council makes the following findings of fact:

1. The Cottage Lake watershed covers 4,300 acres and lies within the Bear Creek Basin located in north King County and south Snohomish County.

2. The King County council adopted Ordinance #8846 in 1989 which adopted the Bear Creek Community Plan including surface water management recommendations for the Cottage Lake watershed.

3. The Cottage Lake watershed includes twelve wetlands, including two number-1-rated, unique and outstanding wetlands, BBC-10 - a large wetland system to the west of Cottage Lake and an extensive wetland system upstream of and associated with Crystal Lake in Snohomish County.

4. Eighty percent of the watershed is currently forest/open space and 20 percent of the watershed is in rural land use. Under future land use, 85 percent of the watershed will be in low, medium, or high density single family residential development.

5. The King County parks and cultural resources department is in the process of implementing the Cottage Lake Master Plan which balances recreational activities in the park with the need to protect water quality in Cottage Lake.

6. Cottage Lake water quality is biologically productive or eutrophic with an average summer surface total phosphorus concentration of 32 μg/L and chlorophyll a concentration of 32 μg/L. Under unmitigated future land use conditions, external phosphorus loadings could potentially

BE IT ORDAINED BY THE COUNCIL OF METROPOLITAN KING COUNTY:

SECTION 1. Ordinance No. 7590, Section 15 as amended and K.C.C. 9.08.120 are each hereby amended to read as follows:

Administrative Procedures. Pursuant to K.C.C. 2.98 the director shall develop administrative procedures relating to the implementation of this chapter. This includes but is not limited to:

A. Procedures for the imposition and collection of services and/or for filing of liens and initiation of foreclosures on delinquent accounts and the collection of the debt service portion of the service charge in areas that annex or incorporate.

B. Lake Management Plans for:

1. Beaver Lake

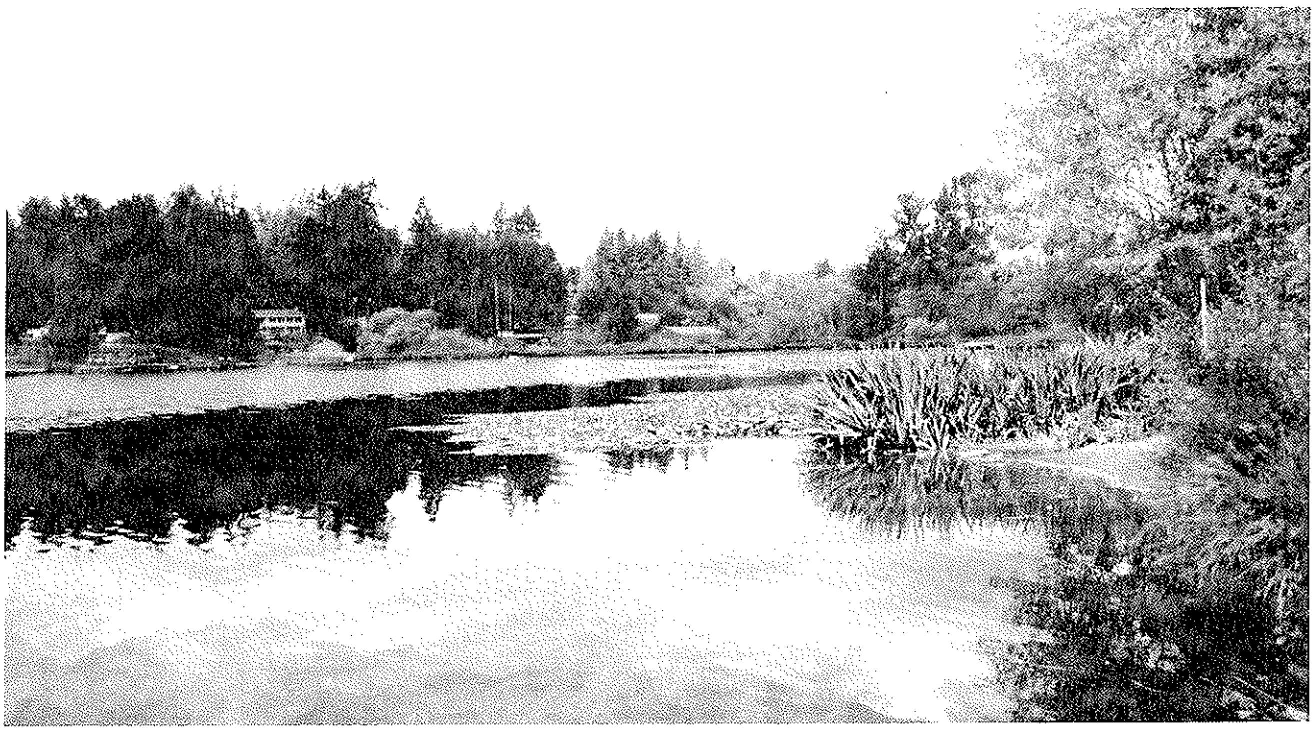
Gerald A. Peterson
Clerk of the Council

APPROVED this 14th day of November, 1996.

Paul Tanaka
Deputy King County Executive

Attachments:
A. Cottage Lake Management Plan
B. Regulatory Note Checklist

Cottage Lake Management Plan



February 1996

King County Surface Water Management
Everyone lives downstream

WASHINGTON STATE DEPARTMENT OF ECOLOGY

KCM

King County
Surface Water Management Division

Department of Natural Resources
700 5th Avenue Suite 2200
Seattle, WA 98104

(206) 296-6519
(206) 296-0192 FAX

April 12, 1996

TO: Final Plan Recipients

FM: Bob Storer, Senior Water Quality Specialist R.S.

RE: Final Cottage Lake Management Plan

Enclosed is a copy of the *Final Cottage Lake Management Plan*. A grant application was submitted in February 1996 for state funding to implement portions of the Plan. The Cottage Lake community has started discussions on formation of a lake management district. The next step will be to take the plan through the King County Council adoption process.

If you have questions concerning the plan or implementation steps, please contact me at 296-8383. Thank you for your time and interest in Cottage Lake and its watershed.

RAS:pra5

Enclosure

cc: Pam Bissonnette, Director-Designee, Department of Natural Resources
Jim Kramer, Manager, Surface Water Management Division
Bill Eckel, Manager, Watershed Services Unit

Cottage Lake
Management Plan

Final Plan

Grant No. TAX G9300181

February 1996

Prepared by:

King County
Surface Water Management Division
700 Fifth Avenue, Suite 2200
Seattle, WA 98104
(206) 296-6519

KCM, Inc.
1917 First Avenue
Seattle, WA 98101
(206) 443-5300

Funded in part by the Washington State Department of Ecology, Centennial Clean Water Fund

ACKNOWLEDGMENTS

This project was funded through a Centennial Clean Water Fund (CCWF) grant by the Washington State Department of Ecology (WSDOE). Local matching funds were provided by the King County Department of Public Works, Surface Water Management (SWM), and Department of Metropolitan Services (DMS) Environmental Laboratory Divisions. Local in-kind services were provided by members of the Friends of Cottage Lake and other residents of the Cottage Lake area.

Dr. Fran Solomon, the project manager with the SWM Division, directed the project, developed the lake management plan, and maintained communication among the project team members. Bob Storer of the SWM Division initiated the project through several meetings with residents of the Cottage Lake community; these meetings led to the SWM Division's decision to seek CCWF grant funding. Debra Bouchard, KCM, Inc., managed the consulting portions of the project, including the development of the lake model and restoration analysis. Allen Moore, WSDOE, provided agency perspective and grant assistance.

Many residents of the Cottage Lake community contributed time, equipment, and services to the project. Individual thanks go to Carol Porter, Bruce McCain, and Stan Merrell for allowing the use of their boats during the monitoring portion of the project, and to Leno Bassett for allowing access to his property for sampling the lake outlet. Thanks also to Carol Porter and Bruce McCain for monitoring lake level; to Stan Merrell and Terry Mackaman for monitoring precipitation; to Bruce McCain for collecting stormwater samples from the lake inlets; to Mike Almond and Michael Mendlik for their assistance in groundwater collection; to Tom Keenan, Pat Tartar, and Gina Tartar for their assistance in the fisheries assessment; and to Tom Keenan, Carol Porter, and Bruce McCain for their planning of the 1994 purple loosestrife pull.

We would also like to thank the members of the Cottage Lake Technical Advisory Committee for their important role in the development of the lake management plan. Members of the Committee included the following:

- Leno Bassett, Friends of Cottage Lake
- Susan Cyr, King County Executive Horse Council
- Jonathan Frodge, King County DMS
- Ray Heller, King County SWM Division
- Tom Keenan, Water Tenders
- Glenn Kost, King County Parks
- Gwenn Maxfield, Woodinville Water and Sewer District
- Bruce McCain, Friends of Cottage Lake
- Allen Moore, Washington State Department of Ecology
- Kathryn Neal, King County SWM Division
- Bob Pfeifer, Washington State Department of Fish and Wildlife
- Carol Porter, Friends of Cottage Lake
- Ellouise Pritchett, Water Tenders
- Deborah Rannfeldt, Woodinville Water and Sewer District
- Nancy Stafford, Water Tenders
- Lyle Stoltman, King Conservation District
- Teresa Valentine, Gary Merlino Construction Company
- Gene Williams, Snohomish County SWM Division
- Bob Wright, Cottage Lake Beach Club
- Lane Youngblood, City of Woodinville

This report was prepared by the following people:

- Fran Solomon, King County SWM Division
- Sharon Walton, King County SWM Division
- Kent Easthouse, King County SWM Division
- Debra Bouchard, KCM, Inc.
- Phil Noppe, KCM, Inc.

Appreciation is extended to the following individuals and companies for their professional work in conducting portions of the monitoring program, analyzing field data, reviewing this report, producing report graphics, or contributing recommendations for the lake management plan:

- Aquatic Research, Inc.
- Theresa Barclay, Seattle-King County Dept. of Public Health
- Caroline Barnes, KCM, Inc.
- Todd Bennett, King County SWM Division
- Fred Bentler, King County SWM Division
- Kathy Brown, King County Roads Division
- Jeff Burkey, King County SWM Division
- Wendy Cooke, King County SWM Division
- Wayne Daley, KCM, Inc.
- Jack Davis, King Conservation District
- DMS, Environmental Laboratory Division
- Bill Eckel, King County SWM Division
- Aaron Feik, Northshore School District
- Del Feild, King County SWM Division
- Wendy Gable, King County SWM Division
- Harry Gibbons, KCM, Inc.
- Maribeth Gibbons, WATER Environmental Services, Inc.
- Kirt Hanson, King County SWM Division
- David Hartley, King County SWM Division
- Ray Heller, King County SWM Division
- Hong West & Associates, Inc.
- Sandy Kilroy, King County SWM Division
- DeeAnn Kirkpatrick, King County SWM Division
- Louise Kulzer, King County SWM Division
- Steve Majerick, King County SWM Division
- Pentec Environmental, Inc.
- Dan Portman, KCM, Inc.
- Laurel Preston, King County SWM Division
- Kate Rhoads, King County SWM Division
- Doug Rice, King County SWM Division
- Mike Rice, King County Parks Division
- Kathleen Rismoen, King County Parks Division
- Ruth Schaefer, King County SWM Division
- Bob Storer, King County SWM Division
- Mark Sytsma, KCM, Inc.
- Steve Todd, KCM, Inc.
- Sharon Walton, King County SWM Division
- Nancy Young, Bear Creek Elementary School
- Ruoxi Zhang, King County SWM Division

COTTAGE LAKE MANAGEMENT PLAN

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EXECUTIVE SUMMARY

CONDITIONS SUMMARY

Cottage Lake is located approximately four miles east of the city of Woodinville, in Metropolitan King County Council District Three. Access to the public park on the north shore of the lake is via Woodinville-Duvall Road, which intersects Avondale Road.

Cottage Lake is 63 acres in size, has a mean depth of 15 feet, a maximum depth of 25 feet, and a total lake volume of 970 acre-feet. The watershed encompasses approximately 4,300 acres in the upper Bear Creek Basin of northeastern King County and southern Snohomish County.

Cottage Lake is a nutrient-rich lake characterized by frequent and intense algal blooms in the spring and fall, which degrade the lake for recreational uses, including swimming, boating, and fishing. The aesthetic appeal normally associated with the lake also decreases dramatically during the bloom periods. Public meeting discussions and written surveys of community residents have indicated that existing water quality and associated biological productivity in Cottage Lake are unacceptable to many people who live on or near the lake.

Based on "historical" water quality data, Cottage Lake has been characterized as a biologically highly productive, or eutrophic, system since the early 1970s (see Glossary in Appendix A for definitions of technical terms). No water quality data are available from earlier decades, but long-time residents of the Cottage Lake area remember much clearer water with much less algae in the 1950s and 1960s. In addition, examination of the sediment phosphorus profiles (Chapter 4) suggests that productivity has increased significantly since the early 1970s. Increased shoreline and watershed land development and associated nonpoint pollution loading are likely contributing factors.

Existing water quality in Cottage Lake is classified as eutrophic based on concentrations of the nutrient phosphorus, concentrations of the plant pigment chlorophyll *a*, and lake water transparency (Secchi depth). For this study, the physical, chemical, and biological components of Cottage Lake were characterized from April 1993 to April 1994, during which spring and summer were significantly cooler and wetter than normal, while fall and winter were warmer and drier than normal. Whole-lake volume-weighted total phosphorus concentrations averaged 105 micrograms per liter (μg/L) during the study period, and 141 μg/L during the summer (June through September). Chlorophyll *a* values averaged 18 μg/L during the study period, and 32 μg/L during the summer. The annual Secchi depth averaged 1.9 meters. The lake is usually characterized by nuisance blue-green algae blooms in the spring and fall. Peak chlorophyll *a* values of 55 μg/L and 43 μg/L were recorded on August 10 and August 24, 1993. A fall peak in chlorophyll *a* was not observed during the study year (most likely due to the unusually cool, wet summer), but has been documented for previous years (Metro, 1994).

Mesotrophic lakes, or lakes of medium biological productivity such as Lake Washington, have average total phosphorus concentrations of 10-20 μg/L, average chlorophyll *a* values of 4-10 μg/L, and Secchi depth values of 2-4 meters or greater. Cottage Lake values for these parameters are indicative of a lake with a greater level of biological productivity and poorer water quality (that is, a eutrophic lake).

Cottage Lake had low dissolved oxygen levels in the bottom waters (hypolimnetic oxygen depletion) and high surface water temperatures typical of a relatively shallow and productive lake. This restricted the cold water fish habitat to the oxygenated, but warmer, upper waters for the summer months. In spite of this limitation of cold water habitat, the lake's fishery was generally healthy, with a mixed assemblage of warm water species, including bass and yellow perch. The microscopic plant and animal (planktonic) community included species typical of eutrophic lakes. The plant or phytoplankton community was dominated by the blue-green alga *Aphanizomenon flos-aquae*, while the animal or zooplankton community was composed largely of rotifers.

Existing land use in the watershed (Table 2-3) is composed of forest/open land (79 percent), low density residential uses (20 percent), and commercial property (1 percent). External phosphorus loading from surface and subsurface flows associated with existing land use accounted for 69 percent (256 kilograms per year) of the phosphorus loading to the lake. Internal phosphorus loading and precipitation accounted for 29 percent (107 kilograms per year) and 2 percent (8 kilograms per year), respectively, of the remaining annual phosphorus load to the lake during 1993-1994.

Much of the Cottage Lake watershed will be developed in the future (Table 2-3). This will result in a future land use scenario in which 85 percent of the watershed is developed for residential uses of various zoning densities and 6 percent is developed for commercial uses. At maximum buildout, in approximately 20 years, only 9 percent of the 4300 acres in the watershed are predicted to remain as forest or open land. Estimates for future buildout conditions indicate external phosphorus loading could potentially increase to 355 kilograms per year. Without mitigation, this loading increase will exacerbate the existing lake water quality problems.

MANAGEMENT APPROACH

The management approach for the restoration of Cottage Lake is designed to address both watershed and in-lake sources of nutrients that contribute to the existing water quality problems. By reducing the amount of phosphorus entering the lake from external sources (e.g., gardening products and septic systems), and reducing the amount of phosphorus released into the lake from internal sources (e.g., lake sediments and decaying plants), lake water quality and beneficial uses would be improved. The lake's water clarity would improve somewhat, nuisance algal blooms would be less frequent, and better swimming, fishing, and boating would be provided.

Restoration of Cottage Lake will require a long-term investment and commitment to reducing future nutrient loading from the watershed through source control best management practices, restoration of watershed and lakeshore wetlands, retrofitting of existing stormwater facilities for pollutant removal, and the removal and management of non-native aquatic plants. In the near term, in-lake water quality is proposed to be improved using a combination of a buffered alum treatment and an in-lake aeration system to reduce internal nutrient cycling in the lake. While short-term water quality benefits will be realized by in-lake restoration measures, maintenance of improved water quality over the long-term can only be achieved by successful implementation of watershed protection measures.

LAKE AND WATERSHED MANAGEMENT GOALS

Lake and watershed management goals established by the Cottage Lake community were used in the restoration alternatives analysis and in the development of the subsequent management plan recommendations. The seven management goals are as follows:

- Improve water quality and change lake trophic status to a less eutrophic condition.
- Preserve a healthy lake fishery.
- Protect human health.
- Avoid adverse impacts downstream of the lake caused by restoration actions.
- Educate and involve watershed residents and schoolchildren in lake restoration and protection.
- Prevent and control infestations of invasive, non-native aquatic plants.
- Promote interagency coordination on lake restoration and land development projects.

Improving lake water quality is the primary management goal for Cottage Lake. This would be evidenced by decreased concentrations of chlorophyll *a* and phosphorus in the lake (the natural tea color of the lake may prevent an increase in water clarity). Phosphorus loading to the lake should be reduced through aeration of the lake hypolimnion and the implementation of watershed source control measures, resulting in less frequent and severe algal blooms and improved water quality.

If lake water quality is improved, other management goals, including protection of human health and lake fisheries, will also be met. Improving lake water quality will reduce water-quality-related dermatitis and the occurrence of blue-green algal blooms, thereby improving human health protection. In-lake aeration will benefit the lake fisheries and overall aquatic habitat by expanding the oxygenated area of the lake.

The remaining management goals are designed to be accomplished through the management plan recommendations (CL-5, CL-6, CL-10, CL-11, and CL-12). All agencies with jurisdictional authority throughout the Cottage Lake watershed will need to coordinate closely with each other throughout plan implementation. A cooperative working relationship among the Cottage Lake community, King County, and Snohomish County will also be needed to achieve these lake and watershed management goals. Without this combined long-term commitment and investment by watershed residents and local government, the goal of improving lake water quality and associated beneficial uses will likely remain unmet for Cottage Lake.

RECOMMENDATIONS

The 14 recommendations for the Cottage Lake Management Plan (Table ES-1) are divided into four groups: watershed measures; in-lake measures; aquatic plant management; and monitoring. Watershed recommendations address stormwater treatment, forest retention, lake and stream wetland restoration, ditch maintenance, homeowner and business best management practices (BMPs), agricultural BMPs, and wastewater treatment. These measures are intended to reduce existing and future external nutrient and contaminant loading to the lake.

In-lake restoration measures are recommended to reduce existing and future internal nutrient loading to the lake. Hypolimnetic aeration is a long-term remedy that would be facilitated in the short-term by a buffered alum treatment. Water quality improvement made through in-lake measures will not be maintained over the long term, however, unless watershed measures are successfully implemented as well.

MANAGEMENT PLAN IMPLEMENTATION

Management plan implementation is contingent on a variety of factors, including the finalization of the management plan, the decision to pursue public funding, the availability of public funding, the successful award of public funding, and the successful formation of a lake management district (LMD). The fact that the Cottage Lake watershed lies in both King County and Snohomish County adds complexity to the implementation of the watershed source control measures of the plan. A preliminary schedule for management plan implementation, assuming that public funding and LMD formation will be pursued as the preferred funding alternative, is as follows:

- Final Management Plan — February 1996
- Apply for Centennial Clean Water Fund grant — February 1996
- Transmittal of Management Plan to Metropolitan King County Council — March 1996
- Initiate lake management district (LMD) by FOCL — November 1995
- Complete LMD formation — December 1996
- Initiate plan implementation — March 1997

Table ES-1: Lake and Watershed Recommendations

No.	Recommendations	Lead Implementor(s)	Estimated Costs
Watershed Measures			
CL-1	Stormwater Treatment	SWM/DDES/Parks	EP
CL-2	Forest Retention	SWM/DDES/Sno Cty	EP
CL-3	Wetland Restoration, Buffer Maintenance	SWM/Parks/FOCL	$4,000
CL-4	Ditch Maintenance	Roads/SWM/FOCL/WT	EP
CL-5	Homeowner/Business BMPs	FOCL/WT/CLBC/SWM/SKCDPH/Sno Cty	$3,000
CL-6	Agricultural BMPs	SWM/KCD/KCEHC/SCD	EP
CL-7	Wastewater Treatment	WWSD/SKCDPH	EP
In-Lake Measures			
CL-8	Buffered Alum Treatment	SWM/FOCL/CLBC	$153,000
CL-9	Hypolimnetic Aeration	SWM/FOCL/CLBC	
	(design and engineering)		$100,000
	(SEPA)		$ 50,000
	(construction)		$495,600
	(ongoing O/M)		$26,500/yr
Aquatic Plant Management			
CL-10	Milfoil Prevention	FOCL/WT/CLBC/SWM	EP
CL-11	Purple Loosestrife Removal	FOCL/WT/CLBC	$5,000
CL-12	Water Lily Reduction	FOCL/CLBC	$4,500
Monitoring			
CL-13	Lake, Fishery, and Watershed Monitoring	FOCL/WT/CLBC/SWM/ DMS/WSDFW	$35,000
CL-14	Wetland Monitoring	SWM	$5,000
		Total	**$855,100**
		Total with 5-year O/M	**$987,600**

Abbreviations:

SWM—King County Surface Water Management Division; DDES—King County Department of Development and Environmental Services; Sno Cty—Snohomish County; Parks—King County Parks Division; Roads—King County Roads Division; FOCL—Friends of Cottage Lake; WT—Water Tenders; CLBC—Cottage Lake Beach Club; SKCDPH—Seattle King County Department of Public Health; KCD—King Conservation District; SCD—Snohomish Conservation District; KCEHC—King County Executive Horse Council; WWSD— Woodinville Water and Sewer District; DMS—King County Department of Metropolitan Services (Metro); WSDFW—Washington State Department of Fish and Wildlife; O/M—Operation/Maintenance for aeration; EP—existing programs are expected to cover costs

CHAPTER 1: INTRODUCTION

This document presents the findings of a Phase I lake diagnostic/feasibility study (restoration project) performed for Cottage Lake. Phase I lake projects typically focus on identifying the sources and effects of lake water quality problems, and developing a lake management plan with corrective actions to restore lake water quality. The Cottage Lake Restoration Project was initiated in response to community concerns about declining lake water quality, as evidenced by the presence of extensive blue-green algal blooms in the lake during the spring and fall. The project began in April 1993 with the initiation of a one-year detailed limnological assessment of the lake and surrounding watershed. A management plan was developed for the lake during 1994 and 1995, and finalized in February 1996.

The project was funded through a Washington State Department of Ecology (DOE) Centennial Clean Water Fund grant, with local grant match provided by the King County Department of Public Works, Surface Water Management (SWM) Division, and Department of Metropolitan Services (DMS; formerly Metro), Environmental Laboratory Division. In-kind services to the project (including boat use; lake level, precipitation, and groundwater monitoring; and assistance with fisheries assessments) were provided by citizens of the Cottage Lake community, including Friends of Cottage Lake (FOCL) and Water Tenders.

BACKGROUND

Lake Location

Cottage Lake is located in the upper Bear Creek Basin of northeast King County and south Snohomish County, approximately four miles east of the city of Woodinville, as shown in Figure 1-1. More than one-quarter of its drainage basin is in Snohomish County.

The general public has had access to the lake only since 1992, when King County purchased the former Norm's Resort property on the north end of the lake. Cottage Lake Park, a new King County park, is being developed at this location. Access to Cottage Lake Park and to the north shore of Cottage Lake is by way of the Woodinville-Duvall Road, which intersects Avondale Road, a major roadway extending north from the end of State Highway 520.

Lake Eutrophication

Lakes are characterized according to their level of biological productivity, or trophic state. Lakes that are nutrient-poor and biologically unproductive are classified as oligotrophic; Washington's alpine lakes are classic examples. Lakes that are nutrient-rich and biologically highly productive are called eutrophic. Lakes between these two classes are called mesotrophic. Most of the lowland lakes in western King County are mesotrophic or eutrophic; Lake Sammamish and Lake Washington are examples of mesotrophic lakes. Cottage Lake and Lake Desire, a 71-acre lake located in the Cedar River Basin of southeastern King County, are examples of eutrophic lakes; both have nutrient-rich waters and frequent algal blooms.

A lake's natural level of productivity is determined by a combination of factors, including the geology and size of the watershed, depth of the lake, climate, and water sources entering and leaving the lake. Some lakes are naturally eutrophic based on their inherent physical attributes and watershed characteristics.

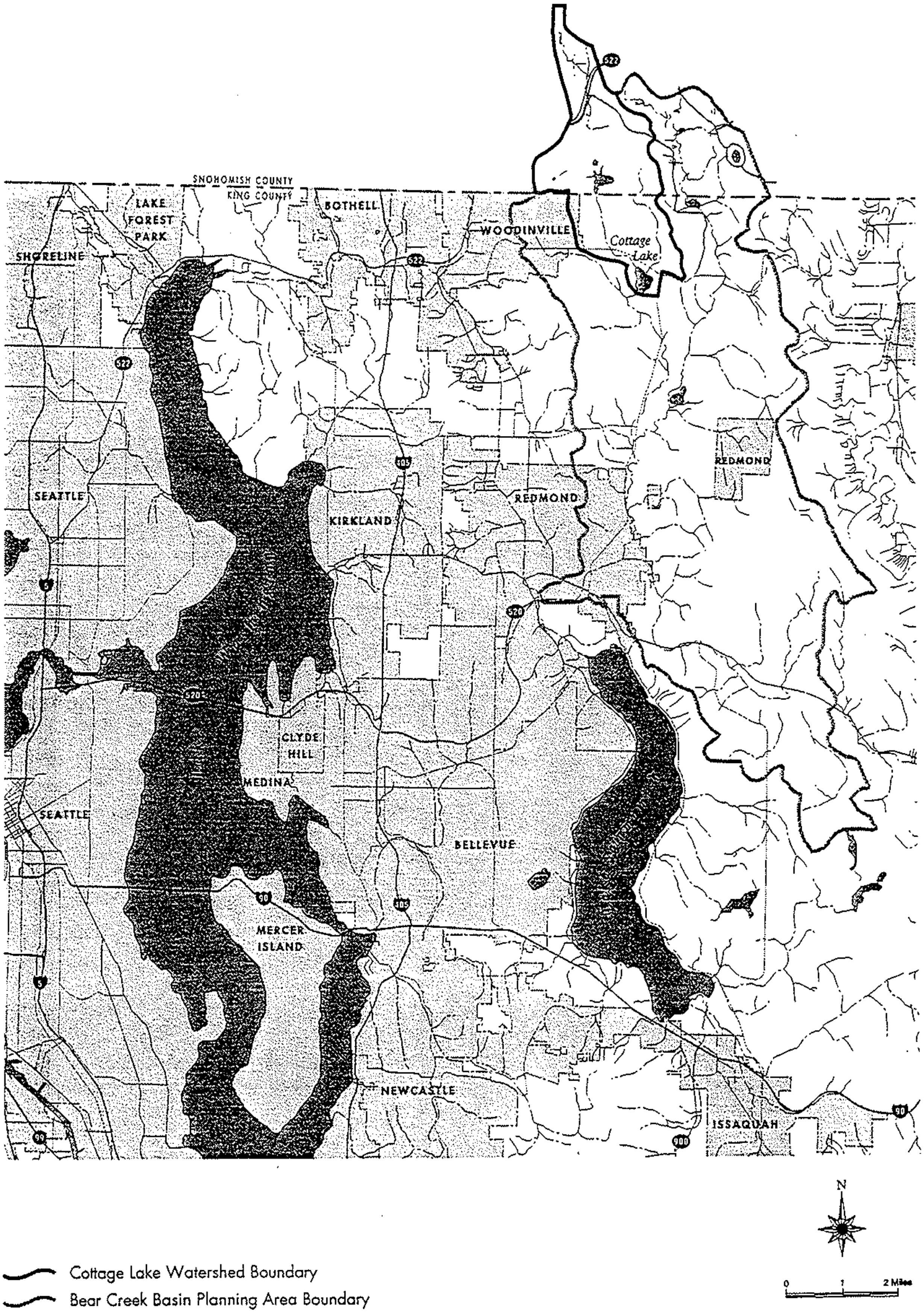


Figure 1-1
COTTAGE LAKE LOCATION MAP

Increases in a lake's natural productivity over time, a process called eutrophication, occur naturally in some lakes, and may be accelerated in others by human activities. For many small lakes, natural eutrophication typically occurs over hundreds or thousands of years, and is hence not observable in a single lifetime. What we can observe in a single lifetime is the human-induced, or cultural, eutrophication of lakes. Our land-based activities, including home-building, agriculture, forestry, resource extraction, landscaping, gardening, and animal husbandry, all contribute nutrients and sediments to surface waters, which in turn contribute to increasing a lake's biological productivity.

Nutrient levels, frequency of algal blooms, and water clarity in a lake are often used as indicators of lake trophic status. Swimming, fishing, boating, and other beneficial uses of a lake may be severely restricted, depending on the timing, frequency, duration, and severity of the algal blooms. Beneficial uses of a lake may also be degraded by other water quality problems related to eutrophic conditions, including low dissolved oxygen levels, fish kills, algal toxicity, and excessive aquatic macrophyte or plant growth.

Typically, lake restoration involves reducing the impact of human activities on lake water quality, with the goal of decreasing biological productivity and improving water quality and associated beneficial uses. A variety of tools is used to accomplish this goal, including watershed best management practices and in-lake restoration techniques.

Cottage Lake Water Quality

Since the early 1970s, Cottage Lake has suffered from low transparency, high nutrient levels, frequent algal blooms, and excessive shoreline aquatic plant growth, including the non-native, invasive species purple loosestrife (*Lythrum salicaria*).

King County DMS sampled the lake from 1971 to 1974, and from 1991 to the beginning of the Cottage Lake Restoration Project in 1993. During both sampling periods, Cottage Lake had the worst water quality of the 16 small lakes sampled, and was consistently classified as eutrophic. The poor lake water quality reduces the lake's beneficial uses, including boating, fishing, swimming, fish and wildlife habitat, and aesthetic value.

PROJECT OBJECTIVES

The purpose of this project was to develop a lake management plan for Cottage Lake based on DOE's Phase I lake restoration study process. Education and involvement of the public is essential in meeting the project goals of improving current water quality and reducing the impact of future watershed changes on lake water quality. In order to successfully complete this project, the following five objectives were defined:

1. Provide education and involvement opportunities for the public throughout the project to foster public ownership and commitment to the development and implementation of the lake management plan.

2. Quantify and characterize the physical, chemical, and biological components of the lake and its watershed.

3. Develop nutrient and water budgets to be used as analytical tools for the evaluation of restoration alternatives and the development of a lake management plan.

4. Identify existing sources of point and nonpoint pollution and estimate their importance in determining the trophic condition of Cottage Lake.

5. Develop a comprehensive management plan for the improvement and protection of water quality in Cottage Lake.

PROJECT MANAGEMENT

The project was managed by the King County Department of Public Works, Surface Water Management Division (SWM). Project tasks and associated activities were carried out by SWM staff with the assistance of KCM, Inc., the project consultant.

A technical advisory committee included representatives from the Washington State Departments of Ecology and of Fish and Wildlife; King County Parks, Surface Water Management, and Water Pollution Control Divisions; Snohomish County Surface Water Management; King Conservation District; Woodinville Water and Sewer District; City of Woodinville; Friends of Cottage Lake; Water Tenders; Cottage Lake Beach Club; and lakeside and watershed property owners. The committee met quarterly throughout the duration of the project and participated in the development of the Cottage Lake Management Plan.

UNITS

The units used in this document are from the International System of Units (the metric system), which is the standard for most scientific work. Exceptions are found in Chapters 1 and 2, where English units are used to locate the lake and to describe the lake and watershed. Also in Chapter 2, the physical characteristics of the lake and watershed are reported in both metric and English units for reader convenience. Metric values exclusively are used throughout the remainder of the document. A conversion table between metric and English measurements can be found in Appendix A.

GLOSSARY AND ABBREVIATIONS

Many terms specific to the study of lakes and watersheds are used in this plan. A glossary of these terms has been included in Appendix A. Abbreviations used in this plan are also defined in Appendix A.

CHAPTER 2: STUDY AREA DESCRIPTION

Background information on Cottage Lake and its watershed was collected and assembled by the King County SWM Division (King County, 1993a). The watershed characterization included a description of the study site, water resources, and pollutant loadings. The following is a summary of this information.

LAKE AND WATERSHED DESCRIPTION

A lake's physical characteristics (size, maximum and mean depths, basin shape, and geology) and watershed influence how the lake will respond to alterations of the watershed and the corresponding changes in nutrient/pollutant loading. Cottage Lake is 63 acres in size, has a mean depth of 15 feet, a maximum depth of 25 feet, and a volume of 970 acre-feet (USGS, 1976). Increasing areal coverage of the lake by water lilies in the past 22 years suggests decreasing lake depths (Bruce McCain, Friends of Cottage Lake, Personal Communication). Several long-time lake residents have observed that the lake has indeed become more shallow.

The Cottage Lake watershed encompasses approximately 4,300 acres in northern King County and southern Snohomish County, as shown in Figure 2-1. The following table summarizes other physical characteristics of Cottage Lake and its watershed.

Table 2-1: Physical Characteristics of Cottage Lake and its Watershed

Characteristic	English System	Metric System
Surface Area	63 acres	25.5 hectares
Mean Depth	15 feet	4.6 meters
Maximum Depth	25 feet	7.6 meters
Lake Volume	970 acre-feet	1,200,000 cubic meters
Shoreline Length	1.4 miles	2.25 kilometers
Lake Altitude	231 feet	70.4 meters
Watershed Area	4,300 acres	1,736 hectares
Thermocline Depth (summer months)	6.5 - 10 feet	2 - 3 meters

Watershed topography ranges from 240 to 600 feet (74 to 185 meters) above mean sea level. The majority of the terrain is a mixture of gently sloping forested hills, and valleys containing large wetland and open water areas. Immediately northeast of the lake is a steep canyon area incised by small drainages. The King County Sensitive Areas Map Folio shows these steep drainages as an erosion hazard area (King County, 1990b).

GEOLOGY

The oldest sediments in the Cottage Lake watershed were deposited by the Puget lobe of the Cordilleran continental ice sheet, which advanced into the Puget Sound Basin about 20,000 years ago. However, the existing geology of the watershed is derived largely from the most recent glacial period, the Vashon stade of the Fraser glaciation, which began approximately 15,000 years ago and lasted approximately 2,000 years (Minard, 1985).

The glacial till deposited during this period consists of nonsorted mixtures of clay, silt, sand, pebbles, cobbles, and boulders. Water percolates readily through the upper one or two meters of loose, sandy, weathered material, but tends to pond and move laterally along the compact till deposit often referred to as hardpan. Such conditions will result in wetlands in flat areas surrounded by uplands, with broad areas of saturated weathered till on hillsides during the winter and spring.

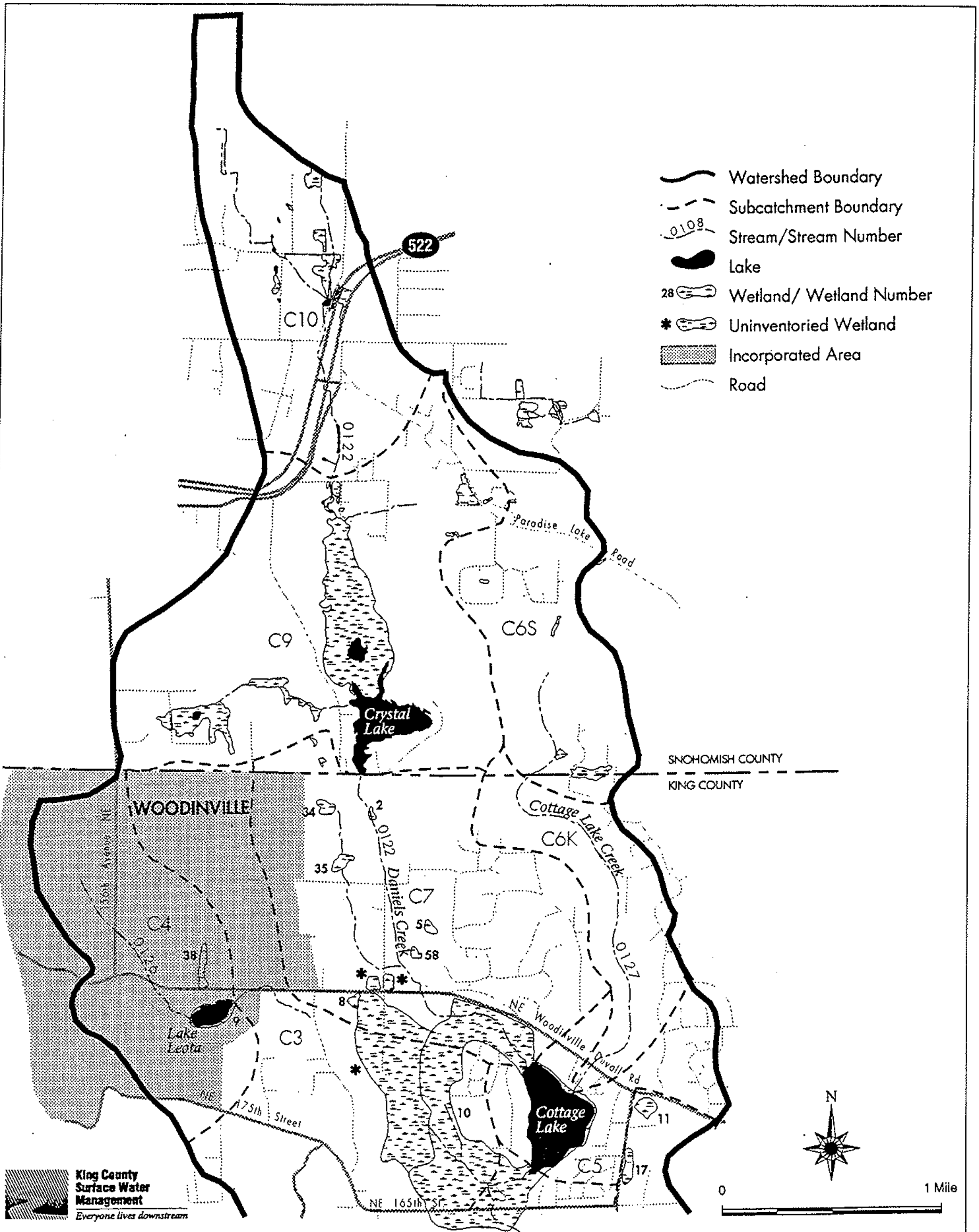


Figure 2-1
COTTAGE LAKE WATERSHED

The immediate vicinity of Cottage Lake consists of recessional outwash deposited by meltwater flowing from the receding Vashon glacier. These deposits are clean, stratified, unoxidized-to-oxidized sand and gravel, with some beds cemented by iron oxide. Sand in these deposits includes particles and minerals from some or all of the following rock types: basalt, metabasalt, diabase, gabbro, volcanic breccia, andesite, rhyolite, pink granite, gray granite, granodiorite, quartz-hornblend gneiss, schist, quartzite, vein and crystalline quartz, limestone, sandstone, conglomerate, shale, argillite, and phyllite.

SOILS

Soils in the Cottage Lake watershed were surveyed by the United States Department of Agriculture (USDA) Soil Conservation Service (USDA, 1973; USDA, 1983) and are shown in Figure 2-2. Table 2-2 lists the soil types present in the watershed.

Table 2-2: Soil Types in the Cottage Lake Watershed

Soil Type	Occurrence in Watershed
Alderwood Gravely Sandy Loam (AgC)	High
Everett Gravely Sandy Loam (EvC)	Moderate
Indianola Loamy Sand (InA)	Low
Mukilteo Muck (MM)	Low
Norma Sandy Loam (No)	Low
Orcas Peat (Op)	Low
Ragnar/Indianola Association (RdC)	Low
Seattle Muck (Sk)	Low

The Alderwood gravely sandy loam type represents approximately 80 percent of the watershed, and is generally found on slopes ranging from 2 to 15 percent. This soil, formed in glacial till, is moderately well-drained on till plains and moderately deep over a hardpan. Depth to the hardpan ranges from 20 to 40 inches (0.5 to 1 meter). Permeability is moderately rapid above the hardpan, and very slow through it. Available water capacity is low, runoff is slow, and the hazard of water erosion is slight. This soil type is located throughout the watershed.

The Everett gravely sandy loam is a deep, excessively drained soil formed in glacial outwash, and is found on terraces and outwash plains. Permeability of this soil is rapid and available water capacity is low. Runoff is slow and the hazard of water erosion slight. This soil type represents approximately 10 percent of the watershed, in the immediate vicinity of Cottage Lake.

The Indianola loamy sand soil is made up of somewhat excessively drained soils formed under conifers in sandy, recessional, stratified glacial drift. Permeability of this soil type is rapid and available water capacity is low. Runoff is slow to medium and erosion potential is slight to moderate, depending upon slope. This soil type, approximately two percent of the watershed, is found immediately west of Cottage Lake and immediately east of Crystal Lake.

The Mukilteo Muck soil is a very deep, poorly drained soil formed in organic material derived mainly from sedges. This soil type is generally located in depressional areas. Permeability of this soil is moderate and available water capacity is high. Runoff is usually ponded and erosion is minimal. This soil type represents approximately one percent of the watershed, north of Crystal Lake.

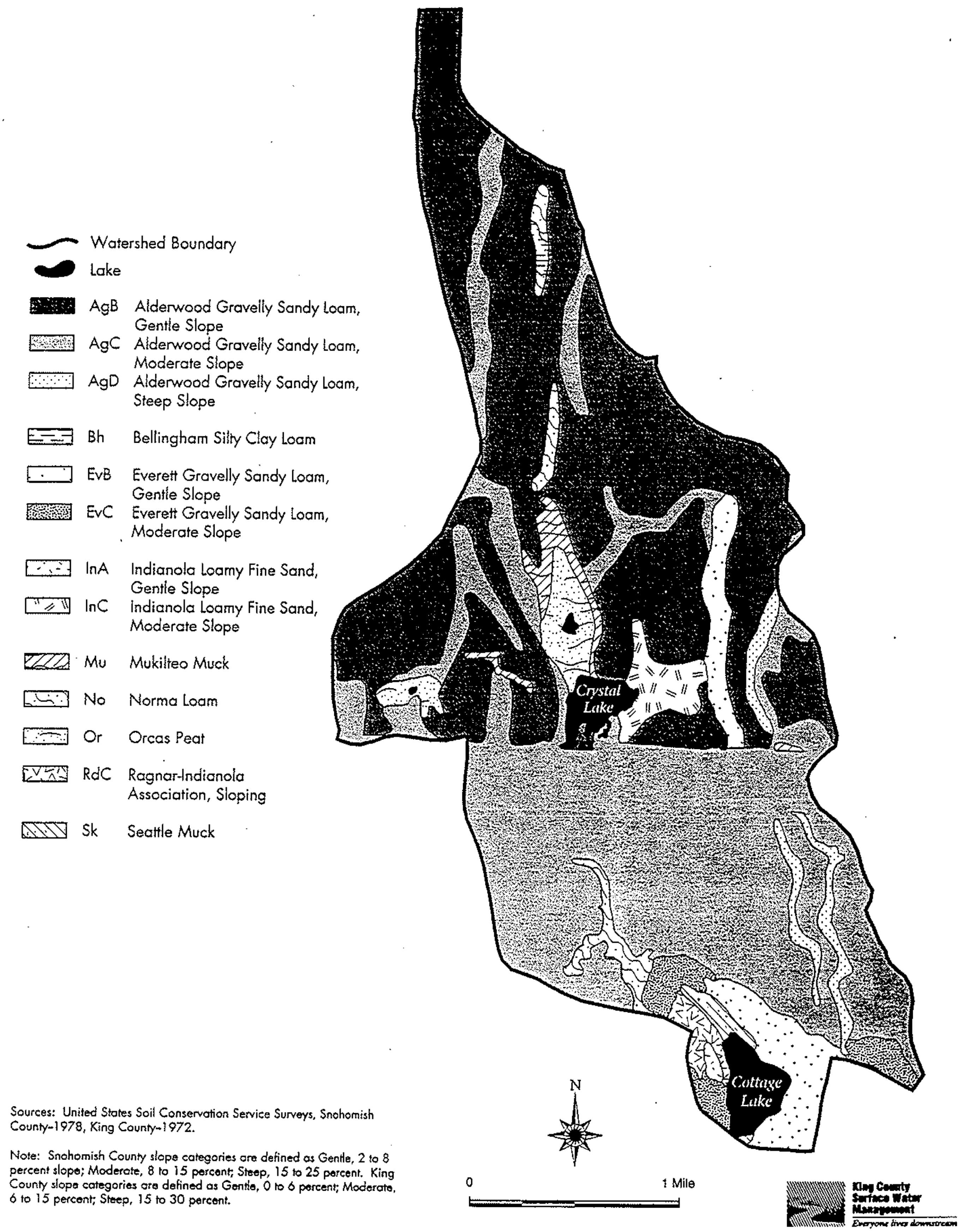


Figure 2-2
COTTAGE LAKE SOILS

The Norma sandy loam is a very deep, poorly drained soil formed in alluvium and located in depressional areas on outwash plains and till plains. Permeability of this soil type is moderately rapid and available water capacity is moderate. The seasonal water table is at or near the surface. Runoff is very slow, and the hazard of water erosion is slight. This soil type represents approximately two percent of the watershed, along Daniels Creek (tributary 0122) before the creek enters and after it leaves Crystal Lake.

The Orcas peat soil type is a very deep, poorly drained soil formed in sphagnum moss and small amounts of Labrador tea and cranberry plants. This soil is generally located in basins and on undulating, rolling uplands. Permeability is rapid, available water capacity is high, runoff is ponded, and there is no erosion hazard. This soil type represents approximately two percent of the watershed and is found in the extensive wetland area extending north from Crystal Lake along Daniels Creek.

The Ragnar/Indianola series soil type is an association of equal parts Ragnar and Indianola soils. Indianola soils were described previously; Ragnar soils are well-drained, gently sloping to strongly rolling soils formed in glacial outwash terraces. Permeability is moderately rapid in the upper soil and rapid in the substratum. Silty layers in the substratum are slowly permeable. Runoff is moderate and the erosion hazard is moderate. This soil type represents approximately two percent of the watershed, immediately west of Cottage Lake.

The Seattle muck soil type is a poorly drained soil formed in material derived primarily from sedges. These soils are located in depressions and valleys on the glacial till plain. Permeability is moderated, and there is a seasonal high water table at or near the surface. Runoff is ponded and there is little to no erosion hazard. This soil type represents approximately one percent of the watershed, at the inflow of Daniels Creek to Cottage Lake.

WATER SOURCES

Due to its proximity to the Pacific Ocean and its latitude (approximately 47 degrees north), the Puget Sound region receives moderate amounts of precipitation and maintains a mild year-round climate. Long-term rainfall records from the National Oceanic and Atmospheric Administration (NOAA) weather station at Carnation, 10 miles southeast of the watershed at a similar elevation, indicate that rainfall averages approximately 46 inches per year in the watershed. King County SWM maintains a rain gauge (02W) near the Safeway store at the Cottage Lake Mall (19150 NE Woodinville-Duvall Road), approximately 0.5 mile east of the entrance to Cottage Lake Park. This gauge has been in service since November 1992 and has recorded about 95 percent of the total rainfall measured at the Carnation weather station.

Water enters Cottage Lake via Daniels Creek (Tributary 0122), Cottage Lake Creek (Tributary 0127), overland runoff from surrounding hill slopes, direct precipitation, and groundwater seepage (see Figure 2-1).

Daniels Creek (Tributary 0122)

Daniels Creek is a class AA stream (WAC 173-201A) and drains approximately 3,100 acres, 70 percent of the total Cottage Lake watershed. The drainage area is a mixture of forested hills and ridges, wetlands, lakes, pasture lands, and residential and commercial development. The creek originates in southern Snohomish County in the northern part of the Cottage Lake watershed. The topography of the drainage area is relatively flat except near the creek headwaters, where the gradient increases considerably. Upstream from Crystal Lake, the creek flows through an extensive wetland. Downstream of Crystal Lake, the creek flows through pasture land, residential areas, and small wetlands prior to entering Cottage Lake.

Between Crystal Lake and Cottage Lake, the Daniels Creek Tributary is recognized as a Locally Significant Resource Area due to the large number of salmonids that spawn in this system (King County, 1989). The King

County Sensitive Areas Map Folio identified this section of Daniels Creek as a Class II stream (year-round flow) with salmonids (King County, 1990b). The Washington State Department of Fish and Wildlife releases juvenile coho salmon into this section of the creek each year. Both coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Oncorhynchus clarki*) may spawn and rear here (King County, 1989). The continued loss of riparian habitat to pasture land and residential use in the Daniels Creek watershed could reduce the quantity and quality of salmonid spawning and rearing habitats in the creek.

Cottage Lake Creek (Tributary 0127)

Cottage Lake Creek is a third order, Class AA stream (WAC 173-201A) and drains approximately 1000 acres, 23 percent of the total Cottage Lake watershed. The drainage area is a mixture of rolling forested hills and residential development. The creek originates in southern Snohomish County, approximately 2.3 miles north of the lake. The upper stretch is relatively flat and passes through forest and small residential areas; the lower stretch has a moderate grade and passes through a steep-walled canyon prior to entering the lake.

A survey of an 819-foot reach of the creek flowing through Cottage Lake Park showed that the ability of the creek to support juvenile coho salmon is limited due to a lack of pools (David Evans and Associates, Inc., 1994). Runs and low gradient riffles with gravel substrate comprised the dominant habitat type. Little year-round vegetation cover was present along the stream reach surveyed, and there was low diversity of benthic (bottom-dwelling) animals.

Groundwater

According to the Bear Creek Basin Plan (King County, 1989), groundwater is located where subsurface materials are coarse-grained and permeable. In the Cottage Lake watershed, such coarse-grained, permeable deposits are located only in the Vashon-age recessional outwash. These outwash deposits are found in the vicinity of Cottage Lake, Crystal Lake, and at the headwaters of the Cottage Lake Creek inlet.

Till underlying the recessional outwash prevents most of the water contained in the outwash from percolating downward out of the base of the outwash. Instead, the water moves laterally over the till and can emerge as surface flow at the base of the outwash. This type of groundwater system is called a shallow aquifer. The large amounts of outwash near and around Crystal Lake and Cottage Lake are likely responsible for maintaining flows in the inlet streams and for directly discharging groundwater into the lakes, thereby maintaining lake levels (King County, 1989).

Cross-sections of the Cottage Lake watershed suggest that the extensive till layer found in the basin overlies the Vashon-age advance outwash, which is typically 100 to 200 feet thick. Because of the till overlay, the water contained in advance outwash deposits is effectively prevented from moving to the surface. This type of system is generally called a confined aquifer (King County, 1989).

Sources of groundwater in the Cottage Lake watershed would thus be the shallow aquifer located in recessional outwash in the vicinities of Cottage and Crystal lakes, and a confined aquifer located in advance outwash overlain by till. Recharge to the shallow aquifer would be from direct precipitation and from side slope streams that descend from the hills and travel long distances over the recessional outwash deposits. Recharge to the confined aquifer would be from direct precipitation in upland regions where this deposit is exposed (King County, 1989).

