SECTION 2
Water Quality Monitoring Programs

King County has conducted an extensive marine monitoring program for over 35 years to assess water quality. 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 implement a monitoring program that will 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 regards 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 assess 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 with stations removed from the direct influence of point source discharges to better understand regional water quality and provide data needed to identify trends that might indicate impacts from long-term cumulative pollution.

An overview of the County's ambient and outfall monitoring programs in 2004 is provided in Table 2-1.

Table 2-1. Summary of 2004 Marine Monitoring Programs

			Number of Stations Sampled	
Location	**Matrix**	**Parameter**	***Ambient***	***Outfall***
Beach	Water	Bacteria	18	6
		GWQP [1]	5	4
	Sediment	Organics	1	4
		Metals	1	4
		Conventionals [2]	1	4
	Shellfish	Organics	3	4
		Metals	3	4
	Macroalgae	Metals	3	5
Offshore	Water	Bacteria	5	6
		GWQP	5	6
	Sediment	Organics	7	0
		Metals	7	0
		Conventionals	7	0

[1] GWQP = general water quality parameters. Includes temperaure, salinity, nutrients, dissolved oxygen. Dissolved oxygen is not monitored at beach stations.

[2] Conventionals include total solids, total volatile solids, total sulfide, total organic carbon, and grain size.

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 both physical and chemical parameters is an important component of the County's monitoring programs. Excess nutrients and pathogens can cause water quality 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 for the 2004 outfall monitoring program. Beach water, sediment, shellfish tissue, and macroalgae were also collected in areas in the vicinity of treatment plant outfalls. Water samples were collected from multiple depths at the offshore stations and from a single depth at the beach stations. Station locations are shown in Figure 2-1 and station coordinates are provided in Appendix E.

Outfall stations sampled in 2004 were also sampled in previous years. Locations for outfall stations were based upon the following: stations KSSK02, LSEP01, VO50E, LTBC42, 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, VO50E is at the end of the Vashon TP outfall prior to the extension of the outfall pipe (a station has been established at the end of the new pipe), LTBC42 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 were placed at these locations in order to characterize water quality at the point where effluent is discharged into the marine environment.

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 and to assess if the effluent plume is discernable in nearshore areas. Two stations, KSSN04 and KSSN05, are located on the north and south side of West Point, respectively. Two stations, LSKR01 and LSKS01, are located north and south 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. Shellfish and algae were collected near all outfall sites, with the exception of the South TP and the Denny Way CSO TP, due to lack of shellfish and algae habitat in the vicinity of the outfalls.

