	**6 - 20**	**21 - 50**	**>50**	**Samples**
Elliott Bay	0%	41.7%	29.2%	25%	4.2%	0%	72
Quartermaster H.	21.7%	45.6%	17.4%	15.2%	0.0%	0.0%	46
All other offshore	22.2%	66.5%	10.7%	0.3%	0.0%	0.3%	337

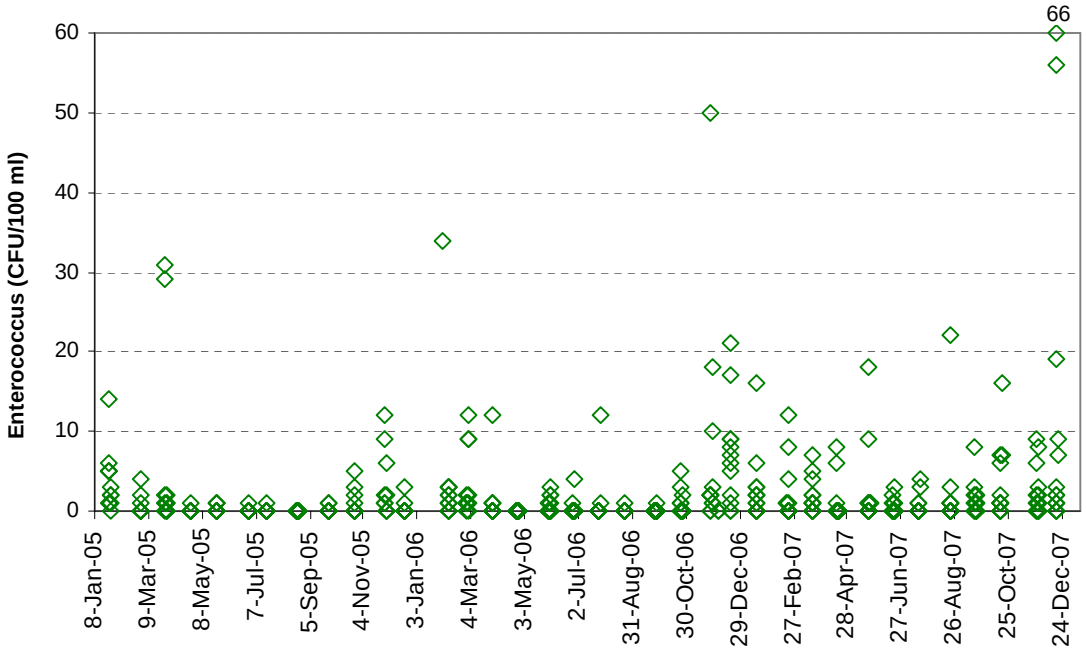

Figure 3-6. 2005-2007 Offshore Station Surface Water Enterococcus Counts (n=476)

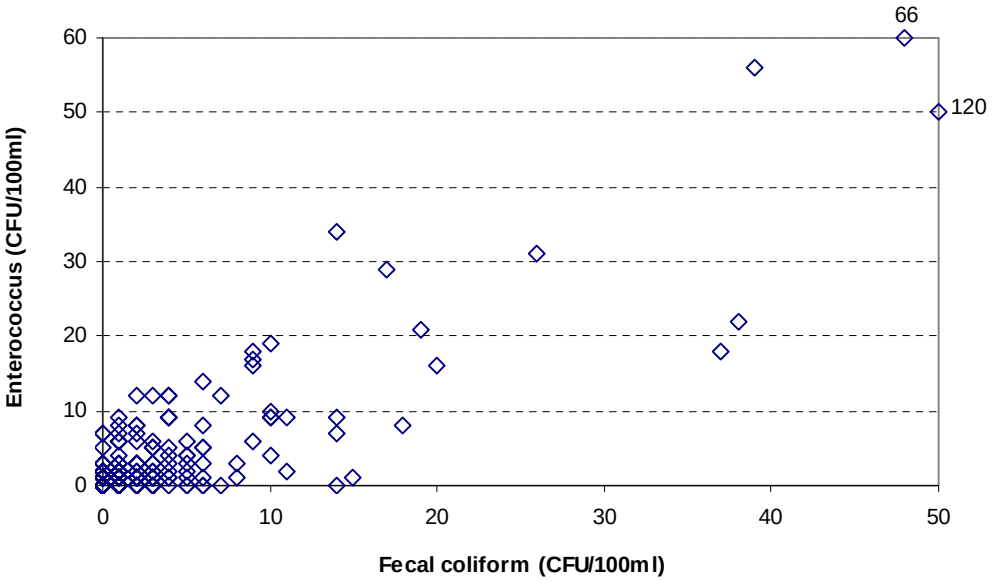

Figure 3-7. 2005-2007 Offshore Station Surface Water Paired Fecal Coliform and Enterococcus Counts

The low numbers of fecal indicator bacteria seen in offshore surface water samples between 2005 and 2007, as well as in previous sampling years, are explained by the low survival rates of fecal indicator bacteria in estuarine waters (Rhodes and Kator, 1988) in addition to distance from nearshore sources of bacteria. An EPA-sponsored study also supports these data results as it showed that the greatest single determinant of fecal indicator level is distance from the shoreline at which the sample was collected (Wymer *et al.*, 2005).

Beach Waters. Fecal coliform levels at beach stations are more variable than offshore stations due to their varying degrees of proximity to freshwater sources. Tables 3-5 through 3-7 provide a summary of station results between 2005 and 2007. Of the 15 stations monitored in all three years, 2 passed both standards all years (KSSN04 and MSSM05) and 3 failed either one of both standards all years (KSLU03, KSQU01, and LTEH02). Stations KSLU03, KSQU01, and LTEH02 have also consistently failed standards in the past as these sites are near a freshwater bacteria source. The other 10 stations varied from year to year with respect to standards compliance. As in previous years, no spatial patterns were detected in fecal coliform distributions from north to south. Additionally, no seasonal patterns were apparent. The highest fecal coliform counts were observed January of 2005 and 2006, particularly at stations near a freshwater source. The sampling dates in these months corresponded with major precipitation events within two days prior to sampling.

Eight stations were added to the beach sampling program in 2007 to increase spatial coverage within King County. Of the eight stations, five passed both fecal coliform standards and two failed both standards. The two sites that failed standards were Des Moines Creek Park and Redondo. The Redondo station, NTFK01, had consistently high bacteria counts from May through August. The geometric mean for NTFK01 was 40 CFU/100 mls and was calculated in

December using 12 sample results for the year. This geometric mean value was the highest of any of the marine beaches sampled between 2005 and 2007. The reason for high bacteria counts at this site is not evident but will be investigated further in 2009.

To rank the extent of fecal coliform levels at King County marine monitoring stations, a Frequency of Exceedence (FOE) Index was calculated for the all beach and offshore stations at which sufficiently consistent data had been collected for non-seasonally biased geometric mean determination. This index was modified from the Washington State Department of Health's fecal coliform index developed by Tim Determan. The FOE index is a weighted average that is calculated by tabulating the monthly geometric mean and ninetieth percentile (peak) values for each month on a yearly basis. Each value is then replaced by a weighting factor based on state water quality guidelines.

Table 3-5. Summary of 2005 Beach Station Compliance with Fecal Coliform Standards

	Meets Primary Contact Recreation												
	Moving Geometric Mean [a]												**Peak [b]**
Station	**(≤14 CFU/100 mL)**												**(43 CFU/100 mL)**
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	
Outfall													
KSHZ03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**N**	**N**	**NO**
KSSN04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSN05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKR01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJL01	**N**	**N**	**N**	**N**	**N**	Y	Y	**N**	Y	Y	**N**	**N**	**NO**
Ambient													
ITEDWARDSPT	Y	Y	Y	Y	Y	**N**	**N**	Y	Y	Y	Y	Y	**NO**
JSVW04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
ITCARKEEKP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KTHA01 [c]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSLU03	**N**	**N**	**N**	**N**	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
KSQU01	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LTAB01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTEH02	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LSGY01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
LSFX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
LSKS01	**N**	**N**	**N**	**N**	**N**	**N**	Y	Y	**N**	**N**	**N**	**N**	**NO**
LSHV01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSVW01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MTLD03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSSM05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NTAK01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a] The geometric means were calculated using the 12 most recent fecal coliform values.

[b] The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

[c] Values were compared to the freshwater secondary contact fecal coliform standards.

Table 3-6. Summary of 2006 Beach Station Compliance with Fecal Coliform Standards

Station	Meets Primary Contact Recreation												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
KSHZ03	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
KSSN04	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
KSSN05	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
LSKR01	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
LSKS04	--	--	--	--	--	--	--	--	--	--	--	**N**	**NO**
MSJL01	**N**	--	**N**	**N**	Y	Y	Y	Y	Y	Y	--	Y	YES
Ambient													
ITEDWARDSPT	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
JSVW04	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
ITCARKEEKP	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
KTHA01 [c]	Y	--	Y	Y	Y	Y	Y	Y	**N**	**N**	--	**N**	**NO**
KSLU03	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
KSQU01	**N**	--	**N**	**N**	**N**	**N**	Y	Y	Y	Y	--	**N**	**NO**
LTEH02	**N**	--	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	--	**N**	**NO**
LSGY01	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
LSVW01	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
MTLD03	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
MSSM05	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES

[a] The geometric means were calculated using the 12 most recent fecal coliform values.

[b] The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

[c] Values were compared to the freshwater secondary contact fecal coliform standards.

The FOE index for each station is determined by calculating the arithmetic mean of the weighted factors for each station.

The weighting factors for calculating the FOE index are defined as follows:

Weighting factor	Definition
0	Value is less than 0.5X the water quality guideline
0.5	Value is greater than 0.5X and less than 1X the water quality guideline
1	Value is greater than 1X and less than 2X the water quality guideline
2	Value is greater than 2X and less than 3X the water quality guideline
3	Value is greater than 3X the water quality guideline

Table 3-7. Summary of 2007 Beach Station Compliance with Fecal Coliform Standards

Station	Meets Primary Contact Recreation												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
KSHZ03	Y	Y	Y	Y	Y	Y	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
KSSN04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSN05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
LSKR01	Y	Y	Y	Y	Y	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
MSJL01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
Ambient													
ITEDWARDSPT	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
JSVW04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
ITCARKEEKP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
KTHA01 [c]	**N**	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
KSLU03	Y	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
KSQU01	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	Y	**NO**
LTBD27	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LTEH02	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LSGY01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSHV01	--	--	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKS01	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LSLT02	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LSVW01	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N	**NO**
MTEC01	Y	Y	Y	Y	Y	Y	Y	**N**	**N**	Y	Y	Y	**NO**
MTLD03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
MSSM05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MRUW01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
MTUJ01	--	--	--	--	--	--	--	--	--	--	--	**N**	**NO**
MSXK01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
MTXA01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
NTFK01	--	--	--	--	--	--	--	--	--	--	--	**N**	**NO**
NSJY01	--	--	--	--	--	--	--	--	--	--	--	Y	**NO**

[a] The geometric means were calculated using the 12 most recent fecal coliform values.

[b] The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

[c] Values were compared to the freshwater secondary contact fecal coliform standards.

The results of ranking stations by the FOE index calculated between 2005 and 2007 are shown in Figure 3-8. The Redondo station, NTFK01, exhibited a twofold exceedence of the geometric mean bacteria guideline and a threefold exceedence of the peak guideline. The stations at Des Moines Creek Park (MTUJ01), Elliott Bay off Pier 48 (LTEH02), and Dumas Bay (NSJY01) also frequently exceeded the bacteria guidelines. All offshore stations, including the outfall stations, had the lowest FOE index for fecal coliforms.

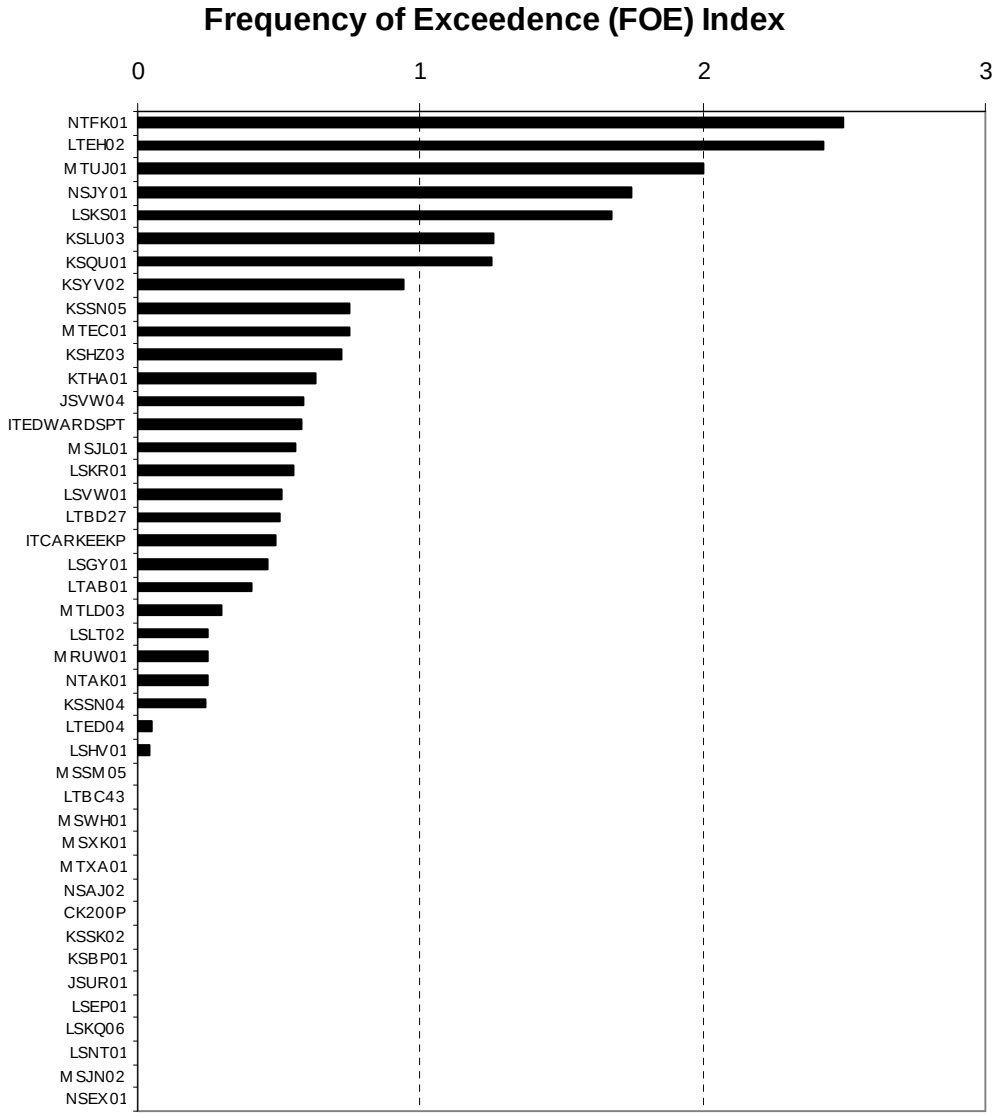

Figure 3-8. 2005-2007 FOE Index

Enterococcus counts at beach stations varied geographically and temporally. Values were generally highest in the winter months, although high counts were observed in the summer months at some locations. Correlation between fecal coliform and enterococcus counts varied considerably from location to location. Figure 3-9 shows enterococcus counts between 2005 and

2007 at all marine beach stations. The highest counts were seen at the Seattle waterfront station, LTEH02, followed by the Redondo station, NTFK01. The enterococcus counts at sites in the vicinity of outfalls were either similar to or lower than ambient stations. The counts near the outflow of Piper's Creek (station KSHZ03) were significantly higher than values at the site just north (ITCARKEEKP) and outside the influence of Piper's Creek.

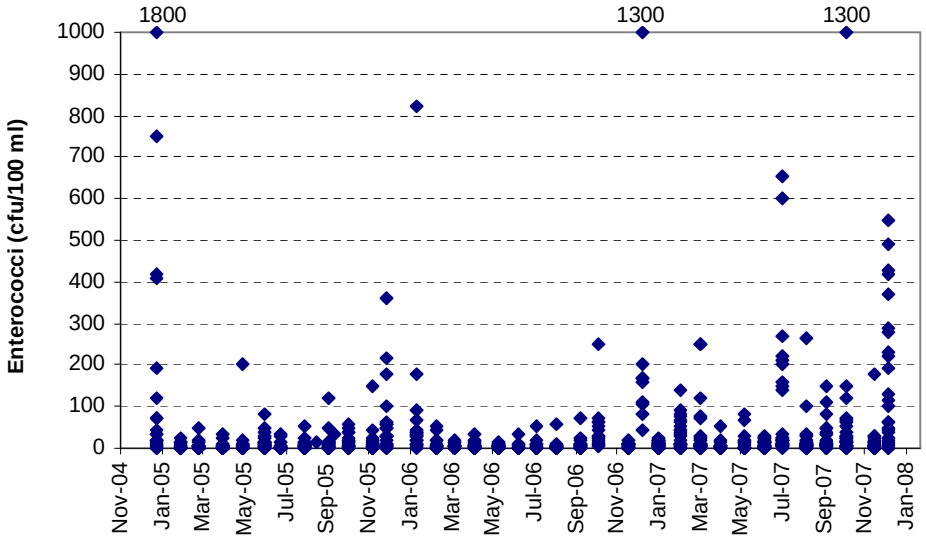

Figure 3-9. 2005-2007 Enterococcus Counts at Beach Stations

3.2.2 Water Temperature

Offshore Stations. Monthly temperature measurements were taken throughout the water column from the surface to just above the seafloor at each offshore station. For offshore stations sampled in 2005, 2006, and 2007, temperatures ranged from 4.6 to 19.5 °C (including data from all depths), with the greatest temperatures found at or near the surface. The mean temperature between 2005-2007 was 10.5 °C, which is similar to the mean temperature of 10.7 °C in 2004. Temperatures ranged in 2005 from 4.9 to 15.6 °C (mean = 10.7°C), in 2006 from 7.4 to 19.5 °C (mean = 10.6 °C), and in 2007 from 4.6 to 18.9 °C (mean = 10.2 °C). For all three years, the warmest temperatures were measured in surface waters in July. In 2006 and 2007, the warmest temperatures were seen at the shallow Quartermaster Harbor stations (NSAJ02 and MSWH01) and in 2005 at station KSBP01. The coldest temperature was also seen in Quartermaster Harbor.

The average air temperature for the month of July for 2005, 2006, and 2007 was 65.6, 67.5, and 67.8 °F, respectively. Air temperatures heavily influences sea surface temperatures and this relationship can be seen during the summer months in many of the offshore stations (Figures 3-10 and 3-11). This relationship was especially pronounced in 2006 due to the onset of El Niño conditions midway through the year. Figure 3-12 shows the changing steepness of the June thermocline over the course of the three years for stations CK200P, KSBP01, and LTED04.

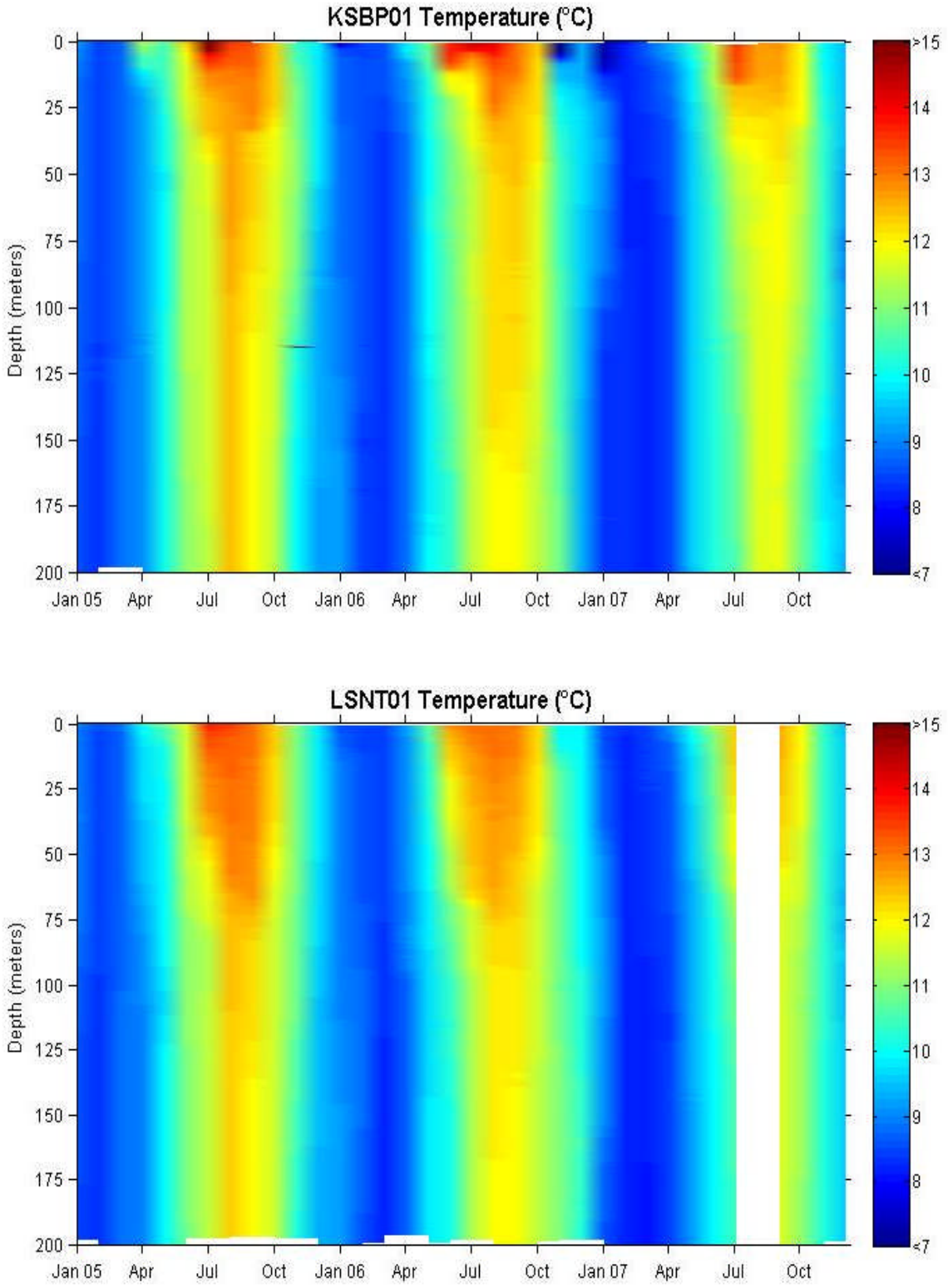

Figure 3-10. 2005-2007 Temperature Variations at Stations KSBP01 and LSNT01

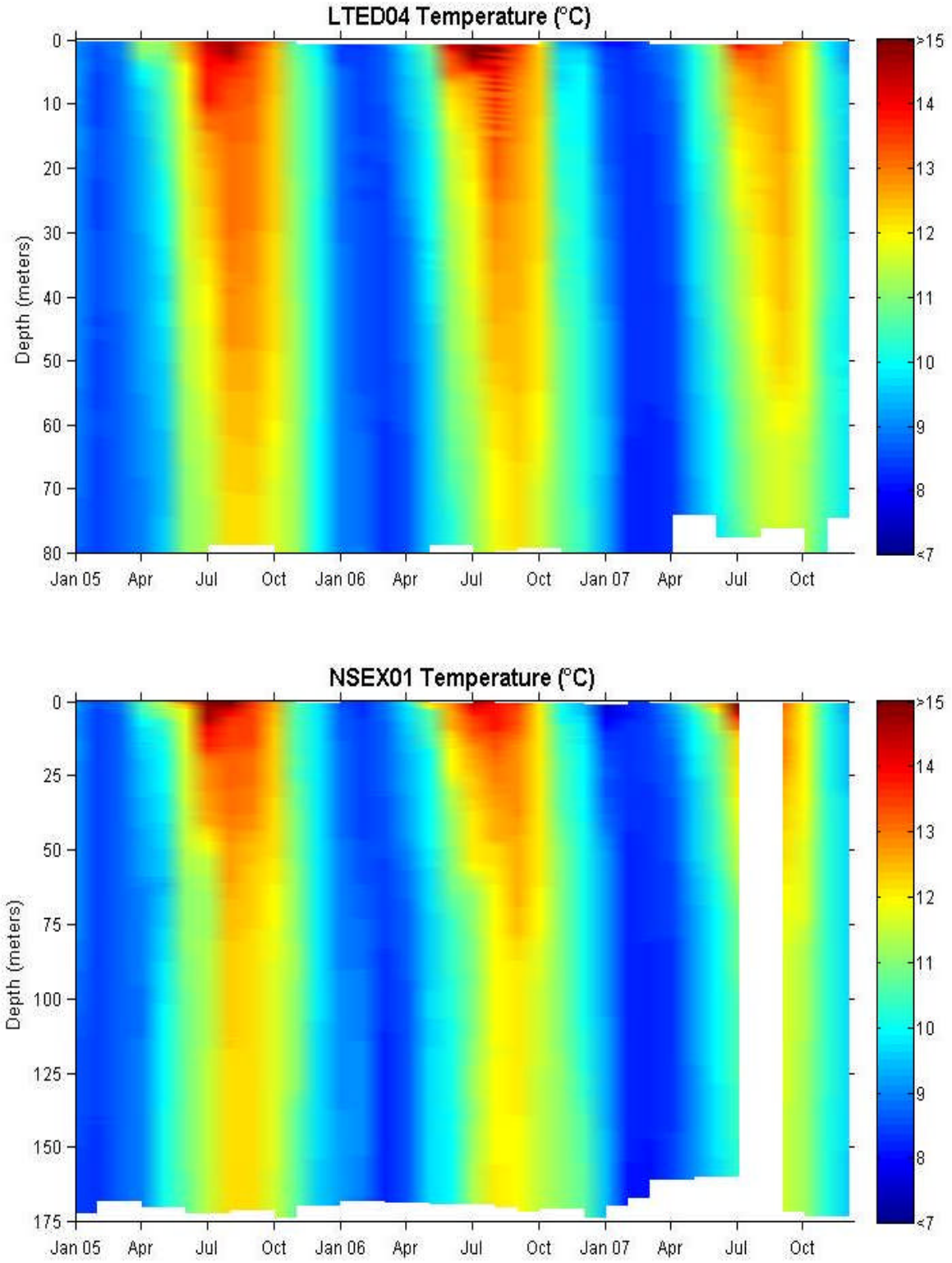

Figure 3-11. 2005-2007 Temperature Variations at Stations LTED04 and NSEX01

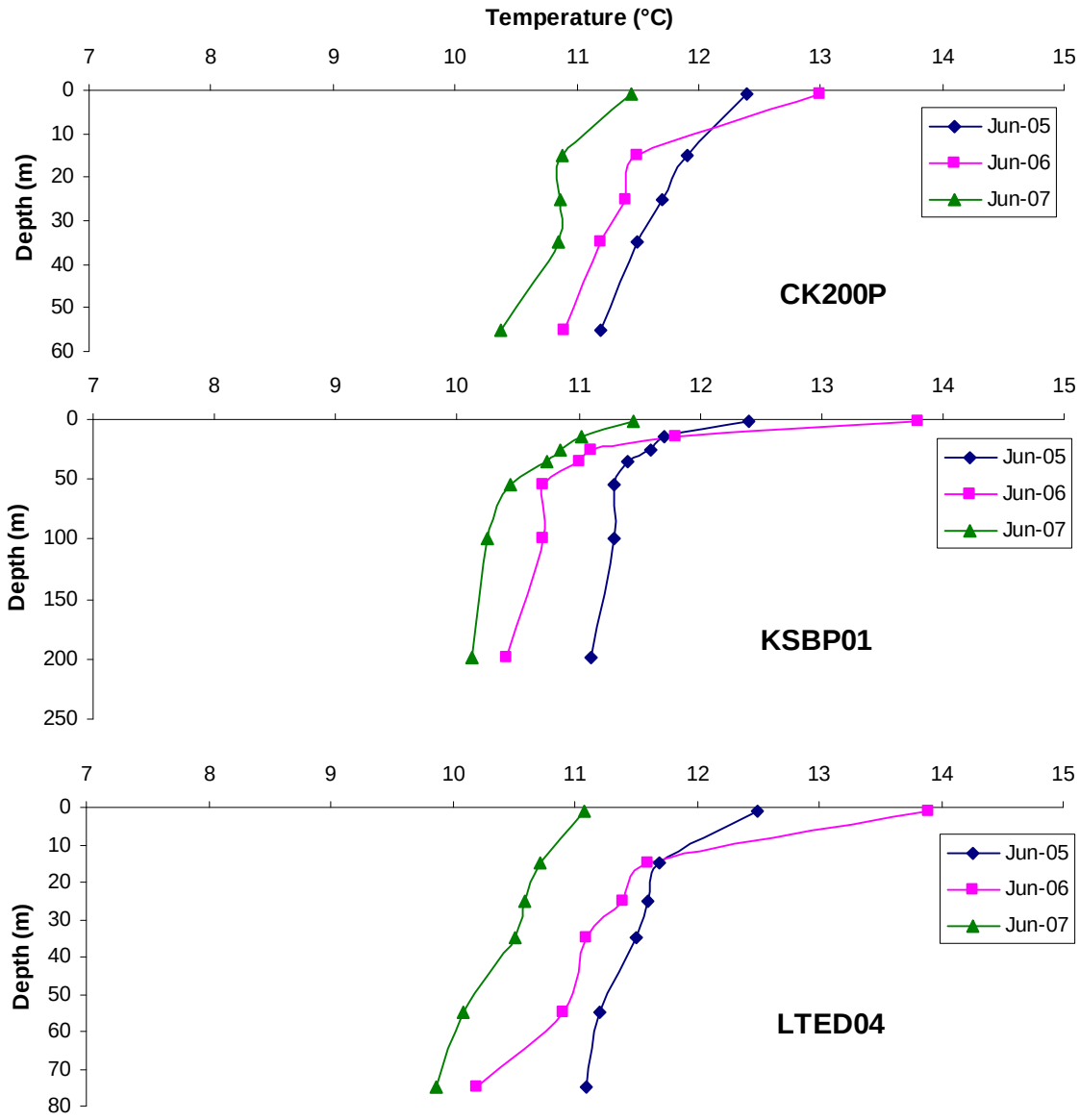

Figure 3-12. 2005-2007 June Temperatures for Selected Offshore Stations

In all three years, a seasonal thermocline (a depth range over which temperature decreases rapidly with depth) developed sometime between April and June at several of the offshore stations, particularly at stations CK200P and KSPB01. The thermoclines were much more pronounced in 2006 than in 2005 and 2007, likely due to El Niño conditions in mid-2006. By May, the thermoclines had developed more fully and extended deeper into the water column. By June, the temperature gradients in the upper water column had reached near maximum and began

to decrease in July and August as the water temperature of the deeper water increased. By October the water column was well-mixed and thermoclines were no longer evident.