WETLANDS

Daniels Creek Subbasin

The 1990 King County Sensitive Areas Map Folio indicates the location and identifying numbers for wetlands in the Cottage Lake watershed shown by the 1990 King County wetland inventory (King County, 1990b; King County, 1991). Seven wetlands were identified in the Daniels Creek subbasin of the Cottage Lake watershed (Figure 2-1): Big Bear Creek (BBC)-2, BBC-5, BBC-8, BBC-10, BBC-34, BBC-35, and BBC-58. Detailed information on the vegetative classification, plant and animal species identified, and overall King County wetland ranking for each of these wetlands is presented in King County, 1996. BBC-10, partially within the Cottage Lake watershed, is a Class 1 wetland. The other wetlands are Class 2 or Class 3.

Snohomish County has identified an extensive wetland of approximately 150 acres along Daniels Creek north of and including Crystal Lake (Figure 2-1). This wetland area is designated an environmentally sensitive area of importance by Snohomish County, but has no formal wetland rating or classification (Snohomish County, 1987; Gene Williams, personal communication, January 30, 1995).

The U.S. Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI) maps indicate more wetlands than those inventoried by King and Snohomish Counties. In particular, the maps show two moderate-sized wetland areas near Daniels Creek north of Woodinville-Duvall Road: a five-acre area along the creek immediately north of the road, and a seven-acre area immediately north of the road and west of Daniels Creek (USFWS, 1989).

In Snohomish County, the NWI map shows a 200-acre wetland north of and including Crystal Lake (USFWS, 1989). Because of its size and complex vegetative structure, this wetland is an important part of the Daniels Creek ecosystem and would thus likely be rated a Class 1 wetland by King County (King County, 1990b) and a Category 1 wetland by the Washington Department of Ecology (WSDOE, 1991).

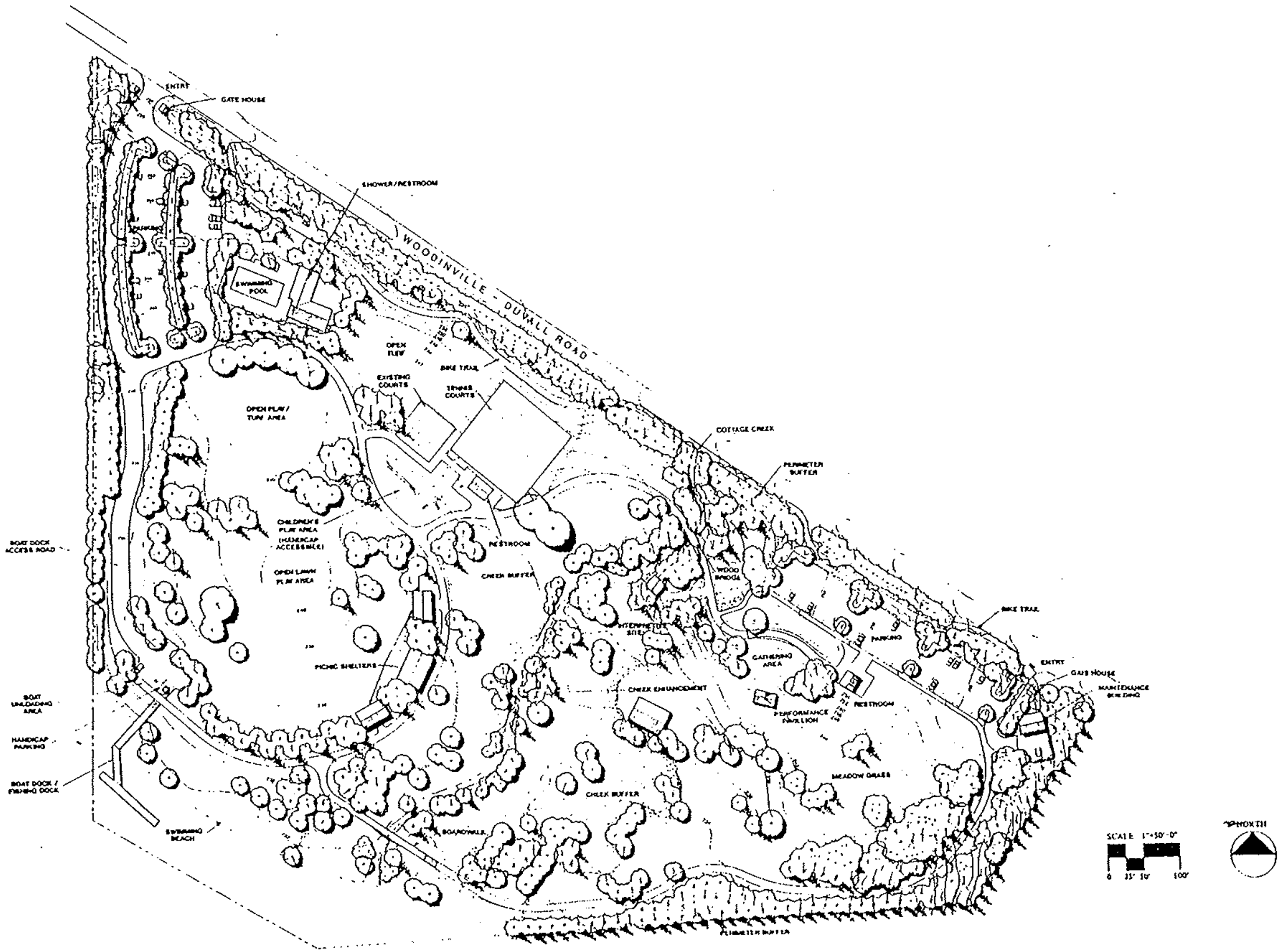
Cottage Lake Creek Subbasin

The 1990 King County Sensitive Areas Map Folio (King County, 1990b) shows one wetland in the Cottage Lake Creek sub-basin upstream from Cottage Lake (BBC-11) and one wetland slightly outside the sub-basin (BBC-17). For detailed information on these wetlands, see King County, 1996.

Approximately 16 acres of wetlands have been delineated within Cottage Lake Park (formerly Norm's Resort); two of these acres are lacustrine (associated with the lake), and 14 acres are emergent vegetation, mostly mowed, wet lawn (David Evans and Associates, Inc., 1994). In addition to mowing the wetland, past owners of the property have planted non-native ornamental shrubs throughout the area. Part of these wetlands, converted to lawn, also appear to have been partially filled and graded during initial development of the resort. These highly disturbed wetlands have been rated as Class 2 wetlands by King County.

COTTAGE LAKE PARK

Cottage Lake Park, on the north shore of Cottage Lake, is a recent acquisition of King County; the property was transferred to the County in May 1992. The Cottage Lake Park Master Plan (Figure 2-3), adopted September 12, 1994, balances recreational activities in the park with the need to protect water quality in Cottage Lake Creek and associated wetlands. The plan requires buffers of 150 feet on either side of Cottage Lake Creek in order to re-establish a functional wetland and stream corridor through the park and rehabilitate salmonid spawning and rearing habitat in the creek. The wetland/stream corridor perimeter will be heavily planted to discourage direct access by park visitors (David Evans and Associates, Inc., 1994).



KCM
1917 First Avenue
Seattle, WA 98101

King County Surface Water Management
COTTAGE LAKE MANAGEMENT PLAN

Figure 2-3.
COTTAGE LAKE PARK MASTER PLAN

Approximately 300 lineal feet, representing 40 percent of the lake shoreline at the park site, will also be planted with native vegetation in order to restore a portion of the lacustrine wetland. The western half of the lake frontage will be re-developed as a swimming and sunning beach. To the west of the swimming beach, a boat dock/fishing pier will be provided in association with a car-top boat launching area. Other park amenities will include open play meadows, a children's playground, basketball and tennis courts, a swimming pool, picnic shelters, and rest rooms (David Evans and Associates, Inc., 1994).

A complete public access inventory is included in Appendix B. The inventory follows guidelines established by WSDOE for the public access requirements for Phase II Centennial Clean Water Fund grant funding.

LAND USE

Cottage Lake is within the Bear Creek Community Planning Area, which had the second highest rate of growth among King County planning areas during the 1980s. From 1980 to 1991 the population increased 87 percent, from 13,250 in 1980 to 24,800 in 1991. The population is projected to reach 37,100 by the year 2000, a 50 percent increase over 1991 (King County, 1992).

In the past, Cottage Lake's watershed was largely rural. Surveys by the United States Geological Survey (USGS) in 1973 estimated basin land use to be one percent residential, six percent agricultural, and 90 percent forested (USGS, 1976). By 1985, considerable development was occurring in the watershed and land use was estimated to be one percent commercial, 20 percent residential, and 76 percent forested/grassland/agricultural (King County, 1989). This increased residential use is also reflected in the population change in the Bear Creek Community Planning Area, which experienced a 193 percent population increase between 1970 and 1985 (King County, 1986).

Current and future land use zoning in the Cottage Lake watershed are set forth in the Bear Creek Community Plan (King County, 1989; King County, 1990b) and the Cathcart Maltby Clearview Area Comprehensive Plan (Snohomish County, 1987). Table 2-3 shows total acreage of various land uses in the watershed under both current and future buildout conditions. Forest/open lands represent the majority of the watershed under current land use conditions; most of this forest land will be converted to residential housing in the future. Currently, developed conditions are dominated by single-family residential units ranging in density from one unit per 2.5 acres to three to seven units per acre (the latter density around Cottage Lake). As indicated in Table 2-3, buildout conditions will be zoned for low density development (either one unit per acre or one unit per 2.5 acres in most of the watershed).

Table 2-3: Current and Future Land Use in the Cottage Lake Watershed (King County, 1989)

	Land Use (Acres)							
	Forest/ Open	Com	MF	SF1	SF2	SF3	SF4	SF5
Current	3,463	46	0	123	444	295	0	0
Future	371	275	0	259	1,792	1,602	52	20
Change in Land Use	-3,092	229	0	136	1,348	1,307	52	20

Land Use Abbreviations:
Forest/Open— undeveloped land; SF1— 3 to 7 dwelling units/acre; SF2— 1 dwelling unit/acre; SF3— 1 dwelling unit/2.5 acres; SF4— 1 dwelling unit/5 acres; SF5— 1 dwelling unit/12.5 acres; MF—Multi-Family; Com— Commercial

CHAPTER 3: METHODS

The methods used to conduct the Phase I diagnostic/feasibility study for Cottage Lake are briefly described in this chapter. The hydrologic and water quality monitoring program elements are described first, followed by biological monitoring, wetland assessment, and nonpoint pollution assessment methods. Lake and tributary sampling station locations are shown in Figure 3-1. Sampling station descriptions are found in Appendix C. The quality assurance/quality control plan is described in King County, 1996.

HYDROLOGIC MONITORING

Inflow

Surface water inflow was monitored at site locations CLIN1 and CLIN2 (Figure 3-1) using a continuous stage recorder installed in November 1993. Stage (stream level) was recorded in 15-minute intervals. A stage discharge rating curve was developed using SWM staff's measurements of stream flow from December 1993 to April 1994, and used to calculate mean daily flows for the same period. The Hydrologic Simulation Program-FORTRAN (HSPF) computer model was used to develop the lake water budget (volumes of water entering or leaving the lake from various sources during the study year).

Outflow

Lake outflow was monitored at site location CLOUT (Figure 3-1), downstream of the water quality monitoring site, using a continuous stage recorder also installed in November 1993. Stage was recorded in 15 minute intervals. A stage discharge rating curve was developed using SWM staff's measurements of stream flow from December 1993 to April 1994, and used to calculate mean daily flows for the same period.

Groundwater Flow

Groundwater flow was measured by the project consultant at four locations consisting of paired land-based (CL-1, CL-3, CL-5, and CL-7) and lake-based (CL-2, CL-4, CL-6, and CL-8) drive points (Figure 3-2). A citizen volunteer performed monthly groundwater level readings in the drive point installations.

Hydraulic conductivity was evaluated at each of the four locations using slug test methodology (Hong West and Associates, Inc., 1994). A conceptual groundwater model of the site hydrostratigraphy and groundwater flow was developed using existing groundwater data and information collected during the study. The model includes maps and cross-sections to illustrate the direction of groundwater flow.

On September 15, 1993, the project consultant installed a seepage meter at each of the four monitoring sites. Each seepage meter, consisting of an approximately 30 cm end section of a 220 liter drum with a three cm hole on the top, was installed in 0.6 to one meter of water. The amount of groundwater entering the lake was calculated by installing a plastic bag, void of air, connected to a hose through a rubber stopper. Any groundwater entering the drum section from below forces the same amount of water into the bag. After one day, the bag was removed from the drum and weighed. The rate of groundwater inflow to the lake was calculated by dividing the amount of water by the time the bag was attached, and multiplying the result by the area of the drum.

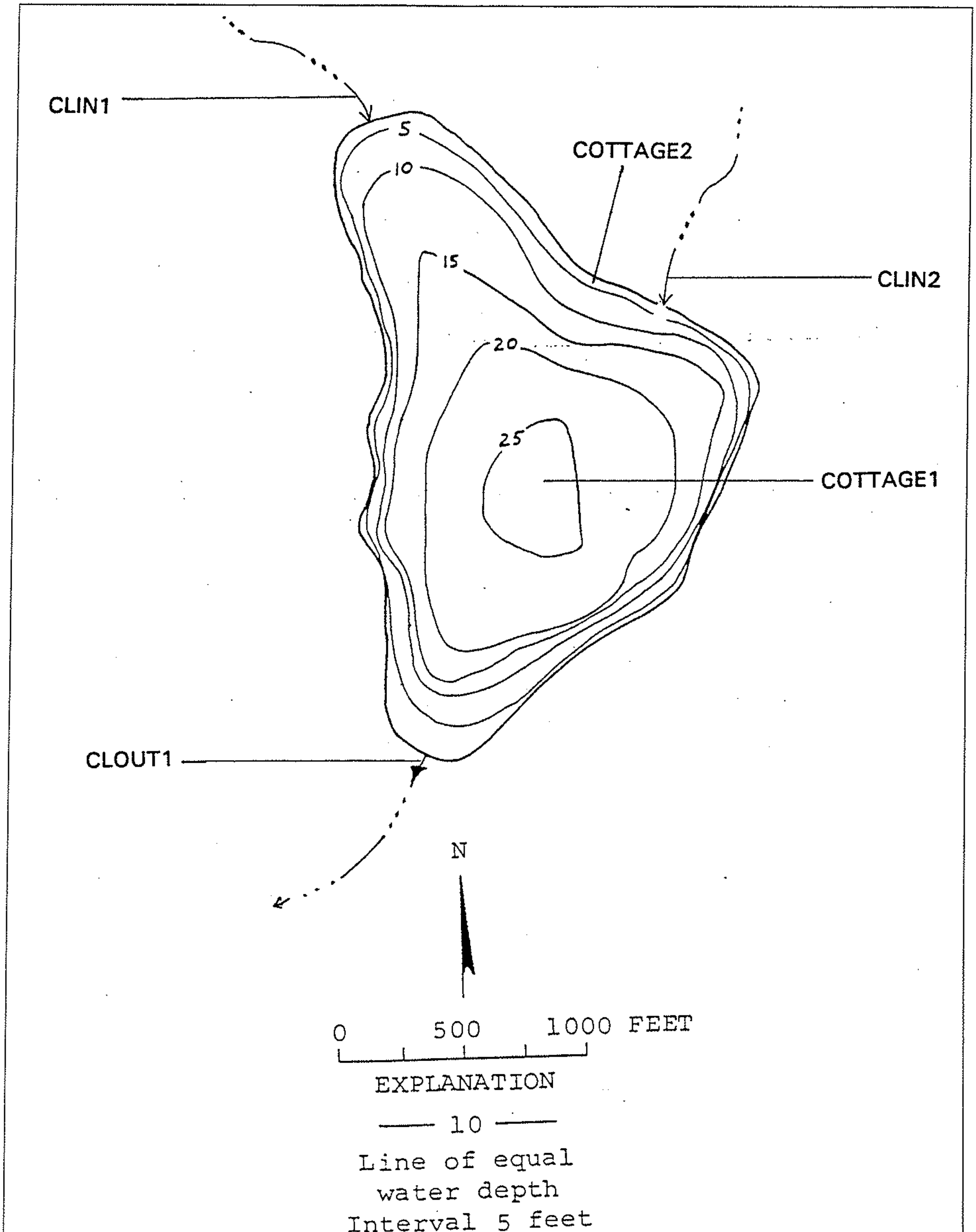


Figure 3-1
IN-LAKE AND IN-STREAM SAMPLE SITE LOCATIONS FOR COTTAGE LAKE

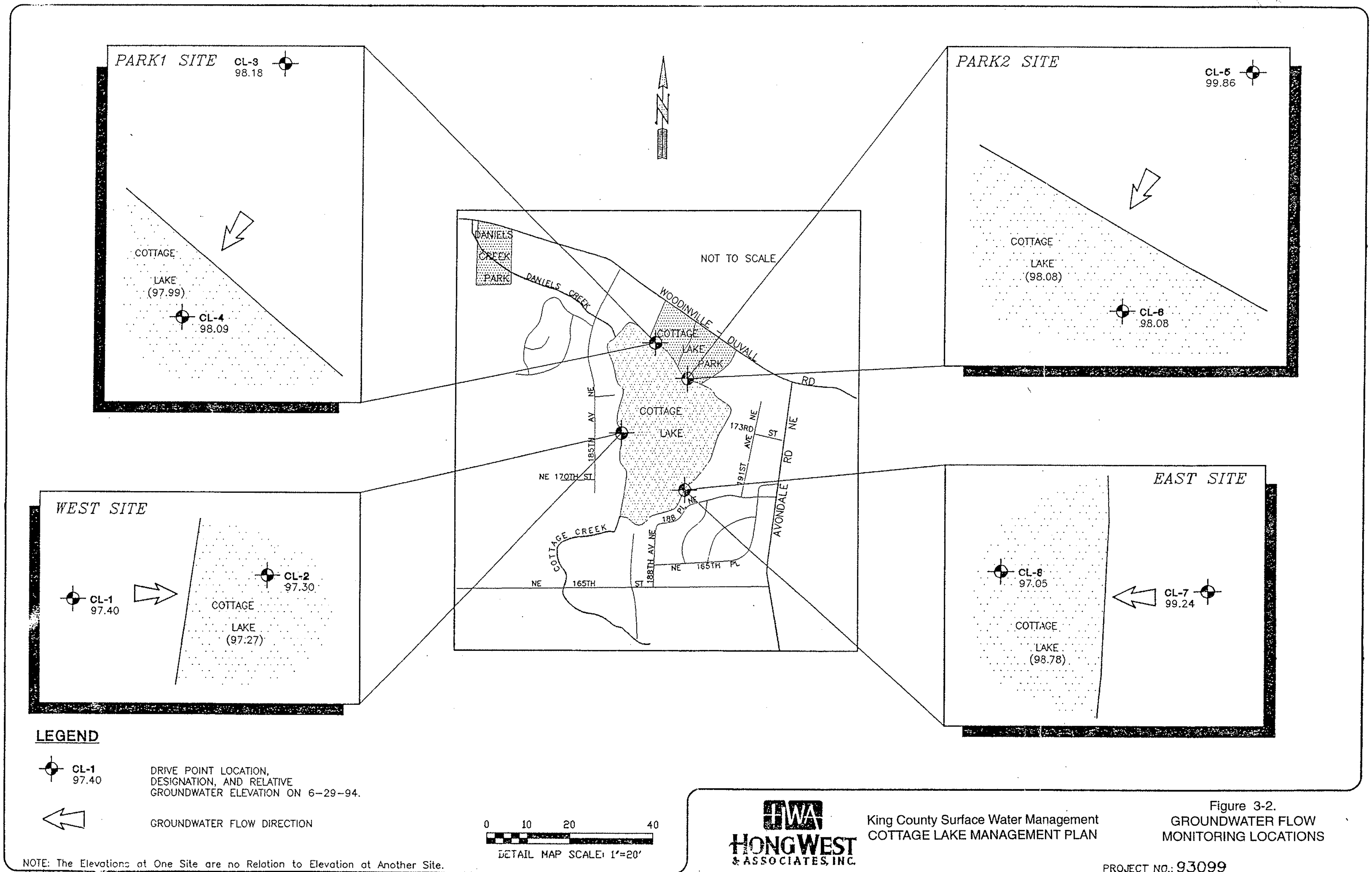


Figure 3-2.
GROUNDWATER FLOW MONITORING LOCATIONS

Lake Level

Lake level was measured weekly by a resident volunteer from August 1993 through December 1993, and again from February 26, 1994, through April 1994. These data were used to check the HSPF model for those periods.

Precipitation

Precipitation was measured at the King County SWM precipitation gauging station 02W, located near the Safeway Store in the Cottage Lake Mall (19150 NE Woodinville-Duvall Road), and also measured daily by two resident volunteers from September 1993 to April 1994.. Station 02W uses a tipping bucket gauge that records precipitation in 15 minute intervals. The tipping bucket precipitation record was checked against the local data, and used for the HSPF model.

WATER QUALITY MONITORING

Cottage Lake water quality was measured through a combination of field and laboratory methods, both fully described in the Quality Assurance/Quality Control Plan for Cottage Lake (King County, 1996). Table 3-1 summarizes the monitoring program, sampling frequency, and target parameters for the water quality component of the project.

The water quality monitoring program began in April 1993 and was completed in April 1994, except for groundwater, which was completed in June 1994. From April through September, in-lake water quality was monitored twice monthly; inlet and outlet water quality were monitored monthly. From October through March, this pattern was reversed. This monitoring schedule allowed for an in-lake water quality focus during the growing season and a watershed loading focus during the wet season.

In-lake

All on-site field measurements (dissolved oxygen, conductivity, pH, temperature, and Secchi depth) were made with calibrated equipment according to the recommended protocols or manufacturers' suggested calibration. Vertical profiles for dissolved oxygen, conductivity, pH, and temperature were measured at one meter intervals from the surface to the lake bottom and recorded in the field notes.

Water samples were collected at two in-lake stations, COTTAGE1 and COTTAGE2 (Figure 3-1). At COTTAGE1, samples were collected at 1-meter intervals beginning at the surface using a vertical Alpha TM bottle (2.2 L Van Dorn bottle) water collection device. Collected samples were transferred to pre-labeled containers prepared according to the recommended Quality Assurance/Quality Control Plan protocols. At COTTAGE2, a surface water sample was collected for analysis of fecal coliform bacteria only. All samples were placed on ice until delivery to the analytical laboratory.

Nutrient Limitation Assessment

An *in situ* (in-place) bioassay developed by Petersen (Portland State University) was used to evaluate nitrogen and phosphorus limitation of phytoplankton production in Cottage Lake. The exact methods are detailed in *Response of Phytoplankton in Cottage Lake to Nutrient Enrichment* (KCM, 1993) and are briefly described below.

Table 3-1: Cottage Lake Water Quality Monitoring Program

Sampling Frequency	Stations	Parameters
In-lake		
Monthly: Oct-Mar Biweekly: April-Sept	1 station, deep spots, each meter, duplicate TP at surface and bottom	Temperature, pH, Dissolved Oxygen, Conductivity, Total Phosphorus, Soluble Reactive Phosphorus, Nitrite+Nitrate-Nitrogen, Ammonia, Total Nitrogen, Turbidity, Alkalinity,
	1 station	Secchi depth
	1 station, water column composite (@0.5m, 1.5m, 2.5m, and 3.5m), triplicate chl a	Chlorophyll *a*, Phaeophyton a, Phytoplankton species, biovolume, and identification
	1 station, vertical tow	Zooplankton species, enumeration, and identification
Monthly	2 stations, surface only @ deep spot and park shoreline	Fecal Coliform
Quarterly	1 station, deep spots, each meter	Calcium, Magnesium, Sodium, Potassium, Chloride, Sulfate, Aluminum, Iron, Total Soluble Phosphorus, Dissolved Organic Carbon, Total Organic Carbon
Inlets/Outlets		
Monthly: April-Sept Biweekly: Oct-Mar	3 stations, triplicate TP at inlets	Temperature, pH, Dissolved Oxygen, Conductivity, Total Phosphorus, Soluble Reactive Phosphorus, Total Nitrogen, Nitrite+Nitrate-Nitrogen, Ammonia, Alkalinity, Chloride, Fecal Coliform (inlets)
Storm Events	2 stations, composited over storm	Base flow parameters plus Turbidity, Total Suspended Solids, Oil/Grease, Hardness, Copper, Lead, and Zinc (total and dissolved forms of metals)
Groundwater		
Quarterly	8 sites: existing wells or shallow monitoring wells	Total Phosphorus, Soluble Reactive Phosphorus, Nitrite+Nitrate-Nitrogen, Ammonia, Total Nitrogen, Chloride
Sediment characterization		
Once	three depth strata (0-2m, 2-4m, and >4m) four cores from each stratum, 0.5 m core, analyzed at 10 cm increments	Total Phosphorus, Total Nitrogen, Percent Water, Total Organic Carbon, Iron
Sedimentation rate		
Once	1 station, 2 cores/ station, 1-2m cores, 2 cm increments	Zinc and Lead
Precipitation		
Monthly	2 stations, composited	Total Phosphorus, Total Nitrogen

The bioassay was conducted in October 1993 using eight 20-liter cubitainers (plastic carboys). Each carboy was filled with lake water, and received one of four possible nutrient additions: nitrogen only, phosphorus only, nitrogen and phosphorus, or no addition. Each treatment was replicated twice and the cubitainers were suspended at 0.75 meter depth for five days.

After incubation was complete, carbon assimilation was measured by adding carbon-14 to three 40-ml subsamples from each of the cubitainers. Following carbon-14 incubation, samples were evaluated for carbon assimilation, a measure of new plant growth.

Sediment

The purpose of sediment sampling was twofold: to estimate the rate of sedimentation; and to quantify sediment nutrient content. To estimate the sedimentation rate, two cores, each one meter in length, were collected from the deep areas of the lake. Samples were collected using a piston-corer with 1 m × 34.5 mm inside diameter plastic core holders. The weighted coring device was dropped from the side of the sampling boat and then retrieved. As the sampler was pulled to the surface, the bottom of the tube was capped, and the tube was removed from the sampling device. Upon removal, the core was capped and stored in a bucket prior to delivery to the analytical laboratory. Cores for sedimentation rate analysis were sectioned into 2 cm sections and analyzed for percent solids, lead and zinc concentrations. Surface (0-2 cm) sections were also analyzed for total phosphorus concentrations.

Sediment cores for nutrient characterization were stratified along three depth ranges (0-2 m, 2-4 m, and >4 m. Four 0.5-m cores were collected from each stratum as described above. Cores for sediment nutrient content were sectioned into the top 2 cm, and 10 cm sections thereafter. Core sections were analyzed for percent solids, volatile solids, total phosphorus, total Kjeldahl nitrogen, and iron.

Streams

Inlet and outlet stations are shown in Figure 3-1. Manual grab sampling methods (U.S. EPA, 1988) were used to collect both base flow and storm flow inlet and outflow samples.

A combination of grab sampling methods and flow-compositing was used to sample two storm events (December 9, 1993, and February 13, 1994). On May 16, 1994, a community volunteer collected grab samples at two upstream locations (Figure 3-1): Cottage Lake Creek at the Cottage Lake Mall, and Daniels Creek at the Woodinville-Duvall Road crossing. For the purpose of this study, storm events were defined as either 0.5 inch of rainfall in a 6-hour period, or 1.0 inch in a 24-hour period, following 60 to 72 hours of dry conditions (less than 0.25 inch of rain per day).

Additional Stormwater Sampling

Stormwater runoff samples were obtained during two additional storms, in September and December 1995, to address community concerns about isolating nonpoint pollution sources and prioritizing the implementation of watershed source controls and best management practices. A fall "first flush" storm event was sampled on September 27, 1995, after approximately 0.96 inches of precipitation. Five sampling locations in Daniels Creek were sampled (Stations D1, D2, D3, D7, and D9; see Figure 3-3).

To further identify and isolate sources of contaminants to Cottage Lake, eight additional sampling locations were added to Daniels Creek, and five to Cottage Lake Creek (Figure 3-3). Stormwater samples were subsequently obtained during a larger storm event (approximately 1.90 inches of precipitation) on

December 10, 1995. Table 3-2 shows the water quality parameters analyzed at each sampling location during the 1995 stormwater sampling. Two additional rounds of stormwater sampling are proposed for 1996.

Table 3-2: Cottage Lake Inlet Stormwater Sampling Parameters for 1995-1996.

Station	Parameters									
	Turb	TSS	NH_3	NO_{2+3}	OrthoP	TP	Cl	FC	O/G	Cu, Zn, Pb	Hardness
C1	X	X				X			X	X	X
C2	X	X				X			X	X	X
C3	X	X				X			X	X	X
C4	X	X				X			X	X	X
C5	X	X	X	X	X	X	X	X	X	X	X
D1	X	X	X	X	X	X	X	X			
D2	X	X	X	X	X	X	X	X			
D3	X	X	X	X	X	X	X	X			
D4	X	X	X	X	X	X	X	X			
D5	X	X	X	X	X	X	X	X			
D6	X	X	X	X	X	X	X	X			
D7	X	X	X	X	X	X	X	X			
D8	X	X	X	X	X	X	X	X			
D9	X	X	X	X	X	X	X	X			
D10	X	X	X	X	X	X	X	X			
D11	X	X	X	X	X	X	X	X			
D12	X	X	X	X	X	X	X	X			
TX	X	X	X	X	X	X	X	X			

Abbreviations: Turb—turbidity; TSS—total suspended solids; NH_3—ammonia; NO_{2+3}—nitrite+nitrate-nitrogen; OrthoP—orthophosphorus (soluble reactive phosphorus); TP—total phosphorus; Cl—chloride (analyzed in December 10 samples); FC—fecal coliforms; O/G—oil and grease; Cu, Zn,, Pb—copper, zinc, and lead.

Precipitation

Two resident volunteers at Cottage Lake recorded precipitation and collected rainfall in a sample bottle daily from September 1993 through April 1994. Samples were stored in their freezers and picked up monthly for delivery to the analytical laboratory.

At the laboratory, the two samples were composited and analyzed for total nitrogen and total phosphorus. The protocols used by the volunteers are outlined in the Quality Assurance/Quality Control Plan (King County, 1996).

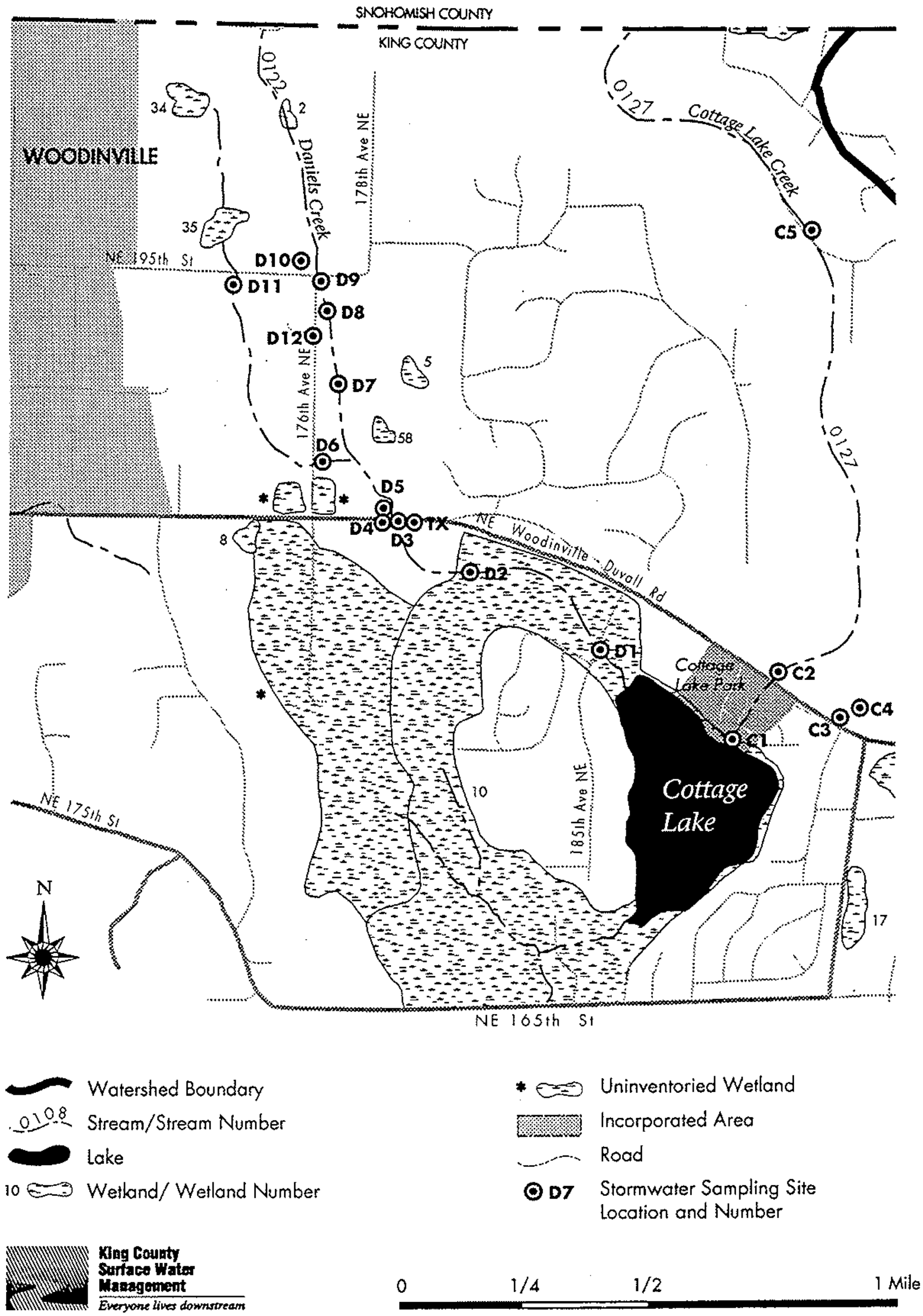


Figure 3-3
STORMWATER SAMPLE SITE LOCATIONS FOR COTTAGE LAKE INLETS

Groundwater

Groundwater was sampled quarterly during September 1993 through June 1994 at the same locations as groundwater flow monitoring. Due to the low permeability of shoreline soils and surrounding well recharge rates, special well sampling procedures were used, consisting of bailing the drive point dry and installing the seepage meter bag on the first day of the sampling event; on the second day, the recovered water was sampled and the seepage meters were pulled. A 25.4-mm diameter stainless steel bailer was used to purge the wells on the first day; a peristaltic pump was used to sample on the second day. Conductivity, pH, and temperature readings were taken in the field from the groundwater following sample collection. Groundwater samples were delivered to the analytical laboratory for nutrient and chloride analyses.

BIOLOGICAL MONITORING

Phytoplankton

Phytoplankton samples were collected from the surface of Cottage Lake from April to mid-June 1993 by submerging to 0.5 m and filling a sample bottle. Beginning in mid-June, the phytoplankton sampling procedure was modified to collect a composite sample from the *photic zone* (the zone where light penetrates the water and photosynthesis can occur). This was accomplished by collecting vertical Alpha TM bottle (2.2 L Van Dorn bottle) samples at 0.5, 1.5, 2.5, and 3.5 m, and compositing them into a clean 22-L white bucket at the surface. The composite sample was hand-mixed, and sub-samples were collected for chlorophyll *a* and taxonomic analyses.

Chlorophyll *a* samples were taken in triplicate in darkened one-liter bottles, placed on ice, and delivered to the analytical laboratory for filtration, preservation, and analysis. All taxonomic samples were preserved with Lugol's solution and stored in a cool, dark cabinet until transferred for taxonomic analysis. Phytoplankton enumeration, identification, and cell volume determination were made on preserved one-liter samples. Phytoplankton taxonomic methods are detailed in Gibbons, 1994a.

Zooplankton

Zooplankton samples were collected with a 75 μm mesh, 25 mm inside diameter, vertical tow net, lowered over the side of the boat to a depth of 5 or 6 m and pulled vertically through the water column. Haul depth and tow numbers were recorded in the field notes and used to calculate zooplankton densities.

Zooplankton samples were preserved using a 37 percent formaldehyde solution, a 70 percent isopropyl alcohol solution, or a blend of 400 ml formaldehyde, 200 ml isopropyl alcohol, 200 ml glycerin, 4 mg mercurous chloride, and a dash of magnesium carbonate diluted to a 2-liter volume with distilled water. The preservative was added to an approximate 10 percent concentration to each lake zooplankton sample. Samples were stored in a cool, dark cabinet until delivery for taxonomic analysis. Zooplankton identification, densities, and biomass determination were made on preserved samples. Zooplankton taxonomic methods are detailed in Gibbons, 1994a.

Benthic Invertebrates

Benthic invertebrates were sampled in June, August, and October 1993 at two in-lake stations, COTTAGE1 (deep zone) and COTTAGE 3 (littoral zone on west shore of lake). A single sediment sample was collected at each site using an Eckman dredge sampler (3,540 cubic cm). The collected sample was transferred from the sampler to a 2-liter, stainless steel pan and sieved into a 22-L bucket through a 2-mm screen. The sample was sieved a second time using a 500 µm screen, and the collected material was placed in a sample jar and preserved with isopropyl alcohol. Population density and species composition were determined for each sample. Organisms were identified to genus, except for chironomids and oligochaetes, which were identified to family (Gibbons, 1994a).

Fisheries

The lake fishery was surveyed in the fall (November 1993) and spring (May 1994) with the assistance of community volunteers. Electrofishing and fyke net traps were used to capture fish for assessment of the quality of the fishery.

Electrofishing, using a Smith-Root GPP 5 electroshocking unit operated in a pulsed mode of direct current with power outputs from 3 to 5 amperes (KCM, 1994a; KCM, 1994b), was conducted between 3:30 and 6:30 PM for the fall fishery assessment and between 6:00 and 10:00 PM for the spring fishery assessment (i.e., during daylight, dusk, and darkness). During the course of the electrofishing period, the boat was maneuvered along the shoreline and the probes were pulsed on and off. Stunned fish were collected using dip nets, placed in a live well, counted, measured, and released. Fish with a length greater than 150 mm were weighed. Scale samples were collected from several fish to determine age and growth information. During the spring fishery assessment, several fish were retained for gut analysis (KCM, 1994a; KCM, 1994b).

Two fyke nets were set in six to eight feet of water on the north and southwest sides of the lake with the 50-foot leads perpendicular to shore and weighted trap-ends on the lake bottom. As fish encountered the net, they followed it to the deeper water and into the trap. Nets were set prior to electrofishing and were pulled the following morning. The fish in the traps were measured, and weighed if greater than 150 mm, and returned to the lake (KCM, 1994a; KCM, 1994b).

Aquatic Plants

Macrophyte (aquatic plant) community composition, areal distribution, and phosphorus content were determined during peak abundance (September 1 and 2, 1993). In mapping aquatic plants, the lake shoreline and littoral areas were randomly divided into 23 sections and visually surveyed by boat. Within each section, the community type (submersed, floating, or emergent), species present, and relative section cover (sparse, moderate, or dense) were determined and mapped.

Plant biomass and phosphorus content were sampled by throwing a 0.25 square meter raking device and net into the plant bed along eight transects (Figure 3-4). Submersed plants were collected by scuba diver. Samples were rinsed, placed in a labeled bag, and iced for pressing and positive identification back at SWM, where the plant samples were washed, weighed, and sorted by species, and a representative subsample was taken. Subsamples were delivered to the Aquatic Research Inc. laboratory for dry weight and total phosphorus determination.

Fecal Coliform Bacteria

Fecal coliform bacteria are normally found in the intestinal tracts of humans and other warm-blooded animals. They do not threaten human health in and of themselves. However, their presence in large numbers in a water body indicates the presence of other, disease-causing microorganisms associated with human waste (e.g., *Salmonella*, *Shigella*).

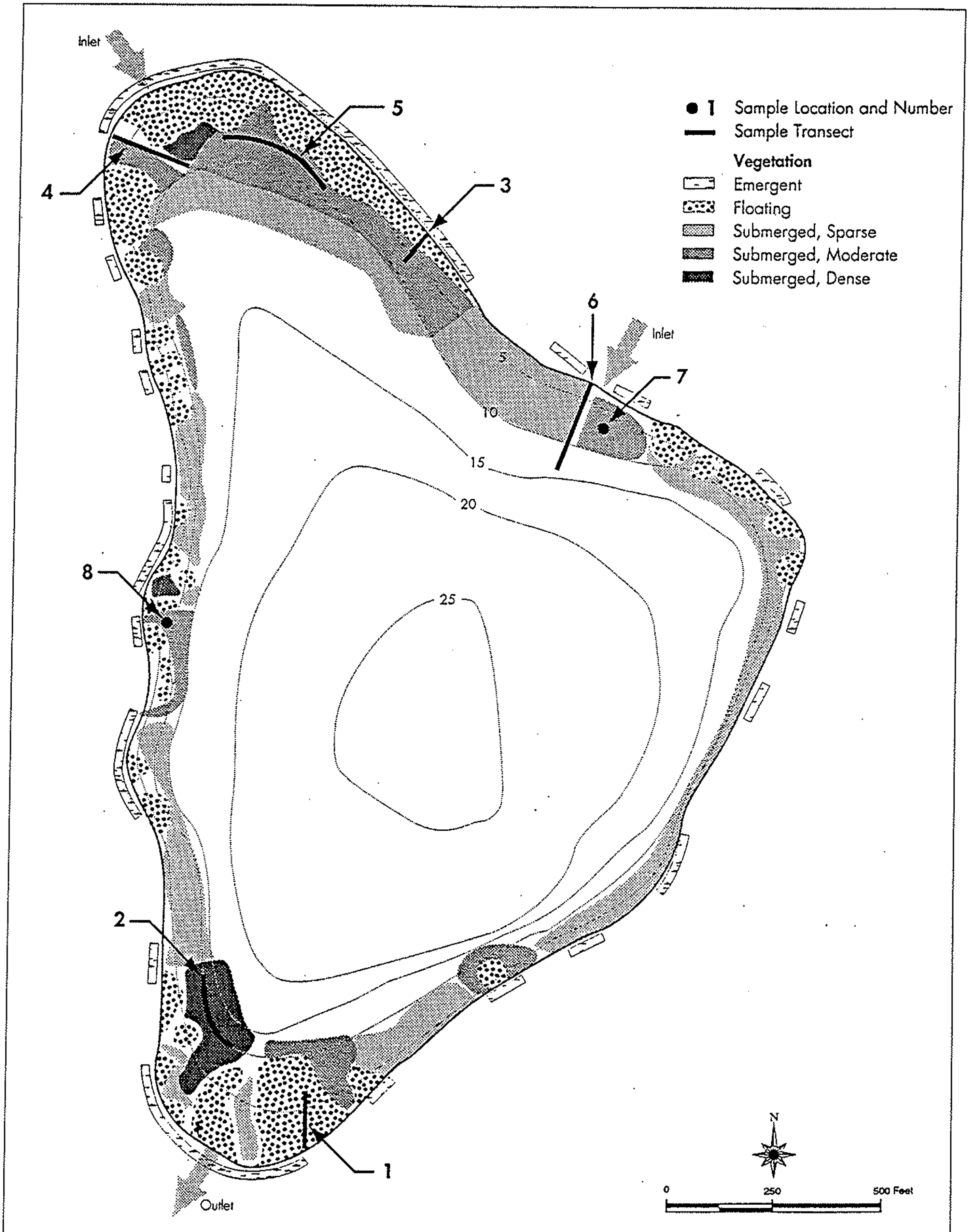


Figure 3-4
COTTAGE LAKE MACROPHYTE MAP

Fecal coliform bacteria samples were collected at the lake inlets (CLIN1 and CLIN2) and at in-lake stations (COTTAGE1 and COTTAGE2) during routine monitoring (Table 3-1). Samples were collected as described for other stream and in-lake samples; the only differences being the use of sterile bottles for sample collection and inversion of the bottles prior to filling.

WETLAND ASSESSMENT

An on-site evaluation of all wetlands on the shore of Cottage Lake and at the two inlets was conducted by the project consultant on October 15, 1993. The wetland evaluation consisted of a characterization of the plant communities, including species present, percentage cover, and vegetation community type; wetland conditions; inlet and outlet conditions; soils evaluation; and a functions and values assessment (Pentec Environmental, Inc., 1994).

Standard field methods were used for vegetation analysis and soil sample collection. Hydrologic indicators and water depth were noted. The condition of the wetland was evaluated on the basis of observed disturbances, such as areas of bare soil, the presence of refuse, the lack of native vegetation, and the percentage of invasive and exotic vegetation. Soils were evaluated through review of US Soil Conservation Service (SCS) soil maps prior to site visits. Soils were analyzed for hydrologic indicators through on-site soil collection and compared using standard SCS protocols (Pentec Environmental, Inc., 1994).

Wetland functions and values assessed included groundwater exchange, hydrologic support, erosion prevention/shoreline protection, water quality improvement, food chain support, ecological support, and cultural/socioeconomic value. Recommendations were made for improving these functions and values, and for restoring lake shore wetland habitat (Pentec Environmental, Inc., 1994).

NONPOINT ASSESSMENT

Septic Survey

Aerial Shoreline Analysis (ASA) was used to assess the potential for on-site septic system contributions to lake phosphorus loading. Flights for the aerial imaging occurred in January 1994. Aerial imaging provided a low-altitude, oblique view of the lake shoreline and nearshore areas, allowing the analyst to see beneath trees and shrubs, and view both vertical banks and horizontal land surfaces at the same time. Both visible color and modified color infrared films were used at Cottage Lake for each segment of shoreline examined for evidence of nonpoint pollution and nutrient loading problems (KCM, 1994c).

In conjunction with ASA analysis, field or shoreline surveys were conducted in October 1993 and May 1994 to establish a baseline prior to ASA (October survey) and to verify findings revealed during ASA (May survey). The surveys consisted of visual observation of the shoreline area extending approximately 100 meters from the lake shore. Nearshore areas were observed for the presence of the following characteristics:

- Surfacing sewage or ponding over drainfield
- Conspicuously lush vegetation in drainfield area
- Dead vegetation in drainfield area
- Soggy or odorous drainfields

- Dark soil where excess organic matter has accumulated
- Excessive aquatic plant growth at the shoreline.

Particular attention was given to areas where septic system drainfields were likely to be located or where failures were suspected. This activity included verification of findings from the background resource materials (Seattle-King County Department of Public Health, 1981-1993) and the ASA (KCM, 1994c; Resource Management, Inc., 1994).

The septic surveys were conducted from the water by boat. This allowed a view of drainfield areas near the lake while respecting private property. Conductivity was measured continuously from the moving boat during the October 1993 site visit using a Hydrolab TM water quality multiprobe instrument. Field notes and photographs were taken during both site visits to document locations where leachate intrusion or other conditions relevant to sources of lake water degradation were observed (KCM, 1994c).

TROPHIC STATUS

Annual and summer epilimnetic mean values for total phosphorus, chlorophyll *a*, and Secchi depth were used to evaluate trophic status, using Carlson's Trophic State Index (Carlson, 1977). Existing lake trophic status was also compared with historical Cottage Lake data, and with other small lakes in King County.

DATA REDUCTION METHODS

Mean, minimum, and maximum values were calculated for all in-lake (surface only), inflow, outflow, stormwater, groundwater, and precipitation water quality data. Summer mean, minimum, and maximum values were also calculated for in-lake (surface only) data.

Weekly volume-weighted total phosphorus values were calculated from monthly and biweekly phosphorus concentration data by depth and the corresponding lake volume/depth curve value for the weekly time period. The lake volume/depth curve was developed from a lake bathymetry map. Daily lake level data were used to establish maximum and minimum lake level, from which corresponding weekly lake volumes were calculated. These lake volumes were, in turn, multiplied by corresponding lake phosphorus concentrations at one meter depth intervals (from the lake surface) to determine volume-weighted lake phosphorus concentrations.

For weeks with no data, concentration values were interpolated between the values from the sampling dates immediately before and after the target week. For the stratified period, the epilimnion was defined as 0-2 meters, the metalimnion as 2-4 meters, and the hypolimnion as 4-7 meters.

CHAPTER 4: LIMNOLOGICAL DESCRIPTION

This chapter presents the physical, chemical, and biological characterization of Cottage Lake. A description of nonpoint pollution survey results, and discussions of lake trophic status and historical water quality, and a comparison of Cottage Lake water quality with other local lakes have also been included.

HISTORICAL WATER QUALITY

In-lake

Historical water quality data for Cottage Lake are shown in Table 4-1. King County DMS (formerly Metro) sampled the lake from 1971 to 1974, initially as part of a preliminary water quality survey of all lakes over 20 acres located in King and lower Snohomish counties, and later as part of an intensive water quality survey of 16 lakes in the Lake Washington and Green River drainage basins (Metro, 1973; Metro, 1976). DMS sampled Cottage Lake again from 1991 to 1993 (until the beginning of the Cottage Lake Restoration Project). In 1983 DMS began annual monitoring of approximately 20 lakes in King County through its Small Lakes Volunteer Monitoring Program; Cottage Lake was added to this program in 1992 when the acquisition of a park on the north shore created public access to the lake (King County, 1993a).

The historical measured chemical and biological parameters in Cottage Lake indicate a highly productive lake system in a eutrophic state. The lake's density of phytoplankton growth, frequency of algal blooms, types of dominant algae, high phosphorus levels, and low transparency led DMS to rate Cottage Lake as having the poorest water quality of the 16 lakes surveyed between 1973 and 1974 (Metro, 1976a).

Transparency (Secchi depth), total phosphorus, and chlorophyll *a* are the three water quality parameters most often used to rate a lake's overall trophic condition. Based on the data collected by DMS, Cottage Lake was classified as eutrophic due to the low summer transparency, and high winter total phosphorus and high summer chlorophyll *a* levels. Nitrate-nitrogen and ammonia levels were moderate, and similar to those in other lakes monitored in the Puget Sound region (Metro, 1976a). However, high ammonia levels occurred near the lake bottom during extended anoxic conditions. Although fecal coliform bacteria samples occasionally exceeded 100 organisms/ml, geometric means were well below the state lake criterion of 50 organisms/ml (WAC 173-201A). Alkalinity, pH, and conductivity measurements were similar to those in other lakes in the region. Dissolved oxygen levels taken at various depths showed that anoxic conditions persisted near the lake bottom during the summer months. No data exist on metal or organic carbon concentrations in the lake (Metro, 1976a). The data collected by DMS from 1991 to 1993 indicate continuing eutrophic conditions in the lake.

Tributary Quality

No water quality data existed for Daniels Creek prior to the Cottage Lake Restoration Project. Water quality characteristics, such as nutrients, temperature, pH, dissolved oxygen, total suspended solids, and metal levels, are of interest because of the salmonid populations that spawn and rear in the creek.

