Green Lake Integrated Phosphorus Management Plan

Prepared for

Seattle Parks and Recreation

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Prepared for

Seattle Parks and Recreation
800 Maynard Avenue South
Seattle, Washington 98134-1336

Prepared by

Herrera Environmental Consultants, Inc.
2200 Sixth Avenue, Suite 1100
Seattle, Washington 98121
Telephone: 206/441-9080

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Introduction

Green Lake is a shallow eutrophic lake that is very productive due to high concentrations of dissolved nutrients such as nitrogen and phosphorus that promote algae and plant growth. Located just north of downtown Seattle, the lake is an important recreational and aesthetic resource for city residents. Although the lake remains heavily used, enjoyment of it has been diminished by its poor water quality. Intense blooms of blue-green bacteria (formerly known as blue-green algae) have plagued the lake since at least 1916 (KCM 1995). In addition, the rooted aquatic plant Eurasion watermilfoil (*Myriophyllum spicatum*) expanded during the 1980s to cover over 90 percent of the lake surface area, further restricting enjoyment and use of the lake (KCM 1995).

Physical and chemical processes within the lake, as well as drainage to the lake from the surrounding urban watershed, supply the nutrients that support the algal blooms. Phosphorus is the main nutrient causing the problem. Previous studies have found that most of the phosphorus in the lake during the summer can be attributed to internal processes, with sediments on the lake bottom identified as the most likely source. The movement of blue-green bacteria from the sediments to the water above also has been identified as a significant source of internal phosphorus loading (Barbiero 1991; Barbiero and Welch 1992). However, other processes common to shallow lakes are probably more important (Welch and Cooke 1995).

Green Lake is listed by the Washington Department of Ecology (Ecology) as an impaired water body in terms of total phosphorus (Ecology 1998). The action required to address this impairment is the establishment of a total maximum daily load (TMDL) for Green Lake. However, Green Lake is not included on Ecology's most recent list of funded water clean-up projects (FY 2004) for water resource inventory area (WRIA) 8 to be addressed in the next 5-year cycle (Ecology 2003).

Seattle Parks and Recreation, with funding assistance from Ecology and the U.S. Environmental Protection Agency (U.S. EPA), implemented a lake restoration program for Green Lake (URS 1987) based on the Phase I diagnostic feasibility study of the lake in 1981 (URS 1983) and subsequent restoration analyses (URS 1990a, 1990b, 1990c). The goals of the lake restoration program included reducing the mean total phosphorus concentration in the summer to less than 30 micrograms per liter (µg/L) and the average water transparency in the summer to greater than 2.5 meters (8.2 feet) (KCM 1995).

The cornerstone of the Phase II restoration project was the application of aluminum sulfate (i.e., alum) to inactivate sediment phosphorus, thereby reducing internal phosphorus loading and availability to blue-green bacteria. Green Lake was treated with alum and the buffering agent sodium aluminate in October 1991. According to monitoring results for 3 years (December 1991 through February 1995) after the alum treatment and other management efforts, the phosphorus concentrations in the lake were meeting the target of less than 30 µg/L (KCM 1995). Other project management efforts included stormwater controls, dilution of the lake with City drinking water, waterfowl management, and public education (KCM 1995). The restoration project completion report concluded that an alum treatment would be necessary every 5 to 8 years to control the phosphorus levels in the lake and prevent summer algal blooms (KCM 1995). In addition, the report recommended that the mean summer phosphorus target be set at less than 25 μg/L.

Coverage under the state's National Pollutant Discharge Elimination System (NPDES) Waste Discharge General Permit for Aquatic Nuisance Plant and Algae Control (Permit No. WAG-994000, effective July 5, 2002) is required for a lake alum treatment. This permit requires that an integrated aquatic vegetation management plan (IAVMP) be prepared and submitted to Ecology with the permit application for nuisance plant and algae control. However, because alum would be used to control phosphorus, rather than nuisance vegetation, the state requires that an integrated phosphorus management plan (IPMP), instead of an IAVMP, be submitted to Ecology for review and approval by Ecology.

Per guidance from Ecology, this IPMP includes a problem statement and a discussion of the following: past phosphorus management efforts, phosphorus management goals, lake and watershed characteristics, current and potential beneficial and recreational uses of the lake, phosphorus management alternatives, selected methods for phosphorus management, and a public involvement plan (Shoblom 2003). The Green Lake Alum Treatment Study is included as Appendix A. The State Environmental Policy Act (SEPA) checklist and water quality monitoring plan are included in this IPMP as Appendices B and C, respectively.

Problem Statement

As reported in Herrera (2003), recent (1995–2000) sampling by the City of Seattle indicates that the summer mean phosphorus concentration in Green Lake is 25 µg/L, which does not meet the goal of less than 25 µg/L recommended by the Phase II restoration project completion report (KCM 1995). In addition, the summer mean Secchi depth (measure of transparency) is 2.3 meters, which does not meet the goal of greater than 2.5 meters.

When lake phosphorus levels are high, summer blue-green bacteria outbreaks occur resulting in lake closures because of the toxicity of the blue-green bacteria. The lake has been closed as recently as the late summer of 2003 for this reason. Because of ongoing summer toxic bacteria blooms, Seattle Parks and Recreation proposes to treat the lake with alum. Alum works by inactivating the sediment phosphorus, thereby reducing internal phosphorus loading and the availability of phosphorus to blue-green bacteria.

Past Phosphorus Management Efforts

Seattle Parks and Recreation with grant funding from Ecology and the U.S. EPA completed a Phase I diagnostic feasibility study in 1983 (URS 1983). The study concluded that phosphorus was the growth-limiting nutrient for algae in the lake. The report of the results outlined recommendations for treating the problem of algal blooms, which included the application of alum to inactivate phosphorus. An environmental impact statement (EIS) was completed to assess the impacts of several management efforts to control lake phosphorus levels including dilution with the City's drinking water supply, aeration, installation of test wells (for lake dilution), and other measures considered for phosphorus control (KCM 1995).

With additional grant monies awarded to the City from Ecology and the U.S. EPA, a Phase IIA plan was completed in 1987. The plan's recommendations included diluting the lake with water from Lake Washington or ground water, and apply alum to control phosphorus released from the bottom sediments (KCM 1995). The City received Phase IIB grant money to complete an EIS for the Green Lake Water Quality Improvement Project which assessed possible pipeline routes from Lake Washington to accomplish the dilution (URS 1990a). However, Ecology would not issue a permit for this type of consumptive water use; therefore, this management option was abandoned. The EIS also analyzed other possible solutions including dilution of the lake with treated lake water provided by a small onsite treatment plant, and alum treatment of the lake (URS 1990a).

In late 1990, the City of Seattle adopted a program to improve the quality of Green Lake and included the following measures for controlling both the internal and external sources of phosphorus: stormwater control improvements, inactivation of sediment phosphorus, aquatic macrophyte harvesting, dilution, biomanipulation, monitoring, and public education (KCM 1995). The program adopted by the city council became known as the Phase IIC water quality restoration program. The Phase IIC restoration project completion report concluded that the phosphorus goal should be reduced from a summer mean concentration of less than 30 µg/L to less than 25 µg/L (whole-lake average) (KCM 1995). The goal of a summer mean Secchi depth of greater than 2.5 meters has remained unchanged since the water quality improvement plan was adopted in 1990.

In addition to these phosphorus control management measures, recent lake management has also included stocking the lake with sterile tiger musky in 2000 to control common carp and stocking the lake with sterile grass carp in 2001 to control Eurasian watermilfoil. The City of Seattle has monitored the water quality in the lake to document lake phosphorus levels and Secchi depth. Seattle Public Utilities (SPU) is in the process of initiating a water quality study of the Densmore basin to investigate the existing water quality characteristics and problems within the basin.

Phase IIC Restoration Program

Phosphorus control measures in the Phase IIC restoration program included the 1991 alum treatment and a follow-up 3-year monitoring program, biomanipulation, Eurasian watermilfoil harvesting, stormwater control, dilution of the lake with excess City drinking water, and public education. These measures, which are described in the following subsections, either targeted significant sources of phosphorus or conditions that contribute to phosphorus loadings.

Alum Treatment

In October 1991, Green Lake was treated with 181 tons of alum and 76.5 tons of sodium aluminate to obtain a lake dose of 8.6 milligrams of aluminum per liter of water (mg Al/L) (KCM 1995). Sodium aluminate was added during the treatment as a buffering agent which maintained the lake's pH above 6.7 and its alkalinity above 27 mg/L of calcium carbonate ($CaCO_3$) (KCM 1995). After the lake's alum treatment, the phosphorus concentration dropped to 14 µg/L and water clarity (Secchi depth) increased from 1.9 to 6.1 meters (KCM 1995). After treatment, the summer mean total phosphorus concentrations were 20 µg/L in 1992, 26 µg/L in 1993, and 18 µg/L in 1994. The alum treatment was deemed successful at controlling sediment-bound phosphorus for a period of at least 3 years as measured by post-application water quality monitoring. However, by the late 1990s summer toxic bacteria blooms had returned, resulting in lake closures in 1999, 2002, and 2003.

Biomanipulation and Waterfowl Management

If a large population exists, Canada geese can be a significant contributor of phosphorus to the lake. Because their diet consists mostly of weeds, grass, and other vegetation, phosphorus constitutes a large component of goose excrement. Furthermore, the geese are rather productive in terms of waste generation. Because the vegetation they eat is mostly from the lake and surrounding area, this source of phosphorus is considered internal. However, through digestion, the geese produce a soluble form of phosphorus, which contributes to the lake's total phosphorus concentration (KCM 1995).

