City of Seattle
State of the Waters 2007

Volume II: Seattle Small Lakes

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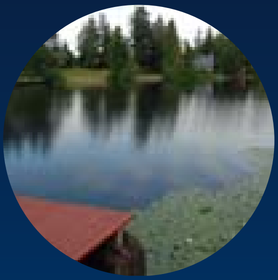
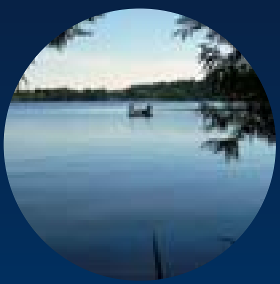


Bitter Lake

Haller Lake



Green Lake

State of the Waters 2007

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Part 1 Introduction

Understanding the State of Seattle Waters

The State of the Waters report, prepared by Seattle Public Utilities (SPU), describes the current hydrologic, chemical, physical, and biological conditions in watercourses, lakes, and shorelines located within the city limits of Seattle. These conditions define the overall watershed health and the ability of city watersheds to perform critical functions and provide services, such as filtering water, moderating floods, and capturing sediment. Based on a number of research, monitoring, and assessment reports, this information has been collectively compiled and organized for the first time to be readily accessible to City of Seattle staff and interested citizens.

Downtown Seattle from Elliott Bay (photo by Bennett)

Interconnectedness between terrestrial and aquatic environments is among the most important concepts for managing watercourses, lakes, estuaries, and marine environments. Evolving watershed characteristics can lead to impacts in nearby and not-so-nearby areas, sometimes with unintended or unexpected consequences. The unpredictability of impacts on these connections often creates difficult challenges in managing land, drainage, development, and other watershed uses without leading to adverse effects on the ecosystem as a whole. Hence, there is a need to integrate management and stewardship across a watershed at many levels of action—from pesticide use in residential landscaping to stormwater management in large shopping malls. For water resources, this means looking at our actions on land and understanding how those actions affect conditions in our watercourses, lakes, and Puget Sound. Within Seattle, integrated watershed management is a delicate balance between desired human land uses and equally desired ecological health.

The City of Seattle is committed to restoring, protecting, and enhancing its water bodies, and inspiring citizens and businesses to do likewise. In 2004, Mayor Greg Nickels issued an executive order to create a citywide program that would balance urban growth and development with the benefits of restoring critical water resources. The Restore Our Waters initiative is a long-term effort to protect and restore aquatic habitat, improve water quality, and manage stormwater drainage. Seattle's investments under this program are to be guided by clear goals that are based in science and tracked through time to show progress. This report, State of the Waters, is a critical first step in setting these goals by documenting the baseline conditions of Seattle's surface water bodies.

Downtown Seattle across Lake Union (photo by Bennett)

In addition to documenting Seattle's current, or baseline, conditions, this report serves as an important foundation step for other city efforts and activities that will affect the health of Seattle water bodies in the coming years. The assessment provided in this document was used to develop a companion report, Science Framework for Ecological Health (SPU and Stillwater Sciences 2007), which outlines what healthy urban water bodies could look like, identifies potential pathways for improvement, and defines a structure for measuring ecological health, based on the best scientific information about urban watercourses.

The actions of the City of Seattle, citizens, and businesses, individually and collectively, have a large influence over the state of the waters in and around Seattle. It is hoped that the State of the Waters report will enhance public awareness of the role we play in protecting the health of our water bodies, providing a foundation for determining effective and efficient aquatic restoration investments and for integrated management of Seattle's urban watersheds.

Contents of the State of the Waters Report

Volume II of the State of the Waters report focuses on Seattle's small lakes. Volume I focuses on Seattle watercourses, and Volume III addresses the larger aquatic systems, including large lakes, estuaries, and marine systems. Following this introduction, Volume II contains these chapters:

- A Brief Primer on Lake Ecosystems describes how hydrology, water quality, and physical conditions work together to shape lake habitat and the plant and animal communities that use them.
- Assessing the State of the Waters describes the methods used to evaluate Seattle's small lakes for the purposes of this report.
- Conditions in Seattle's Small Lakes describes water quality and physical habitat conditions in Bitter Lake, Green Lake, and Haller Lake, along with the results of analyses of low-quality and high-quality habitat areas associated with each of these small lakes.
- Small Lakes Summary and Conclusions summarizes current conditions and conclusions about the state of Seattle's small lakes.

Overview of Seattle-Area Water Bodies

Seattle contains four types of aquatic ecosystems that differ in their physical characteristics, the habitat they provide, and the species and human uses they support:

- Watercourses and streams
- Lakes
- Estuaries
- Marine waters.

Watercourses and Streams

Surface water in Seattle is transported to receiving water bodies by a complex system of pipes, ditches, culverts, and open stream areas. For clarity, the City of Seattle has adopted the word "watercourse" to refer to this network. "Watercourse" means the route, constructed or formed by humans or by natural processes, generally consisting of a channel with bed, banks, or sides, in which surface waters flow. Watercourses include small lakes, bogs, streams, creeks, and intermittent artificial components (including ditches and culverts) but do not include receiving waters (Seattle Municipal Code 22.801.240).

Volume I of the State of the Waters report focuses on those parts of watercourses that are not in culverts, in particular, on watercourse segments where there is an open stream channel with natural habitat. The City of Seattle contains five major watercourses: Fauntleroy Creek, Longfellow Creek, Piper's Creek, Taylor Creek, and Thornton Creek.

These five watercourses have year-round flow and support salmon and trout. There are also numerous smaller watercourses that do not support salmon and may have only intermittent flow, including Mapes Creek, Puget Creek, Yesler Creek, Fairmount Creek, Madrona Creek, Frink Creek, Arboretum Creek, Wolfe Creek, Blue Ridge Creek, Ravenna Creek, Schmitz Creek, Licton Springs, and 25 other small watercourses.

Lakes

Lakes are formed in topographic depressions that retain fresh water. Lakes receive inflow from their surrounding watersheds through rivers, watercourses, overland and subsurface flow, and—in developed areas—from drainage pipes. Water typically exits a lake through a watercourse or river, although the outflows of most lakes in Seattle have been channeled into constructed drainage systems. Lakes can range in size from a few acres to many square miles. Plants and animals that depend on lake environments inhabit shallow-water and deep-water areas and interact in a complex food web.

Green Lake (photo by Bennett)

Seattle contains three small lakes: Haller Lake, Bitter Lake, and Green Lake, shown in Figure 1. These lakes are the focus of this volume (Volume II) of the State of the Waters report. The city also contains two larger lakes, Lake Union and parts of Lake Washington. Lake Washington is the second largest natural lake in Washington state. These larger lakes will be described in a subsequent volume.

Estuaries

Estuaries are areas where freshwater and marine water mix, on the interface between an ocean and a watercourse or river. These ecosystems are shaped by saltwater tidal fluctuations and freshwater flows. Plants and animals that inhabit these environments must respond to rapidly changing salinity levels and flow conditions. Estuaries are nursery areas for many fish and bird species.

The Duwamish River estuary primarily serves as the meeting point for Puget Sound and the Green/Duwamish river system, lies within the City of Seattle. The city also contains the estuary of the Lake Washington watershed at the Hiram M. Chittenden Locks (the Ballard Locks), which was created by redirecting the lake outlet in the early 1900s. The Lake Washington estuary, created by manmade changes, provides limited estuarine habitat.

Marine Ecosystems

Marine waters are areas of saline water, typically connected to or part of the ocean. Marine systems are shaped by tides, currents, sea floor shape, and sunlight. Plants and animals that inhabit marine environments are adapted to high-salinity conditions, and their use of habitats can vary across water depths. Many species are adapted to periods of inundation and exposure with fluctuating tides.

Seattle sits along 30 miles of Puget Sound marine shoreline. While Puget Sound is a saltwater body, it is actually considered an estuary because of the numerous tributary rivers that dilute salinities in the sound to lower levels than typically found in the Pacific Ocean.

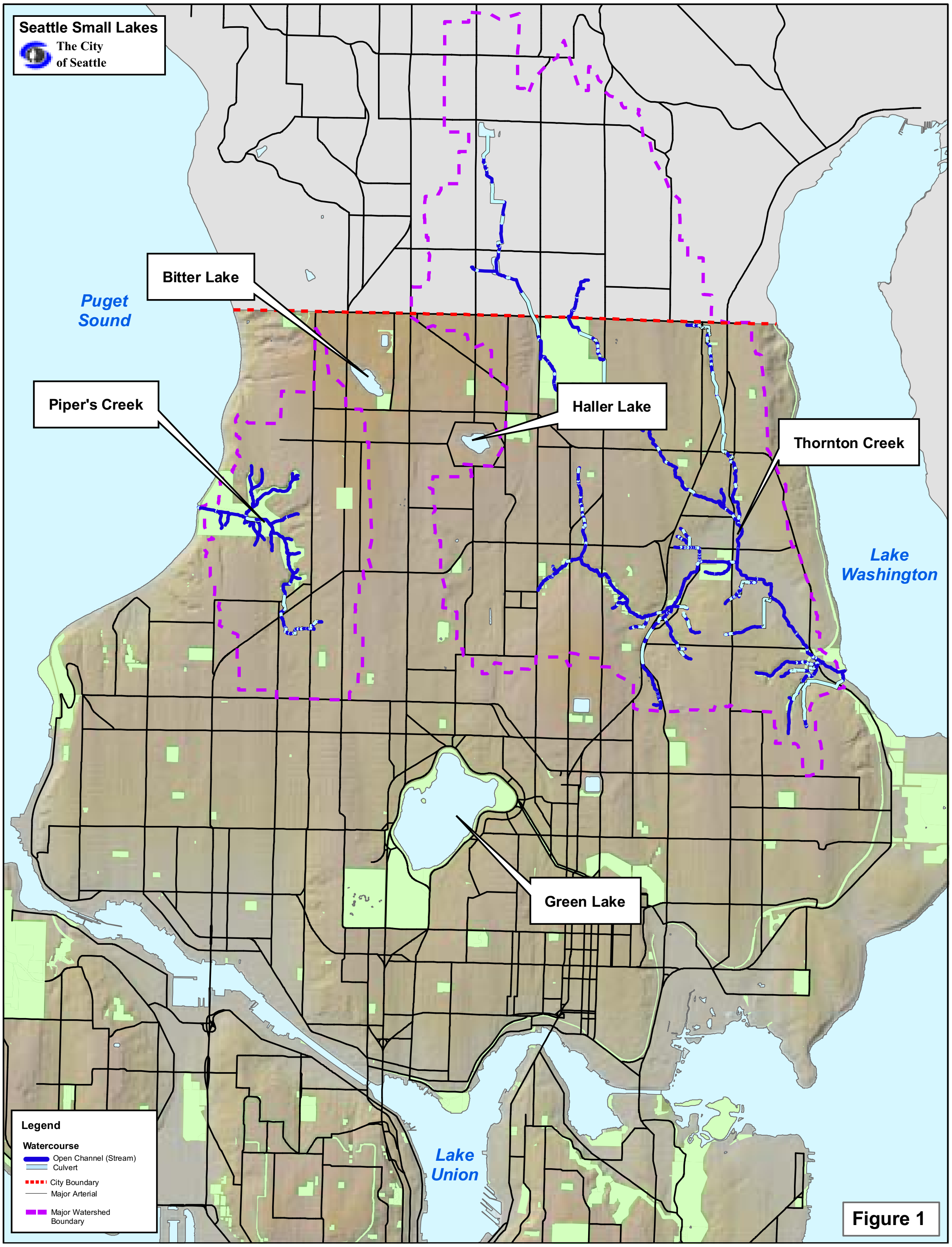
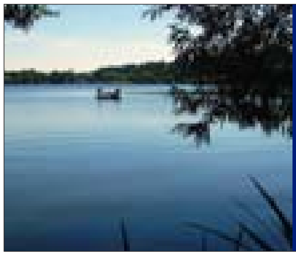


Figure 1. Seattle small lakes.



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Part 2 A Brief Primer on Lake Ecosystems

Lake Ecosystem Processes

Bitter Lake (photo by Bennett)

Aquatic habitats are produced by the interaction of physical, chemical, and biological processes that occur both in an aquatic system and in adjacent areas within a watershed (Naiman et al. 1995). These ecosystem processes form aquatic habitats that provide certain essential functions for organisms, such as refuge habitat for fish or foraging habitat for birds. The use of habitat by plants and animals is a response to dynamic ecosystem processes, and disruptions to these processes, whether natural or human-induced, can alter the distribution and behavior of biota (Karr 2000).

Haller Lake (photo by Bennett)

The watershed, or drainage basin, of a lake is a critical component in lake processes. Lake ecosystems are shaped by the hydrology and topography of the watershed and the lake basin, as well as by wave energy, currents, and light (Wetzel 1983; Horne and Goldman 1994). The drainage basin regulates the delivery of water, organic matter, substrate, nutrients, and contaminants to the lake. Upland areas store and filter rainfall, controlling flows that discharge to the lake and moderating the introduction of nutrients and contaminants (Ziemer and Lisle 1998).

Lakes contain less than 0.01 percent of all the water on earth, yet they hold over 98 percent of the liquid fresh water that is available on the surface. Because lakes are the geographic endpoints for the physical and chemical inputs in many watersheds, a lake and its watershed are often considered a single ecosystem (Likens 1985).

Trophic Status and Eutrophication

Lake trophic status is a measure of the nutrient status, or eutrophication, of a lake. Degrees of eutrophication, in increasing levels of nutrient enrichment, typically range from oligotrophic, to mesotrophic, to eutrophic, to hypereutrophic.

A lake is generally placed into one of three categories based on its productivity, or nutrient richness. These categories, while somewhat imprecise, fall onto a continuum and can give an indication of a lake's relative trophic status. On one end of the continuum are oligotrophic lakes, typically large, often deep, having cold, clear water and a rocky or sandy shoreline and substrate. Oligotrophic lakes contain very low concentrations of the essential nutrients for plant growth. Few nutrients enter the lake from the watershed, and those that do are diluted by the large volume of water. The production of phytoplankton, aquatic weeds, and other plants is very low in these lakes, and the populations of zooplankton and fish are small. There is very little organic matter settling to the lake bottom, and this keeps bacteria at low levels. With so few plants and bacteria, oxygen consumption is minimal, and oligotrophic lakes often are rich in dissolved oxygen from top to bottom.

On the other end of the continuum are eutrophic lakes, which are highly productive and rich in nutrients, shallow with soft substrates, and often contain cloudy, greenish water. Plant growth can be very high, especially near the water surface, with a resultant increase in the densities of zooplankton and fish. Much of the organic matter accumulates on the lake bottom, providing food for high numbers of bacteria. As a result, the water in eutrophic lakes is often depleted of oxygen near the bottom (Figure 2).

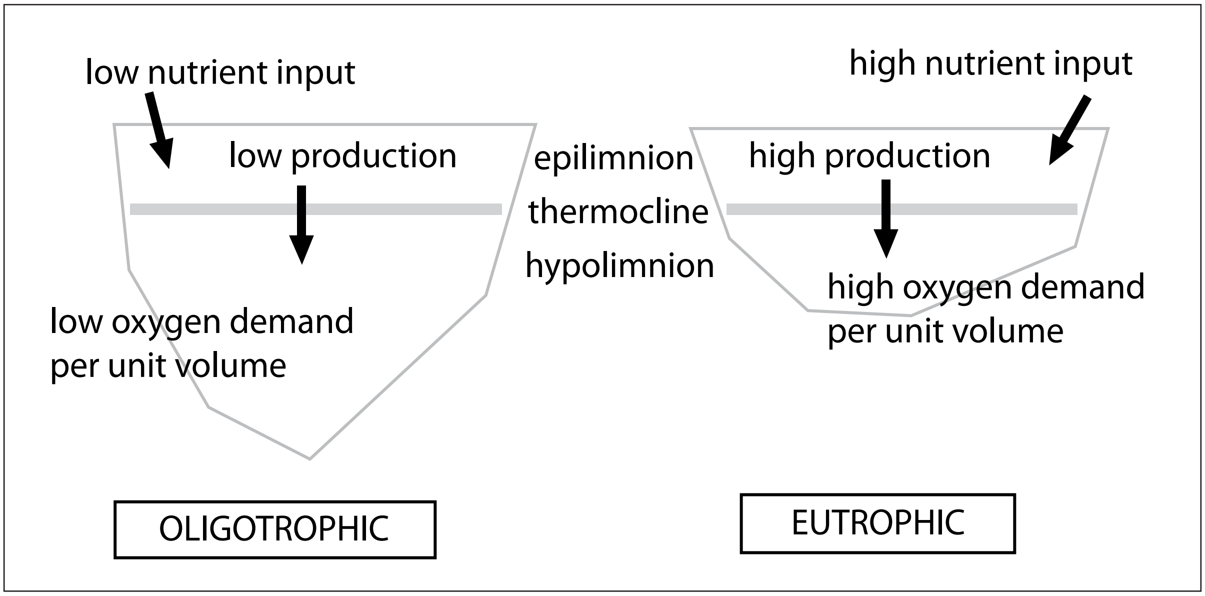

Figure 2. Conceptual model of oligotrophic and eutrophic lake ecosystems.

Lakes that have intermediate productivity lie between oligotrophic and eutrophic on the continuum and are categorized as mesotrophic. Many factors can shape these intermediate conditions, including the volume, depth, and age of the lake, as well as climate change. As a general rule, lakes naturally become more eutrophic over long periods of time, as sediments slowly accumulate to make the lake shallower and the nutrients become more concentrated. Under natural conditions, a mesotrophic lake will not become oligotrophic without major changes in climate patterns or watershed geomorphology.

The rate of eutrophication can be greatly affected by human disruption of ecological processes within a lake basin. Lakes collect fertilizers used throughout their watersheds, and people historically have used lakes as convenient depositories for wastes and sewage. The resulting human-induced increase in nutrients, particularly nitrogen and phosphorus (sometimes called cultural eutrophication) can lead to hypereutrophic conditions. Lakes that undergo very rapid enrichment can experience extreme shifts in dissolved oxygen concentrations due to plant decomposition, leading to fish kills and shifts in the species composition of the biota. Limiting the amount of nutrients, phosphorus in particular, can return a lake to mesotrophic conditions.