Table 4-1: Summary of Yearly Average Chemical Data for Cottage Lake [a]

Constituent	1971-72	1973	1974	1991-93
pH				
Average	...	...	...	...
Maximum	9.4	8.4	8.5	8.1
Minimum	6.5	6.4	6.5	6.6
Conductivity (µS/cm)[b]				
Average	94	103	75	104
Maximum	158	290	120	110
Minimum	58	59	50	87
Turbidity (NTU)[c]				
Average	4.1	2.4	2.8	...
Maximum	26	16	10.7	...
Minimum	0.8	1	0.7	...
Alkalinity (mg/L)[d]				
Average	32	28	26	...
Maximum	40	45	50	...
Minimum	29	14	14	...
Transparency (meters)				
Average	2	2.1	2.1	1.6
Maximum	3.2	2.9	2.9	2.2
Minimum	1.3	0.6	1.6	1
Dissolved Oxygen (mg/L)				
Average	6.9	7.9	7.5	9.2
Maximum	12.4	12.1	12.8	14
Minimum	0.1	0.4	0.1	1.4
Ammonia (µg/L)[e]				
Average	140	30	60	...
Maximum	1,200	430	580	...
Minimum	10	10	10	...
Nitrate (µg/L)				
Average	152	240	250	...
Maximum	640	1,100	1,180	...
Minimum	10	10	10	...
Total Phosphorus (µg/L)				
Average	80	70	110	49
Maximum	740	590	480	97
Minimum	10	10	20	5
Chlorophyll *a* (µg/L)				
Average	10.7	9.9	8	16.9
Maximum	31.8	21.9	22	56.4
Minimum	2	1.5	1.9	3.5
Fecal Coliform (orgs/100 ml)				
Geometric Mean	...	26.9	20.9	...
Maximum	...	132	150	...
Minimum	...	0	0	...

a. Data collected by DMS (1973, 1976, 1992); averages are for surface water samples only
b. µS/cm = microSiemens per centimeter
c. NTU = nephelometric turbidity units
d. mg/L = milligrams per liter
e. µg/L = micrograms per liter

DMS has monitored the Bear Creek Basin system extensively and has a monitoring station on Cottage Lake Creek approximately one mile downstream of Cottage Lake. Based on data collected from 1986 to 1990 during non-storm conditions, the water quality in Cottage Lake Creek (lake outlet) is good, with cool temperatures, high dissolved oxygen, low-to-moderate suspended solids, and moderate nutrient levels, as shown in Table 4-2.

Table 4-2: Summary of Historical Yearly Average Chemical Data for Cottage Lake Creek (lake outlet)[a]

	Water Year				
Constituent	1986-87	1987-88	1988-89	1989-90	1987-90
pH					
Average	...	...	...	...	...
Maximum	7.9	8.1	8	8.1	8.1
Minimum	6.9	7.3	7.1	6.7	6.7
Percent [b] <6.5 or > 8.5					
Temperature (degrees C)					
Average	9.7	10	9.7	9.7	9.8
Maximum	15	16	15.8	15	16
Minimum	4.4	5.2	3	3.2	3
Percent [b] > 16	0	0	0	0	0
Conductivity (µS/cm)					
Average	121	128	124	121	123
Maximum	139	140	145	140	145
Minimum	93	110	95	100	93
Total Suspended Solids (mg/L)					
Average	4.4	4.6	5.6	3.9	4.6
Maximum	10.8	6.8	10.3	6.6	10.8
Minimum	2.3	2.3	2.3	1.9	1.9
Dissolved Oxygen (mg/L)					
Average	10.8	11.1	11.1	11.1	11
Maximum	12	12.4	12.7	12.2	12.7
Minimum	9.7	9.8	10.2	10.1	9.7
Percent [b] <9.5	0	0	0	0	0
Nitrate (µg/L)					
Average	929	800	846	834	853
Maximum	1,210	1,210	1,220	1,100	1,220
Minimum	798	659	629	477	477
Total Phosphorus (µg/L)					
Average	55	49	55	53	53
Maximum	80	69	71	84	84
Minimum	44	31	37	41	31
Fecal Coliform (Orgs/100 ml)					
Average	133	132	171	200	156
Maximum	560	480	1,520	580	1,520
Minimum	18	40	36	70	18
Percent [b] > 100	50	67	58	83	60

a. *Data collected by DMS (1987, 1988, 1989, 1990)*

b. *Water quality standards for Class AA streams (there are currently no state standards for conductivity, total suspended solids, or nutrients)*

In all of 48 samples taken between 1986 and 1990, dissolved oxygen levels met the Class AA minimum standard of 9.5 mg/L, temperatures met the standard of not exceeding 16 degrees C, and pH levels were within the Class AA range of 6.5 to 8.5. However, high fecal coliform counts were detected in the creek, and are thought to be the result of animal waste, increased development, or potentially failing on-site septic systems in the watershed near the sampling location (Metro, 1989). Fecal coliform counts consistently exceeded 50 organisms/100 ml, the maximum geometric mean allowable in a Class AA stream. The standard of not more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 100 organisms per 100 ml was exceeded every year during this period (King County, 1993a).

Phytoplankton

DMS sampled Cottage Lake for phytoplankton (algae) in 1971, 1973, and 1974 (Metro, 1973; Metro, 1976a). Table 4-3 lists the types and genera of phytoplankton found in the lake and indicates in bold-face which were dominant. The majority of dominant algal types were blue-green algae (cyanophytes) or yellow-green algae (diatoms). Diatoms dominated during the spring, while blue-greens dominated in the summer and fall. From 1973 to 1974, Cottage Lake had consistently high chlorophyll *a* concentrations (average concentration approximately 10 µg/L) and phytoplankton densities (average density approximately 4.7 cm^3/m^3), indicating the existence of a highly productive phytoplankton population in the lake. The high phytoplankton densities in the summer and fall contributed to the overall rating of Cottage Lake as eutrophic.

Table 4-3: Types of Phytoplankton Found in Cottage Lake in 1976

Types and Genera	Dominant
Cyanophyta (Blue-Green Algae)	
Anabaena	yes
Aphanizomenon	yes
Coelosphaerium	yes
Chroococcus	yes
Anacystis	no
Oscillatoria	yes
Plectonema	no
Chlorophyta (Green Algae)	
Chlamydomonas	no
Eudorina	yes
Pandorina	no
Volvox	no
Gleocystis	no
Sphaerocystis	no
Ankistrodesmus	no
Oocystis	no
Quadriqula	no
Dictyosphaerium	no
Cruciquenia	no
Scenedesmus	no
Elakatothrix	no
Closterium	no
Cosmarium	no
Staurastrum	no

Data Collected by DMS (1976)

Types and Genera	Dominant
Euglenophyta (Euglenophytes)	
Euglena	no
Phacus	no
Trachelomonas	yes
Lepocinclis	no
Pyrrophyta (Dinoflagellates)	
Gymnodiunium	no
Glenodinium	no
Peridinium	no
Ceratium	yes
Cryptophyta (Cryptophytes)	
Cryptomonas	yes
Rhodomonas	yes
Chrysophyta (Yellow-Green Algae, Diatoms)	
Chromulina	no
Ochromonas	no
Dinobryon	yes
Mallomonas	yes
Synura	yes
Melosira	yes
Cyclotella	no
Rhizosolenia	no
Asterionella	yes
Fragillaria	yes
Synedra	yes
Tabellaria	yes
Nitzschia	no

Macrophytes

DMS conducted macrophyte surveys on Cottage Lake in 1976 and 1978 (Metro, 1976b; Metro, 1978). Between 1976 and 1978, macrophyte areal coverage varied, most likely due to natural yearly fluctuations in plant growth. However, the dominant species remained the same, with pond weed (*Potamogeton* spp.), water lilies, and water weed (*Elodea*) the most common aquatic plants. In 1976, from 40 to 60 percent of the lake bottom was covered by submersed plants. Approximately 10 and 17 acres of the lake were covered by macrophytes in 1976 and 1978, respectively. No exotic plant species were detected in the lake in 1976 and 1978. Most notably, Eurasian watermilfoil (*Myriophyllum spicatum*) was absent.

CURRENT WATER QUALITY—PHYSICAL CONDITIONS

Water Temperature

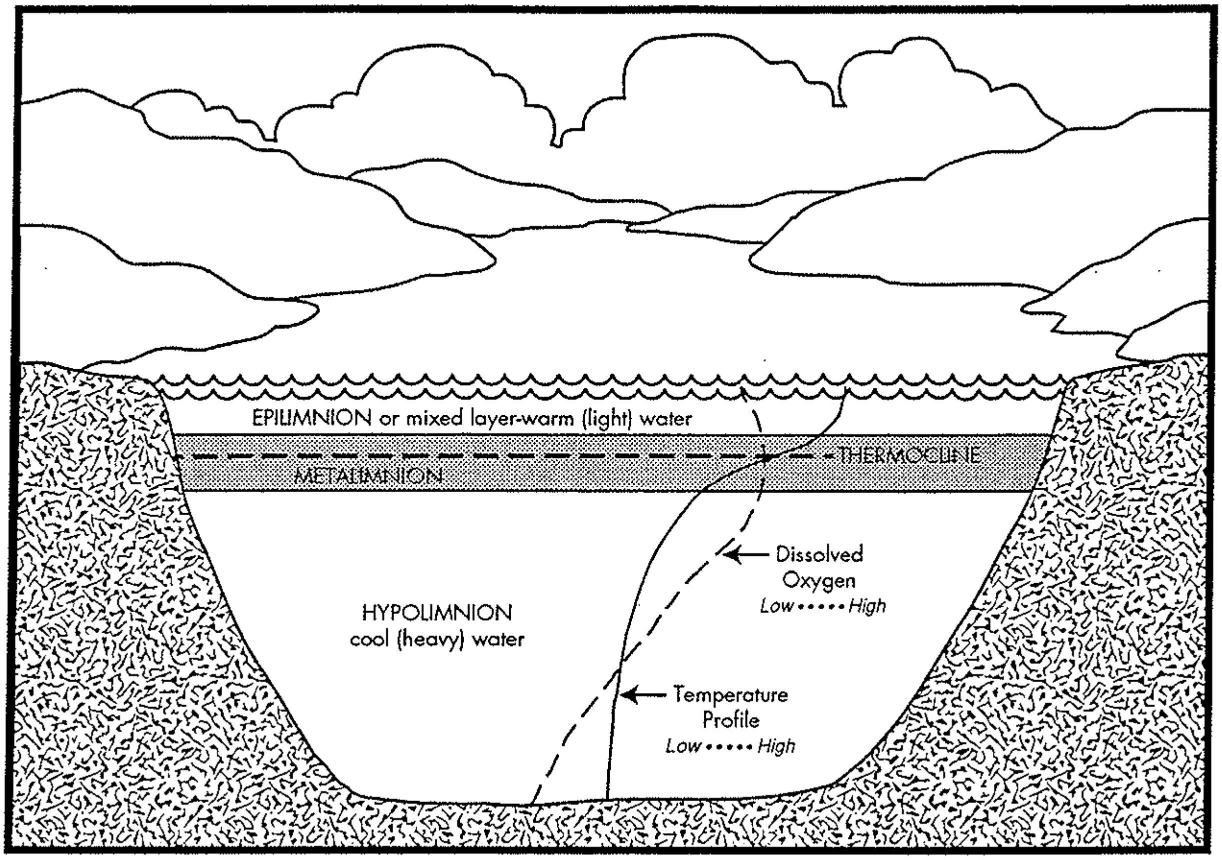
Temperature-related characteristics of water have a large effect on the water quality and ecology of lakes. Water is at its densest at 4 degrees Celsius (C), which allows ice to float and form at the surface of lakes at 0 degrees C or less, and thermal stratification to occur during the warmer, summer weather. As lakes leave their winter state, in which the water column is completely mixed, light energy from the sun heats the upper water layer. The warmer, less dense surface waters float on top of the cooler, denser bottom waters. This results in the upper water layer, or *epilimnion,* becoming isolated from the lower layer, or *hypolimnion* (Figure 4-1). The two layers are separated by the middle layer, or *metalimnion,* where large temperature changes occur with changes in depth. Since there is little or no exchange of water between the epilimnion and the hypolimnion, water quality can be quite different in each layer.

In western Washington lakes, this type of thermal stratification is common during the summer and early fall. After the summer, the epilimnion tends to cool, and by late fall or early winter the temperature difference between the two water layers is small enough that the winds will mix the water throughout the lake, which will then remain fully mixed until the onset of stratification in late spring. Lakes that undergo this type of seasonal pattern are known as monomictic lakes. Cottage Lake follows this pattern of complete mixing in winter and stratification in summer.

The temperature profiles in Figure 4-2 demonstrate the progression of thermal stratification in Cottage Lake though the year. A summary of selected water quality variables, including temperature, is shown in Table 4-4. Cottage Lake was thermally stratified during the spring, summer, and early fall months of 1993. Lake turnover occurred in November, 1993, as evident from the uniform water column temperature (Figure 4-2). Lake surface water temperatures averaged 14.1 degrees C, with a summer mean value of 19.6 degrees C. During the summer, epilimnion temperatures ranged from 18 to 22 degrees C, while hypolimnion temperatures ranged from 9 to 14 degrees C. The lowest water column temperature was recorded on February 8, 1994, at 3.8 degrees C. These water temperatures may have been atypical, as the spring and summer of the study year were unusually cool and the fall and winter were unusually warm.

Transparency (Clarity)

The quality and quantity of light in the water column, which, along with temperature, often limits the growth of plants and algae, is largely determined by the clarity of the water, which itself is influenced by a variety of factors, including algae, turbidity from sediments or other suspended particles, and the natural color of the water in the lake.



USEPA, 1990

A cross-sectional view of a thermally stratified lake in mid-summer. The water temperature profile illustrates how rapidly the temperature decreases in the metalimnion compared to the nearly uniform temperatures in the epilimnion and hypolimnion. The metalimnetric density gradient associated with this region of rapid temperature change provides a strong, effective barrier to water column mixing.

Figure 4-1
THERMAL STRATIFICATION

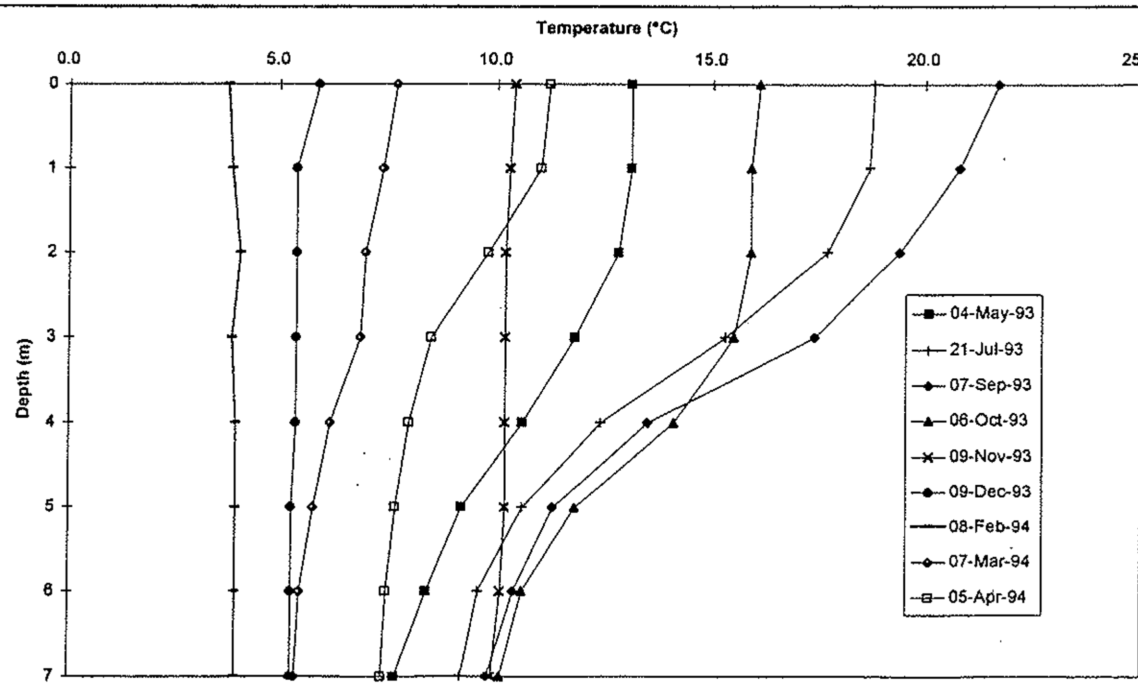


Figure 4-2
TEMPERATURE PROFILES FOR COTTAGE LAKE

Table 4-4: Summary of Select Water Quality Variables for the April 1993 to April 1994 Study Year (averages are for surface concentrations only)

Parameter	Unit	Average	Range
Temperature	degrees C	14.1	3.8-21.7
Dissolved Oxygen (DO)	mg/L	9	2-14
pH	units	7.1	6.4-8.8
Conductivity (Cond)	μmhos/cm	107	88-151
Total Phosphorus (TP)	μg/L	48	18-130
Ortho-phosphorus (SRP)	μg/L	18	0-80
Total Nitrogen (TN)	μg/L	702	96-1400
Nitrate-Nitrogen (NO3)	μg/L	302	<6-745
Ammonia-Nitrogen (NH3)	μg/L	65	<7-3100
Alkalinity (Alk)	mg CaCO3	40	29-60
Color	units	46	10-90
Fecal Coliforms (FC) *	organisms/100 ml	11	0-45
		18	0-51
Transparency	meters	1.9	1.5-2.7
Chlorophyll *a*	μg/L	18	0-55

a. *The first average and range numbers are from the COTTAGE1 sampling station; the second average and range numbers are from the COTTAGE2 sampling station (see Figure 3-1).*

Water transparency is most often measured in lakes by the depth at which a black and white disk, called a Secchi disk, can no longer be seen. This is referred to as the Secchi depth. The transparency of a lake often depends directly on the density of the algae suspended in the water. Because eutrophic lakes are usually associated with high algal densities and high chlorophyll *a* concentrations, Secchi depths of less than two meters are often indicative of eutrophic conditions.

As shown in Figure 4-3, the Secchi depth in Cottage Lake ranged from 1.5 to 2.7 meters, and averaged 1.9 meters during the study year and during the summer months (June to September). This average is low compared to other King County lakes.

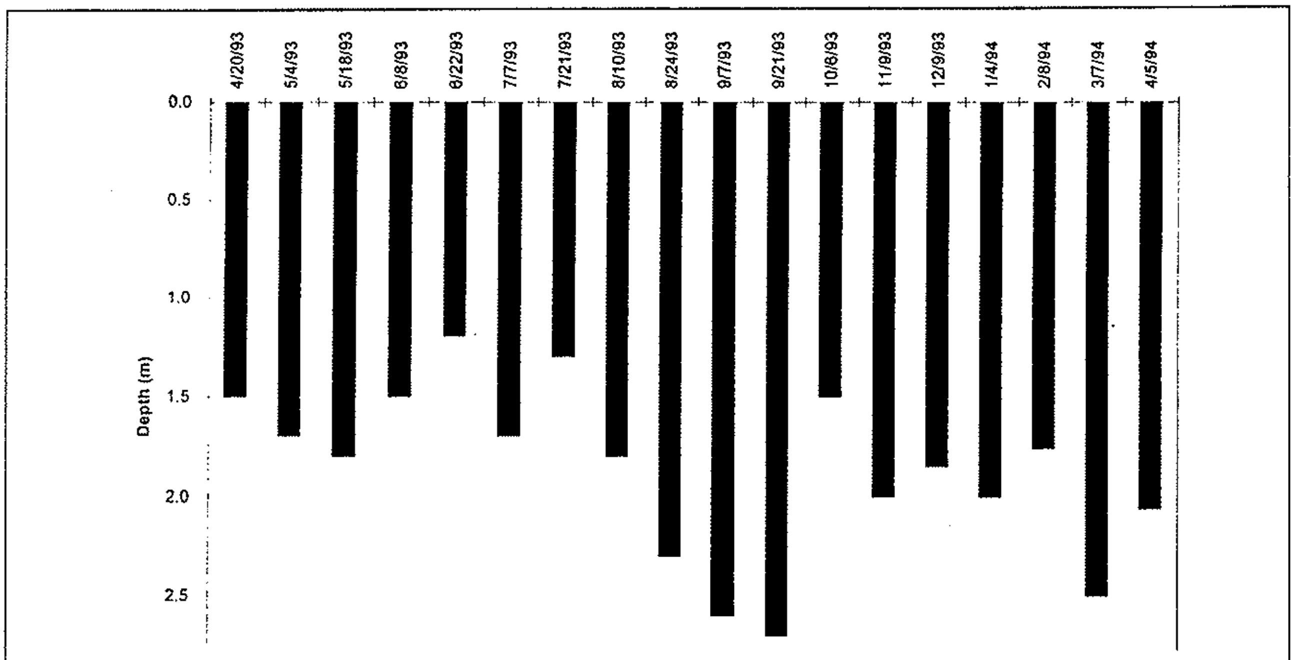


Figure 4-3
SECCHI DISK TRANSPARENCY FOR COTTAGE LAKE

However, these low water transparency values must be interpreted in the context of color concentrations. The transparency of Cottage Lake water is naturally influenced by its wetland inflows, which are high in organic acids, giving the lake its natural tea color. Color concentration ranged from 10 to 90 units and averaged 46 units in Cottage Lake during the sampling year. Color concentration was high during both periods with and periods without algal blooms. There was no strong correlation between Secchi depth and algal densities, or between Secchi depth and chlorophyll *a* concentrations.

CURRENT WATER QUALITY—CHEMICAL CONDITIONS

Dissolved Oxygen

The level of dissolved oxygen (DO) in lakes is one determinant of the habitat available to aquatic organisms. It also affects natural chemical processes such as nutrient release from lake sediments. *Anoxic* (lack of oxygen) conditions at the water-sediment interface on the lake bottom usually increase the potential for nutrient release by converting iron phosphate in the sediments from a water-insoluble to a water-soluble form. Oxygen is added to a lake from exposure to the air, and by the contribution of aquatic plants through photosynthesis. Oxygen is removed from a lake by the respiration of aquatic organisms and plants, and the bacterial decomposition of organic matter in the water and sediments.

Surface DO concentrations averaged 9 mg/L during the study period, with a minimum value of 3 mg/L (November 9, 1993) and a maximum value of 12 mg/L (July 7, 1993). As shown in Figure 4-4, DO profiles for Cottage Lake are fairly typical for a shallow stratified lake. Soon after Cottage Lake became thermally stratified, the hypolimnion became anoxic. Only the upper 2 meters of lake water remained significantly oxygenated during the summer and early fall months. DO levels in the hypolimnion were less than 2 mg/L, and in most cases were less than 1 mg/L. These oxygen levels, too low for most animal life, persisted until the lake destratified and mixed again in late fall. Therefore, most animal activity would have been restricted to the upper waters while the lake was stratified.

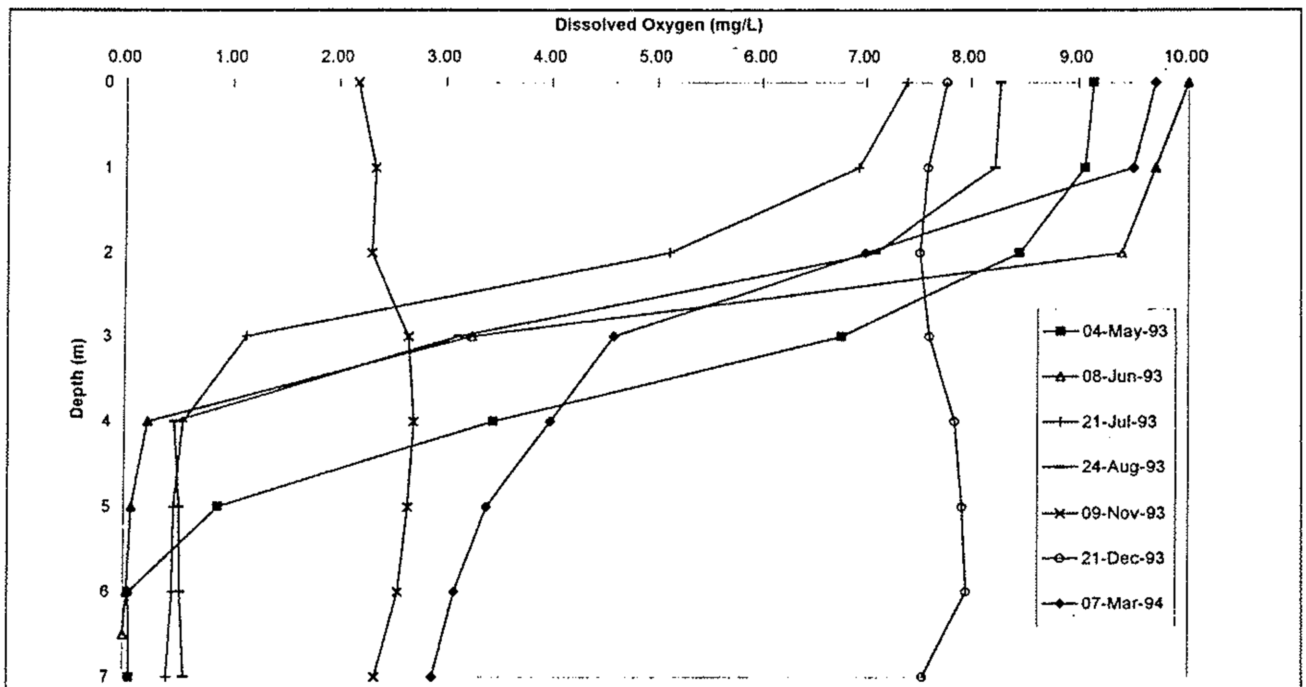


Figure 4-4
DISSOLVED OXYGEN PROFILES FOR COTTAGE LAKE

No fish kill was reported in Cottage Lake in November, 1993, despite the extremely low DO concentration measured on November 9. It is likely that this sampling occurred right after the mixing of lake waters. On the previous sampling date, oxygen levels were approximately 9 mg/L in the upper two meters of the water column. When the lake destratified, this concentration of oxygen was diluted throughout the entire water column, resulting in low oxygen concentrations of 2.3 to 3 mg/L throughout. Fish generally require 4 to 7 mg/L of DO to survive, depending on species and life stage. DO was measured again on November 23, 1993, and ranged from 4.8 to 5.2 mg/L, reflecting wind action on the lake and the resulting addition of oxygen throughout the water column. On the next sampling date (December 9, 1993), DO levels ranged from 6.3 to 8.2 mg/L.

Conductivity

Conductivity is a measure of a solution's ability to conduct electricity and is used as an indicator of the amount of dissolved ions present: the conductivity of a solution increases with increasing ion concentration. Surface water conductivity of Cottage Lake averaged 107 micromhos per centimeter (µmhos/cm) and ranged from 88 to 151 µmhos/cm. The high value occurred on December 9, 1993, during storm conditions. Conductivity in most freshwater systems ranges between 100 to 1,000 µmhos/cm. In King County streams and lakes, conductivity is generally low, averaging less than 100 µmhos/cm during base (non-storm) flows.

Alkalinity and pH

Alkalinity of water generally refers to the presence of compounds that buffer changes in pH. The property of alkalinity is usually imparted by the presence of bicarbonates, carbonates, and hydroxides, and is expressed in units of milligrams of calcium carbonate per liter (mg $CaCO_3$/L)(Wetzel, 1983).

Cottage Lake surface water alkalinity ranged from 29 to 60 mg $CaCO_3$/L and averaged 40 mg $CaCO_3$/L. Alkalinity values of surface waters in western Washington are generally low due to the lack of sedimentary carbonate (Carroll and Pelletier, 1991).

Alkalinity did not vary greatly with lake depth during the fall and winter months when the lake was not stratified. However, when the lake was stratified in spring and summer, alkalinity measurements were often higher in the hypolimnion than in the epilimnion.

The pH of a body of water is a measurement of the hydrogen ion concentration and indicates the acidity of the body of water. Most surface water has a pH between 6.0 and 8.5, which is the neutral range, neither very acidic nor very base. The pH of surface water in Cottage Lake ranged from 6.4 to 8.8, and averaged 7.1. Elevated surface pH values were noted on a few late spring and early summer dates, and could be attributed to photosynthetic activity of algae in the lake epilimnion.

Nutrient Limitation

Most lake water quality problems are associated with an overabundance of nutrients, which results in excessive plant growth. In managing such water quality problems, it is important to assess what nutrient limits plant growth. In most lakes, the limiting plant nutrient is either nitrogen (N) or phosphorus (P); in highly productive lake systems, phosphorus is often the nutrient in shortest supply, and thus the most limiting. Most lake management strategies therefore focus on reducing phosphorus loading.

Epilimnetic total nitrogen to total phosphorus ratios (TN:TP) greater than 17:1 generally indicate that the growth of algae in a lake is limited by phosphorus (Carroll and Pelletier, 1991). On the other hand, TN:TP less than 10:1 generally indicate nitrogen limitation. During much of the growing season, Cottage Lake appears to be phosphorus-limited, as shown in Figure 4-5, with an average TN:TP ratio of 20.2 from April 20, 1993, through August 1993, and an average TN:TP ratio of 41.2 from March 1994 through April 5, 1994. TN:TP dropped below 17:1 in September and below 10:1 in October, suggesting that nitrogen limited algal growth during the fall and winter.

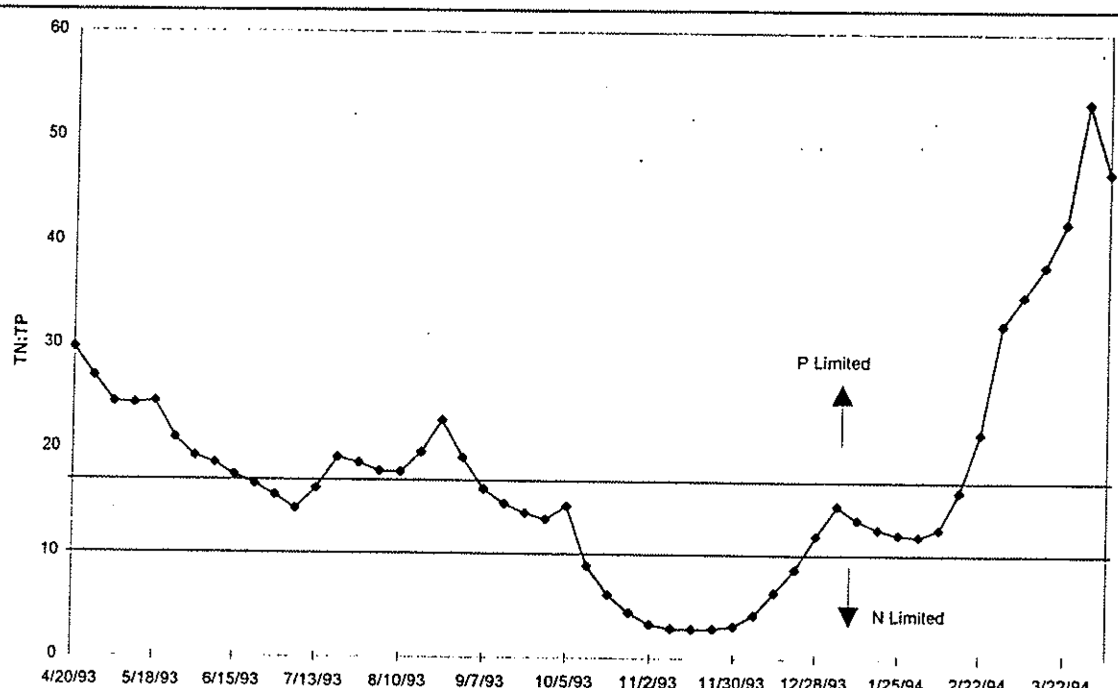


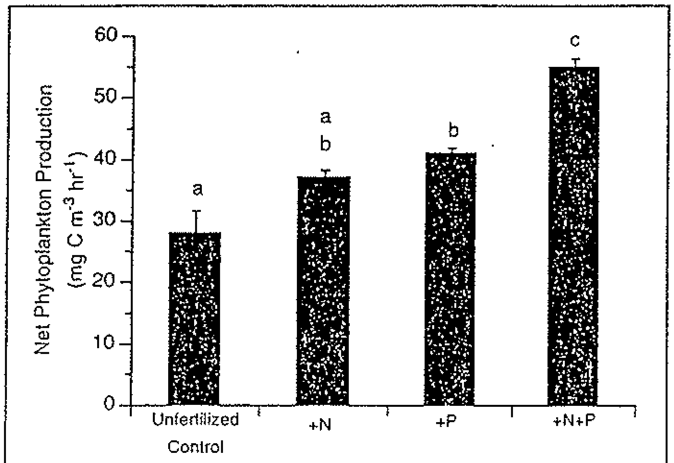
Figure 4-5
WEEKLY VOLUME-WEIGHTED TN/TP RATIO FOR COTTAGE LAKE

Nutrient limitation in Cottage Lake was also evaluated using an in-lake algal fertilization technique. In October 1993 native algal communities were fertilized with nitrogen, phosphorus, or a combination of the two. Response to fertilization was measured after a five day incubation period. The results suggested that both phosphorus and nitrogen were important in controlling algal biomass (KCM, 1993). Phytoplankton enrichment response, measured as milligrams of carbon per cubic meter per hour, showed a 33 percent increase with the addition of nitrogen alone, a 50 percent increase (1.5-fold) with the addition of phosphorus alone, and a 100 percent increase (twofold increase) with the addition of both phosphorus and nitrogen, as shown in Figure 4-6.

Phosphorus

Phosphorus is a common element in the environment. It occurs naturally in soil and rock, and can be found in plant and animal tissue as well as in the atmosphere. Phosphorus is important in algal growth, as described above. Only when phosphorus, or some physical factor such as light or temperature, becomes limiting is algal growth significantly reduced.

Phosphorus was measured as both total phosphorus (TP) and soluble reactive phosphorus (SRP) during the study period. TP represents both organic and inorganic forms of phosphorus. SRP generally represents that portion of phosphorus (dissolved) available for algal growth.



Response of Cottage Lake phytoplankton to fertilization (Mean ± Standard Deviation, n=2). Treatments with the same letter are not significantly different (p=0.05).

Figure 4-6
RESPONSE OF COTTAGE LAKE PHYTOPLANKTON TO FERTILIZER

Annual TP and SRP concentrations in the surface waters of Cottage Lake are shown in Figure 4-7. SRP concentrations were lowest during the spring and summer months. Maximum differences between TP and SRP concentrations were found during the summer, when phytoplankton biomass was consistently high. Annual surface water concentrations averaged 48 µg/L for TP and 18 µg/L for SRP; summer surface water concentrations averaged 31 µg/L for TP and 5 µg/L for SRP.

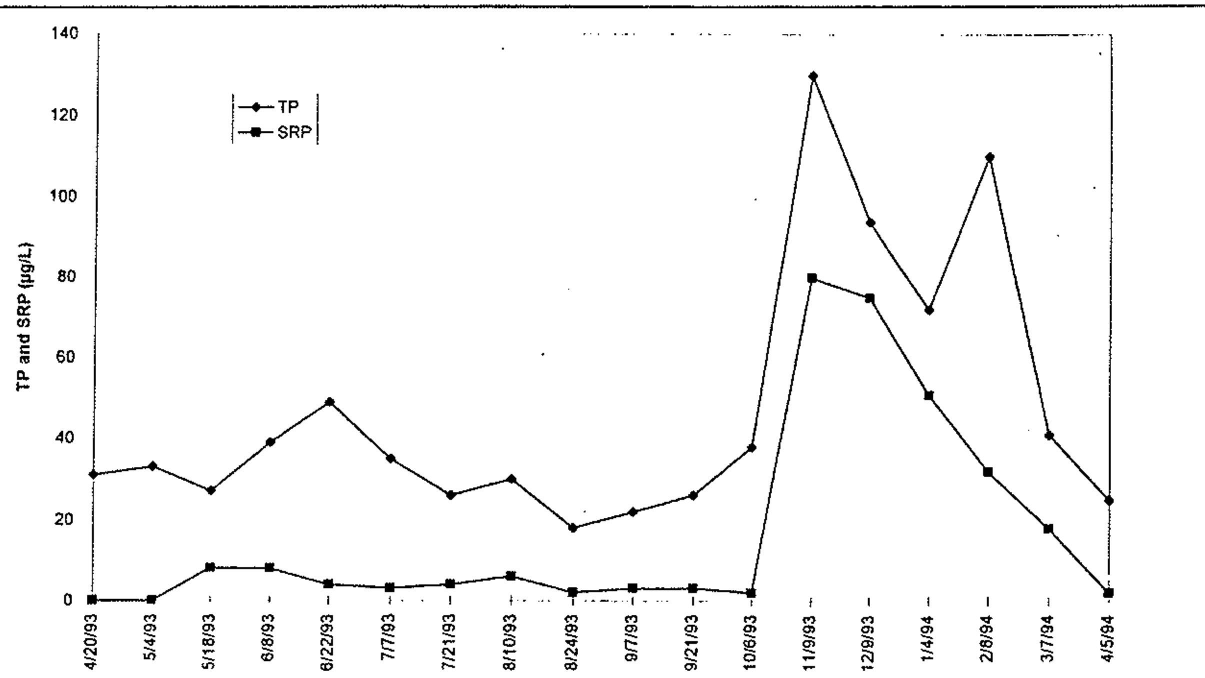


Figure 4-7
ANNUAL SURFACE WATER TP AND SRP CONCENTRATIONS FOR COTTAGE LAKE

Volume-weighted concentrations of TP (whole-lake and by depth) are summarized in Table 4-5 and Figures 4-8 and 4-9. Whole-lake TP levels ranged from 28 to 178 µg/L, with a mean concentration of 105 µg/L during the study year, and 141 µg/L during the summer months (June through September).

Table 4-5: Volume-Weighted Total Phosphorus Summary

Period	Epilimnetic Mean	Hypolimnetic Mean	Whole-Lake Mean
Annual	56 µg/L	248 µg/L	105 µg/L
Summer (June-Sept)	32 µg/L	450 µg/L	141 µg/L

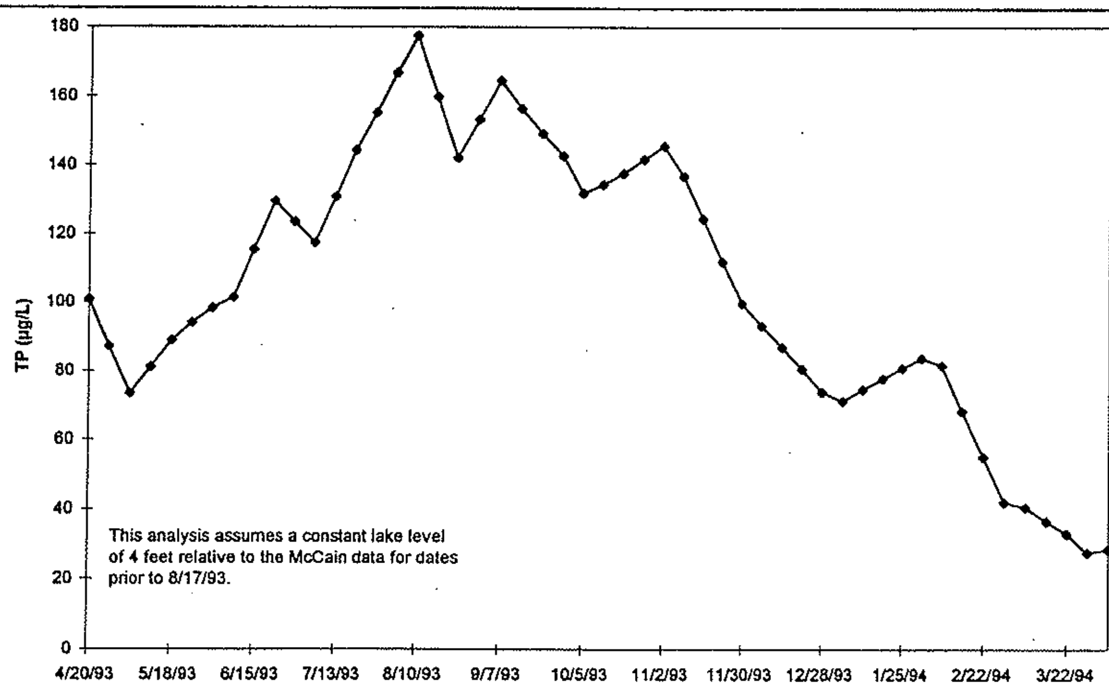


Figure 4-8
COTTAGE LAKE VOLUME-WEIGHTED TOTAL PHOSPHORUS (WHOLE-LAKE)

Volume-weighted concentrations of TP in the top two meters of Cottage Lake (corresponding to the epilimnion in late spring, summer, and early fall) ranged from 13 to 86 µg/L, with a mean annual concentration of 56 µg/L and a mean summer concentration of 32 µg/L. Volume-weighted concentrations of TP in the bottom three meters of Cottage Lake (corresponding to the hypolimnion in late spring, summer, and early fall) ranged from 39 to 594 µg/L, with a mean annual concentration of 248 µg/L and a mean summer concentration of 450 µg/L. The highest concentrations were found in the summer months due to the release of phosphorus from anoxic sediments. Decaying plants in the hypolimnion may have also contributed to these high summer concentrations.

Nitrogen

Nitrogen exists in several forms in aquatic systems, including nitrite+nitrate-nitrogen, nitrate-nitrogen, ammonia-nitrogen, organic nitrogen, and elemental nitrogen. The dissolved forms of nitrogen, including ammonia-nitrogen and nitrate-nitrogen, are most commonly used by algae and aquatic plants for growth.

Total nitrogen, nitrite+nitrate-nitrogen, and ammonia-nitrogen were measured in Cottage Lake during the study period. Surface water concentrations averaged 702 µg/L, 302 µg/L, and 65 µg/L respectively. Total nitrogen concentrations over 180 μg/L are indicative of eutrophic conditions in a lake (Porcella et al., 1980); whole lake total nitrogen concentrations in Cottage Lake averaged 830 μg/L.

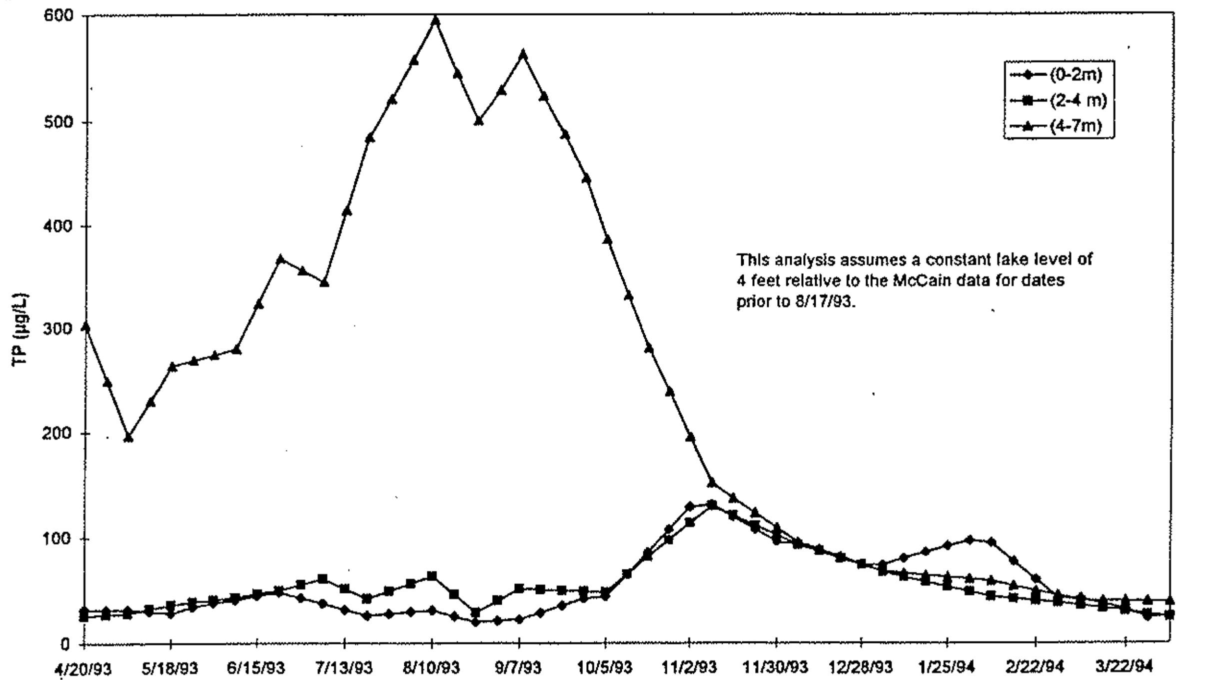


Figure 4-9
COTTAGE LAKE VOLUME-WEIGHTED TOTAL PHOSPHORUS (BY DEPTH)

As shown in Figure 4-10, ammonia-nitrogen concentrations typically increased in the hypolimnion during the months the lake was stratified. This reflects anoxic conditions in the hypolimnion. The concentration of ammonia-nitrogen at the bottom of the lake during the stratified period ranged from 310 μg/L (May 4, 1993) to 3,500 μg/L (August 10, 1993), with an average value of 1,375 μg/L.

Sediment Quality

Sediment chemistry and type play significant roles in nutrient cycling in most lakes. In particular, the capacity of sediments to release or retain phosphorus to or from the hypolimnion is dependent on the ability of sediments to bind phosphorus and the length and severity of the anoxic period during the months the lake is stratified.

Table 4-6 summarizes mean values for sediment quality in Cottage Lake for the three lake depths at which cores were taken: 0-2 m, 2-4 m, and >4 m. Sediment total phosphorus concentrations in the upper 0-2 cm fractions of each core increased with core sampling depth in the lake. Cores taken from a lake depth of >4 m averaged 1,640 mg/kg total phosphorus, while those taken from a depth range of 0-2 meters averaged 896 mg/kg total phosphorus. In general, total phosphorus concentrations increased with core sampling depth for each of the sediment fractions sampled within a given core, as shown in Figure 4-11. Total iron to total phosphorus ratios were generally low for all three lake depths. The highest ratio (15.9) was found in the sediment cores taken from a lake depth of 0-2 m.

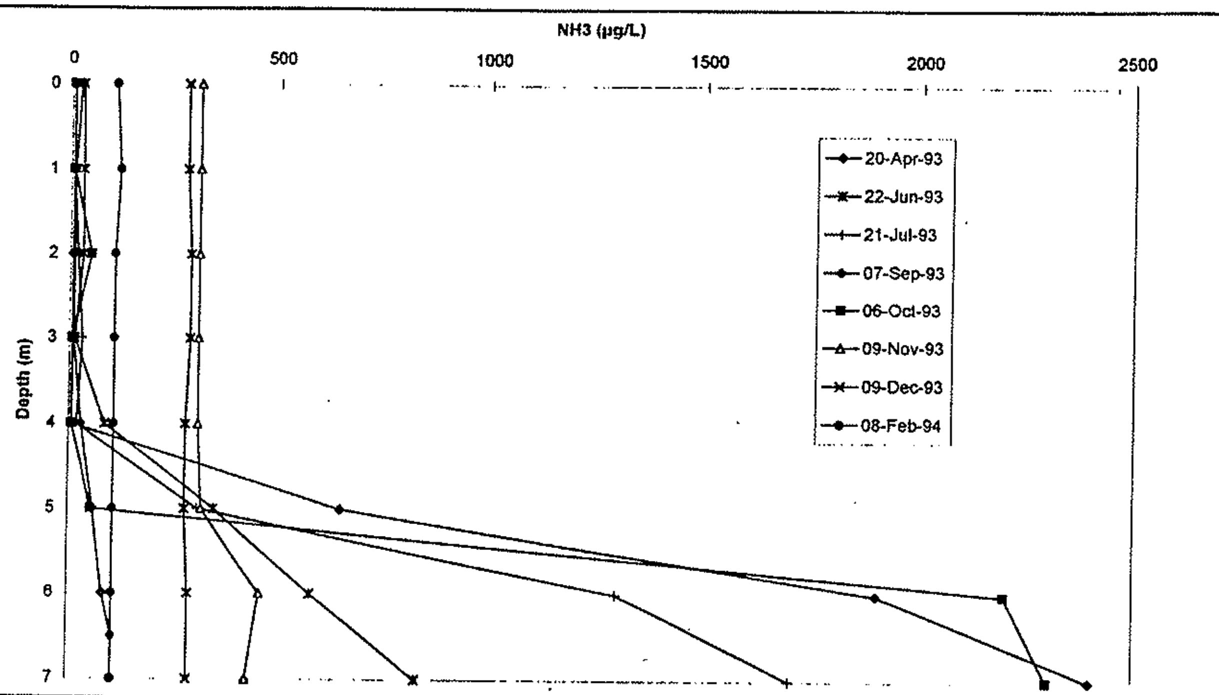


Figure 4-10
AMMONIA PROFILES FOR COTTAGE LAKE

Table 4-6: Sediment Quality for Cottage Lake by Sediment Core Fractional Depth and Lake Depth Strata

Parameter	Unit	0-2 cm	2-12 cm	12-22 cm	22-32 cm
0-2 m Lake Depth					
Number of Samples		4	4	1	0
% Solids	%	13.4	27.2	10.3	--
% Volatile Solids	%	42.8	33.7	43.6	--
Total Phosphorus (TP)	mg/kg	896	646	232	--
Total Kjeldahl Nitrogen	mg/kg	12,814	8,339	10,509	--
Iron	mg/kg	14,228	12,251	5,831	--
Total Iron/TP		15.9			
2-4 m Lake Depth					
Number of Samples		4	4	4	3
% Solids	%	7.0	8.1	9.1	6.9
% Volatile Solids	%	37.8	36.9	38.9	30.3
Total Phosphorus	mg/kg	1,364	1,419	1,150	802
Total Kjeldahl Nitrogen	mg/kg	9,543	13,080	12,491	10,368
Iron	mg/kg	16,387	14,811	12,272	8,102
Total Iron/TP		12.0			
>4 m Lake Depth					
Number of Samples		4	4	4	1
% Solids	%	5.7	8.2	9.2	8.6
% Volatile Solids	%	35.6	33.2	34.7	36.4
Total Phosphorus	mg/kg	1,640	1,375	1,208	1,277
Total Kjeldahl Nitrogen	mg/kg	13,918	11,900	12,701	13,956
Iron	mg/kg	17,170	15,240	12,640	10,572
Total Iron/TP		10.5			

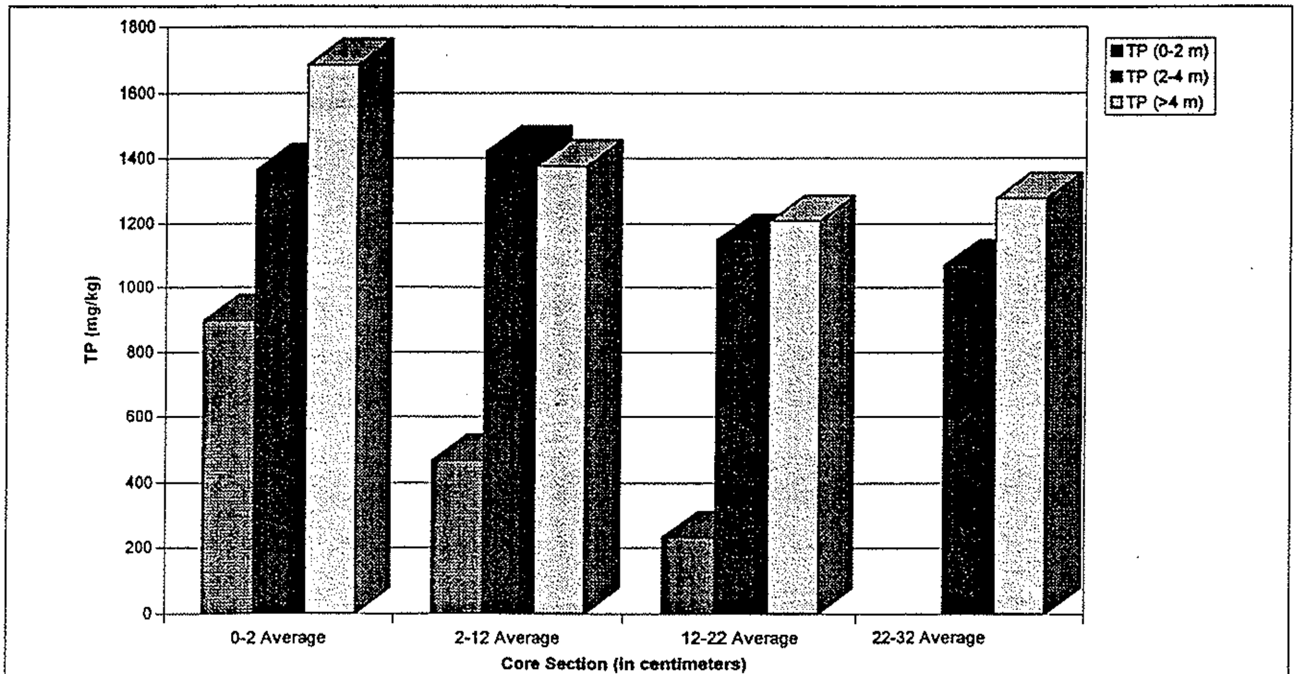


Figure 4-11
SEDIMENT TOTAL PHOSPHORUS CONTENT BY SEDIMENT CORE FRACTIONAL DEPTH FOR THREE LAKE DEPTH STRATA

Average sediment zinc and lead concentrations are shown in Figure 4-12 for two 0.25 meter cores. Zinc concentrations decreased below the 8-10 cm mark; lead concentrations increased from the 18-20 cm mark to the 10-12 cm mark, this point most likely representing the maximum use of leaded gasoline in the United States prior to the introduction of unleaded gasoline. In the upper 10 cm, lead concentrations show a decreasing trend, which most likely represents the reduction of leaded gasoline use.