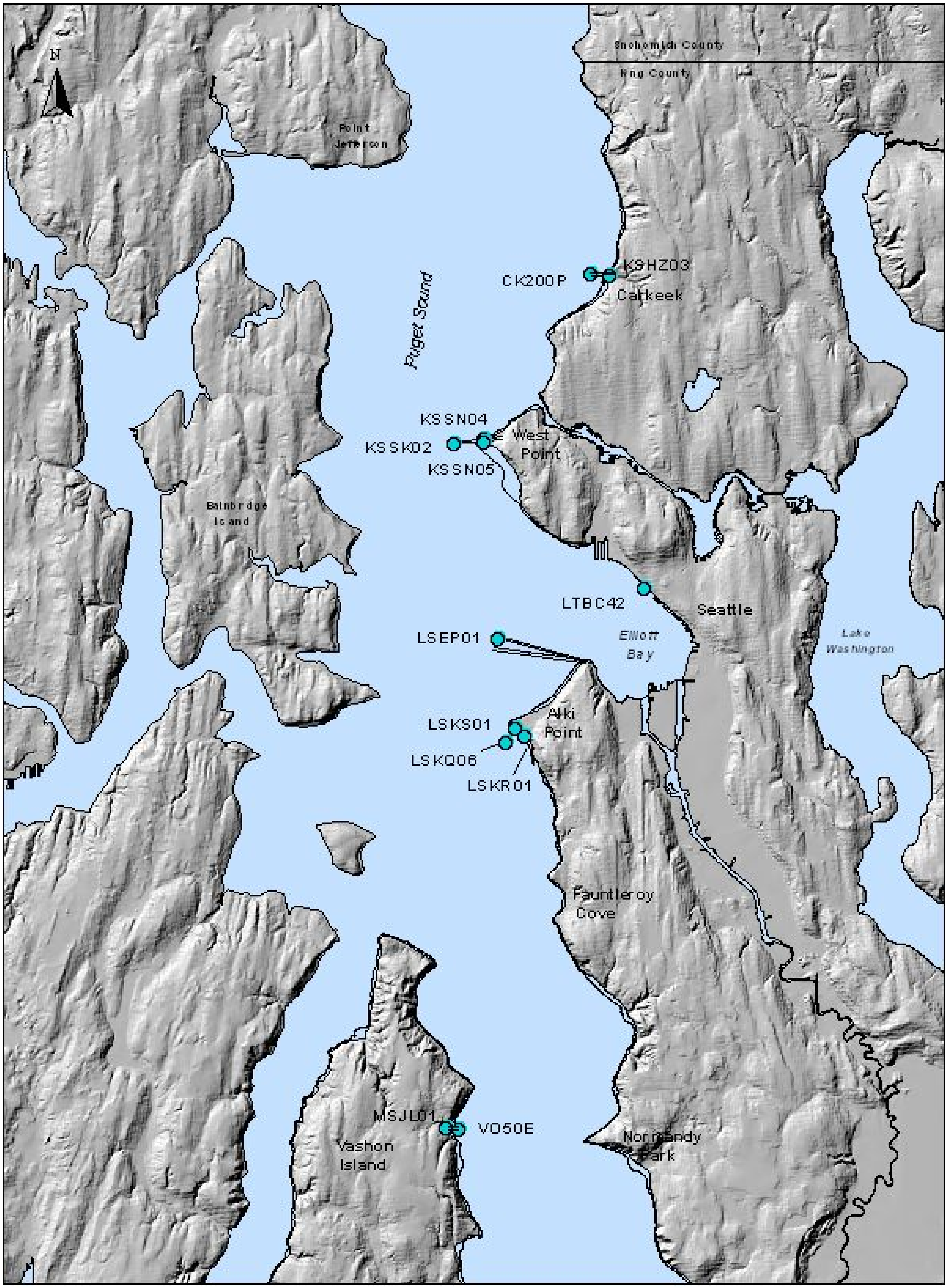

Figure 2-1. Outfall Monitoring Station Locations

A summary of parameters measured and the frequency sampled for each station is provided in Table 2-2. 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 and analyzed for organic compounds, metals, and conventional parameters (total organic carbon, total solids, total volatile solids, and grain size). Shellfish tissues were analyzed for organic compounds, metals, and conventional parameters (total solids and percent lipids). Macroalgae samples were analyzed for metals. Shellfish and algae samples were collected in August.

Table 2-2. 2004 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				
LTBC42	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				
VO50E	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.

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.

The 2004 ambient monitoring program included collection of water samples at beach and offshore stations in addition to shellfish, macroalgae, and sediments at beach stations (see Table 2-1). Sediments were also collected at offshore stations as part of the biennial ambient sediment monitoring program. Water samples were collected from multiple depths at the offshore stations and from a single depth at the beach stations. Station locations are shown in Figure 2-2 and station coordinates are provided in Appendix E.

All but one ambient station sampled in 2004 was also sampled previously. A new beach water station at Saltwater State Park, NTAK01, was added to the ambient program to increase monitoring coverage in the southern portion of King County. 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. All offshore sediment stations sampled in 2004 were sampled previously. Table 2-3 provides a summary of ambient station selection.

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). 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.

Beach sediment was collected in August at Point Wells 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 were analyzed for organic compounds, metals, and conventional parameters (total solids and percent lipids). Macroalgae samples were analyzed for metals. Shellfish and algae samples were collected in August. A summary of parameters measured and the frequency sampled for each station is provided in Table 2-4.