Bitter Lake is considered a mesotrophic lake (photo by Bennett)

Thermal Stratification

The temperature throughout the water column in a lake is affected by seasonal changes in solar radiation and wind activity. During the late spring, water near the surface gradually heats up, and dissolved oxygen levels rise due to wind mixing and increased plant production. This warming and blending results in a layer of well-oxygenated water at the surface that is less dense than the cool, unmixed layer below it. The depth of this surface layer, the epilimnion, depends on the intensity of sunlight, clarity of the water, and strength of the wind.

The deeper layer, or hypolimnion, stays cool and dense and is poorly oxygenated due to the lack of photosynthesis and the decomposition of organic matter by bacteria. As the summer progresses, these two layers become increasing stratified as the temperature differential widens. Between these layers, a thermocline develops, a region defined by a rapid decrease in temperature (Figure 3).

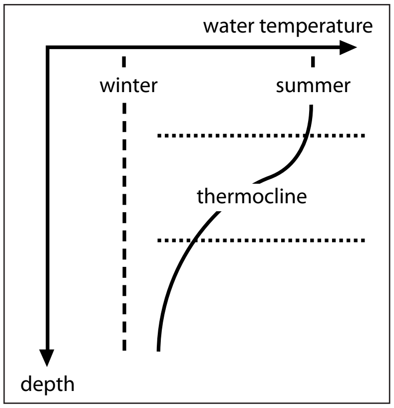

Figure 3. Conceptual model of the seasonal thermocline in lakes.

As surface temperatures cool in the fall, the water in the epilimnion becomes denser and sinks. Aided by fall winds, the entire water column in a lake can mix. As the thermocline disintegrates, the temperature, density, and dissolved oxygen in the lake all become more uniform. The color and smell of a lake can change as nutrients and decaying organic matter are cycled up to the surface. This phenomenon is known as fall turnover. Lakes that ice over in the winter experience inverse stratification, where the coldest water near the ice is actually slightly less dense than the rest of the lake water, and the ice prevents wind mixing. As the ice breaks apart with warming weather, spring turnover can occur. Lakes in the Puget Sound region generally do not ice over and tend to be continually mixed during the winter.

Lake Zonation

The physical processes outlined above play out in the pelagic, benthic, littoral, and riparian zones of a lake, with processes and ecological interactions in one zone affecting those in other zones (Schindler and Scheuerell 2002). These four ecological zones are described separately below.

Pelagic Zone

The pelagic zone of a lake is open water, without contact with the lake bottom or shore (Horne and Goldman 1994). Pelagic zone habitats change with water depth and do not vary substantially within a given water depth (Schindler and Scheuerell 2002). Light levels, water temperatures, and chemical concentrations (e.g., dissolved oxygen, nutrients such as nitrogen, and phosphorus) change from the surface waters to the depths of the lake, in particular during times of stratification when warm surface waters become separated from cooler water at deeper depths. The penetration of light and occurrence of photosynthesis (primary production) follow and exacerbate the differences above and below the stratification point in the lake (i.e., the thermocline). These factors of light, nutrient concentrations, water temperatures, and stratification shape open-water habitat and therefore affect the distribution of organisms in the lake water column (Horne and Goldman 1994).

Bitter Lake (photo by Bennett)

Planktonic organisms, which are nonmobile or weak-swimming microscopic animals or plants that float and drift with lake currents, dominate the pelagic zone. Examples of plankton include bacteria, viruses, protozoa, phytoplankton (i.e., small plants), zooplankton (i.e., small animals), and early life stages of insects. An important process that occurs in the pelagic zone of lakes is nutrient processing, as plankton is the driving force in the food web. Lake turnover is also important for this production, as benthic lake sediments provide nutrients for planktonic production (Schindler and Scheuerell 2002). Fish also inhabit this zone of the lake. The vertical differences in the water column of the lake are important for providing fish refuge and foraging habitats.

Benthic Zone

The benthic zone is the area associated with the lake bottom, in both deep- and shallow-water areas. Benthic habitats are associated with bottom substrates and can vary substantially across horizontal distances and water depth. Differences in habitat are influenced by physical structure, such as sediment types, rocks, aquatic plants, and woody debris, and by chemical components in the sediment (Schindler and Scheuerell 2002).

Benthic habitats contain a diverse array of organisms that vary depending on structure and water depths, which in turn influence light levels available for photosynthesis and other primary production. These organisms include fish, attached algae, shallow floating algae (i.e., metaphyton), aquatic plants (i.e., macrophtyes, both attached to substrate and floating), bacteria, protozoa, aquatic insects, and other aquatic invertebrates (e.g., crayfish). With this diverse array of organisms, benthic food webs are rather complex; they can be fueled by the settling of pelagic plankton, by benthic algae production, or by terrestrial-based inputs (from the surrounding land, e.g., riparian areas).

Nutrient processing and production in the benthic zone are important for the lake ecosystem. The benthic zone is also important in providing refuge and rearing opportunities. Amphibians, reptiles, birds, and mammals can also be present in the benthic zone, although they are more typically found in shallow littoral and riparian areas.

Littoral Zone

Littoral zones are the shallow areas of the lake, adjacent to and associated with the lake shoreline. The littoral zone extends out to a depth where light levels are low enough to dramatically reduce photosynthesis (Wetzel 1983; Schindler and Scheuerell 2002). This zone is coupled closely with both the benthic and riparian zones, which provide and help to regulate much of the physical structure (i.e., substrates and woody debris) and chemical structure in the littoral zone.

Bitter Lake shoreline and littoral zone (photo by Bennett)

Riparian Zone

The riparian zone is the area along the lake shoreline and some portion of the adjacent uplands. Collectively, the littoral and riparian areas are transition zones between the terrestrial watershed and the aquatic ecosystems of the lake (Schindler and Scheuerell 2002).

The riparian area around Haller Lake includes varying amounts of lawns, mature trees, and shrubs (photo by Bennett)

The littoral zone is occupied by the same suite of organisms as the benthic zone: algae, aquatic plants, aquatic invertebrates, and fish, among others. The riparian zone contains more of the land-based animals and plants. Plants at the edge of the lake must be adapted to periods of inundation and exposure as lake levels fluctuate, and to wet soils such as in wetland conditions. Littoral zone food webs are based upon both in-water production from algae and plants, and terrestrial-based organic inputs from upland plants (Schindler and Scheuerell 2002). The condition of the riparian and littoral zones is important for nutrient processing and production and for providing foraging, refuge, spawning, and migration options.

Disruptions to Lake Ecosystems

Seattle's small lakes are subject to pressures related to development in the watershed and recreational and residential uses of the shoreline. As with watercourses, development in the watershed can alter the amount, timing, and content of stormwater runoff to lakes.

Shoreline and shallow-water habitat can be affected by adjacent land uses and on-water uses. Water-dependent uses, such as recreation and fishing, typically require docks and piers for boat access and moorage. Residential land owners often remove shoreline vegetation and install bulkheads and other forms of bank armoring to take advantage of water views and secure the property.

Development along Bitter Lake (photo by Bennett)

Land use practices in lake watersheds affect riparian and littoral habitat structure, light conditions, sediment dynamics, and water and sediment quality. The typical disruptions to lake ecosystems are discussed below, first focusing on those that are most common in Seattle lakes.

Altered Hydrology

The delivery of water into a lake, coupled with the lake's size and outlet, determine how long water stays in the lake, or the residence time, which is strongly related to how nutrients and lake pollutants are processed and stored (Horne and Goldman 1994). The amount of water reaching a lake is affected by watershed runoff and discharge from watercourses and rivers that enter the lake. The amount and timing of water coming into the lake can be affected by detention or diversion of water for human consumption, flood control, navigation, irrigation, and industrial purposes.

Water delivery is also affected by urbanization in the lake watershed. Urban development in upland areas, which entails vegetation clearing, soil compaction, and construction of roads and buildings, increases the impervious surface area within watersheds. This in turn increases the volume and rate of stormwater runoff, causing high watercourse discharge or high direct delivery of water to the lake shoreline (Dunne and Leopold 1978; Arnold and Gibbons 1996; Poff et al. 1997).

In addition, changes to the lake outlet can affect lake hydrology by either increasing or decreasing the volume and rate of water leaving the lake system. This in turn affects water level fluctuations in the lake, with resulting impacts on riparian and wetland plants that vary in their capacity to deal with inundation and exposure. Finally, changes in lake hydrology can affect shoreline habitat, particularly in the littoral and riparian zones. Hydrology also affects nutrient cycling and the basic productivity in the lake.

Water Quality

The water quality of a lake is determined by physical, chemical, and biological processes. These processes involve the interactions of many constituents, including water temperatures, dissolved oxygen levels, alkalinity or pH status, nutrients (e.g., phosphorus and nitrogen), and contaminants such as metals, pesticides, and organic compounds (including polycyclic aromatic hydrocarbons [PAHs] and polychlorinated biphenyls [PCBs]). For example, water temperature (a physical characteristic) affects the breakdown of organic material into nutrients (a chemical process), as well as phytoplankton and zooplankton production and the metabolism of fish species (biological processes).

Human-induced changes to water quality, through industrial effluents, sewer overflows, and urban runoff, can alter lake water temperatures, turbidity, and oxygen content, as well as nutrient and contaminant concentrations (Karr 1995; Welch and Lindell 2000). For instance, the warmer temperatures typically caused by stormwater inputs or atmospheric warming can produce short-term increases in fish metabolism that may in turn increase predation. Predatory fish need to find more prey to maintain their metabolism and grow. However, temperatures above 20 degrees Celsius (°C) can become stressful for salmonids, and can even cause mortality above 25°C.

Water temperature, plant respiration, and biological decomposition are also inversely related to dissolved oxygen levels, which play a critical role supporting aquatic organisms such as salmonids. Similarly, alkalinity/pH conditions and nutrient concentrations influence biological processes, particularly phytoplankton production. Historically, the natural background levels of nutrients limited growth of algae in lakes through much of the year. By contrast, artificial inputs of excess nutrients can now lead to an abundance of undesirable algal blooms in urban lakes.

Finally, all components of water quality can be affected by the contaminants in urban runoff (e.g., fertilizers, pesticides, and vehicular pollutants) and by discharges from recreational, industrial, and commercial activities (e.g., heavy metals, dioxins, and PCBs).

Sediment Quality

A portion of the contaminants that can enter lakes through direct discharges and stormwater runoff are present as particulate matter, or pollutants bound to particulate matter. These pollutants typically settle to the lake bottom, contaminating the sediments of the benthic zone. In addition, treated lumber in docks and piers may introduce organic contaminants (e.g., creosote) into lake sediments.

Once present in lake sediments, contaminants may break down slowly, or in some cases not at all. Some contaminants enter the food web through the plants and animals that reside in the bottom sediments. Once in the food web, these contaminants can bioaccumulate and be ingested by animals higher up in the food chain, including humans. Such bioaccumulation can ultimately cause a range of problems, from chronic effects (i.e., persistent and long-term effects) such as reduced immune system efficiency, to acute effects (i.e., quick and severe responses) such as sickness and death.

Sediment Dynamics

Maintenance of a lake's shallow-water habitat and beaches is important for providing adequate substrates for benthic production and as refuge for juvenile fish, because coarser substrates tend to provide ambush habitat for predatory fish. The recruitment and transport of sediments is essential to the maintenance of lake beaches and the adjacent shallow-water habitat. Generally, sediment comes into the lake through two sources. One source is surface inflow from tributary rivers, watercourses, and stormwater. The other source is the lake shoreline, where wave action and inundation pull sediment from shallow areas. However, lake shoreline sediment recruitment is limited where bulkheads and other bank armoring are present, and by lake water level fluctuations.

Shoreline Connectivity

The connections between shallow aquatic areas and the adjacent land along the shoreline are important for creating and maintaining littoral habitat structure. These shallow-water habitats are important areas for refuge and rearing opportunities for juvenile fish. Riparian vegetation introduces wood and sediment into the water, producing habitat structure. The littoral habitat structure shapes wetland and aquatic plant distribution, and coupled with the input of nutrients and organic matter from the riparian zone, this habitat supports production of benthic communities (Schindler and Scheuerell 2002). Leaf litter and woody debris provide nutrients to fuel the aquatic food web and support invertebrate production. Riparian vegetation also provides habitat for terrestrial insects and the terrestrial life stages of aquatic insects. These insects are an important part of the aquatic food web for fish that live or make forays into shallow-water areas.

The importance of riparian contributions to aquatic areas depends on the size and type of vegetation, the degree of shoreline complexity, and the productivity of the aquatic system (Schindler and Scheuerell 2002). The function of riparian vegetation along lake shorelines is often undermined by invasive plant species, conversion of riparian areas to landscaped yards, and the presence of bulkheads or docks.

The quantity and quality of shallow-water habitat are affected by the presence of shoreline docks and armoring (e.g., bulkheads and riprap) (Carrasquero 2001). Armoring is often present within or below the inundation zone of a lake, where it reduces the amount of shallow-water habitat that can be used by benthic communities and juvenile fish (Koehler 2002; Tabor and Piaskowski 2002). Docks shade shallow-water habitat, affecting the amount of primary production, and shading can affect fish behavior (Carrasquero 2001; Tabor et al. 2004). Nonnative predatory fish have been shown to aggregate around over-water structures; this behavior may affect predator-prey interactions.

Haller Lake (pictured) and Bitter Lake contain many docks and shoreline structures (photo by Bennett)

Nonnative Species

Species from other areas are sometimes introduced, either intentionally or accidentally, into new habitats. Nonnative species can include plants (e.g., Eurasian watermilfoil, reed canarygrass), invertebrates (e.g., Asian clam), amphibians (e.g., bullfrog), fishes (e.g., small- and large-mouth bass, yellow perch), and mammals (e.g., nutria). These nonnative invasive species can alter habitat conditions by changing substrate composition or local water quality conditions. For example, dense growth of Eurasian watermilfoil or other macrophytes can lead to dissolved oxygen depletion and fish mortality (Frodge et al. 1995). Nonnative species can also alter food web dynamics and compete with or prey upon native species.

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Part 3 Assessing the State of the Waters

Pertinent water quality, sediment quality, and habitat data have been compiled from a variety of sources and evaluated for this report. This chapter describes the data compilation and evaluation procedures used to assess conditions in Bitter Lake, Green Lake, and Haller Lake.

Water and Sediment Quality Assessment Methods

Water and sediment quality data for small lakes in Seattle are fairly limited. Haller Lake has been routinely monitored as part of the King County volunteer lake monitoring program since 1997, and the program has monitored Bitter Lake since 1985. Green Lake was intensively monitored from 1992 through 1995 for the Phase II restoration program, and was sporadically monitored by Seattle Parks and Recreation between 1996 and 2003. Since Green Lake was treated with alum in the spring of 2004, the lake has been monitored twice each month during the summer by Seattle Parks and Recreation. In 2005, SPU contracted with King County to include Green Lake in the volunteer monitoring program.

While water and sediment quality are extremely important aspects of aquatic conditions for plants and animals as well as humans, data gaps limit the ability to accurately describe existing conditions in Seattle lakes. The King County volunteer lake monitoring program measures temperature, phosphorus, chlorophyll a, and Secchi depth (a visual measure of water clarity) to assess lake trophic status. Information on the levels of metals and toxic organic pollutants present in Seattle lakes is generally not available, with the exception of one study of water and sediment in Bitter Lake and one study of sediment in Green Lake.

Water Quality Indicators

People use local water bodies for a wide variety of purposes such as swimming, boating, fishing, and aesthetic benefits, and those water bodies provide valuable habitat and food needed by fish and other aquatic organisms. While humans typically see aquatic ecosystems only from the outside, there are many components to healthy aquatic communities hidden under the surface or at the edge of the water. Small lakes support a variety of aquatic and terrestrial organisms, including submerged and emergent plants, riparian vegetation, insects, fish, and mammals. Less easy to see but equally important are the microscopic bacteria, fungi, and organisms that provide food for other aquatic animals. A healthy aquatic environment operates in a dynamic fashion to maintain a diverse physical habitat and the species that reside there. Together, both the human and wildlife uses of Seattle's aquatic systems rely on clean water.

Fishing in Seattle's Green Lake (photo by Bennett)

Table 1 summarizes the benefits and uses of Seattle's small lakes, as well as the water quality indicators used in this assessment to evaluate their overall condition. Water quality indicators are select chemical and physical parameters and indices that can be used to characterize overall conditions; they provide criteria and benchmarks for assessing the success of watershed management efforts. More information about key water quality indicators can be found in Volume I of this report.

Table 1. Uses and benefits of Seattle lakes, and water quality indicators of lake conditions.

Use	Benefit	Key Water Quality Indicators
Contact recreation	Providing suitable water quality and sediment quality for human use of surface waters for contact recreation, including swimming, wading, snorkeling, and diving.	Fecal coliform bacteria
Passive recreation	Providing opportunities for people to enjoy walking and hiking, playing, observing wildlife and connecting with nature.	Fecal coliform bacteria and trophic state index
Human consumption	Providing suitable water quality and sediment quality for fish and shellfish harvesting.	Metals and organic compounds
Aesthetics	Preventing visual and odor-related degradation of surface waters to protect their aesthetic value.	Total petroleum hydrocarbons and trophic state index
Aquatic health	Providing water quality and sediment quality conditions to support valuable aquatic species.	Conventional parameters (dissolved oxygen, temperature, pH, nutrients), trophic state index, metals, organic compounds

Data Compilation

Information for this assessment was obtained from the following sources:

- King County Water quality data for Bitter Lake, Haller Lake, and Green Lake from the King County volunteer lake monitoring program (King County 2001a, 2001b, 2002a, 2002b, 2003, 2005)
- Bitter Lake water and sediment quality studies (Seattle Lakes Alliance 2000)
- Green Lake sediment quality data (SPU unpublished).

Table 2 summarizes the water quality data sources used in this study. Monitoring station locations in the three small Seattle lakes are shown on Figures 4, 6, and 8 (presented in Part 4 under the discussion of each individual lake).

Table 2. Water quality data sources for Seattle's small lakes.