Water temperatures measured over the three year period shown in Figures 3-10 and 3-11 for stations KSBP01, LSNT01, and NSEX01 are typical for offshore waters in the Central Basin, excluding Elliott Bay. As shown in Figure 3-11, the warm waters in Elliott Bay during the summer months extend deeper through the water column than at other sample sites. With the exception of the summer months, the figures indicate a well-mixed water column throughout the year. Temperature values at discrete depths are provided in Appendix A.

***Beach Stations*.** Temperatures at beach stations ranged from 6.9 to 19.3 °C (mean = 11.6 °C) in 2005, from 7.6 to 19.2 °C (mean = 11.3 °C) in 2006, and from 4.1 to 18.3 °C (mean = 11.0 °C) in 2007. As shown in Figure 3-13, temperatures varied dependent upon location sampled. Temperature data for beach stations are provided in Appendix A.

Between 2005 and 2007, water temperatures were lower at the Vashon Island station MSJL01, which is influenced by freshwater runoff from Gorsuch Creek. Station KSQU01 located at the exit of the Lake Washington Ship Canal near Shilshole Bay had some of the highest overall water temperatures. This station is highly influenced by freshwater exiting Lake Washington and Lake Union through the Ship Canal.

During the winter months, the coldest temperatures were observed at stations with the most freshwater input: Shilshole Bay (KSQU01), Piper's Creek (KTHA01), and the Seattle Waterfront (LTEH02). In January 2007, the Burton Acres station (MSXK01) in Quartermaster Harbor had the coldest temperature observed of 4.1 ^{o}C. Ice was observed floating on the surface in inner Quartermaster Harbor when samples were collected in January 2007.

During the summer months, the two Vashon Island stations generally had the lowest temperatures. Although the Shilshole Bay station had colder temperatures during the winter months, this station had some of the highest temperatures during the summer months. As stated above, this station is highly influenced by the warm Lake Washington waters exiting through the Ship Canal.

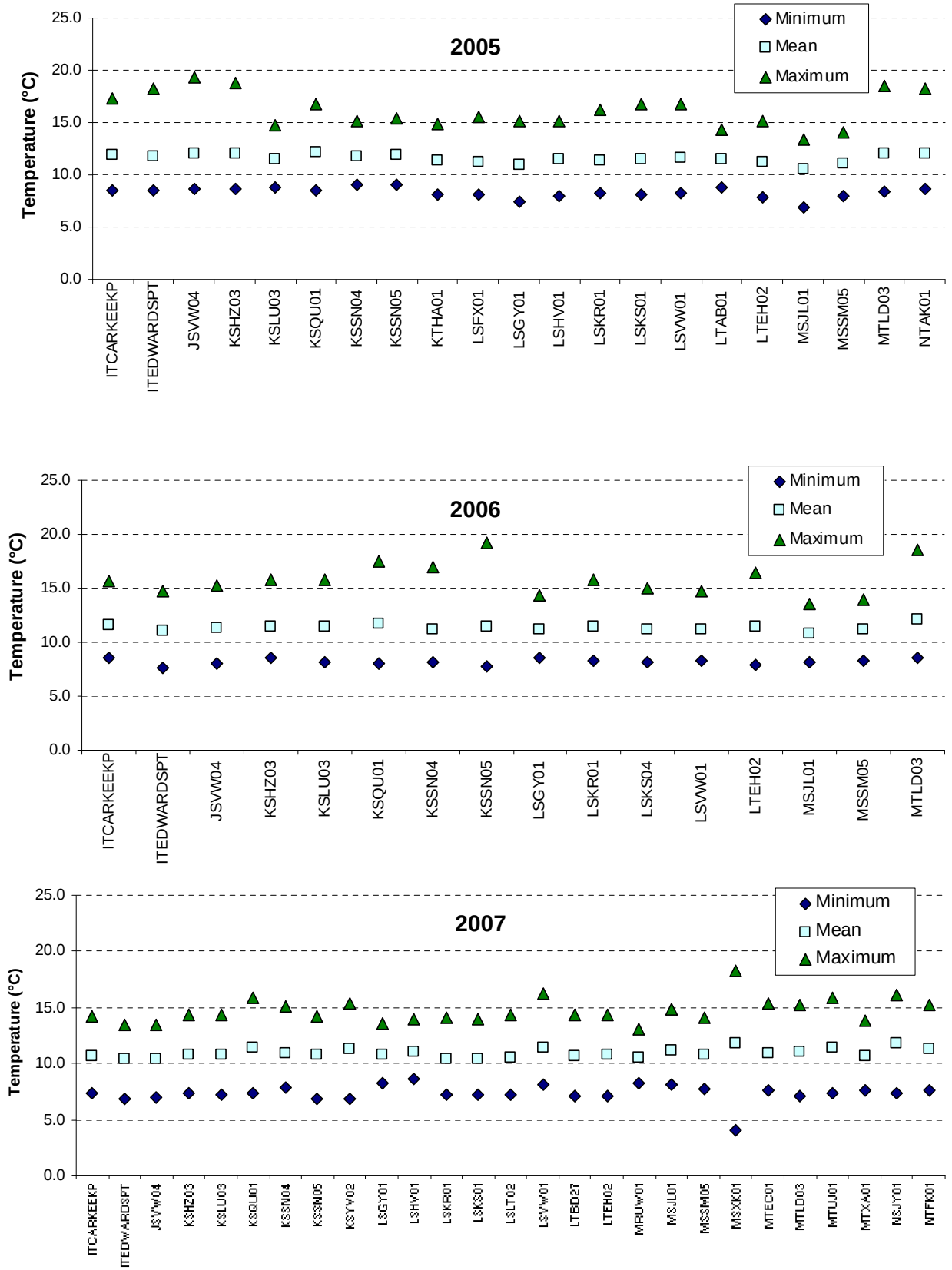

Figure 3-13. Water Temperature at Beach Stations from 2005 to 2007

3.2.3 Salinity and Density

Offshore Salinity. Salinity measurements were collected throughout the water column at all offshore stations. For offshore stations sampled in 2005, 2006, and 2007, salinities ranged from 14.85 to 31.06 on the Practical Salinity Scale (PSS), with a mean salinity of 29.65 PSS. Salinities ranged in 2005 from 26.86 to 30.97 PSS (mean = 29.91 PSS), in 2006 from 23.60 to 31.08 PSS (mean = 29.57 PSS), and in 2007 from 14.85 to 30.74 PSS (mean = 29.47 PSS). Low salinity values occurred in surface waters of various stations for all three years, where river input and heavy rain events can be strong influencing factors. The highest salinities for all three years were found offshore at depths greater than 150 m during the month of October. This may be attributed to the increased input of salty deep oceanic water upwelled along the Pacific coast and entering Puget Sound during late summer and fall. Salinity values at discrete depths are provided in Appendix A for offshore stations.

Salinities varied due to seasonal influences as shown in the vertical salinity profiles for stations CK200P and KSSK02 (Figure 3-14). Apart from the surface layer where wide ranges were observed, salinity showed little variability over the depth profile indicating a well-mixed water column. In 2005, the lowest salinities were found in the surface waters of Elliott Bay (stations LTBC43 and LTED04) primarily due to freshwater runoff from the Duwamish River following rain events and summer snow melt. In 2006, the lowest salinities occurred at the northern Central Basin stations (KSBP01, KSSK02, JSUR01). Station KSBP01 (Jefferson Head) had a salinity value of 23.60 PSS in November 2006, which can be attributed to the 15.63 inches of rain experienced that month. Stations KSSK02 and JSUR01 (West Point Outfall and Point Wells) had salinity values of 24.95 and 25.53 PSS, respectively, in early February 2006 which can also be attributed to large rain events. A total of 11.65 inches of rain was recorded in January 2006, with over 3 inches falling within the last four days of the month.

In 2007, the lowest salinities occurred at station KSRU03 (outer Salmon Bay) which is located on the marine (west) side of the Hiram Chittendum Locks. Salinities were recorded as low as 14.85, 16.28, and 16.63 PSS in the months of March, April and December, respectively, which is due to input of freshwater from Lake Washington and rain events during those months. Besides station KSRU03, low salinities occurred at the usual Elliott Bay stations (LTBC43 and LTED04). Generally, salinities were highest from August to December, likely from an increased contribution of saltier, deep Pacific Ocean water from upwelling along the outer coast during late summer in combination with a decrease in freshwater input from rivers and runoff.

Salinity profiles between 2005 and 2007 are shown in Figures 3-15 and 3-16 for four selected stations throughout the Central Basin. Overall, the figures indicate a well-mixed water column throughout much of the year, particularly from November through January. Development of a halocline (a rapid change in salinity with depth) occurs in the winter and spring for reasons described previously. The halocline is more defined at station LTED04 due to the greater influence of freshwater at this location compared to the other three stations. A strong decrease in salinity can be seen in January of 2006 at all four stations due to major rain events that month. The cycle of coastal upwelling and its influence upon the waters of Puget Sound is seen as a deep, salty signal in late summer and fall of each year.

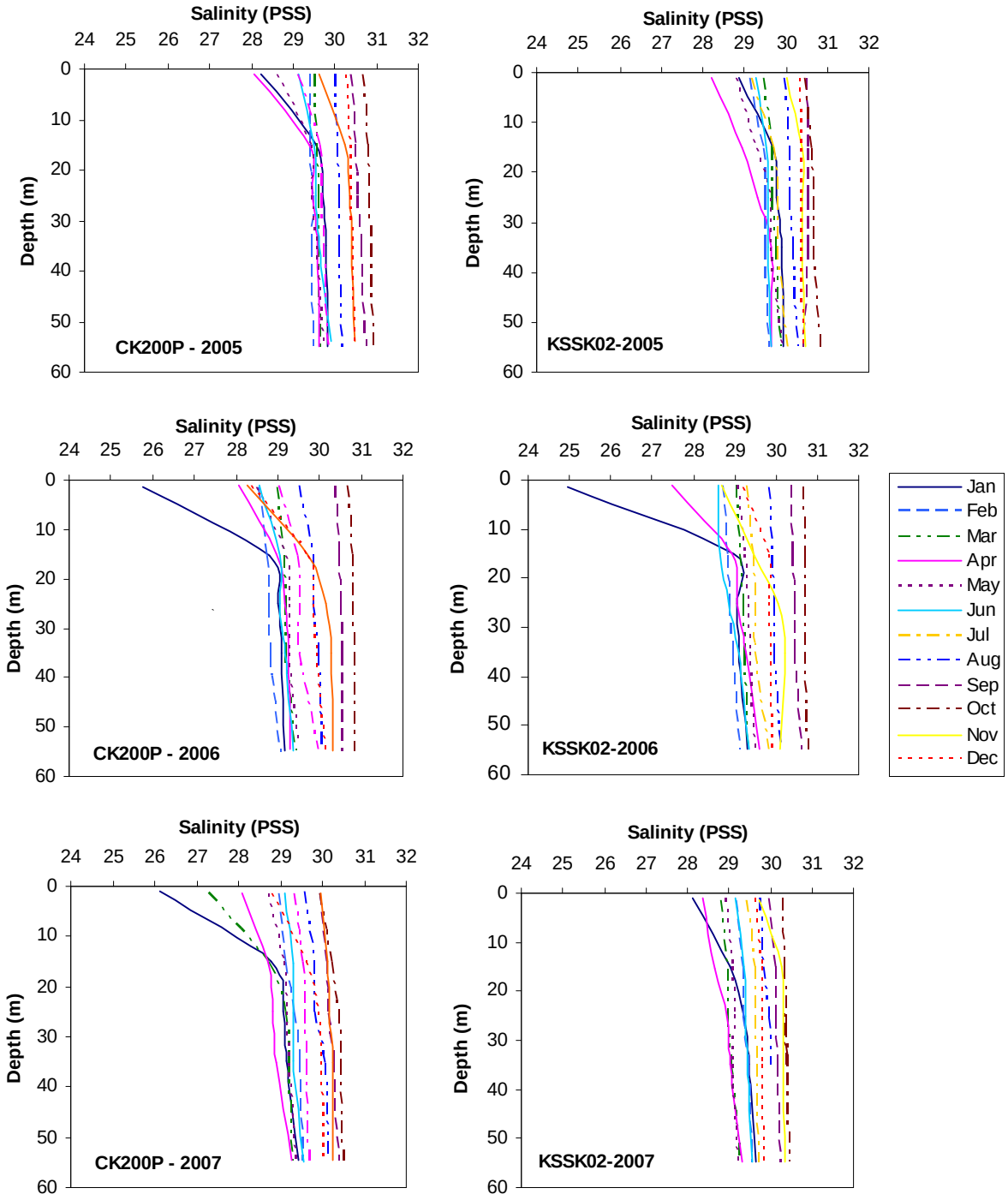

Figure 3-14. 2005-2007 Vertical Salinity Profiles from Stations CK200P and KSSK02

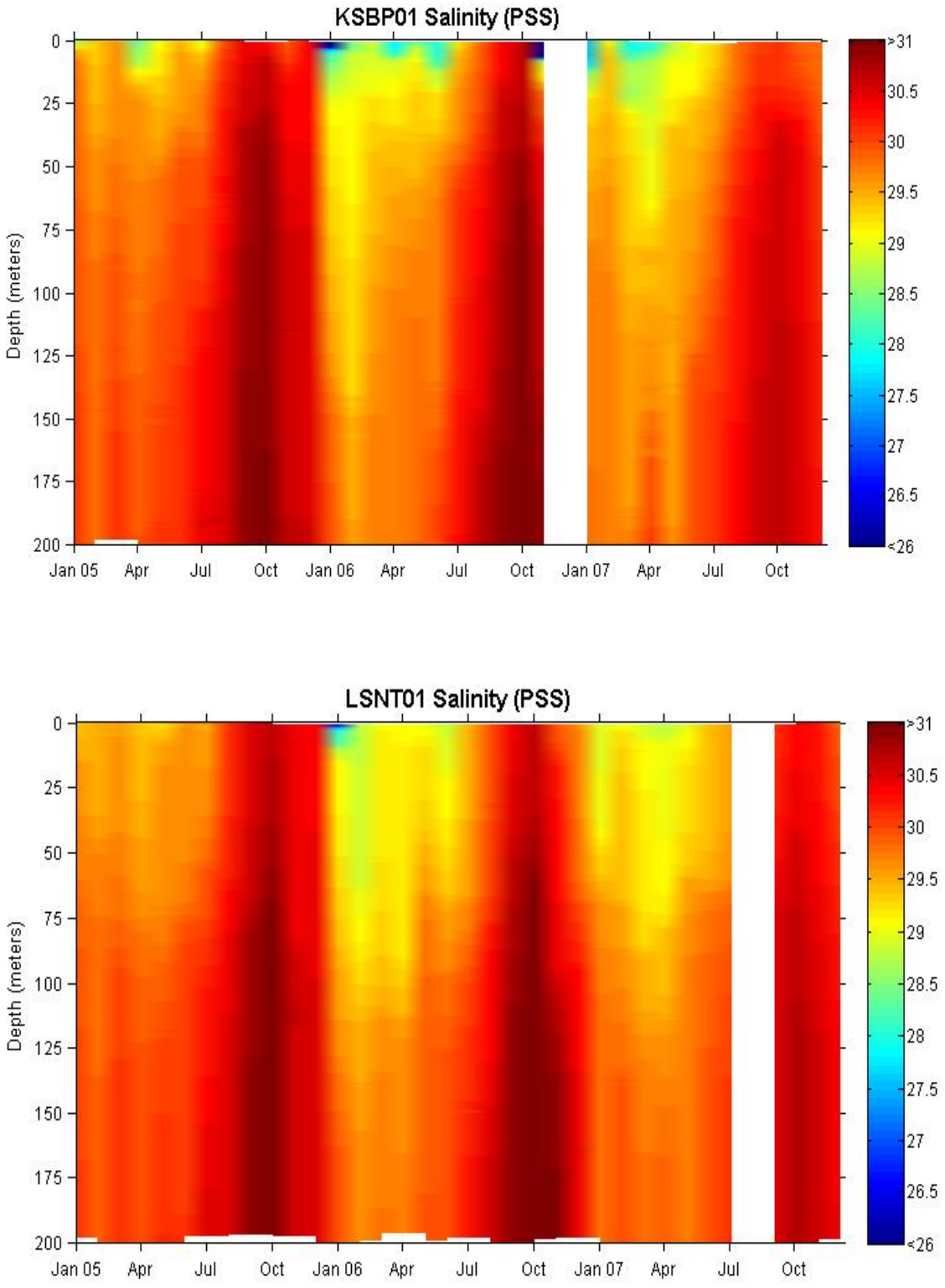

Figure 3-15. Salinity Variations at Stations KSBP01 and LSNT01 from 2005-2007

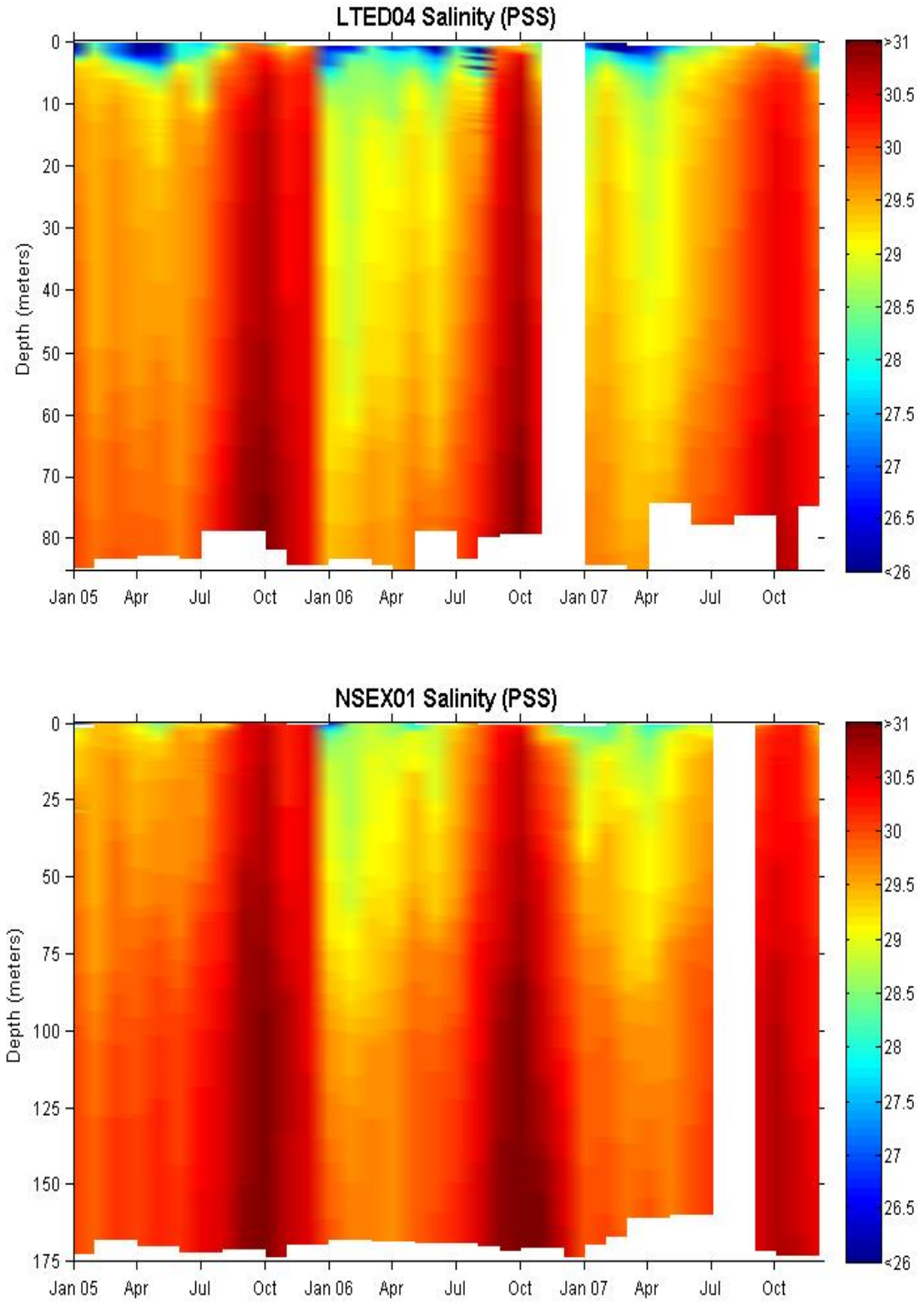

Figure 3-16. Salinity Variations at Stations LTED04 and NSEX01 from 2005-2007

Beach Salinity. Salinity at beach stations ranged from 23.07 to 30.66 PSS (mean = 29.12 PSS) in 2005, from 8.79 to 30.62 PSS (mean = 27.25 PSS) in 2006, and from 9.79 to 30.44 PSS (mean = 27.70 PSS) in 2007. Figure 3-17 shows salinities at all beach stations between 2005 and 2007 as well as the range in salinities at individual stations for 2007. The number of sampling stations increased in 2006, which is reflected in the top figure. Salinities were lowest at stations near a freshwater source. The lowest salinity in 2006 was at station KSQU01 located at the exit of the Lake Washington Ship Canal and in 2007, the lowest salinity was found at station NSJY01 (Dumas Bay Park). Low salinities are routinely measured at stations KSQU01 and KSHZ03 due to their proximity to freshwater sources. There was no notable pattern in salinity values from north to south, other than variations due to freshwater inputs. Seasonal changes in salinity showed highest values from September to November and decreasing values in December due to increased precipitation and runoff, reaching a minimum in February and March. Salinity data for beach stations is provided in Appendix A.

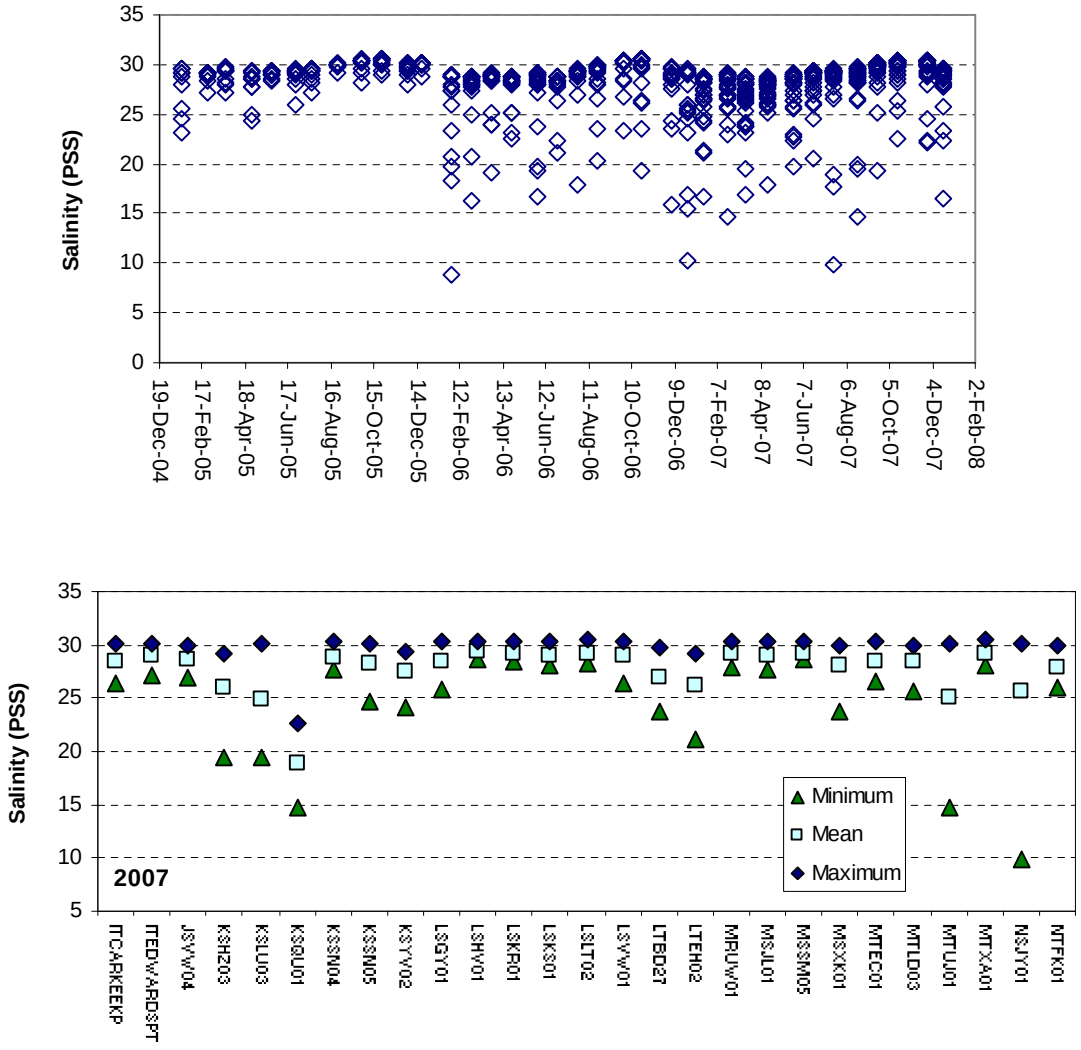

Figure 3-17. Salinity at Beach Stations in 2005, 2006, and 2007

Offshore Density. Water density is a function of both salinity and temperature, with density increasing with higher salinity and lower temperature. Salinity tends to be a stronger influence than temperature on density structure in Puget Sound. Density stratification within the water column impedes vertical mixing and can, therefore, affect the concentration of substances found at differing depths in the water column. Figure 3-18 shows the vertical density profiles for offshore stations CK200P and KSBP01. In general, density stratification is strongest during the summer due to increased solar heating and freshwater runoff from snow melt, both of which lead to a decrease in surface water density. Stratification weakens in the winter due to reduced solar influence and increased mixing of the water column.

Due to the seasonal cycles of temperature and salinity in Puget Sound, a light density phase, particularly at surface depths, occurs during the spring and summer months (Figures 3-19 and 3-20). This is followed by a dense phase in fall and winter. Exceptions to this trend were seen in January 2006 and November 2006, where instead of a typical dense phase a lighter dense phase occurred. These low density values are attributed to the heavy rain events during those months in 2006. Densities at the Elliott Bay stations indicate that the water column exhibits strong-intermittent stratification, with stratification occurring throughout most of the summer. Densities at other Central Basin locations show that the stratification intensity only occurs on a moderate and infrequent basis. Density values at discrete depths are provided in Appendix A for offshore stations.

3.2.4 Dissolved Oxygen

Physical processes affecting dissolved oxygen (DO) distributions in Puget Sound include the input of fresh and ocean water, stratification intensity within the water column, circulation patterns and mixing regimes, and the exchange of oxygen across the air-sea interface. Biological activity (e.g. photosynthesis, respiration) and chemical oxidation also affect ambient levels of DO and its distribution within the physical system both vertically and horizontally. Throughout the year, the surface marine waters remain well oxygenated. However, the water below the photic zone is less oxygenated due to the consumption of oxygen by the remineralization of organic material descending through the water column from the photic layer. Low dissolved oxygen concentrations can occur when organic matter is decomposed in waters that do not mix to the surface where aeration with atmospheric oxygen can occur. Upwelled deep waters and deep waters with overlying high organic production can have naturally occurring low dissolved oxygen concentrations.