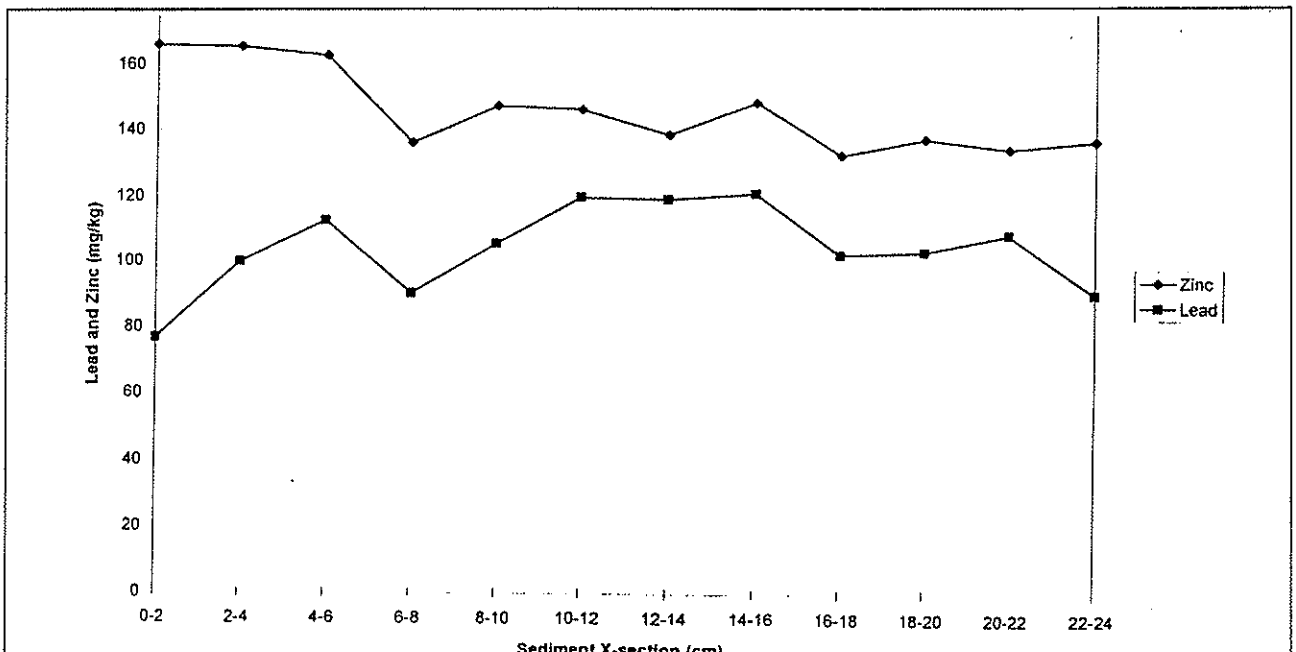


Figure 4-12
COTTAGE LAKE LEAD AND ZINC SEDIMENT PROFILES

The use of leaded gasoline began in 1930 and decreased again around 1972 (Cooke et al., 1993a). From this, it can be estimated that the sedimentation rate in Cottage Lake was 0.24 cm per year between 1930 and 1972, and almost doubled, to 0.45 cm per year, between 1972 and 1994. This is a significant increase, and probably reflects logging and land development in the watershed during this time period.

Tributary Water Quality

Tributary water quality was evaluated during base flow and high or storm flow conditions. Evaluation of tributary water quality is used to assess the significance of watershed or external nutrient loading to the lake. Much of the external nutrient loading to lakes enters lakes during the wet months of the year (typically October through April).

Table 4-7 summarizes inlet and outlet water quality during base flow and storm flow conditions for various water quality parameters. Water temperatures did not exceed the state water quality criterion of 16 degrees C in the Cottage Lake Creek inlet on any date, and exceeded the criterion in the Daniels Creek inlet on only September 7, 1993. Outlet temperatures exceeded 16 degrees C during June through September of 1993.

Table 4-7: Inlet and Outlet Water Quality During Base Flow and Storm Flow Conditions in 1993-1994

Parameter	Unit	CLIN1 [a]		CLIN2 [b]		CLOUT [c]
		base (average / range)	storm (avg.) [d]	base (average / range)	storm (avg.) [d]	(average / range)
# Samples		18	2	18	4	18
Temp.	deg. C	9 / 2-17	6	9 / 3-15	7	11 / 4-20
DO	mg/L	11 / 8-14	12	12 / 10-14	12	8 / 2-12
pH	units	6.9 / 6.4-7.6	6.5	7.1 / 6.0-7.7	6.0	6.7 / 6.5-7.5
Cond	µmhos/cm	109 / 64-160	65	120 / 81-148	65	112 / 78-132
TP	µg/L	54 / 34-110	160	41 / 22-82	57	56 / 25-120
SRP	µg/L	27 / 12-80	82	23 / 7-30	33	27 / 0-80
TN	µg/L	957 / 530-1,700	1,750	1,363 / 840-2,400	1,500	908 / 360-2,500
NO3	µg/L	614 / 270-1,100	1,100	1,296 / 730-1,800	1,375	418 / 22-930
NH3	µg/L	36 / 7-71	113	17 / 7-40	23	101 / 9-350
Chloride	µg/L	5,056 / 3,500-9,300	4,800	4,235 / 3,000-6,000	3,250	4,215 / 3,690-5,800
Alk	mg/L $CaCO_3$	36 / 16-63	25	40 / 30-54	28	42 / 27-55
FC	CFU/100 ml	432 / 46-1,400	2,700	157 / 2-210	2,493	not measured

a. *CLIN1 is the Daniels Creek inlet (Tributary 0122).*
b. *CLIN2 is the Cottage Lake Creek inlet (Tributary 0127).*
c. *CLOUT is the Cottage Lake Creek outlet.*
d. *Temperature, pH, dissolved oxygen, and conductivity measurements during storm conditions were taken on one sample from Daniels Creek and two samples from Cottage Lake Creek.*

Dissolved oxygen (DO) levels averaged 11 mg/L in the Daniels Creek inlet and 12 mg/L in the Cottage Lake Creek inlet. Individual readings in Daniels Creek did not meet the state water quality criterion of 9.5 mg/L during May, June, July, August, September, or the first sampling date in October, 1993. As water temperatures decreased during the cooler months of the year, DO concentrations increased. DO concentrations in the Cottage Lake Creek outlet averaged 8 mg/L during the sampling year, and were generally similar to the measured DO levels in Cottage Lake.

Total phosphorus concentrations in Daniels Creek averaged 60 µg/L during the sampling year, and exceeded the federal water quality guidelines of 50 µg/L on 8 of 19 sampling dates. Total phosphorus concentrations in Cottage Lake Creek were lower, averaging 43 µg/L, and exceeded the federal water quality guidelines on 5 of 20 sampling dates.

Fecal coliform counts ranged from 46 to 1,400 colony forming units (CFU)/100 ml in Daniels Creek, and exceeded the state water quality criterion of 50 CFU/100 ml on 14 of 18 sampling dates. Fecal coliform counts were lower in Cottage Lake Creek, ranging from 2 to 210 CFU/100 ml, and exceeding the state water quality criterion on 7 of 18 sampling dates.

During storm flow, total phosphorus concentrations were elevated, averaging 160 µg/L for Daniels Creek and 57 µg/L for Cottage Lake Creek. Fecal coliform counts were also elevated, averaging 2,700 CFU/100 ml in Daniels Creek and 2,493 CFU/100 ml in Cottage Lake Creek. An especially high fecal coliform count of 22,000 CFU/100 ml was measured in a stormwater sample collected on May 16, 1994, from Daniels Creek at the Woodinville-Duvall Road highway crossing. The sample was collected, following proper sampling procedures, by a biologist who lives on Cottage Lake.

Total nitrogen concentrations and ammonia-nitrogen concentrations were elevated in Daniels Creek during storm events, averaging 1,750 µg/L, compared with 957 µg/L during base flow conditions for total nitrogen, and 113 µg/L, compared with 36 µg/L during base flow conditions for ammonia-nitrogen. In Cottage Lake Creek, there was little difference in total nitrogen concentrations or ammonia-nitrogen concentrations during base flow conditions and storm events.

Stormwater Quality

As indicated in Chapter 3, additional stormwater sampling took place in fall 1995 for the purpose of isolating nonpoint pollution sources. Final laboratory analytical results from the September 27, 1995, storm event, presented in Table 4-8, revealed extremely high fecal coliform bacteria densities (6,200 to 84,000 CFU/100 ml) and relatively high phosphorus concentrations (151 to 353 ug/L) at the five Daniels Creek sampling stations.

Table 4-8: Stormwater Sampling Results (September 27, 1995) at Daniels Creek Locations

			PARAMETERS Units				
Station	NH_3 µg/L	NO_{2+3} µg/L	OrthoP µg/L	TP µg/L	TSS mg/L	Turb NTU	FC CFU/100 ml
D1	80	754	118	353	37.1	536	84,000
D2	35	714	85.4	276	27	6.2	72,000
D3	ND [a]	740	76.8	247	17	8.6	64,000
D7	ND [a]	1,000	57.2	151	9	4.0	60,000
D9	31	864	107	195	3	2.6	73,000

a. ND = Not detected

Laboratory results from the December 10, 1995, storm event, shown in Figure 4-13 and Table 4-9, were not considered final at the time of this writing. These data, nevertheless, indicate seven potential problem areas, listed by "pollution priority" and detailed below. Final laboratory results, including sampling data from stations C1, C2, C3, and C4 along Cottage Lake Creek, will be available in 1996.

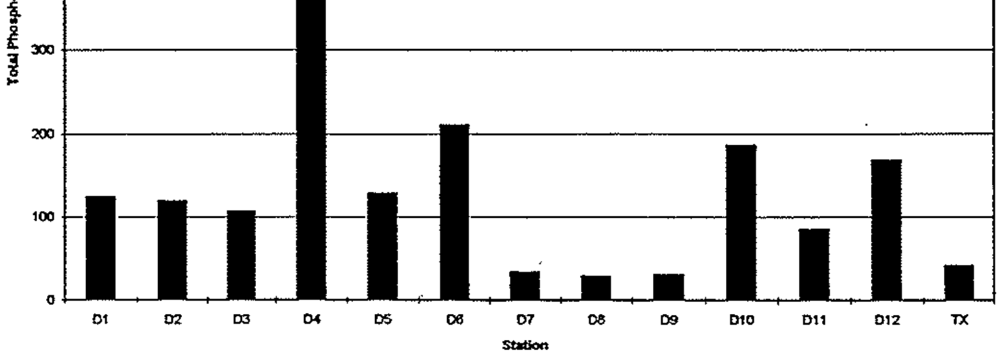


Figure 4-13
DANIELS CREEK STORMWATER SAMPLING, DECEMBER 10, 1995

Station D4

This station (a drainage ditch) had the highest phosphorus concentration (662 ug/L) and fecal coliform bacteria densities (3,100 CFU/100 ml) among the stations sampled on December 10, 1995. High ammonia (385 ug/L) was also detected. Poor pasture management and animal-keeping practices from several properties that drain to this ditch contribute to the poor water quality.

Station D12

This station (a drainage ditch) had the highest ammonia (435 ug/L) and nitrite+nitrate-nitrogen (1,530 ug/L) concentrations. Relatively high phosphorus (168 ug/L) was also detected. An equestrian facility directly to the west of this sampling location and private residences in the area may be contributing to the poor water quality. Stormwater runoff from several paddock areas associated with the equestrian facility was observed draining to this sample location during the December 10, 1995, storm event. Several property owners to the west of this location should be contacted and a cooperative survey of land use practices (including lawn maintenance, septic system maintenance, and animal keeping) encouraged.

Station D10

This station (a drainage ditch) had relatively high phosphorus concentrations (186 ug/L) and fecal coliform bacteria densities (960 CFU/100 ml). Additional monitoring is needed to isolate nonpoint pollution sources that drain to this station. Several property owners directly to the west of this location should be contacted and a cooperative survey of land use practices (including lawn maintenance, septic system maintenance, and animal keeping) encouraged.

was detected here. Additional sampling is recommended to isolate potential sources, targeting the two drainages from the immediate north and northeast. The two immediate upstream landowners associated with the horse stables/riding club and concrete pond should be contacted and encouraged to participate in a cooperative survey of land use practices.

Station D11

This station had a high nitrite+nitrate-nitrogen concentration (1,390 ug/L). Property owners directly upstream should be contacted and encouraged to cooperatively participate in a land use practice survey. An inventory of small farms should also be conducted.

Station C5

This station had relatively high fecal coliform bacteria densities (1,200 CFU/100 ml). The station is located in a developing residential area in the northernmost King County portion of the Cottage Lake watershed. Land use practices from homes upstream of Cottage Lake Creek, including homes in the southern Snohomish County portion of the watershed, may be contributing to the high bacteria counts. Property owners upstream of this sampling station should be contacted and a cooperative survey of land use practices encouraged.

Table 4-9: Stormwater Sampling Preliminary Results (December 10, 1995) at Daniels and Cottage Lake Creeks

Station	NH_3 µg/L	NO_{2+3} µg/L	OrthoP µg/L	TP µg/L	TSS mg/L	Turb NTU	FC CFU/100 ml
C5	ND [a]	336	23	41	2.7	3.2	1,200
D1	176	790	60	124	12.2	4.6	1,000
D2	193	831	72	119	9.4	4.0	1,000
D3	215	616	54	107	8.7	3.5	1,000
D4	385	691	665	662	11.4	1.0	3,100
D5	214	640	50	128	17.2	5.2	1,000
D6	347	1,430	116	210	10.7	6.0	1,000
D7	92	381	20	34	1.8	1.6	160
D8	93	322	18	29	2.3	1.4	100
D9	96	322	17	31	1.9	1.0	68
D10	32	723	103	186	3.4	8.4	960
D11	110	1,390	50	85	4.7	3.0	600
D12	435	1,530	55	168	11.5	7.5	400
TX	60	3,910	24	42	6.0	2.6	180

a. ND = Not detected

Groundwater

Several groundwater quality trends were noted in the limited groundwater data collected for Cottage Lake, presented in Table 4-10. Total nitrogen, chloride, and nitrite+nitrate-nitrogen concentrations were notably higher at the west and east sites than at the two park sites. Total phosphorus concentrations were higher at the west site and Park 1 than at the Park 2 and east sites (Hong West and Associates, Inc., 1994).

Table 4-10: Groundwater Quality at Cottage Lake Sampling Sites
(average concentrations in mg/L, n = 8 samples/site)

Site	TN [aA]	Chloride	Nitrite+Nitrate	TP [b]
West	4.4	8.03	4.35	0.08
Park 1	0.41	3.75	0.23	0.10
Park 2	0.53	3.06	ND [c]	0.03
East	2.98	5.80	2.57	0.03

a. *TN = total nitrogen.*
b. *TP = total phosphorus.*
c. *ND = not detected.*

The west and east sampling sites were within well-developed residential areas, while the other two sites were within Cottage Lake Park, in which development is just beginning. The above trends indicate that the developed areas may be a source of nitrogen and chloride to the lake, possibly from septic systems, fertilizers, or other, unknown, sources.

CURRENT WATER QUALITY—BIOLOGICAL CONDITIONS

Phytoplankton

Phytoplankton, or algae, are microscopic plants found in the lake water column. Algal species may occur in many different forms, including filamentous, colonial, and single-celled. Algae are easily carried by wind-generated currents and will often accumulate in windward areas of the lake, forming surface scums and sometimes resulting in nuisance conditions. When populations increase rapidly, algae can also become a nuisance by forming high concentrations in the water column, or even surface accumulations, called algal blooms.

Several different algal species can usually be found at any time of the year. A variety of environmental factors, including light, temperature, nutrient levels, and zooplankton densities, affect phytoplankton production and the occurrence of algal blooms. Most lakes in the Puget Sound region are monomictic; as a result, nutrient levels in the water can increase after fall turnover and remain elevated throughout the winter. A large source of nutrients is thus available for phytoplankton growth during the spring when light is not at its summer maximum and temperatures are still cool. These conditions often lead to a spring diatom bloom due to the ability of this species to reproduce and grow in cooler temperatures and less light. During the summer, increased water temperatures and available light, as well as micronutrient ratios, create conditions that favor green or blue-green algae. As the green or blue-green algae grow during the summer, they use the available nutrients and tend to decline in productivity as the nutrients are depleted. Nutrients are released from the hypolimnion when a lake turns over in the fall, creating conditions for another bloom.

Algae is another index used to evaluate the water quality conditions of a lake. Two important aspects of algal or phytoplankton surveys are biomass and dominant species composition. By measuring chlorophyll *a* (an indicator of algal biomass) and examining species type, a component of a lake's trophic state can be determined. Blue-green algae can form nuisance blooms and are most frequently associated with eutrophic conditions; they are particularly problematic because they will float to the surface, forming scums that affect the recreational uses and aesthetic qualities of a lake.

Phytoplankton populations in Cottage Lake were dominated by blue-green algae, or Cyanophyta, on all sampling dates except for May 18, 1993, when golden-brown algae, or Chrysophyta, began to dominate. Golden-brown algae were the second most abundant type during the study period. Blue-greens comprised 88.7 percent and golden browns 9.5 percent of the total cell numbers/ml during the study period.

Figure 4-14 shows total phytoplankton volume during the study period. Peak volumes were seen in June 1993, November 1993 (two weeks after the fall turnover, the mixing of epilimnetic and hypolimnetic waters), and April 1994. In terms of total volume, blue-green algae (52.5 percent) were still dominant through much of the year, with green or Chlorophyta algae the next largest component (23.3 percent).

Aphanizomenon flos-aquae was the dominant blue-green species present in Cottage Lake. Other blue-green species included *Anabaena* spp., *Oscillatoria* spp., *Spirulina* spp., and *Coelospaerium naegelianum*. Chrysophyta species found in the samples were *Dinobryon* spp., *Asterionella formosa, Fragilaria crotonensis, Melosira* spp., *Synedra* spp., pennate diatom spp., *Mallomonas* spp. B, *Ochromonas* spp., and *Synura ulna*.

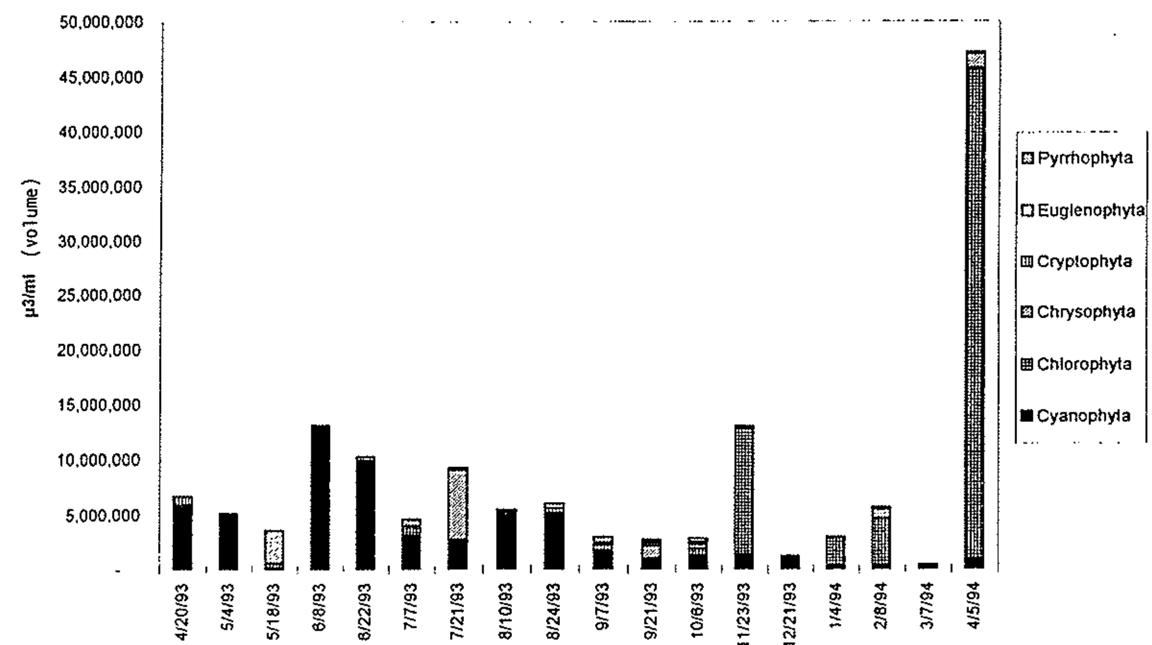


Figure 4-14
TOTAL VOLUME OF PHYTOPLANKTON AT COTTAGE LAKE

Chlorophyll *a* was also measured throughout the study to assess algal densities. Figure 4-15 shows the average chlorophyll *a* concentrations in the lake during the study period. Chlorophyll *a* concentrations averaged 18 µg/L during the study year, and 32 µg/L during the summer months (June through September). Concentrations generally greater than 10 µg/L indicate an algal bloom. Peak values of 55 µg/L and 43 µg/L were recorded on August 10, 1993, and August 24, 1993. The warm, sunny weather during this two week period, following unusually cool and wet weather in June and July, may have contributed to a higher rate of photosynthesis.

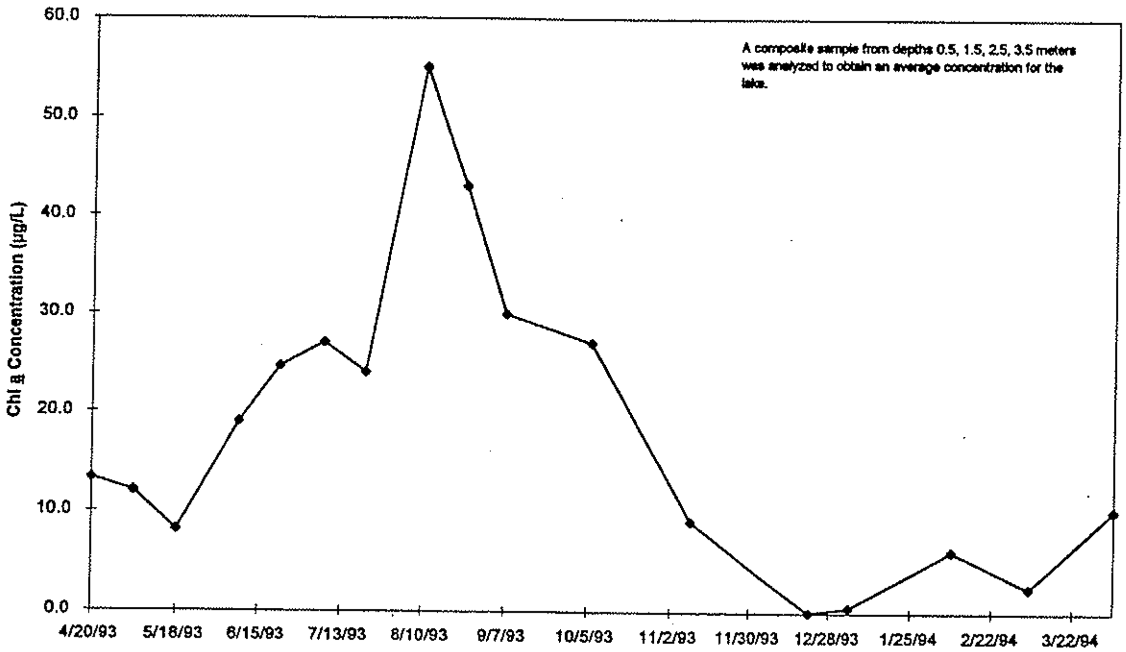


Figure 4-15
CHLOROPHYLL *a* CONCENTRATION FOR COTTAGE LAKE

Zooplankton

Zooplankton are the microscopic animals found in the lake water column. They are visible to the naked eye on close inspection of a glass of lake water. Zooplankton are important in the food web of a lake because they consume algae and, in turn, are consumed by planktivorous fish. The types and number of zooplankton present are also indicative of lake water quality. Generally, large grazing species improve water quality by eating algae; on the other hand, a general decrease in the size of zooplankton species, with their reduced capacity to graze the phytoplankton, is a response to the greater availability of bacterial detritus resulting from the relatively ungrazed algae (Welch, 1992). Therefore, the presence of large zooplankton in a lake usually indicates good water quality, while the presence of smaller zooplankton generally indicates more nutrient-rich waters.

Zooplankton density in Cottage Lake ranged from 41,890 to 549,787 organisms/cubic meter. Rotifers (66 percent) were the dominant zooplankton group throughout much of the study year, as shown in Figure 4-16. The remaining zooplankton community was dominated by Cladocerans, including *Daphnia* (16.6 percent) and *Nauplii* (13.5 percent). As total dry weight biomass, Cladocerans and Dipterans were the dominant components (62.8 percent and 19.3 percent, respectively) of the zooplankton community, as shown in Figure 4-17.

Benthic Invertebrates

Benthic invertebrates are small animals that live in the bottom sediments of lakes and streams. The species found in a given area are usually indicative of the surrounding water quality. Some invertebrates, such as mayflies, are intolerant of low DO conditions; their presence in large numbers in freshwater ecosystems indicates good water quality. Other invertebrates, such as oligochaetes and chironomids, are more tolerant of low DO conditions; their presence in large numbers in a lake may indicate the presence of pollutants or degraded water quality.

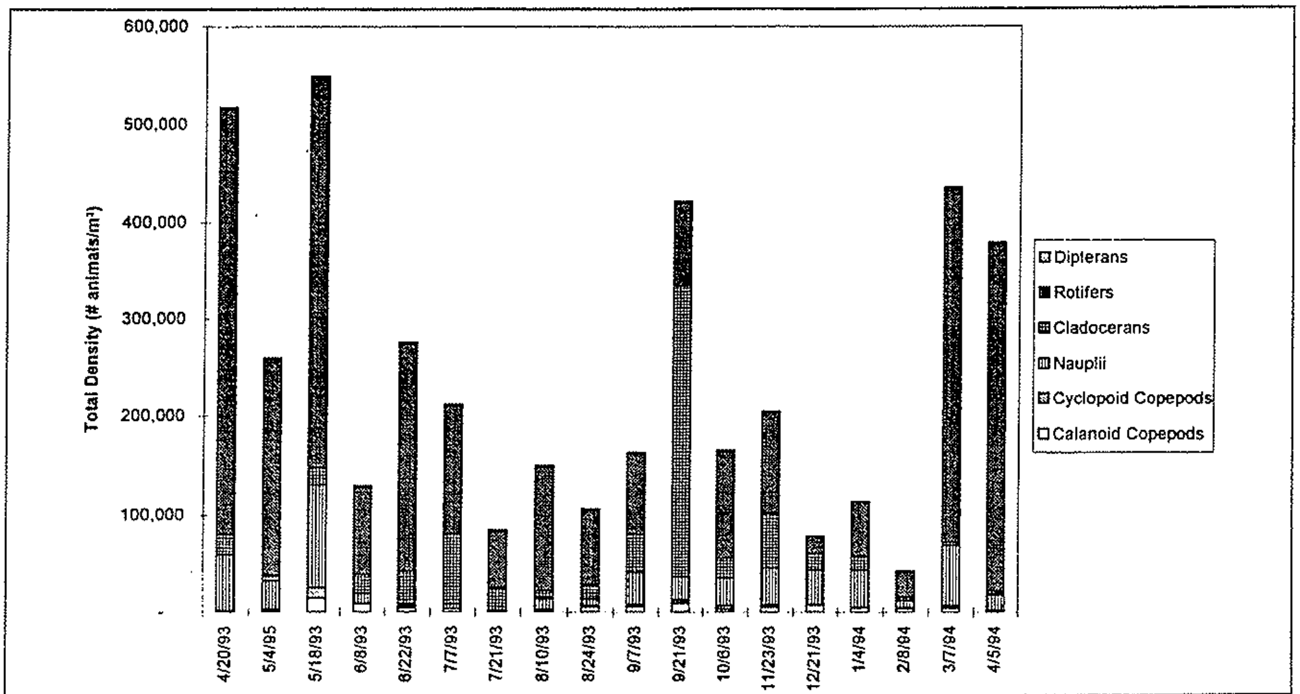


Figure 4-16
TOTAL DENSITY OF ZOOPLANKTON AT COTTAGE LAKE

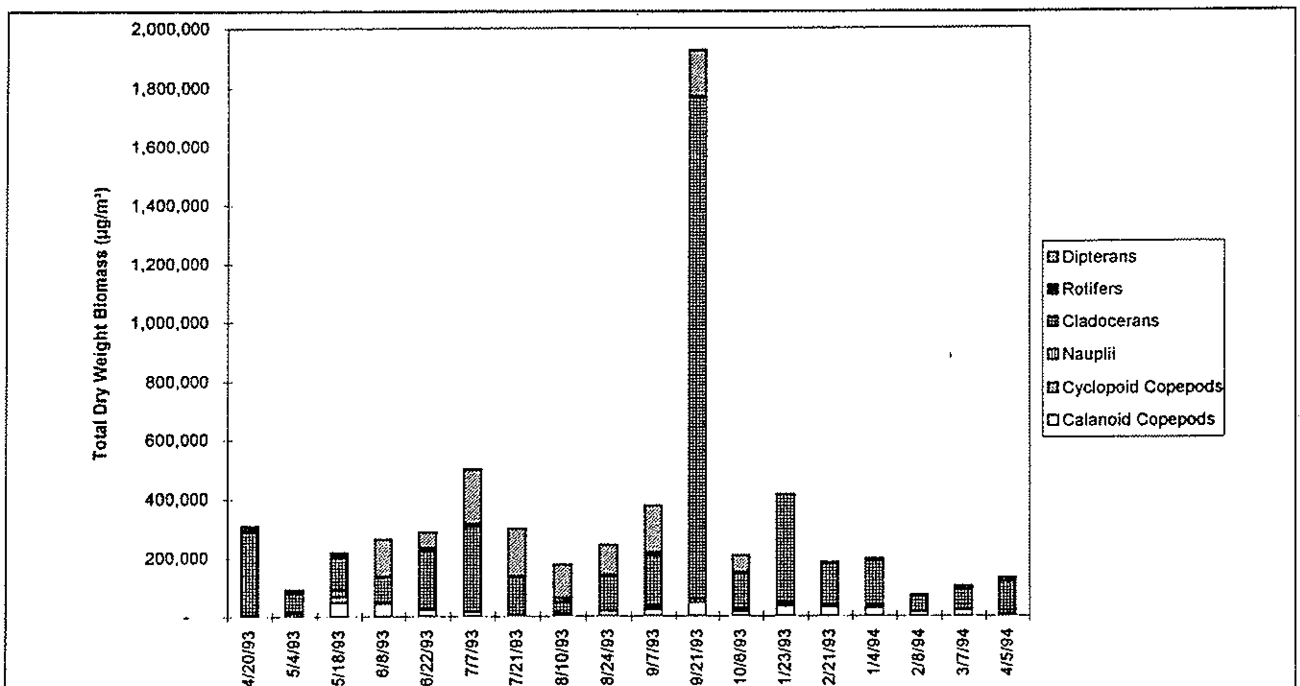


Figure 4-17
TOTAL DRY WEIGHT BIOMASS OF ZOOPLANKTON AT COTTAGE LAKE

The greatest density and diversity of benthic invertebrates is usually found in the *littoral* zone (shorelines) of a lake, where ample vegetation and oxygen are present. Here, habitat and food resources can be found to support benthic communities. The benthic communities, in turn, provide food for larger invertebrates, fish, amphibians, and birds.

Benthic invertebrate densities in Cottage Lake ranged from 1,391 to 6,087 organisms/square meter at the littoral station (2.3 meters), and from 1,520 to 3,522 organisms/square meter at the deep station (5.5 meters). Littoral animals included insects (the family Chironomidae and the genera *Palpomyia*, *Chaoborus*, and *Haliplidae*), crustacea (the genus *Asellus*), and annelids (the families Oligochaeta and Hirudinea). Chironomidae, *Asellus*, and Oligochaeta comprised the largest portion of littoral samples, with densities ranging from 174 to 2,609 organisms/square meter, from 522 to 1,087 organisms/square meter, and from 391 to 2,217 organisms/square meter, respectively for the three samples collected.

Benthic invertebrates present in the deep station included insects (the family Chironomidae and genera *Chaoborus* and *Palpomyia*) and annelids (the family Oligochaeta). No crustacea were found. *Chaoborus* was found most frequently, with densities ranging from 1,217 to 2,174 organisms/square meter.

Fecal Coliform Bacteria

Fecal coliform bacteria were sampled in Cottage Lake in order to evaluate contamination from animal wastes in the watershed and the potential failure of on-site septic systems. The Washington Department of Ecology states that for lakes, fecal coliform bacteria should not exceed a geometric mean of 50 organisms/100 ml of water, and not more than 10 percent of the samples should exceed 100 organisms/100 ml (Washington Department of Ecology, 1992). In-lake geometric mean counts were 11 organisms/100 ml (11 CFU/100g) at the COTTAGE1 sampling station, and 18 organisms/100 ml at the COTTAGE2 sampling station. Ranges were 0 to 45 organisms/100 ml and 0 to 51 organisms/100 ml, respectively. The only instance of the state water quality standard being exceeded was a count of 51 organisms/100 ml at COTTAGE2 on December 21, 1993.

Fisheries

Cottage Lake is known to have a high-quality fish population; the Washington State Department of Fish and Wildlife rates the lake as a moderately important fishery. Fish species known to inhabit Cottage Lake are shown in Table 4-11. Of particular interest is the presence of juvenile coho salmon in the lake. They migrate out to sea for their adult lives, and return to spawn downstream of Cottage Lake, in Bear and Cottage Lake Creeks, which are considered important salmon spawning streams (King County, 1990b).

Table 4-11: Fish Species Known to Inhabit Cottage Lake

Scientific Name	Common Name
Oncorhynchus mykiss	Rainbow Trout
Oncorhynchus clarkii	Cutthroat Trout
Oncorhynchus kisutch	Coho Salmon (juvenile)
Perca flavescens	Yellow Perch
Pomoxis nigromaculatus	Black Crappie
Salvelinus fontinalis	Eastern Brook Trout
Lepomis gibbosus	Pumpkinseed
Micropterus salmoides	Largemouth Bass
Mylocheilus caurinus	Peamouth
Gasterosteus aculeatus	Threespine Stickleback
Ictalurus nebulosus	Brown Bullhead

Data from Bob Fuerstenberg, SWM Division Biologist (King County, 1993a)

The Washington State Department of Fish and Wildlife stocked Cottage Lake with rainbow trout fry until the late 1970s, and stocked the lake again in 1992 (when there was once again public access) with 25,000 fry. Data from creel surveys, a tool used to assess the success of the stocked rainbow trout fishery, are available from the late 1970s, 1980, and 1993; Table 4-12 presents the results of creel surveys from these time periods. These surveys suggest a fairly productive trout fishery in the lake (King County, 1993a).

Table 4-12: Cottage Lake Creel Surveys

Year	Number of Anglers	Number of Fish Caught
1979	1,960	4,080
1980	1,857	722
1993	475	710

Table 4-13 presents the results of the fall 1993 fisheries assessment in Cottage Lake. Seven species of fish were represented among the 40 fish caught and released. The fishery was dominated by rainbow trout, which accounted for 32.5 percent of the fish caught, followed by largemouth bass (20 percent) and yellow perch (20 percent). Other observed species were crappie, sunfish, cutthroat trout, and brown bullhead. Six fish (15 percent of the total) exceeded 400 mm in length. In addition to the captured fish, a large mature salmon was observed in the lake near the Daniels Creek Inlet (KCM, 1994a).

Table 4-13: Fall Fish Sampling of Cottage Lake

Species	Number of Fish Caught		Percentage of Total Catch
	Electrofishing	Fyke Trap	
Largemouth Bass	7	1	20
Crappie	1	3	10
Yellow Perch	8	0	20
Sunfish	0	1	2.5
Brown Bullhead	0	5	12.5
Rainbow Trout	8	5	32.5
Cutthroat Trout	1	0	2.5
Total Catch	**25**	**15**	**100**

Table 4-14 presents the results of the spring 1994 fisheries assessment. Seven species of fish were represented among the 38 fish caught, including a juvenile coho salmon. The species composition was similar to that of the fall fishery, but the percentage distribution was significantly different. In the spring, the fishery was dominated by largemouth bass, which accounted for 55.3 percent of the total catch, followed by yellow perch (21.1 percent), and crappie (15.8 percent). Only one rainbow trout and one brown bullhead were caught, in addition to the one coho (KCM, 1994b).

Table 4-14: Spring Fish Sampling of Cottage Lake

Species	Number of Fish Caught		Percentage of Total Catch
	Electrofishing	Fyke Trap	
Largemouth Bass	21	0	55.3
Crappie	6	0	15.8
Yellow Perch	8	0	21.1
Sunfish	0	0	0
Brown Bullhead	1	0	2.6
Rainbow Trout	1	0	2.6
Coho Salmon	1	0	2.6
Total Catch	**38**	**0**	**100**

The absence of yellow perch larger than 190 mm in both the fall and spring fishery may indicate that the perch are being consumed by the large bass in the lake. Scale samples taken from three perch and three bass indicated that there is no reduction in growth due to overpopulation. The data collected from the scale samples and length measurements was compared to historical data (Scott and Crossman, 1973). This comparison showed that the growth rate of perch and bass in Cottage Lake is similar to that in lakes of similar size in other regions (KCM, 1994b).

The spring size distribution of the largemouth bass is shown in Figure 4-18. Lengths of all fish over 90 mm were recorded and are presented with weight data in King County, 1996. There is a good mix of age classes when the fall and spring data are combined, as shown in Figure 4-19.

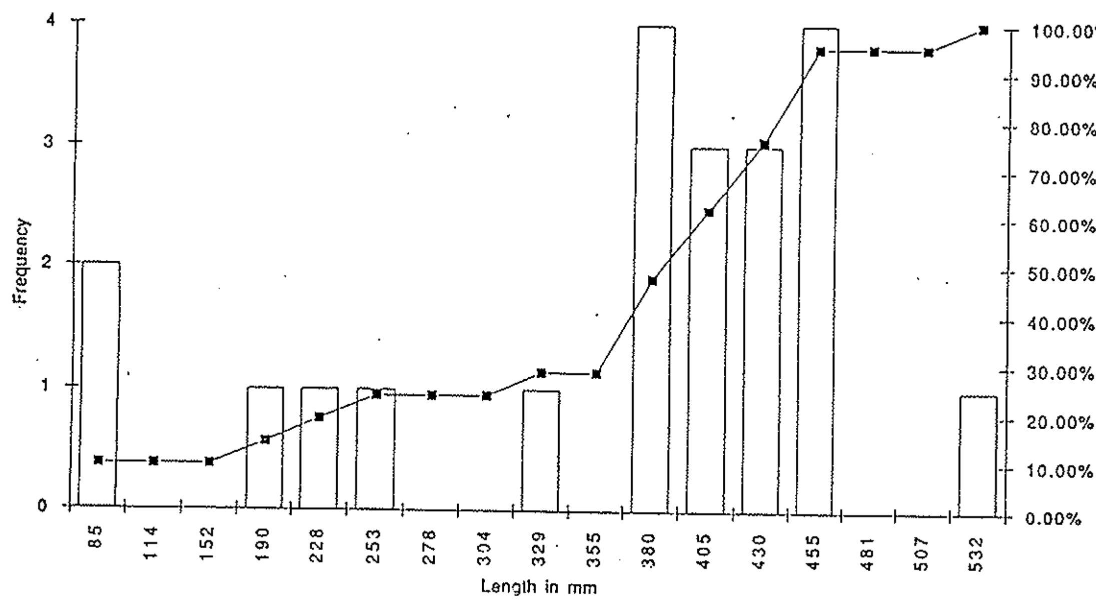


Figure 4-18
COTTAGE LAKE LARGEMOUTH BASS LENGTH FREQUENCY

The larger bass captured during the spring fishery had empty stomachs. This is not unusual, as bass do not feed as aggressively during the spawning season when water temperatures reach 15 degrees C (the surface water temperature in Cottage Lake at the start of the electrofishing effort was 17.8 degrees C). At other seasons, largemouth bass will feed predominantly on other fish. The stomach contents of the other captured fish indicated that they were feeding on caddisfly larvae and zooplankton. There were no gut contents indicating predation on other fishes (KCM, 1994b).

Based on the fish species captured, the distribution of age classes, and the amount of fishing activity observed on the lake during the fall and spring fishery assessments, Cottage Lake continues to be a valuable fishery. However, the impact of urban development in the watershed and around the lake should be carefully controlled to minimize additional nutrient loading, which contributes to excessive weed and algae growth. This can result in poor habitat and degraded conditions for the fishery (KCM, 1994b).

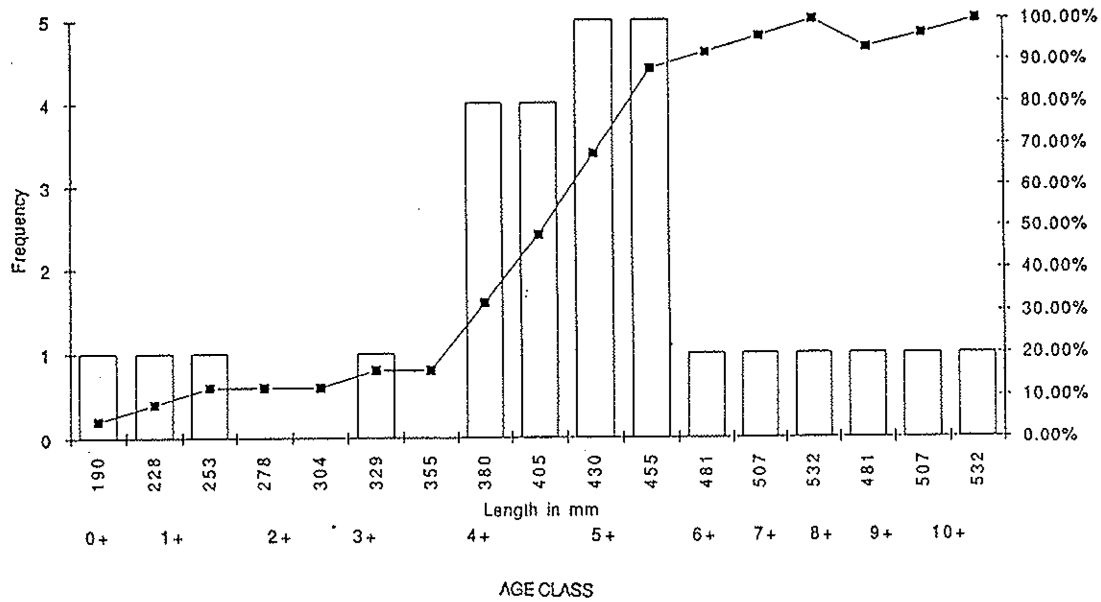


Figure 4-19
COTTAGE LAKE LARGEMOUTH BASS CATCH DATA

Aquatic Plants

Aquatic plants are the large, visible plants located within the littoral areas of the lake shoreline, and can be divided into three main groups: 1) emergent; 2) floating (free-floating and rooted-floating); and 3) submersed. Figure 4-20 illustrates these community types and common examples of plants associated with each type.

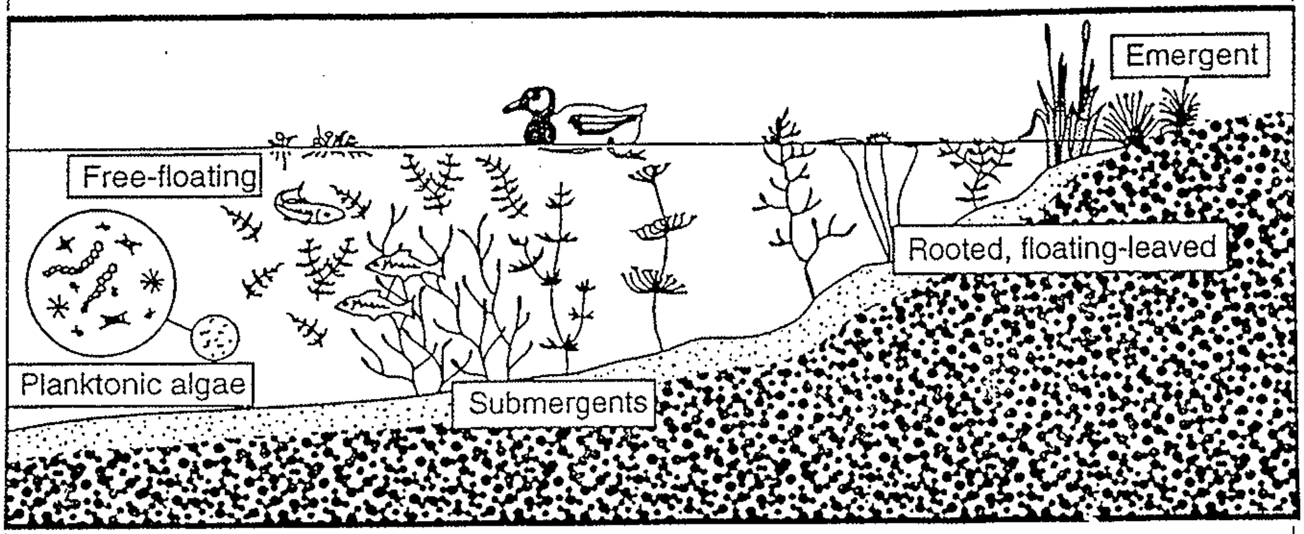


Figure 4-20
MACROPHYTE COMMUNITY TYPES

Aquatic plants provide many benefits, including sediment and shoreline stabilization; food source and habitat for benthic invertebrates, fish, and wildlife; oxygenation of the water column; and aesthetics. Most rooted macrophytes obtain their nutrients from bottom sediments rather than the water column, and take up phosphorus during the active growing season that would otherwise have been available for algal growth.

About 30 percent of the lake area supports macrophyte growth (see Figure 3-4 for the location of the major macrophyte beds in Cottage Lake). The submersed community constitutes the largest percentage of the plants by area in Cottage Lake, followed by floating plants. Much of the shoreline of the lake has been altered by residential development and past activities associated with Norm's Resort, thereby reducing the percentage of emergent macrophytes. In other lakes, where the shoreline is less altered, the percentage of emergents is usually higher.

Table 4-15 summarizes the various plant species found in Cottage Lake by community type. Dominant species observed in the 1993 survey were water weed (*Elodea canadensis*), pondweed (*Potamogeton* spp.), and white water lilies (*Nymphaea odorata*). White water lilies, yellow iris, and purple loosestrife, which was growing abundantly adjacent to and on the shoreline, are non-native plants. The Washington State Department of Agriculture classifies purple loosestrife as a noxious weed. There was no Eurasian watermilfoil found in Cottage Lake in the summer of 1993. This may become more of a threat now that there is public access to the lake via boat launching in Cottage Lake Park.

Table 4-15: Macrophyte Species Found in Cottage Lake

Scientific Name	Common Name
Emergent Plants	
Iris pseudacorus	Yellow iris
Juncus spp.	Rushes
Lythrum salicaria	Purple loosestrife
Typha latifolia	Cattail
Floating Plants	
Brasenia schreberi	Watershield
Nuphar variegatum	Yellow water lily
Nymphaea odorata	White water lily
Submerged Plants	
Ceratophyllum demersum	Coontail
Chara schweinitzii	Muskgrass
Elodea canadensis	Water weed
Najas flexilis	Water nymph
Potamogeton berchtoldii	Berchtold's pondweed
Potamogeton epihydrus	Ribbon-leafed pondweed
Potamogeton richardsonii	Richardson's pondweed

The total phosphorus content measured in 23 aquatic plant samples averaged 0.258 percent (dry weight) in Cottage Lake. Plant biomass averaged 71.4 grams per square meter.

CURRENT WATER QUALITY—WETLAND ASSESSMENT

Wetland communities were evaluated on the lake shore and along the tributaries. Following is a summary of observations on current wetland conditions and functions (Pentec Environmental, Inc., 1994).

Lake Shore

The majority of the lake shore contains saturated soils supporting such plants as cattail (*Typha latifolia*), reed canarygrass (*Phalaris arundinacea*), hardstem bulrush (*Scirpus acutus*), willow (*Salix* spp.), red osier dogwood (*Cornus seracia*), and red alder (*Alnus rubra*).

Most of the houses around the lake have lawns extending to the edge of the water and lacking wetland vegetation, or with a thin, two to five foot, band of non-native vegetation along the shoreline. No native vegetative buffers were observed on any of the lots.

Cottage Lake Park Wetland

The 16-acre wetland along the north shore of the lake within Cottage Lake Park has been adversely affected by fill and grading; it is classified as a Class II wetland due mainly to its size. Two acres of the wetland are aquatic bed and open water dominated by evergreen blackberry (*Rubus lacinutus*), willow, reed canarygrass, yellow iris (*Iris pseudacorus*), soft rush (*Juncus effusus*), hardstem bulrush, American brookline (*Veronica americana*), bittersweet nightshade (*Solanum dulcamara*), and purple loosestrife. The remaining 14 acres are emergent vegetation, mostly wet, mowed lawn. Non-native ornamental shrubs have been planted throughout the area, along with big-leaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera*), and Douglas fir (*Pseudotsuga menziesii*). On November 20, 1993, community volunteers and King County SWM staff planted various native trees and shrubs along the Cottage Lake Creek inlet and on the lawn area in order to restore the wetland community.

The Cottage Lake Park wetland currently has low potential for groundwater recharge and discharge. The lake receives nutrient inputs from lawn maintenance, and petroleum hydrocarbons from the parking lot area. There is little vegetation along the lake shore to prevent erosion. Thus, the site's ability to retain and transform these materials is low under current conditions. These productivity characteristics, low vegetation cover, low species richness, and high percentage of invasive species, provide low to non-existent food chain support. There is consequently a low potential for habitats for invertebrates, amphibians, mammals, or birds other than waterfowl. The wetland has some aesthetic recreational value.

Daniels Creek Wetland

The Daniels Creek inlet wetland is located on the east and west sides of 185th Avenue NE, between the road and the open-water area of Cottage Lake. The wetland community is dominated by hardhack spirea to the west of the road, and Sitka willow, red osier dogwood, Pacific willow, and nootka rose (*Rosa nutkana*) to the east of the road.

The intact wetlands north of Daniels Creek have moderately high potential for groundwater recharge, water quality improvement through biofiltration, and wildlife habitat. The wetland along the northwestern shore of the lake adjacent to Daniels Creek has moderate potential for flood water attenuation, and low to moderate potential for flood water detention and retention based on topography. The potential for sediment stabilization is moderate to high, given the dense vegetation at the inlet to Cottage Lake; the potential for retention of sediments, nutrients, and toxicants is moderate to high for the same reason. Moderate to high decomposition within the wetland contributes to moderate to high primary productivity. This wetland has moderate to high invertebrate, amphibian, bird, and mammal habitat potential.