Location	Reference	Station ID	Storm Flow	Non-storm flow	Type of Sample	Sediment	Period of Record	Frequency (Samples/Year)	Quality Assurance Category	Temperature	Dissolved Oxygen	Coliform Bacteria	Nutrients	Other Conventional Parameters	Metals, Total	Metals, Dissolved	Petroleum Hydrocarbons
Bitter Lake																	
Mid-lake	1	–		√	G		1985-pres	10-14	2	√			√				
Multiple stations	2	–	√		G	√	2000	4-8	2						√		√
Haller Lake	1	–		√	G		1997-pres	10-14	2	√			√				
Green Lake																	
Mid-lake	3	–		√	G		2005-pres	10-14	2	√			√				
Multiple stations	4	–			G	√	2004	7	2					√	√		√

G = grab sample C = composite sample
References:
1. King County (2001a, 2001b, 2002a, 2002b, 2003, 2005)
2. Seattle Lakes Alliance (2000)
3. King County (unpublished)
4. SPU (unpublished)

Data Quality Assurance Review

To identify the data sources of acceptable quality for the purpose of assessing water quality conditions, the available data were subject to a data quality assurance review prior to use. Electronic data files were examined to verify that the data had been checked for quality and accuracy (i.e., quality assurance and quality control [QA/QC] verification). Where possible, written reports were also examined to characterize the level of data quality and accuracy review performed. Based on this review, the compiled data from each source were placed into one of three categories:

- Data of known and acceptable quality (category 1): Quality assurance information from field sampling and laboratory analysis is included in the summary report for the particular source. This quality assurance information has been reviewed against specific, predefined objectives for assessing data quality. Based on this review, qualifying remarks are assigned to those data that do not meet quality assurance objectives. Data having minor quality assurance issues are identified in summary tables and analyses. Data having severe quality assurance issues are excluded from all data summaries or analyses.

- Data believed to be of acceptable quality (category 2): Qualifying remarks are assigned to specific data to indicate the presence of quality assurance issues. However, the specific quality assurance objectives for the data are not clearly identified, and quality assurance information from field sampling and laboratory analysis is not presented along with the data.

- Data of unknown quality (category 3): Qualifying remarks are not assigned to any data to indicate the presence of quality assurance issues. No information is presented on the specific quality assurance objectives for the data, and quality assurance information from field sampling and laboratory analysis is not presented along with the data.

Data sources assigned QA category 1 and 2 classifications are included in this summary report, while QA category 3 data are excluded. The category assigned to each data source is listed in Table 2.

Data Analysis

The data compiled for this report were evaluated using the following techniques:

- Plotting of time series graphs to check overall trends in water quality conditions for key water quality parameters
- Comparison of sample results to Washington state water quality criteria and other applicable benchmarks, in order to evaluate overall toxicity to aquatic organisms
- Calculation of summary statistics (including arithmetic mean, median, minimum, maximum, and confidence limits, shown in box plots)
- Comparison of trophic state indices to characterize water quality conditions in lakes.

A brief description of each analysis is provided separately in the following subsections.

Time Series Analysis

Time series analyses are simple graphs of chemical concentration versus time. The overall scatter and distribution in the chemical values provide an indication of general trends and variability in the sample population.

Washington State Water Quality Standards

The state water quality standards (Washington Administrative Code [WAC] 173-201A) provide criteria for evaluating water quality conditions in Seattle receiving water bodies. The standards have been established to protect public health and aquatic life in freshwater and marine water systems, based on specific or designated uses of those water bodies. Established designated uses include public recreation (e.g., fishing, boating, and swimming) and other miscellaneous uses such as commerce, navigation, and aesthetic benefits, as well as the propagation and protection of fish, shellfish, and wildlife.

The freshwater standards apply to Seattle small lakes and large lakes (Lake Washington and Lake Union), while the marine standards apply in Puget Sound and the estuarine portion of the Duwamish Waterway. Standards have been established for many conventional water quality indicators (including pH, temperature, dissolved oxygen, turbidity, bacteria, and total dissolved gas) and toxic substances (including metals, organic compounds, and radioactive materials).

Two levels of protection have been established for toxic substances to prevent injury or death to aquatic organisms: the acute and the chronic toxicity criteria. The acute toxicity criteria are based on short-term exposure. Depending on the chemical, the acute toxicity criterion might be the instantaneous maximum concentration not to be exceeded at any time, or a one-hour average concentration, or a 24-hour average concentration. The chronic toxicity criteria reflect long-term exposure limits, which range from one-hour duration up to 4-day duration. For this analysis, stormwater samples are compared to the acute toxicity criteria, and non-storm flow data are compared to the chronic toxicity criteria.

The Washington Department of Ecology (Ecology) revised the state water quality standards in 2006. The 2006 rules are used in this report where samples have been collected appropriately to allow comparison to the revised 2006 criteria. The 1997 rule is used where the existing data are not directly comparable to the 2006 rule. For example, the temperature criterion in the 2006 rule is based on the 7-day average of the daily maximum temperatures, while the 1997 rule is based on a single measurement. Most of the available data for water temperature were collected on a monthly basis and therefore cannot be compared to the 2006 criterion. Consequently, these data are compared to the 1997 temperature criterion.

The beneficial use designations that apply to Seattle lakes under the 1997 and 2003 rules are listed in Table 3.

Table 3. Beneficial use designations applicable to Seattle's small lakes under state water quality standards.

	1997			2006 Amended												
				Aquatic Life			Recreational Use		Water Supply Uses			Miscellaneous Use				
	Class AA	Class A	Lake Class	Char	Core Summer Habitat [a]	Spawning, Rearing, & Migration [b]	Rearing & Migration Only [c]	Extraordinary Contact Recreation	Primary Contact Recreation	Domestic Supply	Industrial Supply	Agricultural Water Supply And Stock Watering	Wildlife Habitat	Fish Harvesting	Commercial/Navigation	Aesthetics	Boating
Bitter Lake			√		√	√		√		√	√	√	√	√	√	√	√
Green Lake			√		√	√		√		√	√	√	√	√	√	√	√
Haller Lake			√		√	√		√		√	√	√	√	√	√	√	√

[a] Summer (June 15–September 15) salmonid spawning or emergence, adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char; spawning outside the summer season, rearing, and migration by salmonids.

[b] Salmon or trout spawning and emergence that only occurs outside of the summer season (September 16–June 14); rearing and migration by salmonids.

[c] Used for rearing and migration only, not used for spawning.

Lake Trophic State Index

Bitter Lake (photo by Bennett)

A common way to characterize the overall health of a lake according to its level of biological activity is the trophic state index (TSI) rating (Carlson 1977). The trophic state index, which calculates trophic status based on three key indicators (chlorophyll *a*, total phosphorus, and Secchi depth), is used in this assessment to compare water quality conditions in small lakes. As shown in Table 4, this index is based on a scale of zero to 100 and provides a standard measure for evaluating lake quality.

Table 4. Trophic state index values used to assess lake water quality conditions.

TSI value	Lake Class	Description
<40	Oligotrophic	Low biological activity associated with high water clarity, low phosphorus concentrations, and low algal levels
40-50	Mesotrophic	Moderate biological activity associated with moderate water clarity, low phosphorus concentrations, and moderate algal levels
>50	Eutrophic	High biological activity associated with low water clarity, high phosphorus concentrations, and high algal levels

TSI = trophic state index (Carlson 1977).

Lake Sediment Standards

Washington state has not established standards for freshwater sediment quality. For the purposes of this report, lake sediment data are evaluated based on comparisons to the following sediment quality guidelines or criteria.

Ontario Ministry of the Environment Guidelines

Sediment quality guidelines have been established by the Ontario Ministry of the Environment to protect bottom-dwelling (i.e., benthic) organisms (Persaud et al. 1993). The following three threshold levels are defined:

- No-effect level—the concentration at which no toxic effects have been observed in aquatic organisms
- Lowest-effect level—the concentration at which the majority of benthic organisms are unaffected
- Severe-effect level—the concentration at which pronounced disturbance of the sediment-dwelling community can be expected.

National Oceanic and Atmospheric Administration Guidelines

These freshwater sediment quality guidelines are based on a compilation of sediment chemistry and biological effects in freshwater sediments and were developed as a preliminary screening tool for evaluating sediment quality (NOAA 1999). The guidelines establish the following three threshold levels:

- Threshold effects level (TEL)—the concentration at which adverse effects are expected to occur only rarely. The TEL is calculated as the geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set.
- Probable effects level (PEL)—the concentration at which adverse effects are frequently expected. The PEL is calculated as the geometric mean of the 50th percentile concentration of the toxic effects data set and the 85th percentile of the no-effect data set.
- Upper effects threshold (UET)—the concentration at which adverse effects would always occur based on the lowest adverse effect threshold (AET) from a compilation of endpoints analogous to the marine AET endpoints. The UET is based on 1 percent total organic carbon content in the sediment.

Consensus-Based Standards

Consensus-based standards for freshwater sediment have been developed by MacDonald et al. (2000). These guidelines establish two threshold levels:

- Threshold effects concentration (TEC)—the concentration below which adverse effects are not expected to occur
- Probable effects concentration (PEC)—the concentration above which adverse effects are expected to occur more often than not, based on a compilation of available sediment quality guidelines reported in the literature.

The TEC and PEC are calculated as the geometric mean of all the values assigned to each threshold classification.

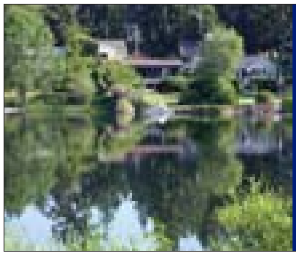
Washington State Proposed Criteria

The Department of Ecology has evaluated freshwater sediment quality criteria using the probable apparent effects threshold (PAET, calculated as the 95th percentile of stations exhibiting no biological effects based on the Microtox bioassay) for organic compounds, and the marine sediment management standards for metals (Cubbage et al. 1997). Although much progress has been made in evaluating AET values calculated using the updated freshwater sediment data, Ecology has not yet developed freshwater sediment standards (Avocet 2003). For the purposes of this report, the 1997 interim freshwater sediment quality values are used to evaluate sediment data for Seattle-area receiving water bodies.

Habitat Assessment Methods

Seattle lake habitat and fish use information was gathered from existing reports, brief visual surveys of the lake shorelines, and Washington Department of Fish and Wildlife fish stocking records. Overall, little of the needed habitat information is available for Seattle's small lakes.

Historically, when these small lakes had surface stream connections with larger lakes, fish such as stickleback, minnows, chub, suckers, and trout were common inhabitants.



State of the Waters 2007

Part 4 Conditions in Seattle's Small Lakes

Near-shore and riparian habitat within the small lakes of Seattle have not been intensively studied. Water and sediment quality studies are limited, focusing on those conditions relevant for swimming, boating, and wading. Therefore, unlike the assessment of watercourse conditions in Volume I, this report (Volume II) summarizes the existing information but does not provide maps of habitat and water quality conditions.

Bitter Lake

Bitter Lake is an 18.4-acre lake in north-central Seattle, bordered by Linden Avenue North, North 130th Street, North 137th Street, and Greenwood Avenue North (Figure 4). The lake, which was created by glaciation, today has a mean depth of 16 feet and a maximum depth of 31 feet. Early in Seattle history, a sawmill was located on the lake (Fiset 2001a). Tannic acid from logs stored in the lake gave its water a bitter taste, hence the name Bitter Lake. Current land use in the basin is a mixture of single-family and multifamily residential development. Multifamily properties are concentrated primarily along the main transportation corridors, along Linden Avenue North and Greenwood Avenue North.

Bitter Lake (photo by Bennett)

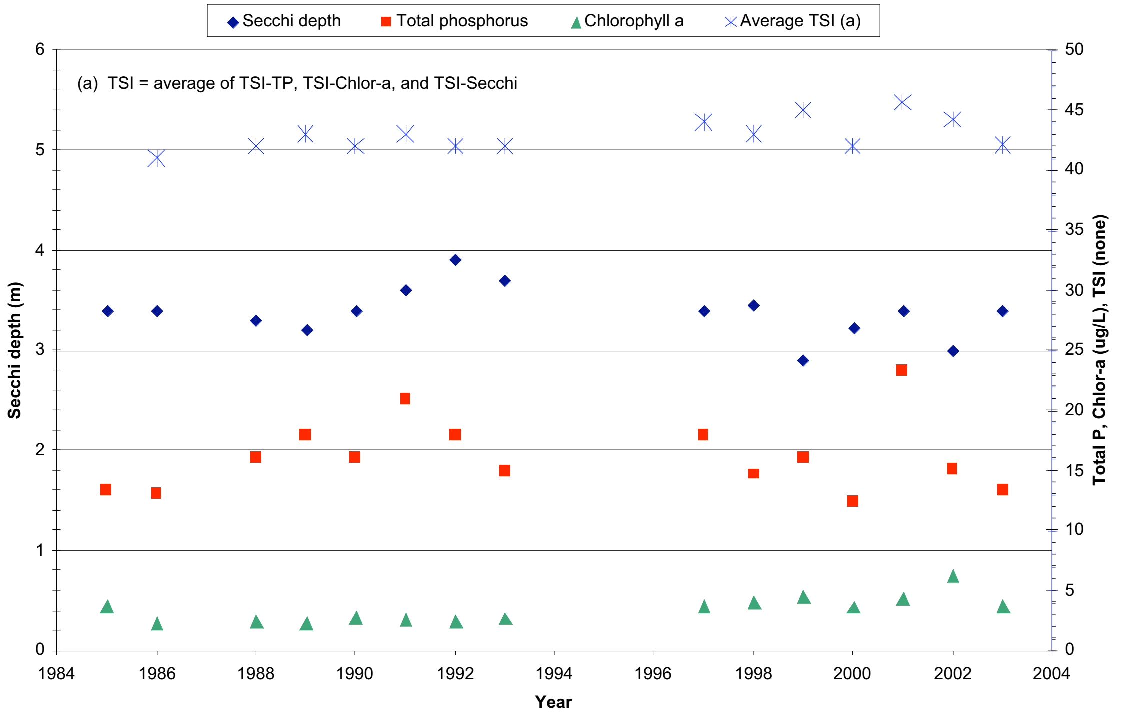
Figure 4. Bitter Lake.

Surface water runoff from the approximately 159-acre basin is the primary source of inflow to Bitter Lake. In the past, seepage losses from the Bitter Lake drinking water reservoir also discharged to Bitter Lake. However, this source of inflow was eliminated in 2001 when the reservoir was lined and covered. Currently, discharge from the reservoir to Bitter Lake occurs only when the reservoir is drained for cleaning and maintenance purposes, approximately once every 5 to 10 years.

At its southeastern end, Bitter Lake drains through a piped outlet that runs through a series of small ditches and culverts before entering the Densmore storm drain system on Aurora Avenue North. The Densmore system is equipped with a low-flow bypass, which conveys runoff directly to Lake Union. Under high-flow conditions, runoff passes through Green Lake before discharging to Lake Union.

Water and Sediment Quality Conditions

Bitter Lake is considered a moderately productive (or mesotrophic) lake with relatively good water quality (King County 2001a). Volunteers for the King County small lakes program have monitored water quality in Bitter Lake since 1985. Water samples are collected twice each month from May through October. King County monitoring results for 1985–2003 are displayed in Figure 5.



Reference: King County (1999a, 2001a, 2001b, 2002a, 2002b, 2003, 2005).
Note: Secchi depth is a measure of water clarity. The higher the value, the better the water clarity.

Figure 5. Bitter Lake water quality monitoring data summary for 1985–2003.

Average water clarity (as measured visually by Secchi depth) generally ranges from about 3.2 to 3.4 meters, although high values of 3.6 to 3.9 meters were observed in 1991–1993.

Average total phosphorus concentrations in Bitter Lake have been below the recommended maximum of 20 micrograms per liter (μg/L) established by Ecology (WAC 173-201A) for lower mesotrophic lakes in all years monitored, with the exception of 1991 (average of 21 μg/L) and 2001 (average of 23 μg/L),

The average trophic state index for Bitter Lake over the 18-year monitoring period has also remained relatively constant (41 to 45.6) and well within the 40–50 range established for mesotrophic lakes.

One water sample collected on August 3, 1998 contained 110 colony-forming units per 100 milliliters (cfu/100 mL) of fecal coliform bacteria (King County 1999a). This concentration exceeds the state water quality standard for extraordinary primary contact recreation, established as a geometric mean of 50 cfu/100 mL, with no more than 10 percent (or any single sample when less than 10 sample points exist) exceeding 100 cfu/100 mL. No other bacteria data are available.

The Seattle Lakes Alliance (2000) collected one water sample from each of eight locations in Bitter Lake during a storm event on February 5, 2000. The samples were collected immediately offshore of the four major storm drain outfalls (two public outfalls and two private ones), as well as from four swimming areas in the lake (stations SW1–SW8; Figure 4). In addition, lake sediment samples were collected from the top 6 inches of sediment offshore of the four storm drain outfalls. Samples were collected within 5 feet of the end of the outfall pipe. Water and sediment samples were analyzed for total metals, volatile and semivolatile organic compounds, polychlorinated biphenyls (PCBs), and total petroleum hydrocarbons.

Arsenic, chromium, copper, lead, and zinc were detected in the water samples collected from Bitter Lake. Antimony, beryllium, cadmium, mercury, selenium, and silver were not detected in any of the seven samples analyzed.

State water quality standards are based on dissolved metals concentrations and are dependent on the hardness level in the water column (with the exception that the arsenic standard is not dependent on water hardness). Although dissolved metals and hardness were not analyzed, it is possible to compare Bitter Lake sample results to state standards based on a reasonable assumption for hardness and application of a conversion factor to adjust the standards to a total metals concentration rather than a dissolved metals concentration.

State standards were not exceeded for the detected metals in any of the water samples, assuming a typical hardness of 20 milligrams per liter (mg/L) for lakes in the Puget Sound lowlands, and comparison to acute toxicity criteria (i.e., one-hour average for storm conditions) for total metals (using a conversion factor of 1.0).

As shown in Table 5, the in-lake metals concentrations were relatively low compared to levels typically observed in urban stormwater runoff. The highest concentrations of chromium, copper, lead, and zinc were measured in the water sample collected offshore of the largest storm drain outfall (SW-1), which discharges into the northwestern corner of Bitter Lake near Greenwood Avenue North and North 137th Street. Metals concentrations in the other samples were fairly comparable, ranging within ±15 percent of the mean concentration.