Dissolved oxygen measurements were made throughout the water column from the surface to just above the seafloor at each offshore station. Values at discrete water depths are provided in Appendix A. Dissolved oxygen concentrations ranged in 2005 from 4.9 to 15.1 mg/L (mean = 7.5 mg/L), in 2006 from 4.1 to 15.4 mg/L (mean = 7.5 mg/L), and in 2007 from 3.6 to 12.1 mg/L (mean = 7.6 mg/L). The range and mean values observed in 2005, 2006, and 2007 are similar to measurements made in previous years. A DO concentration of 5.0 mg/L is the level at which biological stress may be induced by low dissolved oxygen and areas where DO concentrations are below 5.0 mg/L should be closely examined. DO levels for all offshore stations in 2005 were

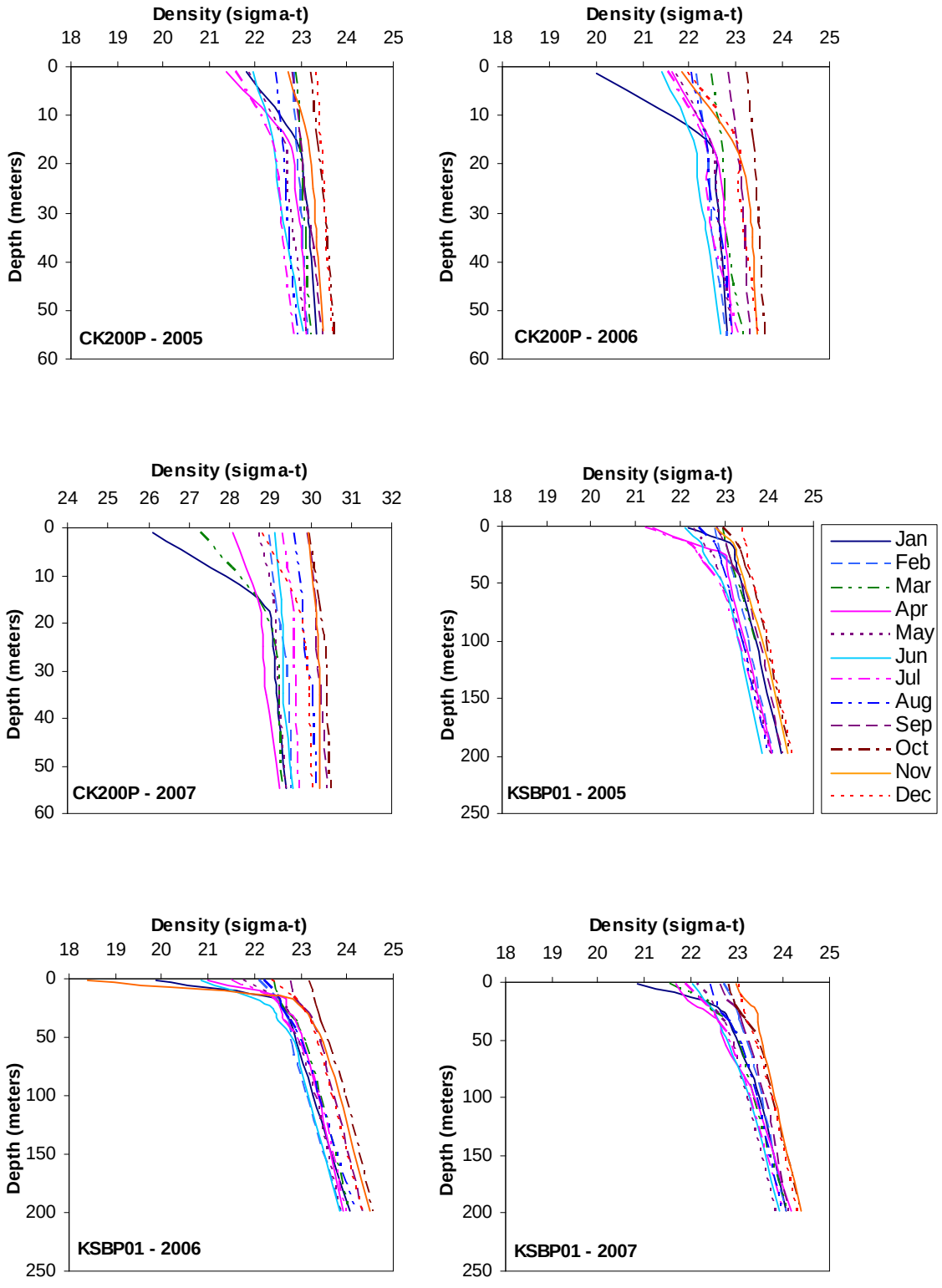

Figure 3-18. 2005-2007 Vertical Density Profiles from Stations CK200P and KSBP01

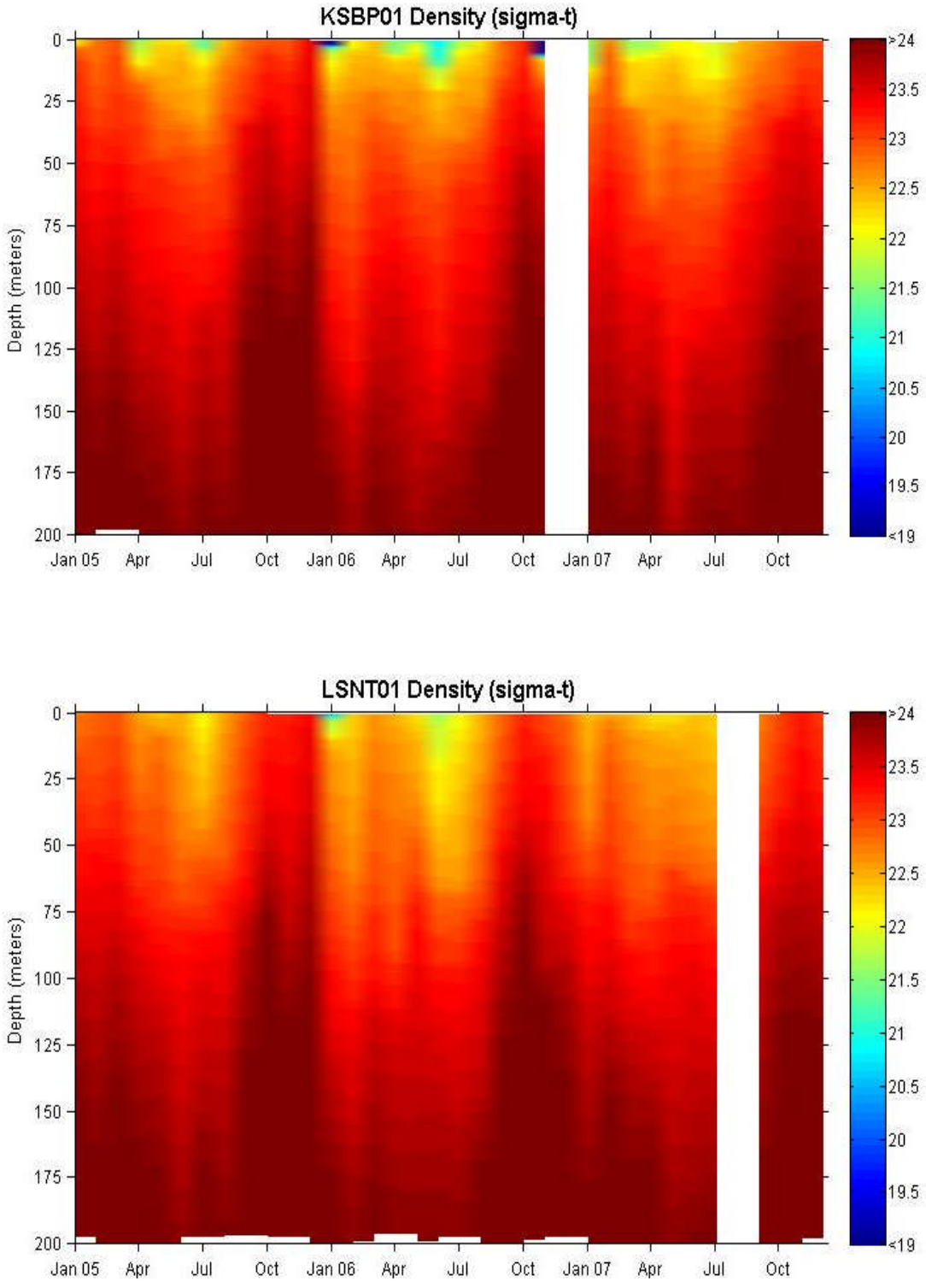

Figure 3-19. Density Variations at Stations KSBP01 and LSNT01 from 2005-2007

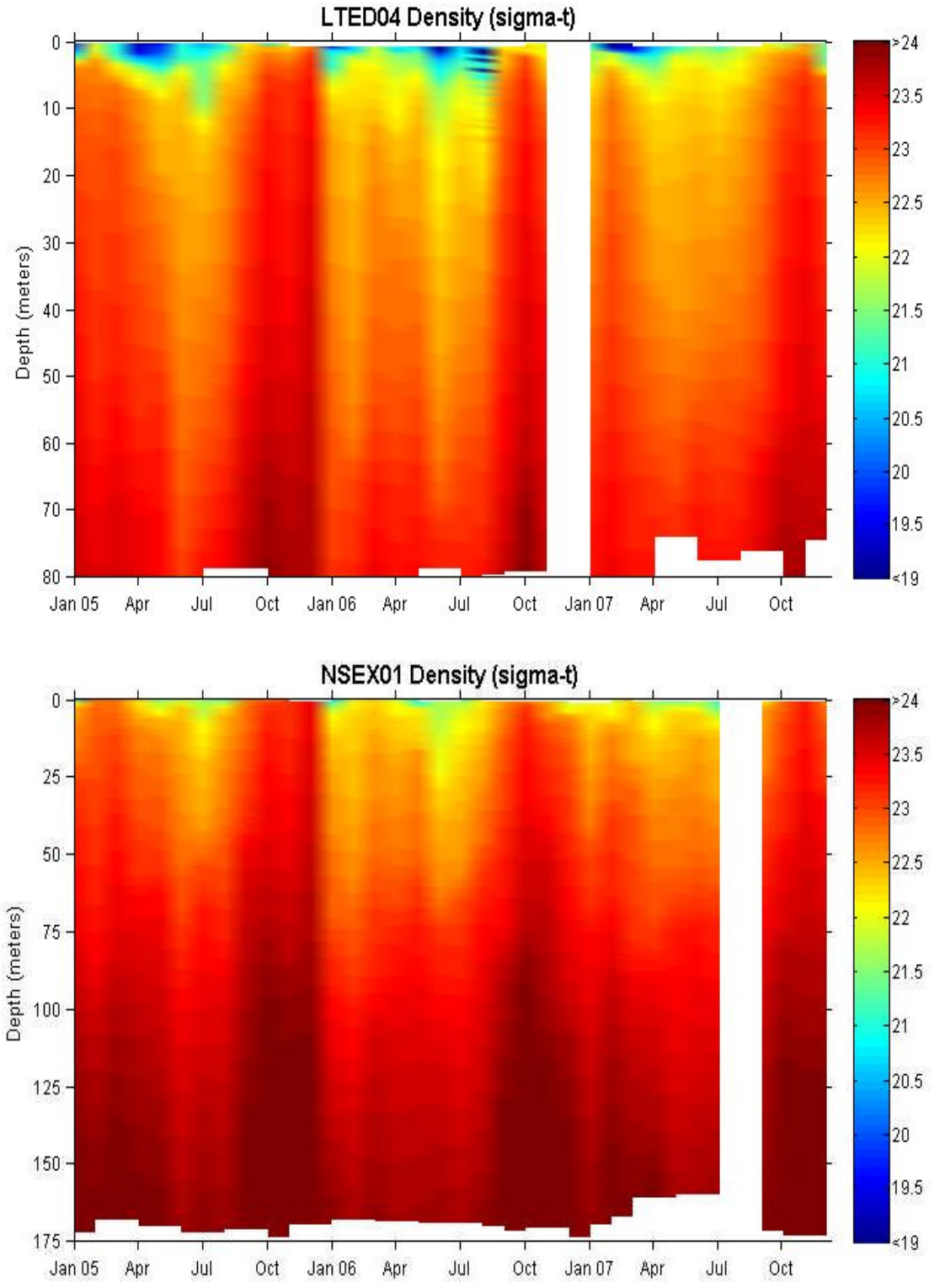

Figure 3-20. Density Variations at Stations LTED04 and NSEX01 from 2005-2007

at or above 5.0 mg/L. The minimum values in 2006 and 2007 (most importantly, the 3.6 mg/L in 2007) were found at stations MSWH01 and NSAJ02, both located in Quartermaster Harbor.

These especially low levels of dissolved oxygen are of great concern and are the reason monitoring stations were placed in Quartermaster Harbor. Low levels of DO in this area may be in part due to the shallow depths and the fact that it is a harbor, where flushing and introduction of oxygenated water is limited. Other than the previously mentioned exceptions, minimum dissolved oxygen levels were observed below approximately 50 m in late summer and fall during all three years. This is a result of the seasonal influx of Pacific Ocean water, which has low ambient concentrations of DO, into deep Puget Sound coinciding with the oxidation of organic matter from spring, summer, and early fall phytoplankton blooms. Increased water column density stratification in the spring and summer also contributes to low DO levels in the deeper layers as it impedes vertical mixing. A surface/subsurface DO maximum was seen in spring and summer at stations in the upper 35 m approximately. The maximums in dissolved oxygen correspond with maximums in chlorophyll-a concentration, temporally and spatially, and may therefore be attributed to primary productivity.

Seasonal DO variations from 2005-2007 at stations KSBP01, LTED04, LSNT01, and NSEX01 are shown in Figures 3-21 and 3-22. Patterns due to the input of low-oxygenated Pacific water and consumption of oxygen by bacterial respiration over the late summer/fall months are evident in the deep layers of the water column. The production of oxygen through primary production in the upper layers during the late spring and summer is also discernable in each year. As the density gradient break down in the fall and winter, the water column becomes well-mixed with little variability in DO levels from surface to depth.

Dissolved oxygen concentrations in Puget Sound are generally above 7.0 mg/L in the late winter and early summer months at all depths and locations sampled. Throughout the year, DO levels sometimes fell below 5.0 mg/L (as previously discussed above), the level at which biological stress may be induced by low DO (NOAA, 1998). During summer and fall, a seasonal influx of deep oceanic water low in DO results in naturally occurring DO concentrations below 7.0 mg/L. Figure 3-23 shows the seasonal variation in DO concentrations for 2005, 2006, and 2007, respectively, at both ambient and outfall offshore sites at discrete depths. At the 7.0 mg/L standard level, little difference was observed between ambient and outfall sites, with a higher percentage of samples above the standard seen at outfall sites. This indicates that effluent from the outfalls is not affecting dissolved oxygen concentrations.

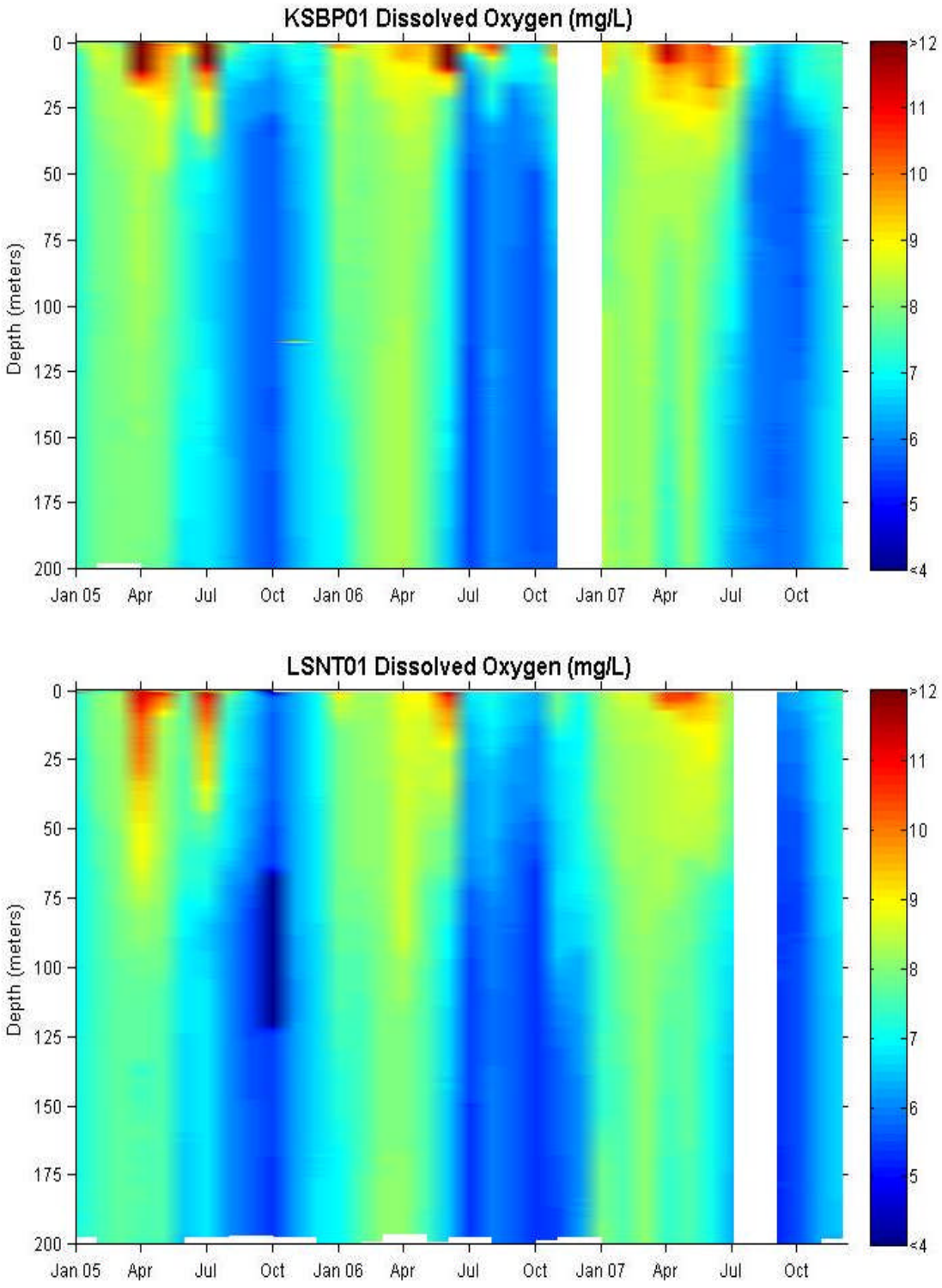

Figure 3-21. Dissolved Oxygen at Stations KSBP01 and LSNT01 from 2005-2007

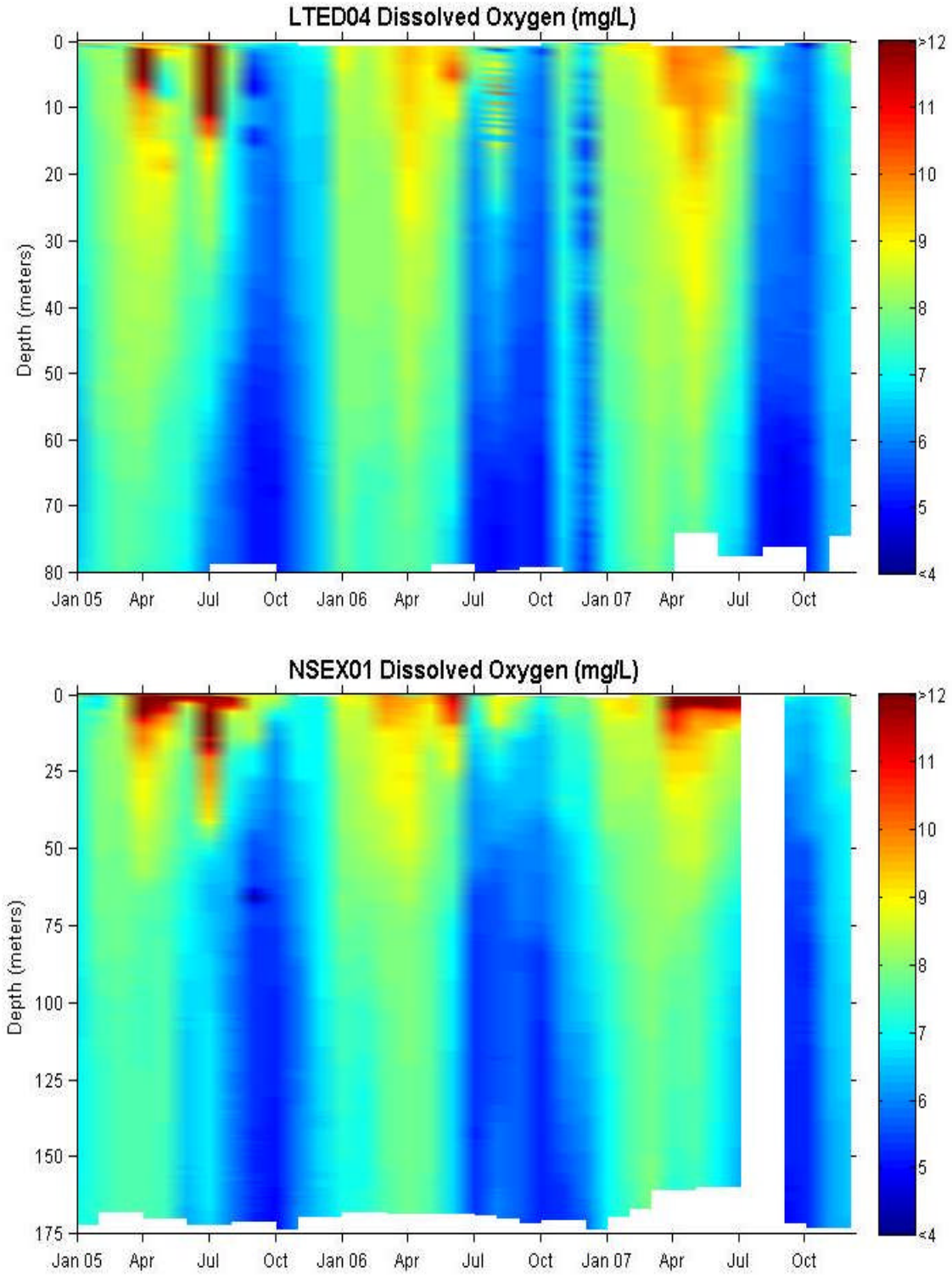

Figure 3-22. Dissolved Oxygen at Stations LTED04 and NSEX01 from 2005-2007

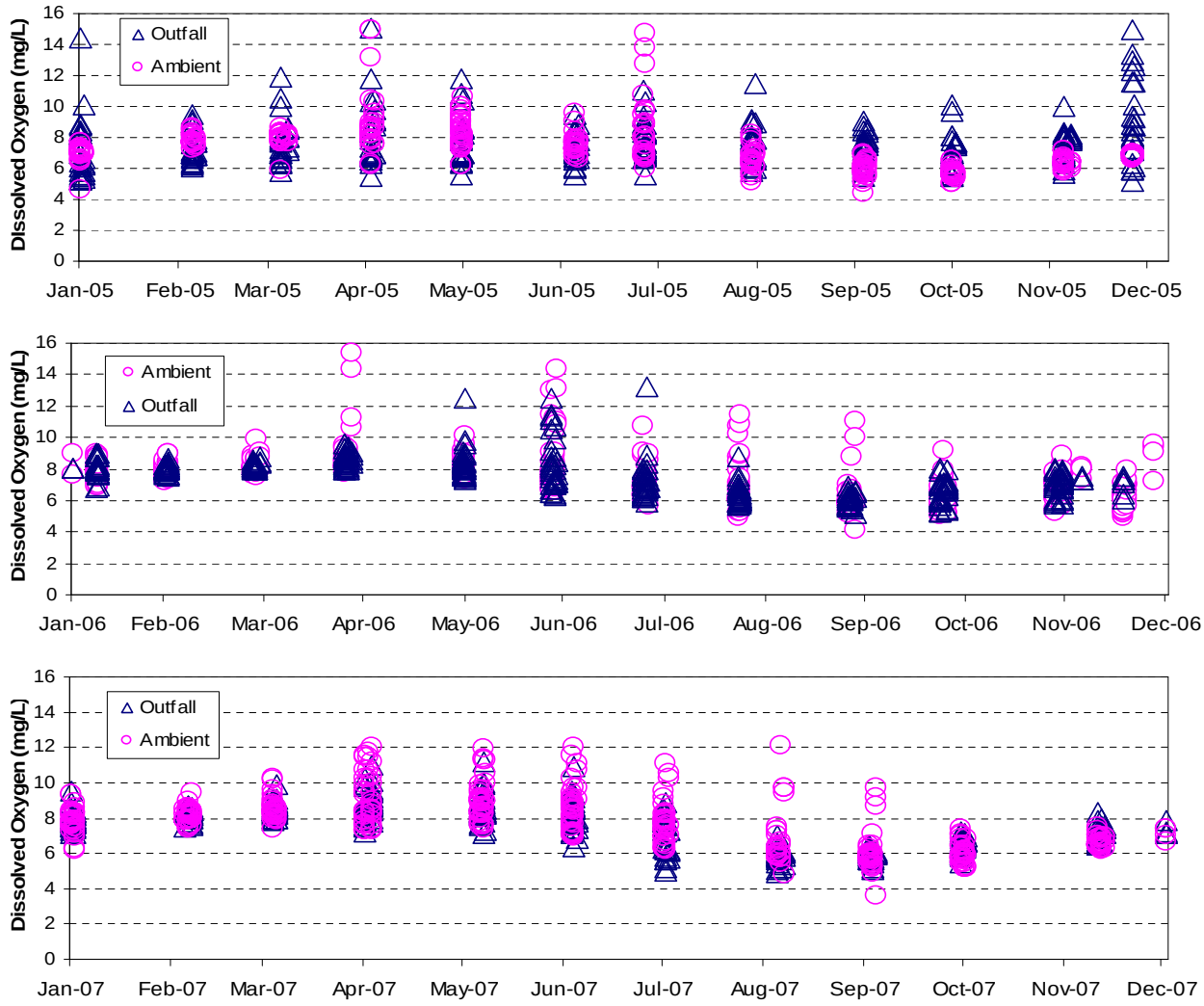

Figure 3-23. 2005-2007 Dissolved Oxygen Concentrations at Discrete Depths Ranging from 1-200 meters

3.2.5 Transparency and Light Intensity

Secchi Disk. Secchi disk measurements were taken at all offshore stations on a monthly basis in order to evaluate the transmission of visible light through the water at the surface. These measurements of water clarity provide an approximate transparency value and are taken by lowering the disk into the water and recording the depth at which it is lost to sight. The greater the Secchi depth value, the greater the water transparency. Environmental factors that influence Secchi transparency include turbidity, riverine input, runoff, shoreline erosion, resuspension of bottom sediment, and phytoplankton biomass. Secchi disk values ranged from 2.1 to 13.0 m in

2005, from 2.0 to 15.0 m in 2006, and from 1.7 to 15.0 m in 2007. Table 3-8 lists the minimum, maximum, and average Secchi depths by station for all three years. As in previous years, there was no difference in transparency between ambient and outfall stations. In general, minimum values were observed late spring/early summer due to phytoplankton abundance, and maximum values were observed in late summer/early fall due to reduced productivity and lower rainfall. Monthly Secchi transparency depths, along with the mean chlorophyll-*a* levels, for stations CK200P (outfall), KSBP01 (ambient), and LTED04 (ambient) during 2005 to 2007, are presented in Figure 3-24. Secchi depths were fairly constant from January through March in all three years. In April 2005, June 2006, and April 2007, the first phytoplankton bloom of the year occurred during which a corresponding decline in Secchi transparency was seen. Additional blooms were seen in July 2005, August 2006, and June 2007 which also had low Secchi transparency values associated with them. In September 2006, a notable increase in Secchi transparency was seen at all three stations, which is due to calm weather and low to non-existent chlorophyll-*a* levels. In general, lower Secchi depths correspond to higher chlorophyll-*a* values. An exception to this trend can be seen January and November of 2006, which both had low Secchi transparency values during times of low chlorophyll-*a* values. These dips in Secchi depth measurements were most likely due to the rough weather and heavy rains that occurred during those months. All Secchi measurements from 2005 to 2007 can be found in Appendix A.

Turbidity and Transmissivity. Turbidity is another measure of water clarity but differs from Secchi disk measurements in that it is an expression of the amount of light scattered or reflected (the lower the turbidity value, the more transparent the water). Dissolved and suspended solids (including detritus, plankton, and particulates), can affect the water's optical properties resulting in high turbidity values. Wind and waves can indirectly increase turbidity by stirring up particulates in the water. Turbidity measurements were taken at offshore stations in 2005. Turbidity values ranged from less than 0.5 (MDL) to 5.6 Nephelometric Turbidity Units (NTU). The maximum value was measured in March at station JSUR01 at 173 m. The next five out of six highest turbidity values were also measured at a depth equal to or greater than 170 m. The highest values were generally found at surface and bottom depths, where the amounts of dissolved and suspended solids were greatest.

Starting in 2006, a change in instrumentation was made from turbidity to transmissivity. Transmissivity measures the percent of light present at a given depth. Transmissivity values ranged from 43 to 88% light in 2006 and from 52 to 87% light in 2007. Transmissivity is inversely related to turbidity, so that the lowest transmissivity values were found at surface and bottom depths, and the highest around 15 to 35 m. Higher turbidity results in a lower transmissivity measurement. Appendix A contains turbidity and transmissivity values for all offshore stations.

Table 3-8. Minimum, Maximum, and Average Secchi Disk Depths (m) by Station for 2005-2007

Year	Station	Mean Secchi Depth (m)	Minimum Secchi Depth (m)	Maximum Secchi Depth (m)
2005				
	CK200P	6.8	2.5 (Jul)	10.6 (Sep)
	JSUR01	6.9	3.2 (Apr)	11.0 (Oct)
	KSBP01	6.9	3.9 (Apr)	9.8 (Sep)
	KSSK02	6.9	3.6 (Apr)	10.0 (Sep)
	LSEP01	7.3	3.5 (Apr)	12.8 (Sep)
	LSKQ06	7.4	4.0 (Jul)	11.5 (Sep)
	LSNT01	7.6	4.7 (May)	10.5 (Sep)
	LTBC43	6.3	2.1 (Jan)	10.0 (Sep)
	LTED04	6.3	2.7 (Jan)	9.2 (Sep)
	MSJN02	7.4	4.9 (Apr)	12.7 (Sep)
	NSEX01	6	2.7 (Aug)	13.0 (Mar)
2006				
	CK200P	7.1	2.5 (Jun)	13.5 (Sep)
	JSUR01	7.4	2.7 (Jun)	15.0 (Sep)
	KSBP01	6.4	2.6 (Jun)	12.5 (Sep)
	KSSK02	6.4	2.7 (Jun)	12.0 (Sep)
	LSKQ06	7.3	3.5 (Jun)	12.0 (Aug)
	LSNT01	7.6	4.0 (Jun)	15.0 (Aug)
	LTBC43	5.9	2.0 (Dec)	14.3 (Sep)
	LTED04	5.5	2.5 (Dec)	10.5 (Sep)
	MSJN02	8.1	4.0 (Jun)	13.0 (Sep)
	NSEX01	7	3.5 (Dec)	13.5 (Aug)
	RT625NP	7.3	3.0 (Jun)	14.5 (Aug)
	RT625SP	7.5	2.7 (Jun)	15.0 (Aug)
2007				
	CK200P	7.3	4.8 (Jun)	9.1 (Nov)
	JSUR01	6.8	4.0 (Jun)	8.0 (Dec)
	KSBP01	7	4.2 (Jun)	9.0 (Sep)
	KSRU03	4.9	2.3 (Jun)	6.4 (Oct)
	KSSK02	7.6	5.8 (Jan)	11.0 (Oct)
	LSEP01	8.2	6.8 (Jan)	11.6 (Sep)
	LSKQ06	7.8	4.0 (May)	10.2 (Sep)
	LSNT01	8.3	5.0 (May)	12.6 (Sep)
	LSVV01	7.4	3.7 (Aug)	11.8 (Sep)
	LTBC43	6.8	1.7 (Feb)	11.7 (Oct)
	LTED04	7	1.7 (Feb)	15.0 (Oct)
	MSJN02	7.6	4.2 (Aug)	12.0 (Sep)
	NSEX01	6.8	3.0 (May)	14.5 (Oct)

Outfall stations
Ambient stations

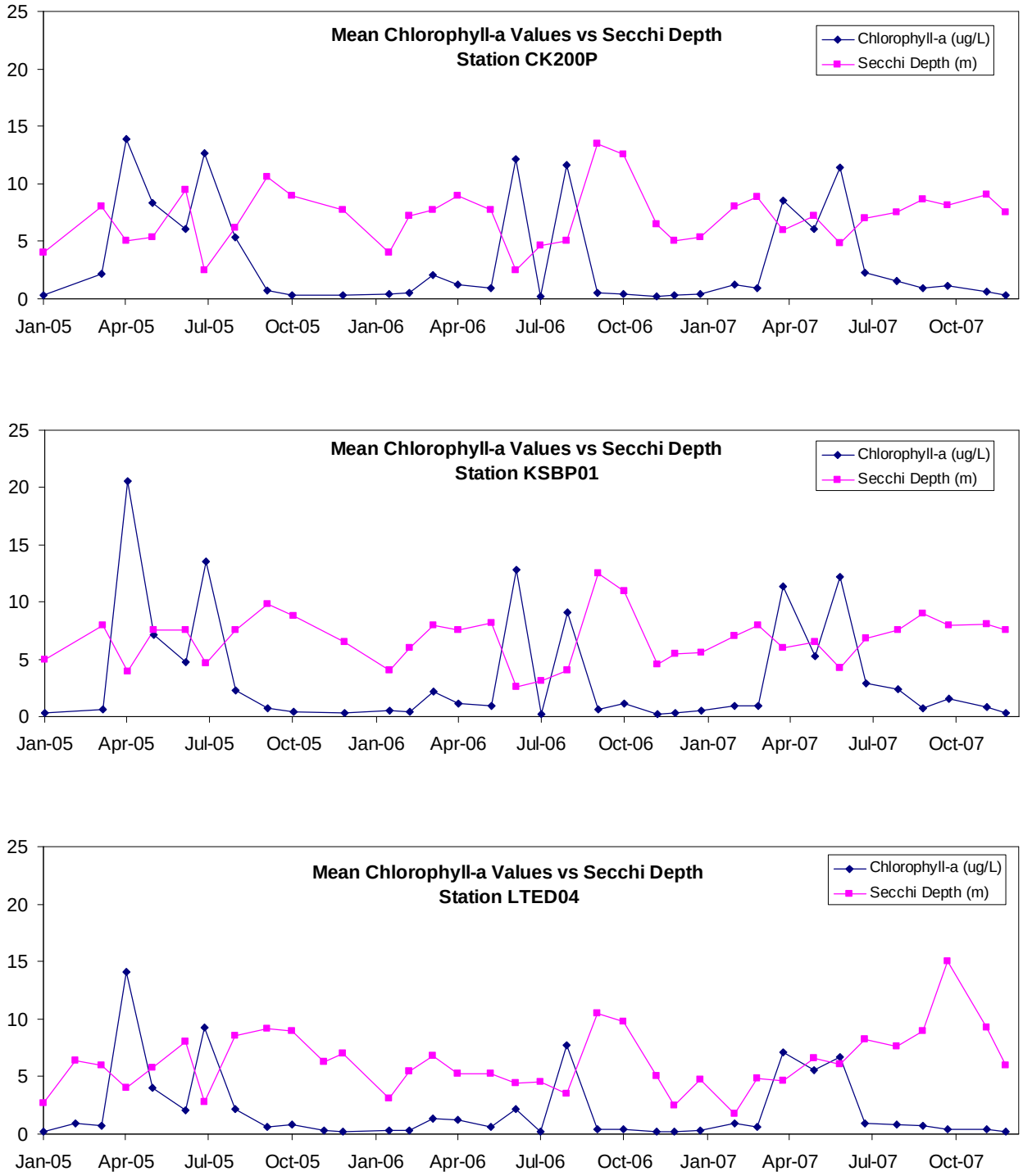

Figure 3-24. 2005-2007 Mean Values for Chlorophyll-a vs Secchi Depth Values for Stations CK200P, KSBP01, and LTED04.