Instead of migrating seasonally out of the area, Canada geese have become year-round residents in and near the lake. The grassy areas near the lakeshore attract the birds, who have found the habitat ideal for feeding. Furthermore, the birds are nesting in the area and raising their offspring in and near the lake.

To address the increasing number of resident geese at the lake, the City began a Goose Management Program in 1987. The program initially focused on assessing the problem and conducting geese population studies. As a first step, approximately 100 Canada geese were relocated to eastern Washington and northern Idaho from 1990 through 1995 to help reduce the resident population (Stoops 2003a).

In 1993, an egg-addling program was started by the U.S. Department of Agriculture (USDA) to control the number of offspring generated by the resident goose population (Stoops 2003a). Currently, the program prevents approximately 1,500 eggs per year from hatching in the Puget Sound area and is successful at reducing the number of hatchlings, which potentially contribute to the resident population. No nests were found at Green Lake during spring 2003 (Linnell 2003).

In 1997, the USDA began a capture, removal, and euthanasia program, which has removed up to 2,500 geese per year from the Lake Washington basin (Stoops 2003a). Although site-specific data are not available, in recent years Green Lake has not been a major source of geese for this management program.

Aquatic Plant Harvesting

In 1981, when the Phase I diagnostic feasibility study began, a limited occurrence of Eurasian watermilfoil (*Myriophyllum spicatum*) was documented in the lake (Stoops 1996). During the next several years as the milfoil became more abundant, the City mounted hand-pulling efforts to remove the milfoil with the aid of volunteers. However, by 1991 the milfoil growth had covered most of the lake in areas where the water depth was greater than 5 feet and less than 20 feet (Stoops 1996).

The City purchased an aquatic plant harvester in 1992 to control the abundant growth of Eurasian watermilfoil, which at one point covered 75 to 90 percent of the lake between depths of 1.5 and 5.5 meters (KCM 1995). The cutting and removal of Eurasian watermilfoil began in late summer 1992 (KCM 1995). The biomass of the milfoil removed (via harvester) was 483 grams per square meter (g/m^2) in 1991, 87 g/m^2 in 1992, 185 g/m^2 in 1993, 130 g/m^2 in 1994, and 58 g/m^2 in 1995 (Seattle 2001). The amount of milfoil removed from the lake decreased from a high of 1,200 tons in 1992 to only 30 tons in 1995 (Seattle 2001). In addition to milfoil removal with the harvester, removal of plants that had accumulated at the shoreline occurred in 1992 and 1993 (Stoops 2003b).

Since 1995, the amount of milfoil removed from the lake (via harvester) has been minimal, ranging from approximately 15 to 30 tons/year (Stoops 2003b). The aquatic plant harvester is currently used approximately 5 to 10 days per year, mostly in the rowing lanes before regattas or other boating events. No harvesting has been necessary in the lake in 2003 (Stoops 2003b).

Stormwater Controls

As part of the lake's restoration program, measures were implemented to remove the amount of stormwater entering the lake. These projects included diverting stormwater runoff in mid-1993 from the Densmore drainage basin to the City's Metro University Regulator storm drain and away from Green Lake (KCM 1995). The Densmore diversion reduced the stormwater phosphorus loadings by 68 kilograms (kg) annually (86 percent) within the basin (KCM 1995).

Lake phosphorus loadings were further reduced by the addition of stormwater treatment facilities to treat stormwater runoff from a portion of Green Lake Way and the parking lots at the south end of Green Lake Park (nearshore basin) before it enters the lake. The stormwater treatment facilities included oil/water separators and biofiltration vaults consisting of either gravel or crushed glass. North of Green Lake, some stormwater was directed to the Licton Springs system for water quality treatment, which includes a wetland and small pond. Based on the results of water quality monitoring associated with the restoration program, these stormwater controls resulted in a reduction in annual phosphorus loading to the lake of 89 kg/year or by 55 percent (KCM 1995).

Dilution with City Water

Prior to the 1991 alum treatment, water from the City's drinking water supply was directed to Green Lake to dilute the lake water in an attempt to lower the phosphorus levels. This water was discharged from the City's outfalls located near the shore at the lake's surface. From 1976 through 1991, the average annual discharge rate ranged from 1.9 to 6.1 million gallons per day (mgd), average monthly rates ranged from 1.7 mgd in December to 5.2 mgd in May, and the overall average rate was 3.12 mgd (Capron 2003). This average discharge rate is equivalent to an annual volume of 4.32 million cubic meters or 105 percent of the lake volume. Intentional dilution of Green Lake with drinking water has not occurred since the 1992 drought (KCM 1995; Capron 2003).

Since the 1991 alum treatment, drinking water has been discharged to Green Lake only when Maple Leaf reservoir or Roosevelt reservoir (formerly known as Green Lake reservoir) required flushing to reduce bacteria concentrations, or when they were drained prior to cleaning (Capron 2003). From 1992 through 1995, the average discharge rate was 0.5 mgd, which is equivalent to only 17 percent of the lake volume per year. Due to an inoperable flow meter, discharge monitoring was discontinued in October 1996 (Capron 2003). Average annual discharge rates since 1996 are estimated to be similar to the rate of 0.5 mgd for the 1992–1995 period.

Public Education

Before the 1991 lake alum treatment, the City held an information fair and installed two kiosks to help educate the public about the lake alum treatment and other ongoing lake restoration efforts. The City also distributed written information throughout the watershed and held public meetings to explain the alum treatment and the ongoing restoration program and to further increase public awareness about urban watershed management issues (KCM 1995). A video was developed at the conclusion of the Phase II project that described the lake restoration program and water quality issues related to the lake.

Post-treatment Management Efforts

Since the Phase IIC restoration project was completed in 1995, additional lake management efforts have been undertaken to help control lake phosphorus levels and are described in the following subsections.

Fisheries

In an effort to control the population of common carp, Washington Department of Fish and Wildlife (WDFW) stocked Green Lake in November 2000 with 150 sterile tiger musky, which is a cross between muskellunge (*Esox masquinongy*) and northern pike (*Esox lucius*) (Herrera 2003). The tiger musky were 18 inches long and expected to grow to 36 inches in 1 year. Fish surveys conducted by WDFW since the stocking indicate that common carp continue to dominate (75 percent) the fish biomass in the lake, but tiger musky now represent the second largest fish population (18 percent of biomass).

In an effort to control Eurasian watermilfoil, Seattle Parks and Recreation stocked Green Lake in August 2001 with 777 triploid (sterile) grass carp. The potential for these grass carp to consume and control Eurasian watermilfoil have not been evaluated by the City or WDFW.

Densmore Drainage Basin Study

The Densmore basin consists of 1,698 acres, representing approximately 91 percent of the Green Lake watershed. Seattle Public Utilities (SPU) is in the process of conducting an investigation of stormwater drainage and water quality in the Densmore basin. This project involves compiling and reviewing available water quality and sediment quality data; characterizing existing drainage features; identifying methods for improving water quality in the basin; identifying capital improvement projects that may improve water quality within the basin; and identifying needs for water quality data. The goals of the project are to provide recommendations for improving water quality within the basin through stormwater pollution prevention efforts and capital improvement projects for stormwater treatment.

In addition, these basin management efforts will identify alternatives for reducing the amount of flooding within the basin. The amount of stormwater runoff entering the lake will likely increase as a result of the proposed drainage improvements within the basin. The investigation will identify potential limnological and water quality impacts on Green Lake under drainage improvement alternatives proposed for the Densmore basin.

Public Education

The City conducts numerous public education and outreach programs directed at reducing the amount of nonpoint source pollution, including phosphorus, in Seattle's receiving waters. These programs include natural lawn care, green gardening, storm drain stenciling, and environmental education programs in schools (Seattle 2002).

Phosphorus Management Goals

The phosphorus management goals for Green Lake are: a mean summer total phosphorus concentration of less than 25 µg/L based on a whole-lake average, and a Secchi depth (transparency) of greater than 2.5 meters. Comparison of summer mean values for the post-treatment period (i.e., three years following the 1991 alum treatment) to those for recent years (1995 through 2000) indicates that the total phosphorus concentration has increased from 21 to 25 µg/L and Secchi depth has decreased from 3.1 to 2.3 feet (Herrera 2003). Although the lake has not been routinely monitored in recent years, intense blue-green bacteria blooms have been observed each summer since 1999, suggesting that mean phosphorus concentrations may have been higher and mean Secchi depths may have been lower than those reported.

Seattle Parks and Recreation proposes to treat the lake with alum again to lower the lake phosphorus levels and to increase the water clarity. It is anticipated that this treatment will prevent future lake closures due to outbreaks of toxic blue-green bacteria and maximize the recreational and aesthetic uses of the lake for the next 10 years.

Watershed Characteristics

Green Lake is located in King County, Washington, in an area just north of downtown Seattle and Lake Union. Green Lake is located in WRIA 8, which includes the Cedar-Sammamish watershed and Lake Washington, Lake Union, Lake Sammamish, and most of Seattle. The Green Lake watershed consists of 4,270 acres (1,728 hectares [ha]) and encompasses three major basins, which are shown in Figure 1. The basins include the Densmore basin with an area of 1,698 acres (687 ha), the Woodland Park basin with an area of 72 acres (29 ha), and the nearshore basin with an area of 103 acres (42 ha). A fourth basin, the Phinney Ridge basin, contributes base flow of ground water to the lake but does not contribute measurable amounts of stormwater runoff (Herrera 1995).