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*,

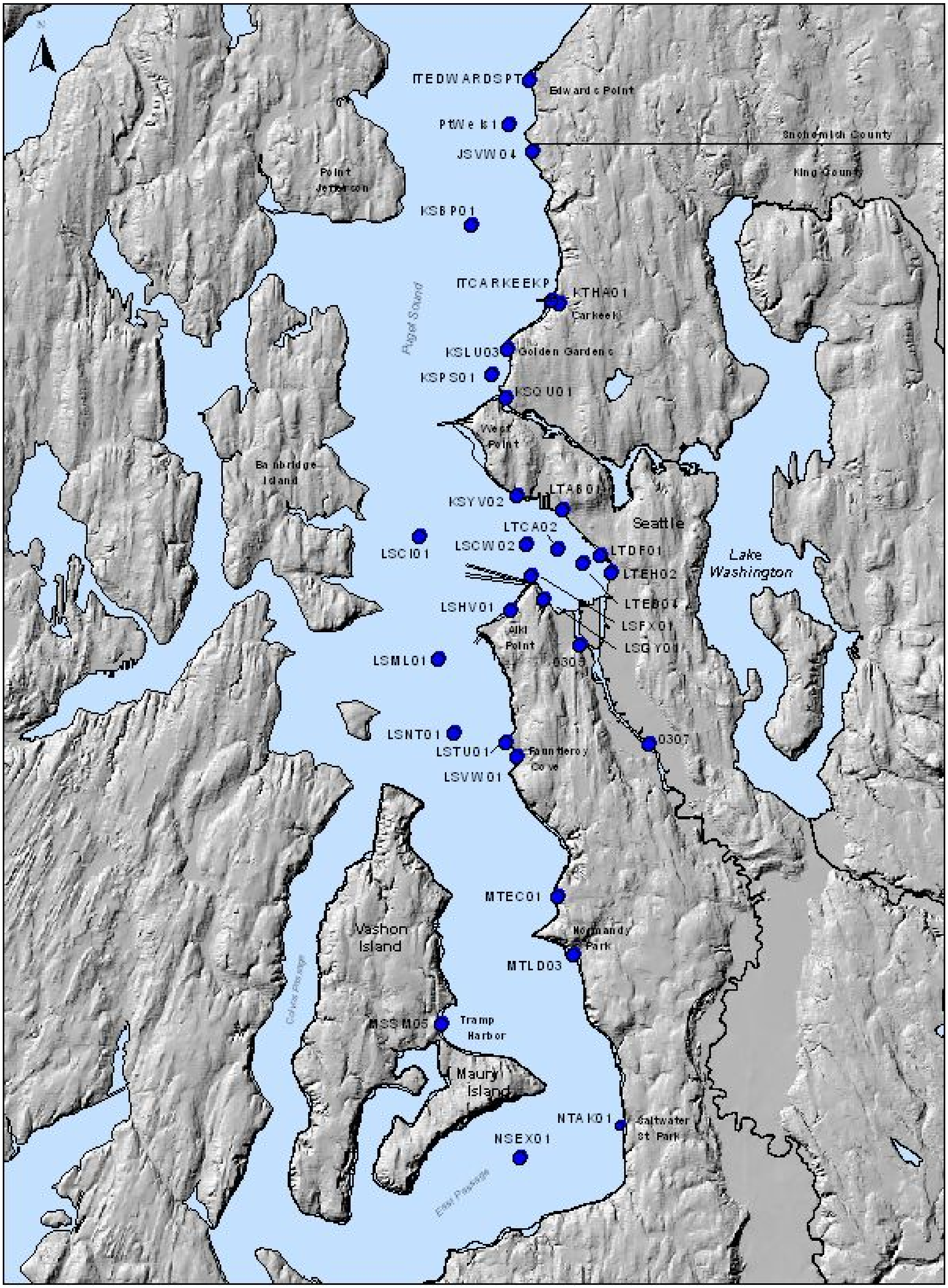

Figure 2-2. Ambient Monitoring Station Locations

Table 2-3. Ambient Station Selection

Rationale for Sampling Location	Station Name	Location	Comments
High-use public area for either swimming, wading, SCUBA diving, or beachcombing	ITCARKEEKP	Carkeek Park	
	KTHA01	Piper's Creek	part of long-term dataset
	KSLU03	Golden Gardens	freshwater source nearby, part of long-term dataset
	LSGY01	Seacrest	
	LSFX01	Duwamish Head	
	LSTU01	Lincoln Park	
	MTEC01	Seahurst Park	
	MTLD03	Normandy Park	
Potential for water quality problems due to physical characteristics, such as poor tidal flushing, or increased risk of contaminants from freshwater source	LTAB01	inner Elliott Bay	part of long-term dataset
	LTEH02	inner Elliott Bay	part of long-term dataset
	LTED04	Elliott Bay	
	LSVW01	Fauntleroy Cove	
	MSSM05	Tramp Harbor	
To assess physical and biological water column properties within the Central Basin	KSBP01	Point Jefferson	part of long-term dataset
	LTED04	Elliott Bay	
	LSNT01	Dolphin Point	part of long-term dataset
	NSEX01	East Passage	
To assess sediment contaminants within Elliott Bay, a known problem area	LTDF01	inner Elliott Bay	
	LTCA02	inner Elliott Bay	
	LSCW02	inner Elliott Bay	
	LSCI01	Central Basin	located outside Elliott Bay for comparative purposes
	LTED04	Elliott Bay	
	LSML01	West Seattle	located outside Elliott Bay for comparative purposes
	KSPS01	Shilshole Bay	located outside Elliott Bay for comparative purposes
Sampled as part of the rivers & streams program to assess inputs from the Duwamish River	0305	West Waterway	
	0307	Duwamish River	
To assess Lake Washington Ship Canal freshwater influence at entrance into Sound	KSQU01	Shilshole Bay	part of long-term dataset
To assess water quality prior to additional wastewater TP effluent input from Brightwater outfall	ITEDWARDSPT	Edwards Point	
	PTWells1	Point Wells	
	JSVW04	Point Wells	part of long-term dataset

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 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.

Table 2-4. 2004 Ambient Stations, Parameters, and Frequency Measured

STATION	LOCATION	OFFSHORE/ BEACH	SEDIMENT			WATER		SHELLFISH			ALGAE