Table 5. Bitter Lake metals concentrations sampled during a storm event compared to human health risk criteria.

Total Metals (µg/L)	Number of Detections	Bitter Lake Samples [a]	Urban Runoff [b,d]	U.S. EPA Human Health Risk Criteria [c]	
				Water and Tissue	Tissue Only
Arsenic	7/7	1.04–1.1	NA	0.018	0.018
Chromium	7/7	0.185–0.38	<1.94–20	NA	NA
Copper	7/7	2.12–2.69	<1–8.1	1,300	NA
Lead	6/7	<1–4.78	<1–17.5	NA	NA
Zinc	7/7	13.9–16.1	19–40	9,100	69,000

µg/L = micrograms per liter.

[a] Sample SW-4 was not analyzed for metals.

[b] Ranges in average concentrations from stormwater sampling conducted in Madison, Milwaukee, and Superior, WI and Marquette, MI (Pitt et. al. 2004).

[c] U.S. EPA (2002).

[d] Copper, lead, and zinc ranges are for four stormwater samples collected from two drains discharging to Bitter Lake and Haller Lake (Seattle University 2001, 2002).

Arsenic concentrations in Bitter Lake water samples exceeded the U.S. EPA risk criteria for human health based on fish and water consumption. Risk is calculated based on consumption of 6.5 grams per day of fish and 2 liters per day of water. However, Bitter Lake is not used for drinking water, and the extent to which residents consume fish caught in Bitter Lake is unknown.

Metal pollutants accumulate on impervious surfaces in urban watersheds and are washed off during storms. In addition, some metals are bound to sediments; so as storm flows entrain soil and sediment, metals are more easily transported to lakes. Sources of metal pollutants include wear and tear of vehicle parts (e.g., brake pads, tires, rust, and engine parts), atmospheric deposition, common building materials (e.g., galvanized flashing, metal downspouts), and roof maintenance activities (e.g., moss control).

Naphthalene, bis(2-ethylhexyl)phthalate, and heptachlor are the only organic compounds detected in Bitter Lake water samples. Concentrations were low, generally near or at the reporting limit. Naphthalene and bis(2-ethylhexyl)phthalate results are qualified as estimated values because these chemicals were also found in the method or equipment blank samples. Sample results are summarized in Table 6.

Table 6. Bitter Lake organic compounds detected in stormwater samples.

Compound (µg/L)	Number of Detections	Bitter Lake Samples
Naphthalene [a]	6/8	<0.1–0.138
Bis(2-ethylhexyl)phthalate [b]	2/8	<50–13.3
Heptachlor	1/8	<0.03–0.0187

[a] Detected in method blank

[b] Detected in the equipment blank at 18.4 micrograms per liter (µg/L).

Metals and organic compounds detected in sediment samples collected offshore of the four major outfalls to Bitter Lake in 2000 are summarized in Tables 7 and 8 (Seattle Lakes Alliance 2000). Because the state has not established standards for freshwater sediment quality, freshwater sediment guidelines or criteria from other jurisdictions, along with the Department of Ecology's 1997 proposed freshwater sediment quality values, are used in this report to evaluate the Bitter Lake sediment data.

Table 7. Bitter Lake sediment metals concentrations compared to freshwater sediment guidelines.

	Bitter Lake		Consensus-Based Guidelines [a]		Ecology Sediment Quality Values [b]	Ontario [c]		NOAA [d]			
Compound Units = mg/kg	**Number of Detections**	**Range**	**TEC**	**PEC**	**FSQV**	**LOEL**	**SEL**	**TEL**	**PEL**	**UET**	**Test org**
Arsenic	4/4	1.95–.79	9.79	33	57	6	33	5.9	17	17	I
Cadmium	4/4	2.05–5.98	0.99	4.98	5.1	0.6	10	0.596	3.53	3	I
Chromium	4/4	20.1–43.8	43.4	111	260	26	110	37.3	90	95	H
Copper	4/4	14.1–81.4	31.6	149	390	16	110	35.7	197	86	I
Lead	4/4	7.74–255	35.8	128	450	31	250	35	91.3	127	H
Mercury	4/4	0.036–0.193	0.18	1.06	0.41	0.2	2	0.174	0.486	0.56	M
Selenium	2/4	0.206–0.438	NA	NA	NA	NA	NA	NA	NA	NA	M
Silver	2/4	<0.5–0.0536	NA	NA	6.1	NA	NA	NA	NA	4.5	I
Zinc	4/4	63.4–401	121	459	410	120	820	123.1	315	520	I

[a] MacDonald et. al. (2000)
[b] Cubbage et al. (1997)
[c] Persaud et. al. (1993)
[d] NOAA (1999).
mg/kg = milligrams per kilogram
FSQV: freshwater sediment quality value
TEC: threshold effect concentration
PEC: probable effect concentration
LOEL: lowest observed effect level
SEL: severe effect level
TEL: threshold effect level or concentration below which adverse effects are expected to occur only rarely. Geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set.
PEL: probable effects level, the level above which adverse effects are frequently expected. Geometric mean of the 50th percentile of impacted, toxic samples and the 85th percentile of the non-impacted samples.
UET: Upper effects concentration derived as the lowest adverse effects threshold (AET) from a compilation of endpoints analogous to the marine AET endpoints.
M = Microtox bioassay
I = Infaunal community impacts
H = Hyalella azteca bioassay

Table 8. Bitter Lake sediment organic compounds concentrations compared to freshwater sediment guidelines.

	Bitter Lake			Consensus-Based Guidelines [a]		Ecology Sediment Quality Values [b]	Ontario [c]		NOAA [d]			
Compound	Number of Detections	Range [e] (µg/kg)	Range (mg/kg OC)	TEC (µg/kg)	PEC (µg/kg)	FSQV (µg/kg)	LOEL (µg/kg)	SEL (mg/kg OC)	TEL (µg/kg)	PEL (µg/kg)	UET (µg/kg)	Test org
LPAH												
Anthracene	1	672	NA	57.2	845	2,100	220	370	NA	NA	260	M
Phenanthrene	1	1,790	NA	204	1,170	5,700	560	950	41.9	515	800	I
HPAH												
Benzo(a)anthracene	1	1,340	NA	108	1,050	5,000	320	1,480	NA	NA	NA	
Benzo(a)pyrene	1	1,570	NA	150	1,450	7,000	370	1,440	31.9	782	700	I
Benzo(b)fluoranthene	1	2,130	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Benzo(k)fluoranthene	1	672	NA	NA	NA	NA	240	1,340	NA	NA	13,400	B
Benzo(b+k)fluoranthene	1	2,802	NA	NA	NA	11,000	NA	NA	NA	NA	13,400	
Benzo(g,h,i)perylene	1	1,570	NA	NA	NA	1,200	170	320	NA	NA	300	M
Fluoranthene	1	3,030	NA	423	2,230	11,000	750	1,020	111	2,355	1,500	M
Pyrene	1	3,250	NA	195	1,520	9,600	490	850	53	875	1,000	I
Phthalates												
Bis(2-ethylhexyl)phthalate	1	16,700	NA	NA	NA	640	NA	NA	NA	NA	750	M
Petroleum hydrocarbons												
Diesel	4/4	10.9–4,750	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Motor oil	3/4	144–9,840	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Reference: Seattle Lakes Alliance (2000).
NA = Not available
[a] MacDonald et. al. (2000)
[b] Cubbage et al. (1997)
[c] Persaud et. al. (1993)
[d] NOAA (1999).
[e] Detection limits varied from 20 µg/kg to as high as 16,800 µg/kg, depending on sample matrix.
TEC: threshold effect concentration
PEC: probable effect concentration
LOEL: lowest observed effect level
SEL: severe effect level
TEL: threshold effect level or concentration below which adverse effects are expected to occur only rarely. Geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set.
PEL: probable effects level, the level above which adverse effects are frequently expected. Geometric mean of the 50th percentile of impacted, toxic samples and the 85th percentile of the non-impacted samples.
UET: Upper effects concentration derived as the lowest adverse effects threshold (AET) on 1% TOC basis from a compilation of endpoints analogous to the marine AET endpoints.
M = Microtox bioassay
I = Infaunal community impacts
B = Bivalve

mg/kg = milligrams per kilogram
µg/kg = micrograms per kilogram
OC = organic carbon
FSQV = freshwater sediment quality value
LPAH = low molecular weight polynuclear aeromatic hydrocarbon
HPAH = high molecular weight polynuclear aeromatic hydrocarbon

With the exception of cadmium, metals concentrations in Bitter Lake sediment samples were well below Ecology's proposed freshwater sediment values. Cadmium (5.98 milligrams per kilogram [mg/kg]) exceeded the freshwater sediment quality value of 4.98 mg/kg at one of the four stations (SED-1 located offshore of the Greenwood Avenue North storm drain outfall). All of the metals except silver exceeded the freshwater sediment guidelines established by other jurisdictions. Arsenic, cadmium, chromium, copper, and mercury exceeded one or more of the lower-effects levels (i.e., the TEC, TEL, or LOEL), the concentrations below which biological effects are unlikely to occur. Cadmium, lead, and zinc exceeded an upper-effects level (i.e., the PEC, PEL, or SEL), the concentration above which biological effects are probable. With the exception of copper, all exceedances occurred at station SED-1. Copper concentrations also exceeded the lower-effects level at stations SED-2 and SED-3. Copper and zinc are common pollutants in urban runoff. Both are used in automobiles (e.g., brake pads, tires, and engine parts). Zinc is also found in galvanized products often used as building materials (e.g., flashing, downspouts, and fencing), pipes (e.g., corrugated metal pipe used in many storm drains), and some products used to control moss growth on roofs and other surfaces.

Volatile organic compounds, PCBs, and pesticides were undetected at all of the sediment sampling stations in Bitter Lake, at detection limits ranging from 1 to 8,570 micrograms per kilogram (µg/kg). Polycyclic aromatic hydrocarbons (PAHs) and bis(2-ethylhexyl)phthalate were detected only at station SED1-1. However, because the samples were diluted prior to analysis, analytical detection limits for these semivolatile organic compounds were quite high, ranging from 1,680 to 84,000 µg/kg.

At station SED-1, benzo(g,h,i)perylene was detected at 1,570 µg/kg, and bis(2-ethylhexyl)phthalate was detected at 16,700 µg/kg, exceeding Ecology's proposed freshwater sediment quality values of 1,200 and 640 µg/kg, respectively. Although it is difficult to evaluate the sediment data due to the high analytical detection limits, it appears that discharges from the Greenwood Avenue North storm drain have degraded sediment quality directly offshore of the outfall. Further evaluation is needed after Ecology develops freshwater sediment standards for Washington state.

Bis(2-ethylhexyl)phthalate has been detected in Seattle watercourses as well. Phthalates belong to a class of chemicals known as plasticizers that are used in the production of many polyvinyl chloride (PVC) construction and consumer products. Plasticizers have been used for a long time but have recently become an environmental concern because they have been found at elevated concentrations in sediment in urban receiving water bodies. Phthalates are used to make a wide variety of plastic products such as flexible tubing, vinyl flooring, wire insulation, weather-stripping, upholstery, clothing, plastic containers, and plastic wraps.

Diesel oil was detected in all four sediment samples tested (from 10.9 to 4,750 mg/kg), and motor oil was detected (from <25 to 9,840 mg/kg) in three of the four samples collected offshore of the storm drain outfalls. The samples collected offshore of the outfall at Greenwood Avenue North and North 137th Street (i.e., station SED-1) exceeded the Model Toxics Control Act (MTCA) Method A soil cleanup level for total petroleum hydrocarbons (i.e., 2,000 mg/kg). Total petroleum hydrocarbons detected in sediment samples collected at the other three stations (from <25 to 245 mg/kg) were well below the state soil cleanup levels. Although MTCA soil cleanup levels are not directly applicable to lake sediment samples, those values provide an indication of lake sediment quality.

Residents living along the Bitter Lake shoreline have complained to Seattle Public Utilities about the accumulation of sediment in the northwestern corner of the lake in the vicinity of the Greenwood Avenue North storm drain outfall. In 2001, SPU crews removed about 8 cubic yards of sediment from around the outfall. Total petroleum hydrocarbon concentrations were measured in two samples of the dredged sediment (diesel oil was detected at 80 mg/kg, and motor oil was measured at 1,500 to 2,700 mg/kg). These concentrations were lower than the concentrations measured near the outfall at station SED-1 by the Seattle Lakes Alliance study (i.e., diesel oil at 4,750 mg/kg and motor oil at 9,840 mg/kg), although one dredge sample exceeded the MTCA Method A soil cleanup level of 2,000 mg/kg.

A potential source of these pollutants is stormwater runoff. In urban areas, stormwater runoff can have elevated levels of pollutants typically associated with motor vehicles, including oil and grease, total petroleum hydrocarbons, and metals.

Habitat Conditions

The habitat of Bitter Lake has not been well studied, although the water quality studies indicate that the lake is moderately productive and therefore able to support a variety of fish and wildlife species. The Washington Department of Fish and Wildlife has stocked the lake with rainbow trout and warm-water fish species such as large-mouth bass, yellow perch, black crappie, pumpkinseed, and brown bullhead (WDFW 2005a, 2005b). The lake is also used by ducks and geese. The habitat along the lake shoreline consists primarily of landscaped yards (grass and shrubs) and a park, with a number of residential docks. The lake also contains some aquatic plant species.

Geese along Bitter Lake shoreline (photo by Bennett)

Green Lake

Green Lake circa 1936 (photo courtesy Seattle Municipal Archives)

Green Lake, located north of Lake Union between Aurora Avenue North and East Green Lake Way, covers approximately 259 acres (Figure 6). The lake is relatively shallow, with a mean depth of about 13 feet and a maximum depth of approximately 30 feet. Similar to other lakes in the area, Green Lake was formed by the Vashon glacial ice sheet about 50,000 years ago. Early in Seattle history, the lake was fed by springs and streams in surrounding forests to the north, and water exiting the lake via Ravenna Creek ultimately reached Union Bay in Lake Washington.

Today, the major sources of water in Green Lake are rainfall, direct stormwater runoff from lands immediately adjacent to the lake (including Phinney Ridge and Woodland Park), and overflows from the Densmore Avenue storm drain system. Green Lake now discharges to Lake Union through a single outlet located near Meridian Avenue North. In the past, Green Lake also discharged to the combined sewer system via a number of outlets around the lake. However, these outlets were recently blocked and now are used by Seattle Parks and Recreation only during rainstorms of long duration when the Meridian Avenue North outlet is not adequate to maintain water levels in Green Lake.

Green Lake was once larger than it is today, but in 1911 the lake level was lowered by 6 feet and portions of the lake were filled (Sherwood, undated; Fiset 2000). Since that time, the lake has been subject to additional filling and dredging, as well as shoreline modifications including a paved public footpath around the lake perimeter. Today the lake is contained in a 324-acre public park, surrounded primarily by residential and commercial (retail) land uses.

Since about 1980, large-scale invasions of exotic plants and animals such as watermilfoil and carp have been observed, and in some cases authorized, in Green Lake. In 1992 Seattle Parks and Recreation purchased an aquatic plant harvester to manage watermilfoil in the lake. The department also initiated a waterfowl reduction program as a way to reduce fecal coliform bacteria levels from geese.

In the early 1960s, Seattle Public Utilities began diverting water to Green Lake from the city drinking water system in an effort to improve algae problems that have existed in the lake since at least 1916 (Herrera 2003a). In this way the lake was diluted at an average annual discharge rate ranging from 1.9 to 6.1 million gallons per day (Herrera 2003b). However, due to increased drinking water demand, the availability of water to dilute Green Lake has decreased. Between 1992 and 1994, the average daily diversion from April through September was generally less than 1 million gallons per day. In recent years, dilution water discharges to Green Lake typically occur only once or twice each year, when the Roosevelt and Maple Leaf reservoirs are emptied for cleaning. Over a 48-day period during the summer of 2002, approximately 200 million gallons was discharged to Green Lake in an attempt to control a large blue-green algae bloom.

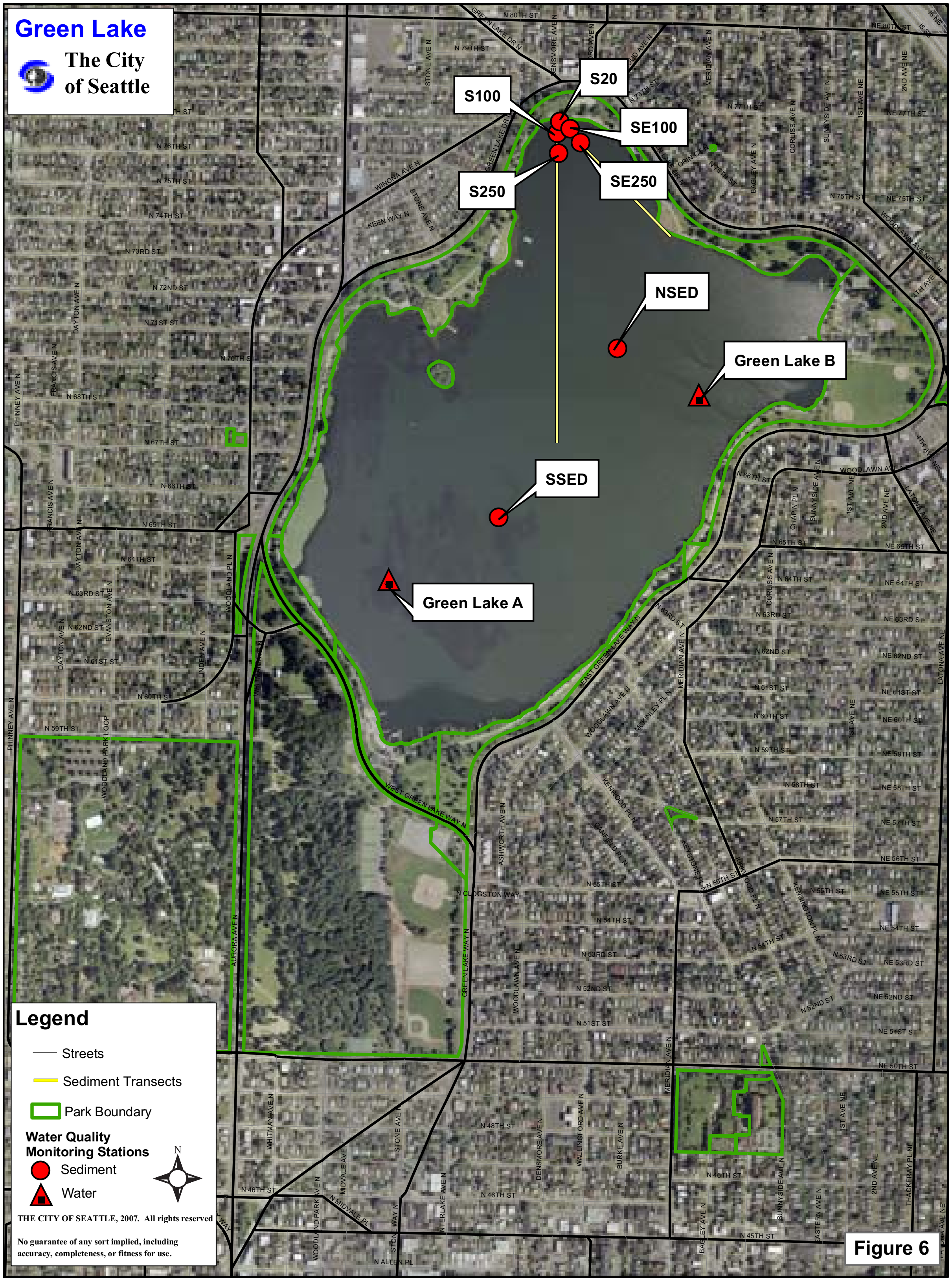


Figure 6. Green Lake.