Photosynthetically Active Radiation. Photosynthetically active radiation (PAR), also expressed as light intensity, is a measure of the amount of light available to macrophytes and phytoplankton for photosynthesis. Light penetration refers to the amount of sunlight that penetrates the water column and reaches various depths. Sunlight is absorbed and scattered by suspended particles, dissolved substances, and the water itself. Light penetration is monitored in order to determine if it is sufficient to support photosynthesis. As expected, the highest PAR levels occurred at or near the surface throughout the year, for all three years, at each station. The highest penetration of surface PAR occurs during winter when productivity is relatively low. Light penetration decreases during the spring and summer blooms. Even at the 1m depth, light penetration during phytoplankton blooms generally decreases to about 20% of available light. In Elliott Bay, light penetration at the surface can be as low as 9%, as was measured in August 2007.

By the 15 m depth, light penetration generally decreases to about 2% of the available surface light and less than 1% of light penetrates to 20 m and below. PAR measurements at discrete depths are located in Appendix A.

3.2.6 Nutrients

Nitrogen Compounds

Nitrogen is ubiquitous in the marine environment and occurs in many organic and inorganic chemical forms. Nitrogen compounds are frequently the limiting factor affecting phytoplankton growth in marine systems. The most abundant components of the marine nitrogen cycle affecting phytoplankton growth are nitrate (NO_3^-), nitrite (NO_2^-), and the ionic form of ammonia (NO_4^+). In the water column of most estuaries, nitrate + nitrite concentrations are frequently inversely correlated with chlorophyll-a concentrations in surface waters; especially when observed on a seasonal time scale. Conversely, patterns in ammonium concentrations are more volatile indicating rapid, year-round efficient uptake by nitrifying bacteria and phytoplankton. King County reports dissolved ammonia concentrations (ammonium ion that has been converted to ammonia), and the sum of nitrate and nitrite concentrations (nitrate+nitrite) due to the analytical methodology employed. Nitrite concentrations in the water column are naturally low compared to nitrate, so the nitrate + nitrite results can be considered almost entirely nitrate. All nutrient samples are filtered prior to analysis; therefore, the concentrations reported are for the dissolved fraction. The monitoring of nitrogen compounds allows King County to assess nutrient concentrations at wastewater and CSO treatment plant marine outfalls and to determine whether ammonia concentrations are at toxic concentrations to aquatic organisms in the Central Basin.

Ammonia

Offshore Waters. Of the nutrients measured by King County, ammonia is the only one with a published criterion for marine water quality as it can be toxic to marine plants and animals in high concentrations. In marine waters, ammonia can be found at elevated concentrations as a byproduct of sewage (both municipal and septic treatment systems), agricultural practices, and

fertilization practices in urban areas. Elevated ammonia levels are also seen following large phytoplankton blooms as ammonia is produced during the decay process. Ecology's water quality standards for ammonia in marine waters with respect to aquatic organisms are based upon un-ionized ammonia and are less than 0.035 mg/L for long-term effects (chronic) and less than 0.233 mg/L for short-term effects (acute) (WAC, 173-201A, 2003). Ecology cites an EPA document for more specific criteria for total ammonia (which King County measures) based on temperature, salinity, and pH values. Assuming a temperature of 15 °C, a salinity of 30 PSS, and a pH of 8.0, the total ammonia chronic criterion is 1.6 mg/L (EPA, 1989).

Concentrations of ammonia ranged from less than the MDL (0.010 mg/L) in all three years to 0.25 mg/L in 2005, 0.19 mg/L in 2006, and 0.20 mg/L in 2007. As in previous years, the maximum concentration in 2005 was detected at station KSSK02 (West Point outfall) at 55 m. The maximum concentrations in 2006 and 2007 occurred at stations RT625NP (South Plant Outfall) and MSWH01 (Quartermaster Harbor), respectively. The mean concentration for all stations and depths was 0.02 mg/L for all three years. The highest concentrations of ammonia usually occur in the summer and fall months and the lowest concentrations occur in the winter months. Figures 3-25 and 3-26 show the vertical profiles for ammonia concentrations at selected ambient and outfall stations from 2005 to 2007. If any sample result was below the 0.01 mg/L detection limit, a value of 0.01 mg/L was assigned to that result in order to create the figures. The ammonia values in surface waters for the East Passage station (NSEX01) in 2007 (see Figure 3-25) are likely due to degradation of phytoplankton, as indicated by high chlorophyll values.

Ammonia concentrations from both outfall and ambient offshore stations generally increased with depth, illustrating that uptake is primarily from phytoplankton in the photic zone and lowered uptake and increased excretion by zooplankton is occurring below the photic zone. The highest concentration measured was more than six times lower than the criterion. The complete dataset of 2005-2007 offshore ammonia concentrations can be found in Appendix A.

Beach Waters. Ammonia concentrations at beach stations ranged from a minimum of less than MDL (0.010 mg/L) in all three years to 0.050 mg/L in 2005, 0.083 mg/L in 2006, and 0.164 mg/L in 2007. The mean concentrations were 0.019 mg/L, 0.020 mg/L, and 0.027 mg/L in 2005, 2006, and 2007, respectively. The highest concentrations generally occurred during warmer months (May – October), particularly during times when large amounts of decaying seaweed are typical along the shoreline (Figure 3-27). This was particularly evident in July of 2006 and 2007 when the highest average concentrations were measured. An abundance of the green seaweed *Ulva spp*. was observed along much of the shoreline in 2006 due in part to climate conditions—warm air temperatures in early spring and summer. Warmer than normal conditions began in April 2006 with exceptionally warm air temperatures occurring in July. July 2006 temperatures were almost four degrees higher than the long-term average which provided optimal growing conditions for seaweed. Although not as warm as in 2006, the first two weeks in July 2007 were warm, including one 98 degree day. The increase in ammonia concentrations throughout the summer in 2006 and 2007 at station KSQU01 shown in Figure 3-28 corresponds to an abundance of seaweed. An excess of *Ulva spp*. at this site during the summer was noted by residents living near Shilshole in both 2006 and 2007.

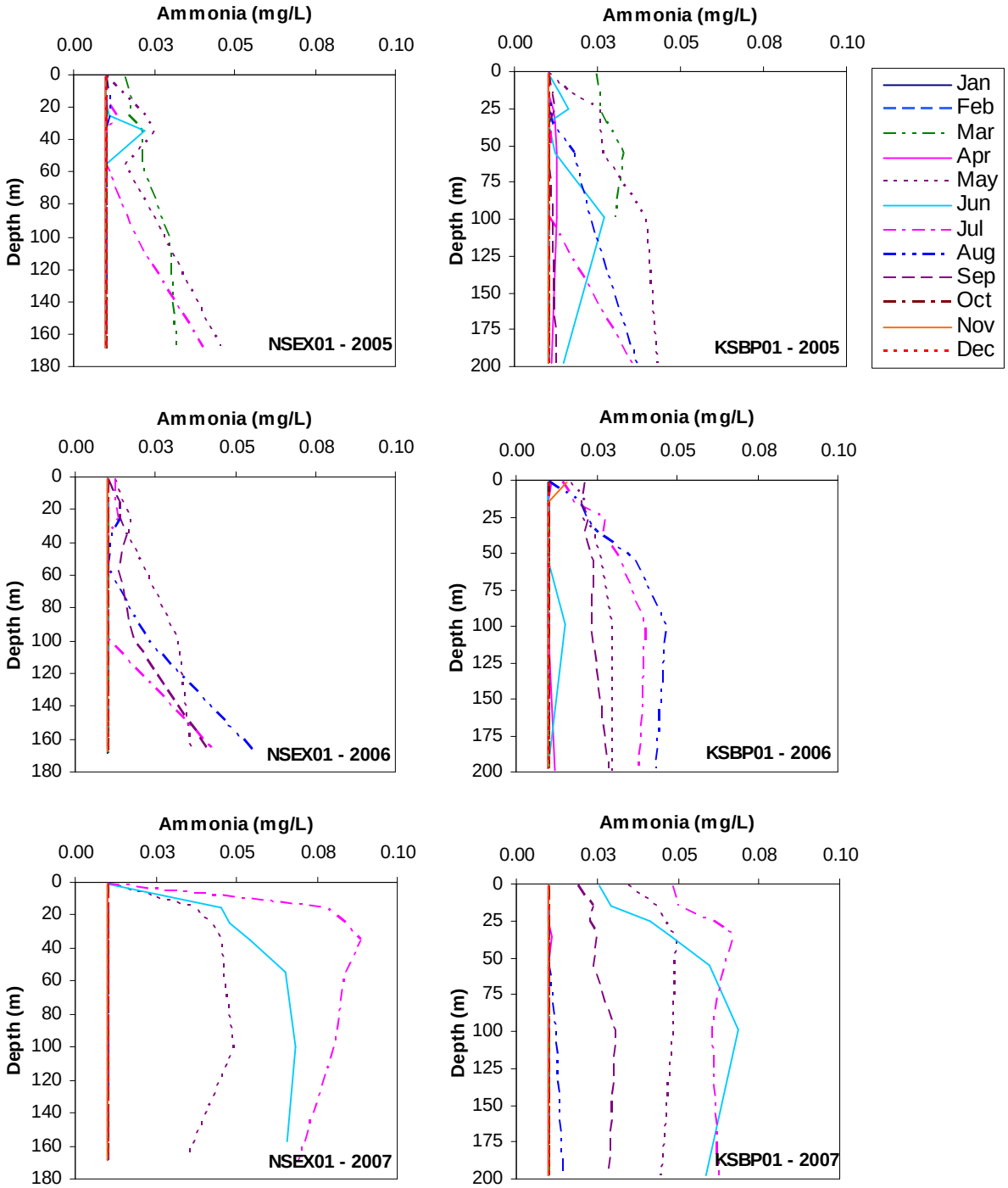

Figure 3-25. 2005-2007 Ammonia Profiles for Ambient Stations NSEX01 and KSBP01

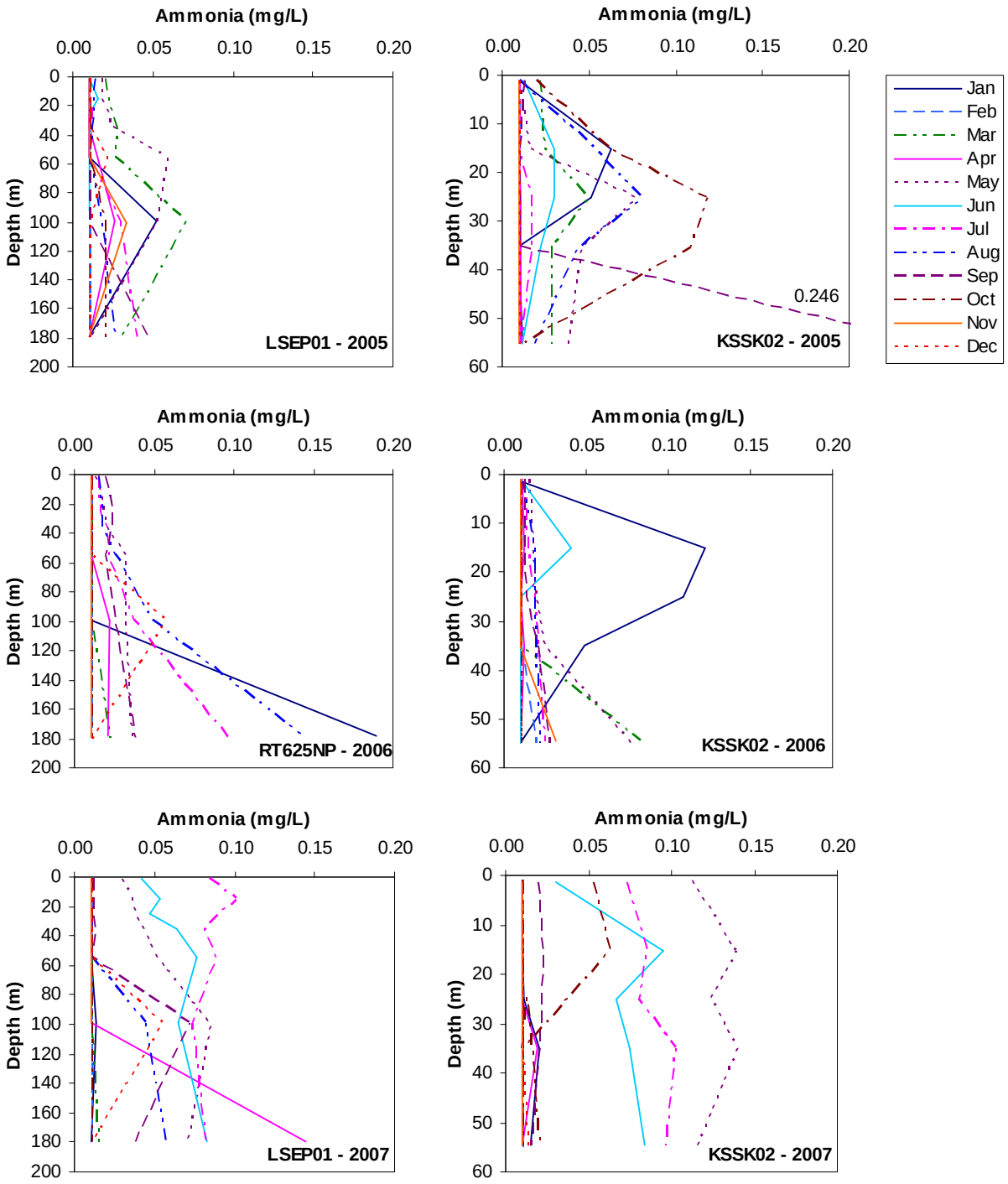

Figure 3-26. 2005-2007 Ammonia Profiles for Outfall Stations LSEP01 and KSSK02

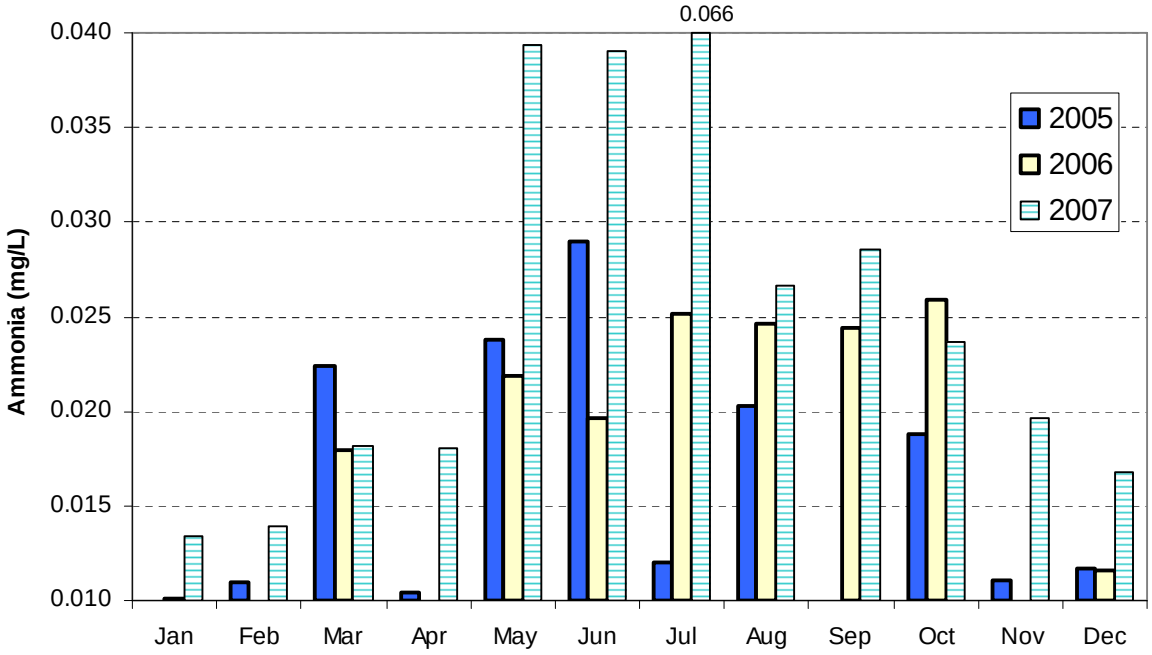

Figure 3-27. Average Monthly Ammonia Values for Beach Stations

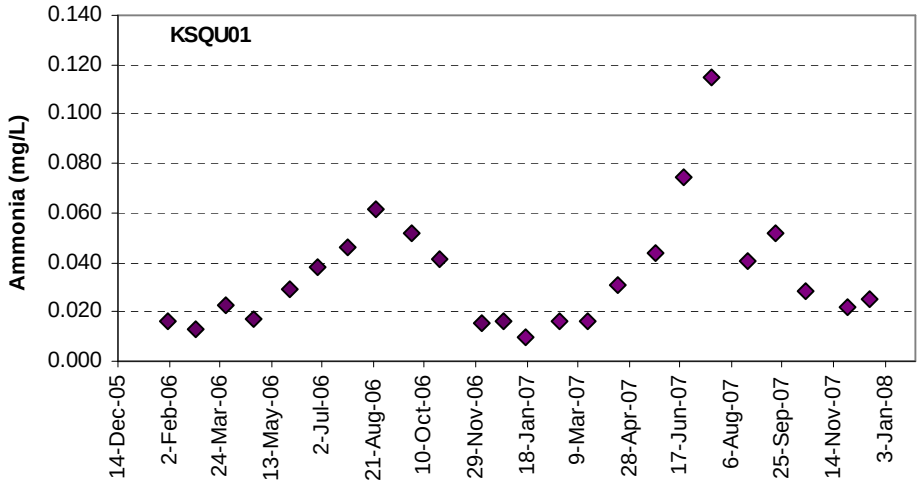

Figure 3-28. Ammonia Values at Station KSQU01 in 2006 & 2007

The ammonia concentrations at stations near the West Point and Carkeek TPs were similar to, if not lower, than concentrations at ambient stations. Values at the LSKS01 located in the vicinity of the Alki CSO TP outfall were higher than ambient stations, likely due to proximity to a storm drain along the shoreline which drains the hillside. A shoreline inspection in 2006 showed that this station is directly in front of a storm drain with a constant discharge.

Station MSJL01 in the vicinity of the Vashon Treatment Plant, along with station LSKS01, had the highest average ammonia concentrations in 2005. Gorsuch Creek is near station MSJL01 and has a considerable influence on water quality at this site. The highest concentrations in 2006 were measured at Normandy Park (MTLD03) and Shilshole (KSQU01). In 2007, the highest concentration (0.164 mg/L) was measured at Seahurst Park (MTEC01). This station was added to the sampling program in 2007 and was not sampled in either 2005 or 2006. Figure 3-29 shows ammonia values at all beach stations between 2005 and 2007. It should be noted that 11 new stations were sampled in 2007 that were not sampled in 2005 or 2006.

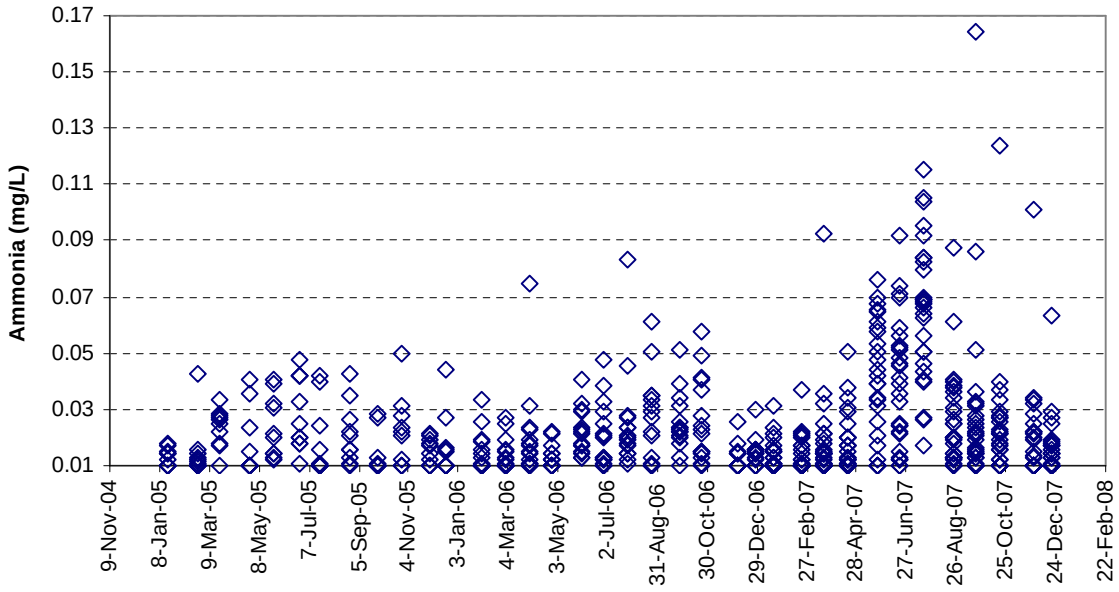

Figure 3-29. Ammonia Values at Beach Stations from 2005-2007

All measured ammonia concentrations at beach stations were significantly lower than the water quality criterion recommended by the EPA.

Nitrate + Nitrite

Offshore Waters. Nitrate+nitrite concentrations ranged from less than the MDL (0.02 mg/L) in all three years to 0.56 mg/L in 2005, 0.48 mg/L in 2006, and 0.46 mg/L in 2007. Surface concentrations of nitrate+nitrite were highest in late fall through early spring when nutrient uptake by phytoplankton is at a minimum and fluvial input was highest. Concentrations declined in the upper portion of the water column during the spring and summer months due to increased levels of nutrient uptake by phytoplankton. The mean concentrations for all stations and depths combined were 0.32 mg/L in 2005, 0.34 mg/L in 2006, and 0.33 mg/L in 2007. Figure 3-30 shows vertical profiles for nitrate+nitrite concentrations at stations KSSK02 and KSBP01 for 2005 to 2007. Concentrations generally increase with depth due to nitrate uptake in the photic

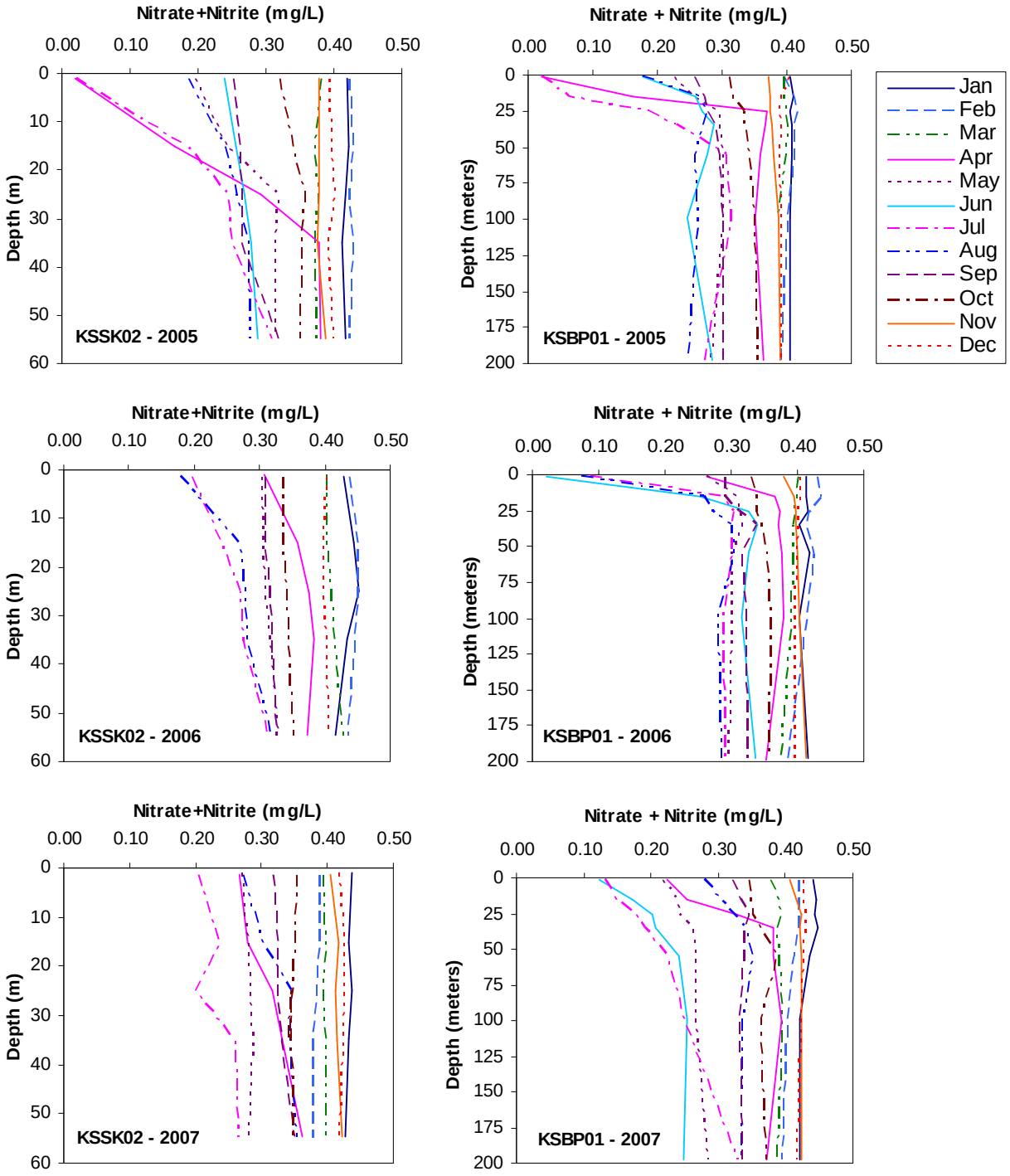

Figure 3-30. 2005-2007 Nitrate+Nitrite Profiles for Stations KSSK02 and KSBP01

zone by phytoplankton. The complete dataset of 2005-2007 offshore nitrate+nitrite concentrations can be found in Appendix A.

Beach Waters. Concentrations of nitrate+nitrite at beach stations (excluding the Piper's Creek station) ranged from less than the MDL (0.02mg/L) in all three years to 0.84 mg/L in 2005, 1.01 mg/L in 2006, and 0.87 mg/L in 2007. Mean concentrations for all beach stations combined were 0.25, 0.30, and 0.28 mg/L, respectively in 2005, 2006, and 2007. Figure 3-31 shows nitrate+nitrite concentrations at all beach stations sampled between 2005 and 2007. In 2005 and 2006, the highest concentrations were found at stations KSHZ03 and ITCARKEEKP, respectively. This is most likely due to the freshwater influence of nearby Piper's Creek. In 2007, the highest concentration was measured at the Dumas Bay station (NSJY01). Overall, the patterns were similar to those of the offshore stations; concentrations were highest in the winter and lowest in the summer. This seasonal variation at beach locations is typical of an ecosystem containing marine vegetation. Nitrate+nitrite concentrations are lower in the summer months when vegetation, including phytoplankton, seaweed, and kelp, take up nitrates for biological processes. Nitrate+nitrite was depleted to levels below the detection in April and July in 2005, June 2006, and at various times throughout the spring and summer in 2007. A notable exception was the site at Burton Acres in Quartermaster Harbor. Nitrate+nitrite was depleted below 0.02 mg/L from April to September, which was not seen at other stations nor for that length of time.

The Piper's Creek station (KTHA01) had much higher concentrations than the marine sites, with maximum concentrations between 1.59 and 3.09 mg/L from 2005 to 2007. Nitrate+nitrite concentrations and the seasonal pattern exhibited in Piper's Creek are typical of those in urban creeks and streams draining into Puget Sound (Figure 3-32).