Land use in the Green Lake watershed consists largely of single-family and multifamily residences with small commercial developments. However, land use activities vary greatly between the major basins. Most of the development in the Densmore basin is characterized by single-family residential use. However, small areas of the basin are developed for commercial use, such as the Aurora Avenue North traffic corridor (Herrera 1995). In contrast, the Woodland Park and nearshore basins are largely undeveloped; approximately 87 percent of the two basins is covered with brush or grass, with pavement covering the remaining 13 percent (Herrera 1995). The immediate surroundings of the lake include park grounds, parking lots of various sizes, small buildings, and residential streets that encircle the lake (KCM 1995).

No natural streams flow into Green Lake (KCM 1995). A small wetland north of Green Lake, known as the Licton Springs wetland, discharges into a small detention pond before ultimately discharging into the Densmore basin drainage system.

Direct precipitation is the major source of inflow to Green Lake. Total annual inflows of precipitation were estimated at 39 percent from 1992 to 1994, accounting for the largest source of inflow during that time period (Herrera 1995).

Domestic freshwater inputs from the Maple Leaf drinking water reservoir and the Roosevelt drinking water reservoir (formerly known as the Green Lake reservoir) provide another major source of inflow to Green Lake. The inputs of City drinking water vary a great deal from year to year, depending on water availability and demand (see the Past Phosphorus Management Efforts section). The average drinking water input from 1992 to 1994 was estimated at 33 percent of the total lake inflow (Herrera 1995). Drinking water input accounted for 62 percent of the total inflow in 1981 (KCM 1995), and was approximately three times higher in 1976 than in the 1981 diagnostic study year (Capron 2003).

Stormwater runoff from the Densmore, Woodland Park, and nearshore basins contributed a relatively small volume of water to the lake in the 1992 to 1994 Phase IIC study, totaling an average of only 13 percent of the total lake inflow (Herrera 1995). Although the Densmore basin is much larger than the other basins, runoff from the Densmore basin represented only 50 percent of the total stormwater inflow because most of the runoff from the Densmore basin is diverted

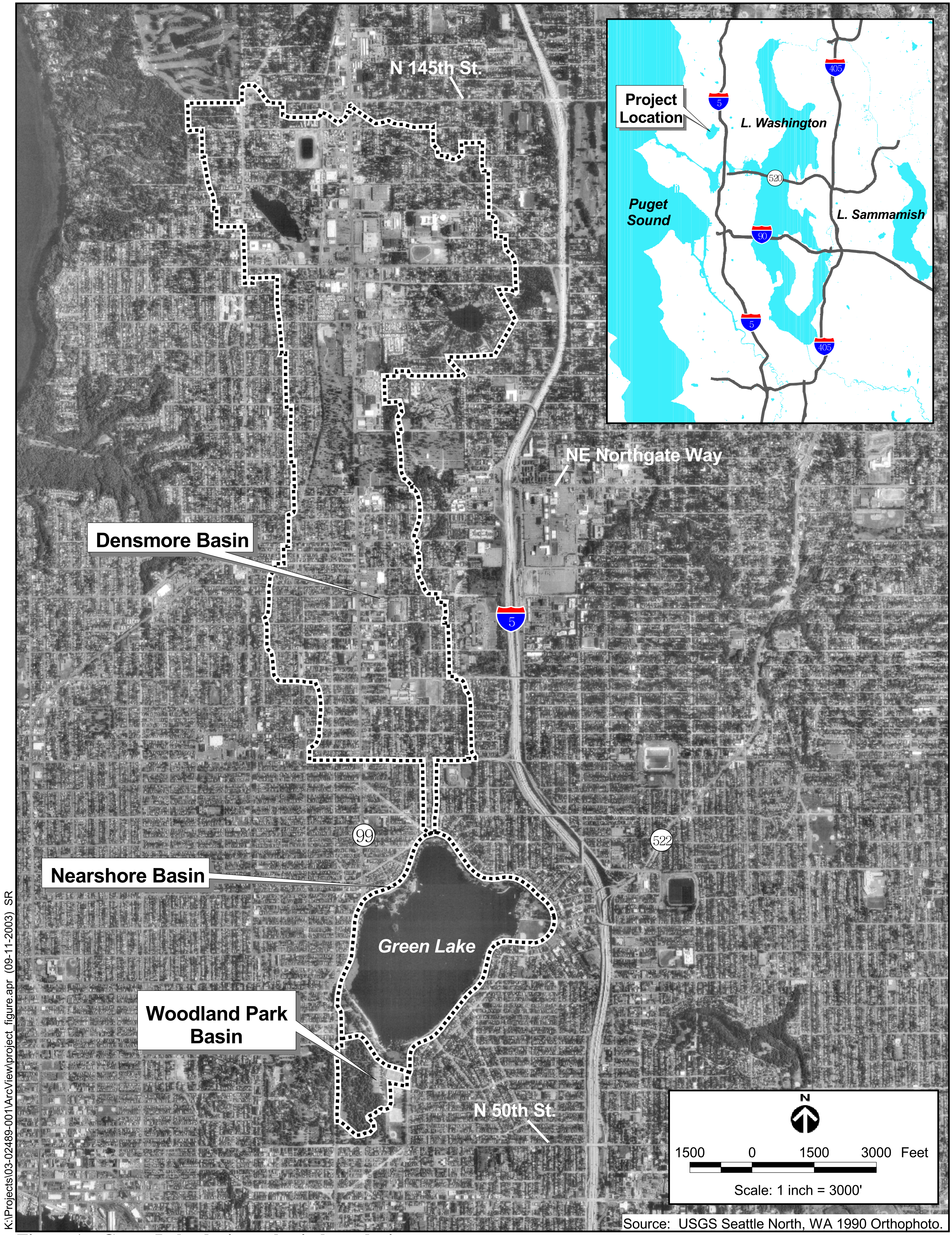


Figure 1. Green Lake drainage basin boundaries.

away from Green Lake. Before 1993, base flow and most of the runoff from the Densmore basin drained to Seattle's combined sewer system. Upon completion of King County's University Regulator project in 1993, this drainage was diverted from the sewer system to Lake Union, and stormwater discharge to Green Lake was reduced by the construction of a new diversion structure in the Densmore drain. Inputs of base flow from the Woodland Park and Phinney drains constituted 12 percent of the total lake inflow. (Inputs of phosphorus from the drainage basins are summarized in the Lake Characteristics section).

Lake Characteristics

Green Lake covers an area of 259 acres (104 ha) and is considered to be a fairly shallow lake, with a mean depth of 3.9 meters and a maximum depth of 9.1 meters. The deepest area in Green Lake is located near the northeastern shore of the lake (Figure 2). The volume of Green Lake is 4.12 million cubic meters (m^3). A variety of water sources discharge into Green Lake, greatly influencing the flushing rate and residence time of the water. The estimated mean residence time of water in Green Lake ranged from 2.6 years in 1994 to 5.0 years in 1992 (KCM 1995).

Water Quality

The water quality in Green Lake has been periodically analyzed for the following parameters to determine the trophic state of the lake: total phosphorus, Secchi depth, and chlorophyll *a*. Table 1 compares the water quality of samples from Stations A and B in Green Lake. Decreasing water quality is indicated by substantial increases in recent (1995–2000) mean values of total phosphorus and chlorophyll *a* and decreases in Secchi depth compared to the post-treatment period (1992–1994). A comparison of the mean summer (June through September) values of Secchi depth and total phosphorus in Green Lake from 1981 to 2000 is provided in Table 2. In a trend similar to that indicated in Table 1, improvement in both total phosphorus and Secchi depth is evident after Green Lake was treated with alum in 1991. In addition, the recent data (1995–2000) show diminishing water quality during the summer months. Observations of intense blue-green bacteria blooms since 1999 suggest that the water quality may have been even worse than that shown for recent years in Tables 1 and 2.

Table 1. Comparisons of post-treatment and recent water quality data for depth-composited samples from composite A and B stations in Green Lake.

	Post-treatment (1992–1994) [a]			Recent (1995–2000) [b]		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Secchi depth (meters)	3.7	1.2	7.8	2.4	0.5	4.8
Soluble reactive phosphorus (µg/L)	3.4	1	11	3.5	1	15
Total phosphorus (µg/L)	18.7	7	38	24.6	13	51
Chlorophyll *a* (µg/L)	7	1	24	13.1	2.6	68

[a] Source: KCM (1995) (49 sampling dates) [b] Source: Seattle (2003a) (18 sampling dates)

Several additional water quality parameters, including temperature, dissolved oxygen, and pH, have been monitored in Green Lake to determine the health of the lake. During the post-alum-treatment monitoring period (1992–1994), temperature measurements ranged from 8 to 25 degrees Celsius (°C), pH values ranged from 7.8 to 9.3, and dissolved oxygen levels varied from 4 to 12 mg/L (KCM 1995). More recent temperature, dissolved oxygen, and pH data are available in Appendix A of Green Lake Alum Treatment Study (Herrera 2003), (included as Appendix A of this management plan).