Cottage Lake Outlet Wetland

The wetland at the Cottage Lake Creek outlet from Cottage Lake is dominated by white water lilies, with cattails in the shallow areas. The vegetation adjacent to the creek for the first few hundred feet is dense scrub-shrub in character, dominated by willow, salmonberry (*Rubus spectabilis*), small red alders, red osier dogwood, hardhack spirea, western red cedar, and western hemlock (*Tsuga heterophylla*). Water storage and flood desynchronization, as well as the water quality improvement functions of biofiltration and particulate settling, are low for this wetland. Primary productivity is moderate by virtue of the dense vegetation community.

The ditched creek flows southwest into an emergent wetland meadow (see Figure 2-1) dominated by reed canarygrass, soft rush, small fruited bulrush (*Scirpus microcarpus*), water horsetail (*Equisetum fluviatile*), giant horsetail (*Equisetum telmateia*), small bedstraw (*Galium trifudum*), creeping spikerush (*Eleocharis palustris*), creeping buttercup (*Ranunculus repens*), American brooklime (*Veronica americana*), birdsfoot trefoil (*Lotus corniculatus*), and slender bentgrass (*Agrostis capillaris*). This meadow area has high potential for groundwater discharge and recharge, flood water detention/retention, and flood peak desynchronization. The current ditch configuration precludes the fields from serving many water quality or nutrient retention functions, except for those surface flows that originate in the upland areas to the north. There are excellent opportunities for bird watching in the area. The field offers some moderate to high quality wildlife habitat for amphibians, invertebrates, birds, and small mammals.

During August and September 1993, a beaver repeatedly built a dam across the creek. Consequently, the water level of the lake was unusually high for the season. In early October 1993, the beaver was captured and transported away from the creek by the Washington State Department of Fish and Wildlife, and the lake water level returned to normal.

CURRENT WATER QUALITY—NONPOINT POLLUTION

Nonpoint pollution originates from diffuse land use practices, including animal keeping, on-site septic systems, forestry, land clearing, construction, and residential and urban uses. Pollutants are typically transported from land surfaces during rainfall into receiving water, such as wetlands, streams, and lakes. Nonpoint pollution is often a mix of constituents, not readily associated with a single source; in contrast, point source pollutants discharge from a single location. The diffuse character of nonpoint pollution makes its identification, isolation, and control all the more difficult. Implementation of best management practices (BMPs) and structural controls is the strategy often taken to reduce pollutant loading associated with such sources.

Septic Survey

Under normal conditions, properly maintained and operated on-site septic tank and drainfield disposal systems are a negligible source of pollutants (particularly phosphorus) to surface waters. The degree of treatment provided by the system and the limited mobility of phosphorus in the soil drainfield are such that septic tanks are usually disregarded as a significant source of nutrient or pollutant loading to a lake, except where drainfields are close to the lake or a direct feeder stream (within 100 meters), or where systems are failing and significant amounts can reach water courses through overland flow (US EPA, 1988).

Proper site conditions must exist for septic systems to operate effectively. Conditions that prevent or interfere with proper septic system function include unsuitable soils, high water tables, steep slopes, poor system design, poor maintenance, and improper use. Many of these conditions are found around lakes, and can make a lakeside lot unsuitable for septic systems. Typically, on-site septic systems have not been shown to be the main contributor of total phosphorus loading to the lake system. However, lake water quality problems have been conclusively associated with septic system failures (US EPA, 1988; KCM, 1994c).

Aerial Shoreline Analysis (ASA) and field surveys were performed to assess nonpoint pollutant loading from on-site septic systems. Vegetation patterns indicative of septic system drainfield failures were noted for two Cottage Lake sites, one on the west shore and one on the east shore. The lack of additional findings using ASA may be attributed to the time of year, vegetation dormancy, or the presence of landscaping that may obliterate evidence of on-site septic system failure (KCM, 1994c, Resource Management, Inc., 1994).

There are 74 on-site septic systems on Cottage Lake. The Puget Sound Water Quality Authority maintains that most septic systems have a maximum effectiveness of 20 to 40 years (PSWQA, 1989). Those systems already in use around the lake may pose a threat to the lake in the near future, while the newer systems may pose a water quality problem in the long-term future when the population in the watershed increases. Failure rates as high as 23 percent have been reported for developments with aging systems (King County, 1992b); however, the overall failure rate in the Puget Sound region is approximately 3.5 to 5 percent (PSWQA, 1989).

Figure 4-21 indicates that the general soil types found within most of the lake's shoreline are Everett and Ragnar series soils. These soils are generally rated for rapid permeability, which may allow subsurface leaching into nearby water bodies. A portion of the north end of the lake shore is composed of Seattle series organic soils. These soils exhibit severe limitations for septic system functioning and represent a potential for nutrient and fecal coliform bacteria loading to the lake (KCM, 1994c).

On-site septic system drainfields in soils over shallow water tables can contribute contamination through groundwater. Topographically low areas exist generally throughout the north end of the lake, where poorly drained soils are also found. On-site septic systems located within Everett and Ragnar soils on sloping hillsides are more susceptible to leaching than those in relatively flat areas; the west side of Cottage Lake contains sloping hillsides, and possible leaching drainfields (KCM, 1994c).

Figure 4-22 shows the locations of 13 historic and probable failing on-site septic systems. In many cases, these systems may be functioning adequately, but should be inspected to confirm their status (KCM, 1994c).

The potential phosphorus loading to Cottage Lake from septic systems was calculated based on the following assumptions: 74 on-site septic systems, per capita loading of four grams total phosphorus per day (US EPA, 1988), two persons in each residence, and nutrient attenuation of 90 percent for the waste disposal systems, based on review of literature. The resulting potential annual phosphorus loading from septic systems is 22 kilograms (KCM, 1994c).

Other Residential-based Sources

Besides septic systems, another important source of nonpoint pollutant loading is stormwater runoff from the shoreline lots surrounding Cottage Lake. Homeowner use of pesticides and fertilizers, removal of native vegetation, dumping of yard waste near the shoreline, improper composting, and soil erosion on residential lots all contribute to nonpoint loading. The significance of this contribution is difficult to quantify because of the diffuse nature of the loading, but was estimated for the lake nutrient budget (Chapter 6). The absence of shoreline vegetation on numerous waterfront lots only exacerbates the problem by allowing the delivery of the nonpoint load directly to the lake without buffering. Shoreline lots with vegetative buffers of at least 10 to 15 feet offer some filtering of surface water runoff before the runoff enters the lake.

Several animal-keeping operations within the Cottage Lake watershed may contribute to phosphorus or nitrogen loading to the lake. This is particularly true in areas where animals have direct access to streams, and where pastures are overgrazed and manure is not properly disposed of.

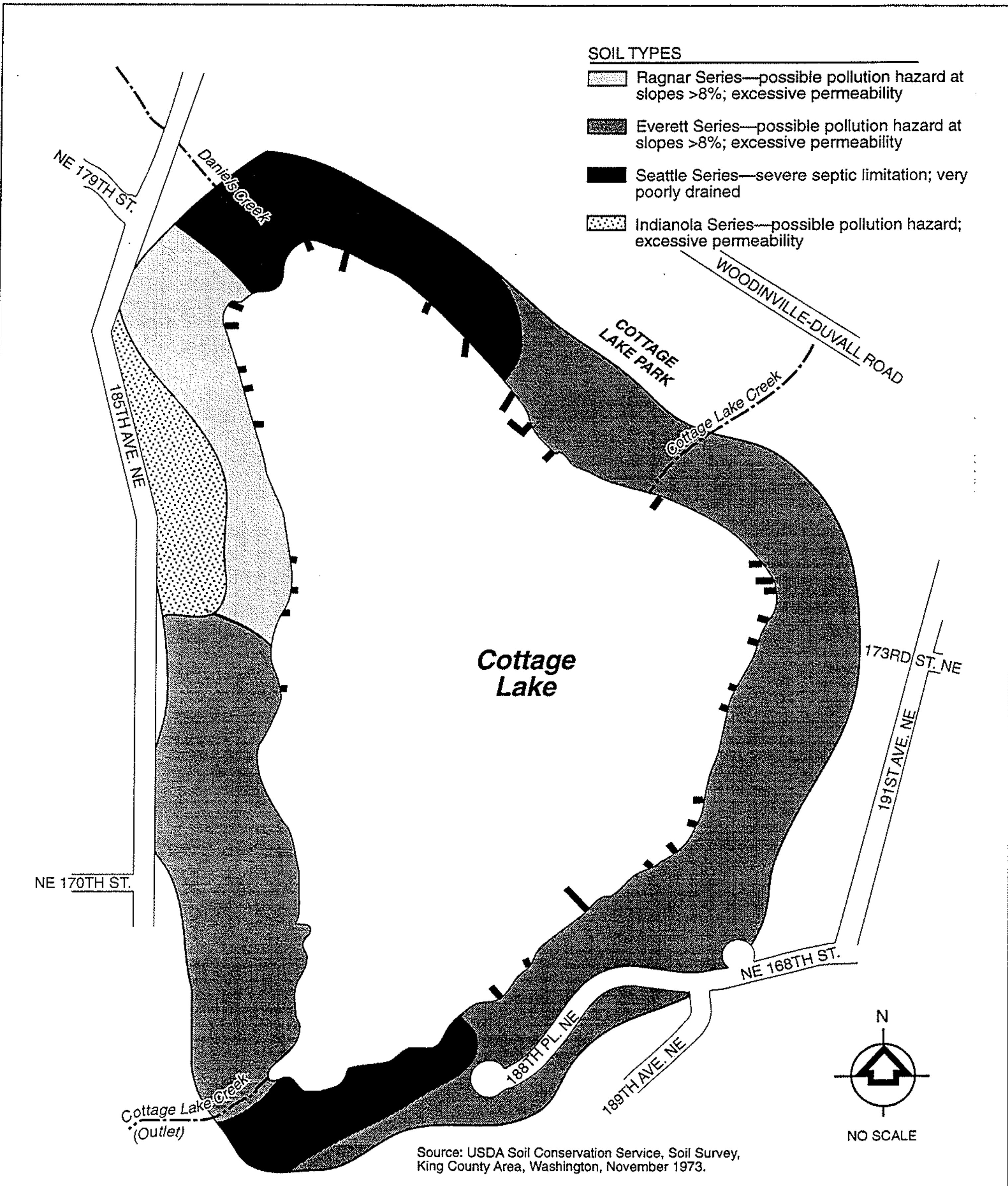


Figure 4-21
SOIL TYPES IN THE SEPTIC SURVEY AREA

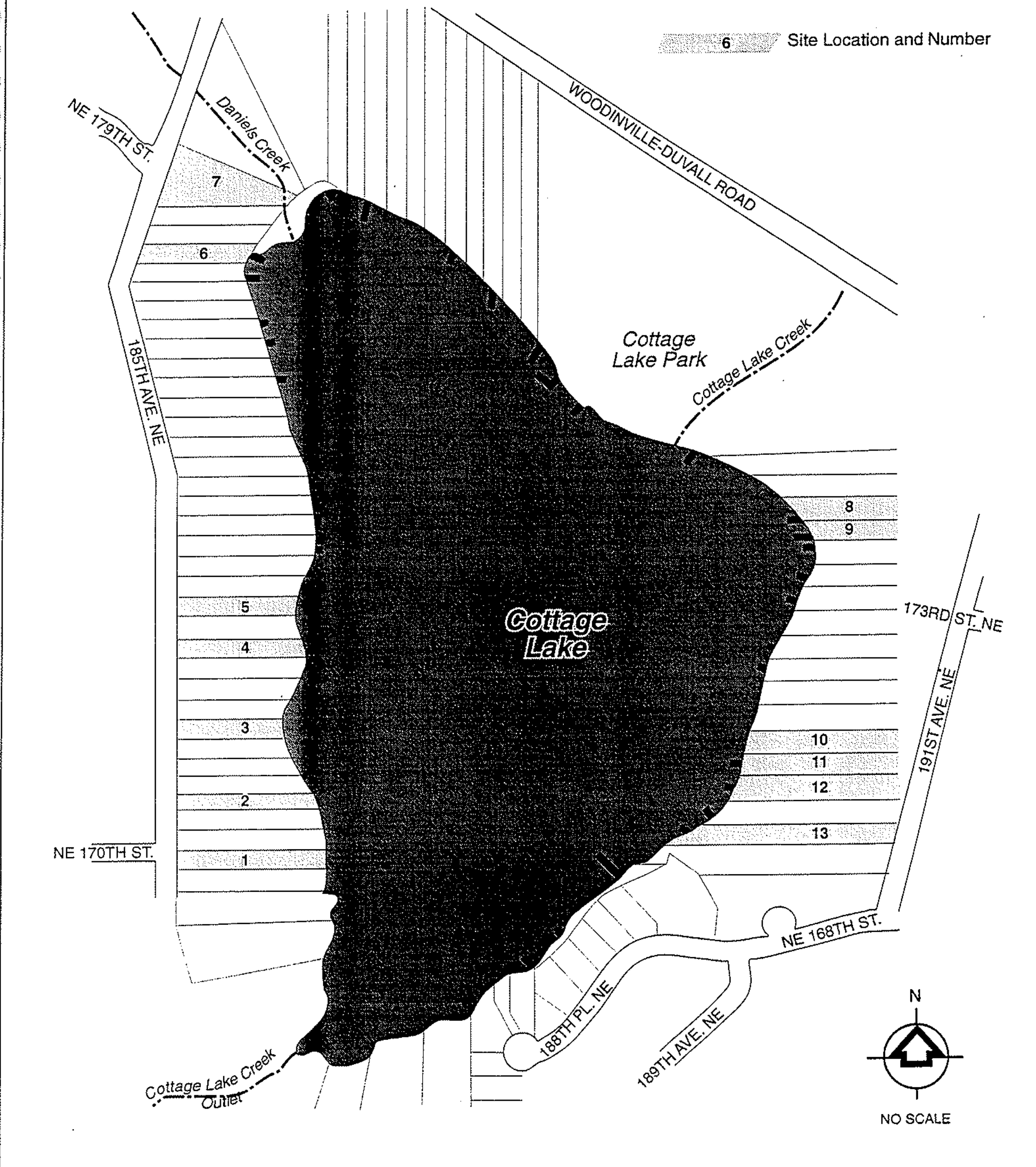


Figure 4-22
POSSIBLE SEPTIC SYSTEM PROBLEM SITES

Several horse stables are located directly above Daniels Creek. Leachate from used stable bedding and animal wastes are entering the creek, primarily when it rains. This leachate is likely to have a high concentration of bio-available phosphorus, which can cause rapid growth of algae. Sediments are also entering the creek from poor pasture management practices and unpaved parking areas (Robert Wright, WSDOE, Personal Communication).

There is a commercial shopping mall with parking lot storm drains that discharge to the Cottage Lake Creek Inlet. There is the potential for stormwater contamination from oil and grease, other hydrocarbons, and metals on the pavement, and subsequent transport of these toxics to the lake via the storm drains. These same toxic contaminants may also enter Cottage Lake directly via stormwater runoff from the parking lot in Cottage Lake Park.

TROPHIC STATUS

Lakes are usually classified and compared by their trophic status, or degree of biological productivity. Secchi depth (transparency), chlorophyll *a*, and total phosphorus are most frequently used to assign trophic status. The general relationship between these lake water quality parameters and trophic status index (TSI) is summarized in Table 4-16.

Table 4-16: Trophic Status and Associated Values

Trophic Status	Secchi (m)	Chl *a* (µg/L)	TP (µg/L)	TSI (average)
Oligotrophic	>4	<3	<14	<40
Mesotrophic	2-4	3-9	14-25	40-50
Eutrophic	<2	>9	>25	>50

Carlson, 1977; Chapra and Tarapchak, 1977; Cooke et al., 1993; Porcella et al., 1980

Cottage Lake's current trophic status is eutrophic, based on summer and annual average Secchi depth, chlorophyll *a*, and total phosphorus concentrations. Table 4-17 summarizes the trophic state variables and corresponding Carlson's Trophic State Index (TSI) values. Based on Carlson's Trophic State Index, Cottage Lake is considered very eutrophic, with a summer TSI value of 57 and annual TSI value of 57.7.

Table 4-17: Cottage Lake Trophic Status Summary

Time	Secchi (m)	Chl *a* (µg/L)	TP * (µg/L)	TSI Secchi	TSI Chl *a*	TSI TP	TSI Average
Annual	1.9	18.3	56.2	51	59	63	57.7
Summer	1.9	31.8	32.3	51	65	55	57.0

* *volume-weighted epilimnetic concentrations*

Comparing the trophic parameters of Cottage Lake to those of several local lakes, Cottage Lake consistently ranks as one of the most biologically productive lakes in King County. Of the lakes examined, Cottage Lake had the highest summer chlorophyll *a*, annual chlorophyll *a*, and annual total phosphorus concentrations, as shown in Table 4-18. Cottage Lake also had the second highest summer total phosphorus concentration, the second lowest annual Secchi depth, and the third lowest summer Secchi depth.

Table 4-18: Comparison of Secchi Depth, Chlorophyll *a*, and Total Phosphorus Concentrations for Eight King County Lakes.

Lake	Summer Secchi (m)	Summer Chl *a* (µg/L)	Summer TP (µg/L)	Annual Secchi (m)	Annual Chl *a* (µg/L)	Annual TP (µg/L)
Beaver1	1.0	15	20	1.2	11	28
Beaver2	2.3	4.9	11	2.5	4.2	18
Cottage	**1.9**	**32**	**32**	**1.9**	**18**	**56**
Desire	1.6	15	34	2.0	14	42
Pine	5.7	2.3	—	—	—	—
Spring	2.5	6.4	—	—	—	—
Shady	3.7	4.2	—	—	—	—
Twelve	3.6	7.3	6.3	—	—	—

Source: King County, 1993b; Welch et al., 1993

CHAPTER 5: LAKE WATER BUDGET

A water budget is a measure of the sources of water discharging into and flowing out of a lake over the course of a year. A water budget was calculated for Cottage Lake using a combination of field data and the Hydrologic Simulation Program—Fortran (HSPF) computer model for the Upper Bear Creek watershed, developed by King County in 1988. This chapter describes the study year water budget and the methods and data used in its calculation. Weather patterns were unusual during the study year (i.e., unusually cool and wet spring and summer, and unusually warm and dry fall and winter).

METHOD OF ANALYSIS

As part of the Cottage Lake Phase I Restoration Project, King County SWM personnel and local citizen volunteers conducted hydrologic field monitoring from April 1993 through March 1994. Data obtained through this effort included precipitation, stream flow into and out of the lake, and lake surface elevation (water level); these data were used to calibrate the HSPF model. The water budget was then calculated using the model.

The Cottage Lake Creek subbasin is located in the Upper Bear Creek watershed. The model was revised so that only the subcatchments and stream reaches relevant to the water budget would be included in the analysis. Subcatchments C10, C9, C7, C6S, and C6K drain to Subcatchment C5 (see Firgure 2-1), which surrounds Cottage Lake (King County, 1990a). The model input data file is included in KCM, 1994d. Precipitation and evaporation data were also used as inputs to the model. Model output included simulated flows of water into and out of the lake and changes in lake water level and volume.

Model results were evaluated by comparison with observed data collected during the study period. Results of a hydrogeologic study were used to determine how well the model simulated subsurface (groundwater) flows into the lake (Hong West and Associates, Inc., 1994). Groundwater flow is typically the most difficult portion of the water budget to quantify because the cross-section of flow cannot be monitored in its entirety. Therefore, groundwater flows are calculated based on field measurements at specific well or seepage meter locations, or on water budget calculations solved for groundwater flow when all other inflows and outflows are known. All these approaches were used to determine groundwater flow into Cottage Lake. Groundwater was assumed to flow into the lake only from Subcatchment C5 because groundwater from upstream catchments must flow through Subcatchment C5 to reach the lake.

DATA USED IN ANALYSIS

Data used as input for the HSPF model are summarized in Table 5-1. Pan evaporation data were not available for the entire period. Missing data were calculated using a computer program provided by King County and maximum and minimum daily temperature data for the period, obtained from the National Weather Service station at Monroe, Washington. Calculated pan evaporation data were compared with observed data for the period in which both were available. Calculated values were found to be acceptable and were therefore used to fill in missing data.

Table 5-1: Description of Data Used in Water Budget

Location	Data Type (units)	Data Interval	Dates	Data Use
Daniels Creek (Tributary 0122)	discharge (cfs) [a]	1 value in spring and summer months, 2 values in fall and winter months	5/93, 8/93-3/94	evaluate simulated versus observed
Cottage Lake Creek inflow (Tributary 0127)	discharge (cfs)	same as above	same as above	same as above
Cottage Lake Creek outflow (Leno Bassett property)	discharge (cfs)	same as above	same as above	same as above
Bruce McCain property	lake level (feet)	weekly	8/93-12/93, 2/94-3/94	same as above
Safeway Store at Cottage Lake Mall (gauge 02W)	precipitation (inches)	15 minutes	4/1/93-3/27/94	model input
Puyallup	pan evaporation (inches)	daily	6/93-8/93	model input
None	pan evaporation, calculated (inches)	daily	4/93-5/93, 9/93-3/94	model input

a. cfs = cubic feet per second

RESULTS

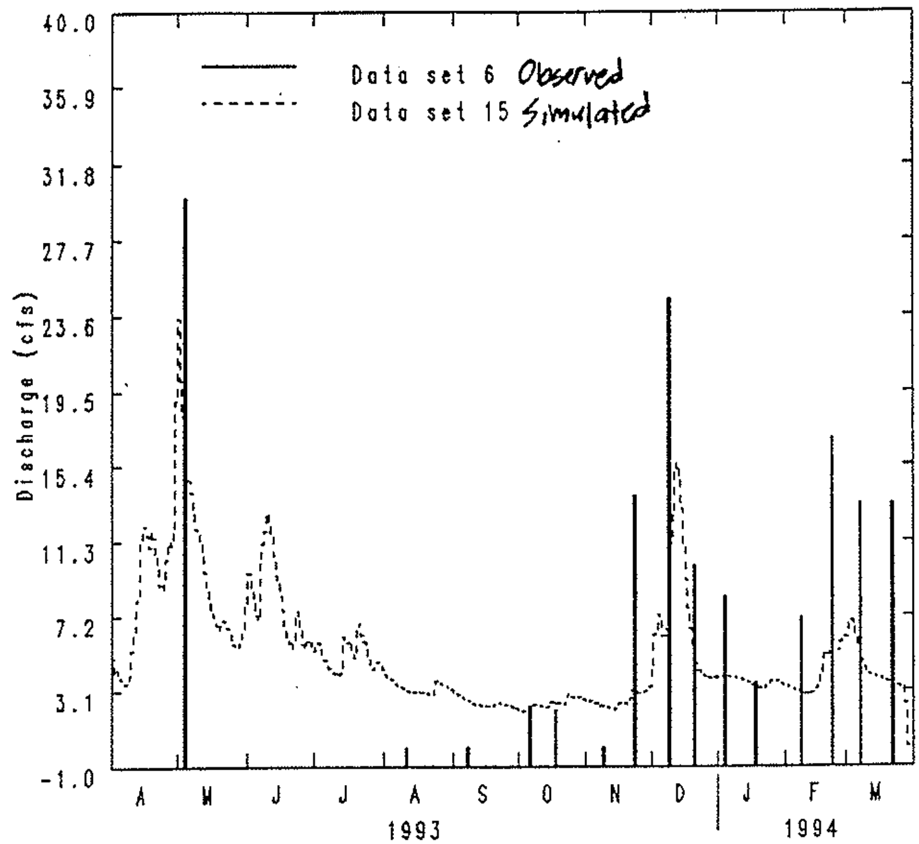
Model Verification

The acceptability of data from the model output was evaluated by comparing plots of simulated versus observed stream flow data for the Cottage Lake Creek outflow from the lake (Figure 5-1), the Cottage Lake Creek inflow to the lake (Figure 5-1), and the Daniels Creek inflow to the lake (Figure 5-2). Plots of time series calculated by the model were prepared to further examine the data: simulated Cottage Lake inflow and outflow rates, precipitation on the surface of Cottage Lake, and evaporation from the surface of the lake. The plot of inflow and outflow rates includes a time series representing flows from Subcatchment C5. Runoff from this subcatchment enters the lake as nonpoint surface and subsurface flow (KCM, 1994d).

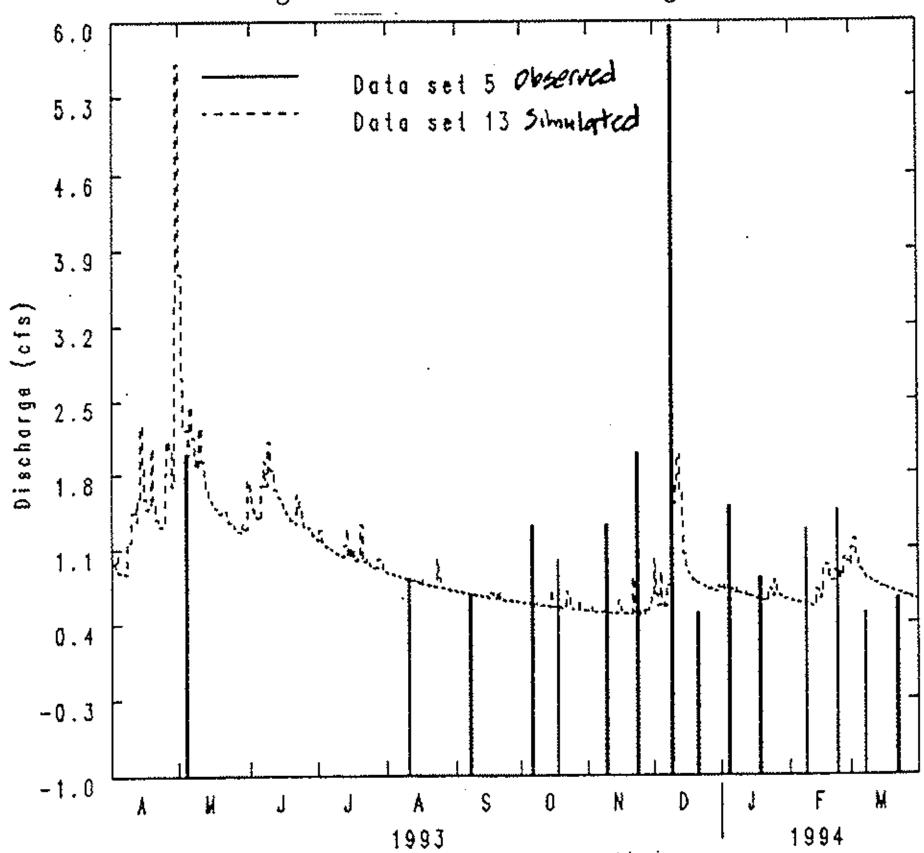
Modeled subsurface monthly flows were approximately two to four times greater than those estimated by the hydrogeologic study. As long as the difference is less than one order of magnitude (tenfold), the model results are considered to be sufficiently accurate to be used.

Study Year Water Budget

Following examination of model output, monthly totals were calculated and plotted for all lake inflows and outflows, as presented in Figure 5-3 and Table 5-2. Pie charts were prepared to depict the distributions of inflows and outflows. The pie chart for Cottage Lake inflows, presented in Figure 5-4, includes Subcatchment C5, Cottage Lake Creek, Daniels Creek, and precipitation. The pie chart for Cottage Lake outflows, also presented in Figure 5-4, includes the outflow creek and evaporation (KCM, 1994d).



Cottage Lake Creek Outflow from Cottage Lake



Cottage Lake Creek Inflow to Cottage Lake

Figure 5-1
OBSERVED VS. SIMULATED DISCHARGE
COTTAGE LAKE CREEK

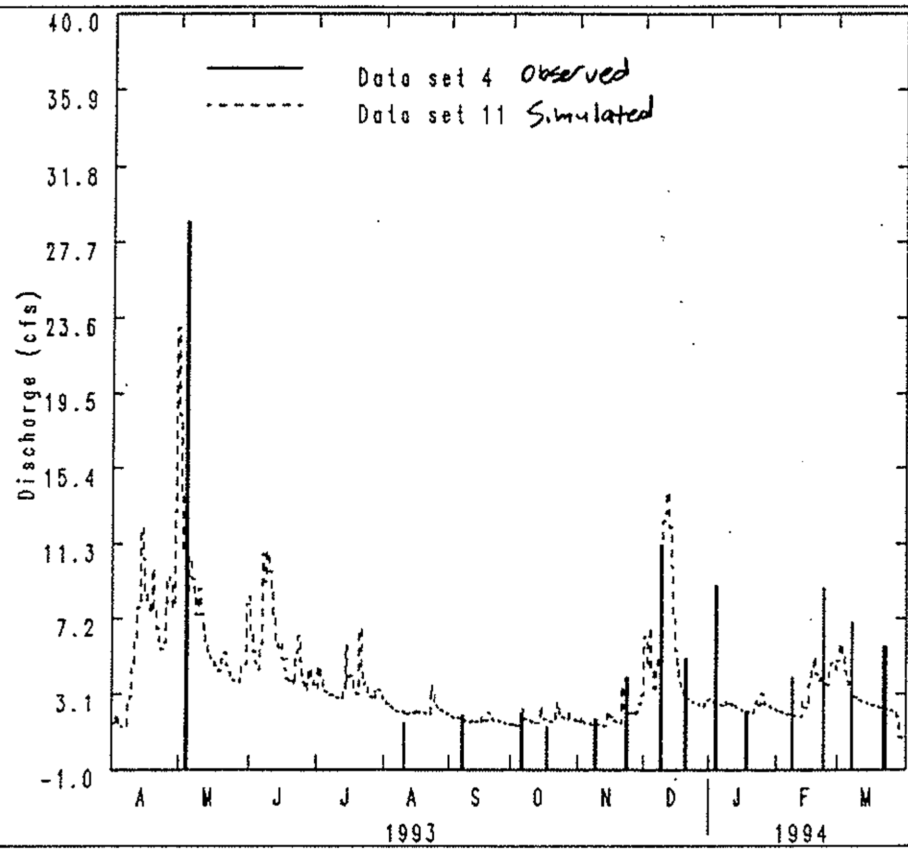


Figure 5-2
OBSERVED VS. SIMULATED DISCHARGE
DANIELS CREEK INLET TO COTTAGE LAKE

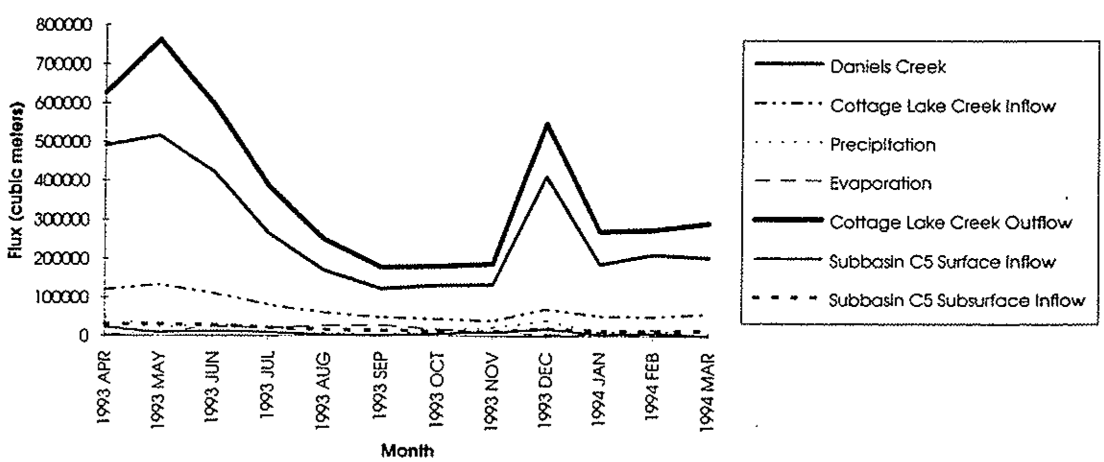


Figure 5-3
COTTAGE LAKE MONTHLY WATER BUDGET

Table 5-2: April 1993 to March 1994 Water Balance in Cubic Meters

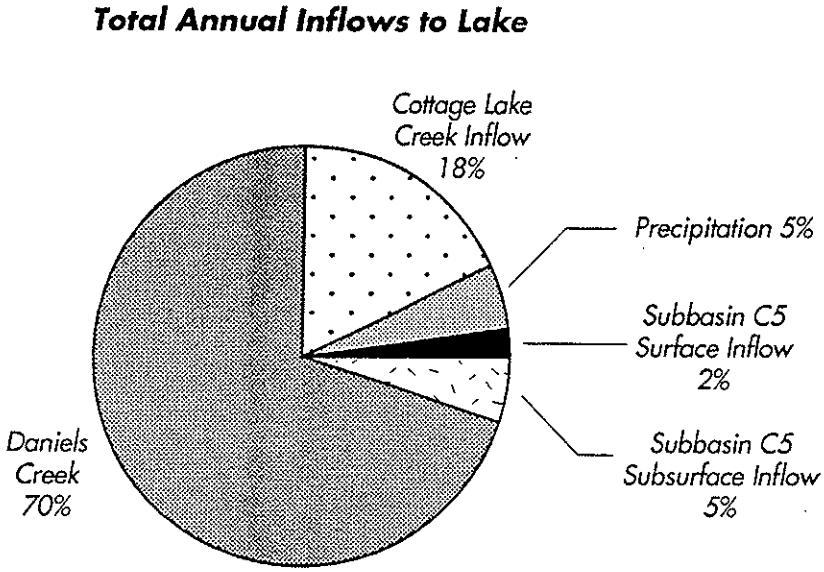
Month/Year	Daniel's Creek	Cottage Lake Creek Inflow	Precipitation	Subcatchment C5 Surface Outflow	Subcatchment C5 Subsurface Outflow	Evaporation	Cottage Lake Creek Outflow
April '93	491300	120000	49300	23200	29700	3600	627100
May '93	516100	132900	21900	8800	30400	10000	761700
June '93	422600	110600	30400	12600	27400	24700	598100
July '93	265000	80200	23700	9100	21200	20700	385500
August '93	169300	60300	8600	3200	16800	26900	248200
September '93	121200	47700	3200	1000	13500	27500	177200
October '93	130300	43800	14900	5700	12000	17700	179800
November '93	131700	38500	21400	9100	10300	7600	185500
December '93	409600	70100	39600	18400	19000	4900	547100
January '94	185900	51100	10200	4000	13500	3600	269500
February '94	210800	50400	16500	7500	12900	2100	273900
March '94	203700	58100	2700	1300	14300	3100	291600
Total	**3257500**	**863700**	**242400**	**103900**	**221000**	**152400**	**4545200**

Change in Storage = Daniel's Creek + Cottage Lake Creek Inflow + Precipitation + Subcatchment C5 Inflow - Evaporation - Cottage Lake Creek Outflow = -9,400 cubic meters

The total annual inflow to the lake for the study period was 4,688,400 cubic meters; the total annual outflow from the lake was 4,697,800 cubic meters. This represents a net loss of 9,400 cubic meters in lake volume, equivalent to a decrease in lake elevation of approximately 3.8 cm.

There are many more pathways for water flowing into than out of the lake. The largest inflow to the lake was Daniels Creek, accounting for approximately 70 percent of the total inflow during the year. Cottage Lake Creek contributed 18 percent of the annual inflow, while the remaining three pathways combined contributed approximately 12 percent of the annual inflow (Figure 5-4). Lake outflow occurred only through evaporation and the outlet stream (Figure 5-4); neither the HSPF model nor the available water data showed any groundwater outflow from the lake. Evaporative losses were minor compared to water lost via the outlet stream (KCM, 1994d).

Monthly total precipitation and pan evaporation data for the analysis period (April 1993 to March 1994) were compared to long-term monthly averages for Sea-Tac and Puyallup respectively. These comparisons showed that the spring and summer of the monitored year were wetter than normal, while the autumn and winter were drier than normal. Pan evaporation data for the period closely approximated the long-term averages, even though values were consistently higher than the long-term average between August and December 1993. Precipitation from April through August 1993 was consistently higher, while that from September 1993 through March 1994 was generally lower than the long-term average. Total annual precipitation for the study year at the 02W gauge at the Cottage Lake Mall was 37.35 inches, compared to a long-term annual average of 38.31 inches at Sea-Tac (KCM, 1994d).



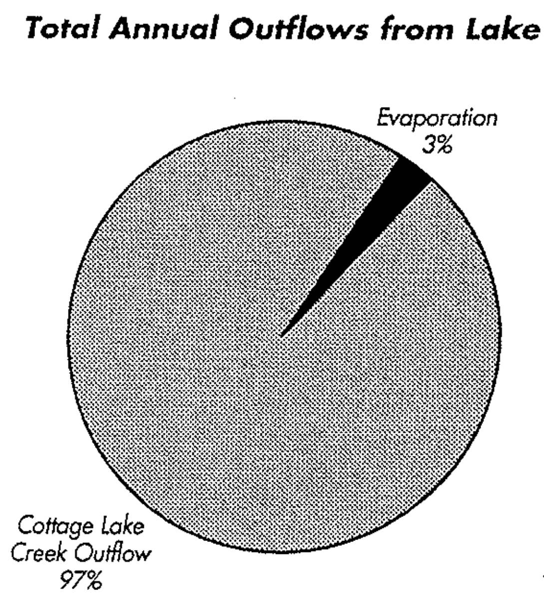


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Figure 5-4
COTTAGE LAKE ANNUAL WATER BUDGET

CHAPTER 6: NUTRIENT BUDGET AND LAKE RESTORATION ANALYSIS

METHOD OF ANALYSIS

Nutrient loading to Cottage Lake was calculated on the basis of the water budget developed for the lake (Chapter 5) and measured nutrient concentrations in the lake, outlet, precipitation, inlets, and groundwater (KCM, 1994e). Because phosphorus loading to Cottage Lake was shown to enhance phytoplankton production in the nutrient enrichment bioassay (KCM, 1993), and because total nitrogen to total phosphorus ratios were greater than 17:1 for most of the growing season (Figure 4-7), phosphorus was determined to be the limiting nutrient, and the loading analysis was conducted for phosphorus only. Phosphorus sources were divided into six major components: internal loading, direct precipitation (to the lake surface), Daniels and Cottage Lake Creeks, overland flow through Subcatchment C5 (the subcatchment immediately surrounding the lake), and subsurface flow through Subcatchment C5.

The model used to define lake phosphorus loading is based on the assumption that phosphorus input to the lake equals phosphorus loss from the lake plus or minus the change in the total amount of phosphorus stored in the lake:

$$\Delta P = D_{in} + C_{in} + Int + Pre + C5 + Gr - C_{out} - Sed$$

where:

ΔP = Change in phosphorus mass (storage) within the lake

D_{in} = Daniels Creek flow inputs of phosphorus

C_{in} = Cottage Lake Creek flow inputs of phosphorus

Int = Internal input of phosphorus from sediments over and above phosphorus sediment/water exchange

Pre = Direct precipitation of phosphorus to the lake surface

C5 = Input of phosphorus from overland flow via Subcatchment C5

Gr = Input of phosphorus from subsurface flow via Subcatchment C5

C_{out} = Cottage Lake Creek outlet loss of phosphorus

Sed = Loss of phosphorus to sediments over and above phosphorus sediment/water exchange

Groundwater loading was determined by multiplying the subsurface inflow volume from Subcatchment C5 by the mean concentration of phosphorus (80 µg/L) measured in the groundwater samples (Hong West and Associates, Inc., 1994). Phosphorus inputs originating from on-site septic systems were assumed to be included in the groundwater flows.

Surface loading from Subcatchment C5 was calculated using stormwater phosphorus concentrations from both inlet creeks. Excluding the exceptionally low value (9 µg/L) reported from the December 9, 1993, event, the mean stormwater total phosphorus concentration was 91 µg/L. This mean concentration was multiplied by the volume of water entering the lake via surface flows in the subcatchment as determined for the water budget using the HSPF model (KCM, 1994e).

Phosphorus loading from direct precipitation was estimated by multiplying the monthly precipitation volume falling on the lake surface by a mean concentration, 33 µg/L, measured in rainfall samples collected by citizen volunteers throughout the study year. Six precipitation samples were analyzed for phosphorus. Two of the six had concentrations exceeding the normal range for precipitation in this region; these were assumed to have been contaminated and were not used in the calculation of the mean (KCM, 1994e).

Inlet flow loadings from Daniels Creek and Cottage Lake Creek were estimated by multiplying the inlet flow volume by the monthly mean phosphorus concentration. The monthly mean phosphorus concentration was calculated from samples collected during routine monitoring events. Losses of phosphorus from outlet flows were estimated using the same method (KCM, 1994e).

The monthly net gain in phosphorus from sediment phosphorus release and net loss of phosphorus to sedimentation were determined through the development of a transitional phosphorus model for Cottage Lake. The model, the Vollenweider (1975) non-steady-state model as modified by Larsen et al. (1979), calculates whole-lake total phosphorus concentrations through the development of sediment release rates and sedimentation rates, and is calibrated to simulate current lake conditions.

The change in lake phosphorus mass was calculated as the residual of the mass balance equation. A gain of phosphorus mass indicates that the weighted mean phosphorus concentration increased from that of the previous month. A decrease in lake phosphorus mass indicates that phosphorus was lost to the sediments or through the outlet (KCM, 1994e).

External loading under future maximum buildout conditions was estimated based on land use changes for each subcatchment as shown in the Bear Creek Basin Current and Future Conditions Analysis (King County, 1989). Land use within each subcatchment was categorized into forest, suburban, and impervious areas under current and future buildout conditions. Runoff coefficients from literature values for each land use type within each subcatchment were assigned, and the resulting phosphorus concentration calculated. The resulting calculations indicate an increase of 27 percent in phosphorus loading for surface water runoff in Subcatchment C5, a 34 percent increase in the Daniels Creek Subcatchment, and a 62 percent increase in the Cottage Lake Creek Subcatchment. The cumulative increase in external loading from these subcatchments to Cottage Lake is estimated to be 90 kg total phosphorus under unmitigated future conditions.

STUDY YEAR RESULTS

The Cottage Lake phosphorus budget for the study year is presented in Table 6-1 and summarized in Table 6-2. Phosphorus inputs to and outputs from Cottage Lake are presented graphically as kilograms (kg) of phosphorus (Figure 6-1) and percentage contribution for each source (Figure 6-2). Internal loading is caused by a release of phosphorus from the sediments during anoxic conditions or through decay of macrophytes; external loading originates from watershed sources or the atmosphere. Approximately 29 percent of the phosphorus in the lake was from internal sources. The remaining 71 percent was from external sources, including Daniels Creek, Cottage Lake Creek, Subcatchment C5 surface and subsurface flows, and direct precipitation (KCM, 1994e).

Table 6-1: April 1993 to March 1994 Phosphorus Balance in Grams

Month/Year	Inputs						Outputs		ΔLake Storage
	Daniel's Creek Inflow	Cottage Lake Creek Inflow	Precipitation	Subcatchment C5 Surface	Subcatchment C5 Sub-surface	Internal Loading	Sedimentation	Cottage Lake Creek Outflow	
April '93	23,580	4,321	1,628	2,090	2,373	6,841	0	-22,575	18,258
May '93	25,805	5,981	724	788	2,430	19,873	0	-19,044	36,557
June '93	32,119	6,744	1,002	1,133	2,192	39,649	0	-28,707	54,132
July '93	21,469	6,578	781	817	1,697	22,909	0	-21,586	32,665
August '93	11,514	4,042	283	284	1,344	18,183	0	-11,664	23,986
September '93	9,209	2,575	106	89	1,080	0	-5,613	-5,671	1,775
October '93	5,474	2,103	491	514	960	0	-14,333	-8,271	-13,062
November '93	5,928	1,231	706	821	826	0	-22,052	-21,336	-33,876
December '93	29,078	2,032	1,307	1,655	1,518	0	-46,044	-45,408	-55,862
January '94	8,177	1,534	337	362	1,082	0	-15,625	-15,091	-19,224
February '94	8,643	1,513	546	679	1,029	0	-12,710	-14,245	-14,545
March '94	8,148	1,743	90	118	1,142	0	-11,353	-10,790	-10,902
Total	**189,144**	**40,397**	**8,001**	**9,350**	**17,673**	**107,455**	**-127,730**	**-224,388**	**19,902**

Table 6-2: April 1993 - March 1994 Phosphorus Budget Summary

		Amount (kg)	% of Total
Inflow			
Daniel's Creek		189	51
Cottage Lake Creek		40	11
Precipitation		8	2
C5 Surface		9	2
C5 Subsurface		18	5
Internal		107	29
	Total	371	100
Outflow			
Creek		-224	64
Sedimentation		-128	36
	Total	-352	100
ΔLake Storage		19	

External Loading

The largest external source of phosphorus was Daniels Creek, which contributed 189 kg, or 51 percent of the total phosphorus loading during the study year (Table 6-2, Figures 6-1 and 6-2). Base flow and storm flow concentrations in Daniels Creek averaged 60 µg/L, ranging from 40 to 160 µg/L, throughout the year. Daniels Creek also provides the largest volume of water to the lake (70 percent). The large volume of water flowing through the creek, as well as the relatively high phosphorus concentrations, results in the large nutrient load to the lake (KCM, 1994e).

Cottage Lake Creek contributed 40 kg, or 11 percent of the total phosphorus load to Cottage Lake (Table 6-2, Figures 6-1 and 6-2). The average total phosphorus base flow and storm flow concentration in Cottage Lake Creek was 43 µg/L for the study year, with a range of 22 to 82 µg/L. Flows from Cottage Lake Creek were only one fourth those from Daniels Creek (KCM, 1994e).

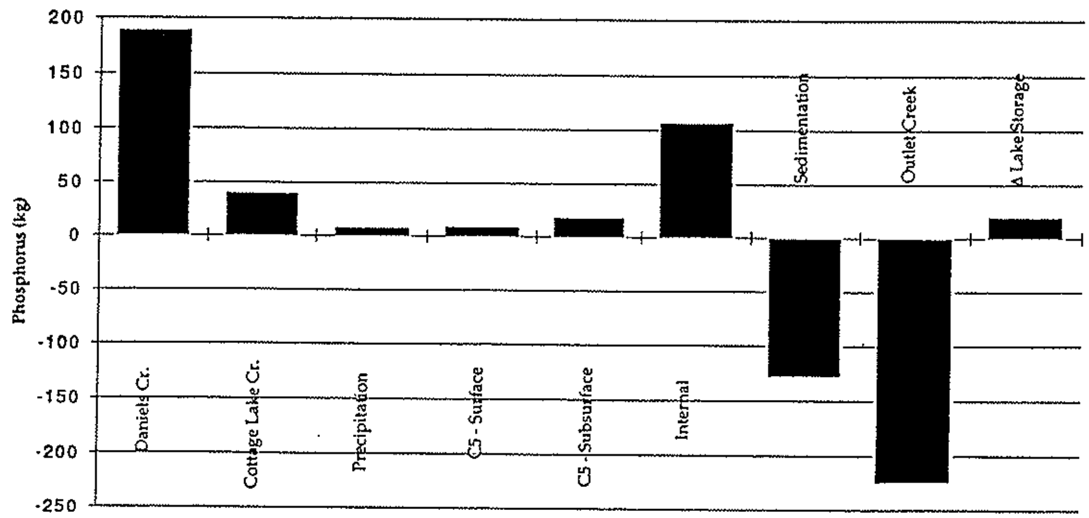

Figure 6-1
PHOSPHORUS LOADING AND LOSSES BY CATEGORY DURING THE STUDY YEAR

Eight kilograms of phosphorus were contributed from direct precipitation (Table 6-2), which is generally considered a background component of a lake nutrient budget. Air quality influences the concentration of phosphorus in precipitation. Air pollution control recommendations are usually not made in a lake watershed unless the phosphorus loading from precipitation is considered significant.

The subsurface flows constitute five percent of the total phosphorus loading during the study year. The 18 kg of phosphorus from subsurface flows (Table 6-2) excludes loading from the deep aquifer because only the shallow aquifer contributes groundwater to Cottage Lake. The average phosphorus concentration in the groundwater samples was 80 µg/L. The cause of this high level of nutrients in groundwater has not been determined (Hong West and Associates, Inc., 1994). However, land use practices in the Cottage Lake vicinity that increase nutrient loading to the shallow groundwater, and thus to the lake, should be prevented or controlled. Soils in the watershed are primarily of the Everett and Ragnar series; these soils are generally highly permeable, which may allow subsurface leaching into nearby water bodies (KCM, 1994c). Because of the hydrogeological character of the watershed, almost any land use activity involving water has the potential to affect the quality of groundwater (KCM, 1994e).

On-site wastewater disposal (septic) systems can contribute significant amounts of nutrients to the lake via subsurface flows. The potential contribution of phosphorus to Cottage Lake from on-site waste disposal systems can be calculated based on the following assumptions:

- Approximately 74 permanent residences along the shoreline, all using on-site waste disposal systems.
- Per capita loading of four grams total phosphorus per day (US EPA, 1988).
- Two persons in each residence.
- Nutrient attenuation of 90 percent for the waste disposal systems, based on review of the literature.

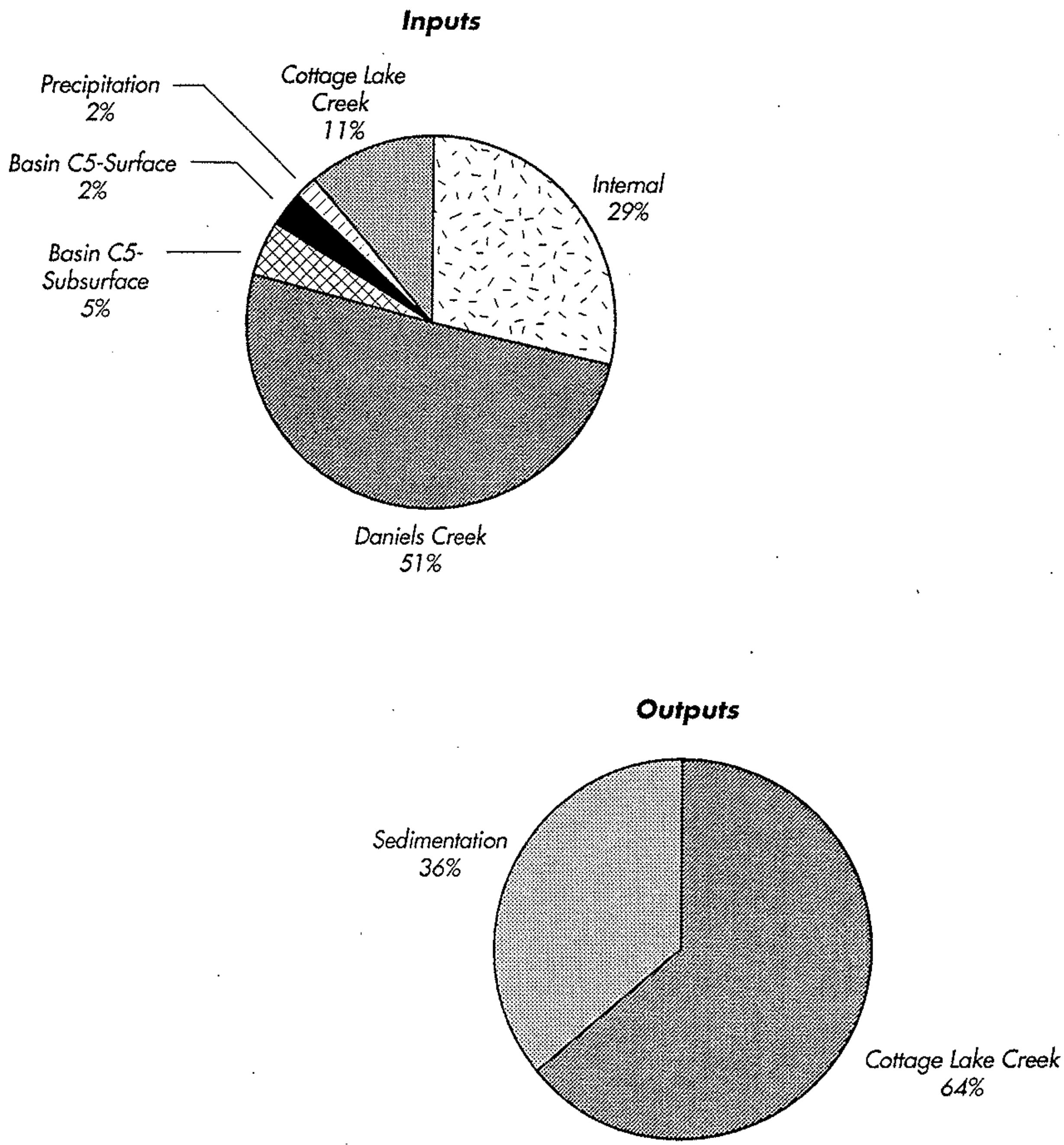

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Figure 6-2
COTTAGE LAKE TOTAL PHOSPHORUS INPUTS AND OUTPUTS

The resulting potential annual phosphorus loading from on-site waste disposal systems is 22 kg, which can easily account for the 18 kg of total phosphorus estimated by the mass balance phosphorus model to enter Cottage Lake via subsurface flows (KCM, 1994e).