Water Quality Conditions

City of Seattle water quality volunteer monitoring on Green Lake (photo by Bennett)

Green Lake is a shallow, highly productive (i.e., eutrophic) lake with high concentrations of nutrients such as nitrogen and phosphorus that promote plant and algae growth. Green Lake water quality data have been collected by a series of agencies, including Seattle Parks and Recreation, Seattle Public Utilities, Seattle University, King County, and the Washington Department of Fish and Wildlife. Water quality investigations have focused on the lake's production of blue-green bacteria (also commonly called blue-green algae or cyanobacteria) and the human health risks caused by the toxic compound microcystin, which is produced by the algae (Herrera 2003a).

Green Lake has a long history of algae problems. Physical and chemical processes within the lake, as well as drainage to the lake from the surrounding watershed, supply the nutrients that support the blue-green algae blooms. Phosphorus is the main nutrient causing the problem (Herrera 2003a). The Department of Ecology included Green Lake on the 2004 list of threatened and impaired water bodies under Clean Water Act Section 303(d), listing the lake as a category 5 water body (Ecology 2004). Accordingly, a total maximum daily load (TMDL) limit is required for Green Lake based on demonstrated exceedances of the state water quality standard for total phosphorus.

Previous studies have found that most of the phosphorus in Green Lake during the summer months can be attributed to the internal cycling of phosphorus stored in sediment on the lake bottom. The movement of blue-green algae from the sediment to the water column has also been identified as a significant source of internal phosphorus loading.

To control blue-green algae blooms in Green Lake, Seattle Parks and Recreation, with funding assistance from Ecology and the U.S. EPA, has adopted a program to improve the lake water quality, aimed at reducing phosphorus concentrations and increasing water clarity during the summer months (Herrera 2003b). Controlling the blooms reduces production of microcystin and eliminates the need for periodic closure of the lake to recreational users. The cornerstone of the project is the application of aluminum sulfate (i.e., alum) to inactivate phosphorus in the sediment, thereby reducing internal phosphorus loading and availability to blue-green bacteria.

Green Lake was treated with alum in October 1991. Following the treatment, phosphorus concentrations dropped and water clarity improved, effectively reducing the numbers of algae living in the lake. However, the treatment effects do not last indefinitely; treatment was expected to remain effective for about 5 to 8 years. In the summers of 1999, 2002, and 2003, blooms of blue-green algae again became problematic. During these blooms, potentially toxic levels of microcystin were produced, and the lake was closed to all contact recreation (Herrera 2003a). In March 2004 the city treated the lake with alum again, applying nearly three times the amount applied in 1991.

Other elements of the Green Lake water quality improvement program include the following:

- Harvesting of aquatic plants from 1992 to 2003 to reduce phosphorus loading associated with biomass die-off in the lake and improve recreational use (Herrera 2003b)
- Installation of experimental facilities in 1992 to treat stormwater runoff from parking lots along West Green Lake Way
- Construction of a low-flow diversion structure on the Densmore storm drain system in 1995 to divert some of the runoff from a 1,000-acre subbasin north of Green Lake away from the lake. The structure diverts the lower flows (from small storms and portions of larger storm events) to Lake Union, while only the peak flows from high-intensity storms are routed through Green Lake. The diversion structure is intended to divert the most polluted runoff from smaller storms, as well as early portions (e.g., first flush) of larger storms, away from the lake.
- Discharge of excess drinking water from the city water system to dilute phosphorus concentrations in the lake. In the past, SPU provided dilution water for Green Lake at no cost. However, due to increased drinking water demands, the long-term availability of dilution water is uncertain, and Seattle Parks and Recreation may be charged for this water.
- Relocation of Canada geese from Green Lake to wildlife areas in eastern Washington and northern Idaho, along with an egg sterilization program to control the resident goose population. Euthanasia has also been used to control Canada geese at Green Lake in recent years.
- Implementation of a public information program for Green Lake residents and park users.

Water quality data collected from May through September 2005, during the second summer following the 2004 alum treatment, are summarized in Table 9. Samples were collected from three stations, including one depth composite sample collected from two stations (stations Green Lake A and B) by Seattle Parks and Recreation, and one surface grab sample collected from station Green Lake B by the King County volunteer monitoring program. The sampling results show improved water quality, with water clarity, chlorophyll, and phosphorus levels comparable to levels measured in Bitter Lake and Haller Lake, which—unlike Green Lake—are classified as mesotrophic.

Table 9. Green Lake water quality data for May–September 2005.

Parameter	n	Minimum	Maximum	Average
Temperature (degrees C) [a]	38	16.3	23.1	19.9
Dissolved oxygen(mg/L) [a]	38	7.5	10.3	9.2
Secchi depth (meters) [b,c]	30	1.3	5.6	3.3
Chlorophyll-a (µg/L) [c]	28	1.5	6.2	2.7
Total phosphorus (µg/L) [c]	30	8	20	12.9
Average TSI [c]		35.2	50.1	41.2

[a] Samples collected at 1-meter depth intervals (to 7-meter depth) from Green Lake B (May – August 2005).
[b] Secchi depth is a measure of water clarity. The higher the value, the better the water clarity.
[c] Samples collected from stations A, B, and Index stations (May – September 2005).
mg/L = milligrams per liter
µg/L = micrograms per liter
TSI = trophic state index

The 2005 results met the water quality goals established by the improvement program, which included a summer mean Secchi depth of greater than 2.5 meters for clarity, and a summer mean total phosphorus concentration of less than 25 µg/L. All of the 2005 samples met the recommended level for total phosphorus established by Ecology (WAC 173-201A) for lower mesotrophic lakes (20 µg/L).

In addition to the water quality improvement program, SPU has completed a stormwater management plan for the Densmore drainage basin, the largest single basin in the larger Green Lake watershed. A water quality investigation is also being conducted as part of a basin planning effort to identify water quality needs in the Densmore basin and evaluate options for mitigating potential impacts of proposed drainage improvements. This study includes modeling of phosphorus loading in Green Lake under existing and proposed conditions to determine possible impacts on water quality in the lake. In 2001–2002, the city's surface water quality team inspected individual business sites in the Densmore basin to ensure that local businesses were complying with the city stormwater, grading, and drainage code and to advise business owners of appropriate stormwater pollution prevention practices.

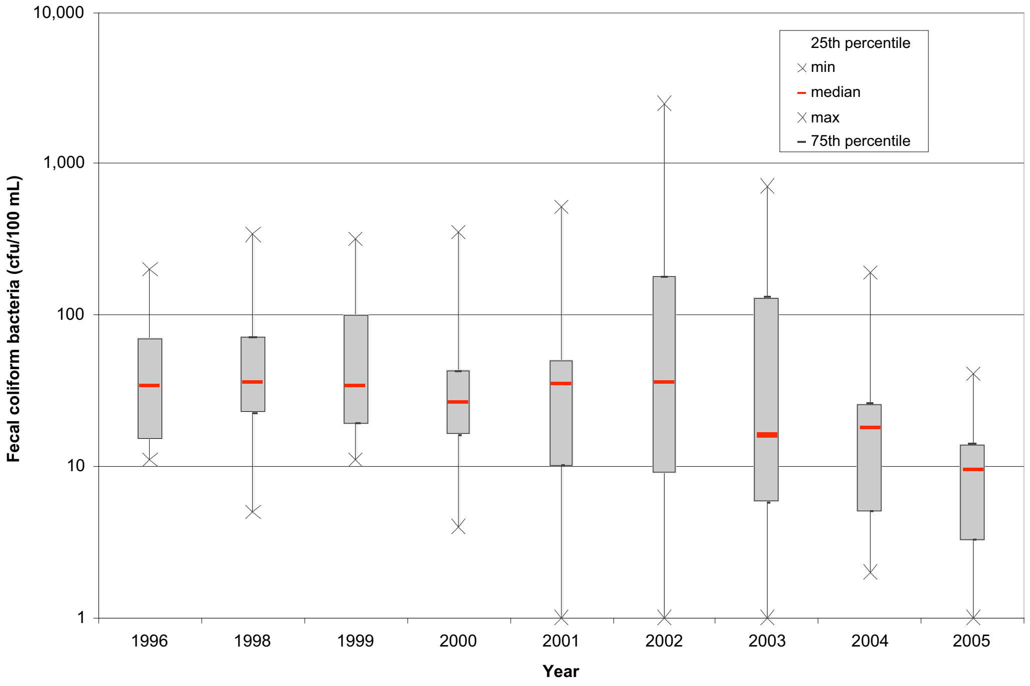
Green Lake also experiences a number of other water quality problems. The Department of Ecology included Green Lake on the 2004 list of threatened and impaired water bodies under Clean Water Act Section 303(d), listing the lake as a category 5 water body (with TMDL limits required based on demonstrated exceedances of state water quality standards) for fecal coliform bacteria, as well as for 4,4'-DDE, chlordane, and total PCBs, which were found in tissue samples of common carp collected in 2001 (Ecology 2004). Another problem for recreational use is the occurrence of swimmer's itch. Swimmer's itch, caused by an allergic reaction to aquatic parasites, can be a problem for people who swim in the lake (Seattle Parks and Recreation, undated).

King County monitors fecal coliform bacteria levels at swimming beaches throughout the county each week during the summer months. Results for the 1996–2005 monitoring period in Green Lake are summarized in Table 10 and displayed in Figure 7. Fecal coliform bacteria levels were generally lower in 2004 and 2005 than in previous years, possibly due to the alum treatment in March 2004. The reduced lake productivity may have reduced the amount of coliform bacteria that commonly grow in decaying organic matter and test positive for fecal coliform bacteria (e.g., Klebsiella), and it may have reduced the abundance of waterfowl that feed on algae and aquatic plants. Water quality in Green Lake consistently met the geometric mean portion of the state water quality standard for lakes (a geometric mean of 50 cfu/100 mL) in all years, but met the 100 cfu/100 mL requirement (no more than 10 percent of all samples used to calculate the geometric mean exceeding 100 cfu/100 mL) in only five of the ten monitoring years.

Table 10. Green Lake summer fecal coliform bacteria levels, 1996–2005.

	All Samples	Summer Geometric Mean
Minimum (cfu/100 mL)	1	6.6
Maximum (cfu/100 mL)	2,500	47
Median (cfu/100 mL)	23	28
Mean (cfu/100 mL)	87	29
Number of samples	174	9

cfu/100 mL = colony-forming units per 100 milliliters.



Source: King County

Figure 7. Green Lake summer fecal coliform bacteria levels, 1996–2005.

No water quality standards for swimming beaches have been established as a basis for determining when to close beaches to protect public health. The Washington Department of Health has recommended using one of the following two fecal coliform bacteria standards to evaluate public health conditions at swimming beaches:

- Geometric mean of 200 cfu/100 mL with not more than 10 percent of the samples exceeding 400 cfu/100 mL (U.S. EPA 1976)
- Geometric mean of 200 cfu/100 mL with no single sample exceeding 1,000 cfu/100 mL (ten-state standard, Great Lakes–Upper Mississippi River Board of State Sanitary Engineers 1990).

Over the 10-year period of record for Green Lake fecal coliform bacteria levels, the seasonal geometric mean has ranged from 7 to 47 cfu/100 mL. Only two samples (1 percent) have exceeded 1,000 cfu/100 mL, and four samples (2 percent) have exceeded 400 cfu/100 mL. A total of 13 samples (7 percent) have exceeded 200 cfu/100 mL. As stated earlier, the source of increased fecal coliform bacteria is likely the presence of waterfowl.

Green Lake data for 1997–1999 indicate that water temperatures in the lake ranged between 8 and 27°C, and dissolved oxygen levels ranged from 4 mg/L at the lake bottom to 12 mg/L at the lake surface. In 2002, anoxic conditions (i.e., 0 mg/L oxygen) were observed at the lake bottom. Extremely low oxygen levels near the bottom result from summer stratification, where a thermocline develops between the warm, well-oxygenated water near the surface and the cool, deeper water. As bacteria degrade the organic matter that has settled to the bottom, nearly all the oxygen can be consumed. Cooler air temperatures and increased wind activity in the fall cause the lake water to mix, disintegrating the thermocline and creating more uniform levels of oxygen and temperature throughout the lake.

As shown in Table 9, data from the second summer season following alum treatment exhibit similar patterns, with temperature ranging from 16.25 to 23.1°C and dissolved oxygen ranging from 7.5 to 10.3 mg/L. However, anoxic conditions did not occur during the 2005 monitoring period. As noted previously, changes in temperature and dissolved oxygen conditions directly affect habitat conditions and the health and vitality of lake biology.

Sediment Quality Conditions

In 2004, SPU collected sediment samples from seven locations offshore of the Densmore Avenue North storm drain outfall in Green Lake to evaluate possible impacts on sediment quality resulting from stormwater discharges (see Figure 6). Samples were analyzed for metals, semivolatile organic compounds, total petroleum hydrocarbons, and PCBs.

Metals were frequently detected at most of the Green Lake sediment sampling stations. Metals detected in Green Lake sediment samples are summarized in Table 11. Cadmium, chromium, lead, and zinc concentrations were higher at stations located 100 and 250 feet from the Densmore outfall (stations S100, S250, SE100, and SE250) than concentrations at the mid-lake stations (NSED and SSED) and the station located 20 feet from the outfall (S20). However, the highest copper concentration (163 mg/kg) was measured at mid-lake station NSED.

Table 11. Green Lake sediment metals concentrations compared to freshwater sediment guidelines.

	Green Lake Sediment Data		Consensus-Based Guidelines [a]		Ecology Sediment Quality Values [b]	Ontario [c]		NOAA [d]			
Compound (mg/kg)	**Number of Detections**	**Range**	**TEC**	**PEC**	**FSQV**	**LOEL**	**SEL**	**TEL**	**PEL**	**UET**	**Test Org**
Arsenic	5/7	8–30	9.79	33	57	6	33	5.9	17	17	I
Cadmium	4/7	<2–3	0.99	4.98	5.1	0.6	10	0.596	3.53	3	I
Chromium	7/7	19.4–64	43.4	111	260	26	110	37.3	90	95	H
Copper	7/7	31.8–163	31.6	149	390	16	110	35.7	197	86	I
Lead	7/7	68–713	35.8	128	450	31	250	35	91.3	127	H
Mercury	4/7	<0.06–0.4	0.18	1.06	0.41	0.2	2	0.174	0.486	0.56	M
Zinc	7/7	85.1–516	121	459	410	120	820	123.1	315	520	M

mg/kg = milligrams of compound per kilogram of sediment.

[a] MacDonald et al. (2000).

[b] Cubbage et al. (1997).

[c] Persaud et. al., (1993).

[d] NOAA (1999).

FSQV: freshwater sediment quality value.
TEC: threshold effect concentration.
PEC: probable effect concentration.
LOEL: lowest observed effect level.
SEL: severe effect level.
TEL: threshold effect level or concentration below which adverse effects are expected to occur only rarely. Geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set.
PEL: probable effects level, the level above which adverse effects are frequently expected. Geometric mean of the 50th percentile of impacted, toxic samples and the 85th percentile of the non-impacted samples.
UET: Upper effects concentration derived as the lowest adverse effects threshold (AET) from a compilation of endpoints analogous to the marine AET endpoints.
M = Microtox bioassay
I = Infaunal community impacts
H = Hyalella azteca bioassay

With the exception of lead and zinc, metals concentrations were below the 1997 Ecology proposed freshwater sediment quality values. However, at one or more stations in Green Lake, all metals exceeded the lower effects levels, the concentrations below which biological effects are unlikely to occur (i.e., TEC, TEL, or LOEL) established by other jurisdictions. Only copper, lead, and zinc exceeded upper effects levels (e.g., PEC, PEL, or SEL), the concentrations above which biological effects are probable. Stations exceeding Ecology freshwater quality values and the upper effects levels are listed in Table 12 (see Figure 6).

Table 12. Green Lake sampling stations with exceedances of freshwater sediment guidelines.