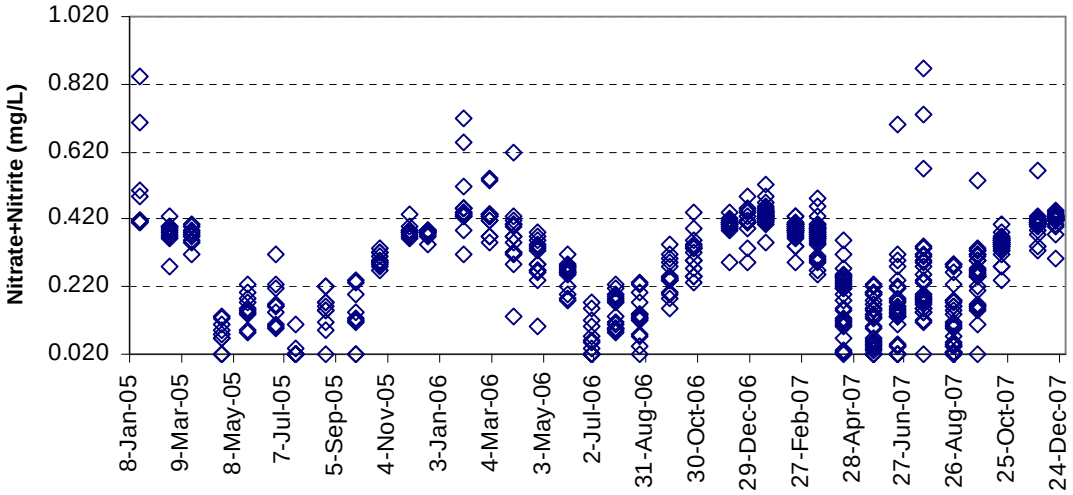

Figure 3-31. Nitrate+nitrite Values at Marine Beach Stations from 2005-2007

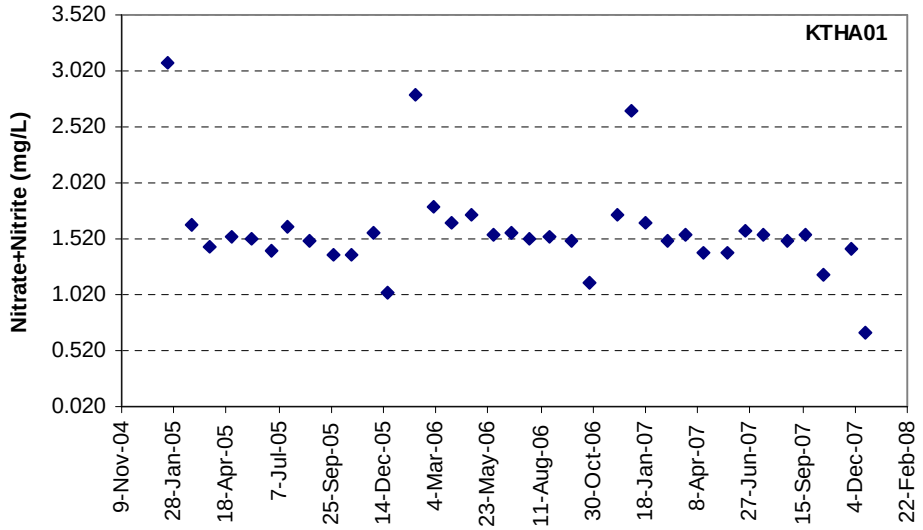

Figure 3-32. Nitrate+nitrite Values in Piper's Creek from 2005-2007

Total Phosphorous

Offshore Waters. Phosphorous occurs as dissolved inorganic, dissolved organic, and particulate phosphorous in seawater. Generally, particulate phosphorous is the most abundant of the three forms. There are several forms of inorganic phosphorous found in the marine environment, with the most abundant being orthophosphate. Total phosphorous, which includes all forms of inorganic and organic phosphorous, is measured by King County.

Phosphorous concentrations at all offshore stations (all discrete measurements combined) ranged from 0.026 to 0.650 mg/L in 2005, 0.029 to 0.110 mg/L in 2006, and 0.038 to 0.110 mg/L in 2007. Mean concentrations were 0.070 mg/L in 2005, 0.072 mg/L in 2006, and 0.076 mg/L in 2007. These results are comparable to previous years. A seasonal trend in phosphorous concentrations was observed; highest concentrations occurred in the winter and lowest concentrations occurred during summer in surface waters where photosynthesis was actively occurring. The complete dataset of 2005-2007 offshore phosphorous concentrations can be found in Appendix A.

Beach Waters. Total phosphorous at the beach stations ranged from 0.024 to 0.284 mg/L in 2005, 0.035 to 0.961 mg/L in 2006, and 0.026 to 0.514 mg/L in 2007. Mean concentrations were 0.083 mg/L in 2005 and 0.085 mg/L in 2006 as well as in 2007. Variability was greater at beach stations that at offshore stations due to differences in freshwater inputs (greater at beach stations due to proximity to streams and rivers). The complete dataset of 2005-2007 beach phosphorous concentrations can be found in Appendix A.

Silica

Offshore Waters. Silica concentrations at offshore stations ranged from less than MDL (<0.050) in both 2005 and 2006 to a maximum of 4.2 mg/L and 5.2 mg/L, respectively. Values ranged from 0.35 to 6.0 mg/L in 2007. Mean concentrations were 2.6 mg/L in 2005, 2.9 mg/L in 2006, and 3.1 mg/L in 2007.

The minimum concentrations seen in 2005 and 2006 were unusual as concentrations are rarely below the detection limit. These low values occurred at stations KSBP01 (Point Jefferson) and JSUR01 (Point Wells) in July of 2005 and at stations MSWH01 and NSAJ02 (Quartermaster Harbor) in June of 2006. In both years the <MDL values were measured during the second large phytoplankton bloom of the year. The first bloom of the year occurred in April of both 2005 and 2006, during which nitrate+nitrite levels were depleted to a level at which they could not be detected (<0.020 mg/L). Silica concentrations, however, ranged from 0.18 to 1.75 mg/L, indicating that the spring bloom was nitrogen limited. The phytoplankton blooms during July 2005 and June 2006 were so large that silica likely became the limiting growth factor, rather than nitrogen. Although sufficient nitrate+nitrite levels were available in the water column to sustain the bloom, silica was depleted before nitrogen could become limiting. Low silica values during the summer months are expected when diatoms that use silica for frustule growth are most abundant; however this was the first time that silica concentrations were below the MDL. Aside from the two unusual circumstances mentioned above, a seasonal trend in silica concentrations was observed. Concentrations tended to be lowest in the surface layer during the summer months and highest during the winter months when uptake by phytoplankton was low and freshwater inputs were relatively high. Figure 3-33 shows vertical profiles for silica concentrations at stations CK200P and KSBP01 for 2005 to 2007. The complete dataset of 2005-2007 offshore silica concentrations can be found in Appendix A.

Beach Waters. Maximum silica concentrations at beach stations were slightly higher than those at offshore station due to the closer proximity of beach stations to sources of silica, but the mean concentrations throughout the year were similar to offshore stations. Silica can enter the marine environment from erosion of natural rock carried in freshwater runoff. Beach silica data are only available for 2005, as measurements stopped after 2005. Values in 2005 ranged from 0.33 to 7.6 mg/L, with a mean concentration of 2.6 mg/L. The highest value was measured in January at station KSHZ03 located at the mouth of Piper's Creek near Carkeek Park. This station had higher values throughout the year than other sites as has been seen in previous years. The complete dataset of 2005 beach silica concentrations can be found in Appendix A.

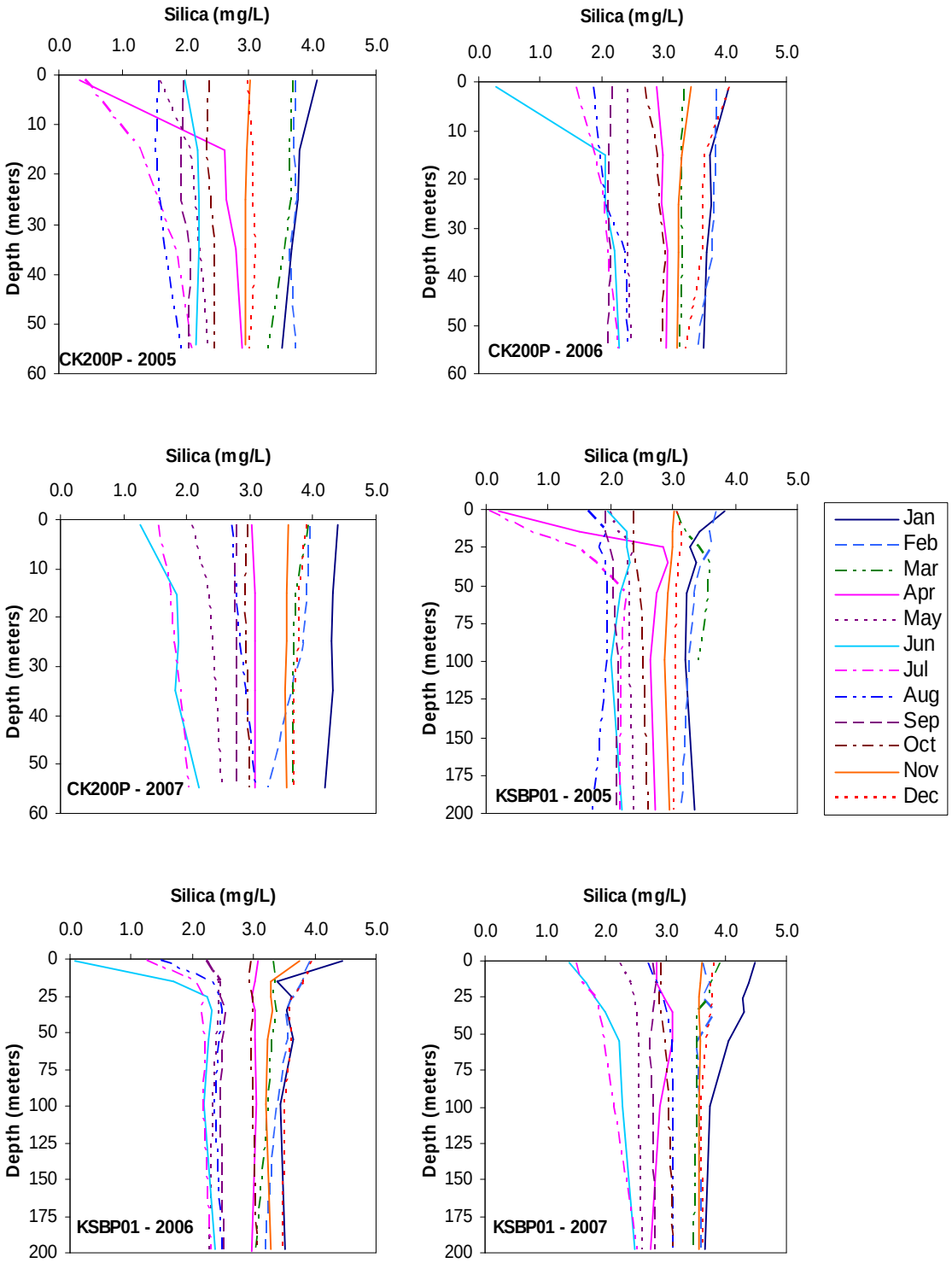

Figure 3-33. 2005-2007 Silica Profiles for Stations CK200P and KSBP01

3.2.7 Chlorophyll-*a* and Pheophytin

Phytoplankton are microscopic photosynthetic plants made up of two major groups, diatoms and dinoflagellates. Chlorophyll-*a*, the main pigment controlling photosynthesis, is the only pigment that is commonly present in all phytoplankton species, therefore, the amount of chlorophyll present can be used as an indicator of phytoplankton biomass. Chlorophyll can be degraded during natural senescence (die-off) of algal cells and also by grazing by herbivorous zooplankton. One of the degradation products of chlorophyll is pheophytin. Pheophytin is used as an indicator of physiological condition and also the amount of grazing on the phytoplankton.

In situ fluorescence measurements (an estimate of chlorophyll-*a*) were made at all offshore stations throughout the water column. In addition, discrete water samples were collected between 1 and 35 m and analyzed for chlorophyll-*a* and pheophytin in the laboratory. Discrete samples were not collected below 35 m as enough light does not penetrate to depths below 35 m to allow phytoplankton growth. Results from samples analyzed in the laboratory will be discussed as these tend to be more accurate quantitative measurements of chlorophyll abundance than those measured *in situ*, particularly when concentrations are high.

Between 2005 and 2007, chlorophyll-*a* values ranged from less than the detection limit to a high of 54.4 µg/L at Station MSWH01 (Quartermaster Harbor) in 2006. Other than the high value at the Quartermaster Harbor station, high values were measured in April of 2005 when large blooms (an accumulation of phytoplankton) were noted at most stations. In general for all three years, the spring bloom in April had the highest chlorophyll concentrations with the June bloom also having high concentrations. These high chlorophyll levels coincided with high oxygen levels in the surface layer produced through photosynthetic activity.

Figure 3-34 shows chlorophyll concentrations for the Point Jefferson and East Passage stations between 2005 and 2007. Figure 3-35 shows the occurrence of phytoplankton blooms between 2005 and 2007 as indicated by chlorophyll concentrations. It should be noted that samples are only collected monthly and it is possible that some phytoplankton blooms were missed. The length of phytoplankton blooms can vary from a day to a month, dependent on a variety of factors such as nutrient availability, the amount of tidal exchange, and weather conditions. Strong winds and a large difference between the high and low tides tend to make blooms dissipate rapidly. Even given the sampling limitations, the data indicate several spatial and temporal patterns. Phytoplankton blooms in the southern portion of the Central Basin (East Passage and Quartermaster Harbor) occurred both earlier and later in the year than at other stations. Blooms in East Passage and Quartermaster Harbor occurred as early as March and as late as October. The October 2006 bloom in Quartermaster Harbor was a large bloom, with a chlorophyll-*a* concentration of 43.5 ug/L at the inner harbor station. The spring bloom in 2005 was evident at all stations and all but one chlorophyll concentration was over 20 ug/L. Blooms in 2005 were captured throughout the spring and summer at most of the stations sampled, whereas no blooms were evident in early spring of 2006, with the exception of the East Passage and Quartermaster Harbor stations. It is likely the spring bloom occurred but was missed with monthly sampling.

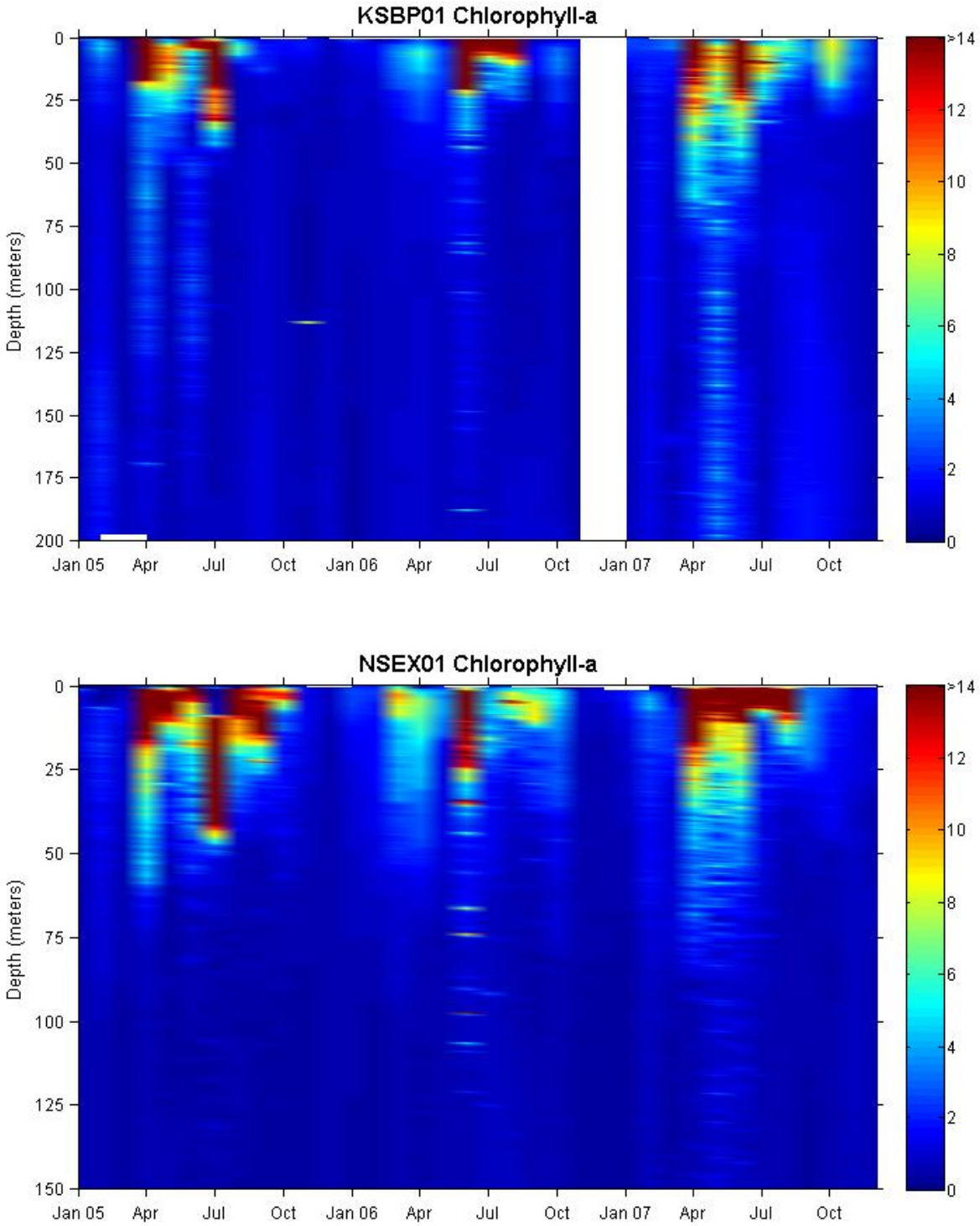

Figure 3-34. Chlorophyll-a Concentrations at Two Stations

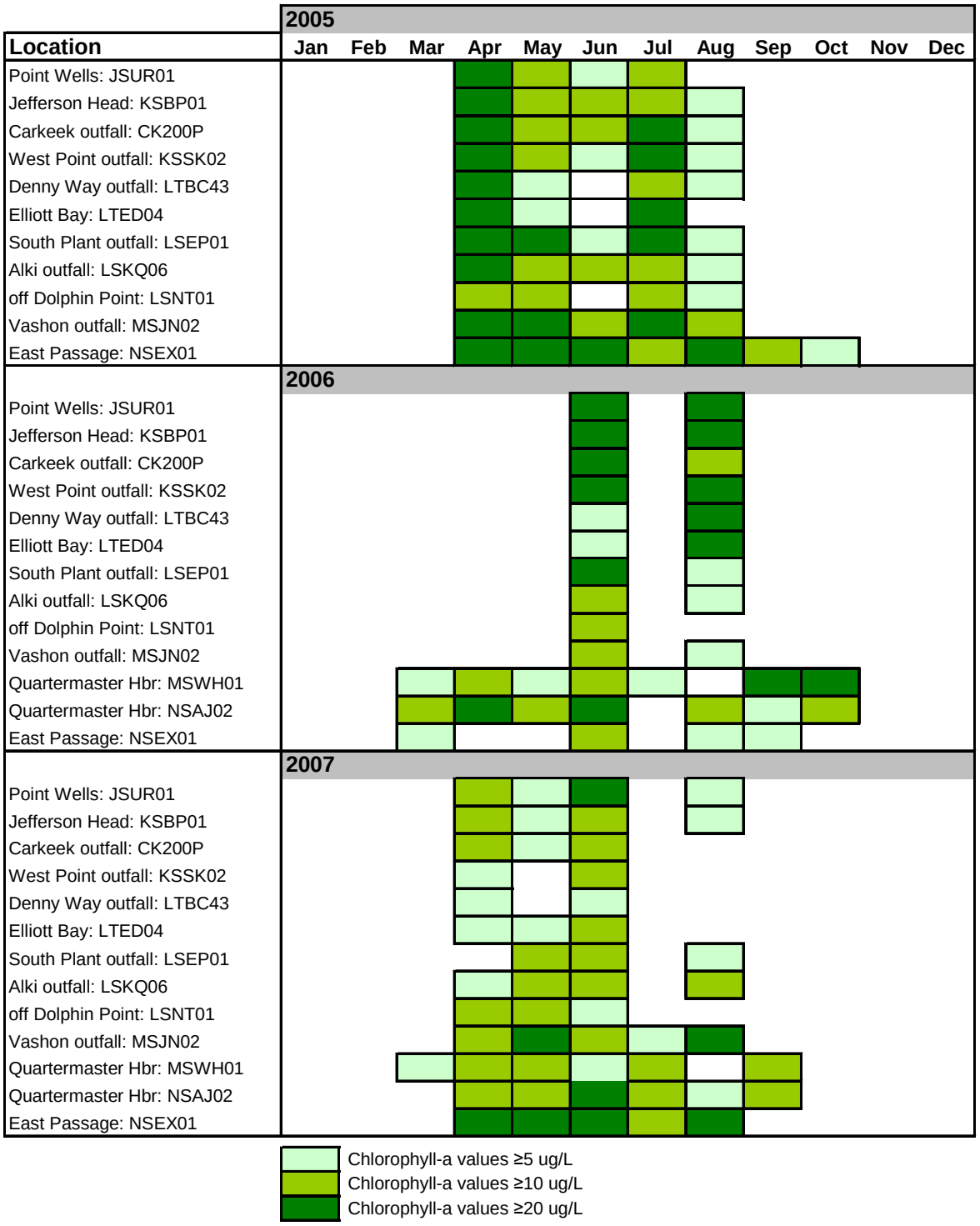

Figure 3-35. Phytoplankton Bloom Occurrence as Indicated by Chlorophyll-*a* Concentrations

Nitrogen, in the form of ammonia and nitrate+nitrite, was depleted in surface waters to levels below the detection limit due to phytoplankton uptake during the large blooms. When chlorophyll concentrations were equal to or above 20 µg/L, nitrate was depleted to undetectable levels approximately 35% of the time. Figure 3-36 shows the relationship between chlorophyll and nitrate+nitrite concentrations at the Point Wells station (JSUR01).

For all stations, the maximum chlorophyll concentration was not at the surface, but rather a few meters below the surface. The chlorophyll maximum was generally between four to six meters dependent upon the station and weather conditions. Several factors can influence the depth of where maximum chlorophyll concentrations are detected, including photoinhibition and water column stratification. Figure 3-37 shows the difference between the surface and bottom depth chlorophyll concentrations for the inner Quartermaster Harbor station MSWH01.

Pheophytin concentrations mirrored the seasonal chlorophyll concentrations, with higher amounts of pheophytin during phytoplankton blooms. Figure 3-38 shows pheophytin and corresponding chlorophyll-a concentrations.

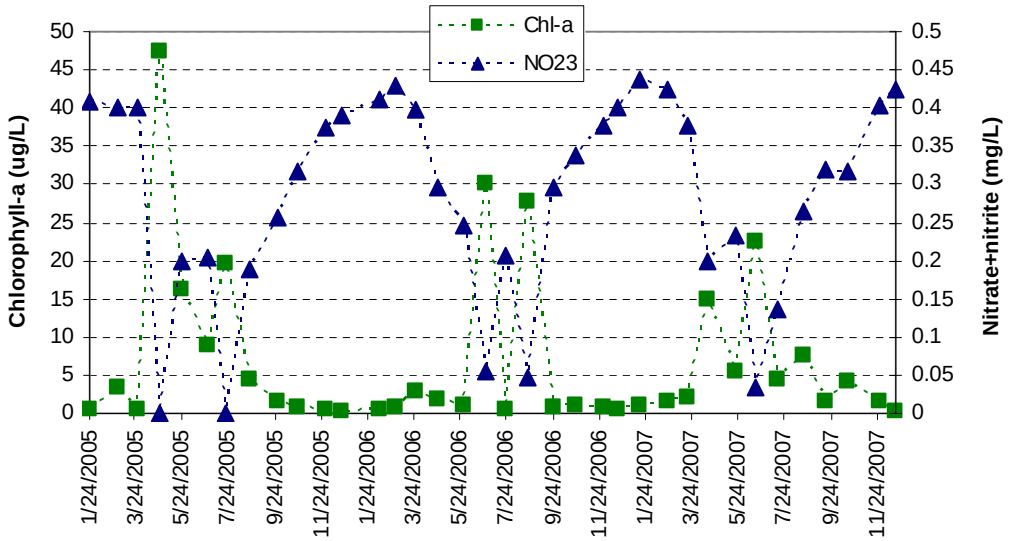

Figure 3-36. Chlorophyll-a and Nitrate+nitrite Concentrations at 1m for Station JSUR01

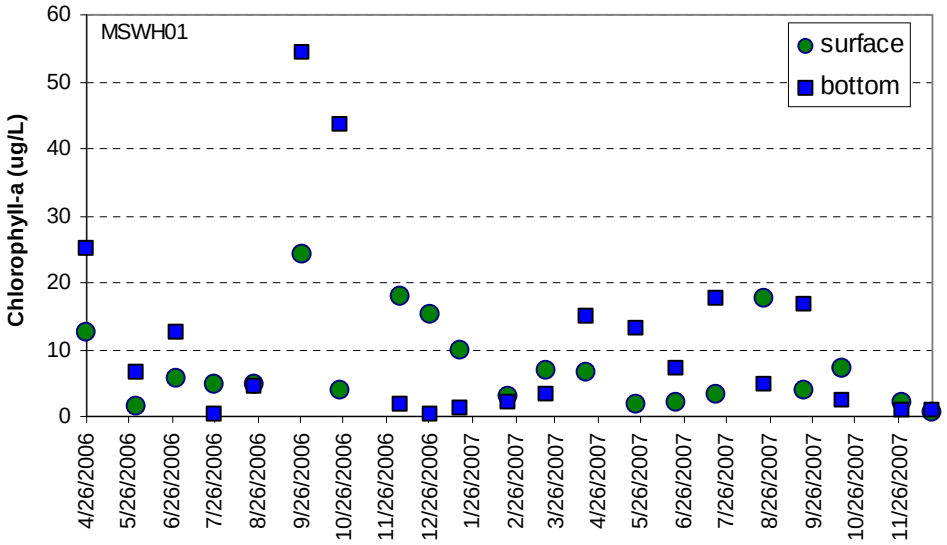

Figure 3-37. Chlorophyll-a Concentrations at Two Depths for Station MSWH01

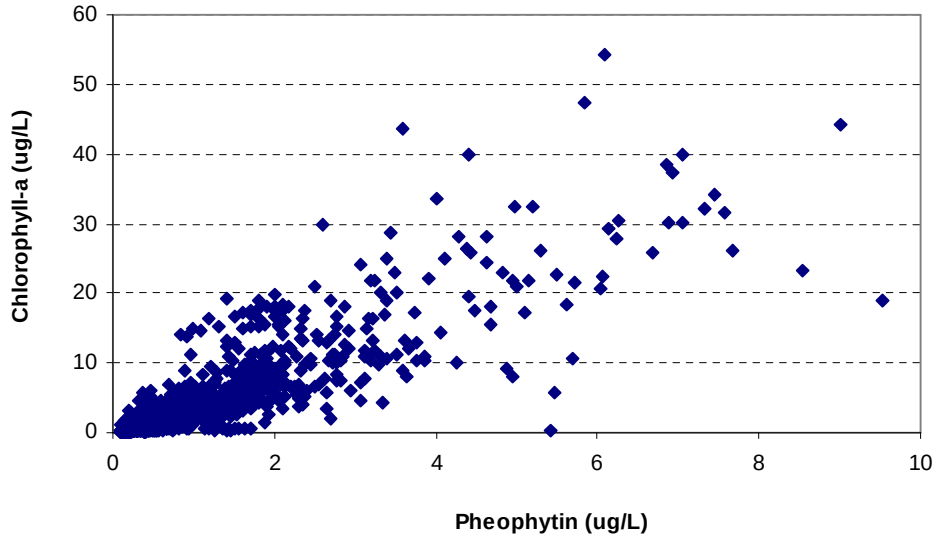

Figure 3-38. Relationship Between Pheophytin and Chlorophyll for Offshore Stations Between 2005 and 2007

SECTION 4
Summary of Sediment Monitoring Data

This section presents sediment chemistry results for both offshore and beach stations sampled between 2005 and 2007. Benthic infauna results for the West Point TP outfall samples analyzed in 2006 are also presented.

Sediment samples were collected from 8 beach stations in 2005, 19 offshore stations around the West Point Treatment Plant outfall in 2006, and 14 ambient offshore stations in 2007. The 2005 sediment data are presented in Appendix B. Station locator maps are provided in Section 2, along with specific station information such as matrix, parameters, and frequency measured. A summary of results for specific parameters (e.g., metals, organics) are provided in this section.

4.1 2005 Beach Sediments

Beach (intertidal) sediment samples were collected in August 2005 from four ambient and four outfall stations located at Richmond Beach, Golden Gardens, Normandy Park, Salt Water State Park, Carkeek Park, West Point, Alki Point, and Vashon Island. Beach sediment sampling stations are shown in Section 2. Samples were analyzed for grain size distribution, oil and grease, total organic carbon, metals, and trace organic parameters, including chlorinated pesticides, polychlorinated biphenyls (PCBs), and semivolatile organic compounds.

4.1.1 Conventionals

Grain size distribution results show that sediments collected from all eight stations were comprised mainly of sand and gravel. Percent fine material in all eight samples was very low, ranging from 1.5 to 4.3%.

Oil and grease was detected at all eight stations with concentrations ranging from 180 to 250 milligrams per kilogram, normalized to dry weight (mg/Kg DW).

Organic carbon was not detected in the samples collected from Richmond Beach (JSVW04), Carkeek Park (KSHZ03), and West Point (KSSN05). Total organic carbon concentrations in samples collected from the other five intertidal stations ranged from 670 to 4,140 mg/Kg DW or 0.07 to 0.41%. These organic carbon concentrations are considered low for Puget Sound and would be expected in coarse sediments such as these.

4.1.2 Metals

Samples were analyzed for 14 metals (see Appendix B). Four metals – arsenic, cadmium, selenium, and silver – were not detected in any of the samples. Mercury was detected in two of the eight samples, collected from Golden Gardens (KSLU03) and Alki Beach (LSKS01). The remaining nine metals were detected in all five samples. Table 4-1 shows the concentration

ranges for the detected metals. There was very little variation in metal concentrations between intertidal stations.

Table 4-1 also shows the Washington State Sediment Management Standards (SMS) sediment quality standard (SQS) chemical criteria for the eight metals regulated under the SMS program (Ecology, 1995). Detected concentrations of chromium, copper, lead, mercury, and zinc in the eight intertidal samples collected in 2005 were all well below their respective SQS chemical criteria.

Table 4-1. Metal Concentrations in 2005 Intertidal Sediment Samples

Metal	Detection Frequency	Concentration Range (mg/Kg DW)	SQS (mg/Kg DW)
Aluminum	8/8	5,360 - 9,170	--
Arsenic	0/8	--	57
Beryllium	8/8	0.068 - 0.12	--
Cadmium	0/8	--	5.1
Chromium	8/8	12.5 - 24.1	260
Copper	8/8	5.13 - 10.4	390
Iron	8/8	8,100 - 13,300	--
Lead	8/8	2.2 - 7.9	450
Manganese	8/8	109 - 204	--
Mercury	2/8	<MDL (0.024) - 0.027	0.41
Nickel	8/8	12.8 - 31.7	--
Selenium	0/8	--	--
Silver	0/8	--	6.1
Zinc	8/8	22.2 - 30.9	410

mg/Kg DW – Milligrams per kilogram on a dry weight basis.

4.1.3 Organics

Samples were analyzed for 20 chlorinated pesticides and seven PCB Aroclors® (see Table B-3, Appendix B). Chlorinated pesticides and PCBs were not detected in any of the eight samples.