			Organics	Metals	Conventionals	Bacteria	GWQP *	Organics	Metals	Conventionals	Metals
ITEDWARDSPT	Edwards Point	Beach				◆ 12	◆ 12				
PTWells1	Point Wells	Offshore				◆ 12	◆ 12				
JSVW04	Richmond Beach	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				◆ 12		◆ 1	◆ 1	◆ 1	◆ 1
KSPS01	Shilshole Bay	Offshore	◆ 1	◆ 1	◆ 1						
KSQU01	Shilshole Bay	Beach				◆ 12					
KSYV02	Magnolia	Beach				◆ 12					
LTAB01	inner Elliott Bay	Beach				◆ 12					
LTEH02	inner Elliott Bay	Beach				◆ 12					
LTDF01	inner Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1						
LTCA02	inner Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1						
LSCW02	inner Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1						
LSCI01	Central Basin	Offshore	◆ 1	◆ 1	◆ 1						
0305	West Waterway	River				◆ 12	◆ 12				
0307	Duwamish River	River				◆ 12	◆ 12				
LSGY01	Seacrest	Beach				◆ 12					
LSFX01	Duwamish Head	Beach				◆ 12					
LTED04	Elliott Bay	Offshore	◆ 1	◆ 1	◆ 1	◆ 12	◆ 12				
LSHV01	West Seattle	Beach				◆ 12					
LSML01	West Seattle	Offshore	◆ 1	◆ 1	◆ 1						
LSNT01	Dolphin Point	Offshore				◆ 12	◆ 12				
LSTU01	Lincoln Park	Beach				◆ 12					
LSVW01	Fauntleroy Cove	Beach				◆ 12	◆ 12				
MTEC01	Seahurst Park	Beach				◆ 12					
MTLD03	Normandy Park	Beach				◆ 12		◆ 1	◆ 1	◆ 1	◆ 1
MSSM05	Tramp Harbor	Beach				◆ 12					
NTAK01	Saltwater St. Park	Beach				◆ 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.

Numbers indicate frequency sampled per year on a monthly basis.

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. Fecal coliforms are found in the intestinal tract of humans and warm-blooded animals. 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, the 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, amount of input of high salinity water from deep Pacific oceanic water, amount of 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 depth at which light capable of supporting plant growth penetrates the water column (euphotic zone). 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 affect 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, and agricultural runoff.

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 used by algae and other green plants 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).