Surface water flows in Subcatchment C5 contributed 3 percent of the overall nutrient load to Cottage Lake (Table 6-2). The 9 kg of total phosphorus from surface water runoff in the subcatchment is a direct reflection of residential, commercial, and agricultural land use in the area. With unmitigated growth in the area, the contribution of total phosphorus from this subcatchment will likely increase with time (KCM, 1994e).

Internal Loading

When oxygen concentrations in the lake hypolimnion (bottom waters) drop below 2 mg/L, the lake sediments are likely to become anoxic (oxygen-starved). Under anoxic conditions, phosphorus bound in the sediments as iron phosphate is released to the water column. As hypolimnetic oxygen concentrations increase above 2 mg/L, iron and phosphorus combine to form an insoluble precipitate that settles to the lake bottom. Phosphorus in the water column in phosphate form is available for phytoplankton uptake. Uptake occurs at any time of the year for blue-green algae, which can inhabit the nutrient-rich hypolimnion (during the stratified period) and migrate to the surface. Uptake occurs at fall turnover for algae that are restricted to the epilimnion during stratification.

In Cottage Lake, the hypolimnetic (depths of 4 to 7 meters) dissolved oxygen concentration decreases rapidly below the thermocline to near zero at the water-sediment interface during thermal stratification (from April through November). Dissolved oxygen concentrations were less than 2 mg/L at the water-sediment interface during the firs t sampling event for this study (April 20, 1993). That condition enhances phosphorus release from the sediments, and is reflected in the high hypolimnetic phosphorus concentrations. Internal loading of phosphorus from lake sediments totaled 107 kg from April through September, providing 29 percent of the overall total phosphorus load to Cottage Lake (Table 6-2, Figures 6-1 and 6-2).

Sediment phosphorus release was also estimated from the accumulation of hypolimnetic phosphorus by using the regression of time versus the volume-weighted total phosphorus concentration in the hypolimnion (Welch et al., 1986). Phosphorus concentrations in the hypolimnion were high at the onset of this study, with a volume-weighted concentration of 302.9 μg/L. An estimate of 40 μg/L was therefore used as the initial concentration for the regression, based on the estimate of phosphorus concentrations before thermal stratification of the lake. The regression sediment release rate was then used to calculate net internal nutrient loading to the lake. Release of phosphorus from the sediments was most intense during the 14-week period from May through mid-August, 1993. To be conservative, a 14 week period was used to calculate the net internal load. Using the regression, a total of 104 kg of phosphorus was estimated to be released from the sediment. This value agrees (within three percent) with the internal load estimated from the transitional mass balance model described above, lending confidence to the overall estimated values (KCM, 1994e).

RESTORATION ALTERNATIVES ANALYSIS

Both watershed management and in-lake restoration measures will be needed to improve existing Cottage Lake water quality and prevent additional degradation in the future. Implementation of watershed management BMPs improves water quality by reducing the quantity of pollutants entering the lake from point and nonpoint sources in the watershed. In-lake restoration techniques can reduce or control nutrients or aquatic plant growth within the lake.

Several in-lake restoration measures were evaluated in combination with an overall watershed management approach for their costs and overall impacts on lake water quality. The results of this evaluation are presented in the following sections.

Method of Analysis

The transitional phosphorus model developed for the nutrient budget was calibrated to simulate whole lake volume-weighted total phosphorus concentrations as observed during the study year. Observed whole lake phosphorus concentrations were higher on April 20, 1993, at 100.9 µg/L, than on May 4, 1993, at 73.5 µg/L due to changes in hypolimnetic total phosphorus concentrations. Predicted monthly mean phosphorus concentrations versus observed monthly mean values are shown in Figure 6-3 (KCM, 1994e).

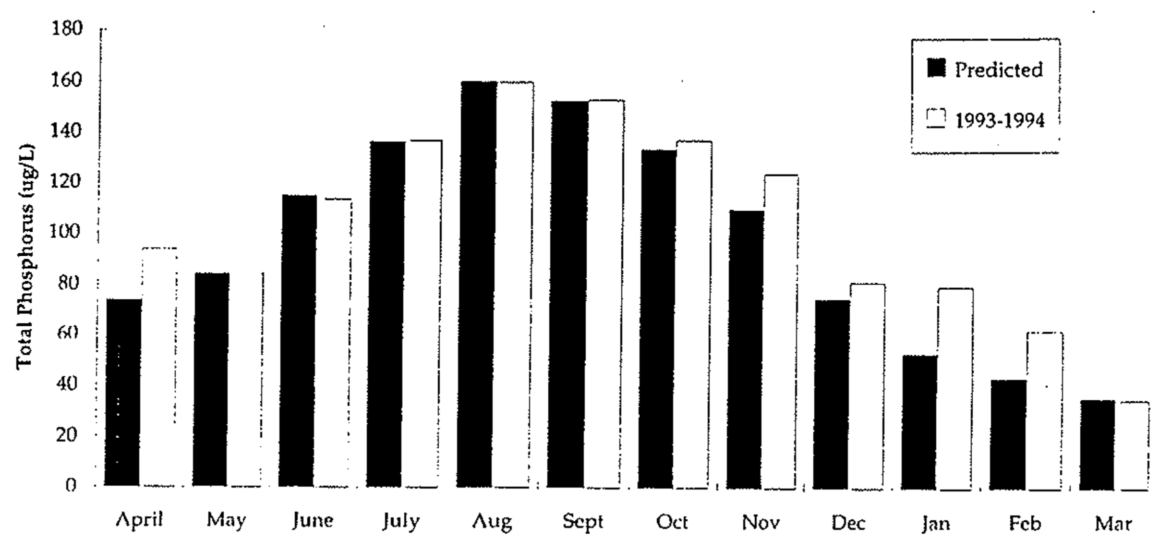

Figure 6-3
COTTAGE LAKE MODELED WHOLE-LAKE TOTAL PHOSPHORUS

Watershed Measures

The water quality of Cottage Lake is critically linked to the quality of the surface waters (e.g., Daniels Creek and Cottage Lake Creek) within its watershed. The quality of the surface waters is directly related to watershed geophysical conditions and human activities. Lake restoration, therefore, must be broad-based, and must extend throughout the watershed using watershed management BMPs. BMPs are structural and non-structural methods, including common sense "housekeeping measures," used to prevent, or reduce to levels compatible with water quality goals, the amount of pollution generated by nonpoint sources. Watershed measures can be basin-wide, or can target management of developed property. The following watershed management BMPs were analyzed for Cottage Lake:

- Application of a lake protection standard to Cottage Lake to require 50 percent total phosphorus removal from stormwater.
- Forested land cover retention.
- Restoration of lakeshore wetland habitats and riparian corridors on the Daniels and Cottage Lake Creek inlets and on the lake shoreline.
- Retention/detention ponds and biofiltration swales for stormwater treatment in Cottage Lake Park.
- Roadside ditch maintenance.
- Homeowner/business owner BMPs to enhance water quality through better landscaping methods, alternative household and gardening practices, animal-keeping practices, drainage controls, and septic system maintenance and repairs.
- Implementation of an incentive program to encourage agricultural land owners to implement farm BMPs.

Over the long term of approximately 20 years, the implementation of these best management practices in the watershed was estimated to reduce external phosphorus loading from Daniels and Cottage Lake Creeks, and surface flows from Subcatchment C5 by 50 percent from existing loadings. The initial (approximately five year) reduction in phosphorus loading was low, at an estimated five percent, due to the time required to effectively implement and maintain non-structural BMPs throughout the watershed (KCM, 1994e).

In-lake Measures

In-lake techniques that can be used to control internal phosphorus loading include sediment removal (dredging), phosphorus inactivation and precipitation (e.g., aluminum sulfate treatment), hypolimnetic aeration, dilution, hypolimnetic withdrawal, and artificial circulation. Because of the prohibitive cost, potential downstream impacts, and expected disposal difficulties, dredging is not recommended for control of phosphorus and algal blooms in Cottage Lake. Since a "clean" (low phosphorus) water source does not exist in the vicinity of Cottage Lake, dilution is not considered a viable alternative for improving water quality. Neither is hypolimnetic withdrawal a viable technique for Cottage Lake, because low quality hypolimnetic water could adversely affect water quality in the outlet, which is an important salmon spawning stream. Artificial circulation has had mixed results in controlling sediment phosphorus release, and may actually increase the potential for algal blooms (Cooke et al., 1993b); artificial circulation was therefore not considered as a technique for improving the water quality in Cottage Lake.

The in-lake restoration measures evaluated to reduce or eliminate sediment phosphorus release included a buffered alum treatment, hypolimnetic aeration, and a combination of the two. These techniques target primarily nutrients and algae. In all cases, planning and regulatory permits and water quality monitoring are required. With any in-lake restoration technique, the long-term extent of benefits will depend on management programs that continue to address watershed BMPs. Cost comparisons among the feasible in-lake restoration alternatives are difficult due to the large number of variables involved. Table 6-3 summarizes the advantages and disadvantages of each of the three alternatives. Where available, recent costs from other local projects were used to develop costs for a comparable project in Cottage Lake (KCM, 1994e).

Table 6-3: In-lake Restoration Alternatives

In-lake Measures	Advantages	Disadvantages	Estimated Cost [a]
Aluminum Sulfate Treatment	• Lowers lake phosphorus content • Inhibits release of phosphorus from sediments • Increases water column transparency	• Temporary measure (1 - 8 year effectiveness) • Potential for toxic impacts • Increase in aquatic weed growth	• $153,000 (62 tons alum, 23 tons aluminate)
Hypolimnetic Aeration	• Maintains oxygen in the hypolimnion • Limits release of phosphorus from sediments • Increases habitat and food supply	• Difficulty in supplying adequate oxygen • Potential for premature destratification and subsequent algal blooms • No impacts on aquatic weeds	• Construction: $495,600 • O&M: $26,500/year

a. Does not include associated costs such as taxes, engineering, administration, permitting, SEPA review, environmental monitoring, or construction management.

Buffered Alum Treatment

Adding aluminum sulfate (alum) reduces the phosphorus content of a lake by precipitating phosphorus and retarding its release from the sediments (Cooke et al., 1993a). When alum is added to the water column, a polymer forms that binds phosphorus and organic matter. The aluminum phosphate-hydroxide compound (commonly called alum floc) is insoluble and settles to the bottom. Dramatic increases in water clarity typically occur immediately following an alum treatment, as suspended and colloidal particles are removed from the water column by the floc. Once on the sediment surface, alum floc retards phosphate diffusion from the sediment to the water through chemical binding.

Alum has been used extensively in the United States, with general success in controlling phosphorus release from lake sediments (Cooke et al., 1993b), its effectiveness lasting up to 20 years in some lakes (Garrison and Knauer, 1984; Cooke et al., 1993b). Although most case studies of alum treatments demonstrate multiple-year success, failures also have occurred. These have been attributed to insufficient dose, lake mixing, inadequate reduction in external nutrient inputs, and a high coverage of macrophytes.

Using alum is a stop-gap measure that may control sediment phosphorus release for several years (Cooke et al., 1993a). If external sources are not controlled, the effectiveness of alum will decrease with time as the alum layer on the sediments becomes covered by nutrient-rich silt and organic material. The lake may therefore need to be treated again. The duration of effectiveness for a specific lake is difficult to predict, but effectiveness and longevity of treatment increase where external nutrient sources have been controlled. Regular long-term water quality monitoring is required in an alum-treated lake to evaluate the effectiveness of the treatment.

The alum dose should be based on the pH and alkalinity of the lake, and the potential toxicity of aluminum to the lake (Cooke et al., 1993a). Relationships to determine safe alum doses are presented in Kennedy and Cooke (1982) and Cooke et al. (1986). As alum is added to a lake, pH and alkalinity decrease and dissolved aluminum concentrations increase; alkaline lakes can tolerate higher alum doses than can softwater lakes. Adding alum to a lake with low to moderate alkalinity, such as Cottage Lake (average alkalinity = 40 mg calcium carbonate per liter), requires careful planning to ensure that pH and alkalinity are not lowered to levels that would stress aquatic biota. The use of sodium aluminate as a buffer would permit a greater alum dose to be used. Such buffering agents have been applied with alum in several northeastern United States lakes and in Green Lake in Seattle, with high success in maintaining pH and alkalinity levels (Dominie, 1978; Cobbossee Watershed District, 1988; Jacoby et al., 1994). The use of sodium carbonate in the October 1991 alum treatment of Long Lake (Kitsap County, WA) was also highly successful in maintaining safe pH and alkalinity levels, as well as in improving lake water quality (KCM, 1994e).

Alum is a promising technique for reducing algae through physical settling and removal during the application and through the long-term control of internal nutrient loading. The treatment does not kill the algae instantaneously in the water column, but settles them on the lake bottom, where they die over a period of up to two weeks. This longer time period and the location at the lake bottom greatly reduce the hazard from toxins that might be released by the dying algal cells. Alum can also provide long-term reduction in the occurrence of algal toxicity if internal phosphorus loading (often a primary cause of blue-green blooms in eutrophic lakes) is reduced. Alum has also been found to reduce the sediment-to-water migration of blue-green algae in Green Lake in Seattle (KCM, 1994e).

The use of alum salts may cause toxic conditions. Alum causes zooplankton to flocculate and settle out of the water column, along with sediment and phytoplankton, which can stress the food chain of a lake. Alum treatments have to date not resulted in adverse effects to fish (Cooke et al., 1993b), and have not damaged invertebrate populations in well-buffered lakes (Cooke et al., 1993a; Narf, 1990). Invertebrate populations may, however, be more sensitive to alum application in softwater lakes. The alum/sodium aluminate treatment of Vermont's Lake Morey, a softwater lake (alkalinity = 30 to 50 mg calcium carbonate/L) unexpectedly resulted in a short-term decrease in density and species diversity of benthic invertebrates (Smelzer, 1990). Benthic invertebrate densities were lower in Green Lake in Seattle following the 1991 alum/sodium aluminate treatment than in 1982 (Jacoby et al., 1994). While alum toxicity is a possible cause, other changes in the lake, such as degraded sediment quality due to extensive milfoil decay, may have contributed to the decline. The absence of recent pre-treatment data for Green Lake makes identification of the causative factor(s) difficult. In both Green Lake and Lake Morey, water column pH was maintained through the use of a sodium aluminate buffer, a procedure that should have prevented the formation of toxic soluble aluminum forms (e.g., $Al(OH)_3$ and Al^{+3}).

Other nutrient inactivation techniques have been used with less success than alum. Calcium hydroxide (lime) has recently been used in hardwater Alberta, Canada, lakes to control nutrient supply and algal growth (Murphy et al., 1990; Kenefick et al., 1992). However, lime would not offer the same phosphorus-binding benefit in a softwater lake such as Cottage Lake (Cooke et al., 1993b).

A whole-lake treatment of Cottage Lake is recommended because nutrient-rich sediments exist throughout the lake basin, and the entire lake is subject to mixing. Alum would primarily reduce internal phosphorus loading, which comprises approximately 29 percent of the annual phosphorus loading to Cottage Lake. Treating the lake with 8 mg Al/L would require approximately 62 tons of alum and 23 tons of sodium aluminate, representing a cost of approximately $105,400; an additional $47,500 would be required for labor and materials, mobilization, demobilization, and taxes. Total costs of an alum treatment of Cottage Lake would likely exceed $153,000. Monitoring and sample analysis costs could add additional fees to the overall project. This cost is low compared to dredging, especially if it remains effective for at least five years (KCM, 1994e).

For modeling purposes, a buffered alum treatment was estimated to reduce internal loading by 90 percent the first year, with a progressive decline in its effectiveness. The alum treatment was estimated to remain

25 percent effective at reducing internal loading through the fifth year, and become ineffective within eight years (KCM, 1994e).

Cottage Lake currently has relatively few aquatic macrophyte problems. By reducing algal populations and improving water clarity, alum could promote aquatic macrophyte growth, including the extension of littoral areas to greater depths (Cooke et al., 1993a). An increase in water clarity might allow macrophytes to colonize greater depths at higher densities.

Bench-top testing and field verification would have to be conducted as part of the preliminary design of the project in order to establish the proper alum and sodium aluminate doses for Cottage Lake. However, dosage and costs of an alum and sodium aluminate treatment in Cottage Lake can be estimated based on information from the October 1991 treatment of Green Lake in Seattle. It is appropriate to use Green Lake costs to estimate costs for Cottage Lake because they are fairly recent and because no alum/sodium aluminate treatment has been performed elsewhere in the Northwest. The Green Lake dose was 12 mg Al/L (5.25 mg Al/L from alum and 6.75 mg Al/L from sodium aluminate) (KCM, 1994e).

Hypolimnetic Aeration

Hypolimnetic aeration is a way to oxygenate the bottom waters of a lake without causing destratification. The technique typically uses air to raise cold hypolimnetic water in a tube to the surface of deep lakes, where the water is aerated through contact with the atmosphere, losing gases such as carbon dioxide and methane, and then returned to the hypolimnion (Olem and Flock, 1990). Figure 6-4 illustrates the hypolimnetic aerator that is proposed for Cottage Lake.

Phosphorus release from the sediments is limited by hypolimnetic aeration if there is sufficient iron in solution. In addition, hypolimnetic aeration increases habitat and food supply for cold-water fish species. The technique has been used with varying levels of success (Cooke et al., 1993a). Unsuccessful treatments have been attributed to inadequate oxygen supplies to the system, disruption of stratification, or lack of iron (KCM, 1994e).

Dissolved oxygen concentrations in Cottage Lake's hypolimnion are below 2 mg/L during thermal stratification. Aeration of the hypolimnion could control the release of phosphorus from anoxic sediments; it is important, however, that hypolimnetic aeration not destratify the water column. Premature destratification can be stressful and become toxic to aquatic life when bottom waters with little dissolved oxygen, low pH, and high concentrations of toxic gases mix with surface waters. Destratification can also stimulate algal growth by supplying hypolimnetic nutrients to surface waters and mixing algae throughout the water column. Cottage Lake is a relatively shallow but strongly stratified lake; as such, it is possible that destratification due to wind mixing could occur (KCM, 1994e). However, hypolimnetic aeration systems have been successfully installed in several lakes with similar geomorphology, such as Newman Lake in eastern Washington.

As indicated above, the effectiveness of hypolimnetic aeration depends on the presence of sufficient iron to bind phosphorus in the re-oxygenated waters. Moderately high iron concentrations measured in Cottage Lake (annual mean approximately 673 µg/L) indicate that available iron is sufficient to remove phosphorus from the water column at fall turnover. The mean hypolimnetic iron-to-phosphorus ratio prior to turnover was 7; following turnover, the ratios were approximately 8 throughout the water column. Ratios greater than 3 are optimal for promoting iron phosphate precipitation at turnover (Staufter, 1981). The moderate iron-to-phosphorus ratios indicate that there is sufficient iron to remove phosphorus from the water column during lake turnover.

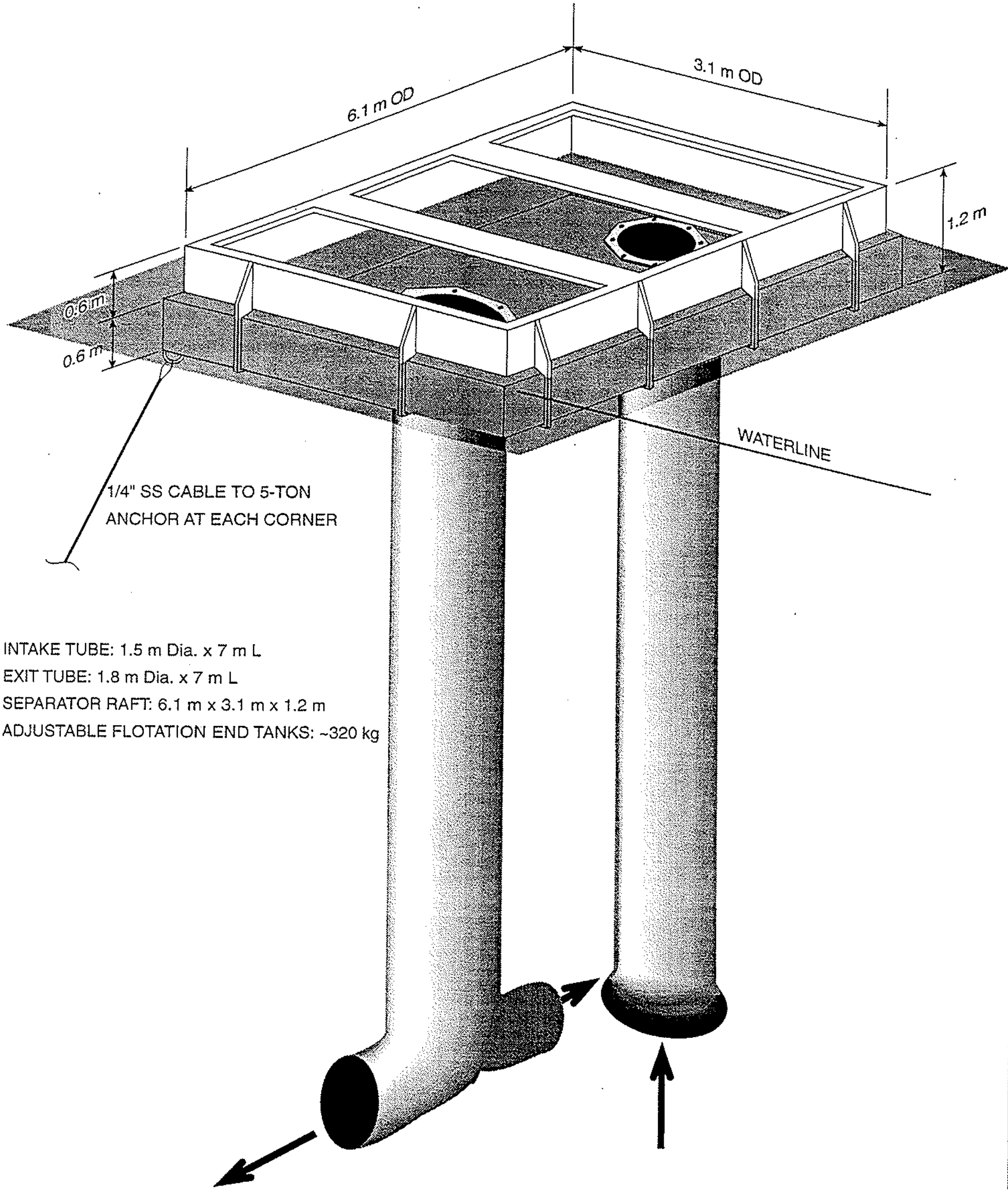

Figure 6-4
PROPOSED COTTAGE LAKE HYPOLIMNETIC AERATOR

There are two types of aeration systems designed for lake restoration: full-lift (Figure 6-5) and partial-lift (Figure 6-6) systems. A full-lift system is recommended for Cottage Lake because the hydraulic characteristics of a partial-lift system are not as favorable in shallow applications. The circulation of hypolimnetic waters using an aerator is a function of the air lift length. In a shallow system, the quantity of water that can move through the aerator is limited. Therefore, full-lift systems are more efficient in aerating shallow lakes. Based on costs developed for aerators in Lake Fenwick (Kent, WA) and Lake Stevens (Snohomish County, WA), and on an engineering analysis for Cottage Lake, the costs of hypolimnetic aeration in Cottage Lake were estimated to be approximately \$495,600 for construction and \$26,500 per year for operation and maintenance (KCM, 1994e).

Hypolimnetic aeration was estimated to reduce internal phosphorus loading by 75 percent. To model this, sediment phosphorus release within the transitional, non-steady-state, mass balance model was reduced by 75 percent (KCM, 1994e).

Results

Seven scenarios were simulated to determine whole-lake total phosphorus concentrations using the mass balance model developed for Cottage Lake. The scenarios were as follows:

- Buffered alum treatment alone
- Hypolimnetic aeration alone
- Combined alum and aeration
- Watershed BMPs
- Watershed BMPs plus alum
- Watershed BMPs plus aeration
- Watershed BMPs plus repeated alum and aeration

The summer (June to September) total phosphorus concentrations estimated from the model for the various scenarios are compared in Table 6-4. The overall benefits of each restoration measure can be assessed in terms of the overall mass of total phosphorus that is prevented from entering Cottage Lake from both external and internal sources. The implementation of BMPs in the watershed would reduce phosphorus loading by 119 kg per year over the long term. However, the whole-lake summer mean total phosphorus concentrations resulting from the implementation of watershed measures alone (approximately 128 µg/L in five years and 114 µg/L in 20 years) indicate that these measures would not be enough to prevent a future decline in water quality due to the high rate of sediment phosphorus release. Alum treatment and hypolimnetic aeration would reduce the loading to Cottage Lake by an additional 107 kg total phosphorus per year. The implementation of in-lake restoration activities in Cottage Lake to mitigate the pressures of further development within the watershed would result in mean summer whole-lake total phosphorus concentrations 40 to 50 percent lower than those measured in the study year (57 to 68 µg/L compared to 114 µg/L), depending upon whether aeration or alum were performed (KCM, 1994e).

Both in-lake restoration measures implemented simultaneously resulted in a modeled internal phosphorus load reduction of 90 percent in the first year of treatment. Using an alum treatment as an initial boost to the lake at the onset of aeration would provide an additional benefit in water quality with regard to mean summer whole-lake total phosphorus concentrations (i.e., 53 µg/L versus 66 µg/L). With the long-term implementation of watershed management measures, using a hypolimnetic aerator results in a mean summer whole-lake total phosphorus concentration of 50 µg/L (KCM, 1994e).

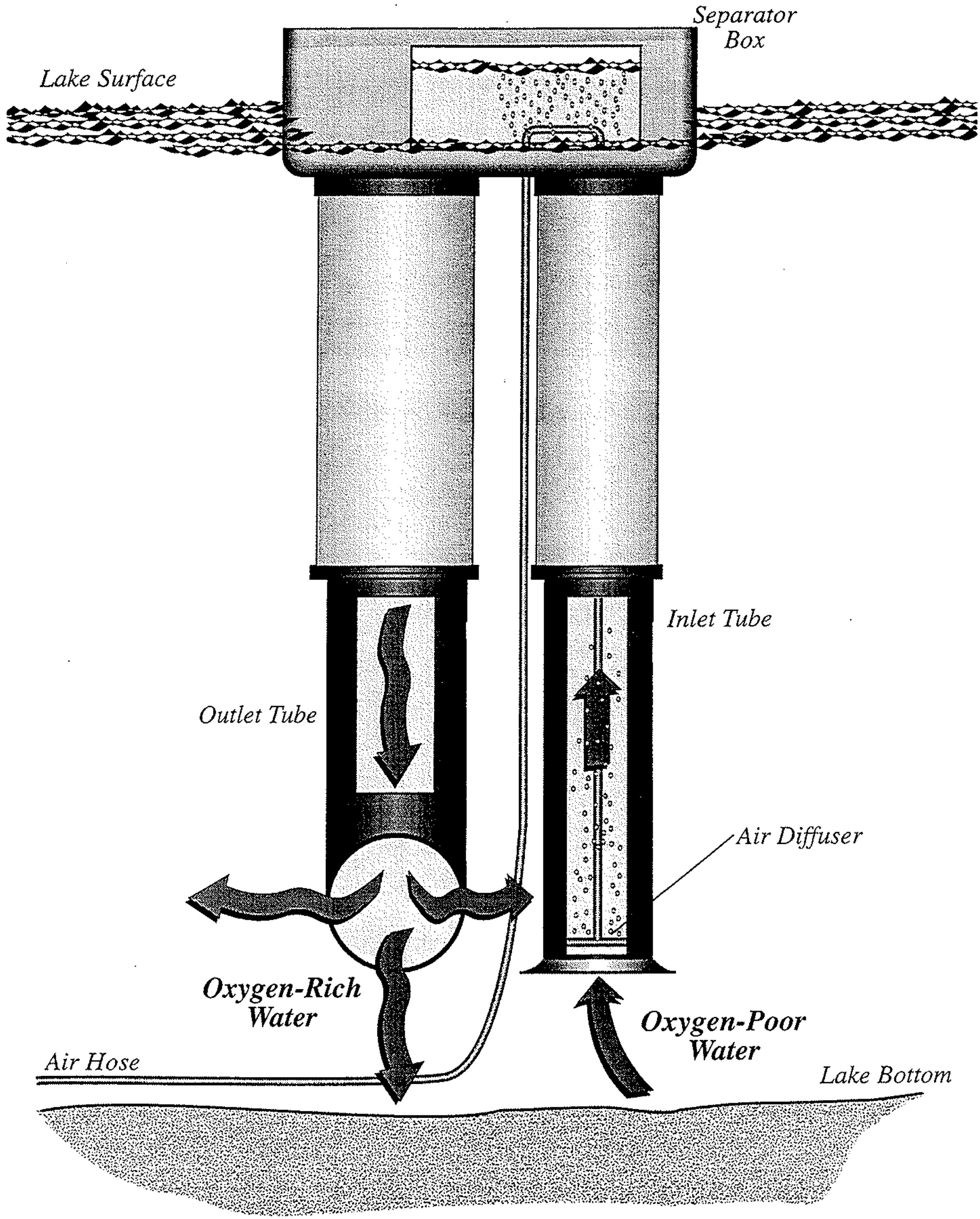

Figure 6-5
FULL-LIFT HYPOLIMNETIC AERATOR

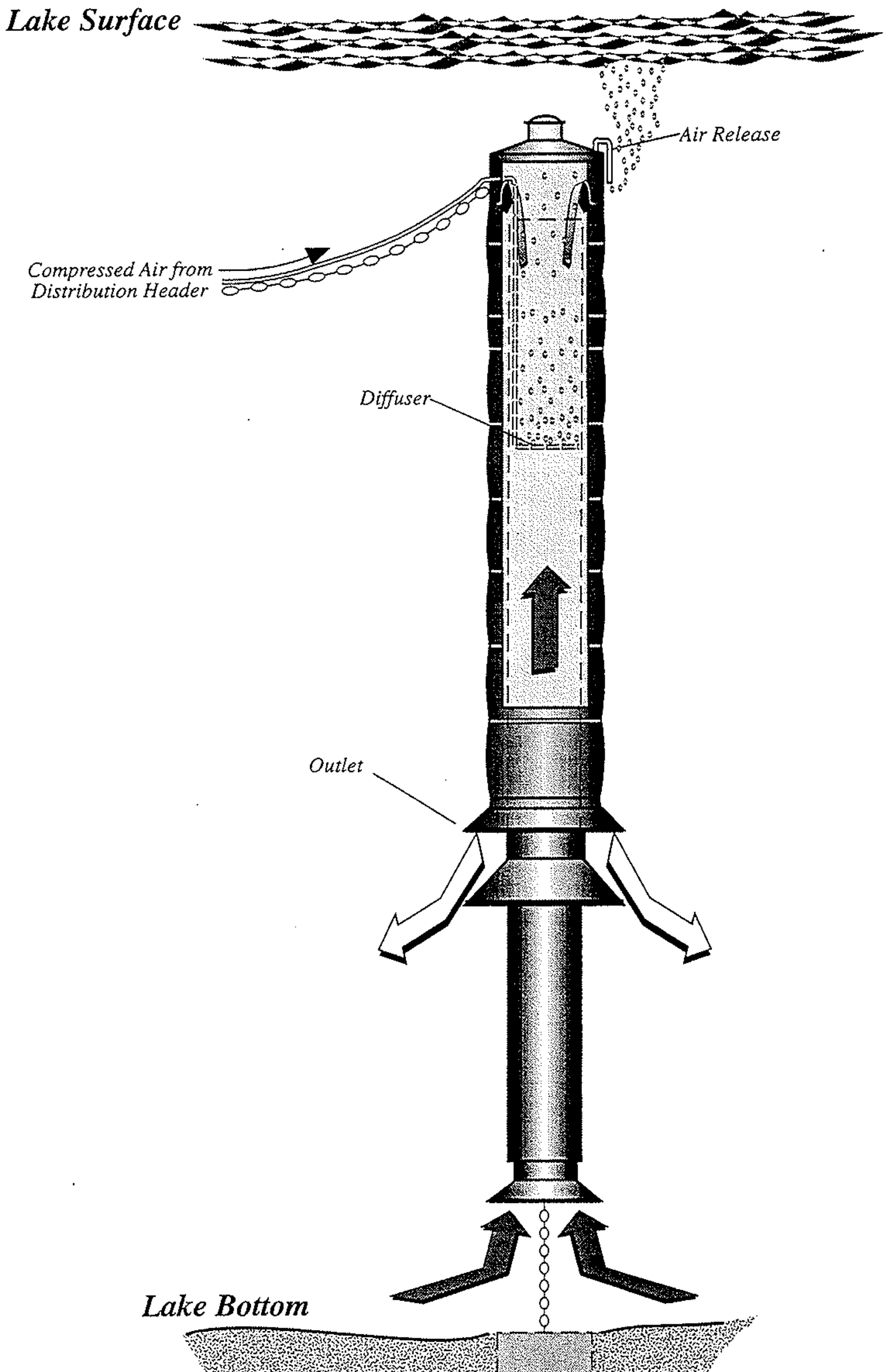

Figure 6-6
PARTIAL-LIFT HYPOLIMNETIC AERATOR

Table 6-4: Modeled Summer Whole-lake Total Phosphorus Concentrations for Cottage Lake

Scenario	Modeled Summer Whole-lake TP (µg/L)
Current Conditions	130
Watershed BMPs	
· 5 years	128
· 20 year	114
Buffered Alum Treatment	
· 1 year (*90 percent internal load reduction*)	53
· 5 years (*25 percent internal load reduction*)	109
Hypolimnetic Aeration (*75 percent internal load reduction*)	66
Watershed BMPs and Alum	
· 1 year (*90 percent internal load reduction*)	53
· 5 years (*25 to 90 percent internal load reduction, depending on age of alum treatment*)	52 - 107
· 20 years (*90 percent internal load reduction*)	37
Watershed BMPs and Aeration (*75 percent internal load reduction*)	
· 5 years	64
· 20 years	50
Watershed BMPs, Aeration and Alum	
· 1 year (*90 percent internal load reduction*)	53
· 5 years (*internal load reduction 75 percent with aeration alone, 90 percent with repeated alum treatment*)	52 - 64
· 20 years (*internal load reduction 75 percent with aeration alone, 90 percent with repeated alum treatment*)	37 - 50

Recommendation

Based on the modeling evaluation, the preferred plan for the restoration of Cottage Lake would be the implementation of all watershed BMPs, plus aeration for long-term oxygenation of the hypolimnion, and an initial alum treatment to break the internal cycling sequence. Though aeration has been successful in other shallow systems, it is a less proven technique than repeated alum treatments. However, the costs and potential environmental impacts associated with repeated alum treatments can be prohibitive over the long term. Installing a hypolimnetic aerator and implementing all the watershed management measures are recommended to maintain long-term improved water quality. An alum treatment after the startup of the aeration system would guarantee an immediate improvement in lake water quality and increase the probability that the aeration will be effective (KCM, 1994e). Engineering analysis for construction of the in-lake hypolimnetic aerator can be found in Appendix D.

Watershed management measures typically take time to implement and may not result in immediate, measurable improvements in lake water quality. However, the long-term protection of Cottage Lake depends on reducing the external nutrient sources. The duration of the benefits and overall long-term costs associated with in-lake restoration activities will ultimately be determined by how effective the watershed management measures are at reducing the overall loading to Cottage Lake (KCM, 1994e).

CHAPTER 7: LAKE AND WATERSHED MANAGEMENT

MANAGEMENT APPROACH

Cottage Lake is a nutrient-rich lake characterized by frequent and intense algal blooms in the spring and fall, which degrade the lake for a variety of recreational activities, including swimming, boating, and fishing. The aesthetic appeal normally associated with the lake also dramatically decreases during the bloom periods. Public meeting discussions and written surveys of community residents indicate that existing water quality and associated biological productivity in Cottage Lake are unacceptable to many people who live on or near or use the lake.

From "historical" water quality data, Cottage Lake has been characterized as a highly productive system since the early 1970s. Unfortunately, there is no water quality data from earlier decades. However, long-time residents of the Cottage Lake area remember much clearer water with far less algae in the 1950s and 1960s. Furthermore, examination of the sediment phosphorus profiles (Chapter 4) suggests that productivity has increased significantly since the early 1970s. Increased land development in the watershed is a likely contributing factor.

The management approach for the restoration of Cottage Lake is designed to address both watershed and in-lake sources of nutrients that contribute to the existing water quality problems. By focusing on minimizing external loading in the watershed and internal loading in the lake, the long-term management goal of improved trophic status could be achieved. This would mean improved beneficial uses of the lake.

Restoration of Cottage Lake will require a long-term commitment to reducing future watershed nutrient loading through instituting best management practices to control the source, restoring the watershed and lake shoreline wetlands, retrofitting of existing stormwater facilities for pollutant reduction, and removing and managing non-native aquatic plants. In the near term, in-lake water quality is proposed to be addressed through a combination of a buffered alum treatment and an in-lake aeration system to reduce internal nutrient cycling in the lake, which contributes to poor lake water quality. Although watershed measures are unlikely to result in an immediate improvement in lake water quality, these measures are essential to reducing future watershed nutrient loading, which would otherwise exacerbate current lake water quality conditions and reduce the effectiveness of in-lake measures under future conditions.

LAKE AND WATERSHED MANAGEMENT GOALS

Lake and watershed management goals were established by the Cottage Lake community, based on the definition of a "good lake" as one that looks good, smells good, and has good swimming and good fishing. These goals were used in the restoration alternatives analysis and in the development of the subsequent management plan recommendations. The seven management goals are as follows:

- Improve water quality and lake trophic status to less eutrophic.
- Preserve a healthy lake fishery.
- Protect human health and prevent swimmer's itch.

- Avoid adverse impacts downstream of the lake from restoration activities.
- Educate and involve watershed residents and schoolchildren in lake restoration and protection.
- Prevent and control infestations of invasive, non-native aquatic plants.
- Promote interagency coordination on lake restoration and land development projects.

Improving lake water quality is the primary management goal for Cottage Lake. This would be evidenced by decreased concentrations of chlorophyll *a* and phosphorus in the lake (although the natural tea color of the lake may prevent an increase in transparency). If lake water quality is improved, other management goals, including protection of the lake fisheries, human health, and downstream resources, will also be met. Through aeration of the lake hypolimnion and the implementation of watershed measures, internal lake phosphorus loading should be reduced, resulting in less frequent and less severe algal blooms. Improving lake water quality will also reduce water-quality-related dermatitis and the potential occurrence of toxic blue-green algal blooms, thereby improving human health protection. In-lake aeration will also benefit the lake fisheries and overall aquatic habitat by expanding the oxygenated area of the lake to include the currently anoxic lake hypolimnion.

The remaining management goals are designed to be accomplished through the remaining management plan recommendations (CL-5, CL-6, CL-7, CL-10, CL-11, and CL-12). All agencies involved in the Cottage Lake Management Plan will need to coordinate closely with each other throughout plan implementation. A cooperative working relationship among the Cottage Lake community, King County, and other implementing agencies will also be necessary to achieve these lake and watershed management goals. Without this combined long-term commitment and investment by watershed residents and local government, the goal of improving lake water quality will likely remain unmet.

RECOMMENDATIONS

The 14 recommendations for the Cottage Lake Management Plan, shown in Table 7-1, are divided into four groups: (1) watershed measures; (2) in-lake measures; (3) aquatic plant management; and (4) monitoring. Watershed recommendations address stormwater treatment, forest retention, lake and stream wetland restoration, ditch maintenance, homeowner and business BMPs, agricultural BMPs, and on-site septic system maintenance. These measures are intended to reduce existing and future external nutrient and contaminant loading to the lake.

In-lake restoration measures will reduce existing and future internal nutrient loading to the lake. Hypolimnetic aeration is a long-term remedy that would be facilitated in the short-term by a buffered alum treatment. Long-term water quality improvement made through in-lake measures will not be maintained unless watershed measures are successfully implemented as well.

Details of the watershed and in-lake measures, and the aquatic plant management and monitoring actions are described in the following sections. This chapter also includes cost estimates (based on 1995 dollars), and a brief discussion of implementation of the management plan. The State Environmental Policy Act (SEPA) checklist and documentation of non-significance (DNS) for the plan can be found in Appendix E.

Table 7-1: Lake and Watershed Recommendations

No.	Recommendations	Lead Implementor(s)	Estimated Costs
Watershed Measures			
CL-1	Stormwater Treatment	SWM/DDES/Parks	EP
CL-2	Forest Retention	SWM/DDES/Sno Cty	EP
CL-3	Wetland Restoration, Buffer Maintenance	SWM/Parks/FOCL/DDES	$4,000
CL-4	Ditch Maintenance	Roads/SWM/FOCL/WT	EP
CL-5	Homeowner/Business BMPs	FOCL/WT/CLBC/SWM/SKCDPH/Sno Cty	$3,000
CL-6	Agricultural BMPs	SWM/KCD/KCEHC/SCD	EP
CL-7	Wastewater Treatment	WWSD/SKCDPH	EP
In-Lake Measures			
CL-8	Buffered Alum Treatment	SWM/FOCL/CLBC	$153,000
CL-9	Hypolimnetic Aeration	SWM/FOCL/CLBC	
	(design and engineering)		$100,000
	(SEPA)		$ 50,000
	(construction)		$495,600
	(ongoing O/M)		$26,500/yr
Aquatic Plant Management			
CL-10	Milfoil Prevention	FOCL/WT/CLBC/SWM	EP
CL-11	Purple Loosestrife Removal	FOCL/WT/CLBC	$5,000
CL-12	Water Lily Reduction	FOCL/CLBC	$4,500
Monitoring			
CL-13	Lake, Fishery, and Watershed Monitoring	FOCL/WT/CLBC/SWM/ DMS/WSDFW	$35,000
CL-14	Wetland Monitoring	SWM	$5,000
		Total	**$855,100**
		Total with 5-year O/M	**$987,600**

Abbreviations:

SWM—King County Surface Water Management Division; DDES—King County Department of Development and Environmental Services; SCD—Snohomish Conservation District; Sno Cty—Snohomish County; Parks—King County Parks Division; Roads—King County Roads Division; FOCL—Friends of Cottage Lake; WT—Water Tenders; CLBC—Cottage Lake Beach Club; SKCDPH—Seattle King County Department of Public Health; KCD— King Conservation District; KCEHC—King County Executive Horse Council; WWSD— Woodinville Water and Sewer District; DMS—King County Department of Metropolitan Services (Metro); WSDFW—Washington State Department of Fish and Wildlife; O/M—Operation/Maintenance for aeration; EP—existing programs are expected to cover costs

Watershed Measures

CL-1 Stormwater Treatment - All new development in the Cottage Lake watershed resulting in at least 5,000 square feet of impervious surface should be required to remove 50 percent of total phosphorus from all surface water leaving the site before the surface water discharges to Cottage Lake or its tributaries. Retention/detention ponds and biofiltration swales should be installed to attenuate peak flows of stormwater runoff to Cottage Lake and its tributaries.

Watershed phosphorus loading is a major contributor to poor in-lake water quality. Land development is occurring rapidly in the Cottage Lake watershed. The *King County Surface Water Design Manual* currently requires on-site stormwater retention and detention facilities to achieve 80 percent removal of total suspended solids in surface water runoff from new, larger developments (i.e., developments that result in at least 5,000 square feet of impervious surface). This is equivalent to about 35 percent total phosphorus removal.

Several revisions have been proposed for the design manual, including a sensitive lake protection standard, which would require additional water quality protection for 5,000 square feet of new impervious surface subject to vehicle use and tributary to phosphorus-sensitive lakes. New development would be required to use stormwater treatment facilities (e.g., biofiltration swales, filter strips, sand filters, wet ponds) larger than the currently required or stormwater treatment BMPs to achieve a goal of 50 percent annual average total phosphorus removal. This is a cost-effective level of phosphorus removal based on comparison of treatment achieved and facility costs. It is recommended that Snohomish County apply the lake protection standard to the Snohomish County portion of the Cottage Lake watershed. The DOE endorses these recommendations.

The goal of 50 percent annual average total phosphorus removal can be achieved by a wetpond or combined detention/wetpond with a permanent pool volume equal to 4.5 times the volume of runoff from the mean annual storm (Vr = 4.5), which is equal to 0.46 inches at Seatac Airport. Runoff can be estimated using a runoff coefficient of 0.9 for impervious areas and 0.25 for pervious areas. Forested areas in tracts dedicated to King County need not be included in the calculation of pond sizing (i.e., zero new runoff volume assumed). If this method is used in other areas and Seatac precipitation statistics underestimate the rainfall as judged by the isopluvial distribution of the 2-year 24-hour precipitation, the mean annual rainfall should be adjusted upward.

Although current King County SWM designs are not complete for sand filtration, incorporation of sand filters into stormwater treatment facility designs (i.e., treatment trains) can be pursued through the variance process. As the King County Surface Water Design Manual is updated and additional treatment options and designs for total phosphorus removal become available, alternative treatment systems may be used providing the standard for phosphorus removal is met.

Redevelopment projects within the Cottage Lake watershed should apply the biofiltration requirement per Core Requirement #3 (biofiltration) or Special Requirement #5 (water quality controls) of the 1990 Surface Water Design (SWD) Manual until such time as the proposed update to the SWD Manual is completed. A redevelopment project is one that proposes to add, replace, or alter impervious surface for purposes other than routine maintenance, resurfacing, regrading, or repair on a site that is already substantially developed (i.e., has at least 35 percent of existing impervious surface coverage). After the 1990 SWD Manual update is complete, redevelopment projects shall comply with requirements stated therein.

Untreated surface water runoff enters Cottage Lake from impervious surfaces within Cottage Lake Park, including the parking lot. The King County Parks Division is planning biofiltration swales for the new parking lot near the swimming beach and for the main parking lot near Woodinville-Duvall Road. These biofiltration swales would help to absorb or break down petroleum hydrocarbons and metals from the parking lot, thereby reducing their discharge to the Cottage Lake Creek inlet and to Cottage Lake. SWM should coordinate with Parks in this effort by recommending appropriate plant materials for the swales.

Parks is also planning to retrofit existing storm drains at Cottage Lake Park for stormwater treatment. DDES should coordinate with Parks by reviewing plans for the new stormwater treatment facilities.

CL-2 Forest Retention - At least 65 percent of the forest cover in the Cottage Lake watershed should be retained.

Land use activities (e.g., development, clearing, additional impervious surfaces) that reduce the amount of forested land typically result in a cumulative increase in the volume of surface water runoff and in nutrient loading to nearby water bodies. Under future maximum buildout (worst case) conditions, only 9 percent of the land in the Cottage Lake watershed would remain as forest or open land (King County, 1989, 1990a). Watershed phosphorus loading to Cottage Lake would increase from 265 kg/year to 355 kg/year.

This estimated annual increase of 90 kg of phosphorus can be partially mitigated by retaining a higher percentage of land in the watershed as forest cover. The effectiveness of forest retention has been demonstrated through empirical evidence and through hydrologic analysis. If forest cover goes below 65 percent, increased runoff and soil erosion will result in further sediment deposition, water pollution, and loss of aquatic habitat in the watershed.

On October 30, 1995, the King County Council passed Ordinance 12015, which adopts a 65 percent forest retention standard for the rural zoned areas in the Bear Creek Basin. Approximately 95 percent of the Cottage Lake watershed is zoned as rural land. The ordinance states that clearing shall be limited to a maximum of 35 percent of lot or plat area or the amount cleared prior to the effective date of the ordinance (November 18, 1995), whichever is greater. Clearing shall be limited to a maximum of 60 percent of the lot or plat area if the permit applicant commits to constructing appropriate on-site retention/detention facilities for the additional 25 percent of clearing. These facilities must be in accordance with the On-Site Detention Standards set forth in the adopted Bear Creek Basin Plan (Ordinance 10513) (King County, 1990a) or standards that may be contained in an update of the King County Surface Water Design Manual.

The Daniels Creek inlet to Cottage Lake originates in the Maltby Creek sub-basin of Snohomish County, which is undergoing deforestation and development. It is recommended that Snohomish County consider similar types of forest retention requirements for the Snohomish County portion of the Cottage Lake watershed because a substantial proportion of the nutrients and fecal coliforms that enter the Daniels Creek and Cottage Lake Creek inlets originate on land in Snohomish County. The DOE supports this recommendation.

CL-3 Wetland Restoration and Buffer Maintenance - Restoration of lakeshore wetland communities should be pursued. A buffer of native vegetation should be maintained along the shoreline of Cottage Lake. Restoration of wetland communities and riparian area buffer zones on the Daniels Creek and Cottage Lake Creek inlets should be pursued.

Currently, there is an almost complete lack of wetland vegetation along most of the Cottage Lake shoreline. Where shoreline vegetation is absent, surface water runoff enters the lake directly, degrading lake water quality. Canada geese graze on the shoreline and affect lake water quality via the nutrients and fecal coliform bacteria in their wastes.

Restoration of wetland vegetation and native plantings/buffers along the lake shoreline and stream riparian corridors could serve multiple functions by improving wildlife habitat, acting as a physical barrier to intrusion by Canada geese, increasing shoreline soil stability, and providing water quality treatment via biofiltration of runoff. This would reduce current and future total phosphorus loading to the lake and reduce shoreline erosion. To provide filtering, the lake shoreline vegetation buffer should be at least 10 to 15 feet wide starting at the edge of the lake. A sample planting list for the buffer is given in Table 7-2 (Pentec Environmental, Inc., 1994).

Table 7-2: Plant Species List for Wetland Restoration Planting

Scientific Name	Common Name	Percentage of Community
Shoreline Community		
Cornus seracia	Red-osier dogwood	20
Loniceria involucrata	Twinberry	10
Rosa pisocarpa	Swamp rose	5
Rubus spectabilis	Salmonberry	20
Salix alba	White willow	15
Salix sitchensis	Sitka willow	15
Spiraea douglasii	Douglas spirea	15
Riparian Community		
Thuja plicata	Western red cedar	5
Picea sitchensis	Sitka spruce	5
Alnus rubra	red alder	15
Acer circinatum	vine maple	10
Cornus seracia	red-osier dogwood	20
Pyrus fusca	western crabapple	5
Rubus spectabilis	salmonberry	10
Salix lucida var. lasiandra	Pacific willow	15
Salix sitchensis	Sitka willow	15

Riparian area buffer zones are areas adjacent to streams, wetlands, or lakes where native vegetation is not disturbed. Healthy native vegetation along a buffer zone provides important functions: (1) stabilizing stream banks/preventing erosion; (2) moderating impacts of surface water runoff by filtering out suspended solids, nutrients, and toxic chemicals; (3) supporting and protecting fish and wildlife species and providing migratory corridors for them; (4) protecting stream habitats from adverse impacts, and (5) maintaining and enhancing habitat diversity and integrity.