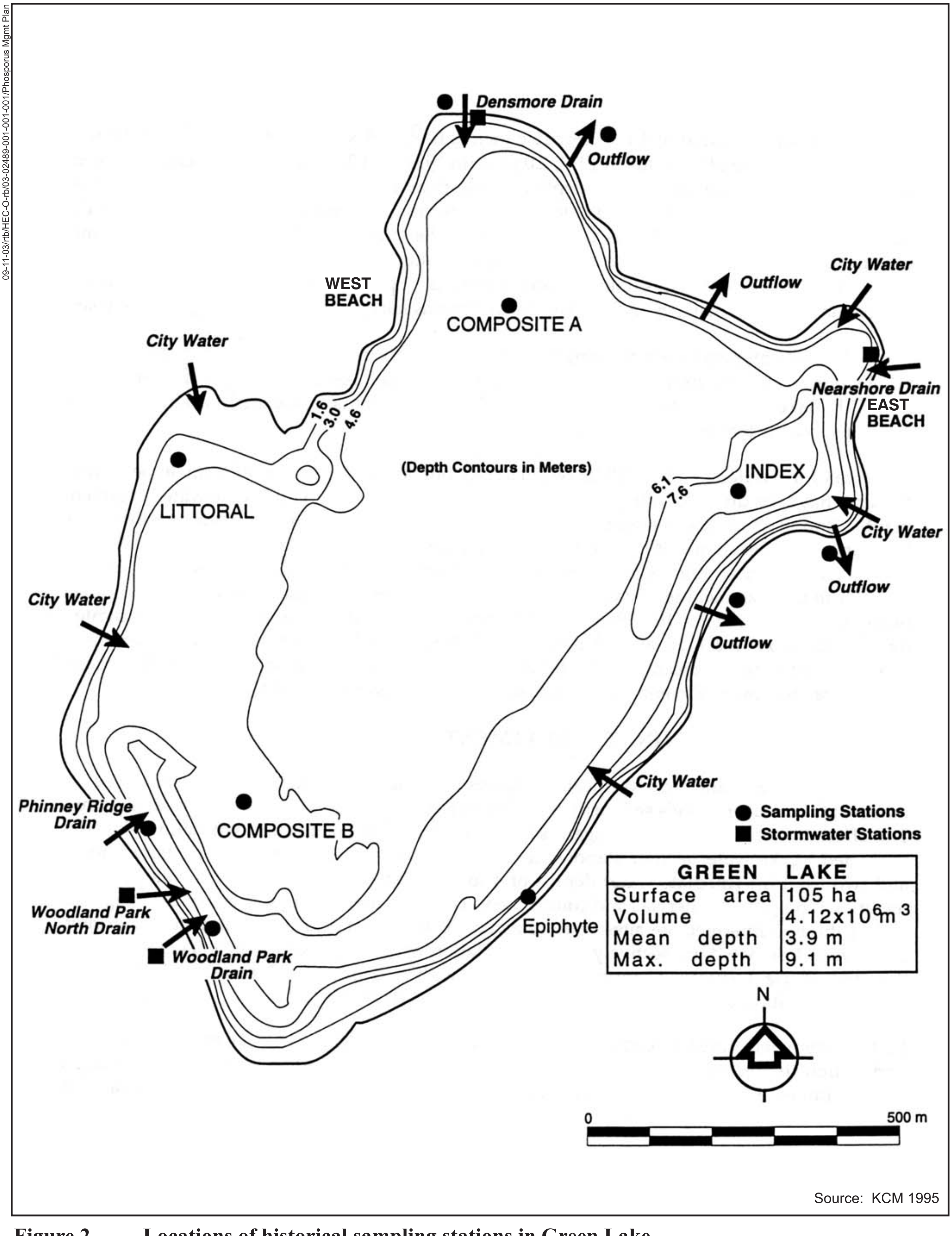


Figure 2. Locations of historical sampling stations in Green Lake.

Table 2. Comparisons of mean summer (June–September) Secchi depths and total phosphorus concentrations to restoration goals for Green Lake.

	Restoration Goal	Pre-treatment [a]			Post-treatment [a]			Recent [b]
		1981	1989	1990	1992	1993	1994	1995–2000
Secchi depth (meters)	>2.5	2.8	NA	NA	3.4	2.9	3.0	2.3
Total phosphorus (µg/L)	<25	52	29	28	20	26	18	25

NA = not available
[a] Data source: KCM (1995)
[b] Data source: Seattle (2003a)

SPU monitors Green Lake for levels of microcystin, which is a hepatotoxin (liver toxin) produced by several species of freshwater blue-green bacteria. Data were collected at least monthly to monitor lake algae levels to determine the presence of blue-green bacteria within the lake from August 2002 through January 2003 (Seattle 2003b, and included in Appendix A). The World Health Organization (WHO) has established a guideline of 1 µg/L for microcystin in drinking water that includes both the free and cell-bound forms of the toxin. Samples were analyzed for microcystin before and after the bacteria cells had been crushed (sonicated) for comparison to the WHO guideline for free and cell-bound toxin. Several of the uncrushed samples exhibited microcystin concentrations above the WHO guideline for drinking water, and all crushed samples exceeded the guideline. The maximum microcystin concentration in a crushed sample was approximately 100 µg/L on October 12, 2002, and the second highest microcystin concentration (approximately 80 µg/L) was observed very late in the season on December 7, 2002.

King County collects water quality samples in Green Lake for purposes of tracking lake bacteria levels for human health purposes (King County 2003b). These data are used to determine the need for beach closures during the summer. Data collected weekly by King County from mid-May through mid-September (1998 to 2001) include fecal coliform bacteria, enterococcus bacteria, and water temperature. Concentrations of fecal coliform bacteria ranged from 1 to 2,350 organisms/100 milliliters (mL). The Washington state surface water quality criterion for fecal coliform bacteria (50 organisms/100 mL) was exceeded in approximately 25 percent of the 92 samples collected.

Phosphorus Loading

The source of the elevated phosphorus concentrations and the associated blooms of blue-green bacteria have been linked to both external loading and internal cycling of this nutrient. Numerous external sources have contributed to elevated phosphorus concentrations in Green Lake: surface runoff from the surrounding watershed, City water, precipitation, ground water, and several additional sources. As shown by the annual phosphorus budgets in Table 3, efforts to reduce phosphorus loading from the lake drainage basins have been successful, especially in the Densmore basin. However, it is also evident that other input sources, such as waterfowl and aquatic macrophytes, continue to contribute substantial amounts of phosphorus to Green Lake.

Table 3. Comparison of annual phosphorus budgets for Green Lake from 1981 to 1994.

	Total Phosphorus (kilograms)			
	1981	1992	1993	1994
Input Source				
Densmore basin	45	79	41	11
Woodland Park basin	30	55	42	39
Nearshore basin	89	21	19	16
Phinney basin	11	6	6	6
City water	39	9	8	4
Direct precipitation	21	19	19	20
Ground water	NA	10	48	36
Waterfowl (new) [a]	NA	16	16	17
Waterfowl (transformed) [b]	NA	144	143	154
Macrophyte	NA	205	283	197
Vertical migration	NA	33	4	1
Internal	3.5	0	0	0
Total	235	597	629	501
Output				
Outlet	178	13	43	23
Sedimentation	NA	478	613	478
Ground water	NA	29	14	19
Total	178	520	670	520
Lake storage change	61	77	–40	–20

Source: KCM 1995
NA = not available
[a] Bird dropping-related phosphorus derived from food sources external to Green Lake (e.g., bread and shoreline grasses)
[b] Bird dropping-related phosphorus derived from food sources within the lake (e.g., aquatic plants)

Studies have indicated that internal cycling and loading of phosphorus is largely responsible for the intense blooms of blue-green bacteria. In 1981, Bolstridge (1982) and Perkins (1983) found that 88 percent of the phosphorus budget during the summer was from internal sources, with lake sediments the principal source (KCM 1995). Other estimates approximate the internal loading rates at 60 to 70 percent (KCM 1995). Several factors play a role in the internal cycling of phosphorus in Green Lake. A source of internal cycling lies in the life cycle of blue-green bacteria; they take up phosphorus from lake sediments before maturing and migrating upward into the water column. The movement of the sediment into the upper portions of the water column has been documented to contribute to significant increases of phosphorus in the lake (KCM 1995).

Phosphorus is also released through aquatic plant (macrophyte) senescence and decay, which is exacerbated by the extremely high biomass accumulations generated by Eurasian watermilfoil in Green Lake (Table 3). In addition, periodic depletion of dissolved oxygen in the hypolimnion can promote increased phosphorus release from sediments into the water column (KCM 1995). Finally, the abundance of common carp, although not quantified, is likely to enhance the cycling of phosphorus in the lake.