The samples were also analyzed for 72 semivolatile organic compounds including polynuclear aromatic hydrocarbons (PAHs), chlorobenzenes, phthalates, and phenols (see Table B-4, Appendix B). A total of 19 semivolatile organic compounds were detected in one or more of the intertidal sediment samples. The detected compounds included benzoic acid, benzyl butyl phthalate, di-n-octyl phthalate, hexachlorobenzene, phenol, pyridine, and 11 PAHs (anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, fluoranthene, indeno(1,2,3-c,d)pyrene, phenanthrene, and pyrene).

Two other phthalate compounds were also detected – bis(2-ethylhexyl) phthalate and di-n-butyl phthalate. These plasticizers are ubiquitous in the environment, however, they are also common

laboratory contaminants. Quality control data indicated that positive analytical results for these two phthalates were most likely the result of laboratory contamination during sample analysis. Results for both of these phthalates should be considered estimated.

Table 4-2 shows the detection frequency and concentration ranges for the detected semivolatile organic compounds. This table also provides the dry-weight normalized SQS criteria for benzoic acid and phenol and the dry-weight normalized Lowest Apparent Effects Threshold (LAET) values for 16 of the other compounds (EPA, 1988). These 16 compounds all have corresponding SQS chemical criteria, which are based on organic-carbon normalized values. When assessing sediment quality, however, it is more appropriate to compare sample data to dry-weight normalized LAET values when the organic carbon content of the samples is less than 0.5% (Ecology, 1992). There are no Washington State sediment quality guidelines for pyridine.

Table 4-2. Organic Concentrations in 2005 Beach Sediment Samples

Trace Organic Compound	Detection Frequency	Concentration Range (µg/Kg DW)	SQS/LAET (µg/Kg DW)
Anthracene	1/8	<MDL (4.8) - 31.3	960
Benzo(a)anthracene	6/8	<MDL (2.4) - 78.1	1,300
Benzo(a)pyrene	5/8	<MDL (3.6) - 93.4	1,600
Benzo(b)fluoranthene	5/8	<MDL (3.6) - 74.4	1,600
Benzo(k)fluoranthene	5/8	<MDL (3.6) - 75.7	1,600
Benzo(g,h,i)perylene	2/8	<MDL (9.6) - 46.8	670
Chrysene	5/8	<MDL (4.8) - 104	1,400
Fluoranthene	5/8	<MDL (9.6) - 275	1,700
Indeno(1,2,3-c,d)pyrene	1/8	<MDL (11) - 41.1	600
Phenanthrene	4/8	<MDL (4.8) - 70.1	1,500
Pyrene	6/8	<MDL (4.8) - 207	2,600
Benzoic Acid	8/8	78 - 257	650
Benzyl Butyl Phthalate	3/8	<MDL (7.2) - 36.3	63
Di-n-octyl Phthalate	1/8	<MDL (9.6) - 31.0	6,200
Hexachlorobenzene	1/8	<MDL (0.79) - 50.5	22
Phenol	4/8	<MDL (11) - 25.8	420
Pyridine	1/8	<MDL (32) - 38	--
Bis(2-ethylhexyl) Phthalate**	8/8**	19.1 - 160**	1,300
Di-n-butyl Phthalate**	7/8**	<MDL (6.7) - 43.0**	1,400

µg/Kg DW – Micrograms per kilogram on a dry weight basis.
**Data are considered highly suspect due to likely laboratory contamination during sample analysis.

A more detailed summary of detected compounds is provided below.

Benzoic acid was detected at all eight intertidal stations at concentrations ranging from 78 to 257 µg/Kg DW. This compound can be introduced into the environment from anthropogenic sources (food preservation, dyes, cigarettes), however, it is also a naturally-occurring byproduct of the

metabolic processes in shellfish and other benthic infauna. The highest detected benzoic acid concentration of 257 µg/Kg DW is well below the SQS chemical criterion of 650 µg/Kg DW.

Benzyl butyl phthalate was detected at the West Point (KSSN05), Normandy Park (MTLD03), and Salt Water State Park (NTAK01) stations at concentrations of 27.8, 36.3, and 23.7 µg/Kg DW, respectively. These concentrations are all well below the LAET value of 63 µg/Kg DW. Benzyl butyl phthalate is a common plasticizer found in many household, commercial, and industrial products.

Di-n-octyl phthalate was only detected at the Salt Water State Park station, at a concentration of 31.0 µg/Kg DW, which is well below the associated LAET value of 6,200 µg/Kg DW. Di-n-butyl phthalate is another common plasticizer.

Hexachlorobenzene was only detected at the Normandy Park station, at a concentration of 50.5 µg/Kg DW. This concentration is greater than the LAET of 22 µg/Kg DW. There is no known potential source for hexachlorobenzene contamination at Normandy Park, however, this compound is still in use as an active ingredient in some pesticides and has been a component of some wood preservatives in the past.

Phenol was detected at two of the ambient stations – Golden Gardens (KSLU03) and Normandy Park – and two of the outfall stations – Alki Beach (LSKS01) and Vashon Island (MSJL01) – at concentrations ranging from 12 to 25.8 µg/Kg DW, all well below the SQS chemical criterion of 420 µg/Kg DW. This compound is a component of many disinfectants, both household and industrial.

Pyridine was only detected at the Richmond Beach station (JSVW04), at a concentration of 38 µg/Kg DW, which is just slightly above the range of method detection limits for this compound (32 to 36 µg/Kg DW). Potential sources of pyridine may include antifreeze and some fungicides.

As discussed, detected concentrations of bis(2-ethylhexyl) phthalate and di-n-butyl phthalate should be considered as estimated and most likely the result of laboratory contamination during sample analysis. The detected phthalate concentrations, while highly suspect, are also all well below their respective LAET values.

One or more PAH compounds were detected in samples collected from three of the four outfall stations and three of the four ambient stations. PAH compounds were not detected at the Richmond Beach or Vashon Island stations. Total PAH concentrations at five of the six remaining stations were very low – ranging from 8.4 to 140 µg/Kg DW. The total PAH concentration of 1,100 µg/Kg DW detected at the Salt Water State Park station was significantly higher than the other five stations at which PAHs were detected. A potential source for elevated PAHs at this station might be stormwater runoff from the large asphalt parking lot in the park, introduced to intertidal sediment either directly or via the stream that runs through the park and empties into Puget Sound. Although elevated, the total PAH concentration at the Salt Water State Park station is still well below the LAET of 9,100 µg/Kg DW.

4.2 2006 West Point TP Outfall Offshore Sediments

The primary goal of the 2006 West Point outfall sediment monitoring event was to meet the sediment monitoring requirement of the County's West Point TP NPDES permit. Secondary goals were to reassess and fully characterize sediment quality at two existing monitoring stations that previously appeared to exceed SMS chemical and/or biological criteria.

Sampling for the 2006 West Point sediment monitoring event was designed to allow a full characterization of sediment quality in the immediate vicinity of the outfall as well as allowing assessment of sediment thought to be outside the direct influence of the outfall. To aid sample station placement, King County deployed four Acoustic Doppler Current Profilers (ADCPs) for five weeks beginning in February 2003 at specific locations around the outfall to better understand oceanographic currents that may affect the effluent plume and sediment deposition. As expected, the current meter study indicated a net northerly flow in the vicinity of the West Point outfall (King County, 2005). As a result of the current meter study and previous data, a total of 19 stations were sampled in October 2006, both proximal (16 stations) and distal (3 stations) to the outfall. The proximal stations were placed in three north-to-south transects (Figure 4-1).

All 19 samples were analyzed for sediment conventionals, metals, and organic compounds and 11 samples (3 replicates per sample) were analyzed for benthic infaunal community abundance and structure. Ten of the benthic community samples were proximal to the outfall and one was distal.

4.2.1 Conventionals

Sediment conventional analyses included grain size distribution, TOC, ammonia nitrogen, and total sulfides. Table 4-3 summarizes analytical results for sediment conventionals.

The grain size analysis shows that sediments in the vicinity of the West Point outfall are coarse-grained, comprised mainly of sand, with a low percentage of fine material (silt and clay). Percent fines ranged from 1.3 to 11.2%. This distribution of particle size is indicative of a high-energy, low-depositional environment.

TOC results ranged from 0.10 to 0.41%, which is considered low for Puget. These low TOC results are expected, given the composition of substrate in the vicinity of the West Point outfall. The 2006 results are similar to past monitoring years (King County 1998, 2000, 2001).

Ammonia was detected in all 19 samples at concentrations ranging from 0.367 to 3.33 mg/Kg DW. Total sulfides were detected in 6 of 19 samples. The dry weight-normalized MDL for total sulfides ranged from 0.63 to 0.70 mg/Kg DW. Detected total sulfide results ranged from 0.69 to 5.87 mg/Kg DW. There is no apparent concentration gradient for either ammonia or total sulfides, with respect to the West Point outfall.

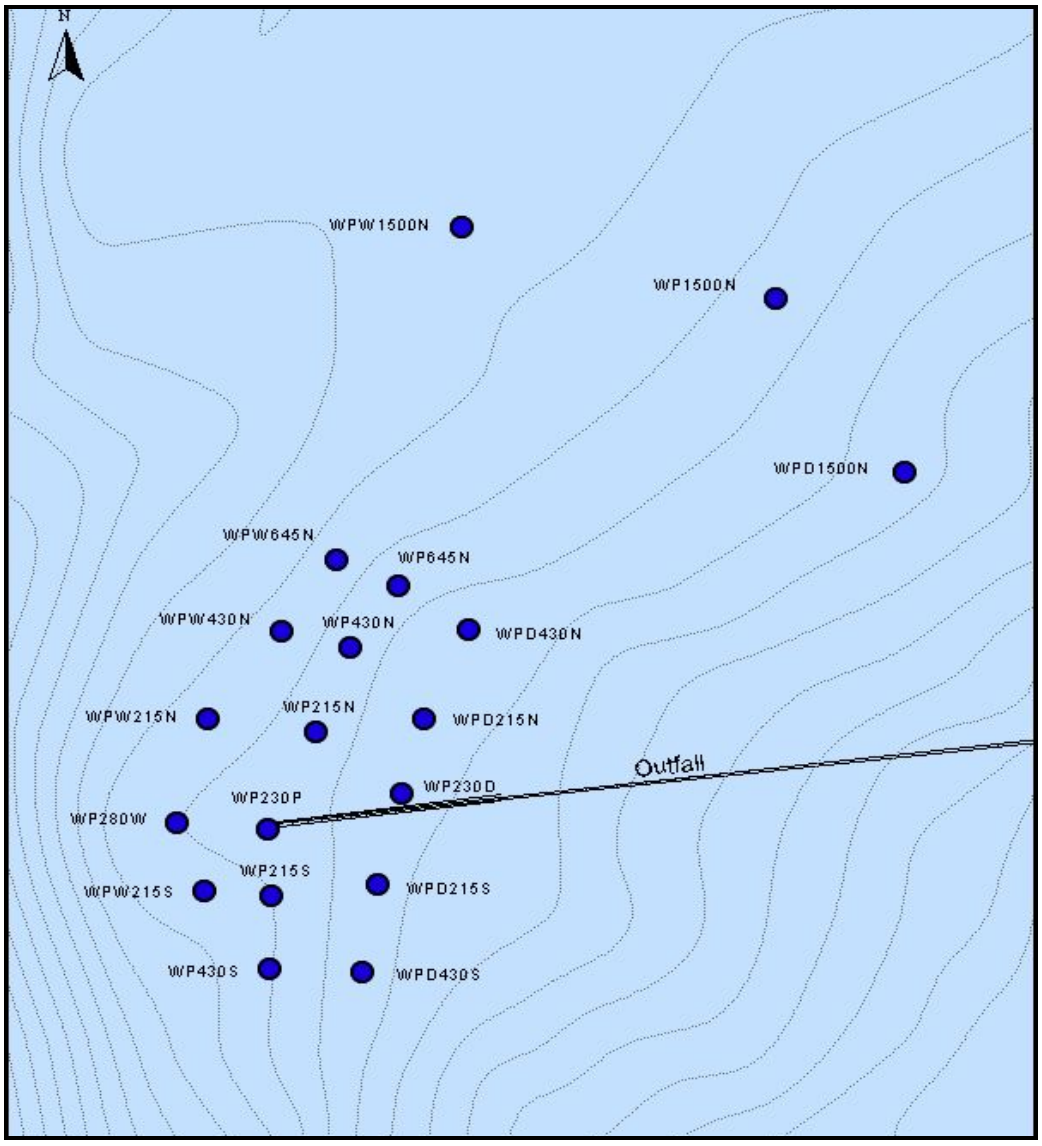

Figure 4-1. West Point 2006 Sediment Stations

4.2.2 Metals

Metals results are presented in units of mg/Kg DW. Three of the eight metals regulated under SMS – chromium, copper, and zinc – were detected in all 19 samples; all at similar concentrations and all well below their respective SQS chemical criteria.

- Chromium – concentrations from 11.7 to 25.7 mg/Kg DW – SQS = 260 mg/Kg DW.
- Copper – concentrations from 5.08 to 13.6 mg/Kg DW – SQS = 390 mg/Kg DW.
- Zinc – concentrations from 19.9 to 40.7 mg/Kg DW – SQS = 410 mg/Kg DW.

Table 4-3. Summary of Sediment Conventional Results

Station	% Fines	% TOC	Ammonia (mg/Kg DW)	Total Sulfides (mg/Kg DW)
WP230P	10.8	0.38	1.78	1.0
WP215N	4.3	0.25	1.21	0.94
WP215S	2.5	0.14	0.796	<MDL (0.68)
WP430N	4.4	0.31	1.97	<MDL (0.69)
WP430S	2.1	0.14	0.895	0.69
WP645N	5.0	0.28	2.06	<MDL (0.68)
WP1500N	4.5	0.39	1.85	4.68
WP230D	1.3	0.10	0.445	<MDL (0.64)
WPD215N	3.0	0.11	0.681	<MDL (0.73)
WPD215S	3.6	0.23	3.33	<MDL (0.64)
WPD430N	4.1	0.11	0.367	<MDL (0.63)
WPD430S	2.3	0.27	2.43	<MDL (0.65)
WPD1500N	1.4	0.18	0.730	5.87
WP280W	11.2	0.45	2.60	<MDL (0.70)
WPW215N	5.1	0.33	1.77	<MDL (0.70)
WPW215S	4.3	0.29	0.918	<MDL (0.67)
WPW430N	5.2	0.27	0.536	<MDL (0.69)
WPW645N	3.9	0.35	0.933	1.1
WPW1500N	5.2	0.41	0.931	<MDL (0.69)

Arsenic was detected in 4 of 19 samples at concentrations ranging from 3.4 to 4.5 mg/Kg DW, very near the MDL range of 3.1 to 3.6 mg/Kg DW. The detected concentrations are all well below the arsenic SQS chemical criterion of 57 mg/Kg DW.

Cadmium was not detected in any of the samples. The MDL range of 0.19 to 0.22 mg/Kg DW is well below the SQS chemical criterion of 5.1 mg/Kg DW.

Lead was detected in 18 of 19 samples at concentrations ranging from 3.0 to 18.6 mg/Kg DW, all well below the SQS chemical criterion of 450 mg/Kg DW.

Mercury was detected in 12 of 19 samples at concentrations ranging from 0.026 to 0.13 mg/Kg DW. The highest detected mercury concentration of 0.13 mg/Kg is less than 35% of the SQS chemical criterion of 0.41 mg/Kg DW.

Silver was detected in one sample, at a concentration of 0.28 mg/Kg DW, which is very near the MDL range of 0.26 to 0.29 mg/Kg DW. The one detected concentration, as well as all of the MDLs, are well below the SQS chemical criterion of 6.1 mg/Kg DW.

4.2.3 Organics

Organic compounds regulated under SMS include polynuclear aromatic hydrocarbons, phthalates, chlorobenzenes, PCBs, acid/alcohol (ionic) compounds, and miscellaneous non-ionic organics. Data for the seven ionic compounds regulated under SMS are normalized to dry weight for comparison with SQS chemical criteria. Data for the remaining non-ionic organic compounds regulated under SMS are generally normalized to organic carbon for comparison with SMS chemical criteria. However, normalization to organic carbon can produce biased

results when the organic carbon content of the sample is very low (Ecology, 1992). When the organic carbon content of a sample is near 0.1 or 0.2% (1,000 to 2,000 mg/Kg DW), even background concentrations of certain organic compounds can exceed the SQS. TOC values in all 19 samples were less than 0.5%, therefore, all analytical results for non-ionic trace organics are presented in units of micrograms per kilogram on a dry weight basis (µg/Kg DW) and compared to LAET chemical criteria.

Polynuclear Aromatic Hydrocarbons (PAHs)

One or more low-molecular weight PAH (LPAH) compounds were detected in 17 of 19 samples. LPAHs were not detected in the samples collected from Stations WP230D and WPD215N. Detected concentrations of individual LPAH compounds were all well below their associated LAET values. Total LPAH concentrations ranged from 3.1 to 687 µg/Kg DW, all well below the LAET value of 3,650 µg/Kg DW. The highest total LPAH concentration, detected at Station WP215N, is less than 20% of the LAET.

One ore more high-molecular weight PAH (HPAH) compounds were detected in 18 of 19 samples. HPAHs were not detected in the sample collected from Station WPD215N. Detected concentrations of individual HPAH compounds were all well below their associated LAET values. Total HPAH concentrations ranged from 21 to 4,060 µg/Kg DW, all well below the LAET value of 13,080 µg/Kg DW. The highest total HPAH concentration, also detected at Station WP215N, is less than 35% of the LAET.

Phthalates

Benzyl butyl phthalate was detected in 7 of 19 samples at concentrations ranging from 7.20 to 13.3 µg/Kg DW, all less than 25% of the LAET value of 63 µg/Kg DW. Bis(2-ethylhexyl) phthalate was detected in all 19 samples at concentrations ranging from 9.4 to 52.9 µg/Kg DW, all less than 5% of the LAET value of 1,300 µg/Kg DW. Di-n-butyl phthalate was detected in all 19 samples, however, this compound was also detected in the associated laboratory quality control method blank. All of the reported di-n-butyl phthalate sample results were less than 10 times the concentration detected in the method blank and, therefore, should be considered as undetected. Di-n-octyl phthalate, diethyl phthalate, and dimethyl phthalate were not detected in any of the samples. Dry weight-normalized MDLs for all undetected phthalate compounds were well below their respective LAET values in all samples.

Chlorobenzenes

Chlorobenzene compounds, including 1,2-dichlorobenzene, 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, and hexachlorobenzene, were not detected in any of the samples. Dry weight-normalized MDLs for all four compounds were well below their associated LAET values in all samples.

Miscellaneous Non-Ionic Organic Compounds

Dibenzofuran was detected in one sample, collected from Station WP215N, at a concentration of 2.8 µg/Kg DW. This detected value is well below the dibenzofuran LAET value of 140 µg/Kg DW. Hexachlorobutadiene and N-nitrosodiphenylamine were not detected in any of the samples. Dry-weight normalized MDLs for all three compounds were well below their associated LAET values in all samples.

Polychlorinated Biphenyls (PCBs)

PCBs, as Aroclors®, were detected in 17 of 19 samples. Total PCB concentrations ranged from 1.7 to 78.7 µg/Kg DW, with the highest concentration detected at Station WPW645N. All of the detected total PCB concentrations are well below the associated LAET value of 130 µg/Kg DW – the highest detected concentration was approximately 60% of the LAET.

Ionic Organic Compounds

Benzoic acid was detected in all 19 samples at concentrations ranging from 53.7 to 140 µg/Kg DW, all less than 35% of the SQS chemical criterion of 650 µg/Kg DW. Benzyl alcohol was detected in 13 of 19 samples at concentrations ranging from 5.3 to 28.2 µg/Kg DW, all less than 50% of the SQS chemical criterion of 57µg/Kg DW. Phenol was detected in all 19 samples at concentrations ranging from 7.0 to 133 µg/Kg DW, all less than 30% of the SQS chemical criterion. Pentachlorophenol, 2-methylphenol, 4-metholphenol, and 2,4-dimethylphenol were not detected in any of the samples. Dry weight-normalized MDLs for the four undetected phenolics compounds were well below their respective chemical criteria for all samples.

Additional Organic Compounds

Additional organic analyses were performed on 9 of the 19 samples. These included chlorinated pesticides, chlorinated herbicides, organophosphorus pesticides, organotins, and polybrominated diphenyl ethers. Analytical results for these additional compounds are presented in units of µg/Kg DW and have been compared to LAET chemical criteria when available.

Chlorinated Pesticides

Chlorinated pesticide analysis included the following 20 compounds. DDT and its metabolites DDD and DDE, Alpha-, Beta-, Delta, and Gamma-BHC, Alpha- and Gamma-Chlordane, Aldrin, Dieldrin, Endosulfan I, II, and Sulfate, Endrin and Endrin Aldehyde, Heptachlor and Heptachlor Epoxide, Methoxychlor, and Toxaphene. Eight of these compounds have associated LAET values; DDD, DDE, DDT, Aldrin, Alpha- and Gamma-Chlordane, Dieldrin, and Heptachlor. One compound, 4,4'-DDD, was detected in the sample collected from Station WP215N at a concentration of 0.63 µg/Kg DW. This concentration is less than 5% of the associated LAET value of 16 µg/Kg DW. This was the only pesticide detected in any of the nine samples. All dry weight-normalized pesticide MDLs were well below their associated LAET values in all nine samples.

Chlorinated Herbicides

Chlorinated herbicide analysis included the following ten compounds: 2,4,5-T, 2,4-D, 2,4-DB, Dalapon, Dicamba, Dichloroprop, Dinoseb, MCPA, MCPP, and Silvex. Chlorinated herbicides were not detected in any of the samples. Dry weight-normalized MDLs for these compounds ranged from 0.68 to 6.6 µg/Kg DW.

Organophosphorus Pesticides

Organophosphorus pesticide analysis included the following seven compounds: Chlorpyrifos, Diazinon, Disulfoton, Malathion; Ethylparathion, Methylparathion, and Phorate. Organophosphorus pesticides were not detected in any of the samples. Dry weight-normalized MDLs for these compounds ranged from 4.1 to 12 µg/Kg DW.

Organotins

Organotin analysis included four isomers of butyltin; mono-, di-, tri-, and tetra-n-butyltin. These four compounds were not detected in any of the samples. Dry weight-normalized MDLs for butyltin isomers ranged from: 11 to 12 µg/Kg DW (mono); 2.3 to 2.6 µg/Kg DW (di); 1.3 to 1.5 µg/Kg DW (tri); and 2.6 to 2.9 µg/Kg DW (tetra).

Polybrominated Diphenyl Ethers (PBDEs)

PBDE analysis included the following 14 congeners: TriBDE-17 and -28; TetraBDE-47, -66, and -71; PentaBDE-85, -99, and -100; HexaBDE-138, -153, and -154; HeptaBDE-183 and -190; and DecaBDE-209. One or more PBDE congeners were detected in all nine samples, with summed PBDE concentrations of the 14 congeners measured ranging from 0.480 to 3.18 µg/Kg DW. The average PBDE concentration for all stations sampled was 1.28 µg/Kg DW.

PBDE concentrations in Puget Sound sediments have not been widely studied. An Ecology study conducted in 2005 at 10 locations in Puget Sound found concentrations of PBDEs (12 congeners) similar to those detected proximal to the West Point outfall (Dutch and Aasen, 2007). King County monitored PBDE concentrations at an ambient site off Point Wells, which will be the future location of the Brightwater wastewater treatment plant. Total PBDE (14 congeners) concentrations detected in 11 stations collected from the Point Wells site ranged from 1.59 to 2.59 µg/Kg DW with a mean value of 2.05 µg/Kg DW (King County 2007). The range of concentrations detected at Point Wells are also similar to those concentrations detected at West Point.

4.2.4 Benthic Community Structure

Benthic infauna analysis was conducted on 11 sediments samples: 10 samples surrounding the end and mid-point of the diffuser and 1 sample north of the outfall (WP1500N) (see Figure 4-1). A complete list of all species identified and enumerated during the 2006 West Point sediment monitoring event is included in Appendix B. There are several indices that can be used to evaluate benthic community assemblages and compare results from sampling stations to one another. These indices include:

- Total Abundance, which is the number of individual organisms per 0.1 m^2;
- Total Richness, which is the number of species per 0.1 m^2 (the area sampled by a standard van Veen grab sampler);
- Total Biomass, which is the combined mass (weight) of all organisms found in a 0.1 m^2 sample;
- Shannon-Wiener Diversity Index (*H'*), which is a measure of the relationship between taxa richness and abundance;
- Pielou's Evenness Index (*J*), which is expressed as the observed diversity in a sample as a proportion of the maximum possible diversity; and
- Swartz's Dominance Index, which is defined as the minimum number of species comprising 75% of the total abundance in a given sample.

All of these indices have been calculated based on averages over the three replicate samples collected from each station.

Abundance

Total abundance ranged from a low of 162 individuals, found at station WPD430N, to a high of 814 individuals, found at station WPW215S. The average abundance value was 472 individuals. Annelids represented the largest proportion of individual organisms at 10 of the 11 stations monitored. Figure 4-2 presents the average total abundance for the stations at which benthic data were collected. The figure shows that four stations clustered around the end of the outfall diffuser (WP230P, WPW215S, WPW215N, and WP215N) had the highest average total abundance. It should be noted that the higher abundance at these four stations was not due to an over-abundance of polychaete or other pollution-tolerant species. Polychaetes of the family Capitellidae, traditional indicators of organic enrichment or pollution, were present at only one station with only two individuals found.

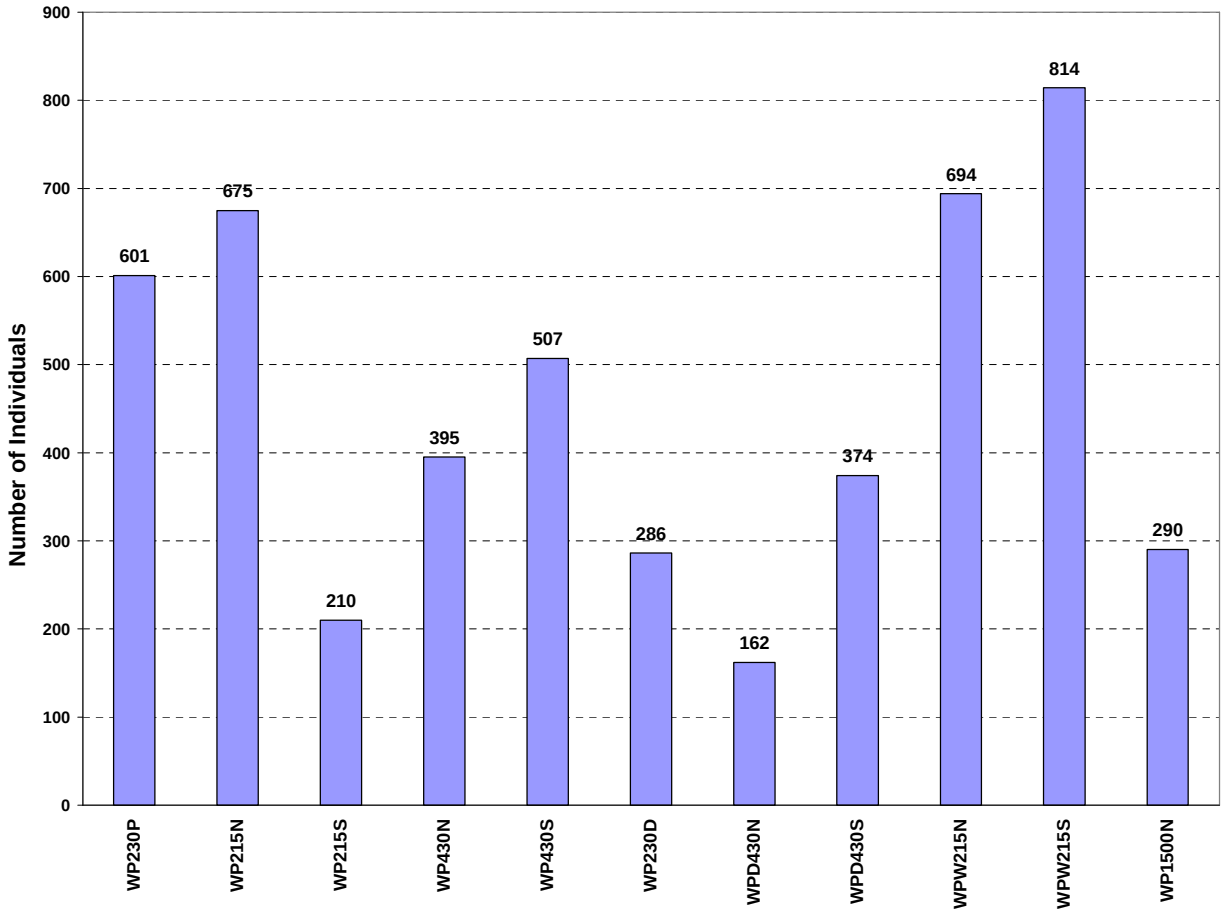

Figure 4-2. 2006 Average Abundance at the West Point TP

Richness

Total richness ranged from a low of 64 different species, found at station WPD430N, to a high of 149 species, found at station WP215N. The average richness value was 125 species. Annelida taxa represented the highest number of species found at each monitoring station, ranging from 35 to 90 different species. Crustacean taxa represented the second highest number of different species at each station. Figure 4-3 presents the relative distribution of total richness for the stations at which benthic data were collected. The figure shows that average total richness values are similar for those stations clustered around the end of the outfall diffuser. Slightly lower average total richness values are exhibited at two stations north of the outfall along the mid-diffuser transect.