Station	Ecology Freshwater Sediment Quality Values	Upper Effects Level
NSED [b]	BEHP	Copper, lead, BEHP, chrysene, benzo(a)anthracene
SSED [b]	None	Copper, lead
S20 [a]	None	None
S100	Lead, zinc, BEHP benzo(g,h,i)perylene, dibenz(a,h,)anthracene, indeno(1,2,3-c,d)pyrene	Copper, lead, zinc, DDD, BEHP, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(g,h,i)perylene, chrysene, chlordane, dibenz(a,h,)anthracene, indeno(1,2,3-c,d)pyrene
S250	Lead, mercury	Copper, lead, zinc, DDD, chlordane,
SE100	BEHP, carbazole, benzo(g,h,i)perylene, dibenz(a,h)anthracene, indeno(1,2,3-c,d)pyrene	Lead, zinc, DDD, BEHP, dieldrin, benzo(g,h,i)perylene, chrysene, benzo(a)anthracene, benzo(a)pyrene, dibenz(a,h)anthracene, chlordane, lindane, indeno(1,2,3-c,d)pyrene
SE250	Lead, BEHP, Aroclor 1260	Copper, lead, zinc, DDD, DDE, BEHP, chlordane, Aroclor 1260

BEHP = bis(2-ethylhexyl)phthalate.

[a] Station S20, located near the Densmore outfall, contained mostly coarse-grained material (70 percent coarse sand and gravel).

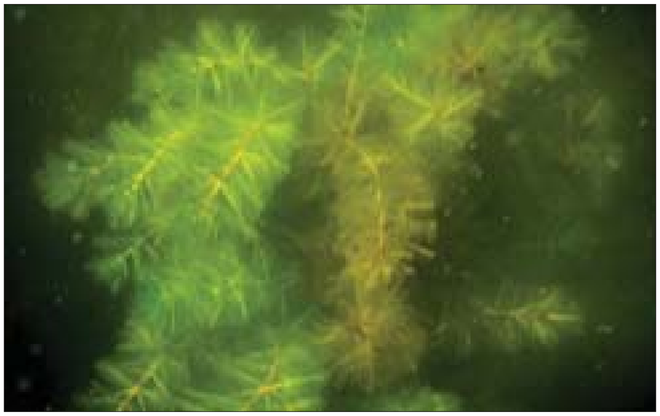
[b] Stations NSED and SSED, located near the center of Green Lake, contained a large amount of fine-grained material (50–56 percent fine silt and clay) and a low amount of total solids (7.7–8.5 percent).

Organic compounds were detected infrequently at the Green Lake sediment sampling stations. Organic compounds detected include polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPH), phthalates (plasticizers), pesticides (DDT and its breakdown products aldrin, dieldrin, gamma chlordane, lindane, and heptachlor), and PCBs (Aroclor 1260). Organic compounds detected in Green Lake sediment are listed in Table 13, and exceedances of available freshwater sediment guidelines are summarized in Table 12. Chemicals exceeding the draft Ecology freshwater quality values included benzo(g,h,i)perylene, carbazole, dibenz(a,h)anthracene, indeno(1,2,3-c,d)pyrene, and bis(2-ethylhexyl) phthalate (BEHP). BEHP exceedances occurred at four of the seven stations (NSED, S100, SE100, and SE250), while HPAH exceedances occurred only at stations S100 and SE100.

Concentrations of pesticides and high and low molecular weight polycyclic aromatic hydrocarbons (HPAH and LPAH) also exceeded the upper effects levels established by other jurisdictions at multiple stations in Green Lake, indicating a strong potential for biological effects. PCBs (Aroclor 1260) exceeded the NOAA upper effects threshold at station SE250. Further evaluation should be conducted when Ecology develops its freshwater sediment management standards.

Habitat Conditions

Green Lake historically was a shallow, highly productive lake. If left in a natural state, the lake would have very slowly filled in through time and become a wetland. However, the lake today serves primarily recreational uses.



Underwater photo of milfoil in Green Lake, Seattle (photo by Zisette)

Generally, the aquatic environment of Green Lake is highly productive, as related to its eutrophic state. However, the native lake ecosystem has been drastically changed by the introduction of a number of nonnative plant and animal species. The rooted aquatic plant Eurasian watermilfoil (known as milfoil) has been the largest problem. Milfoil growth expanded during the 1980s to cover over 90 percent of the lake surface area, severely altering the lake ecosystem and restricting use and enjoyment of the lake (Herrera 2003a).

Milfoil often forms a floating canopy that shades native aquatic plants and reduces their growth. These milfoil mats also cause problems for swimmers and boaters, who can become entangled in the plant. Milfoil contributes to phosphorus loading in the lake sediments through its release of phosphorus during decomposition, decreasing the effectiveness of alum treatments. Milfoil also reduces dissolved oxygen levels through oxygen consumption during respiration at night, as well as decomposition of dead plants.

A survey of aquatic plants by Herrera (2005b) identified only 4 percent (10.5 acres) of Green Lake covered in milfoil, compared to 82 percent (210 acres) covered in 1991. The observed 90 percent decline in milfoil coverage is directly proportional to declines in milfoil biomass and internal phosphorus loading. Aquatic plants, primarily milfoil, contributed 40 percent of the total phosphorus loading to the lake between 1992 and 1995, and are estimated to have contributed less than 5 percent of the total phosphorus loading in 2005.

The white water lily, an introduced nonnative, floating-leaved plant, is the only other abundant aquatic plant in Green Lake, covering 1.7 percent (4.5 acres) of the lake in 2005. Most of the shoreline is dominated by either nonnative species (primarily yellow flag iris, reed canarygrass, and Himalayan blackberry), or aggressive native species (cattails), or is unvegetated due to the presence of retaining walls or disturbances by humans and dogs (Herrera 2005b).

Table 13. Green Lake sediment organic compounds concentrations compared to freshwater sediment guidelines.

	Green Lake			Consensus-Based Guidelines [a]		Ecology Sediment Quality Values [b]	Ontario [c]		NOAA [d]			
Compound	**Number of Detections**	**Range [e] (µg/kg)**	**Range (mg/kg OC)**	**TEC (µg/kg)**	**PEC (µg/kg)**	**FSQV (µg/kg)**	**LOEL (µg/kg)**	**SEL (mg/kg OC)**	**TEL (µg/kg)**	**PEL (µg/kg)**	**UET (µg/kg)**	**Test Org**
LPAH												
Acenaphthene	1/7	<70–140	<0.9–1.0	NA	NA	3,500	NA	NA	NA	NA	290	M
Anthracene	2/7	<69–440	<0.9–6.9	57.2	845	2,100	220	370	NA	NA	260	M
Fluorene	1/7	<69–170	<0.9–1.3	77.4	536	3,600	190	160	NA	NA	300	M
Phenanthrene	6/7	<96–2,500	<0.9–35	204	1,170	5,700	560	950	41.9	515	800	I
HPAH												
Benzo(a)anthracene	6/7	<96–2,000	<0.9–30	108	1,050	5,000	320	1,480	NA	NA	NA	
Benzo(a)pyrene	5/7	<96–2,400	<0.9–30	150	1,450	7,000	370	1,440	31.9	782	700	I
Benzo(b)fluoranthene	6/7	<96–3,100	<0.9–30	NA	NA	NA	NA	NA	NA	NA	NA	
Benzo(k)fluoranthene	4/7	<96–3,100	<0.9–30	NA	NA	NA	240	1,340	NA	NA	13,400	B
Benzo(b+k)fluoranthene		<96–4,200	<0.9–60	NA	NA	11,000	NA	NA	NA	NA		
Benzo(g,h,i)perylene	5/7	<96–1,700	<0.9–23	NA	NA	1,200	170	320	NA	NA	300	M
Chrysene	6/7	<96–2,900	<0.9–38	166	1,290	7,400	340	460	57.1	862	800	I
Dibenz(a,h)anthracene	3/7	<69–520	<0.9–7	33	NA	230	60	130	NA	NA	100	M
Indeno(1,2,3-c,d)pyrene	5/7	<96–1,800	<0.9–25	NA	NA	730	200	320	NA	NA	330	M
Fluoranthene	6/7	<96–5,200	<0.9–68	423	2,230	11,000	750	1,020	111	2,355	1,500	M
Pyrene	6/7	<96–4,900	<0.9–67	195	1,520	9,600	490	850	53	875	1,000	I
Phthalates												
Bis(2-ethylhexyl)phthalate	6/7	<96–8,600	<0.9–101	NA	NA	640	NA	NA	NA	NA	750	M
Butylbenzylphthalate	5/7	<20–1,800	<0.9–17	NA	NA	NA	NA	NA	NA	NA	NA	
Dimethylphthalate	1/7	<20–120	<0.9–0.9	NA	NA	NA	NA	NA	NA	NA	NA	
Di-n-octylphthalate	5/7	<69–3,200	<1–40	NA	NA	NA	NA	NA	NA	NA	NA	
Pesticides												
4,4’-DDD	6/7	<2–98	<0.02–1.4	4.88	28	NA	8	6	3.54	8.51	60	I
4,4’DDE	3/7	<1.4–37	<0.02–0.54	3.16	31.3	NA	5	19	1.42	6.75	50	I
4,4’-DDT	1/7	<0.99–21.9	<0.02–0.24	4.16	62.9	NA	7	12	NA	NA	<50	I
Aldrin	1/7	<0.98–8.21	<0.01–0.06	NA	NA	NA	2	8	NA	NA	40	I

Table 13. (continued) Green Lake sediment organic compounds concentrations compared to freshwater sediment guidelines.

	Green Lake			Consensus-Based Guidelines [a]		Ecology Sediment Quality Values [b]	Ontario [c]		NOAA [d]			
Compound	Number of Detections	Range [e] (µg/kg)	Range (mg/kg OC)	TEC (µg/kg)	PEC (µg/kg)	FSQV (µg/kg)	LOEL (µg/kg)	SEL (mg/kg OC)	TEL (µg/kg)	PEL (µg/kg)	UET (µg/kg)	Test Org
Dieldrin	2/7	<1.8–19.7	<0.025–0.15	1.9	61.8	NA	2	91	2.85	6.67	300	I
Gamma chlordane	6/7	<0.99–65	<0.01–0.61	3.24	17.6	NA	7	6	4.5	8.9	30	I
Lindane	1/7	<0.98–9.64	<0.01–0.06	2.37	4.99	NA	3	1	0.94	1.38	9	I
Heptachlor	1/7	<0.98–8.64	<0.005–0.06	2.47	16	NA	NA	NA	NA	NA	10	I
PCBs									**NA**	**NA**	**NA**	
Aroclor 1260	1/7	<20–58	<0.2–0.84	59.8^{f}	676^{f}	21^{f}	5^{g}	24^{g}	34.1^{f}	277^{f}	26^{f}	M
TPH												
Diesel	7/7	11–850	--	NA	NA	NA	NA	NA	NA	NA	NA	
Motor oil	7/7	55–4,000	--	NA	NA	NA	NA	NA	NA	NA	NA	
Others												
Carbazole	2/7	<70–280	<0.9–4.1	NA	NA	NA	NA	NA	NA	NA	NA	
Dibenzofuran	1/7	<69–80	<0.9–0.59	NA	NA	NA	NA	NA	NA	NA	NA	

NA = not available

[a] MacDonald et. al. (2000).

[b] Cubbage et al. (1997).

[c] Persaud et. al. (1993).

[d] NOAA (1999).

[e] Detection limits varied from 20 µg/kg to as high as 16,800 µg/kg, depending on the sample matrix.

[f] total PCBs.

[g] tentative guidelines.

FSQV: freshwater sediment quality value.
TEC: threshold effect concentration.
PEC: probable effect concentration.
LOEL: lowest observed effect level.
SEL: severe effect level.
TEL: threshold effect level or concentration below which adverse effects are expected to occur only rarely. Geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set.
PEL: probable effects level, the level above which adverse effects are frequently expected. Geometric mean of the 50th percentile of impacted, toxic samples and the 85th percentile of the non-impacted samples.
UET: Upper effects concentration derived as the lowest adverse effects threshold (AET) on 1% TOC basis from a compilation of endpoints analogous to the marine AET endpoints.
M = Microtox bioassay
I = Infaunal community impacts
B = Bivalve
mg/kg = milligrams per kilogram
µg/kg = micrograms per kilogram

Aquatic plant harvesting equipment was purchased in 1992 and operated through 1999 as part of the program to improve water and sediment quality in Green Lake. The harvester was used primarily to clear milfoil from the rowing (crew) lanes in the lake and was not expected to reduce the coverage of milfoil. However, harvesting of milfoil from the lake declined in 1995 (Herrera 2003b), and harvesting was completely suspended in 2000 because of a dramatic decline in milfoil coverage and density reported by Seattle Parks and Recreation (Herrera 2005b). The decline of milfoil coverage in 2000 was attributed to the concurrent decline in water clarity—and resulting light limitation—caused by severe blooms of bluegreen algae (cyanobacteria), which produced potentially toxic levels of microcystin and prompted closure of the lake to all contact recreation in 1999, and again in 2002 and 2003.

An effort to control milfoil was made in 2001 with the introduction of 777 Asian grass carp (made sterile to control their population), which graze on aquatic vegetation. Fish surveys of Green Lake in 2002 and 2005 illustrate that Asian grass carp are healthy in the lake ecosystem, having more than doubled in median length from 32 centimeters in 2002 to 66 centimeters in 2005 (Herrera 2005b). These results and the low abundance of milfoil and other submerged aquatic plants measured in 2005 suggest that the grass carp population is controlling the growth of milfoil in Green Lake. However, it is anticipated that milfoil coverage will increase in response to the dramatic increase in water clarity resulting from the 2004 alum treatment. Qualitative observations of milfoil coverage in the lake indicate that coverage substantially increased from 2004 to 2005 (Herrera 2005a).

The Asian grass carp is but one of an eclectic mix of fish species in Green Lake. The lake contains native rainbow trout (stocked into the lake) and sculpin, along with nonnative largemouth bass, common carp, tiger musky (stocked into the lake), yellow perch, brown bullhead, rock bass, black crappie, pumpkinseed, and channel catfish (WDFW 2005a, 2005b). Fish surveys conducted in the lake since 1993 indicate that common carp and largemouth bass are the dominant species. Given the conditions in the lake, it is unlikely that a self-sustaining population of trout or other native fishes (e.g., three-spine stickleback or northern pike minnow) can be established.

The presence of common carp is one of the impediments to improved water quality in Green Lake; their population likely reduces the effectiveness of alum treatments. Common carp are bottom feeders that root and dig in the sediments for worms and insects. Their feeding and spawning activities suspend bottom sediments and uproot aquatic plants (i.e., macrophytes). When bottom sediments are in suspension, nutrients such as phosphorus are released to the water column, fueling bacterial blooms. The increasing sediment suspended in the water column also reduces light penetration and restricts native plant growth. Common carp may also contribute to the spread of milfoil to other areas of the lake by uprooting or breaking plants into fragments. Milfoil can reroot and grow from these small fragments. In addition, common carp reduce aquatic insect populations by predation and by eliminating native aquatic plants that provide cover. Other fish and some wildlife species can be adversely affected by the loss of insect food sources and aquatic plants that provide cover for larval and juvenile fish.

Common carp are long-lived and grow to large sizes. They have no natural predators and are generally undesirable to fishermen (with the exception of some fishermen who obtain permits from the Washington Department of Fish and Wildlife to net common carp from Green Lake and other lakes in western Washington during the spring). Consequently, common carp have been thriving in Green Lake. Electrofishing catch rates for common carp increased fourfold from 1997 to 1999, and Green Lake common carp were among the largest compared to those caught in 25 other western Washington lakes (WDFW 2000).

In an effort to control common carp populations, the Department of Fish and Wildlife stocked Green Lake in November 2000 with 150 sterile tiger musky, a species that is a cross between muskellunge and northern pike (Herrera 2003b). These fish were expected to feed on juvenile common carp and control their population. The department has conducted 15 fish surveys since the stocking and the combined results show that that common carp is still the dominant species, comprising approximately 75 percent of the total fish biomass and 30 percent of the total fish numbers. The second most abundant species by biomass is tiger musky (18 percent), and by number is largemouth bass (18 percent; Herrera 2003b). The potential impact of tiger musky on the common carp population has not been evaluated.

From May 2004 to June 2005, the Department of Fish and Wildlife conducted a carp removal program in Green Lake for Seattle Parks and Recreation. The capture methods used to remove carp included the use of electrofishing, gillnetting, and fish traps. Based on the mark and recapture data collected during the initial phase of the program, the carp density was estimated at 120.6 kilograms per hectare (kg/ha) before carp removal activities began. Upon completion of the program in June 2005, carp density was estimated to have dropped to 74.2 kg/ha (Herrera 2005a), representing a reduction of the common carp population in Green Lake of approximately 38 percent. Because the size of the carp population is dependent on the lake productivity and food supply, it is likely that the carp population will remain reduced as long as the 2004 alum treatment is effective.

Carp bioturbation modeling results suggest that the sediment suspended by common carp contributes approximately 5 percent of the phosphorus load to Green Lake (Herrera 2005a). Because most of the suspended phosphorus is bound to aluminum and not available for uptake by bacteria and algae, carp removal is not likely to provide a measurable improvement to Green Lake water quality (Herrera 2005a).

The shoreline habitat around Green Lake consists primarily of large areas of open grass and landscaping, with pockets of vegetation both along the shoreline and in setback areas. The pedestrian/bicycle path that circles the lake is immediately adjacent to most of the shoreline, which is reinforced in some places with bank armoring. The lake also has several docks used for fishing and nonmotorized boat use.

Currently, Seattle Parks and Recreation tries to maintain a balance between human use of the lake and protection of habitat for birds. Types of birds that have been seen at Green Lake include ducks, grebes, gulls, various species of songbirds, and some birds of prey. Most birds are not permanent residents at the lake, and their appearance may be seasonal or rare, depending on the species. Bird sightings of particular interest include green heron, hooded merganser, bald eagle, peregrine falcon, and great blue heron (Seattle Parks and Recreation, undated).

Canada geese are common at Green Lake and are considered a nuisance by some because of the droppings they leave around the lake. The droppings are unpleasant to recreational users and can increase phosphorus and fecal coliform bacteria levels in the lake. Habitat conditions at the lake support the goose population by providing plenty of grass and aquatic vegetation to feed on, and easy access from the lake to the surrounding open, grassy areas. Geese and other waterfowl also can carry the parasite that causes swimmer's itch, although waterfowl play only one role in the development of swimmer's itch—transmission—and are not the sole cause.