Plankton

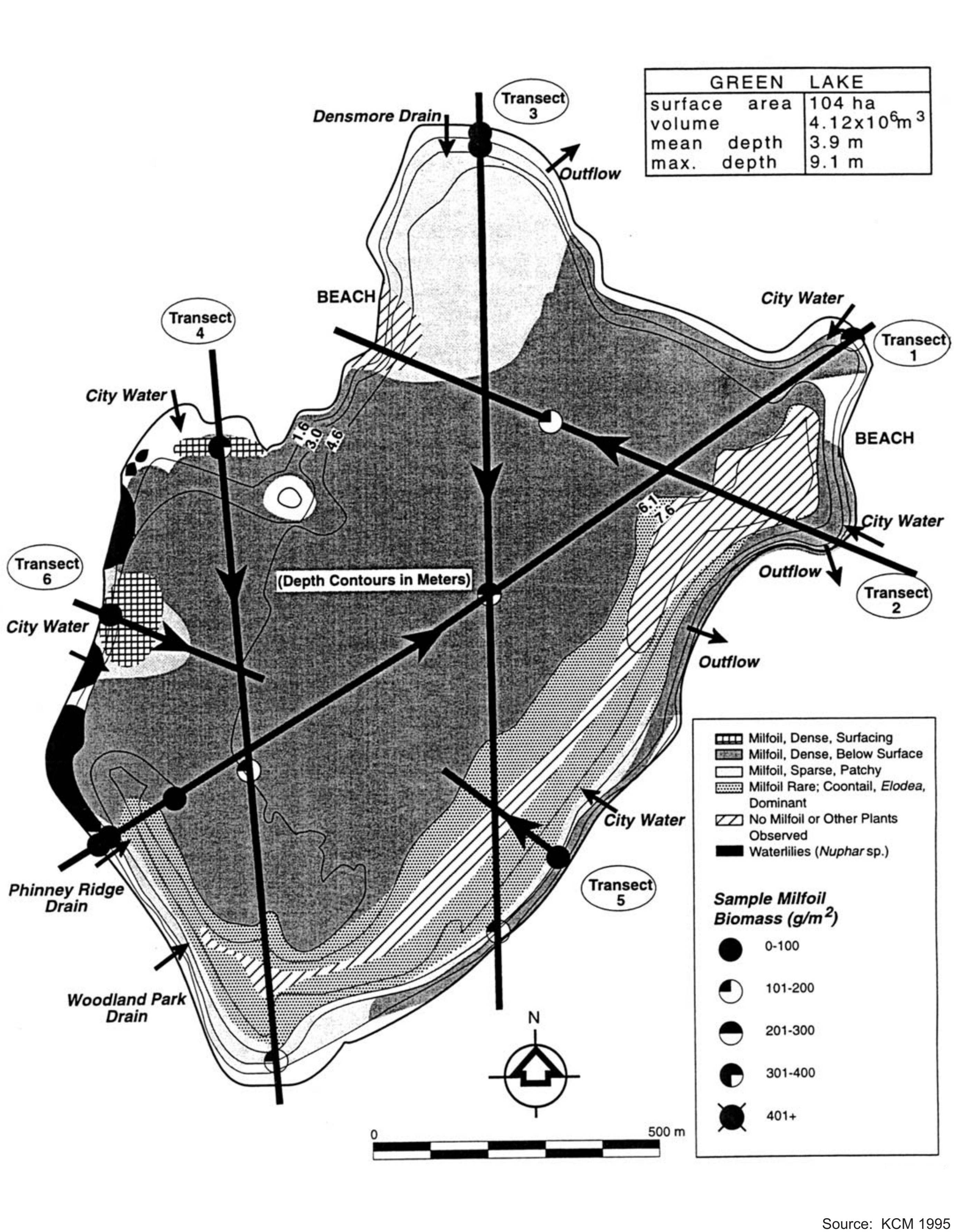
Green Lake contains many species of phytoplankton and zooplankton. The relative abundance of phytoplankton species typically depends on the season. During the spring, the diatoms *Asterionella* and *Fragilaria* can dominate Green Lake, as was observed in 1981 (KCM 1995). However, during the summer (June–September), blue-green bacteria usually become the dominant species in the lake. The dominant blue-green bacteria include *Gloeotrichia echinulata*, *Aphanizomenon flos-aquae, Anabaena* spp., and *Microcysistis aeruginosa*.

During the Phase IIC study in 1992 and 1994, zooplankton biomass peaked in the winter or spring, and was dominated by cladocerans (water fleas including *Daphnia* spp., *Ceriodaphnia* sp., and *Bosmia longirostris*) (KCM 1995). Cyclopoid copepods were also most abundant in the winter and spring, and *Diacyclops bicuspidatus thomasi* was the dominant species. Calanoid copepods were most abundant in summer, and included *Diaptomus oregonensis* and *Epischura nevadensis* as the dominant species. Rotifers (*Keratella* and *Polyarthra*) and immature copepods were typically most numerous in the lake, but did not comprise a substantial portion of the zooplankton biomass due to their small size.

Aquatic Plants

Surveys of Green Lake conducted in 1991–1994 indicated that Eurasian watermilfoil (*Myriophyllum spicatum*) was the dominant species among Green Lake's vascular plants (KCM 1995). Eurasian watermilfoil is native to Europe, Asia, and North Africa and also occurs in Greenland but is not native to the United States (WSNCB 2003). This nonnative species was first documented in Washington in 1965 in Lake Meridian, King County (King County 2003a). Eurasian watermilfoil is classified as a nonnative noxious weed, legally defined by Washington's Noxious Weed Control Law (RCW 17.10) as highly destructive, competitive, or difficult to control once established (WSNCB 2003). This perennial aquatic plant is characterized by feather-like leaves containing 12 to 16 leaflets on each leaf and often forms dense mats of vegetation just below the water's surface. In western Washington, Eurasian watermilfoil frequently over-winters and can maintain substantial biomass (King County 2003a).

The lake surveys indicated that between 75 and 90 percent of the 1.5- to 5.5-meter lake bottom depths were dominated by Eurasian watermilfoil (KCM 1995). The location and type of aquatic plants in the lake during the 1994 growing season are shown in Figure 3. The biomass (weight of vegetation per lake area) of Eurasian watermilfoil before harvesting and in areas left unharvested was approximately 480 grams per square meter (g/m^2) (KCM 1995).



Source: KCM 1995

Figure 3. **Aquatic plant distribution and growth patterns, including locations and relative measures of sample biomass (dry weight), September 14, 1994.**

In order to reduce the abundance of Eurasian watermilfoil at the lake surface, Seattle Parks and Recreation mechanically harvests the aquatic plant. In addition, in 2001 Green Lake was stocked with 777 triploid grass carp, which are herbivores, in an effort to further control the spread of Eurasian watermilfoil.

Additional macrophyte species observed in the lake include the submersed species coontail (*Ceratophyllum demersum*) and emergent species, such as cattails (*Typha*), rushes (*Juncus* and *Scirpus*), and *Iris*. (KCM 1995). Several dense beds of floating waterlilies (*Nuphar* and *Nymphaea*) have also been observed along the southwestern shoreline from 0.5 meters (1.5 feet from the shoreline) to a maximum depth of 2.5 meters (8.2 feet).

Shoreline Use

The shoreline use is largely confined to public activities relating to the park, which encircles the entire lake. Development includes grassed park grounds, associated parking lots, various park-related buildings and structures, and the surrounding street network. A paved trail for walking and running also encircles the lake. Residential and commercial properties dominate the areas adjacent to the park.

Wetland Areas

Very few wetland areas remain around Green Lake due to the development of the surrounding areas for residential, commercial, and park land purposes. One of the only remaining wetlands connected to Green Lake is the Licton Springs wetland. Located at North 97th Street and Ashworth Avenue North, the wetland discharges stormwater into a small pond (0.14 ha in size) before ultimately draining into Green Lake.

Fisheries

Most of the fish species residing in Green Lake have been introduced by the Washington Department of Fish and Wildlife (Herrera 2003). The lake is stocked with some fish species, such as rainbow trout (*Oncorhynchus mykiss*), on a regular basis to provide increased angling opportunities. In addition, two fish species have recently been introduced in the lake as a means of biomanipulation. In November 2000, the tiger musky, a hybridized fish species that is a cross between northern pike (*Esox lucius*) and muskellunge (*Esox masquinongy*), was introduced as a predator to reduce the population of common carp in the lake. In 2001, triploid (sterile) grass carp were introduced in the lake to reduce the abundance of milfoil. The potential effects on milfoil reduction by this recently introduced species has not been evaluated.

The results of the most recent fish survey indicate that the common carp is the dominant species in the lake, constituting approximately 75 percent of the total fish biomass and 30 percent of the total number of fish (Table 4). The second most abundant fish is tiger musky by biomass (18 percent) and largemouth bass by number (18 percent).

Table 4. Green Lake fishery survey conducted by the Washington Department of Fish and Wildlife from July 2001 to March 2003.

	Weight		Number		Total Length Range (millimeters)	
Type of Fish	Kilograms	Percent	Number	Percent	Minimum	Maximum
Brown bullhead (*Ameiurus nebulosus*)	6.0	0.7	23	1.7	157	390
Brown trout (*Salmo trutta*)	18.0	2.2	221	16.1	93	495
Sculpin (*Cottis* sp.)	2.9	0.4	175	12.8	25	180
Carp (*Cyprinus carpio*)	597.9	74.5	410	29.9	97	679
Grass carp (*Ctenopharyngodon idella*)	1.5	0.2	3	0.2	307	343
Largemouth bass (*Micropterus salmoides*)	13.6	1.7	254	18.5	52	531
Pumpkinseed sunfish (*Lepomis gibbosus*)	2.2	0.3	111	8.1	30	166
Rainbow trout (*Oncorhynchus mykiss*)	7.7	1.0	19	1.4	150	432
Rock bass (*Micropterus dolomieui*)	6.7	0.8	76	5.5	40	316
Tiger musky	143.0	17.8	40	2.9	595	920
Yellow perch (*Perca flavescens*)	2.9	0.4	39	2.8	48	232
Total	802.3	100.0	1,371	100		

Species surveys were conducted during 15 electrofishing surveys by the WDFW (2003, included in Appendix A). Data have been corrected for an estimated 10 percent catch rate of carp, most of which were released because of limited boat storage capacity.

Current and Potential Beneficial and Recreational Uses of the Lake

Aesthetics

Green Lake Park is one of the most heavily used parks in Seattle, with thousands of people using the lakeside path and other park facilities each day. The lakeside path extends 2.8 miles around the lake and is used year-round for walking, running, skating, and bicycling. Path and park use is heaviest during the summer months. The centerpiece of the park is Green Lake itself, and the aesthetic character of the lake is a primary draw for park users. Most recreational activities that take place in the park occur on or immediately adjacent to the lake itself, and the aesthetic character of the lake has a determining effect on the quality of the recreational experience of most park users.

Boating

The public is able to enjoy a variety of recreational nonmotorized boating activities on Green Lake. Recreational uses of the lake include rowing, canoeing, kayaking, windsurfing, and sailing. The Green Lake Small Craft Center, located in the southwest area of the lake, provides instructional programs and competitions in such boating activities. Major boating competitions include youth, college, and adult rowing regattas in the spring and fall of each year that include competitors from throughout the Pacific Northwest. Boat access points for hand-carried boats are located at the Green Lake Small Craft Center and at the Green Lake West and Green Lake East beach areas. In addition, the Green Lake Boat Rental, a private company on the eastern side of the lake, offers a variety of canoes and boats for rental by the public. The rental season runs from approximately mid-May to mid-September.