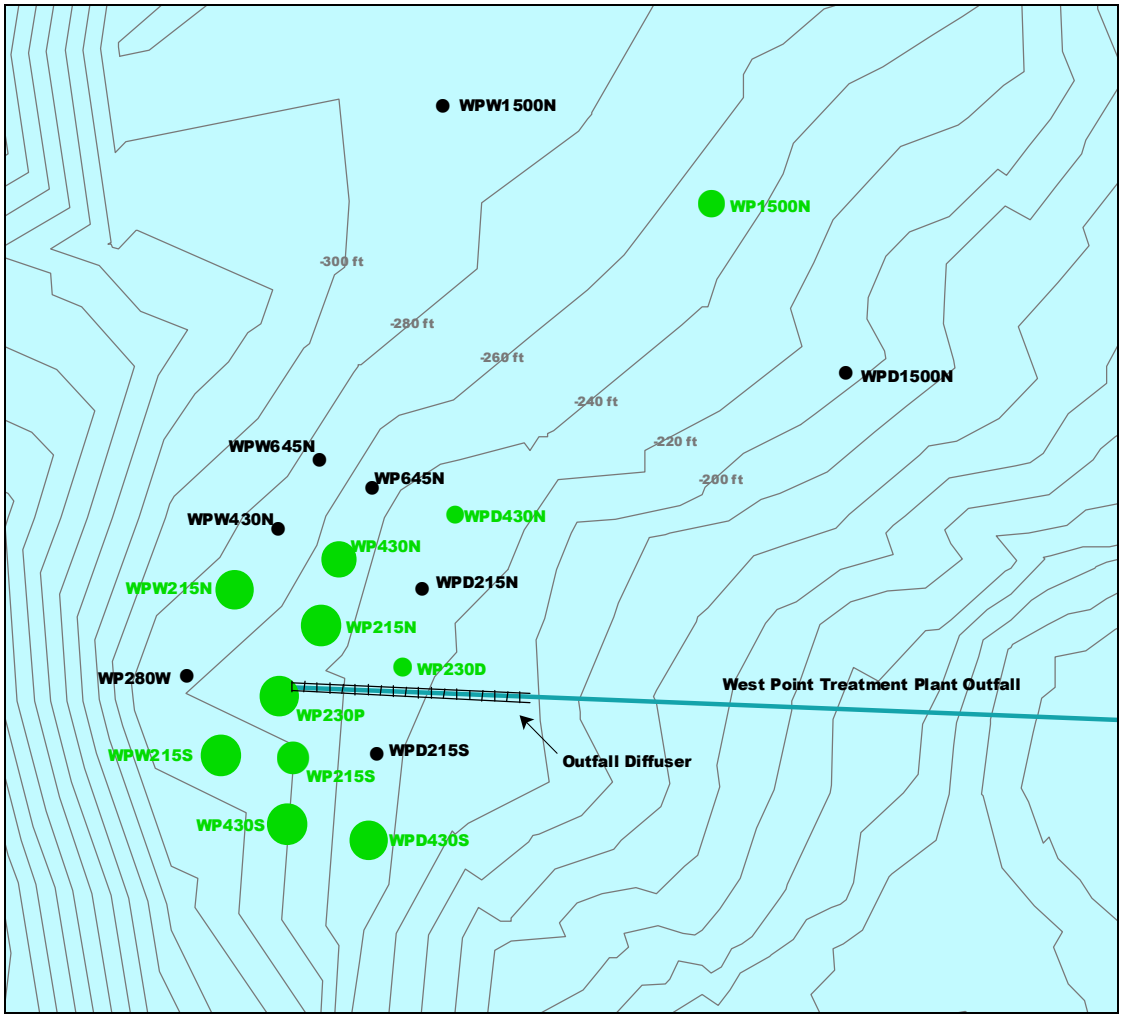

Figure 4-3. Distribution of Average Benthic Richness Values (size of dot is proportional to total abundance)

Biomass

Total biomass is expressed in grams per 0.1 square meter (g/0.1 m^2). Reported total biomass measurements at the 16 stations ranged from 3.72 to 16.45 g/0.1 m^2. The average biomass value was 9.57 g/0.1 m^2. Although always measured, total biomass is not a particularly useful comparative tool for assessing benthic community assemblages, given confounding factors such as differences in shell or carapace size or the presence of one large individual in a sample.

Diversity Indices

Diversity indices calculated for the benthic data included the Shannon-Wiener Diversity Index, Pielou's Evenness Index, and Swartz's Dominance Index. These diversity indices were also calculated from the averages of three replicates at each station.

Shannon-Wiener Diversity Index

The Shannon-Wiener Diversity Index (*H'*) is one of the most widely-used diversity indices due to its ease of calculation and its relative independence of sample size. This index uses the total number of species in a sample as well as the abundances of single species to determine diversity. Increasing index values indicate increasing diversity of the benthic community. *H'* values ranged from a low of 2.01 at station WPD430N to a high of 7.29 at station WPW215S. The average *H'* value was 4.97.

Pielou's Evenness Index

Pielou's Evenness Index (*J*) is another measure of diversity that is commonly used in conjunction with the Shannon-Wiener Diversity Index. Evenness is a measure of the observed diversity in a sample as a proportion of the maximum possible diversity. *J* values close to 1.0 represent a sample composed of many different species while low *J* values indicate a sample composed of only a few dominant species. *J* values ranged from a low of 0.34 at station WPD430N to a high of 1.01 at station WPW215S. The average *J* value was 0.71.

Swartz's Dominance Index

Swartz's Dominance Index (SDI) measures the minimum number of species whose abundance comprises 75% of the total sample abundance. Low values indicate a sample with little diversity while higher numbers indicate a sample comprised of many species. SDI values ranged from a low of 10 at station WPD430S to a high of 64 at station WP230P. The average SDI value was 48. There was no one dominant species evident at all 11 stations, rather a rich mixture of species including some pollution-sensitive species, such as *Cucumaria piperata*.

Table 4-4 provides a summary of the diversity indices for all stations sampled.

Table 4-4. Diversity Indices Summary for West Point Stations

Station	Shannon-Wiener Diversity Index	Pielou's Evenness Index	Swartz's Dominance Index
WP230P	6.12	0.85	64
WP215N	6.43	0.89	56
WP215S	2.53	0.39	54
WP430N	4.41	0.63	63
WP430S	4.91	0.72	41
WP230D	3.08	0.50	45
WPD430N	2.01	0.34	47
WPD430S	6.45	0.90	10
WPW215N	6.44	0.90	50
WPW215S	7.29	1.01	48
WP1500N	3.29	0.50	54

4.3 2007 Ambient Offshore Sediments

Marine sediment was collected from 14 ambient stations in June 2007 (see map in Section 2). Three stations were located in the Central Basin: near Point Jefferson (KSBP01); off of West Seattle (LSML01); and in East Passage (NSEX01). These three stations are all deep and removed from direct anthropogenic inputs.

Three stations were located in shallow embayments; outer Salmon Bay (KSRU03); Fauntleroy Cove (LSVV01); and inner Quartermaster Harbor (MSVK01). These three embayments all have anthropogenic inputs that could impact sediment quality. Station KSRU03 is located on the marine side of the Hiram M. Chittenden locks and receives a high level of both small and large vessel traffic entering and exiting the locks. Station LSVV01 is located near the Fauntleroy/Vashon ferry dock. This area has a history of water quality issues, receives a large amount of freshwater input, and is impacted by ferry traffic. Station MSVK01 is located in a shallow, quiescent embayment that receives a moderate amount of seasonal small vessel traffic

Eight stations were located in Elliott Bay and represent a combination of moderately shallow to deep stations in the center of the bay. Four of the Elliott Bay stations have long-term sediment quality data sets and form a rough east-west transect away from locations of potential point-source impacts to the sediment:

LTDF01 located along the central Seattle waterfront, near Pier 66,
LTED04 located in the center of Elliott Bay,
LTCA02 located in the center of Elliott Bay, west of LTED04, and
LSCW02 located at the hypothetical boundary between Elliott Bay and the Central Basin.

Four new Elliott Bay stations were added to the monitoring program in 2007 to assess specific areas of the bay. These stations are:

KSZY01 located just offshore of Piers 90/91. This area has historically received high heavy-vessel traffic and will continue to receive large ships when cruise liners begin using these docking facilities.
LTAA02 located just offshore of the grain terminal. This area has also historically received high large-vessel traffic.
LTGF01 located just offshore of the northern end of Harbor Island. This location is in an area of heavy industry, including fuel storage and transfer, shipbuilding and repair, and the transportation industry.
LSHZ08 located just offshore of Cove 2 at Seacrest Park. This area has high usage by recreational SCUBA divers, including diving classes, which includes a high incidence of primary contact with bottom sediments, especially by student divers.

Samples were analyzed for conventional sediment parameters, metals, and organic compounds.

4.3.1 Sediment Conventionals

Sediment conventional analyses included grain size distribution, total organic carbon, ammonia nitrogen and total sulfides.

Grain Size Distribution

Grain size distribution varied widely between the 14 sampling stations. Figure 4-4 shows the percent grain size distribution in the four major size-groupings; gravel, sand, silt, and clay. The silt plus clay fractions represent the percent fines content of a sediment sample. Percent fines ranged from a low of 4.0% at Station LSVV01 (Fauntleroy Cove) to a high of 96.0% at Station NSEX01 (East Passage). The three deep main basin stations exhibited differing grain size distributions with percent fines content of 15.5% at KSBP01 (Point Jefferson); 61.5% at Station LSML01 (West Seattle), and 96.0% at Station NSEX01. Of note is the very low percent fine content of 4.0% at Station LSVV01. The prop wash from the Fauntleroy/Vashon ferry as it arrives, departs, and idles may cause the removal of fine material at this station.

Total Organic Carbon

Total organic carbon concentrations ranged from 1,850 to 24,700 mg/Kg DW or, approximately, 0.2 to 2.5%. Total organic carbon correlated well with percent fine material, as shown in Figure 4-5.

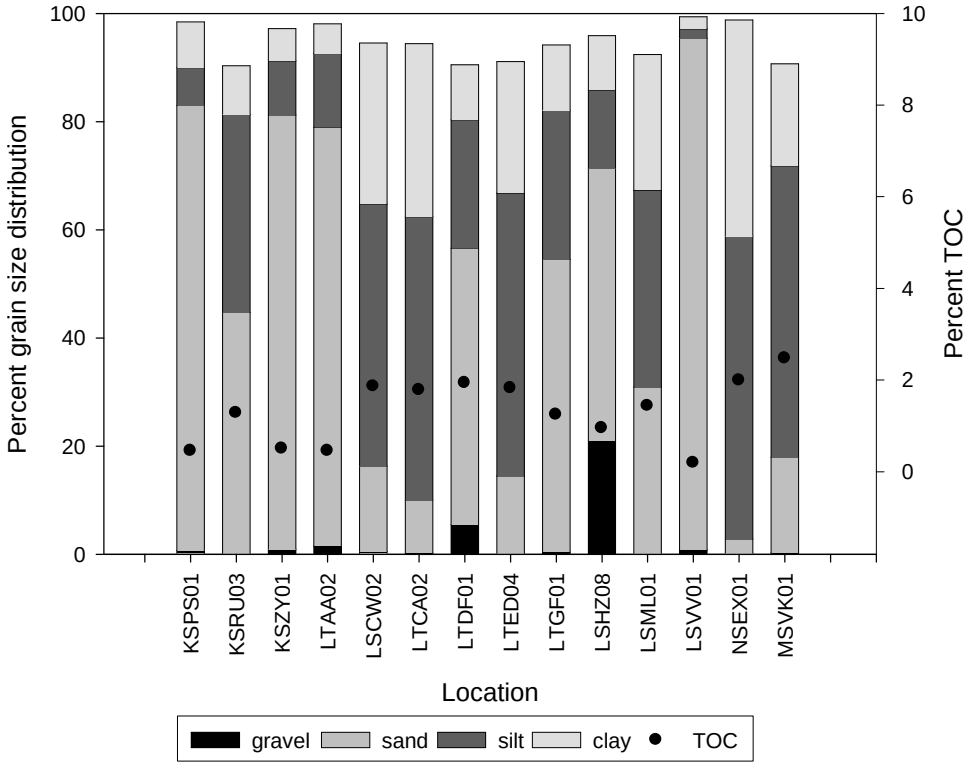

Figure 4-4. Grain Size Distribution and Total Organic Carbon for Ambient Stations

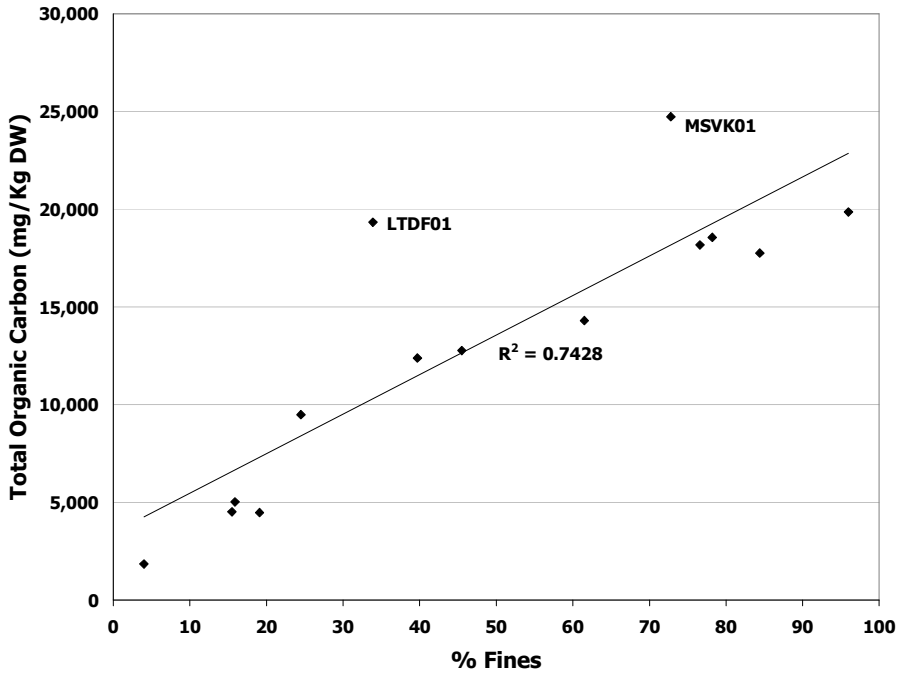

Figure 4-5. Total Organic Carbon vs. Percent Fines for All Stations

Two exceptions to this correlation appear to be at Station MSVK01 in Quartermaster Harbor and Station LTDF01 along the central Seattle waterfront, both of which exhibited somewhat higher total organic concentrations relative to the percent fine material found in the samples. One explanation for the higher organic carbon concentration at Station MSVK01 may be from the settlement/sedimentation of decaying phytoplankton. A large phytoplankton bloom was recorded in Quartermaster Harbor during June 2007, the month in which the sediment sample was collected (see Section 3). The higher organic carbon concentration at Station LTDF01 may also have been the result of a phytoplankton bloom, although the bloom appeared to be of smaller magnitude in Elliott Bay. Anthropogenic inputs of organic carbon may also be present at this station, given its proximity to the waterfront shoreline.

Ammonia and Sulfide

Sediment ammonia concentrations ranged from 1.67 to 20.3 mg/Kg DW and correlated well with percent fine material, as shown in Figure 4-6.

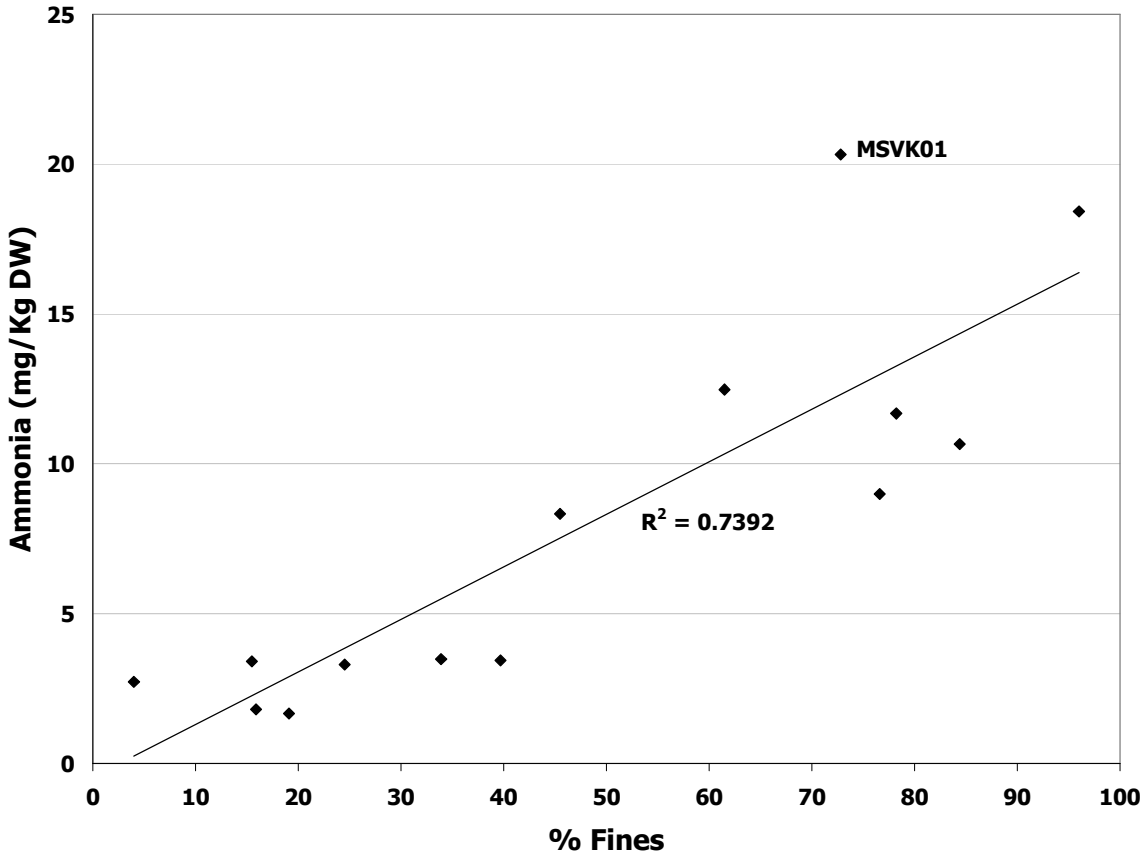

Figure 4-6. Sediment Ammonia Concentration vs. Percent Fines for All Stations

The exception to this correlation appears to be at Station MSVK01 in Quartermaster Harbor, which exhibited a somewhat higher ammonia concentration relative to the percent fine material found in the sample. One explanation for the higher ammonia concentration at this station may be from bacterial decay and settlement/sedimentation of phytoplankton or from zooplankton excretions during phytoplankton grazing during the large June 2007 bloom in Quartermaster Harbor.

Total sulfide was detected in 9 of 14 samples, at concentrations ranging from 1.49 to 562 mg/Kg DW. There was no apparent correlation between total sulfide concentration and any other measured conventional parameter, nor did there appear to be any distinct spatial patterns to total sulfide concentrations.

4.3.2 Metals

Sediment metals analysis included 14 metals: the eight metals regulated under the Sediment Management Standards (arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc); three additional trace metals (antimony, nickel, and tin); and three crustal metals (aluminum, iron, and manganese). The crustal metals were analyzed to provide a method for normalizing trace metal concentrations as a means to evaluate possible anthropogenic inputs. All metals results are presented in units of mg/Kg DW.

Table 4-5 presents results for the 14 metals analyzed, providing the frequency of detection (FOD) along with the minimum, maximum, and median concentrations. The table also compares those concentrations to the Sediment Quality Standard (SQS) chemical criteria for the eight metals regulated under the Sediment Management Standards.

Table 4-5. Sediment Metals Concentrations (mg/Kg DW)

Metal	FOD	Minimum	Maximum	Median	SQS
Aluminum	14/14	5,690	20,800	12,050	--
Antimony	0/14	--	--	--	--
Arsenic	14/14	2.26	22.6	8.07	57
Cadmium	10/14	0.18	1.90	0.36	5.1
Chromium	14/14	17.1	61.7	34.5	260
Copper	14/14	4.25	81.2	45.1	390
Iron	14/14	8,860	30,000	23,100	--
Lead	14/14	5.94	63.7	31.7	450
Manganese	14/14	150	591	307	--
Mercury	14/14	0.013	0.569	0.177	0.41
Nickel	14/14	14.5	38.3	30.2	--
Silver	13/14	0.41	1.07	0.72	6.1
Tin	9/14	2.07	6.08	3.35	--
Zinc	14/14	20.4	98.5	83.4	410

Mercury was the only metal that exceeded an SQS chemical criterion. The mercury concentration of 0.458 mg/Kg DW at Station MSVK01 (Quartermaster Harbor) and 0.569 mg/Kg DW at Station LTGF01 (Harbor Island) both exceeded the SQS criterion of 0.41 mg/Kg DW. Both concentrations, however, were below the mercury Cleanup Screening Level (CSL) chemical criterion of 0.59 mg/Kg DW.

Metals results generally correlated well with both percent fines and crustal metals. Figure 4-7 shows a sampling of these correlations in the graphs of percent fines versus six metals; arsenic, chromium, copper, lead, mercury, and zinc. The correlation graphs were similar when normalizing trace metals to both aluminum and iron as well. These correlations, however, also point out what appear to be some elevated concentrations of specific metals relative to percent fines.

Station MSVK01 in Quartermaster Harbor appears to have elevated concentrations of arsenic, copper, lead, and mercury. Although not shown in Figure 4-7, Station MSVK01 also had an elevated concentration of cadmium, relative to the other stations. Stack emissions from the Asarco smelter may have lead to these increased concentrations of arsenic, lead, cadmium, and mercury in Quartermaster Harbor. An explanation for the elevated sediment copper concentration is not apparent. The remaining elevated metals concentrations shown in Figure 4-7 are all at stations in Elliott Bay, where there are numerous point and non-point sources of metals.

4.3.3 Organics

Organic compounds analyzed in sediment samples included polynuclear aromatic hydrocarbons, phthalates, chlorobenzenes, polychlorinated biphenyls, chlorinated pesticides, butyltins, total 4-nonylphenol, polybrominated diphenyl ethers, and other, miscellaneous semivolatile organic compounds.

All organic compound results are presented in units of μg/Kg DW. The Washington State Sediment Managements standards normalize organic results for 30 compounds to total organic carbon for regulatory purposes. This normalization is generally done when the organic carbon content of the sediment sample is greater than 5,000 mg/Kg DW or 0.5%. When the organic carbon content of the sample is less than 0.5%, results for these 30 compounds are normalized to dry weight (Ecology, 1992). These dry weight normalized results are compared to Puget Sound Lowest Apparent Effects Threshold (LAET) values (EPA, 1988) as a measure of sediment quality.

Total organic carbon concentrations in the 14 samples were both below and above the 0.5% organic carbon normalization threshold. For comparative purposes in this narrative, all results have been normalized to dry weight and evaluated against LAET values. When a LAET value has been exceeded, the result, if appropriate, has also been normalized to organic carbon and compared to the Sediment Management Standards SQS and/or CSL criteria.

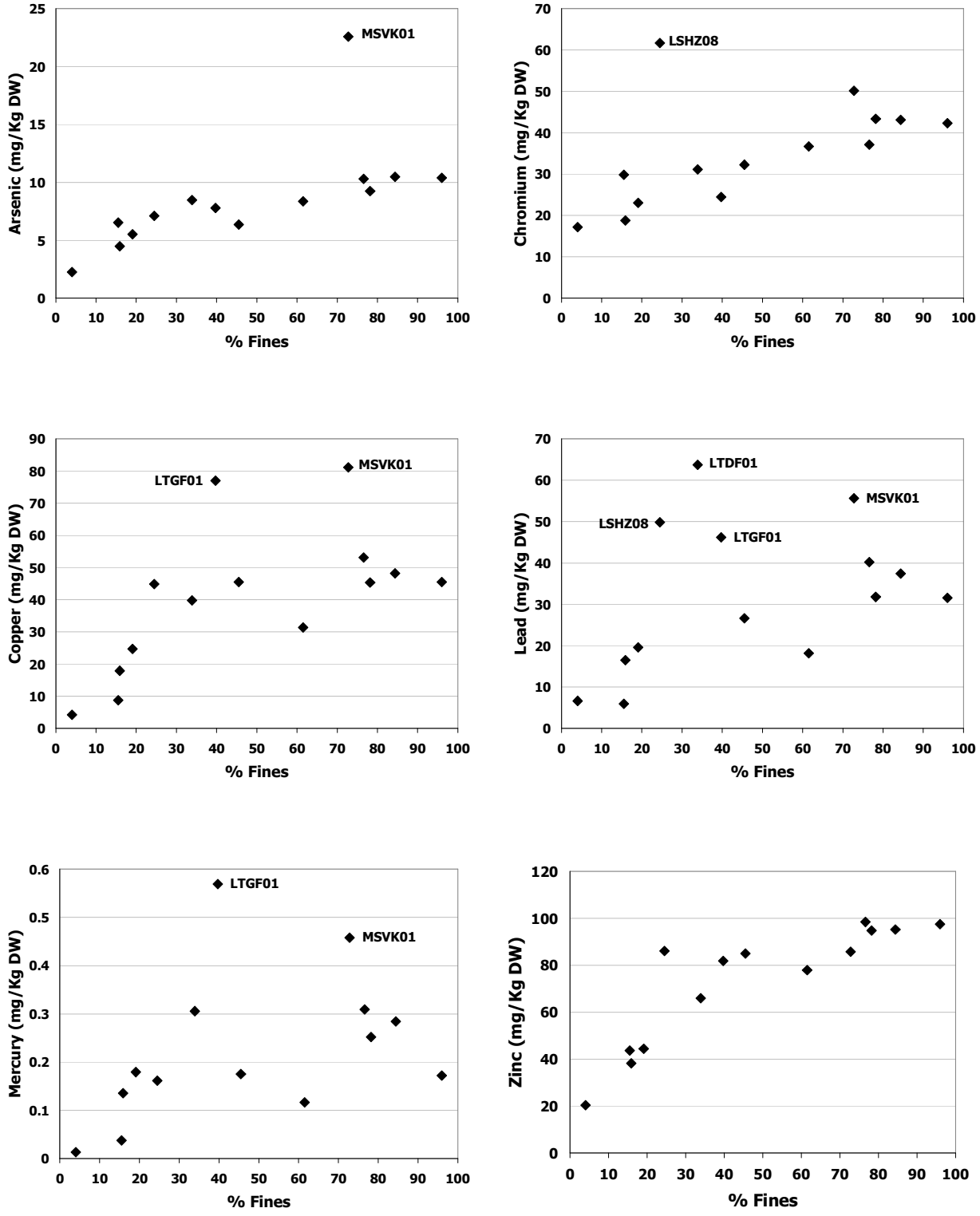

Figure 4-7. Six Sediment Metals Normalized to Percent Fines

Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarbons (PAHs) are hydrocarbon compounds that include multiple benzene rings. These compounds are components of asphalts, fuels, oils, and creosote. Creosote, a compound commonly used on pilings as a wood preservative to deter marine boring organisms, is comprised of up to 80% PAHs (Hutton and Samis, 2000). PAHs are also created through the incomplete or low-temperature combustion of carbon-containing materials such as oil, wood, and coal. Automobile exhaust and industrial emissions also can contain high levels of PAHs. PAHs can enter the marine environment from direct contact with PAH-containing products (creosote, spills) or through stormwater runoff from roadways.

PAH analysis included both low molecular weight PAHs (LPAHs) and high molecular weight PAHs (LPAHs). Due to their higher molecular weight, HPAH compounds tend to be more persistent in the environment. A number of HPAH compounds are also considered to be carcinogenic. A total of 17 PAH compounds (7 LPAHs and 10 HPAHs) were analyzed.

Total LPAH concentrations ranged from 7.84 to 766 µg/Kg DW, all of which are below the LAET value of 1,200 µg/Kg DW. Total HPAH concentrations ranged from 47 to 5,340 µg/Kg DW, also all below the LAET value of 7,900. No individual LPAH or HPAH compound exceeded its respective LAET value. Figure 4-8 shows the range of Total PAHs (the sum of LPAH and HPAH concentrations) detected in the 14 samples.

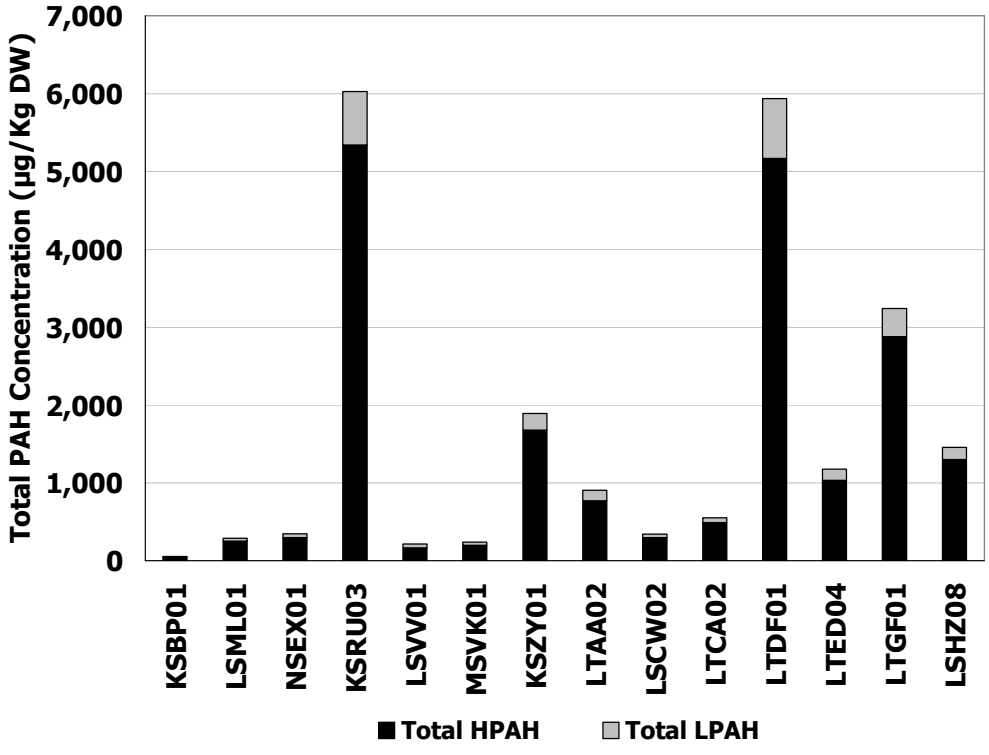

Figure 4-8. Total PAH Sediment Concentrations

Total PAH concentrations ranged from 55 to 6,030 μg/Kg DW. As shown in Figure 4-8, the lowest total PAH concentrations were found at the three deep, main basin stations and two of the three embayment stations, LSVV01 (Fauntleroy Cove) and MSVK01 (Quartermaster Harbor). With the exception of Station LSVV01, these five sampling locations are removed from any direct PAH sources. Although proximal to the Fauntleroy/Vashon dock, which has creosoted pilings, the lack of fine material present in the sediments at Station LSVV01 appears to preclude the accumulation of elevated PAH concentrations. Station KSRU03, located in outer Salmon Bay, had the highest total PAH concentration. This sampling station, located on the marine side of the Hiram M. Chittenden locks is surrounded by many creosoted pilings and wing walls. The second highest total PAH concentration was detected at Station LTDF01, along the central Seattle waterfront. This station is in an area of both current and historic sources of creosote as well as receiving street runoff from many storm drains and combined sewer overflows that line the waterfront's seawall. All of the other higher concentrations in Elliott Bay were detected at stations near shorelines and, as such, in closer proximity to pilings and sources of storm water runoff.

Phthalates

Phthalates, widely used as plasticizers, are ubiquitous in the environment, entering marine waters from both point and nonpoint sources. In addition to being ubiquitous in the environment, phthalates are common sampling and laboratory contaminants. Phthalate analysis included the six phthalates regulated under the Washington State Sediment Management Standards. Three phthalates were detected in all 14 samples. Table 4-6 provides the minimum, median, and maximum concentrations for benzyl butyl phthalate, bis(2-ethylhexyl) phthalate, and di-N-butyl phthalate, compared to their respective LAET values.