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 sampled using a SeaBird Electronics SBE 25 SEALOGGER conductivity-temperature-depth (CTD) profiler. Parameters measured by the CTD included temperature, salinity, turbidity, 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, and bacteria. 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 powdered $MnSO_4$ (manganese sulfate) and AIA (alkali iodide azide) and stored in the dark. With the exception of dissolved oxygen bottles, sample containers were stored on ice until delivered to the King County Environmental Laboratory.

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) and the individual collecting the reading, all field crew were trained to collect measurements in a consistent manner.

Intertidal (beach) water samples were collected at approximately knee-depth by inverting sample containers just above the water surface, then sinking the bottle down to approximately 12-inches below the water surface. The bottles were not filled completely in order to allow room for mixing. Samples were collected from approximately knee-deep water when possible. At some sites where accessibility is difficult, such as LTAB01 located in inner Elliott Bay, samples were collected with a container lowered on a rope from a pier and then transferred into the sample container. Trace metal samples were collected using non-metallic equipment and employing the "clean hands/dirty hands" technique in accordance with EPA Method 1669 (EPA, 1995).

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).

All samples were analyzed within the recommended holding times and 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.

Table 2-5. Laboratory Methods and Detection Limits for Water Samples

Parameter	Units	MDL	RDL	Method
Salinity	PSS	2.0	3.0	SM2520-B
Dissolved Oxygen	mg/L	0.5	1.0	SM4500-O-C
Chlorophyll-*a*	mg/m^3	0.05	0.1	EPA 445.0
Pheophytin-*a*	mg/m^3	0.1	0.2	EPA 445.0
Ammonia-Nitrogen	mg/L	0.01	0.02	SM4500-NH3-H
Nitrate+Nitrite (NO_3+NO_2)	mg/L	0.02	0.04	SM4500-NO3-F
Total Phosphorous	mg/L	0.005	0.01	SM4500-P-B,E
Total Suspended Solids (TSS)	mg/L	0.5	1.0	SM2540-D
Silica	mg/L	0.05	0.1	SM4500-SI-D
Turbidity	FTU	0.5	1.0	SM2310-B
Fecal coliform	CFU/100 ml	--	--	SM9222-D
Enterococci	CFU/100 ml	--	--	SM9230-C
Metals, total & dissolved	µg/L	variable [a]	variable [a]	EPA 1640 (ICP-MS)
Semi-volatile organics	µg/L	variable [a]	variable [a]	EPA 625
Chlorinated pesticides/PCBs	µg/L	variable [a]	variable [a]	EPA 608

PSS = practical salinity scale
mg/L = milligram per liter
µg/L = microgram per liter
mg/m^3 = milligram per meter cubed
CFU = colony forming unit
MDL = method detection limit
RDL = reported detection limit

[a] Detection limits vary with parameter analyzed. Detection limits for individual samples and analytes are provided in Appendix A.

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.

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 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 Total Volatile Solids

Volatile solids are primarily organic solids that burn in the presence of oxygen at a given temperature (usually 550 or 600 ^{o}C). The solids or ash remaining behind are comprised of the non-volatile or fixed solids. The volatile solid value is used as an estimate of organic matter in a sample.

2.3.3 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 those sediments with a large proportion of fine particles tend to have higher chemical concentrations. Grain size also influences benthic and infaunal community structure.

2.3.4 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.

2.3.5 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 and are measured as they may be toxic to some benthic organisms at low concentrations and can create unaesthetic conditions for humans.

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 five 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).

Intertidal (beach) 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 with the exception of particle size distribution and total sulfide. These two analyses were performed by a subcontracted laboratory. Methods and detection limits are provided in Table 2-6. 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). 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.

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 is a component of the County’s ambient and outfall monitoring programs, as contaminants may be bioaccumulated by shellfish and algae.

Clam tissues are monitored for organic and metal contaminants. These measurements provide an indication of potential health risks to both shellfish and humans that consume them. Chlorinated organic compounds (chlorine atoms attached to organic compounds) have been used in pesticides since the 1940s and tend to accumulate in tissue with higher lipid concentrations. Percent lipids in shellfish are also monitored as this parameter affects the concentration of organic pollutants accumulated.

Algae absorb metals directly from seawater (Phillips, 1994; Hou and Yan, 1998), and are monitored to assess metal concentrations in intertidal areas.