The Cottage Lake Park Master Plan requires buffers of 150 feet on either side of Cottage Lake Creek in order to establish a wetland and stream corridor through the park and to rehabilitate the salmon spawning and rearing habitat of the creek. Additionally, 40 percent of the lake shoreline within the park will be planted with native vegetation. The King County Parks and SWM Divisions should coordinate with each other in determining the types of plants to be included in these buffers. Parks and SWM should coordinate with Friends of Cottage Lake and Water Tenders to recruit volunteers to assist with native plant revegetation within Cottage Lake Park. Once the buffers are planted, it is important that King County Parks maintain them as native vegetation.

In addition, wetlands and riparian areas along Daniels and Cottage Lake Creeks farther upstream from the lake (i.e., beyond the park) should also be revegetated to the extent possible using landowner incentives, including current use taxation, cost-sharing for plant materials, and donation of labor by local environmental groups.

CL-4 Ditch Maintenance - Ditch maintenance protocols for roads within the watershed will be reviewed by SWM with the King County Roads Division to identify areas where enhanced maintenance activities could increase lake water quality protection.

King County Surface Water Design Manual requirements pertain only to new developments that result in at least 5,000 square feet of impervious surface, and will therefore not mitigate the cumulative impacts of smaller developments. Water quality protection for Cottage Lake and its tributaries will consequently rely more heavily on source control strategies and BMPs, including the management of the roadside drainage system.

The King County Roads Division has drafted and is in the process of testing ditch maintenance and other roadside BMPs for countywide implementation. SWM will review the proposed ditch maintenance BMPs and coordinate with Roads to determine if there is a need for enhanced activities within the Cottage Lake watershed. Such activities may include retention of ditch vegetation, minimization of soil disturbance during ditch maintenance, maximization of open-ditch system use (versus closed, culvert systems) where beneficial, and involvement of the Friends of Cottage Lake and Water Tenders in trash removal and other appropriate citizen-based adoption and maintenance activities. These additional maintenance activities would reduce soil erosion, increase pollutant removal of stormwater runoff in vegetated ditch areas, and reduce the transport of trash to Cottage Lake.

Potential locations for enhanced ditch maintenance activities are the drainage ditch at the 185th Avenue NE crossing of Daniels Creek and the drainage ditch on Woodinville-Duvall Road in front of the Cottage Lake Mall. These ditches discharge to the Daniels Creek and Cottage Lake Creek inlets, respectively.

CL-5 Homeowner and Business BMPs - Best management practices for lake protection and restoration should be promoted to watershed residents and businesses and facilitated by the Friends of Cottage Lake, Water Tenders, the Cottage Lake Beach Club, and SWM. Schoolchildren in the watershed should be involved in hands-on water quality activities to promote a sense of lake stewardship.

Most nonpoint pollutants within the Cottage Lake watershed result from human activities. Nonpoint pollutants originating on each parcel of land within the watershed can collectively become a serious threat to the receiving water quality. Improper use of fertilizers, pesticides, and other common household chemicals, and many "housekeeping" activities are among the ways that people generate significant amounts of nonpoint pollution.

Property owners upstream of the most polluted Daniels Creek and Cottage Lake Creek stormwater sampling stations should be contacted and encouraged to participate in a survey of land use practices (e.g., lawn maintenance, septic system maintenance, animal keeping) that potentially contribute to poor water quality. Additional storm event monitoring should be conducted to further isolate pollution sources in the watershed.

Residential and business BMPs, including proper lawn fertilization and yard maintenance, proper household hazardous waste disposal, proper car washing practices, animal-keeping practices, and the use of low phosphate household and garden products, should be implemented to reduce water quality impacts from current and future phosphorus loading and from the discharge of toxic chemicals. The details for each BMP are described below and should be the focus of an educational outreach effort by FOCL, Water Tenders, the Cottage Lake Beach Club, and SWM. Snohomish County currently funds a portion of the Bear Creek Steward's activities through an interlocal agreement. Snohomish County and King County will address cost-sharing of educational materials for the Cottage Lake watershed as part of the negotiations each year of the annual work program for implementation of the Bear Creek Basin Plan.

Lawn fertilization and yard maintenance—Alternatives to standard lawn maintenance and landscaping practices should be implemented by residents and businesses. These alternatives include minimal use of fertilizers, reduction in lawn size, regular thatching and aeration if lawns are retained, incorporation of native plants in new landscaping, soil enhancement through mulching and composting rather than chemical fertilizers, integrated pest management techniques, and filling in a couple inches of compost when establishing a lawn or planting area. Residents and businesses should be encouraged to contact the Washington Toxics Coalition, the Washington State University Cooperative Extension, or Master Gardeners for information on less toxic alternatives for lawn maintenance and landscaping practices.

Household hazardous waste disposal—Information on alternatives to common household cleaning products is available from the Seattle-King County Department of Public Health, and the use of such alternatives should be pursued by residents. Household hazardous wastes should be properly disposed of at King County household hazardous waste collection sites. Residents should be encouraged to contact the Hazards Line at 296-4692 for free advice and assistance on household hazardous material alternatives and disposal.

Car washing—When cars are washed near storm drains, wash water carries oils, greases, nutrients, heavy metals, suspended solids, and soaps to local water bodies, i.e., Cottage Lake and its tributaries. Residents of the Cottage Lake watershed should be encouraged to wash their cars at commercial car wash facilities, which discharge wash water to the sanitary sewer system. People who do wash their cars at home should be informed about draining wash water to vegetated areas such as lawns, using a high pressure nozzle with trigger to minimize water usage, and using commercial products that clean vehicles without water.

Animal waste control—The feeding of waterfowl by lakeside residents and visitors to Cottage Lake Park should be discouraged. Pet and domestic animal waste should be properly disposed of away from the lake and surface water pathways that reach the lake.

Low phosphate household garden products—Voluntary use of low phosphate garden and household products such as fertilizers and detergents should be promoted by FOCL, Water Tenders, and the Cottage Lake Beach Club.

Business best management practices—Through the King County Businesses for Clean Water Program, SWM should educate business owners about best management practices, such as proper maintenance and repair of oil-water separators in order to prevent the discharge of petroleum hydrocarbons, metals, and other toxics to Daniels Creek, Cottage Lake Creek, and the lake. Businesses in the King County portion of the Cottage Lake watershed should be encouraged to participate in the Businesses for Clean Water Program, which helps businesses to implement a variety of pollution prevention practices. Businesses can call 296-1900 for a free on-site consultation. Business owners should also be encouraged to contact the Business Waste Line at 296-3976 for free advice and assistance on business hazardous material alternatives and disposal.

Schoolchildren activities—SWM should coordinate with public schools in the Cottage Lake watershed portion of the Northshore School District and with the district's Science Coordinator to give presentations to schoolchildren on lake ecology, water quality problems in Cottage Lake, and what each individual can do to make a difference. Hands-on water quality and habitat monitoring activities and storm drain stenciling activities (the message on the stencils is "dump no waste, drains to lake" or "dump no waste, drains to stream") should be planned for schoolchildren as well. These presentations and hands-on activities would especially complement the water module that is being taught to fourth graders and the environments module that is being taught to fifth graders. SWM should participate whenever possible in teacher training (in-service) activities for the water and environments modules. Results of the monitoring activities should be presented at annual watershed festivals or other annual festivals in the Cottage Lake community.

SWM's Lake Stewardship Program offers annual educational workshops. Topics addressed at past workshops have included backyard BMPs, aquatic plants, septic tank maintenance, waterfowl control, monitoring, and introduction to limnology. The FOCL should offer to host a BMP workshop in 1997; this could encourage a large turnout among residents in the Cottage Lake watershed. BMPs specific to Cottage Lake should include lawn fertilization and yard maintenance activities, proper household hazardous waste disposal, animal waste control, and the use of alternative lawn and household products.

CL-6 Agricultural BMPs and Livestock Waste Disposal - Livestock owners in the Cottage Lake watershed should be encouraged to cooperatively develop and implement farm management plans in compliance with the King County Livestock Management Ordinance. The farm management plans would contain agricultural BMPs to improve pastures, maintain healthy livestock, dispose of or recycle livestock waste, restrict livestock access to Cottage Lake tributaries, and prevent discharge of pollutants from livestock waste and farm operations into Cottage Lake tributaries.

Pollutants associated with animal-keeping and agricultural activities include sediments, nutrients, organic materials, pesticides, and pathogens (disease-causing microorganisms). Activities that generate these pollutants include overgrazing of pastures, unrestricted animal access to streams or wetlands, improper application of animal wastes to pastures, and improper storage and disposal of stable bedding and manure.

Several horse stables and small farms are located directly upstream of Cottage Lake on Daniels Creek. Site drainage for some of the stables passes through areas of horse manure. As indicated in Chapter 4, fecal coliform bacteria counts (these bacteria are not pathogenic, but their presence in large numbers indicates the potential presence of pathogens), averaged 2,700 organisms/100 ml in stormwater samples collected from the Daniels Creek sampling station in 1993-1994 (the Washington State water quality criterion is 50 organisms/100 ml). Fecal coliform counts were exceptionally high (22,000 organisms/100 ml) in a stormwater sample collected from Daniels Creek at the Woodinville-Duvall Road crossing in 1994. Total phosphorus, total nitrogen, and ammonia-nitrogen concentrations were also elevated in Daniels Creek during storm events in 1993-1994.

Each agricultural landowner in the King County portion of the Cottage Lake watershed should be encouraged to contact the King Conservation District for assistance in developing and implementing a farm management plan, which would focus on BMPs to keep livestock and livestock wastes from entering tributaries to Cottage Lake. As indicated in Chapter 4, fecal coliform bacteria densities and nutrient levels were extremely high in the stormwater samples collected at Daniels Creek stations on September 27, 1995, and on December 10, 1995. The King Conservation District should proactively contact small farm owners who are contributing nonpoint pollution to Daniels Creek and cooperatively develop and assist with funding and implementation of farm management plans in 1996. All existing livestock operations that do not develop a site-specific farm management plan by 1998 will be required by King County to follow the stricter standards set forth in the King County Livestock Management Ordinance (e.g., wider vegetated buffers between livestock grazing areas and streams, and stricter storage requirements for manure piles).

At present, an agricultural landowner who fences a stream or wetland as part of a farm management plan can receive up to $1,000 in cost-sharing from the King Conservation District. Property owners who have developed farm management plans should also be encouraged to apply to SWM for technical and financial assistance with fencing and revegetation projects through the Small Habitat Restoration Program. Projects are prioritized by SWM at the beginning of each year. For further information about SWM's Small Habitat Restoration Program or to obtain an application, agricultural landowners should call 296-8042.

SWM should coordinate with the King Conservation District and with the King County Executive Horse Council in educating agricultural landowners about the importance of implementing farm management plans. The King Conservation District will work with the Snohomish Conservation District in planning an agricultural BMP workshop targeted at livestock owners in the Cottage Lake watershed. The workshop will take place in the fall of 1996 (Lyle Stoltman, King Conservation District, Personal Communication, October, 1995).

The King County Livestock Oversight Committee (LOC) is developing recommendations for disposal of stable bedding and manure. The King County Executive Horse Council should work cooperatively with the LOC in this endeavor to facilitate educational outreach and implementation of these recommendations.

CL-7 Wastewater Treatment - Enhanced on-site septic system maintenance should be performed by shoreline and watershed residents to prevent discharge of wastewater to Cottage Lake, thereby reducing subsurface phosphorus loading to the lake and protecting human health.

Maintaining an on-site wastewater treatment system in good working order should be a prerequisite to living on Cottage Lake. Currently, on-site septic systems contribute an estimated 18 kg of phosphorus per year to Cottage Lake, approximately 6 percent of the total annual phosphorus loading. The highest housing density in the Cottage Lake watershed is along the lake shoreline. The soil types present in the shoreline area are not optimal for wastewater treatment. Systems that are currently operational may fail in the future, discharging nutrients and fecal coliform bacteria to the lake.

Although some incremental benefit to lake water quality could be achieved through sewering shoreline properties, the short-term gains of phosphorus reduction may be offset by increased shoreline and watershed land use density and by associated nonpoint pollutant loading. The cost of sewering versus the relative benefit produced in terms of improved lake water quality is high compared with the implementation of other watershed and in-lake measures. Since the closest sewer trunk line is in the City of Woodinville, several miles from the Cottage Lake area, this would further exacerbate costs. Furthermore, by opening the area for urban services, sewering may result in the loss of the rural designation for the Cottage Lake watershed. For these reasons, the implementation of sewering is not recommended at this time.

More effective on-site septic systems are recommended instead, to protect and improve water quality in Cottage Lake and to safeguard human health. Lakeside and watershed residents and business owners should be informed about septic system operation and maintenance practices, such as using no- or low-phosphate detergents, composting organic wastes rather than using garbage disposals, selecting and maintaining optimal vegetative cover over drainfields, and checking and cleaning the system on a regular basis. This can be accomplished through articles in the FOCL, Water Tenders, and Cottage Lake Beach Club newsletters, through brochures, and through workshops conducted by the Woodinville Water and Sewer District, the Seattle-King County Department of Public Health or SWM. FOCL and Cottage Lake Beach Club should pursue discounted fees from private septage companies for community-sponsored multiple site pump-out days.

Residents and businesses should inspect their septic systems annually to ensure proper system functioning. This could be accomplished by dye testing or by contacting the Seattle-King County Department of Public Health for an inspection. Systems identified as not operating properly should be repaired and upgraded professionally.

The on-site septic system assessment (see Chapter 4) conducted along the Cottage Lake shoreline identified thirteen septic systems that potentially pose problems. These systems were referred to the Seattle-King

County Department of Public Health. Any failing systems will be required to be repaired. Low income homeowners should be referred to the King County Low Income Housing Office for funding assistance.

In-lake Measures

CL-8 Alum Treatment - A whole-lake buffered alum treatment should be used to reduce the in-lake phosphorus concentration as a short-term solution to in-lake water quality problems.

Current modeled summer whole-lake total phosphorus concentrations average 130 µg/L. Modeled internal loading currently accounts for 107 kg/year, or 29 percent of the annual phosphorus load to Cottage Lake. A buffered alum treatment is predicted to reduce internal loading by 90 percent during the first year, to 10.7 kg of phosphorus. Summer whole-lake phosphorus concentrations would be substantially lower for the first few years, averaging 53 µg/L based on current modeled phosphorus loading estimates. Thus, alum treatment in the short term would result in a noticeable improvement in Cottage Lake water quality.

Typically within five to eight years, the effectiveness of an alum treatment will have declined, and repeated treatments will be needed to maintain improvements in lake water quality. Because of the short-term nature of the benefits of each alum treatment, the potential aquatic toxicity associated with alum, and the permitting issues and costs associated with repeat treatments, in-lake aeration is recommended for the long-term internal loading control.

CL-9 Hypolimnetic Aeration - Hypolimnetic aeration should be used to reduce in-lake phosphorus concentrations as a long-term solution to in-lake water quality problems.

Hypolimnetic aeration alone is predicted to reduce the internal phosphorus loading to Cottage Lake by 75 percent. Based on existing total phosphorus loading, the estimated average summer whole-lake phosphorus concentration with hypolimnetic aeration would be 66 µg/L. Hypolimnetic aeration combined with watershed controls would maintain a modeled summer whole-lake phosphorus concentration of 50 µg/L.

Alum treatment, after the startup of an in-lake aeration system as described in CL-8, would provide an immediate but short-term improvement in lake water quality. Aeration is recommended as the preferred long-term restoration measure because of its cost-effectiveness and its avoidance of the potential permitting problems associated with repeated alum applications.

Aquatic Plant Management

CL-10 Milfoil prevention - A combination of education and community monitoring should be used to prevent infestations of Eurasian watermilfoil in Cottage Lake.

To date there have been no documented infestations of Eurasian watermilfoil (*Myriophyllum spicatum*), an invasive, non-native, noxious weed, in Cottage Lake. Now that there is public access to the lake, there is the potential for milfoil to be introduced and spread throughout the lake. Prevention of milfoil infestations will be especially important if alum treatment results in increased lake clarity, which could optimize conditions for the spread of milfoil.

In 1994 SWM developed a milfoil prevention sign. It reads, "Stop Milfoil Invasions - Remove all Plant Fragments from Boats and Trailers," and shows what Eurasian watermilfoil looks like. This sign will be posted at the Cottage Lake Park boat launch in 1996.

CL-11 Purple Loosestrife Removal - The Friends of Cottage Lake should sponsor an annual purple loosestrife pull until the plant is eradicated. If biocontrols become available for use in King County for purple loosestrife control, their use should be explored for application at Cottage Lake.

Purple loosestrife is a noxious, non-native weed that invades wet pastures, wetlands, stream and river banks, lake shores, irrigation and roadside ditches, and stormwater detention/retention facilities. Purple loosestrife affects these aquatic areas by crowding out native wetland plants, including cattails, bulrushes, sedges, and hardhack. When purple loosestrife overruns an area, a monoculture of vegetation is established, and waterfowl, wildlife, amphibian, and aquatic insect diversity can be reduced. Purple loosestrife reproduces prolifically through seed production and root propagation. A few plants can spread to an entire lake shoreline within a year.

Purple loosestrife is already widespread throughout the state of Washington; full eradication is unlikely. In smaller areas, such as lake shorelines, eradication can be achieved through the diligent, annual efforts of shoreline residents. Removal methods include hand pulling of plant stems and roots, clipping flower heads prior to seeding to prevent further spread, mowing, mulching with plastic, and restoration of cleared areas with native vegetation. Biocontrols (e.g., insects) may be available for purple loosestrife control in the future, and would present an alternative to hand removal methods. Prior to any removal of purple loosestrife, the King County Department of Development and Environmental Services (DDES) Shorelines Review Section should be consulted.

CL-12 Water Lily Reduction - Where residential lake access is restricted by water lily growth, an area can be cleared by selective hand removal of the water lilies. The area cleared should be no greater than 10 feet in width. Where practical, adjacent neighbors should establish shared access for maximum retention of shoreline aquatic plants.

Some lakeside residents experience a problem of lake access where thick growths of water lilies are present. Cutting and raking plants should provide sufficient access to the lake where entry is restricted. Another option is selective use of the herbicide Rodeo, such as hand-painting Rodeo on specific leaves. A licensed herbicide applicator must obtain permits and carry out this activity.

The Crary WeedRoller, an innovative new technology for removing aquatic plants from lakes, was field-tested in Cottage Lake and other public access King County lakes in the summer of 1995. The WeedRoller was effective in decreasing water lily density and increasing lake access at the two dock areas tested in Cottage Lake. Several Cottage Lake residents or the FOCL could purchase one WeedRoller and share its use. Permits are required from the King County DDES and from WSDFW.

Whatever the method or methods used, plant removal should be minimized at Cottage Lake in order to retain the natural benefits afforded by water lilies and other aquatic plants, including shoreline stability, nutrient removal from the sediments, and aquatic habitat. Prior to any aquatic plant removal, the King County DDES Shorelines Review Section should be consulted.

Monitoring

CL-13 Lake, Fishery, and Watershed Monitoring - A long-term in-lake and watershed monitoring program should be developed by FOCL, Water Tenders, Cottage Lake Beach Club, and SWM to evaluate the effectiveness of in-lake and watershed restoration and protection measures.

The lake and watershed monitoring program should evaluate in-lake and watershed conditions and trophic status on an annual basis, and the effectiveness over time of watershed phosphorus control measures and in-lake restoration measures in improving Cottage Lake water quality. Lakeside residents, in conjunction with a local high school environmental student group or other volunteer groups, should be trained to perform as much of the lake and watershed monitoring as possible. A proposed 5-year monitoring program is summarized in Table 7-3. Community volunteers should also be trained to monitor the lake for the presence of milfoil, purple loosestrife, and algae blooms, and to track the incidence of swimmer's itch.

Table 7-3: Proposed Lake and Watershed Monitoring Program

Sampling Frequency	Stations	Parameters
In-lake		
Monthly	1 station, deep spot, 0,1,2,3,4,5,6,7 m	Temp., pH, DO, Cond., TP, SRP, TN
	1 station, deep spot	Secchi depth
	1 station, water column composite (@ 0.5m, 1.5m, 2.5m)	Chl *a*, Phaeo *a*, Phyto. species, biovolume, identification
	1 station, vertical tow	Zoo. species, enumeration, identification
6 times/year	1 station, surface only	FC, Turb., Alk., Color
Quarterly	1 station, deep spot, 0,1,2,3,4,5,6,7 m	Al, Fe
Inlets/ Outlets		
Monthly	3 stations	Temp., pH, DO, Cond., TP, SRP, TN, FC (inlets)
Sediment quality		
Every 5 years	3 depth strata (0-2m, 2-4m, >4m), 4 cores from each stratum, analyze top 0-2 and 2-10 cm increments	TP, TN, TOC, % solids, Al, Fe
Benthic Invertebrates		
Once prior to alum application, twice post-alum application	Littoral and deep stations	Density, identify to genus except for chironomid and oligochaete families
Fisheries Analysis		
Twice during monitoring period	to be determined	to be determined

Abbreviations:
Temp. = temperature, DO = dissolved oxygen, Cond. = conductivity, TP = total phosphorus, SRP = soluble reactive phosphorus, TN = total nitrogen, Chl a = chlorophyll a, Phaeo a = phaeophyton a, Phyto. = phytoplankton, Zoo. = zooplankton, FC = fecal coliform, Turb. = turbidity, Alk. = alkalinity, Al = aluminum, Fe = iron, TOC = total organic carbon.

CL-14 Wetland Monitoring - Vegetation monitoring should be performed for restored wetland areas three years after restoration to ensure successful establishment and survival of the new plants.

Restoration of the wetlands along the Daniels Creek and Cottage Lake Creek inlets and revegetation of the Cottage Lake shoreline and stream riparian areas should include monitoring of the revegetated areas for plant survival. In areas with significant plant mortality, replanting should be performed in cooperation with the wetland property owners and SWM.

MANAGEMENT PLAN IMPLEMENTATION

A combination of grant funding and local revenue from lake management district formation is proposed in order to fund the implementation of the Cottage Lake Management Plan over an initial 5-year period. Operation and maintenance costs for the lake aeration system will need to be continued indefinitely, and a mechanism for funding such activity will need to be identified. As shown in Table 7-1, the costs of implementing some of the proposed measures will be covered by existing programs.

Grants

Implementation funding for portions of the management plan could potentially be obtained from three grant sources: (1) DOE Centennial Clean Water Fund (CCWF) grants; (2) DOE Aquatic Weed Management Fund (AWMF) grants; and (3) United States Environmental Protection Agency (EPA) Clean Lakes, Section 314 or Section 319 nonpoint grant funds. Staff at DOE are available for assistance in applying for Section 319 funds. Both DOE CCWF and EPA Clean Lakes grants could be used to fund 50 percent of in-lake restoration measures, and potentially 75 percent of watershed protection and monitoring measures. EPA nonpoint grants could also be used to fund up to 75 percent of watershed protection measures. Up to 75 percent of the project costs for Cottage Lake aquatic plant management activities could be met through a DOE AWMF grant.

All grants are either statewide or regional programs, and are awarded on a competitive basis to public agencies. All three programs operate on an annual funding cycle. King County would apply for the grants and indicate in the grant applications that the Cottage Lake community supports the proposals, and would provide matching funds if the proposals are approved.

Lake Management Districts

A lake management district (LMD) is a community-defined assessment to raise revenue for lake protection or improvement activities under which owners of property on or near a lake pay a special charge on their property on either an annual or a one-time basis. LMDs can be formed for a period up to 10 years. LMDs have been operated successfully in Snohomish and Thurston counties, and one was recently formed at Beaver Lake in King County. Grant matching funds could be generated, or specific Cottage Lake Management Plan recommendations could be implemented, through LMD formation. If an LMD were formed for Cottage Lake, the LMD could be renewed to provide continued funding for operation and maintenance of the lake aeration system and/or watershed BMP implementation and monitoring.

Under Section 36.61 of the Revised Code of Washington (RCW), an LMD can be initiated through a petition to the County Council by owners of at least 15 percent of the acreage within the proposed LMD boundary, or by the Council, who can adopt a resolution of intention. The petition or resolution of intention must include the following information: (1) proposed lake protection or improvement activities, (2) total amount of money to be raised, (3) whether money will be collected annually or one time only, (4) amount of annual assessment, (5) duration of LMD, and (6) proposed LMD boundaries.

After the petition is adopted or the resolution of intention is passed, a public notice is sent and a public hearing held. This is followed by a special election in which each property owner has one vote for every dollar of proposed assessment. The proposed LMD must be approved by a simple majority of the votes cast. If there is a positive vote, the County Council adopts an ordinance to create the LMD. If there are no appeals, the King County Assessor prepares a special assessment roll listing each property and the proposed special assessment. There is then a second public hearing, at which individuals can raise objections to the amount of the special assessment. The County Council may revise the special assessment roll in response. The special assessment roll is then confirmed and billing can proceed. The money is administered by King County, but the Council can appoint a community-based advisory board to oversee the project expenditures.

Preliminary Schedule

Full implementation of the Cottage Lake Management Plan is contingent on several factors: plan finalization, the availability of grant funding, the success of grant applications, the decision to form an LMD, and the successful formation of an LMD. Listed below is a preliminary implementation schedule assuming that grant funding and LMD formation will be pursued.

• Final Management Plan	February 1996
• Apply for Centennial Clean Water Fund grant	February 1996
• Transmittal of Management Plan to Metropolitan King County Council	March 1996
• Initiate lake management district (LMD) by FOCL	November 1995
• Complete LMD formation	December 1996
• Initiate plan implementation	March 1997

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APPENDICES

A. Glossary and Conversion Units

APPENDIX A: GLOSSARY AND CONVERSION UNITS

GLOSSARY

Aerobic—Condition characterized by the presence of oxygen.

Algae—Single-celled, non-vascular plants containing chlorophyll, often forming colonies or filamentous chains. Algae form the base of the food chain in aquatic environments.

Algal bloom—Heavy growth of algae in and on a body of water as a result of high nutrient concentrations.

Alkalinity—The acid-combining capacity of a (carbonate) solution; its buffering capacity.

Allochthonous—Arising in another biotope; from outside the lake basin (Gr. *allos*: other, *chthon*: land).

Anaerobic—Absence of oxygen (Gr. *an:* without, *aer*: air).

Anoxic—Lack of oxygen.

Aphotic zone—That part of a body of water to which light does not penetrate with sufficient intensity to maintain photosynthesis (Gr. *a* [*an*]: without, *phos*: light).

Autochthonous—Arising in the biotope under consideration; from within the lake basin (Gr. *autos*: self, same, *chthon*: land).

Autotrophic—The nutrition of those plants able to construct organic matter from inorganic substances (Gr. *autos*: self, *trophein*: to nourish).

Benthic—Bottom area of the lake (Gr. *benthos*: depth).

Biochemical Oxygen Demand (BOD)—The decrease in oxygen content, in milligrams per liter of a sample of water in the dark at a certain temperature over a certain period of time, due to microbial respiration.

Biogenic—Arising as a result of life processes of organisms (Gr. *bios*: life, *genes*: born).

Biomass—The total organic matter present (Gr. *bios*: life).

Buffer—A mixture of weak acids and their salts that is able (in solution) to greatly minimize changes in the hydrogen-ion concentration.

Chlorophyll—The green pigments of plants (Gr. *chloros*: green, *phyllon*: leaf).

Colloids—substances distributed in a liquid as large aggregates of molecules; they are intermediate between true solutions and suspensions.

Colluvium-a loose deposit of rock debris accumulated at the base of a cliff or slope.

Consumers—Organisms that nourish themselves on particulate organic matter.

Core—A sample of soil or sediment taken in such a way as to keep the vertical characteristics of the sediment undisturbed.

Decomposers—Organisms, mostly bacteria or fungi, that break down complex organic material into its inorganic constituents.

Detritus—Settleable material suspended in the water: organic detritus, from the decomposition of the broken down remains of organisms; inorganic detritus, settleable mineral materials.

Dimictic lake—A lake that circulates twice a year.

Drainage basin—The area drained by, or contributing to, a stream, lake, or other water body.

Drumlin—a streamlined hill or ridge of glacial drift (Irish Gaelic *druim*: ridge, OE *ling*: small).

Ecosystem—Any complex of living organisms together with all the other biotic and abiotic (non-living) factors that affect them (Gr. *oikos*: house).

Electrolytic conductivity—The unit is the electrical conductivity, expressed in "reciprocal ohms," of a column of liquid 1 cm^2 in cross section and 1 cm high possessing a resistance of 1 ohm. In dilute solutions the conductivity is approximately proportional to the concentration.

Epilimnion—The turbulent superficial layer of a lake lying above the metalimnion (Gr. *epi*: upon, *limne*: lake).

Euphotic zone—That part of a water body where light penetration is sufficient to maintain photosynthesis (Gr. *eus*: good, *phos*: light).

Eutrophic—Waters with a good supply of nutrients and hence a rich organic production (Gr. *eus*: good, *trophein*: to nourish).

Fall turnover—A natural mixing of thermally stratified waters that commonly occurs during early autumn. The sequence of events leading to a fall turnover includes: 1) cooling of surface waters, 2) density change in surface water produces convection currents from top to bottom, and 3) circulation of the total water volume by wind action. The turnover generally results in a uniformity of the physical and chemical properties of the water.

Fecal Coliform bacteria—A group of organisms common to the intestinal tract of vertebrates.

Glacial drift—a general term for unconsolidated sediment transported by glaciers and deposited directly on land or in the sea.

Glacial till—predominately unsorted and unstratified glacial drift, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.

Hardpan—a cemented or compacted and often clay-like layer of soil that is impenetrable by roots.

Holomictic—Lakes that are completely circulated to the bottom at the time of winter cooling (Gr. *holos*: entire, *miktos*: mixed).

Humus substances—Organic substances only partially broken down, which occur in water mainly in a colloidal state (humus colloids). Humic acids are large-molecule organic acids that dissolve in water (Lat. *humus*: soil).

Hydrogen sulfide gas—A gas resulting from the reduction of sulfate containing organic matter under anaerobic conditions which is frequently found in the hypolimnion of eutrophic lakes.

Hypolimnion—The deep layer of a lake lying below the metalimnion and removed from surface influences (Gr. *hypo*: under, *limne*: lake).

Isohyetals—a series of lines representing a constant depth of total precipitation for a given return frequency (Gr. *isos*: equal, *hyetos*: rain).

Isopleth—A line for the same numerical value of a given quantity (Gr. *isos*: equal, *plethos*: quantity).

Lenitic—slowly flowing (Lat. *lenis*: mild, soft).

Limiting nutrient—The essential nutrient that is most scarce in the environment relative to the needs of the organism.

Limnology—The study of inland waters (Gr. *limne*: lake).

Littoral—The shoreward region of a body of water (Lat. *litus*: shore).

Metalimnion—The layer of water in a lake between the epilimnion and hypolimnion in which the temperature exhibits the greatest difference in a vertical direction (Gr. *meta*: beside, *limne*: lake).

Monomictic lake—A lake that circulates once a year.

Moraine—debris, as boulders or stones, deposited by a glacier (Fr.).

Morphology—Study of configuration or form (Gr. *morphe*: shape, *logos*: speech).

Nannoplankton—Those organisms suspended in open water that, because of their small size, cannot be collected by nets. They can be recovered by sedimentation or centrifugation (Gr. *nannos*: dwarf, *planktos*: wandering).

Net production—The assimilation surplus in a given period of time after subtracting the amount of dissimilation in the same time interval.

Niche—The position or role of an organism within its community and ecosystem (Lat. *nidus*: nest).

Nutrient—Any chemical element, ion, or compound required by an organism for the continuation of growth, reproduction, or other life processes.

Oligotrophic—Waters that are nutrient poor and have little organic production (Gr. *oligos*: few, *trophein*: to nourish).

Outwash—glacial drift deposited by meltwater streams beyond an active glacier.

Oxidation—A chemical process that can occur in the uptake of oxygen.

Periphyton—The biological community attached to substrate (such as rocks, sediments, aquatic plants) that is primarily composed of algae (Gr. *peri*: around, *phyein*: to grow).

pH—The negative logarithm of the hydrogen ion activity.

Phaeophytin—A pigment resulting from chlorophyll degradation found in dead algae or suspended organic matter.

Photosynthesis—Production of organic matter (carbohydrate) from inorganic carbon and water in the presence of light (Gr. *phos*: light, *syn*: together, *tithenai*: to put).

Phytoplankton—Free floating microscopic plants (algae) (Gr. *phyein*: to grow, *planktos*: wandering).

Primary production—The production of organic matter from inorganic materials within a certain period of time by autotrophic organisms with the help of radiant energy.

Producers—Organisms that are able to build up their body substance from inorganic materials.

Profundal—The deep region of a body of water below the light-controlled limit of plant growth (Lat. *profundus*: deep).

Residence time—The average length of time that water or a chemical constituent remains in a lake.

Respiration—An energy-yielding oxidation which can occur in aerobic or anaerobic conditions.

Riparian—Pertaining to the banks of lakes or streams (Lat. *ripa*: bank).

Secchi disk—A 20-cm (8-inch) diameter disk painted white and black in alternating quadrants. It is used to measure light transparency in lakes.

Sediment—Solid material deposited in the bottom of a basin.

Sorb—The process of a compound adhering to a particle.

Stability of stratification—The work that must be done to destroy or equalize the density stratification existing in a lake.

Stagnation period—The period of time in which through warming (or cooling) from above a density stratification is formed that prevents a mixing of the water mass.

Standing crop—The biomass present in a body of water at a particular time.

Suspension—Very finely divided particles of an insoluble solid material dispersed in a liquid.

Thermocline—Zone of temperature decrease (Gr. *therme*: heat, *klinein*: to lean). See metalimnion.

Trophic state—Term used to describe the productivity of the lake ecosystem and classify it as oligotrophic, mesotrophic, or eutrophic.

Watershed—See drainage basin.

Watershed management—The management of the natural resources of a drainage basin for the production and protection of water supplies and water-based resources.

Zooplankton—The animal portion of the plankton (Gr. *zoion*: animal, *planktos*: wandering).

CONVERSION OF SI OR METRIC UNITS TO ENGLISH UNITS

SI or Metric		English
1 kilometer (km)		0.62 miles
1 meter (m)		3.28 feet
1 centimeter (cm)		0.39 inches
1 millimeter (mm)		0.04 inches
1 hectare		2.477 acres
1 square meter		10.764 square feet
1 cubic meter		35.32 cubic feet
1 cubic centimeter		0.061 cubic inches
1 liter (L)		0.26 gallons
1 milliliter (Ml)		0.20 teaspoons
1 kilogram (kg)		2.205 pounds
1 gram (g)		0.035 ounces
1 milligram (mg)		0.015 grains
1 milligram/liter (mg/L)		1 part per million
1 microgram/liter (µg/L)		1 part per billion
degrees Celsius	x 9/5 + 32 =	degrees Fahrenheit

ABBREVIATIONS

Abbreviation	Definition
AWMF	Aquatic Weeds Management Fund
BMPs	Best Management Practices
CCWF	Centennial Clean Water Fund
cfs	cubic feet per second
CFU	colony forming units
CL	Cottage Lake
DMS	Department of Metropolitan Services
HSP-F	Hydrologic Simulation Program-FORTRAN
LMD	lake management district
Metro	Municipality of Metropolitan Seattle
SAO	Sensitive Areas Ordinance
SEPA	State Environmental Policy Act
SWM or KCSWM	King County Surface Water Management
TAC	Technical Advisory Committee
USDA	United States Department of Agriculture
USEPA or EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WAC	Washington Administrative Code
WSDFW	Washington State Department of Fish and Wildlife
WSDOE or DOE	Washington State Department of Ecology

B. Public Access

COTTAGE LAKE PUBLIC ACCESS INVENTORY

NOVEMBER, 1995

The primary beneficial uses of Cottage Lake include fishing, swimming, fishing, boating, aquatic habitat, and aesthetics. Public access to these lake uses is provided via Cottage Lake Park, a 20 acre King County park located on the northern shoreline of the lake (Figure B-1). The park is divided into two approximately equal sections by the Cottage Lake Creek inlet (tributary 0127), which enters the park via culvert under Woodinville-Duvall Road and flows into the north shore of Cottage Lake. There are two park entrances off Woodinville-Duvall Road, approximately 1/2 mile west of the intersection of Woodinville-Duvall Road and Avondale Road.

The site, a private park previously known as Norm's Resort, was transferred to King County in May, 1992. The Cottage Lake Park Master Plan (Figure 2-3), adopted on September 12, 1994, attempts to balance recreational activities in the park with the need to protect water quality in Cottage Lake Creek and associated wetlands. The Master Plan requires buffers of 150 feet on both sides of Cottage Lake Creek in order to re-establish a functional wetland and stream corridor through the park and rehabilitate salmonid spawning habitat in the creek. Approximately 300 lineal feet, representing 40 percent of the lake shoreline at the park site, will also be plantedwith native vegetation in order to restore a portion of the lacustrine wetland and to provide a buffer at the mouth of Cottage Lake Creek.

The western half of the lake frontage will be developed as a swimming and sunning beach. To the west of the swimming beach area are a small boat dock/fishing pier and a car-top boat launching area. A larger fishing pier is planned and the boat launching area will be moved closer to the lake. Other currently existing park amenities include open play meadows, a children's playground, a basketball court, a swimming pool, picnic shelters, and parking lots.

A public access inventory by element per the Washington State Department of Ecology's Centennial Clean Water Fund public access requirements is included below. All information given is for Cottage Lake Park. For further details on the park, see David Evans and Associates, Inc., 1994.

1) Park Identification Signs:

- Cottage Lake Park is signed at the main entrance at 18831 NE Woodinville-Duvall Road.

- Interpretive signs near the Cottage Lake shoreline within the park explain water quality in Cottage Lake and why people should not feed ducks or geese.

2) Boat Launch:

- A pile-supported boat dock/fishing pier is located to the west of the planned swimming beach area and extends into Cottage Lake. A larger boat dock/fishing pier is planned.

- There is a car-top boat launching area approximately 60 to 70 feet from the lake shoreline. The boat launch is intended for small, nonmotorized boats, canoes, and kayaks and can also accommodate off-loading of boats from trailers. The boat launch will be moved closer to the shoreline.

3) Parking Area:

- There are two handicapped parking spaces at the boat dock/launch area. There is also space for people to unload their boats.
- There are 90 parking spaces in the main parking lot, which is located in the northwest corner of the park and accesses Woodinville-Duvall Road. Seven parking spaces are located in front of the park office building and 10 spaces are located near the park entrance.
- There are 42 parking spaces in a parking lot on the east side of the park.

4) Garbage Receptacles:

- There are 25 garbage receptacles in the park. Locations include the boat dock/fishing pier, picnic shelters, and open meadows.

5) Picnic Area:

- The boat dock/fishing pier has a picnic table. There are 40 other picnic tables located throughout the park.
- There are 4 picnic shelters in the park.

6) Sani-Kans or Portable Toilets:

- Sani-Kans are installed near the main parking lot.

7) Play Area:

- Open play meadows are provided for picnicking, informal lawn games, and general play on both the west and east sides of Cottage Lake Creek.
- There is one basketball court in the park.
- A wheelchair-accessible children's play area is centrally located in the park.

8) Swimming Area:

- The western half of the lake frontage will be developed as a swimming and sunning beach. This area will include benches, tables, and an outdoor shower for washing off after a swim.
- A swimming pool opened in the west end of the park in summer, 1995 and was heavily used throughout the summer.

9) Fire Pits:

- There are eight barbecue pits in the park: four outside and four inside the picnic shelters.

10) Permanent Restroom Facilities:

- Two restroom facilities will be provided in the park.

11) Potable Water Supply:

- There is currently one drinking fountain in the park.
- There is a hose bib at the main park entrance.

12) Fishing Pier/Floats:

- As indicated in the response to item #2, there is a pile-supported boat dock/fishing pier that extends into the lake. The pier is used from April through October and is a good viewing point for the rest of the lake.

  The pier will be enlarged. Approximately 75 percent of park usage is by people who are fishing (Kathleen Rismoen, Cottage Lake Park Manager, Personal Communication, November 29, 1995).

13) Nature Trails:

- Boardwalks and bridges will traverse the wetland and stream corridor in the park for public viewing of the wetland/stream habitat without disturbance to the habitat.
- The Cottage Lake Park Master Plan provides for a vegetative and berm buffer along Woodinville-Duvall Road. A bike path within the buffer will eventually be linked with a bike path along Woodinville-Duvall Road. The bike path is aligned in such a way that it will not interfere with the wetland and stream buffer.
- The open meadows and picnic shelters are accessed by perimeter pathways for pedestrians and wheelchairs.

Per DOE requirements, Phase II projects which total less than $400,000 must provide items 1 through 6 as the minimum requirement for public access. For projects between $400,000 and $800,000, items 1-9 must be provided. For projects greater than $800,000, public access elements 1-13 must be present.

At present, items 1-9, and 11-13 are met. It is anticipated that item 10 will be met by the end of 1996.

C. Sampling Locations Descriptions

APPENDIX C: SAMPLING LOCATIONS DESCRIPTIONS

1993-1994 SAMPLING LOCATIONS

Station	Description	Depth (meters)
COTTAGE1	In-lake sampling station, located at maximum lake depth in center of lake	0,1,2,3,4,5,6 & 7
COTTAGE2	In-lake sampling station for fecal coliform bacteria only, located off fishing dock in Cottage Lake Park	0 (surface water)
CLIN1	Tributary 0122 at inlet to Cottage Lake	0
CLIN2	Tributary 0127 at inlet to Cottage Lake	0
CLOUT	Cottage Lake outlet, at Leno Bassett's property, 16916 185th Avenue NE	0

1995 STORMWATER SAMPLING LOCATIONS

Station	Description
Daniels Creek	
D1 (=CLIN1)	Mouth of creek on west side of culvert at 185th NE
D2	Blueberry field at gage (south of 182nd NE)
D3	North of Woodinville-Duvall (W-D) Road above ditch
D4	West edge of 178th NE and W-D Road in ditch to creek
D5	West edge of 178th NE and W-D Road in creek
D6	West tributary to creek on east side of 176th NE
D7	North side of bridge at 176th NE and NE 190th
D8	North side of bridge at 176th NE and NE 192nd
D9	Southeast corner of 176th NE and NE 195th
D10	North side of 176th NE and NE 195th
D11	West tributary to creek on south side of NE 195th
D12	West side of 176th NE between NE 190th and NE 192nd
TX	Unknown tributary on south side of W-D Road (approximately 180th NE)
Cottage Lake Creek	
C1 (=CLIN2)	Mouth of creek in Cottage Lake Park
C2	North side of W-D Road before ditch enters creek
C3	Southwest corner Safeway/W-D Road pond
C4	Northeast corner Safeway/W-D Road pond
C5	North side of 190th NE and NE 195th

D. Engineering Analysis

Cottage Lake Hypolimnetic Aerator Engineering Analysis
King County Surface Water Management Division

INTRODUCTION

The preliminary draft Cottage Lake Management Plan was issued for review by King County SWM in March 1995. The management plan evaluated the Cottage Lake watershed and presented several recommendations for enhancing water quality in the watershed. The preferred long term in-lake activity recommended in the management plan was hypolimnetic aeration. Aeration was recommended for the following reasons:

- It is cost effective for reducing the internal loading of phosphorus.
- It is beneficial to aquatic habitat.
- Minimal permitting problems are associated with implementation compared with other in-lake measures.
- In combination with watershed controls, lake trophic status goals can be met.

This engineering analysis will develop design criteria, analyze alternatives, size facilities, and estimate costs for the recommended alternative.

DESIGN CRITERIA

Physical Characteristics

The design criteria for a hypolimnetic aeration system must consider physical lake characteristics of Cottage Lake and oxygen depletion rates. Relevant physical characteristics are shown in Table 1. The bathymetric contours are shown in Figure 1.

TABLE 1
COTTAGE LAKE PHYSICAL CHARACTERISTICS

Lake volume	1,200, 000 m^3
Hypolimnetic volume	487,400 m^3
Surface area	25 hectares
Mean depth	4.6 m
Maximum depth	7.6 m
Thermocline depth	2-4 m
Watershed area	1,770 hectares

As shown in Figure 1, the lake bottom has a maximum depth of 7.6 meters. The mean depth is 4.6 meters. The hypolimnetic volume of the lake (i.e., the area below 3 meters depth) is 487,400 m^3.

Oxygen Depletion Rate

Figures 2 and 3 show the temperature and dissolved oxygen profiles for Cottage Lake from data collected in 1993 and 1994. These data indicate that the dissolved oxygen levels dropped to less than 2 milligrams per liter (mg/L) from May through November 1993. This oxygen level is too low to support most animal life. The hypolimnetic aeration system is designed to provide enough oxygen to the lake to keep oxygen levels above 2 mg/L. Higher oxygen levels will minimize the internal cycling of phosphorus. The hypolimnetic volume estimate, 487,400 m^3, was based on temperature and oxygen data. The estimate of the maximum oxygen depletion rate was based on the oxygen data. During the period of peak oxygen demand the oxygen level dropped 6.0 mg/L in 14 days. This corresponds to an oxygen depletion rate of 0.43 mg O_2 per day per liter. Taken over the entire hypolimnetic volume this results in an oxygen demand of 210 kilograms O_2 per day. Due to the limited data on which this estimate is based, it is prudent to add a safety factor when sizing the aerator. The aerators will be sized to provide a total of 400 kilograms O_2 per day.

ALTERNATIVES ANALYSIS

There are two general types of hypolimnetic aerators, a full lift aerator and a partial lift aerator. In a full lift aerator (Figure 4) air is injected into the riser tube which lifts the water to the lake surface and oxygenates it before the water is degassed and returned to the hypolimnion. A partial lift aerator (Figure 5) operates much like the full lift aerator except that the water is degassed in a chamber beneath the water surface before it returns to the hypolimnion. The relative shallow depth and the design constraints, in terms of vertical depth required, favors the full lift system over the partial lift system.

The potential concerns regarding the shallow depth include:

- Increased hypolimnetic turbidity due to disruption of the bottom sediments
- Hypolimnetic warming resulting in destratification
- Increase in the hypolimnetic volume which can lead to destratification
- Increased water movement caused by the aerator which may lead to destratification.

Several elements can be incorporated into the design to prevent these effects from occurring. The elements include positioning the aerators at the deepest portion of each basin; splitting and directing the outlet flow parallel to the lake bottom; and installing insulating foam on the inlet and outlet tubes to minimize heat transfer to the hypolimnion, to use a conservatively large volume for the hypolimnion volume in sizing calculations and to incorporate turn down capability in the air supply system.

Aeration System Sizing

The basis for design of a full lift aerator is taken from from a paper by Ken Ashley titled *Oxygen Transfer in Full Lift Hypolimnetic Aeration Systems (1990)*. The paper describes the design of a full lift aeration system for St. Mary Lake in British Columbia, Canada. The air flow requirements for St. Mary Lake were calculated to be 200 standard cubic feet per minute (scfm). Results from the Ashley paper indicated that oxygen transfer rates achieved at St. Mary Lake ranged from 23 to 30 percent and averaged 27 percent using fine bubble diffusers with a pore size of 140 microns. The oxygen transfer rate assumed for the Cottage Lake aerator will be 20 percent because the shallow depth of the air diffuser placement will reduce the oxygen transfer efficiency.

Air Flow Calculation

The following calculations determine the required air flow to transfer 100 kilograms (kg) of oxygen per day to the lake:

Total oxygen required	400 kg O_2/20 % = 2,000 kg O_2/day
Oxygen content of air	0.189 kg O_2/kg air
Weight of air required	[2,000 kg O_2/day] / [0.189 kg O_2/kg air] = 10,582 kg air/day
Volume of air required	[10,582kg air/day] / [0.0367 kg air/cf] = 288,340 cf/day
Air flow rate	[288,340 cf/day] / [1,440 min/day] = 200 cfm

The total air flow rate required is 200 cubic feet per minute (cfm), or 101.6 liters per second (L/s). This is the same air flow rate used at St. Mary Lake. Although St. Mary Lake is much larger and deeper, Cottage Lake has a much higher estimated oxygen depletion rate.

Water Flow Rate Calculation

The water flow rate can be determined by using an empirical equation developed in a paper by Taggart and McQueen, *A Model for Design of Hypolimnetic Aerators* (1982). The equation is based on the air flow rate, height of water in the riser tube, and riser diameter. The equation is as follows:

$$Ql = 5.14(L)^{0.698}(Qg)^{0.459}(5.75)^{D/2}$$

where Ql is the water flow in liters per second (L/s), L is the height of the riser tube in meters (m), Qg is the air flow rate (L/s) and D is the diameter (m). The aeration system at St Mary Lake consisted of two full lift aeration units. The height of the riser tube is assumed to be 7 meters in Cottage Lake. The total air flow rate, Qg, is 101.6 L/s. The riser tube diameter will be assumed to be 1.5 meters, the same at St. Mary Lake.

The calculated water flow rate for Cottage Lake is 450 L/s per unit for a total of 900 L/s (77,800 m^3/day). The hypolimnetic volume of the lake (487,400 cubic meters) will be turned over approximately every six days. Typically hypolimnetic aeration systems are designed to exchange the hypolimnetic volume every 12 to 14 days. The high oxygen depletion rate increases the requirement to aerate greater volumes of water.

The equation predicts a water velocity of 0.8 feet per second (fps) in the 1.5-meter diameter riser tube. This corresponds to flow velocities observed at St. Mary Lake. The observed water-to-air flow ratio for St. Mary Lake was 15:1. Although the equation predicts a water-to-air flow ratio of 9:1 for Cottage Lake, the potential exists for the water flow to be greater than the predictions. While a higher water flow would improve transfer of oxygen to the hypolimnion, it could cause destratification. Therefore, we recommend that the aeration system have the capability to turn down air flows, especially during the spring when thermal stratification is not as well developed.

Oxygen Delivery

The amount of oxygen that can be delivered at lower flows can be improved by utilizing a pure oxygen supply to supplement the air stream to the hypolimnetic aerator. Pure oxygen (90 percent) can be generated through a process called pressure swing adsorption (PSA). PSA systems are being used at Newman Lake in eastern Washington to provide aeration and at Lake Fenwick in Kent to supplement aeration capacity. The predesign air flow rate of 200 scfm per aerator is equivalent to 880 pounds of oxygen per day with the normal ambient 20 percent oxygen content in air. The air flow rates could be reduced when using pure oxygen to address the problem of adding too much mixing energy to the hypolimnion. The gas flow rate can be reduced to 137.7 scfm (16.7 scfm 90 percent oxygen and 121 scfm air) to deliver the equivalent amount of oxygen as the predesign system using 200 scfm of air. This method represents a 31 percent reduction in the air flow.

In addition to being able to deliver the same amount of oxygen at a lower flow rate, the PSA systems would deliver gas with a higher concentration of oxygen. When mixing high purity oxygen and air, the resulting gas has a higher percentage of oxygen which enhances oxygen transfer. Assuming a mixture of 16.7 scfm 90 percent oxygen and 121 scfm air the resulting gas would have an oxygen content of 25 percent rather than the atmospheric concentration of 20 percent.

Henry's Law states that the saturation pressure of a gas in solution, in this case oxygen, is equal to the partial pressure times the coefficient of absorption (a constant at given pressure and temperature). The partial pressure of oxygen in the air flow is directly proportional to the percentage of oxygen in the air/oxygen mixture. In the example sited above where the oxygen concentration is increased from 20 to 25 percent, the partial pressure of oxygen increases by 32 percent. The saturation concentration (Cs) of oxygen in solution at typical hypolimnetic conditions (5 degrees C) is 12.8 mg/L. At 25 percent oxygen the Cs is raised to 15.6 mg/L. The driving force for oxygen transfer is equal to the difference between the Cs and the concentration in the hypolimnion.