Haller Lake

Haller Lake (photo by Bennett)

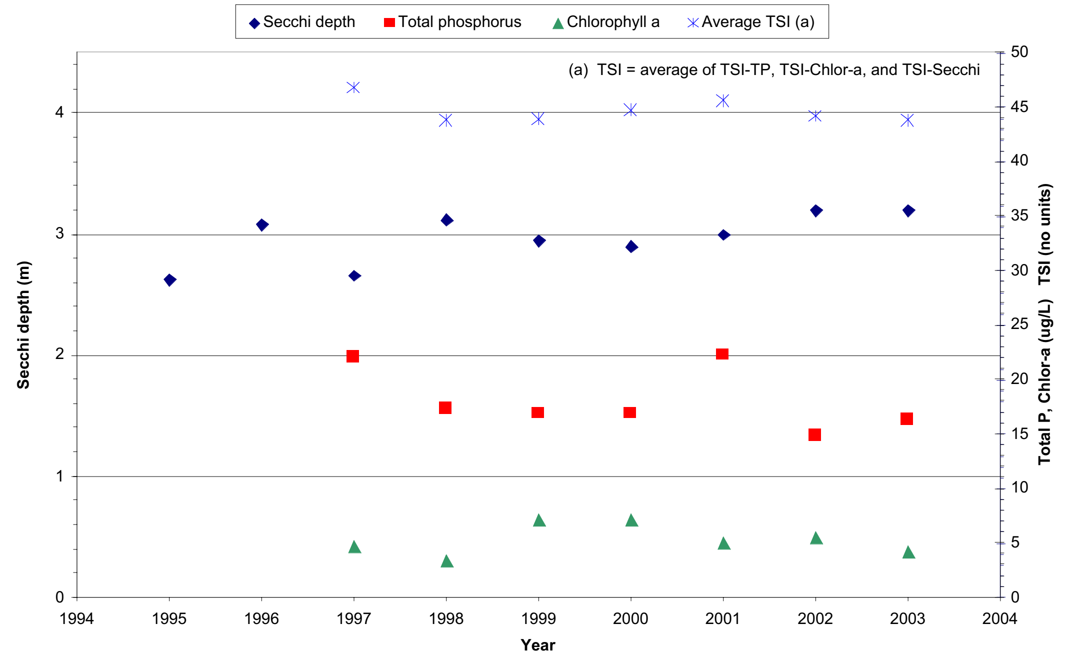
Haller Lake is located in north-central Seattle between Densmore Avenue North, Corliss Avenue North, North 122nd Street, and North 128th Street (Figure 8). Formed by the Vashon glaciation, the lake covers approximately 15 acres, with a maximum depth of 36 feet. Haller Lake originally was called Welsh Lake but was renamed for Theodore N. Haller, who platted the neighborhood in 1905 (Fiset 2001b). The area draining to Haller Lake is primarily residential, with limited public access points at the ends of Meridian Avenue North and North 125th Street.

Haller Lake, which receives stormwater runoff from a drainage area of about 280 acres, discharges through an outlet control structure on the western side of the lake, eventually draining to Lake Union via the Densmore storm drain system. Past attention to Haller Lake has focused on water quality for human uses such as swimming, boating, and wading. Little effort has focused on habitat issues for fish and wildlife.

Figure 8. Haller Lake.

Water Quality Conditions

Overall, water quality in Haller Lake is relatively good, and the lake is classified as moderately productive, or mesotrophic. Volunteers for the King County small lakes program have monitored water quality in Haller Lake since 1995. Water samples are collected twice a month from May through October. Average results for 1995–2003 are displayed in Figure 9.



Reference: King County (1999a, 2001a, 2001b, 2002a, 2002b, 2003, 2005).
Note: Secchi depth is a measure of water clarity. The higher the value, the better the water clarity.

Figure 9. Haller Lake water quality monitoring data summary for 1995–2003.

Average water clarity (measured by Secchi depth) generally ranges from about 2.6 to 3.2 meters. With the exception of 2001, annual average concentrations of total phosphorus in Haller Lake have been below the recommended level established by the Department of Ecology for lower mesotrophic lakes (20 µg/L; WAC 173-201A). The 2001 average total phosphorus concentration (22.3 µg/L) was affected by two unusually high measurements (72 and 36 µg/L) that occurred on June 3 and September 9, respectively. All but one other phosphorus measurement in 2001 were below 20 µg/L. The average trophic state index over the 7-year monitoring period has also remained relatively constant (43.8–46.8) and well within the range established for mesotrophic lakes (40–50).

Only one sample was collected for fecal coliform bacteria in Haller Lake, on August 3, 1998. This sample contained 29 cfu/100 mL fecal coliform bacteria (King County 1999a), meeting the state water quality standard for extraordinary primary contact recreation, established as a geometric mean of 50 cfu/100 mL, with no more than 10 percent (or any single sample when less than 10 sample points exist) exceeding 100 cfu/100 mL.

In 2001, Seattle University students manually collected a composite stormwater sample from the Meridian Avenue North storm drain, the largest storm drain discharging to Haller Lake, as part of an SPU-sponsored drainage improvement evaluation. The results for this sample are similar to results reported for runoff from other urban areas that have been monitored in the Puget Sound region (Table 14). The Meridian Avenue North sample exceeded the state water quality criteria for fecal coliform bacteria and U.S. EPA recommended water quality criteria for nutrients (nitrogen and phosphorus) in rivers and streams. Dissolved copper and lead were not detected in the sample (at 0.001 µg/L detection limits); dissolved zinc was detected at 20 µg/L, well below the state water quality criterion.

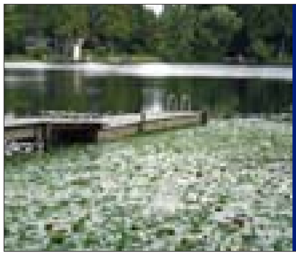
Table 14. Haller Lake drainage sample results from Meridian storm drain compared to other Seattle stormwater data.

	Units	Meridian Drain [a]	Other Seattle Area Runoff [b]
Fecal coliform bacteria	cfu/100 mL	300E	180–8,400 [c]
Total suspended solids	mg/L	39	10–154
Total phosphorus	µg/L	128	57–387
Total copper	µg/L	3.4	3.6–24.8
Total lead	µg/L	<1	<1–36.6
Total zinc	µg/L	46	31–168
Dissolved copper	µg/L	<1	1.4–11.7
Dissolved lead	µg/L	<1	<1–3.1
Dissolved zinc	µg/L	20	10–89

E = estimated value.
[a] Manually composited sample collected on March 1, 2001.
[b] Twenty (20) stormwater samples collected from 25-acre residential area along Lake City Way in north Seattle (Taylor and Seattle Public Utilities 2005).
[c] Twenty-two (22) stormwater samples collected from residential area in north Seattle, 2003–2005 (Engstrom 2004; Seattle Public Utilities unpublished).
mg/L = milligrams per liter
µg/L = micrograms per liter
cfu/100 mL = colony forming units per 100 milliliters

Habitat Conditions

The wildlife habitat of Haller Lake has not been well studied. Fish species inhabiting the lake include rainbow trout, largemouth bass, yellow perch, brown bullhead, and black crappie (WDFW 2005a, 2005b). The Washington Department of Fish and Wildlife stocks rainbow trout into the lake each year. The lake is also used by ducks and geese. The habitat along the lake shoreline consists primarily of landscaped yards, with a small number of residential docks on the lake. Some shoreline sections have relatively intact stands of mature trees. The lake also contains a number of floating, submerged, and emergent aquatic plant species, some of which are classified as noxious weeds (King County 1999b).



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Part 5 Small Lakes Comparison & Conclusions

Comparisons of water quality and sediment quality conditions in Bitter Lake, Green Lake, and Haller Lake are summarized in Table 15.

Table 15. Comparisons of water quality and sediment quality conditions in Seattle's small lakes.

	Bitter Lake	Green Lake [c]	Haller Lake
Aquatic Life Indicators			
Temperature and dissolved oxygen	–	▓	–
pH	–	░	–
Turbidity and total suspended solids	░	░	░
Nutrients [b]	░	■	░
Toxic Pollutants			
Ammonia	–	–	–
Metals	–	–	–
Organic compounds	–	–	–
Public Health Indicators			
Fecal coliform bacteria	▓	■	–
Metals [a]	▓	–	–
Organic compounds [a]	░	–	–
Indicators in Sediment			
Metals	▓	▓	–
Organic compounds	▓	▓	–

[a] Based on U.S. EPA toxics rule (EPA 2002a).

[b] Water quality criteria for nutrients have been established to prevent eutrophication and water quality problems associated with nutrient enrichment.

[c] Nutrient and fecal coliform bacteria levels in Green Lake declined significantly after the 2004 alum treatment.

■	Poor water quality, frequent exceedances of state water quality standards.
▓	Potential water quality problem (e.g., 303d category 2 listing, occasional exceedance of water quality standard).
░	Adequate water quality based on existing data.
–	Insufficient data available to evaluate.

Water and Sediment Quality Conditions

Water and sediment quality conditions in Seattle's small lakes have been evaluated by comparing existing chemistry data to available standards and benchmarks, particularly the Washington state water quality standards and available sediment quality criteria, which represent levels that are protective of aquatic organisms or human health. In addition, the Department of Ecology has recently completed a water quality assessment identifying impaired water bodies in Washington, as required under Section 303(d) of the Clean Water Act (Ecology 2004). The 303(d) listings for Seattle's small lakes are summarized in Table 16.

Table 16. Listings of Seattle's small lakes as threatened or impaired water bodies under Clean Water Act Section 303(d).

	Category 5 [a]	**Category 2** [b]
Bitter Lake	None	Fecal coliform bacteria
Green Lake	Fecal coliform bacteria, total phosphorus, total PCBs[c], 4,4'-DDE[c], chlordane [c]	Total phosphorus
Haller Lake	None	None

Source: Ecology (2004).

[a] Total maximum daily load (TMDL) limit required due to demonstrated exceedances of state water quality standards.

[b] Water of concern.

[c] Based on fish tissue concentrations.

Water quality in Haller Lake and Bitter Lake is relatively good, and both lakes are classified as moderately productive, or mesotrophic. However, Green Lake has a long history of water quality problems related to excessive growth of algae and bacteria caused by an overabundance of nutrients, particularly phosphorus. The Department of Ecology included Green Lake on the 303(d) list of threatened and impaired water bodies as a category 5 water body (i.e., impaired) due to elevated concentrations of total phosphorus (Ecology 2004).

Phosphorus can be contributed to lakes from many sources, including stormwater runoff and waterfowl. However, during the summer months when algal and bacterial blooms are common, the primary source of phosphorus in Green Lake has been attributed to internal processes, such as release of phosphorus stored in the sediment on the lake bottom (Herrera 2003a).

Elevated numbers of fecal coliform bacteria have been reported in Green Lake (1–2,500 colony-forming units per 100 milliliters [cfu/100 mL]), and in Bitter Lake (110 cfu/100 mL, in one sample collected on August 3, 1998). Consequently, Green Lake is listed on the 2004 Ecology 303(d) list (Ecology 2004) as an impaired water body (category 5; see Table 16) for fecal coliform bacteria, and Bitter Lake is listed as a water body of concern (category 2; see Table 16). Haller Lake is not currently listed for any water quality parameter; fecal coliform bacteria concentrations measured in the one sample tested to date (29 cfu/100 mL) were within the state water quality standard.

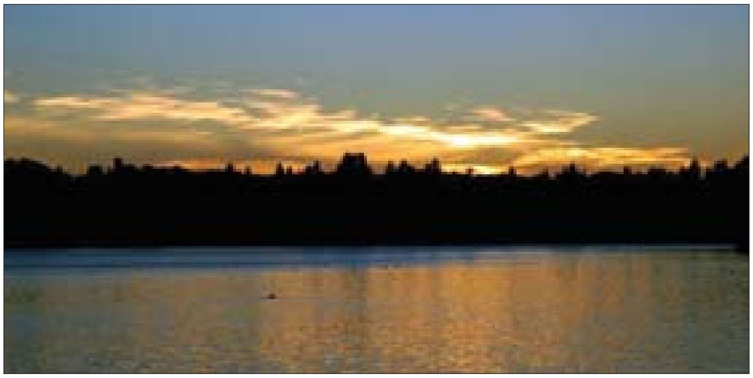
Water quality data for metals and organic contaminants are generally lacking for the three small lakes. Limited sediment data available for Bitter Lake and Green Lake indicate that some metals exceeded probable effects levels (PEL) established by other jurisdictions, particularly in samples collected offshore of storm drain outfalls. However, the Department of Ecology's interim freshwater sediment quality values were exceeded only by Bitter Lake cadmium concentrations (2.05–5.98 milligrams per kilogram [mg/kg]), and by Green Lake lead concentrations (68–713 mg/kg) and zinc concentrations (85–516 mg/kg).

Organic compounds are not commonly detected in sediment samples collected from Bitter Lake and Green Lake. One sampling station in Bitter Lake reported polycyclic aromatic hydrocarbons (PAHs) at 672–3,250 micrograms per kilogram (µg/kg), and bis(2-ethylhexyl)phthalate, a plasticizer, at 16,700 µg/kg. Total petroleum hydrocarbons were detected at multiple locations in Bitter Lake (10.9–4,750 µg/kg diesel and 144–9,840 µg/kg oil). All other organic compounds (PCBs, volatile organic compounds, and pesticides) were undetected in Bitter Lake sediments, although analytical detection limits were high (up to 16,800 µg/kg) for some constituents.

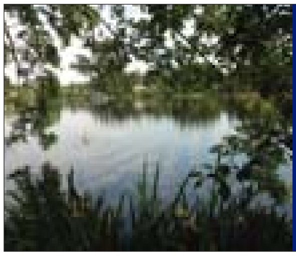
None of the sediment samples collected from Green Lake exceeded the interim Ecology freshwater sediment quality values for organic compounds. However, high and low molecular weight PAH (HPAH and LPAH) compounds exceeded the upper effects levels (UEL)—concentrations at which biological effects are probable—established by other jurisdictions. Total petroleum hydrocarbons (11–850 mg/kg diesel and 55–4,000 mg/kg oil) were also detected at all sediment stations sampled in Green Lake.

Habitat Conditions

The physical conditions for wildlife habitat in Seattle's small lakes have not been well studied. In general, Bitter Lake, Green Lake, and Haller Lake all appear to lack habitat complexity, shoreline vegetation, and connectivity between lake and shoreline. All three small lakes support some fish, although most of these fish are introduced or stocked into the lakes.



Sunset behind Green Lake (photo by Bennett)



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Glossary of Terms

303(d) list A state inventory of impaired water bodies, created according to the federal Clean Water Act, Section 303(d).

acute conditions Changes in an organism's physical, chemical, or biological environment involving a stimulus severe enough to rapidly induce a response, resulting in injury or death to the organism after short-term exposure.

acute exposure value The threshold value below which there should be no unacceptable effects on freshwater aquatic organisms and their uses, if the one-hour average concentration does not exceed that value more than once every 3 years on average. Also known as the criterion maximum concentration (CMC).

aquatic flora and fauna, aquatic biota All forms of plants (flora) and animals (fauna) found living in or rooted in water.

algae Small aquatic plants, containing chlorophyll, that occur as single cells, colonies, or filaments and float in the water or attach to larger plants, rocks, and other substrates. Individuals are usually visible only with a microscope. Excessive numbers can make the water appear cloudy and colored, creating a nuisance when conditions are suitable for prolific growth.

algal bloom Proliferation of living algae on the surface of a lake, stream, or pond; often stimulated by phosphate over-enrichment. Algal blooms reduce the oxygen available to other aquatic organisms.

anoxic Devoid of oxygen.

baseline condition The state of a system, process, or activity before the occurrence of actions or events that may result in changes; used as the starting point for comparative analysis.

basin The area of land drained by a river and its tributaries, draining water, organic matter, dissolved nutrients, and sediments into a lake or stream.

benchmark As the term is used in this report, benchmarks represent interim water quality criteria that are useful for comparison to existing or past conditions found in Seattle surface water bodies. Benchmarks identified in this report are based on U.S. EPA water quality criteria but do not reflect adopted water quality standards. Because these benchmarks represent surface water quality conditions that are minimally influenced by human activity, exceeding a benchmark does not necessarily indicate a violation of the water quality standard.

beneficial uses Those uses of water identified in state water quality standards that must be achieved and maintained as required under the federal Clean Water Act. The terms "beneficial use" and "designated use" are often used interchangeably.

benthic invertebrates Aquatic, bottom-dwelling organisms in streams and lakes, including small invertebrate insects, crustaceans, mollusks, and worms.

benthic zone The area associated with the lake bottom, in both deep- and shallow-water areas

bioaccumulation The process by which substances that are very slowly metabolized or excreted increase in concentration in living organisms, resulting in the accumulation of chemical compounds in their body tissues.

bioavailable Describes the degree to which a substance (e.g., a toxin) is absorbed into a living system or is made available at the site of physiological activity.

biomass The weight of biological matter (e.g., fish, algae, and aquatic plants present in a body of water).

biota All living organisms (plants and animals) within a specified area.

blue-green algae A group of algae having a blue pigment in addition to the green chlorophyll. A stench is often associated with the decomposition of dense blooms of blue-green algae in fertile lakes.

channel A natural stream that conveys water; a natural or artificial watercourse with definite bed and banks to confine and conduct flowing water; or a ditch excavated for the flow of water.

chlorophyll *a* A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae, that is commonly used as a measure of the algal content of water.

chronic conditions Changes in an organism's physical, chemical, or biological environment involving a stimulus of extended duration, resulting in injury or death to the organism as a result of repeated or constant exposure over an extended period of time.

chronic exposure value The threshold value below which there should be no unacceptable effects on freshwater aquatic organisms and their uses, if the 4-day average concentration does not exceed that value more than once every 3 years on average. Also known as the criterion continuous concentration (CCC).