Table 2-6. Laboratory Methods and Detection Limits (wet weight) for Sediment Parameters

Parameter	Units	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Volatile Solids	%	0.005	SM2540-G
Total Oil & Grease	mg/kg	100	SM5520-B
Total Organic Carbon	mg/kg	500	SM5310-G
Total Sulfide	mg/kg	10	PSEP, 1986
Metals, total, ICP	mg/kg	variable[1]	EPA 3050/6010
Mercury, total, CVAA	mg/kg	0.02	EPA 7471
Semivolatile (BNA[2]) Organics	µg/kg	variable[1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable[1]	SW 846 8081/8082
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

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. 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 of metal and organic parameters.

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 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 2-7. 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.

All samples were analyzed within their respective hold times. 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 2-7. 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 2-8.

Marine water quality standards were revised by Ecology in late 2003. Marine standards for conventional pollutants and toxics did not change from the previously published standards, 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 must approve the revisions before they can be used for Clean Water Act purposes. 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 of some components in 2006 and Washington State is currently in the process of proposing revisions to those standards not approved.

Table 2-8. 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**		
Arsenic[a]	69.0	36.0	**Compounds (μg/L)**	**Acute**	**Chronic**
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: WAC 173-201a, November 18, 1997.

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 in Section 2.6.1, 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 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. Although the water use designations were approved by the regional Environmental Protection Agency (EPA) office in 2005, the marine bacteria numeric criteria, in addition to other parameters, have not yet been approved by the regional office. However, Washington State bacteria standards were approved by the national EPA office by the process described below.

The 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 those 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 (L. Schneider, Ecology, pers. comm.). 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 promulgated in 1997 are provided in Table 2-9.

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 30 most recent samples as directed by the National Shellfish Sanitation Program guidelines for systematic random sampling. 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 not yet been approved by the regional EPA office, geometric means will be reported using the 30 most recent monthly samples rather than 12.

Table 2-9. 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: WAC 173-201a, 1997, 2003; NSSP, 1995.

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 and metal compounds (Table 2-10). 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.

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).

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.

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

Table 2-10. Washington State Sediment Standards

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold	Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Metals	**mg/kg dry weight**		**Nonionizable Organic Compounds**	**mg/kg organic carbon**	**μg/kg dry weight**
Arsenic	57		1,2-Dichlorobenzene	2.3	35
Cadmium	5.1		1,4-Dichlorobenzene	3.1	110
Chromium	260		1,2,4-Trichlorobenzene	0.81	31
Copper	390		Hexachlorobenzene	0.38	22
Lead	450		Dimethyl phthalate	53	71
Mercury	0.41		Diethyl phthalate	61	200
Silver	6.1		Di-n-butyl phthalate	220	1400
Zinc	410		Butyl benzyl phthalate	4.9	63
			Bis (2-ethylhexyl) phthalate	47	1300
			Di-n-octyl phthalate	58	6200
Nonionizable Organic Compounds	**mg/kg organic carbon**	**μg/kg dry weight**	Dibenzofuran	15	540
			Hexachlorobutadiene	3.9	11
			N-Nitrosodiphenylamine	11	28
Total LPAHs [a]	370	5200	Total PCBs	12	130
Naphthalene	99	2100			
Acenapthylene	66	1300			
Acenapthene	16	500	**Ionizable Organic Compounds**	**mg/kg dry weight**	
Fluorene	23	540			
Phenanthrene	100	1500			
Anthracene	220	960	Phenol	0.42	
2-Methylnaphthalene	38	670	2-Methylphenol	0.063	
Total HPAHs [b]	960	12000	4-Methylphenol	0.67	
Fluoranthene	160	1700	2,4-Dimethylphenol	0.029	
Pyrene	1000	2600	Pentachlorophenol	0.36	
Benzo(*a*)anthracene	110	1300	Benzyl alcohol	0.057	
Chrysene	110	1400	Benzoic acid	0.65	
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			

[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

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 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 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). Organic carbon normalization is achieved by dividing the dry weight concentration by the dry weight TOC content. 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 0.2%, dry weight values are more appropriate to use than organic carbon normalized values (Michelson, 1992).

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 species. 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 2-11 that were established for the protection of human health.

Table 2-11. 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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