Swimming

Swimming is a common recreational activity at the East Beach and West Beach, where swimming rafts with 1- and 3-meter diving boards are available. A small wading pool is located on the park grounds near the intersection of North 73rd Street and West Green Lake Drive North. Typically, the beaches are open from Memorial Day to Labor Day, serving over 10,000 swimmers each season. Green Lake has been closed for contact recreation on several occasions because the water quality was deemed unsafe for public use. The most recent closures occurred in August/September of 2003 and on August 5, 2002, because of blooms of blue-green bacteria.

Fishing

Fishing is another recreational activity at Green Lake. The numerous fish species in the lake provide a variety of fishing opportunities, including both cold (e.g., rainbow trout) and warm (e.g., bass) fisheries. In addition, the Green Lake Kids Fishing Derby is conducted every April to promote family participation in fishing. Before the derby, the lake is stocked with a large quantity of rainbow trout from WDFW hatcheries.

Three fishing piers are available for public use at Green Lake. The piers are located near the following addresses:

- East Green Lake Drive and Latona Avenue NE, at the foot of 65th Avenue NE
- West Green Lake Drive and Stone Way North, near the south end of the Bathhouse Theater
- West Green Lake Way North, at the Green Lake Small Craft Center.

The lakeside path also provides access to the shoreline areas for fisherman.

Phosphorus Management Alternatives

As part of the Phase I diagnostic feasibility study (URS 1983), numerous lake management alternatives were considered for the reduction of phosphorus in Green Lake. An EIS completed in 1990 (URS 1990a) addressed the feasibility and impacts of the management options identified in the Phase I diagnostic feasibility study. Table 5 presents a summary of these alternatives, separated into those that were implemented and those that were considered infeasible.

In late 1990, the Seattle City Council adopted a program to improve water quality at Green Lake (Seattle 1990). This water quality improvement program included the following lake management alternatives: lake alum treatment, biomanipulation, aquatic plant management, stormwater controls (Densmore diversion and nearshore treatment), and dilution with City drinking water (on a limited basis). The City implemented this program as summarized in the Past Phosphorus Management Efforts section of this plan.

Alternatives that were considered in the EIS but not adopted by the City Council include diversion of stormwater from additional basins, diluting the lake with another surface water or ground water source, construction of a lake water treatment plant, application of algicides, and the use of RIPLOX (sediment oxidation), aeration, dredging to control internal phosphorus sources, and a no action alternative of continuing with current practices. These phosphorus management alternatives were considered to be infeasible and are summarized in the following subsections.

Dilution

The City pursued the possibility of diluting lake waters with water pumped from Lake Washington (or Lake Union or Union Bay or Licton Springs) or with ground water or with City drinking water to reduce the overall phosphorus concentration in the lake. The City completed an EIS in 1990 that addressed these three dilution options (URS 1990a). However, after publication of the final EIS, Ecology determined that a transfer of Lake Washington water to Green Lake was a consumptive use that could not be permitted (KCM 1995). In addition, the total phosphorus concentrations (approximately 30 μg/L) in Lake Union and Union Bay were determined to be too high to provide any dilution benefit to Green Lake (URS 1983).

Ground water wells were drilled at Green Lake Park and in nearby View Ridge Park to serve as sources of ground water for dilution. The well drilled at Green Lake Park did not have a significant water yield. The well drilled at View Ridge Park produced water but had a high total phosphorus concentration (average of 750 μg/L). Dilution with water from the City's drinking water supply was analyzed but proved to be too costly (URS 1983). Dilution with the City's drinking water supply has occurred in the past but has been reduced to negligible amounts in recent years (see the Past Phosphorus Management Efforts section).

Table 5. Summary of alternative lake management methods that are being implemented and were considered for restoration of Green Lake.

Restoration Method	Description
Alternatives Implemented	
Lake alum treatment	First alum treatment occurred in 1991. Inactivates sediment phosphorus release. Much lower cost than dilution.
Biomanipulation	1. Waterfowl management program began in 1989. Methods of control include removal, euthanasia, and egg addling to reduce numbers of resident Canada geese. 2. Fish management. Lake was stocked with tiger musky in 2000 to control common carp.
Aquatic plant management	Harvesting has been conducted since 1992 to remove Eurasian watermilfoil from boating areas. In 2001, the lake was stocked with 777 triploid grass carp to control Eurasian watermilfoil.
Stormwater controls	A new diversion structure was constructed in 1993 that increased the amount of stormwater diverted away from the lake in the Densmore basin. Stormwater treatment facilities were constructed in the nearshore basin.
Dilution with City water	Prior to the 1991 alum treatment, excess City drinking water was delivered to the lake for dilution, but has been limited to when reservoirs are flushed or drained for maintenance since the treatment.
Additional Alternatives Considered [a, b]	
Restoration Method	Considerations
Reduce external phosphorus sources	
Divert nearshore runoff in park	Rejected due to collection, disposal, and safety concerns and ineffectiveness in reducing summer phosphorus levels. [a]
Divert Woodland/Phinney drains	Considered not cost-effective/feasible due to impact on existing storm drain in Aurora Avenue North.
Reduce phosphorus concentration by dilution	
City water	High-quality source (low phosphorus). Sufficient volume not available when needed; currently done on a limited basis. High cost compared with other alternatives. Not reliable during shortage conditions. [a, b]
Lake Washington water	Rejected because Washington Department of Ecology would not issue a permit for a consumptive use. [a, b]
Ground water	Unavailable quantity or quality. [a, b]
Green Lake water treatment	Not feasible due to high cost and required use of park land.
Treated Ship Canal water	Rejected because Washington Department of Ecology would not issue a permit for a consumptive use.
Algicides	Rejected due to environmental effects. [a]
Reduce internal phosphorus sources	
RIPLOX method	Prevents conditions needed for phosphorus release by oxidizing sediment. Eliminated due to lack of confidence in its effectiveness for Green Lake and because of high cost. [b]
Aeration	Prevents conditions needed for phosphorus release and prevents rise of bottom developing algae. Rejected due to adverse impacts on aesthetics and recreation and due to potential vandalism. [a]
Dredging	Removes sediment high in phosphorus. Rejected due to ineffectiveness and high cost of disposal. [a]

Source: Table adapted from URS (1990a) and Herrera (2003).
[a] Green Lake restoration diagnostic feasibility study (URS 1983)
[b] Green Lake water quality improvement plan (URS 1987)

Treatment Plant

The City pursued the possibility of building a treatment plant at the lake, which would treat lake water and recycle the clean water back into the lake, thereby reducing the lake phosphorus concentration. This method would provide an effective, long-term solution; however, because this alternative would require the construction, operation, and maintenance of a treatment plant, the cost of this alternative made it infeasible (URS 1983, 1990a).

Stormwater Diversion

In an effort to reduce combined sewer overflows to Lake Union, King County implemented the University Regulator project, which diverted additional stormwater out of the Green Lake watershed from the Densmore basin (discussed in the Past Phosphorus Management Efforts section). However, stormwater from the Woodland Park and nearshore basins has not been diverted from the lake. The EIS concluded (URS 1990a) that these projects would be costly and because the control would target stormwater, mostly a wet season input, these diversions would likely have minimal effects in reducing summertime phosphorus levels (URS 1990a).

Algicides

Algicides provide effective short-term algae control by poisoning the algae and blue-green bacteria. Algicides (such as copper sulfate) are effective only while the active ingredient is in the water column and available for uptake by the algae (Cooke et al. 1993). Typically, several applications must occur within the same season to provide effective control of algae and blue-green bacteria. Algicides do not reduce phosphorus concentrations and do not provide long-term control. Currently, endothall (Hydrothol® 191) is the only algicide that can be used in the state of Washington, and Ecology will not issue a permit for the use of copper sulfate. The use of algicides is not a suitable option for controlling algae in Green Lake because of their adverse side effects and the potential risk for human health and aquatic life (URS 1983).

RIPLOX (Sediment Oxidation)

By oxidation of the sediments, RIPLOX prevents the conditions needed for their release of phosphorus. The sediments are oxidized by injection with calcium nitrate ($Ca[NO_3]_2$) to stimulate denitrification (reduction of nitrates to nitrogen gas). This method is not an option for Green Lake because of the high cost and its lack of known effectiveness (URS 1983).

Aeration

Anoxic (oxygen poor) conditions result in the release of iron-bound phosphorus from lake sediments. Development of anoxic conditions near the lake's bottom would be prevented by aeration. Aeration may also reduce the rise of bottom-developing algae. URS (1983) determined that lake aeration devices are not a suitable option for Green Lake because they would interfere with the aesthetic and recreational uses of the lake and because of the potential for vandalism of the equipment.

Dredging

One method for removing sediments high in phosphorus is dredging or removing the sediments from the lake. However, dredging occurred in 1935–1937 and in 1962 and was generally ineffective in improving water quality in the lake (URS 1983). Analysis of sediment core samples has indicated that the phosphorus concentrations in the sediments are uniform and that removing the top layer of sediments would not reduce the concentrations (URS 1983). Therefore, the dredging of lake sediments is not considered an option because of the long-term ineffectiveness and the high cost of removal and sediment disposal (URS 1983).

No Action

The no-action alternative for phosphorus management consists of continuing with current practices previously described in Past Phosphorus Management Efforts Section. Established phosphorus and lake management goals would not be achieved under the no-action alternative, as concluded by the *Green Lake Water Quality Improvement Project Final Environmental Impact Statement* (URS 1983). Intense blue-green bacteria blooms would continue to occur in Green Lake during the summer, resulting in severe aesthetic impacts, closures of the lake to recreational activities, and potential public health impacts due to the consumption of toxic blue-green bacteria by lake users. The no-action alternative could result in economic impacts related to a reduced vitality of businesses that are located around the lake and depend on lake users.