Table 4-6. Sediment Phthalate Concentrations (μg/Kg DW)

Phthalate	Minimum	Median	Maximum	LAET
Benzyl Butyl Phthalate	14.8	31.6	75.9	63
Bis(2-ethylhexyl) Phthalate	19.8	74.1	3,390	1,300
Di-N-butyl Phthalate	8.1	18.5	29.5	58

The benzyl butyl phthalate concentration of 75.9 μg/Kg DW detected at Station LTGF01 (Harbor Island) exceeded the LAET value of 63 μg/Kg DW. When normalized to organic carbon, the concentration becomes 6.13 mg/Kg OC, which also exceeds the SQS criterion of 4.9 mg/Kg OC but is below the CSL criterion of 64 mg/Kg OC. The benzyl butyl phthalate concentrations detected at the other 13 stations ranged from 14.8 to 48.1 μg/Kg DW, all below the LAET value.

The bis(2-ethylhexyl) phthalate concentration of 3,390 μg/Kg DW detected at Station NSEX01 (East Passage) significantly exceeded the LAET value of 1,300 μg/Kg DW. When normalized to organic carbon, the concentration becomes 171 mg/Kg OC, which exceeds the CSL criterion of 78 mg/Kg OC. There is not an apparent source of this phthalate at this deep, main basin station.

The bis(2-ethylhexyl) phthalate concentrations detected at the other 13 stations ranged from 19.8 to 506 μg/Kg DW, all well below the LAET value.

The di-N-butyl phthalate concentrations detected at all 14 stations ranged from 8.1 to 29.5 μg/Kg DW, which are all well below the LAET value of 58 μg/Kg DW.

Dimethyl phthalate was detected only at Station KSRU03 (Outer Salmon Bay) at a concentration of 11 μg/Kg DW, which is below the LAET value of 71 μg/Kg DW. Di-N-octyl phthalate and diethyl phthalate were not detected at any of the 14 stations.

Chlorobenzenes

Analysis of chlorobenzene compounds included 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, and hexachlorobenzene. 1,4-Dichlorobenzene, a common compound found in mothballs and urinal deodorant cakes, was the only chlorobenzene detected. It was detected in a single sample, collected from Station LTDF01 (Seattle Waterfront) at a concentration of 1.88 μg/Kg DW, which is below the LAET value of 81 μg/Kg DW.

Polychlorinated Biphenyls (PCBs)

PCBs were formerly used widely, due to their insulating and cooling properties, as dielectric fluids in electrical transformers and capacitors, as lubricants, as additives in flexible PVC wire casings, and in hydraulic fluid. Although PCB manufacturing was banned in the United States in 1977, they are still present in some older electrical equipment and can still be released to the environment. The chemical structure of PCBs make them very persistent in the environment, especially in fine-grained sediments. PCBs are classified as persistent and bioaccumulative and have been demonstrated to be toxic to marine life.

PCBs (as total Aroclors®) were detected in 13 of 14 samples. Total PCB concentrations in the three samples collected from Central Basin stations – KSBP01, LSML01, and NSEX01 - ranged from 1.45 to 5.02 μg/Kg DW. These PCB concentrations, at stations removed from direct anthropogenic influence, correlated well with the percent fine material present in the samples.

PCBs were not detected in the sample collected from Station LSVV01 (Fauntleroy Cove), which is likely due to the very small proportion of fine material – less than 5% silts and clays – in the grain size distribution at this station. Total PCB concentrations in the two other samples collected from embayments were 5.71 μg/Kg DW at Station MSVK01 (Quartermaster Harbor) and 33.1 μg/Kg DW at Station KSRU03 (Outer Salmon Bay).

Total PCB concentrations in the eight samples collected from Elliott Bay ranged from 21.5 to 156 μg/Kg DW. The total PCB concentrations of 144 μg/Kg DW at Station LTGF01 (Harbor Island) and 156 μg/Kg DW at Station LTDF01 (Central Waterfront) exceeded the LAET value of 130 μg/Kg DW. When appropriately normalized to organic carbon, however, these concentrations became 11.6 and 8.06 mg/Kg OC, respectively, neither of which exceeded the SQS criterion of 12 mg/Kg OC. Figure 4-9 shows the relative concentrations of total PCBs between the Central Basin (black), Elliott Bay (hatched), and embayment (gray) stations.

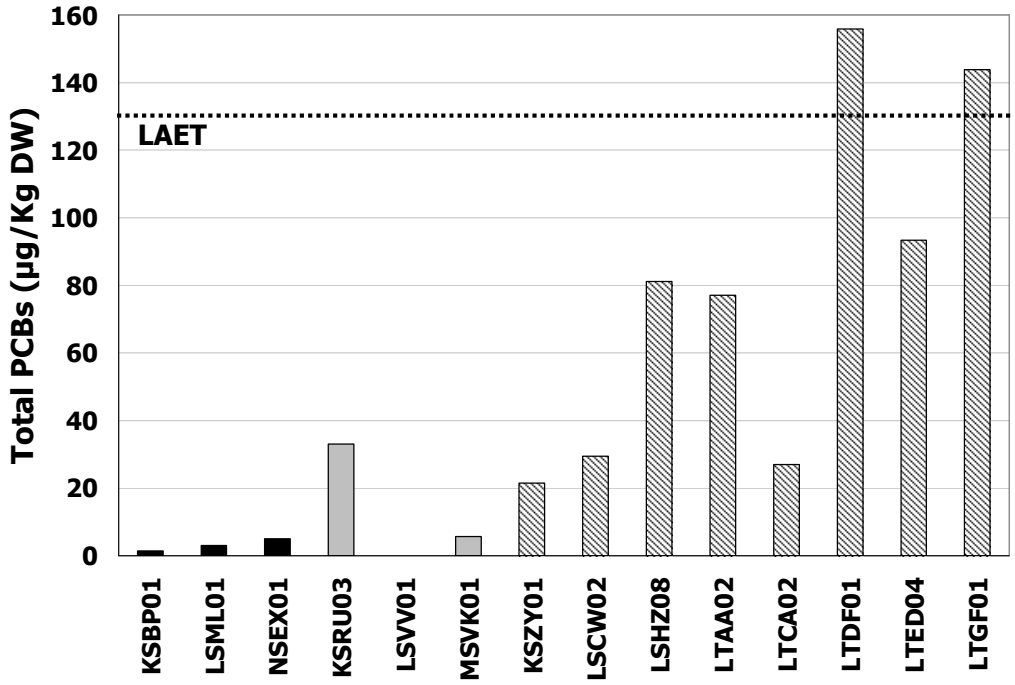

Figure 4-9. Total PCB Sediment Concentrations at Central Basin, Embayment, and Elliott Bay Stations

Chlorinated Pesticides

Chlorinated pesticide analysis included 20 compounds, most of which are not in use today. Due to their persistent nature, however, many are still found in the environment and are considered to be toxic and bioaccumulative. Of the 20 compounds analyzed, only three were detected. The pesticide DDT and its metabolites DDD and DDE were detected at three stations. DDT was detected at a concentration of 4.73 µg/Kg DW at Station KSRU03, in outer Salmon Bay. DDT was also detected at Station LTGF01, near Harbor Island, at a concentration of 2.0 µg/Kg DW. DDD, DDE, and DDT were all detected at Station LTDF01, along the Central Waterfront, at concentrations of 3.66, 4.09, and 25.4 µg/Kg DW, respectively. These three concentrations report as a Total DDT concentration of 32.8 µg/Kg DW. The total DDT concentration of 32.8 µg/Kg DW reported at Station LTGF01 exceeds the LAET value of 11 µg/Kg DW.

Butyltins

Butyltins, especially the isomer tributyltin, were used extensively as an anti-fouling agent in boat paints due to their effectiveness in preventing the attachment of marine organisms, particularly barnacles and algae, to boat hulls. However, tributyltin is also toxic to non-target marine organisms and its use was banned in 1998 on leisure craft. It is still used as a component in anti-fouling paints for commercial vessels. Butyltins can enter the environment both passively, through general degradation of hull paint, or actively, during routine maintenance of vessel hulls, when sandblasting of old paint directly introduces the grit to the marine environment.

Butyltin analysis included four isomers of the organotin; mono-n-, di-n-, tri-n-, and tetra-n-butyltin. Monobutyltin and tetrabutyltin were not detected in any of the samples. Dibutyltin and tributyltin were detected in three samples, all located in areas associated with heavy commercial vessel traffic and/or hull maintenance. The three detected concentrations (sum of dibutyltin and tributyltin) were:

- Station KSRU03 – 37.7 μg/Kg DW. This station is located in outer Salmon Bay on the marine side of the Hiram M. Chittenden locks and receives heavy commercial marine vessel traffic.
- Station LTDF01 – 29.1 μg/Kg DW. This station is located along the central Seattle waterfront, near the Bell Harbor Marine and also receives heavy commercial marine vessel traffic.
- Station LTGF01 – 123 μg/Kg DW. This station is located at the north end of Harbor Island, which is an area of both heavy commercial marine vessel traffic and vessel maintenance drydocks.

Tributyltin alone was detected at a concentration of 4.3 μg/Kg DW at Station KSHZ08, located near Cove 2 at Seacrest Park, on the west side of Elliott Bay.

Total 4-Nonylphenol

Total 4-nonylphenol was analyzed as a surrogate for alkyl phenols, which are widely used in plastics and as surfactants. Nonylphenols, used as surfactants in many detergents, are widely released to the environment, both from point and non-point sources. Total 4-nonylphenol was detected in 4 of 14 samples – collected from stations KSBP01 (Point Jefferson), KSRU03 (Outer Salmon Bay), LSCW02 (Outer Elliott Bay), and LTCA02 (Central Elliott Bay)–at concentrations ranging from 31.9 to 69.3 μg/Kg DW. The detection limits for the 10 samples in which total 4-nonylphenol was not detected ranged from 6.7 to 18 μg/Kg DW. There was no apparent correlation between total 4-nonylphenol concentration and either percent fine material or organic carbon concentration. There was also no apparent pattern of spatial distribution with respect to potential sources of nonylphenols. Currently, there are no regulatory criteria for nonylphenols in marine sediment, however, the Canadian government has an interim sediment quality guidance value of 1,400 μg/Kg DW, which is based on a threshold effects level (Environment Canada, 2005).

Polybrominated Diphenyl Ethers (PBDEs)

Polybrominated diphenyl ethers (PBDEs) are widely used as flame retardants and can enter the environment from both point and nonpoint sources. PBDEs can be found in 209 different chemical forms, or congeners. Samples were analyzed for 14 PBDE congeners, including tri-, tetra-, penta-, hexa-, hepta-, and decaBDEs. PBDEs were detected in every sample. The sum of detected congeners ranged from 1.68 to 15.1 μg/Kg DW in the 14 samples. It should be noted that the sum of congeners does not represent a total PBDE concentration since only 14 out of 209 congeners were analyzed. There was no apparent correlation between PBDE concentrations and either percent fines or total organic carbon. Figure 4-10 shows the relative PBDE concentrations (sum of 14 congeners) between the Central Basin, embayment, and Elliott Bay stations.

The PBDE concentration of 15.1 µg/Kg DW detected in the sample collected from Station KSRU03 (outer Salmon Bay) may be the result of the station's proximity to the locks and the high level of boat traffic in the area. PBDEs are used as a flame retardant in most personal flotation devices (PFDs), which, over time can become friable and enter the marine environment.

King County also evaluated sediment PBDE concentrations at its West Point Treatment Plant outfall and the location of the future Brightwater Treatment Facility outfall. Average PBDE concentrations for the same 14 congeners at these two sites were 1.59 and 2.05 µg/Kg DW, respectively.

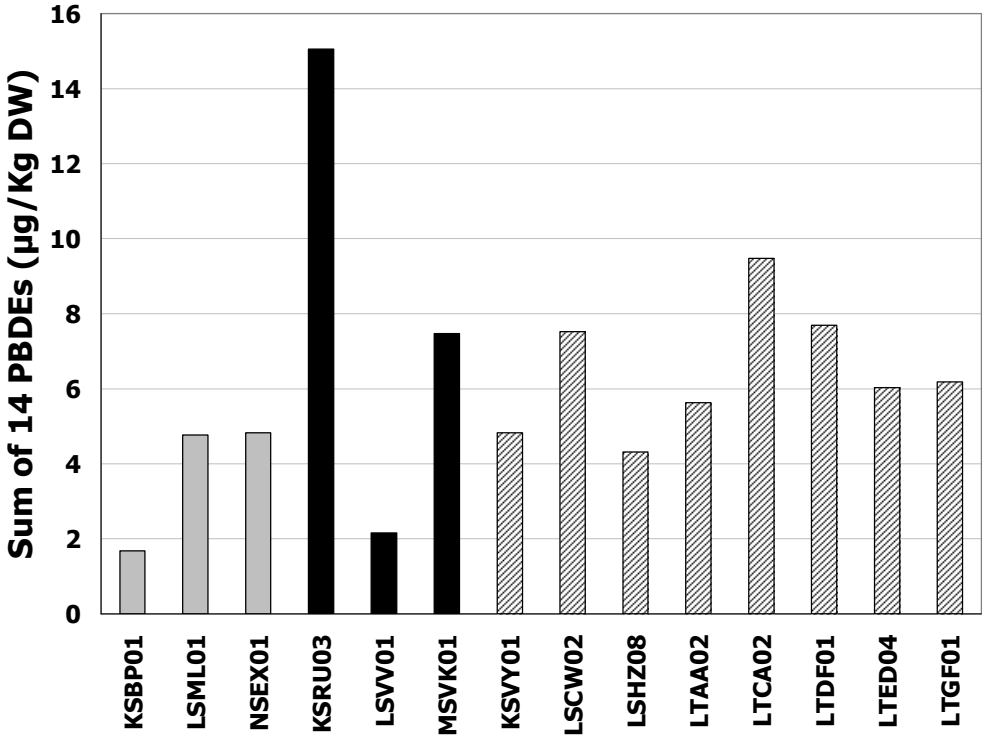

Figure 4-10. Sediment PBDE Concentrations at Central Basin (gray), Embayment (black), and Elliott Bay (hatched) Stations

SECTION 5
Summary of Tissue Data

This section summarizes bivalve (butter clam) data collected in 2005, 2006, and 2007 for the ambient and outfall monitoring programs and macroalgae (sea lettuce) data collected in 2005.

5.1 Shellfish Tissue

Shellfish tissue samples, composed entirely of butter clams (*Saxidomus giganteus*), were collected each year and all data are presented in Appendix C. Station locator maps are provided in Section 2, along with specific station information such as matrix, parameters, and frequency measured.

In 2005, samples were collected in August from four outfall stations; KSHZ03 (Carkeek Park), KSSN05 (West Point), LSKS01 (Alki), MSJL01 (Vashon Island), and three ambient stations; JSVW04 (Point Wells), KSLU03 (Golden Gardens), MTLD03 (Normandy Park). In 2006, the shellfish monitoring program was expanded to twice-yearly sampling, with samples collected in both March and August. One ambient shellfish sampling station was added at Edwards Point (ITEDWARDSPT), near the King-Snohomish County line, and the Alki station was moved to a new location (LSKS04). Twice-yearly sampling continued in 2007 and one outfall shellfish station was added at West Point (KSSN04).

Samples were composited from the tissues of multiple clams, generally between 5 and 10, to provide sufficient sample matrix. Lipid and metal analyses were performed on all samples collected in 2005, 2006, and 2007. Organic analyses, including semivolatile organic compounds, chlorinated pesticides, and polychlorinated biphenyls (PCBs), were only performed on samples collected during the August 2005 sampling event.

5.1.1 Lipids

Shellfish tissue samples were analyzed for lipid content since the concentration of lipids in the organism's tissue can affect the accumulation of certain compounds. Lipid concentrations can also be an indicator of the overall health and reproductive state of the organism. Lipid concentrations in the shellfish tissue samples collected in 2005, 2006, and 2007 are shown in Table 5-1.

Figure 5-1 summarizes lipid concentrations in shellfish tissue samples collected from 1998 through 2007 at the seven most-frequently sampled stations. Note that not every station was collected during each monitoring year. The figure shows that, in spite of some temporal variation at each station, the mean lipid concentration is similar across all seven stations, ranging from 0.52 to 0.64 percent.

Table 5-1. 2005 to 2007 Shellfish Tissue Percent Lipid Concentrations

Sampling Event	Minimum	Maximum	Mean
August 2005	0.34	0.60	0.46
March 2006	0.24	0.44	0.37
August 2006	0.14	0.38	0.29
March 2007	0.27	0.86	0.61
August 2007	0.59	1.13	0.90

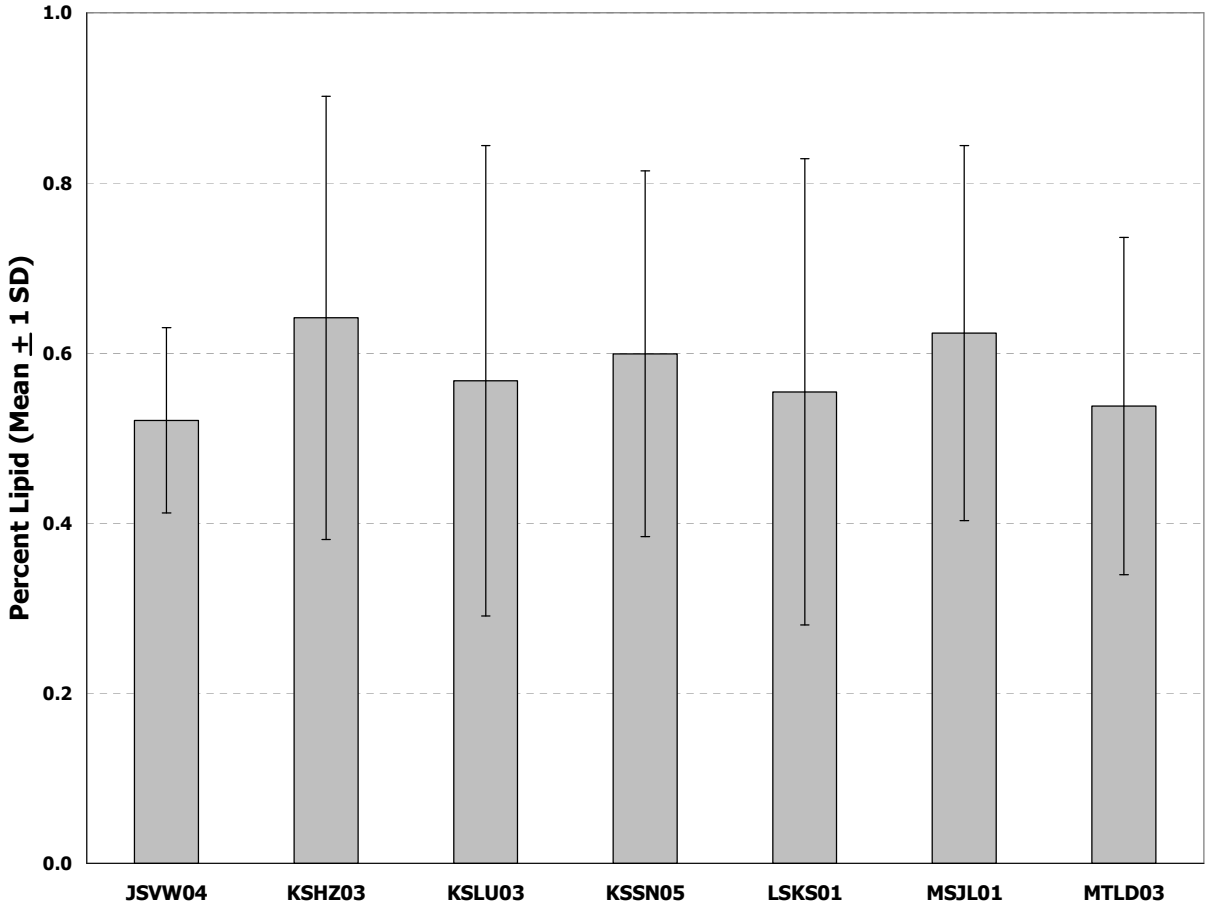

Figure 5-1. Shellfish Tissue Mean Lipid Concentrations (%) by Station – 1998 to 2007

5.1.2 Metals

All shellfish tissue samples were analyzed for 14 metals in 2005, 2006, and 2007; the crustal metals aluminum, iron, and manganese, and the trace metals arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc. Beryllium was not detected in any of the samples. The other 13 metals were detected in all samples.

Washington State has not promulgated criteria or guidance for acceptable levels of metals in shellfish tissue. The United States Food and Drug Administration (FDA) has, however, established guidance values termed Levels of Concern for arsenic, cadmium, chromium, lead, and nickel in bivalves (clams, mussels, oysters). The FDA has also established an Action Level of 1.0 mg/Kg for mercury in fish and shellfish tissues. Food products exceeding the Action Level cannot be commercially traded, an important distinction from the Levels of Concern. Table 5-2 summarizes the ranges of shellfish tissue concentrations detected in 2005, 2006, and 2007 for arsenic, cadmium, chromium, lead, mercury, and nickel and compares them to FDA guidance for metals in shellfish. All of the detected concentrations are well below the FDA Levels of Concern for arsenic, cadmium, chromium, lead, and nickel (FDA, 1993a, b, c, d, e) and the Action Level for mercury (FDA, 1995).

Table 5-2. 2005 to 2007 Shellfish Tissue Metals Concentrations Compared to FDA Criteria

Metal	Minimum	Maximum	Level of Concern	Action Level
Arsenic	1.75	4.72	55	--
Cadmium	0.0410	0.0864	3	--
Chromium	0.160	0.550	11	--
Lead	0.037	0.290	0.8	--
Mercury	0.00323	0.0114	--	1.0
Nickel	0.495	1.18	80	--

Note: All values in mg/Kg on a wet-weight basis.

Metal concentrations in shellfish tissue have shown little variation, either spatially or temporally, over the course of the shellfish monitoring program. Figure 5-2 compares shellfish tissue concentrations of four metals between 1998 and 2007 at the five locations sampled most frequently. The figure shows the mean concentration ($\pm$ 1 standard deviation) of chromium, copper, nickel, and zinc. Note that, for comparative purposes, these metals' data have been normalized to dry weight.

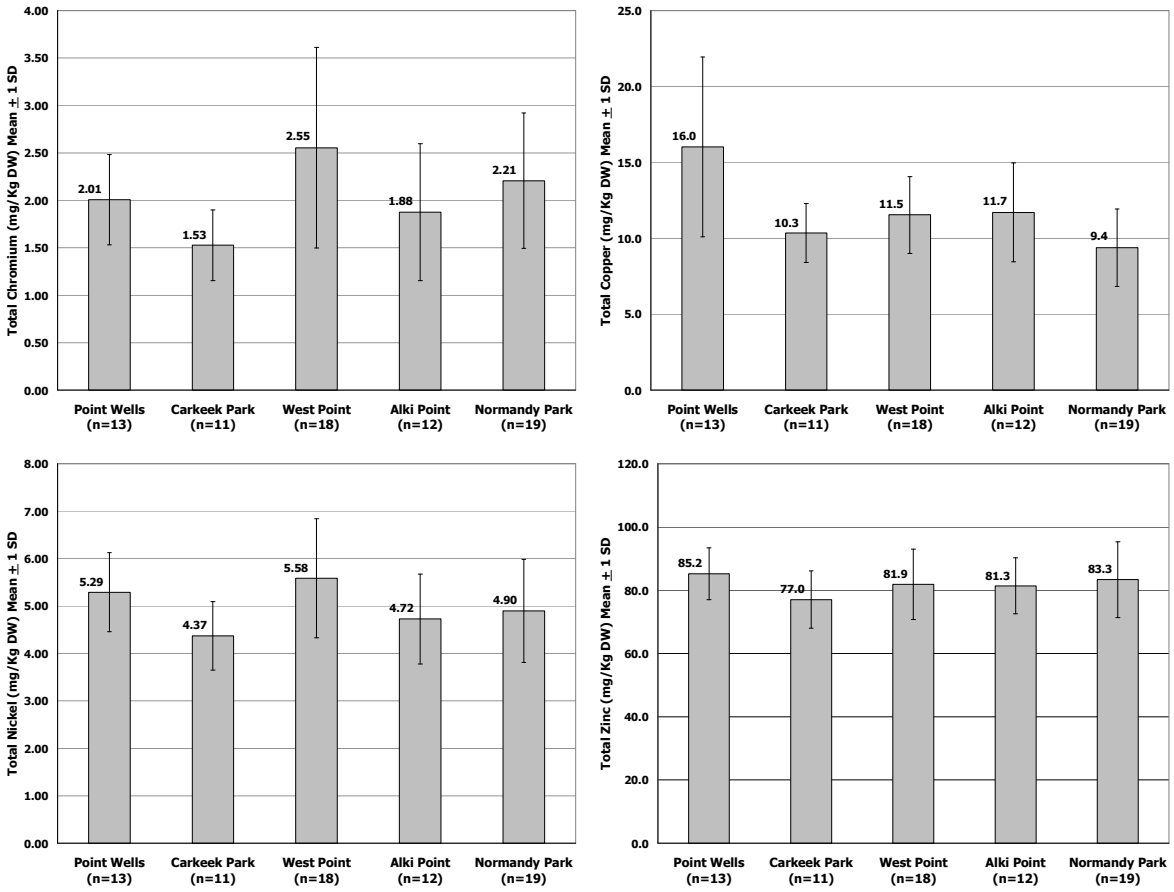

Figure 5-2. Spatial Comparison of Shellfish Tissue Metal Concentrations – 1998 to 2007

5.1.3 Organics

Seven shellfish tissue samples were analyzed in 2005 for 97 trace organic chemicals, including 70 semivolatile organic compounds, 20 chlorinated pesticides, and seven PCB Aroclors®. Of these 97 trace organic chemicals, only five were detected in one or more samples – benzoic acid, benzyl alcohol, beta-BHC (ß-benzene hexachloride), bis(2-ethylhexyl) phthalate, and PCBs.

Benzoic acid was detected in all seven samples at concentrations ranging from 2,690 to 6,390 µg/Kg on a wet-weight basis. Although benzoic acid is produced industrially and can be found in food preservatives and anti-fungal agents, among other uses, it is also a naturally-occurring degradation product produced by metabolic processes in shellfish. Benzoic acid is always detected in shellfish samples.

Benzyl alcohol was detected in four of seven samples, at concentrations ranging from 36 to 93 µg/Kg on a wet-weight basis. This compound was detected in samples from one outfall station, KSHZ03 (52 µg/Kg), and in samples from all three ambient stations; JSVW04 (93 µg/Kg), KSLU03 (91 µg/Kg), and MTLD03 (36 µg/Kg). Benzyl alcohol is a commonly-used chemical

found in a diverse array of products such as perfumes, soaps, solvents, pharmaceuticals, and bacteriostats. There are no regulatory criteria or guidance levels for benzyl alcohol in shellfish.

Beta-BHC was detected in four of seven samples, at concentrations ranging from 0.58 to 1.65 µg/Kg on a wet-weight basis. This chlorinated pesticide was detected at two ambient stations; JSVW04 (1.65 µg/Kg) and MTLD03 (0.58 µg/Kg), and two outfall stations; KSHZ03 (1.04 µg/Kg) and LSKS01 (0.99 µg/Kg). Beta-BHC has been detected previously in butter clam samples at similar concentrations and was widely detected in geoduck tissue samples during another King County study (King County, 2002). Beta-BHC is one isomer of the benzenehexachlorides pesticide mixture, the others being alpha, delta, and gamma. This mixture was widely used as a crop pesticide although its use has now been banned in the United States. Beta-BHC is the most fat-soluble of the four isomers as well as the most persistent in the environment. Gamma-BHC, also known as Lindane, is the one isomer still in use, as a prescription treatment for head lice and as a veterinary insecticide. Beta-BHC is one of the breakdown products of Lindane. There are no regulatory criteria or guidance levels for beta-BHC in shellfish.

Bis(2-ethylhexyl) phthalate was detected in all seven samples, at concentrations ranging from 180 to 235 µg/Kg on a wet-weight basis. Bis(2-ethylhexyl) phthalate is a common plasticizer and ubiquitous in the environment. Given the similarity of the concentrations detected in all seven samples, however, it is most likely that these detected values are artifacts of the sampling process, imparted to the tissue samples through handling with plastic-gloved hands or being stored in plastic bags during the sampling process.

Aroclor® 1254, one of the formerly commercially-produced PCB mixtures, was detected in one shellfish tissue sample, collected from Station KSSN05, at a concentration of 3.9 µg/Kg on a wet-weight basis. PCBs were widely used as insulating material until their production was banned in 1977. They are, however, present in old electrical transformers and capacitors still in use and resist degradation, once in the environment, due to their chemical structure. PCBs have not been detected previously in any shellfish tissue sample collected by King County, nor have PCBs ever been detected at Station KSSN05 in water, sediment, or algae samples. A potential legacy source for this PCB detection in shellfish tissue is unknown at this location. The detected value of 3.9 µg/Kg is extremely low – less than 0.2% of the FDA tolerance level of 2.0 ppm (parts per million) in shellfish (FDA, 2005).

Because so few organic analytes have ever been detected in butter clams, the analysis of trace organic compounds for the shellfish program was discontinued after the August 2005 sampling event.

5.2 Macroalgae

Macroalgae samples, consisting entirely of *Ulva spp.* (sea lettuce), were collected from seven beach stations in August 2005 and analyzed for 14 metals. Outfall beach stations sampled included Carkeek (KSHZ03), West Point (KSSN05), Alki (LSKS01), and Vashon Island (MSJL01). Ambient beach stations sampled included Point Wells (JSVW04), Golden Gardens

(KSLU03), and Normandy Park (MTLD03). Macroalgae metal results are summarized in Appendix D (Table D-1).

Beryllium, selenium, and silver were not detected in any of the macroalgae samples, which is consistent with previous years' results. Mercury was detected in all three ambient samples but not in any of the outfall samples. Macroalgae mercury concentrations in the three ambient samples ranged from 0.00394 to 0.00503 mg/Kg DW.

The trace metals arsenic, cadmium, chromium, copper, lead, nickel, and zinc were detected in all seven macroalgae samples. Table 5-3 shows the concentration ranges for these seven trace metals.

Table 5-3. Macroalgae Trace Metal Concentrations – 2005

Metal	Minimum	Maximum
Arsenic	4.28	9.93
Cadmium	0.53	2.15
Chromium	0.47	6.64
Copper	3.03	7.09
Lead	0.30	1.53
Nickel	1.79	7.41
Zinc	7.60	19.2

All values in mg/Kg DW.

Sampling and analytical inconsistencies in the macroalgae monitoring program have precluded the opportunity to perform spatial or temporal analysis of the data collected over the past several years. Macroalgae data are, therefore, presented only to provide the reader with the range of metals' concentrations detected in samples collected from seven representative King County beaches. The macroalgae monitoring program was discontinued in 2006.

SECTION 6
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