Clean Water Act (CWA) The basic federal water pollution control law in the United States (Federal Water Pollution Control Act, codified at 33 U.S.C. §§1251–1387). Provisions of the statute include technology-based effluent standards for point sources of pollution, a state-administered control program for nonpoint pollution sources, a construction grant program to build or upgrade municipal sewage treatment plants, a regulatory system for spills of oil and other hazardous wastes, and a wetlands preservation program.

combined sewer Drainage system pipes that carry both sanitary sewage (i.e., wastewater from buildings) and stormwater runoff to a wastewater treatment plant.

culvert A pipe or concrete box structure that drains open channels, swales, or ditches beneath a roadway or embankment, typically with no catch basins or manholes along its length.

designated uses Those uses of water identified in state water quality standards that must be achieved and maintained as required under the federal Clean Water Act. The terms "beneficial use" and "designated use" are often used interchangeably.

detection limit The smallest concentration of a constituent that can be measured with a stated level of confidence. (In practice, detection limits can be determined by different methods in different laboratories.)

discharge Runoff leaving an area via built conveyance systems or overland flow, typically described as a volume of fluid passing a point per unit of time, such as cubic feet per second, cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day.

dissolved oxygen The amount of oxygen dissolved in water and available for aquatic life, measured in milligrams per liter. Certain amounts of dissolved oxygen are essential to aquatic animal and plant life, as well as bacterial decomposition of organic matter.

disturbed habitat A habitat in which naturally occurring ecological processes and species interactions have been significantly disrupted by the direct or indirect results of human presence and activity.

drainage basin The tributary area through which drainage water is collected, regulated, transported, and discharged to receiving waters.

ecological health In surface water systems, environmental conditions exhibiting the ecological functions and features necessary to support diverse, native, self-sustaining aquatic and riparian communities.

effluent Liquid wastes from sewage treatment, septic systems, or industrial sources that are released to a surface water body.

emergent plants Aquatic plants that are rooted in the bottom sediment but project above the water surface, such as cattails and bulrushes. These wetland plants often have high habitat value for wildlife and waterfowl and can aid in pollutant uptake.

environmentally critical areas (ECAs) Landslide-prone areas, liquefaction-prone areas, flood-prone areas, riparian corridors, wetlands, steep slopes, fish and wildlife habitat conservation areas, and abandoned landfills, as defined and regulated under the Seattle critical area regulations.

epilimnion The uppermost, warmest, well-mixed layer of a thermally stratified lake (during summertime), extending from the surface to the thermocline.

estuary An area where fresh water meets salt water at the lower end of a river, or where the tide meets the river current (e.g., bays, mouths of rivers and watercourses, salt marshes, and lagoons). Estuaries serve as nurseries and as spawning and feeding grounds for many marine organisms, and provide shelter and food for birds and wildlife.

eutrophic "Well-nourished" (from the Greek), the term describes a lake of high photosynthetic activity and low water transparency, characterized by high nutrient concentrations and associated high organic productivity.

eutrophication The addition of nutrients, especially nitrogen and phosphorus, to a body of water, resulting in high organic production rates that may overcome natural self-purification processes. Frequently resulting from pollutant sources on adjacent lands, eutrophication produces undesirable effects including algal blooms, seasonally low oxygen levels, and reduced survival opportunities for fish and invertebrates.

fall turnover The autumn mixing, top to bottom, of lake water caused by cooling and wind-derived energy.

fecal coliform bacteria Microscopic organisms associated with animal feces, commonly measured in water quality samples as an indirect indicator of the presence of other disease-causing bacteria. Used as a primary parameter and standard of water quality; reported in number of organisms or colony-forming units per 100 milliliters of water.

filling Placement of earthen material to increase the surface elevation at a site using artificial means, usually making the ground especially vulnerable to erosion.

geographic information system (GIS) A computer database system that can input, store, manipulate, analyze, and display geographically referenced data in map formats.

geometric mean A calculated mean or average value that is appropriate for data sets containing a few values that are very high relative to the other values, or skewed. To reduce the bias introduced by these very high numbers, the natural logarithms of the data are averaged, and the anti-log of this average is the geometric mean. The geometric mean is used to compare fecal coliform bacteria levels to water quality standards.

habitat The specific area or environment in which a particular type of plant or animal lives. An organism depends upon its habitat for all of the basic requirements for life.

hardness A measure of the concentration of dissolved calcium carbonate in water; hard water has high concentrations.

heavy metals Metals of high specific gravity, present in municipal and industrial wastes, which pose long-term environmental hazards. Such metals include cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc.

hydrology The science of the behavior of water in the atmosphere, on the surface of the earth, and in the soil and underlying rocks; its occurrence, distribution, circulation, physical and chemical properties, and reaction with the environment.

hypolimnion The dark, cold, bottom layer of water in a thermally stratified lake. It lies below the thermocline, is noncirculating, and remains perpetually cold.

hypereutrophic conditions Excessive nutrient concentrations in a water body, resulting in high productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency.

impaired waters Water bodies not fully supporting their beneficial uses, as defined under the federal Clean Water Act, Section 303(d).

impervious surface A hard surface area that either prevents or retards the entry of water into the soil mantle (as occurs under natural conditions, prior to development), from which water runs off at an increased rate of flow or in increased volumes. Common impervious surfaces include rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled or macadam surfaces.

indicator An observed or calculated characteristic that shows the presence of a condition or trend. Water quality indicators are selected chemical and physical parameters and indices that can be used to characterize overall conditions in the receiving water and also provide benchmarks for assessing the success of watershed management efforts.

invasive species Opportunistic, nonnative species of inferior biological value that tend to out-compete more desirable forms and become dominant.

invertebrates Animals without internal skeletons. Some require magnification to be seen well, while others such as worms, insects, and crayfish are visible to the naked eye (called macroinvertebrates). Benthic invertebrates (living in sediments) are collected as samples to be identified and counted. More varied invertebrate communities generally indicate healthier water bodies.

lake An area permanently inundated by water in excess of two meters deep and greater than 20 acres in area as measured at the ordinary high water marks.

limiting nutrient The nutrient that is in lowest supply relative to the demand. The limiting nutrient will be exhausted first by algae, which require many nutrients and light to grow. Inputs of the limiting nutrient result in increased algal production, but as soon as the limiting nutrient is exhausted, growth stops. Phytoplankton growth in lake waters of temperate lowland areas is generally phosphorus-limited.

littoral zone The shallow shoreward region of a lake having light penetration to the bottom, extending out to the greatest depth occupied by rooted plants.

lowest-effect level (LEL) The concentration of a pollutant in sediments at which the majority of benthic organisms are unaffected (Persaud et al. 1993).

macrophtyes Rooted or floating aquatic vascular plants, commonly called water weeds (as distinct from the microscopic plants).

mesotrophic A term used to describe a lake of moderate plant productivity and moderate water transparency. A mesotrophic lake is not as rich in nutrients as a eutrophic lake but is richer in nutrients than an oligotrophic lake.

metaphyton Shallow floating algae.

mg/L (milligrams per liter) and µg/L (micrograms per liter) Units of measure used in describing the amount of a substance in a given volume of water, as in 5 milligrams of oxygen per liter of water.

microcystin A toxic compound produced by blue-green algae, or cyanobacteria.

monitoring Systematic measurement and data collection by various methods for the purposes of understanding natural systems, evaluating the impacts of disturbances and alterations, and assessing the performance of mitigation measures.

native vegetation Vegetation consisting of plant species (other than noxious weeds) that are indigenous to the region and that reasonably could be expected to occur naturally within the region.

natural conditions Surface water quality that was present before any human-caused pollution. When estimating natural conditions in the headwaters of a disturbed watershed, it may be necessary to use the less disturbed conditions of a neighboring or similar watershed as a reference condition.

nitrate, nitrite (NO_3, NO_2) Two types of nitrogen compounds that are nutrients, or forms of nitrogen that algae may depend upon for growth.

no-effect level (NEL) The concentration of a pollutant in sediments at which no toxic effects have been observed in aquatic organisms (Persaud et al. 1993).

nonpoint source pollution (of water) Pollution that enters a water body from diffuse origins in the watershed and does not have discernible, confined, or discrete points of origin.

noxious weed A plant that is undesirable, troublesome, and difficult to control or eradicate.

nutrient An organic or inorganic chemical essential for growth and reproduction of organisms. In surface water bodies, nutrients affecting water quality include total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, nitrite-nitrogen, and ammonia-nitrogen, measured in milligrams per liter of water.

oligotrophic "Poorly nourished" (from the Greek), the term describes a lake of low concentrations of nutrients and algae, and high water transparency. An oligotrophic lake has lower nutrient levels than a mesotrophic or eutrophic lake.

ordinary high water mark The line on the shore established by the fluctuations of water level and indicated by physical characteristics such as a clearly visible, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, or the presence of litter and debris.

outfall Generally, the point of discharge from a storm drain. Outfalls may discharge to surface waters or ground water.

outlet Generally, the point of water discharge from a watercourse, river, lake, tidewater, or storm drain.

PAHs (polycyclic aromatic hydrocarbons) A class of organic compounds, some of which are persistent and cancer-causing, that are ubiquitous in the environment. PAHs are commonly formed by the combustion of fossil fuels and by forest fires, often reaching the environment through atmospheric fallout, highway runoff, and oil discharge.

parameter One of a set of variable, measurable properties whose values determine the characteristics of a system such as a water body. See water quality parameter.

PCBs (polychlorinated biphenyls) A group of manmade organic chemicals comprising 209 closely related compounds (congeners) made up of carbon, hydrogen, and chlorine. If released to the environment, PCBs persist for long periods of time and can concentrate in food chains.

pelagic zone The open area of a lake, extending from the edge of the littoral zone to the center of the lake.

pesticide A general term describing any substance, usually chemical, used to destroy or control undesirable organisms (pests). Pesticides include herbicides, insecticides, fungicides, algacides, and other substances.

pH A measure of the alkalinity or acidity of a substance on a scale of 0 to 14, determined by measuring the concentration of hydrogen ions in the substance. A pH value of 7.0 indicates neutral water. A 6.5 reading is slightly acidic.

phosphorus One of the elements essential as a nutrient for the growth of organisms. In western Washington lakes, it is usually the algal nutrient in shortest supply; hence adding more phosphorus causes more algal growth. Various measures of phosphorus in water samples are made, including total phosphorus and the dissolved portion of phosphorus.

photosynthesis The process by which living plant cells produce simple sugars and starches from carbon dioxide and water, with the aid of chlorophyll and the presence of light.

phytoplankton Microscopic algae and microbes that float freely in open water of lakes and oceans.

plankton Nonmobile or weak-swimming microscopic animals or plants that float and drift with lake currents, such as bacteria, viruses, protozoa, phytoplankton (i.e., microscopic plants), zooplankton (i.e., microscopic animals), and early life stages of insects.

pollutant A substance introduced into the environment that has adverse effects on organisms, including death, chronic poisoning, impaired reproduction, cancer, or other effects.

pollution (of water) The human-induced alteration of the chemical, physical, biological, or radiological integrity of water.

probable effects concentration (PEC) The concentration of a pollutant in sediments above which adverse effects are expected to occur more often than not, based on a compilation of available sediment quality guidelines reported in the literature (MacDonald et al. 2000).

probable effects level (PEL) The concentration of a pollutant in sediments at which adverse effects are frequently expected. The PEL is calculated as the geometric mean of the 50th percentile concentration of the toxic effects data set and the 85th percentile of the no-effect data set (NOAA 1999).

receiving waters Bodies of water or surface water systems, such as a lake or watercourse, to which surface runoff is discharged.

residence time The amount of time required to completely replace the volume of water in a lake with an equal volume of new water, commonly called the hydraulic residence time.

riparian Pertaining to the bank of a water body. Riparian habitat is associated with stream and lake margins, typically characterized by dense vegetation supporting a variety of waterfowl, songbirds, amphibians, and small mammals.

riprap A facing layer or protective mound of rocks used to line channels, to prevent bank erosion caused by hydraulic forces of surface flow and stormwater runoff.

runoff Water originating from rainfall and other precipitation that flows to drainage facilities, rivers, watercourses, springs, ponds, lakes, wetlands, and shallow ground water.

salmonid A member of the fish family Salmonidae, including Chinook, coho, chum, sockeye, and pink salmon; cutthroat, brook, brown, rainbow, and steelhead trout; Dolly Varden; kokanee; and char species.

Secchi depth A visual measure of water transparency (clarity), measured by lowering a black and white or all white disk (Secchi disk, 20 centimeters in diameter) into the water until it is no longer visible, and recording the depth in units of meters or feet.

sediment Bottom material in a water body that originates from remains of aquatic organisms, precipitation of dissolved minerals, and erosion of surrounding lands. Certain contaminants tend to collect on and adhere to sediment particles.

sediment management standards State regulatory standards pertaining to the quality of sediment, found in the Washington Administrative Code (WAC) 173-204.

severe-effect level The concentration of a pollutant in sediments at which pronounced disturbance of the sediment-dwelling community can be expected (Persaud et al. 1993).

sheet flow Runoff that flows over the ground surface as a thin, even layer, not concentrated in a channel.

spring turnover The stratification of lake water that begins in spring and accelerates in summer, primarily caused by warming of surface waters.

storm event Technical term for a specific precipitation occurrence; for example, the 5-year, 24-hour storm event, the 25-year, 24-hour storm event, or the 100-year, 24-hour storm event.

storm drain Generally, a conveyance or system of conveyances that carries stormwater, surface water, and other drainage (but not sanitary wastewater or industrial wastes) toward points of discharge (sometimes called a storm sewer).

stormwater Generally, precipitation and surface runoff and drainage.

stormwater drainage system Constructed and natural features that function together to collect, convey, channel, hold, inhibit, retain, detain, infiltrate, divert, treat, or filter stormwater.

stormwater runoff Stormwater that directly leaves an area in surface drainage.

stratification of lakes A layering effect of the warming of lake surface waters during summer, caused by differences in water density. Upper waters are progressively warmed by the sun, and deeper waters remain cold. Because of the difference in density (warmer water is lighter in weight), the two layers remain separate; upper waters float on deeper waters, and wind-caused mixing occurs only in the upper layer. Oxygen in the bottom waters may become depleted. In fall as the upper waters cool, the whole lake mixes again and remains mixed throughout the winter. Thermal stratification is typical of most deep lakes during summer.

substrate The nonliving material forming the bed of a water body with particles described in terms of size as boulders, cobbles, gravel, sand, silt, or clay.

swimmer's itch A rash caused by a waterborne parasitic flatworm in the immature (cercarial) stage of its life cycle, when it penetrates beneath the skin of bathers. Although the organism dies as soon as it penetrates the skin, the rash may persist for 2 weeks. (A shower or alcohol rubdown is recommended to minimize penetration.)

thermocline In a stratified lake, a horizontal plane at the depth of the most rapid vertical change in temperature and density.

threshold effects concentration (TEC) The concentration of a pollutant in sediments below which adverse effects are not expected to occur (MacDonald et al. 2000).

threshold effects level (TEL) The concentration of a pollutant in sediments at which adverse effects are expected to occur only rarely. The TEL is calculated as the geometric mean of the 15th percentile concentration of the toxic effects data set and the median of the no-effect data set (NOAA 1999).

total maximum daily load (TMDL) Under Section 303(d) of the federal Clean Water Act, water quality standards must be used to identify threatened and impaired water bodies. Category 2 (threatened) water bodies are those that occasionally exceed water quality standards, while category 5 (impaired) water bodies are those that frequently exceed standards. Impaired water bodies are required to be evaluated to identify the pollutants and sources responsible for the water quality problems. Total maximum daily load (TMDL) limits are then established and allocated to specific pollutant sources in order to reduce pollutant discharges and move toward meeting water quality standards. A TMDL is the sum of the allowable loads of a single pollutant from all contributing point sources and nonpoint sources, including a margin of safety and accounting for seasonal variations in water quality.

toxic Poisonous, carcinogenic, or otherwise directly harmful to life.

transparency Clarity of water in a lake, measured by lowering a black and white Secchi disk into the water and recording the depth at which it is no longer visible. Transparency of lakes is determined by the color of the water and the amount of material suspended in it. Generally in colorless waters of the Puget lowland, water transparency in summer is determined by the amount of algae present in the water. Suspended silt particles, particularly as a result of storm events, may also reduce transparency.

trophic status A rating of the condition of a lake on the scale of oligotrophic–mesotrophic–eutrophic. Transparency, chlorophyll a levels, phosphorus concentrations, amount of macrophytes, and quantity of dissolved oxygen in the hypolimnion can be used to assess the trophic state.

trophic state index A calculation of trophic status based on three key indicators: chlorophyll a, total phosphorus, and Secchi depth (Carlson 1977).

turbidity A measure of the reduced transparency of water due to the suspension of minute particles such as algae, silt, or clay, typically expressed in nephelometric turbidity units (NTU).

upland The general term used for land areas that do not meet the criteria for classification as wetlands.

upper effects threshold (UET) The concentration of a pollutant in sediments at which adverse effects would always occur based on the lowest adverse effect threshold (AET) from a compilation of endpoints analogous to the marine AET endpoints. The UET is based on 1 percent total organic carbon content in the sediment (NOAA 1999).

urban runoff Stormwater from streets and adjacent developed properties.

Washington Administrative Code (WAC) The codified regulations of the state of Washington.

water column In a water body, water between the interface with the atmosphere at the surface and the interface with the sediment layer at the bottom.

watercourse A network of open stream channels, pipes, ditches, and culverts in which surface water is transported to a receiving water body. Watercourses include small lakes, bogs, streams, creeks, and intermittent artificial or constructed components but do not include receiving waters (Seattle Municipal Code 22.801.240).

water quality Generally, the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

water quality criteria Elements of state water quality standards, expressed as quantitative constituent concentrations, levels, measures, or descriptive statements, representing a quality of water that supports a particular use. When criteria are met, water quality generally protects the water's designated use.

water quality parameter One of a set of properties of water that are routinely measured and analyzed to assess water quality, such as temperature, turbidity, conductivity, pH (acidity), dissolved oxygen content, phosphorus concentration, fecal coliform bacteria concentration, and others.

water quality standards Provisions of state or federal law consisting of designated uses for a water body, and water quality criteria based upon such uses, pursuant to the federal Clean Water Act. Water quality standards are established to protect public health or welfare, enhance the quality of water, and serve the purposes of the Clean Water Act.

watershed A geographical region bounded by topographic high points within which water drains into a particular river, watercourse, or body of water. Watersheds can be as large as those identified and numbered by the state of Washington as water resource inventory areas (WRIAs), or they can be identified as smaller drainage areas.

wetland An area that is inundated or saturated by surface water or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

woody debris Logs, stumps, or branches that have fallen or been cut and left in place.