Selected Method for Phosphorus Management

Since the first lake alum treatment in 1991, the City has undertaken numerous management efforts to help maintain the reduced phosphorus concentrations achieved after that treatment. Such measures have included diverting stormwater, biomanipulation, public education, and milfoil harvesting. The City currently has an active waterfowl management program and conducts milfoil harvesting on a regular basis. However, such measures have not proved effective over the long-term at maintaining the total phosphorus concentrations at the recommended summer target level of less than 25 µg/L. Therefore, additional measure(s) are necessary to reduce the internal sediment loading of phosphorus within the lake.

Because of the success of the 1991 alum treatment in controlling sediment phosphorus sources, a second alum treatment is proposed by the City during the winter of 2004. This treatment will inactivate the internal cycling of phosphorus. The alum is applied near the water surface and it removes phosphorus from the water column as it flocculates and settles. It then covers the bottom sediments to further prevent the internal release of phosphorus from the sediments. The effectiveness of this alum treatment should last an estimated 10 years (Herrera 2003, see Appendix A).

The total cost of the lake alum treatment is approximately 1.5 million dollars (Herrera 2003). Compared to the cost of adding dilution water to the lake, at a rate of 300 acre-feet of City water for the next 10 years, the cost of the alum treatment is relatively low. The annual cost of adding 300 acre-feet of City water to the lake is approximately $437,800 (in 2004 dollars). This was calculated on the basis of the general service commodity charge during the peak usage period for 2004 ($3.35 per 100 cubic feet). Over a 10-year period, this would translate to approximately $4.4 million, unadjusted for inflation. This is approximately three times the cost of a 10-year effective alum treatment.

Public Involvement Plan

Past Public Involvement Efforts

In 1980, Seattle Parks and Recreation began a lake restoration program that started with a Phase I diagnostic feasibility study, followed by further analyses of the lake's problems and means of addressing such problems (URS 1983). Attention was initially focused on the continued dilution using ground water or water from the Lake Washington Ship Canal or, alternatively, the use of aluminum salts to inactivate sediment phosphorus. A number of other methods were considered but rejected. Various public meetings regarding Green Lake were held at that time, and a citizens committee convened to help narrow the choice of alternatives that were considered in an EIS in 1989–1990 (URS 1990a, 1990b, 1990c). No low-nutrient ground water source was found, and dilution with water from the Lake Washington Ship Canal was found to require an expensive piping system with very high energy and operating costs, as well as being in conflict with Ecology's nonconsumptive use policy.

Numerous meetings were held associated with the EIS process and the subsequent decision process related to the adoption of a Green Lake water quality improvement plan. These included public meetings held by Seattle Parks and Recreation staff at Green Lake and a hearing before the Board of Parks Commissioners in 1990 after Parks staff recommended a plan with alum treatment as its cornerstone. Before the Seattle City Council considered any adoption of the plan in late 1990, a value engineering analysis was undertaken, culminating in a public forum at Green Lake to answer questions about filtration and alum treatment options. The City Council ultimately adopted the plan in late November 1990. Included in the plan was a detailed public education element.

Alum was first applied to Green Lake in November 1991. Before the treatment was initiated, Seattle Parks and Recreation and its consultant team held an all-weekend information fair at Green Lake to describe the alum treatment process and answer any questions about health and safety risks associated with alum. Brochures were prepared to describe the water quality improvement plan and answer frequently asked questions about alum. Just before the alum treatment, notices were sent to hundreds of residents near Green Lake to describe the alum treatment and to announce the closure of the lake during the treatment activity. Lake monitoring results were shared in meetings during 1992–1993 in which Parks staff met with surrounding community councils in the Green Lake, Roosevelt, University, and Phinney Ridge neighborhoods.

Other public outreach efforts after the initial alum treatment included distribution of flyers to park visitors explaining good stewardship of the lake and mailings to residents and businesses in the watershed north of Green Lake to ask for their assistance in protecting Green Lake from stormwater contamination. A grade school curriculum related to Green Lake, its history, and its natural processes was also produced and made available to three nearby elementary schools. In all of these, the lake's phosphorus issues were noted as well as the use of the alum treatment. Phase IIC of the Green Lake restoration project was a project completion report prepared in late 1995 (KCM 1995). Copies of the report, along with a video that summarizes the written report, were placed in the Green Lake branch of the Seattle Public Library for public review.

In recent years, Seattle Parks and Recreation staff have provided periodic updates for the public regarding the condition of Green Lake. In all cases, Parks staff have noted the consultant's recommendation from the 1995 report that alum treatment would be needed again, probably on a 5- to 8-year cycle. Parks staff met with the Green Lake Community Council on March 12, 2003, to discuss the water quality in Green Lake. This community council, and separately the Green Lake Rowing Advisory Council (which sponsors rowing and sailing activities at Green Lake) have advocated another alum treatment at Green Lake. The closure of the lake three times since 1999 due to algal problems has severely disrupted recreational rowing and boating programs at the lake.

Green Lake Community Council and Lake Restoration Committee

The Lake Restoration Committee was formed March 12, 2003, during a Green Lake Community Council meeting. The council is a volunteer group that meets every 2 months to discuss issues related to Green Lake. The newly formed committee meets monthly to discuss lake water quality issues and is focusing its efforts on finding solutions for the lake water quality problems. The first Lake Restoration Committee meeting was held on March 14, 2003, at the home of Karen Schurr, the new committee's chairperson.

As a first action, the council and committee submitted a letter (via email) to the Seattle City Council and Mr. Ken Bounds, Superintendent of Seattle Parks and Recreation, on June 18, 2003, urging the City to address the lake's water quality issues and to treat the lake with alum. The letter further recommended that Mr. Bounds make an emergency request for funds for the alum treatment and treat the lake with alum as soon as possible.

The committee also gathered signatures on a petition requesting that the City take immediate action to address Green Lake's water quality problems. Signatures were gathered mostly on July 8, 2003, during the Seafair Milk Carton Derby, a popular annual event at Green Lake. The petition urges that the City take immediate action to protect lake users from toxic bacteria blooms and maintain the lake for aquatic recreation. The Lake Restoration Committee met with Seattle Mayor Greg Nickels on August 6, 2003, to discuss the restoration of water quality in Green Lake and to further urge the City to treat the lake with alum. The committee then submitted the petition and signatures and sent a letter to Mayor Nickels and Mr. Bounds.

Proposed Alum Treatment Public Involvement Plan

Seattle Parks and Recreation has developed the following public involvement plan in preparation for the proposed alum treatment at Green Lake. This plan involves signs, public notices, public meetings, briefing of the Seattle Board of Parks Commissioners, and other outreach efforts. The public involvement will comply with Seattle Parks and Recreation's Public Involvement Policy, first enacted in 1999 and revised in 2002. The intent of the public involvement will be to inform park users and nearby residents of the proposed alum treatment. It will provide answers to questions about why alum treatment is the appropriate lake restoration tool at this time and address any public concerns about the use of alum in the lake environment.

Specifically, the plan involves the following elements:

- One or more park signs measuring at least 4 by 4 feet will be erected at Green Lake in late September 2003 to outline the proposed alum treatment, describe why the alum is needed, provide the schedule for the proposed treatment in winter 2004, and announce all the public meetings associated with the proposed treatment. The name of the Seattle Parks and Recreation's project manager, his/her phone number, and his/her email address will be provided as the primary contact person for the project.

- Flyers will be distributed to all households within a ¼-mile radius of Green Lake Park, again stating why the alum is needed, providing the proposed schedule for alum treatment in winter 2004, and announcing the public meetings associated with the proposed treatment. The name, phone number, and email address of the Seattle Parks and Recreation project manager will also be provided. This flyer will also be sent to representatives of the Green Lake Community Center Advisory Council, the Green Lake Rowing Advisory Council, the Green Lake Community Council, and other appropriate organizations interested in Green Lake.

- A public meeting will be held in early October 2003 at the Green Lake Community Center. The purpose of the meeting is to explain the proposed alum treatment and to address any public health concerns about the proposal. The meeting will be advertised in the flyer noted above. Seattle Parks and Recreation will endeavor to have the meeting announced in daily newspapers in Seattle and the weekly neighborhood paper in the Green Lake area.

- In October 2003, the Board of Parks Commissioners (the official citizen advisory body for Seattle Parks and Recreation) will be briefed on the proposed alum treatment and any public concerns related to such a proposal.

- To the degree necessary, Seattle Parks and Recreation will make presentations in October and November 2003 at meetings of the Green Lake Community Center Advisory Council, the Green Lake Rowing Advisory Council, the Green Lake Community Council, and other appropriate organizations interested in Green Lake. The intent of such efforts is to inform users of the lake and other interested citizens about the proposed alum treatment.

- The Washington Department of Fish and Wildlife will be notified of all the meetings noted above.
- Information brochures and fact sheets will be prepared for use at the public meeting, the Board of Parks Commissioners presentation, and other meetings and will be sent to all citizens requesting information on Green Lake.
- Just before the alum application, signs will be posted at Green Lake announcing its closure to all water contact recreation consistent with the state alum treatment policy.
- After the alum treatment, water quality monitoring results will be reported on a public information sign at Green Lake throughout the balance of 2004.
- A public meeting will be held in late 2004 to discuss early water quality monitoring results of the proposed alum treatment and any recommended adjustments in lake management.

Alum Treatment Implementation Strategy

Green Lake would be treated with aluminum sulfate and sodium aluminate to inactivate the internal cycling of phosphorus and aid in the prevention of toxic blue-green bacterial blooms that have plagued the lake periodically. An alum application dose was determined that was sufficient to provide long-term inactivation of sediment phosphorus without resulting in adverse water quality effects on the aquatic resources of the lake. Two separate jar tests were conducted to verify that the alum dose would not adversely affect water quality in the lake and to determine the alum demand in the water column. Additional testing would also be performed before the alum application to ensure that the treatment would not compromise the water quality of lake at any time during the application.

Alum Dose and Timing

The total dose of alum needed to treat Green Lake was determined to be 23 mg Al/L (Herrera 2003). The total dose includes the dosing rate needed to inactivate the sediment-exchangeable phosphorus, which was determined to be 17.2 mg Al/L (Herrera 2003). Incorporating the results of the jar tests, an additional alum dose of 5.8 mg Al/L was calculated to compensate for the demand throughout the water column. The additional alum demand in the water column is primarily due to the presence of humic organic compounds.

The Green Lake alum treatment would be conducted from the beginning of January to March 2004. This time of year was chosen for application because the biomass of rooted aquatic plants would be relatively low compared to other times of the year. For optimal results, the alum must be allowed to settle directly onto the sediment surface and not be intercepted and held suspended by plants above the lake bottom.

Jar Tests

Two jar tests were conducted to determine the appropriate dose of aluminum sulfate (alum) and sodium aluminate (see Appendix A). Data collected from the jar tests were used to determine the amount of phosphorus (total and soluble reactive fraction) in the water column that would bind with the alum, subsequently reducing the effectiveness of the alum at binding sediment phosphorus at the lake bottom. In addition, pH, alkalinity, and dissolved aluminum were measured to determine whether the dose would compromise the water quality and adversely affect fish populations in the lake after the application of the alum-sodium aluminate mixture.

The results from the two jar tests indicated that alum and sodium aluminate applications to Green Lake water would not adversely affect the water quality. All of the samples in the two jar tests were observed with a pH greater than 6.0 over each study period. These results indicate that the pH would not decrease below the threshold (6.0) for protection of aquatic organisms.

Additional Testing Prior to Application

Additional water quality testing would be conducted immediately before the alum treatment. The water quality testing will confirm that the prescribed alum dose is working properly and would not present a danger to the aquatic resources of the lake. Methods (including parameters) proposed for this additional testing are presented in the Water Quality Monitoring Plan (Appendix C).

One jar test would be conducted on the day before the first day of alum treatment. This testing would be performed to verify the 2003 jar test results (Herrera 2003) using the alum treatment chemicals, dose, and application method provided by the treatment contractor with the water quality conditions present at the time of application.

The collected water would be treated with aluminum sulfate and sodium aluminate using the specified dose of 23 mg Al^{3}+/L. The pH of the collected water will be tested immediately before treatment and then again at one hour after treatment. The treatment dose and/or amount or buffer (sodium aluminate) would be adjusted if the pH of the treated water is not within the required range of 6.0 to 8.5. The jar test would be repeated each time that the dose is adjusted.

Water quality monitoring of Green Lake will be conducted during and following the alum treatment in accordance with the Water Quality Monitoring Plan (Appendix C).

References

Barbiero, R.P. 1991. The Contributions of Benthic Stages of Blue-Green Algae to the Development of Planktonic Populations, with Special Reference to *Gloeotrichia echinulata*. Ph.D. dissertation. University of Washington, Civil Engineering, Seattle, Washington.

Barbiero, R.P., and E.B. Welch. 1992. Contribution of Benthic Blue-Green Algae Recruitment to Lake Populations and Phosphorus Translocation. Freshwat. Bio. 27:294-260.

Bolstridge, J.C. 1982. Green Lake: Physical, Chemical, and Biological Analysis in Preparation for Lake Restoration. M.S. thesis. University of Washington, Civil Engineering, Seattle, Washington.

Capron, C. 2003. Personal communication (telephone conversation and data transmitted by electronic mail to Rob Zisette, Herrera Environmental Consultants, Inc., Seattle, Washington). Seattle Public Utilities, Seattle, Washington. September 25, 2003.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R, Newroth. 1993. Restoration and Management of Lakes and Reservoirs. Lewis Publishers, Boca Raton, Florida.

Ecology. 1998. Final 303(d) Water Quality Limited List for Washington State. Washington Department of Ecology, Olympia, Washington.

Ecology. 2003. Focus on Proposed Water Cleanup Plans. Publication No. 03-10-056. Washington Department of Ecology, Olympia, Washington. .

Herrera. 1995. Green Lake Phase IIC Restoration Project. Technical Memorandum. Prepared for KCM, Inc., by Herrera Environmental Consultants, Inc., Seattle, Washington. April 1995.

Herrera. 2003. Green Lake Alum Treatment Study. Prepared for City of Seattle Parks and Recreation, Seattle, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington.

KCM. 1995. Green Lake Phase IIC Restoration Project Volume 1 – Project Completion Report. Prepared for City of Seattle Parks and Recreation, Seattle, Washington, by KCM, Inc., Seattle, Washington. August 1995.

King County. 2003a. King County Lakes Monitoring Program website for east Green Lake. Seattle, Washington. Data obtained April 11, 2003, from agency website: <http://dnr.metrokc.gov/wlr/waterres/lakes/greenacr.htm>.

King County. 2003b. Spring Lake, Integrated Aquatic Vegetation Management Plan. Department of Natural Resources and Parks Water and Land Resources Division. Seattle, Washington. February 2003.

Linnell, M. 2003. Personal communication (telephone conversation with Jennifer Goldsmith of Herrera Environmental Consultants, Inc., Seattle, Washington). United States Department of Agriculture, Olympia, Washington. September 10, 2003.

Perkins, M.A. 1983. Limnological Characteristics of Green Lake. Final Report, Phase 1 Restoration Analysis. Prepared for URS Engineers, Seattle, Washington. University of Washington, Civil Engineering, Seattle, Washington.

Seattle, City of. 1990. Resolution 28248 (authorizing a water quality improvement program). Seattle City Council.

Seattle, City of. 2001. SEPA Checklist for Stocking of Certified Sterile Triploid Grass Carp into Green Lake. Prepared for the Washington Department of Fish and Wildlife, by City of Seattle Parks and Recreation Department. May 2001.

Seattle, City of. 2002. City of Seattle Municipal Stormwater NPDES Permit 2001 Annual Report. Prepared by Seattle Public Utilities, Seattle, Washington.

Seattle, City of. 2003a. Unpublished water quality data provided to Rob Zisette, Herrera Environmental Consultants, Inc., Seattle, Washington, by Kevin Stoops, City of Seattle Parks and Recreation. March 3, 2003.

Seattle, City of. 2003b. Unpublished water quality data, provided to Rob Zisette, Herrera Environmental Consultants, by Elizabeth Johnson, Seattle Public Utilities. February 2, 2003.

Shoblom, T. 2003. Personal communication (email correspondence with Jennifer Goldsmith Herrera Environmental Consultants, Inc., Seattle, Washington). Washington Department of Ecology, Northwest Regional Office, Bellevue, Washington. July 24, 2003.

Stoops, K. 1996. Harvest Today, Eradicate Tomorrow: Eurasian Water Milfoil Control in Green Lake. Paper presented at the Symposium on Non-indigenous Species in Western Aquatic Ecosytems/15th Annual Meeting of the Western Aquatic Plan Management Society/North American Lake Management Society Regional Meeting, March 27, 1996. Portland State University Lakes and Reservoirs Publication 96-8.

Stoops, K. 2003a. Personal communication (telephone conversation with Rob Zisette, Herrera Environmental Consultants, Inc., Seattle, Washington). Seattle Parks and Recreation, Seattle, Washington. August 27, 2003.

Stoops, K. 2003b. Personal communication (telephone conversation with Rob Zisette of Herrera Environmental Consultants, Inc.). Seattle Parks and Recreation, Seattle, Washington. August 28, 2003.

URS. 1983. Green Lake Restoration Diagnostic Feasibility Study. Prepared for City of Seattle Parks and Recreation, Seattle, Washington, by URS Engineers, Seattle, Washington.

URS. 1987. Green Lake Water Quality Improvement Plan. Prepared for City of Seattle Parks and Recreation, by URS Engineers, Seattle, Washington.

URS. 1990a. Green Lake Water Quality Improvement Project. Final Environmental Impact Statement. Prepared for City of Seattle Parks and Recreation, Seattle, Washington, by URS Engineers, Seattle, Washington. April 1990.

URS. 1990b. An Addendum to the Green Lake Water Quality Improvement Project Final Environmental Impact Statement. Prepared for City of Seattle Parks and Recreation, Seattle, Washington, by URS Engineers, Seattle, Washington. September 1990.

URS. 1990c. Technical Memoranda in Support of an Addendum to the Final Environmental Impact Statement for the Green Lake Water Quality Improvement Project. Prepared for City of Seattle Parks and Recreation, Seattle, Washington, by URS Engineers, Seattle, Washington. October 1990.

WDFW. 2003. Unpublished fisheries data provided March 21, 2003, to Lana Krisman, City of Seattle Parks and Recreation, by Bruce Bolding, Washington Department of Fish and Wildlife.

Welch, E.B., and G.D. Cooke. 1999. Effectiveness and Longevity of Alum Treatments in Lakes. Lake and Reservoir Management 15:5-27.

WSNCB. 2003. Eurasian watermilfoil. Information obtained August 20, 2003, from Washington State Noxious Weed Control Board website: <http://www.nwcb.wa.gov/weed_info/milfoil.html>.