Water flow through the aerator is proportional to the gas flow through inlet tube. At reduced gas flow rates, the water flow through the aerator will decrease. In the example with 137.7 scfm, the water flow through the aerator would be reduced to approximately two-thirds of the water flow rate when 200 scfm of air is delivered. However the driving oxygen gradient has been increased by 50 percent. The net increase in oxygen transfer to the hypolimnion is 2 percent at the reduced flow rate based on two-thirds of the water flow times 150 percent increased oxygen transfer. The mixture oxygen and air system will transfer the same amount of oxygen at a lower air and water flow rate.

Compressor Requirements

Typically, aeration systems include two air compressors, each capable of supplying the total air flow required. The Cottage Lake system would require two 40 horsepower (hp) compressors, one for the aerators and one standby compressor. The standby compressor would act as backup or would be used to augment the air flow during periods of high hypolimnetic oxygen demand. If installed, the PSA system would require a compressor that operated continuously in addition to the compressors that provide air flow to the hypolimnetic aerator; therefore, the energy use with the PSA system would be higher. A single PSA system could supply oxygen to both aerators. The air system piping can be arranged so that if the hypolimnetic aerator compressor fails the PSA compressor can be used, without producing pure oxygen, to operate the aerator. As the backup compressor could power the PSA system as well, a total of two compressors would be required for the proposed Cottage Lake system.

Preliminary Design

Figure 6 shows the proposed full lift aerators for Cottage Lake. The aerator box and riser tubes will be constructed of fiberglass reinforced plastic (FRP). The top of the aerator box will be covered with aluminum grating. The in-lake portion of the air supply pipeline will be 6-inch diameter high density polyethylene (HDPE). The piping will switch to schedule 40 aluminum in the aerator. The aluminum air piping will be fitted with a circular air header that will hold the porous diffusers. The air header and diffuser assembly will be constructed so that the entire piece can be removed from the surface of the aerator box. The aerator box will be approximately 20 feet by 10 feet; approximately 3 feet will show above the water surface.

If the mixing energy produced by adding 100 scfm to each aerator is too great, the lake system may become destratified. A way of reducing mixing energy is to reduce the water flow through the aerator by reducing air flow. The problem with this approach is that the reduced air and water flow may not provide sufficient oxygen to the lake to prevent anaerobic conditions in the hypolimnion.

Costs

The cost of installing a PSA oxygen generation system (Table 2) represents a significant investment in terms of the overall project cost.

The additional annual O&M costs associated with operating the oxygen system compressor on a continuous basis is approximately $9,000 per year assuming the oxygen system compressor operates continuously for 4 months. Maintenance costs of the oxygen generation equipment includes changing the oil and filters in the system and maintaining coolant levels in the air dryer. The total O&M cost for the complete aeration system is $26,500.

TABLE 2
PRESSURE SWING ADSORPTION SYSTEM COSTS
AIRSEP MODEL AS-1000

Item	Description	Cost
AS-160 Oxygen Generator	16.7 scfm PSA oxygen generator	$24,000
Air Receiver	600 gallon	1,800
Refrigerated Air Dryer	200 scfm @ 50 F	4,400
Oxygen Surge Tank	120 gallon	800
Oil Filters	Coalescing oil removal	750
Mercoid Switch	Float switch for auto shut down	330
Auto Drains		5,200
Additional Piping		3,000
Subtotal		$40,280
Installation	60% of Material Cost	24,170
Total		**$64,450**

The construction budget is shown in Table 3. The construction cost estimate does not include engineering, administrative, legal or land acquisition costs. The cost estimate was based on the following assumptions:

- A building site can be found within 500 feet of the lake shore.
- The building is constructed of concrete and is partially buried.
- No easements are required for the pipeline right-of-way.
- Three-phase electrical power is located with 100 feet of the building site.
- There are no special drainage, soils conditions or landscaping requirements.

Engineering design and construction services for this project are estimated to be $145,000. The engineering design fees are based on the aeration system recommended by this report. Construction services include bid proposal evaluation and recommendations, attendance at weekly construction meetings, submittal reviews, and pay estimate review.

KCM recommends that the County include a PSA system in the project design for the following reasons:

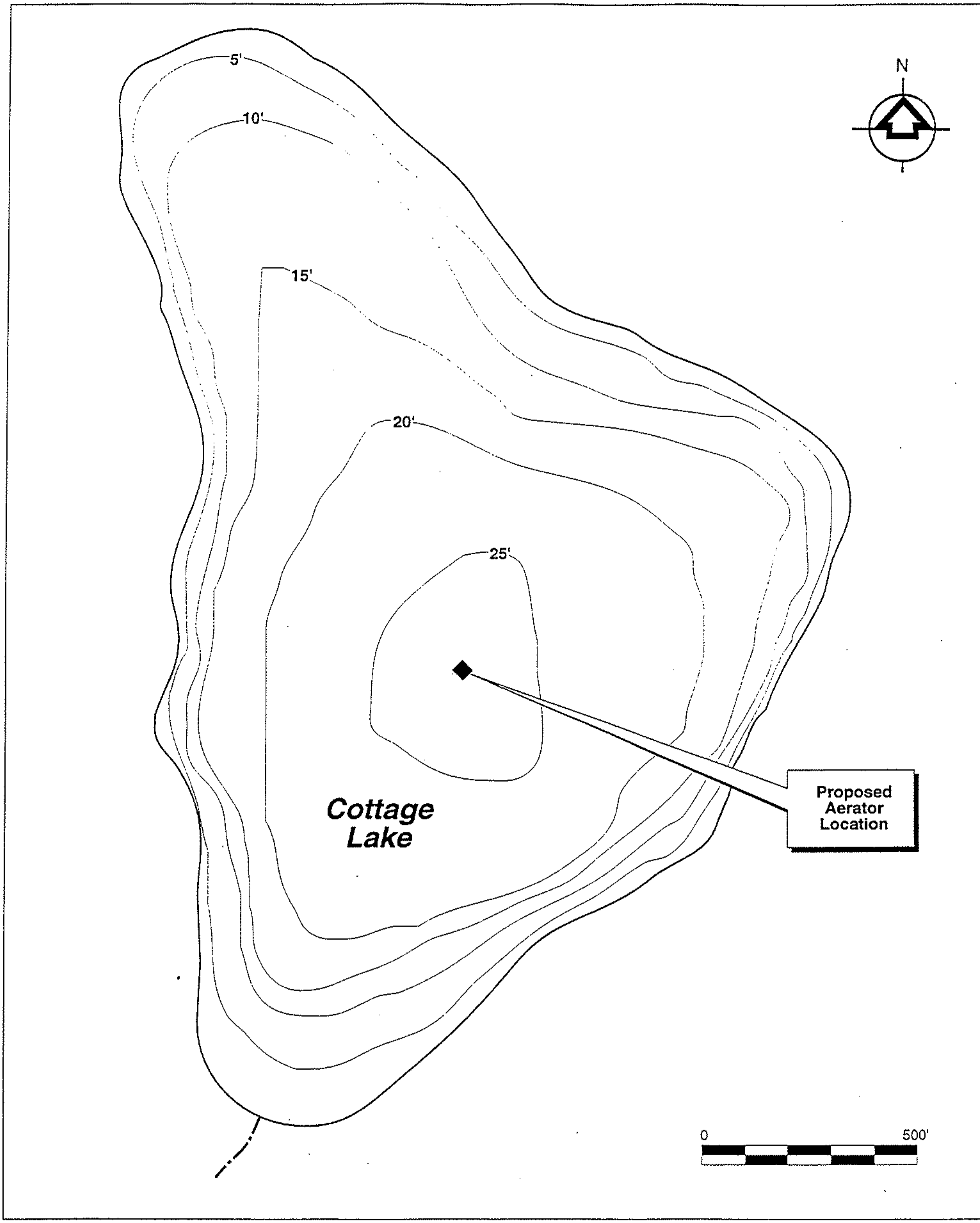
- It is able to transfer an equivalent amount of oxygen to the hypolimnion at a flow rate of 75 percent of the predesign system.

- It has the same general compressor requirements as the predesign system which allows the County to maintain redundant capacity in case one compressor fails.

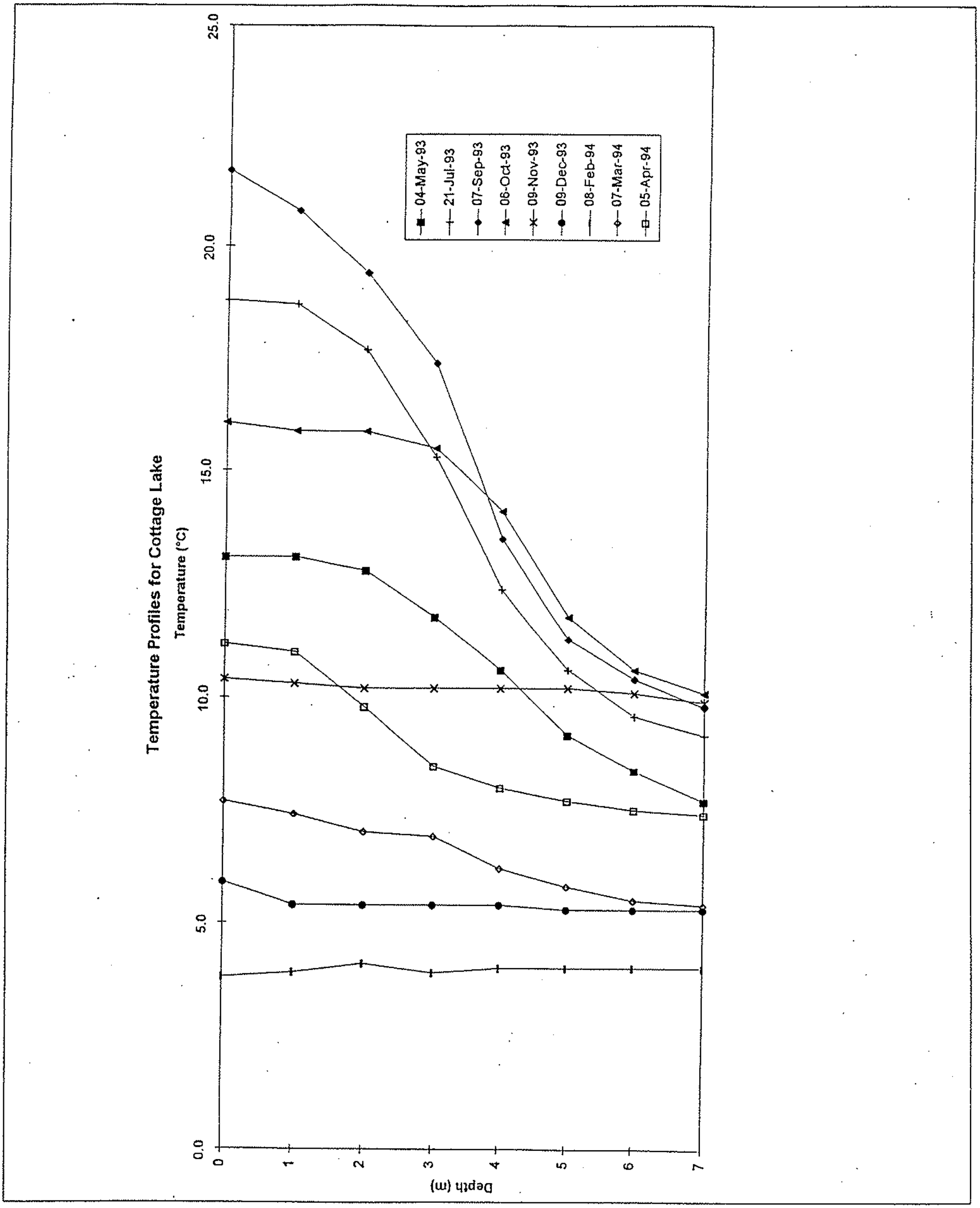
- It provides a means of reducing mixing intensity in the hypolimnion during periods of weak stratification.

TABLE 3
HYPOLIMNETIC AERATION SYSTEM
PRELIMINARY CONSTRUCTION COST ESTIMATE

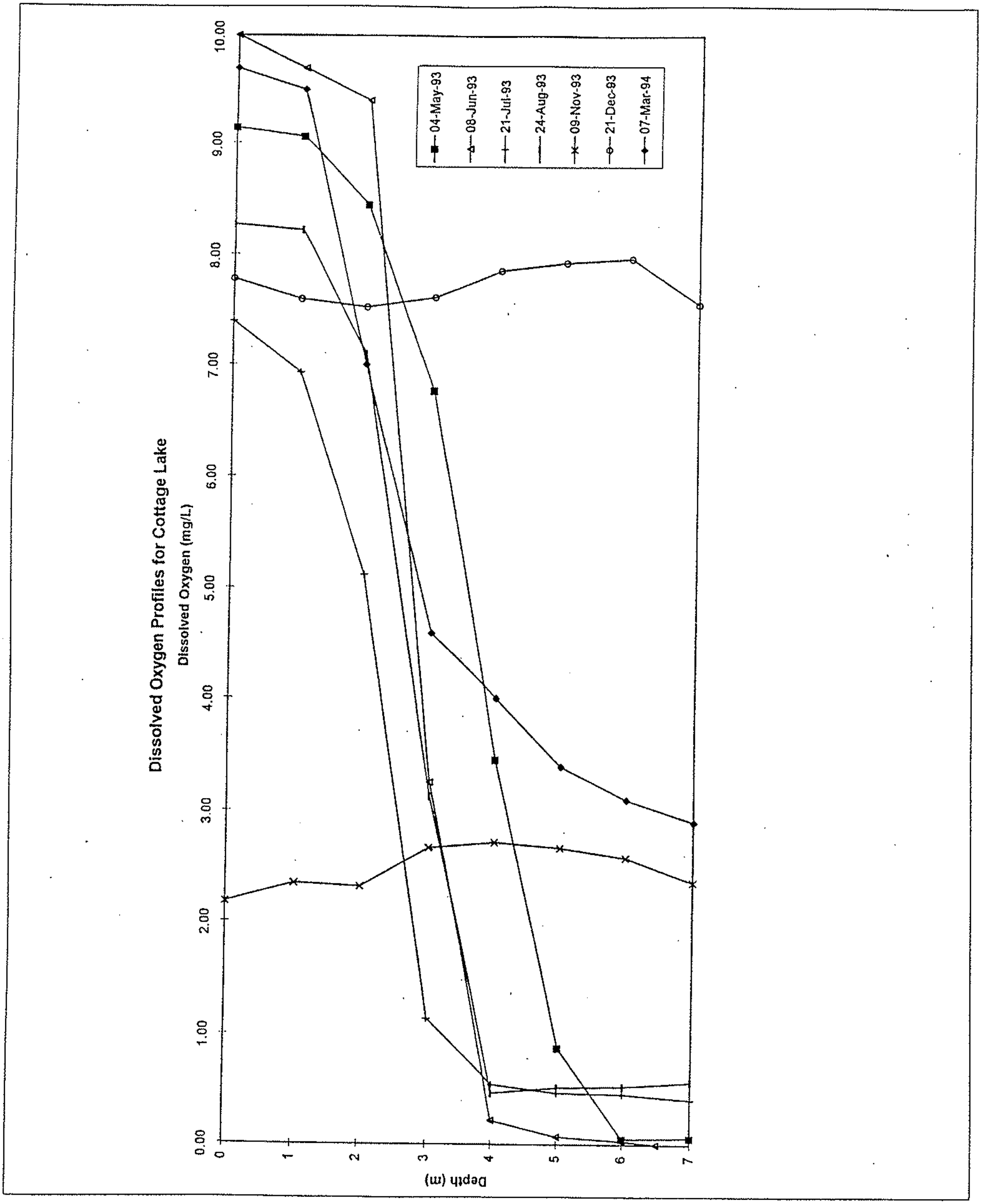
Item	Approximate Amount	Cost
Excavation, haul and disposal	200 cubic yards	$2,500
Foundation Material	1000 cubic yards	2,000
Building	Lump Sum	105,000
Rotary Screw Compressor system	Two 40 hp compressors and piping	45,400
PSA Oxygen System	Lump Sum	64,500
Acoustical board	Lump Sum	600
Electrical	Lump Sum	14,000
Heating and Air Conditioning	Lump Sum	4,500
Final grading and landscaping	Lump Sum	3,000
4" dia. pipeline	500 lineal feet	8,500
4" Butterfly Valve	Two	1,400
4" dia. Air Hose	1,000 lineal feet	7,500
Anchors	Lump Sum	1,200
Diffusers and piping	Lump Sum	10,000
Inlet and outlet FRP pipes	Lump Sum	14,000
Separator box	Lump Sum	95,000
Security fencing	Lump Sum	2,000
Warning signs	Lump Sum	600
Subtotal		$381,700
Contingency (20%)		76,340
Subtotal		$458,040
Washington State Sales Tax		37,560
Total		**$495,600**



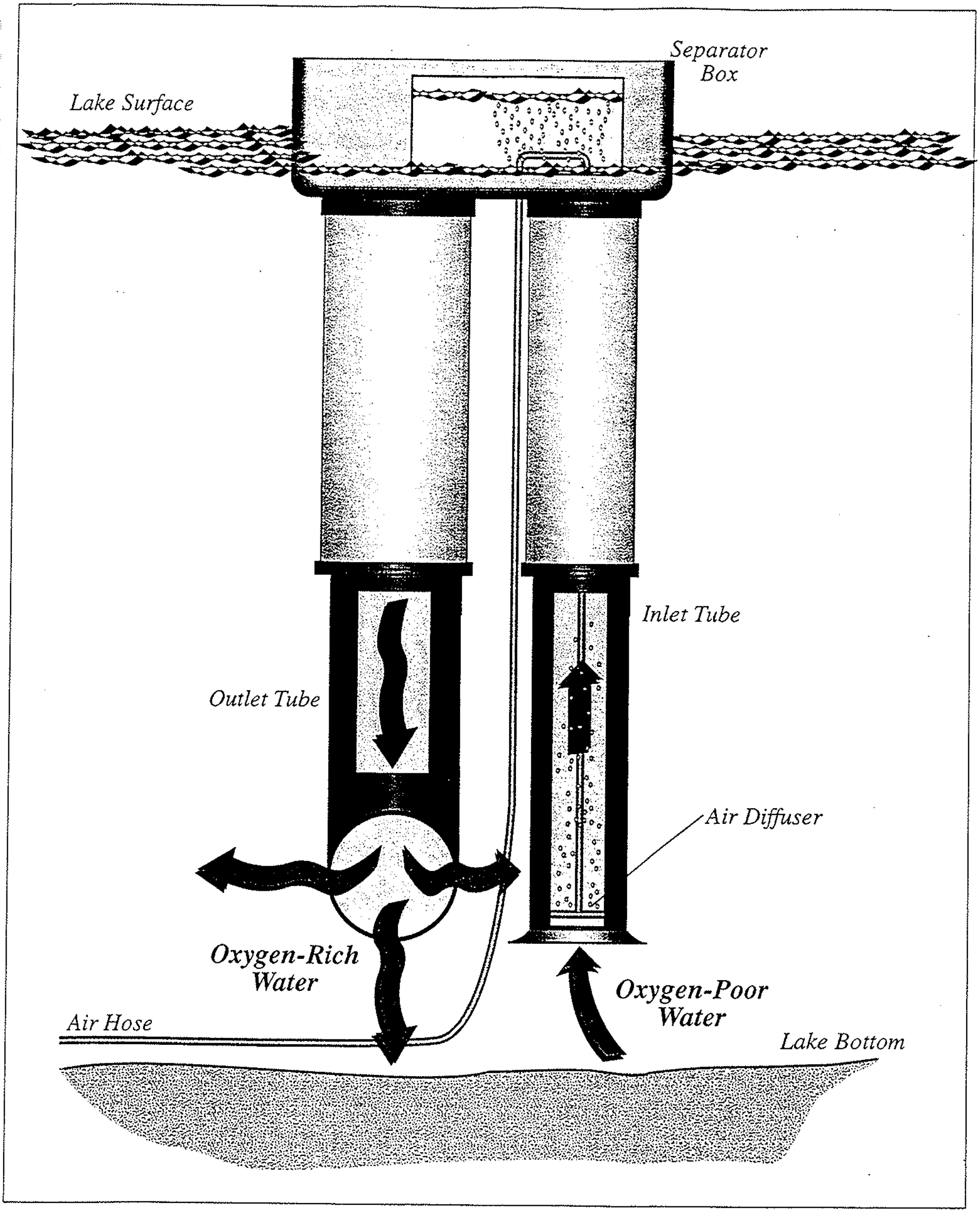
KCM 1917 First Avenue Seattle, Washington 98101	King County Surface Water Management COTTAGE LAKE HYPOLIMNETIC AERATOR ENGINEERING ANALYSIS	Figure 1. BATHYMETRIC CONTOURS AND PROPOSED AERATOR LOCATION



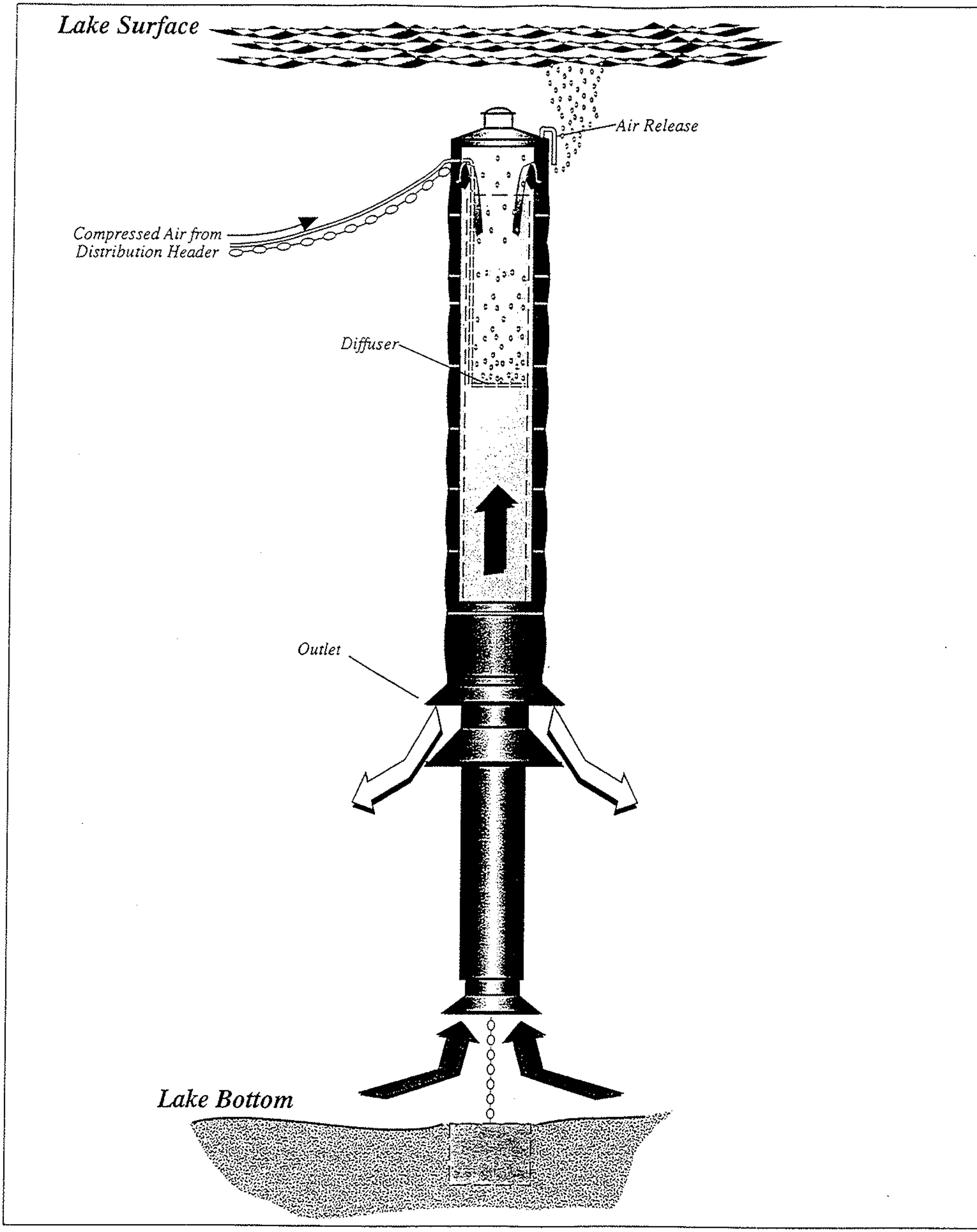
KCM *1917 First Avenue* *Seattle, Washington 98101*	King County Surface Water Management COTTAGE LAKE HYPOLIMNETIC AERATOR ENGINEERING ANALYSIS	Figure 2. TEMPERATURE PROFILES



KCM *1917 First Avenue* *Seattle, Washington 98101*	King County Surface Water Management COTTAGE LAKE HYPOLIMNETIC AERATOR ENGINEERING ANALYSIS	Figure 3. DISSOLVED OXYGEN PROFILES



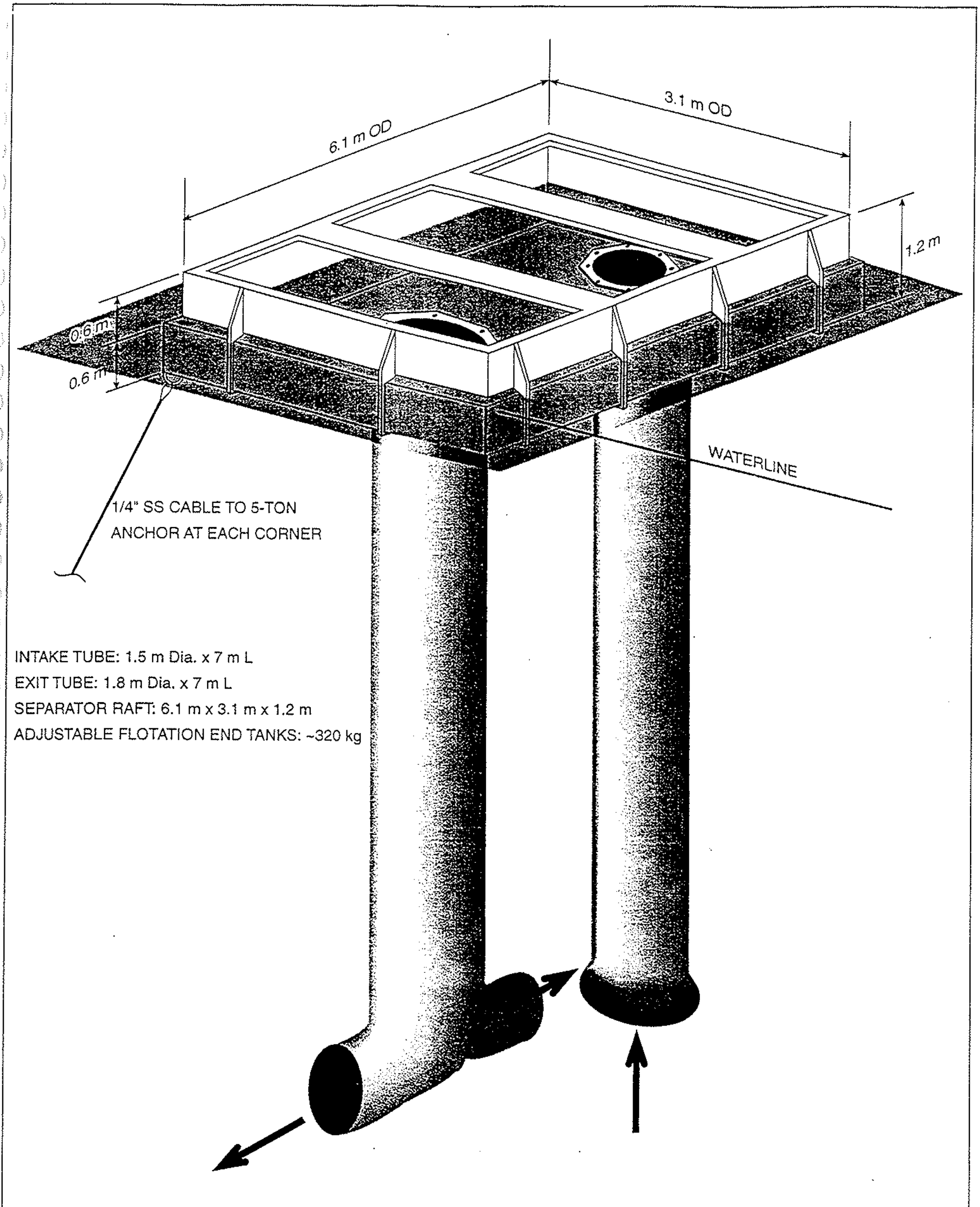
KCM 1917 First Avenue Seattle, Washington 98101	King County Surface Water Management COTTAGE LAKE HYPOLIMNETIC AERATOR ENGINEERING ANALYSIS	Figure 4. FULL-LIFT HYPOLIMNETIC AERATOR



KCM
1917 First Avenue
Seattle, Washington 98101

King County Surface Water Management
COTTAGE LAKE HYPOLIMNETIC
AERATOR ENGINEERING ANALYSIS

Figure 5.
PARTIAL-LIFT
HYPOLIMNETIC AERATOR



KCM *1917 First Avenue* *Seattle, Washington 98101*	King County Surface Water Management COTTAGE LAKE HYPOLIMNETIC AERATOR ENGINEERING ANALYSIS	Figure 6. PROPOSED COTTAGE LAKE HYPOLIMNETIC AERATOR

E. SEPA Checklist

Cottage Lake Management Plan SEPA Addendum
Determination of Non-significance
King County Environmental Checklist

King County
Surface Water Management Division

Department of Natural Resources
700 5th Avenue Suite 2200
Seattle, WA 98104

(206) 296-6519
(206) 296-0192 FAX

January 16, 1996

TO: Cottage Lake Project File

FM: Fran Solomon, Cottage Lake Project Manager

RE: Cottage Lake Management Plan SEPA Checklist Addendum

The following information should be added to the non-project SEPA checklist for the *Cottage Lake Management Plan* in response to comments on the checklist. These comments were submitted respectively by the Washington State Department of Natural Resources on December 29, 1995, the Seattle-King County Department of Public Health on January 3, 1996, and BOAS, Inc. on January 5, 1996.

- Section 4c, Plants, should indicate the presence of Utricularia intermedia (flat-leafed bladderwort) classified as a sensitive plant by the state of Washington, within the Cottage Lake watershed at Crystal Lake.

- Section 7b3, Environmental Health - Noise, should clarify that the building housing the air compressors will be sound-proofed and that compressor operation will not violate the requirements of the King County Noise Code (KCC 12.86 to 12.100).

- Section 13b, Historic and Cultural Preservation, should indicate that one prehistoric archaeological site has been recorded in the Snohomish County portion of the Cottage Lake watershed. The site record refers to a heavily patinated basalt projectile point. The Cottage Lake watershed has substantial potential for the occurrence of additional, as yet unrecorded, archaeological resources.

Given (1) the non-project nature of the DNS; and (2) that the additional information does not alter the recommendations in the Cottage Lake Management Plan, a new determination is not warranted. For all project actions in the plan, separate SEPA compliance will be completed as stated in the *Cottage Lake Management Plan,* non-project SEPA checklist.

FS:pra06

cc: SEPA distribution list

DETERMINATION OF NON-SIGNIFICANCE

Name of Proposal:	Cottage Lake Management Plan
Description of Proposal:	Water quality management plan for Cottage Lake and its watershed.
Location of Proposal:	The plan contains both project and nonproject actions that will apply to Cottage Lake and its watershed in unincorporated King County.
Responsible Official:	Paul Tanaka
Position/Title:	Director, King County Department of Public Works
Address:	400 Yesler Way Room 700 Mail Stop 7Y Seattle, Washington 98104-2637
Phone:	(206) 296-6500

DATE: 12-5-95 SIGNATURE: [signature]

Proponent and Lead Agency:	King County Department of Public Works Surface Water Management Division
Contact Person(s):	Fran Solomon, Senior Limnologist (206) 296-1924

F12:MI015

The lead agency for this proposal has determined that it does not have a probable significant adverse impact on the environment. An Environmental Impact Statement (EIS) is not required under RCW 43.21C.030(2)(c). This decision was made after review of a completed environmental checklist and other information on file with the lead agency. THIS INFORMATION IS AVAILABLE TO THE PUBLIC ON REQUEST (for a nominal photocopying fee).

THE DETERMINATION OF NON-SIGNIFICANCE (DNS) is issued under WAC 197-11-340(2); the lead agency will not act on this proposal until after January 5, 1996. Comments must be submitted or postmarked by this date.

You may appeal this determination by filing a Notice of Appeal with the responsible official of the lead agency given above. In accordance with King County Code 27.48.010 and 27.48.020, all appeals to the Zoning and Subdivision Examiner must be accompanied by a check for $125.00 at the time of submittal to the lead agency. The check should be made out to the King County Surface Water Management Division. This notice will then be filed with the Zoning and Subdivision Examiner's Office and a hearing date will be set. You will be notified two weeks in advance of the hearing date. You should be prepared to make specific factual objections. A Notice of Appeal is a letter stating the following:

1. The name of the proposal
2. The action to which you object (the DNS)
3. The agency taking the action (Public Works)
4. The basis for the objection (why the proposal would have significant adverse impact on the environment)
5. Your name and how you can be reached

Any Notice of Appeal for this Determination of Non-Significance must be received or postmarked no later than **January 5, 1996**. You should be prepared to make specific factual objections. If you have any questions regarding this project, please call Fran Solomon, Senior Limnologist, at 296-1924.

If you wish to file a Notice of Appeal, please send it to:

Jim Kramer, Manager
King County Surface Water Management Division
700 Fifth Avenue, Suite 2200
Seattle, WA 98104

If you have any questions about the procedures for SEPA appeals, please call the Zoning and Subdivision Examiner at (206) 296-4660.

KING COUNTY
ENVIRONMENTAL CHECKLIST

COTTAGE LAKE MANAGEMENT PLAN

Purpose of the Checklist:

The State Environmental Policy Act (SEPA), Chapter 43.21 RCW, requires all governmental agencies to consider the environmental impacts of a proposal before making decisions. An environmental impact statement (EIS) must be prepared for all proposals with probable significant adverse impacts on the quality of the environment. The purpose of this checklist is to provide information to help you and the agency identify impacts from your proposal (and to reduce or avoid impacts from the proposal, if it can be done) and to help the agency decide whether an EIS is required.

Instructions for Applicants:

This environmental checklist asks you to describe some basic information about your proposal. Governmental agencies use this checklist to determine whether the environmental impacts of your proposal are significant, requiring preparation of an EIS. Answer the questions briefly, with the most precise information known, or give the best description you can.

You must answer each question accurately and carefully, to the best of your knowledge. In most cases, you should be able to answer the questions from your own observations or project plans without the need to hire experts. If you really do not know the answer, or if a question does not apply to your proposal, write "**do not know**" or "**does not apply**." Complete answers to the questions now may avoid unnecessary delays later.

Some questions ask about governmental regulations, such as zoning, shoreline, and landmark designations. Answer these questions if you can. If you have problems, the governmental agencies can assist you.

The checklist questions apply to all parts of your proposal, even if you plan to do them over a period of time or on different parcels of land. Attach any additional information that will help describe your proposal or its environmental effects. The agency to which you submit this checklist may ask you to explain your answers or provide additional information reasonably related to determining if there may be significant adverse impact.

Use of Checklist for Nonproject Proposals:

Complete this checklist for nonproject proposals, even though questions may be answered "**does not apply.**" In addition, complete the SUPPLEMENTAL SHEET FOR NONPROJECT ACTIONS (PART D).

For nonproject actions, the references in the checklist to the words "**project,**" "**applicant,**" and "**property or site**" should be read as "**proposal,**" "**proposer,**" and "**affected geographic area,**" respectively.

A. BACKGROUND

1. *Name of the proposed project, if applicable:*

   Cottage Lake Management Plan

2. *Name of Applicant:*

   King County Department of Public Works
   Surface Water Management (SWM) Division

3. *Address and phone number of applicant and contact person:*

   Fran Solomon, Senior Limnologist
   King County SWM Division
   700 Fifth Avenue, Suite 2200
   Seattle, WA 98104
   Phone: (206) 296-1924
   FAX: (206) 296-0192

4. *Date checklist prepared:*

   November 9, 1995

5. *Agency requesting checklist:*

   King County Department of Public Works
   SWM Division

6. *Proposed timing or schedule (including phasing, if applicable):*

   Implementation of the management plan is proposed to be funded through a Centennial Clean Water Fund (CCWF) grant and lake management district (LMD) formation. CCWF application will occur in February, 1996. LMD formation will be initiated in March 1996 and is proposed to be completed in March, 1997. Depending upon implementation funding, design and engineering for the in-lake aeration system could be initiated in 1997. Depending upon funding, the remaining management plan activities would be initiated and performed between 1997-2001.

7. *Do you have any plans for future additions, expansion, or further activity related to or connected with this proposal? If yes, explain.*

   No additional work is planned beyond what is currently contained in the management plan.

8. *List any environmental information you know about what has been prepared, or will be prepared, directly related to this proposal:*

   Gibbons, M.V., 1994. Cottage Lake/Lake Desire Plankton Analyses Methods. Water Environmental Services, Inc., Bainbridge Island, WA.

Hong West and Associates, Inc. 1994. King County Lakes: Cottage Lake Hydrologic Evaluation. Prepared for King County SWM.

KCM, Inc., 1993. Response of Phytoplankton in Cottage Lake to Nutrient Enrichment. Prepared for King County SWM.

KCM, Inc., 1994. Cottage Lake Nutrient Budget. Prepared for King County SWM.

KCM, Inc., 1994. Cottage Lake On-Site Septic System Assessment. Prepared for King County SWM.

KCM, Inc., 1994. Cottage Lake Water Budget. Prepared for King County SWM.

KCM, Inc., 1994. Fall and Spring Fisheries Assessments of Cottage Lake. Prepared for King County SWM.

King County, 1993. Existing Water Quality Conditions in the Cottage Lake Watershed. Surface Water Management Division, Department of Public Works, King County, WA.

King County and KCM, Inc. Cottage Lake Management Plan, Public Draft, September 1995. Final Plan, January 1996.

9. *Do you know whether applications are pending for governmental approvals of other proposals directly affecting the property covered by your proposal? If yes, explain.*

King County is intending to assist the Cottage Lake community in the formation of an LMD to fund a portion of the implementation costs of the Cottage Lake Management Plan. The process for LMD formation will be initiated in 1996. If formed, the LMD will be operational for five years.

King County is also intending to apply for funds from the Washington State Department of Ecology CCWF to cover a portion of the implementation costs. The grant application will be submitted in 1996. If awarded, funds will be available in 1997.

10. *List any government approvals or permits that will be needed for your proposal, if known:*

Environmental Checklist
King County Council adoption of the Cottage Lake Management Plan
Washington State Department of Ecology approval of the Cottage Lake Management Plan

11. *Give a brief, complete description of your proposal, including the proposed uses and the size of the project and site. There are several questions later in this checklist that ask you to describe certain aspects of your proposal. You do not need to repeat those answers on this page. (Lead agencies may modify this form to include additional specific information on project description.)*

The proposal will involve the implementation of watershed measures, in-lake measures, aquatic plant management measures, and long-term lake, watershed, fishery, and wetland monitoring programs as described in Chapter 7 of the Cottage Lake Management Plan. The watershed measures will be applied throughout the 4300 acre Cottage Lake watershed. The lake is 63 acres in size and will be the site for alum treatment (one-time application) and installation of an in-lake aeration system. Separate SEPA compliance will be conducted for in-lake measures.

12. *Location of the proposal. Give sufficient information for a person to understand the precise location of your proposed project, including a street address, if any, and section, township, and range, if known. If a proposal would occur over a range of area, provide the range or boundaries of the site(s). Provide a legal description, site plan, vicinity map, and topographic map, if reasonably available. While you should submit any plans required by the agency, you are not required to duplicate maps or detailed plans submitted with any permit applications related to this checklist.*

Cottage Lake is located in the upper Bear Creek Basin of northeast King County and southern Snohomish County, approximately four miles east of the city of Woodinville (Figures 1-1 and 2-1). Public access to the lake has existed since 1992 when King County purchased the former Norm's Resort property on the north end of the lake. Cottage Lake Park, a new King County park, is being developed at that location. Access to Cottage Lake Park and to the north shore of the lake is via Woodinville-Duvall Road. This road intersects Avondale Road, a major roadway extending north from the end of State Highway 520. The watershed includes portions of Township 26, Range 5, Sections 01, 02, and 12; Township 26, Range 6, Sections 05 through 08; Township 27, Range 5, Sections 13, 14, 23 through 26, 35, and 36; and Township 27, Range 6, Sections 30 through 32.

B. ENVIRONMENTAL ELEMENTS

1. Earth

a. *General description of the site (underline one): Flat, rolling, hilly, steep slopes, mountainous, other.*

The land on the Cottage Lake shoreline is flat to rolling. Watershed topography ranges from 240 to 600 feet above mean sea level. The majority of the terrain is a mixture of gently sloping forested hills interspersed with valleys containing large wetland and open water areas.

b. *What is the steepest slope on the site (approximate percent slope)?*

Immediately northeast of the lake is a steep canyon area incised by small drainages. A steep hill rises 400 vertical feet in approximately 1000 horizontal feet. The approximate slope is 40 percent.

c. *What general types of soils are found on the site (for example, clay, sand, gravel, peat, muck)? If you know the classification of agricultural soils, specify them and note any prime farmland.*

The predominant soil type in the watershed is Alderwood Gravely Sandy Loam. This soil type represents approximately 80 percent of the watershed, and is generally found on slopes ranging from 2 to 15 percent. Other soil types present and the percent of the watershed that they represent include Everett Gravely Sandy Loam (10 percent), Indianola Loamy Sand (2 percent), Mukilteo Muck (1 percent), Norma Sandy Loam (2 percent), Orcas Peat (2 percent), Ragnar/Indianola (2 percent), and Seattle Muck (1 percent).

d. *Are there surface indications or history of unstable soils in the immediate vicinity? If so, describe.*

Immediately northeast of Cottage Lake is a steep canyon area incised by small drainages. The King County Sensitive Areas Map Folio shows these steep drainages to be an erosion hazard area.

e. *Describe the purpose, type, and approximate quantities of any filling or grading proposed. Indicate source of fill.*

Does not apply.

f. *Could erosion occur as a result of clearing, construction, or use? If so, generally describe.*

Not applicable to the plan itself. Erosion could result during the installation of the in-lake aeration system. Appropriate measures will be taken to prevent sediment and turbid water from entering the lake.

g. *About what percent of the site will be covered with impervious surfaces after project construction (for example, asphalt or buildings)?*

Not applicable to the plan itself. A 300- to 400-square-foot building will be constructed to house the air compressor for the in-lake aeration. The final design and location of the compressor building remains to be determined.

h. *Proposed measures to reduce or control erosion, or other impacts to the earth, if any:*

Not applicable to the plan itself. Appropriate measures will be taken during construction to control erosion. All disturbed areas will be stabilized following construction.

2. Air

a. *What types of emissions to the air would result from the proposal (for example, dust, automobile, odors, industrial, wood smoke) during construction and when the project is completed? If any, generally describe and give approximate quantities, if known.*

Not applicable to the plan itself. Minor dust emissions during the construction of the compressor building could occur in the immediate area. No impacts to air quality will occur upon completion of the project construction.

b. *Are there any off-site sources of emissions or odors that may affect your proposal? If so, generally describe.*

Does not apply.

c. *Describe proposed measures to reduce or control emissions or other impacts to air, if any:*

Appropriate dust control from the construction of the compressor building will be employed if necessary.

3. Water

a. *Surface:*

1) *Is there any surface water body on or in the immediate vicinity of the site (including year-round and seasonal streams, saltwater, lakes, ponds, and wetlands)? If yes, describe type and provide names. If appropriate, state what stream or river it flows into.*

Cottage Lake, Daniels Creek Tributary (0122), Cottage Lake Creek Tributary (0127)

2) *Will the project require any work over, in, or adjacent to (within 200 feet) the described waters? If yes, please describe and attach available plans.*

Not applicable to the plan itself. Implementation of the lake management plan will attempt to improve the trophic status of Cottage Lake through in-lake restoration techniques and watershed source control measures. Alum application will occur on the lake and will not have any land surface impacts. Temporary modification of water quality will occur during the alum application process. Construction of the in-lake aeration system will take place during the summer to minimize land and water impacts. Once installed, the aeration system may possibly have a short-term impact on water quality by stirring up the sediments. Separate SEPA compliance will be conducted for in-lake measures.

3) *Estimate the amount of fill and dredge material that could be placed in or removed from surface water or wetlands and indicate the area of the site that will be affected. Indicate the source of fill material.*

Does not apply.

4) *Will the proposal require surface water withdrawals or diversions? Give general description, purpose, and approximate quantities, if known.*

Does not apply.

5) *Does the proposal lie within a 100-year floodplain? If so, note location on the site plan.*

Does not apply.

6) *Does the proposal involve any discharges of waste materials to surface waters? If so, describe the type of waste and anticipated volume of discharge.*

Does not apply.

b. *Ground:*

1) *Will ground water be withdrawn, or will water be discharged to ground water? Give general description, purpose, and approximate quantities, if known.*

Does not apply.

2) *Describe waste material that will be discharged into the ground from septic tanks or other sources, if any (for example: domestic sewage, industrial chemicals, agricultural, etc.). Describe the general size of the system, the number of such systems, the number of houses to be served (if applicable), or the number of animals or humans the system(s) are expected to serve.*

Does not apply.

c. *Water Runoff (including stormwater):*

1) *Describe the source of runoff (including stormwater) and method of collection and disposal, if any (include quantities, if known). Where will this water flow? Will this water flow into other waters? If so, describe.*

Not applicable to the plan itself. Stormwater from the compressor building will be minimal and will flow through existing treatment systems, be infiltrated into the ground, or directed to a vegetated area prior to entering the lake depending upon final site design.

2) *Could waste materials enter ground or surface waters? If so, generally describe.*

Not applicable to the plan itself. All implementation activities are designed to improve water quality in and around the lake.

d. *Proposed measures to reduce or control surface, ground, and runoff water impacts, if any:*

Not applicable to the plan itself. The final project plans for in-lake measures will address the possible short-term impacts from construction activities related to the installation of the in-lake aeration system. These impacts are expected to be insignificant compared with the long-term benefits associated with lake aeration.

4. Plants

a. *Check or underline types of vegetation found on the site:*

_x_ deciduous tree: alder, maple, aspen, other
_x_ evergreen tree: fir, cedar, pine, other
_x_ shrubs
_x_ grass
_x_ pasture
___ crop or grain
_x_ wet soil plants: cattail, buttercup, bulrush, skunk cabbage, other
_x_ water plants: water lily, eelgrass, milfoil, other
___ other types of vegetation

b. *What kind and amount of vegetation will be removed or altered?*

Not applicable to the plan itself. Construction of the compressor building for the in-lake aeration system may require up to 500 square feet of vegetation removal, depending upon the location of the building.

c. *List threatened or endangered species known to be on or near the site:*

Does not apply.

d. *Proposed landscaping, use of native plants, or other measures to preserve or enhance vegetation on the site, if any:*

Revegetation of watershed wetlands and lake shoreline with native plants is included among plan recommendations.

5. Animals

a. *Underline any birds and animals which have been observed on or near the site, or are known to be on or near the site:*

_ birds: <u>hawk</u>, <u>heron</u>, <u>eagle</u>, <u>songbirds</u>, other
___ mammals: <u>deer</u>, <u>bear</u>, elk, <u>beaver</u>, other
___ fish: <u>bass</u>, <u>salmon</u>, <u>trout</u>, herring, <u>shellfish</u>, other

b. *List any threatened or endangered species known to be on or near the site:*

Bald eagles.

c. *Is the site part of a migration route? If so, explain.*

The lake and watershed wetlands provide resting sites for waterfowl during annual migration. The lake and wetlands also support resident waterfowl populations.

Juvenile coho salmon are found in Cottage Lake. They migrate out to sea for their adult lives and then return to spawn downstream of Cottage Lake in the Cottage Lake Creek outlet.

d. *Proposed measures to preserve or enhance wildlife, if any:*

Restoration of the lake shoreline should improve wildlife habitat. In-lake aeration is also expected to improve aquatic habitat.

6. Energy and Natural Resources

a. *What kinds of energy (electric, natural gas, oil, wood stove, solar) will be used to meet the completed project's energy needs? Describe whether it will be used for heating, manufacturing, etc.*

Not applicable to the plan itself. Electric power will be used to run the on-shore air compressor for the in-lake aeration system.

b. *Would your project affect the potential use of solar energy by adjacent properties? If so, explain.*

Does not apply.

c. *What kinds of energy conservation features are included in the plans of this proposal? List other proposed measures to reduce or control energy impacts, if any:*

Does not apply.

7. Environmental Health

a. *Are there any environmental health hazards, including exposure to toxic chemicals, risk of fire and explosion, spill, or hazardous waste, that could occur as a result of this proposal? If so, describe.*

Does not apply.

1) *Describe special emergency services that might be required.*

Does not apply.

2) *Proposed measures to reduce or control environmental health hazards, if any:*

Does not apply.

b. *Noise:*

1) *What types of noise exist in the area which may affect your project (for example: traffic, equipment operation, other)?*

Does not apply.

2) *What types and levels of noise would be created by or associated with the project on a short-term or a long-term basis (for example: traffic, construction, equipment operation, other)? Indicate what hours noise would come from the site.*

Not applicable to the plan itself. Short-term noise would be expected during the construction process for in-lake aeration. Construction activities will likely take place from April through October during normal working hours.

3) *Proposed measures to reduce or control noise impacts, if any:*

Not applicable to the plan itself. Construction hours will be limited to comply with local noise ordinances. Noise will be emitted from the building where the air compressors are located. However, the final noise level is expected to be below local noise thresholds or standards.

8. Land and Shoreline Use

a. *What is the current use of the site and adjacent properties?*

Cottage Lake is used primarily for swimming, fishing, and boating. Public access to the lake is from Cottage Lake Park on the north shore of the lake. Properties adjacent to the lake are single family residences. The remaining watershed properties are single family residences, multi-family residences, small and large farms, and small businesses.

b. *Has the site been used for agriculture? If so, describe.*

The Cottage Lake shoreline has not been used for agriculture. There are several small and large farms, including horse stables, in the watershed.

c. *Describe any structures on the site.*

Not applicable to the plan itself. A building will be constructed to house the air compressors for the in-lake aeration system.

d. *Will any structures be demolished? If so, what?*

Does not apply.

e. *What is the current zoning classification of the site?*

SF1 (three to seven dwelling units/acre) or single family residential is the zoning designation in the immediate lake shoreline area. Other zoning designations of lesser density (one dwelling unit/acre and one dwelling unit/2.5 acres) are present elsewhere in the watershed.

f. *What is the current comprehensive plan designation of the site?*

The King County Comprehensive Plan designates at least 95 percent of the Cottage Lake watershed as rural. A small piece, within the City of Woodinville, is designated as urban.

g. *If applicable, what is the current shoreline master program designation of the site?*

The entire shoreline is designated rural.

h. *Has any part of the site been classified as an "environmentally sensitive" area? If so, specify.*

Daniels Creek (tributary 0122) between Cottage Lake and Crystal Lake is designated as a Locally Significant Resource Area due to the large numbers of salmonids which spawn in this system. The northwest shoreline of the lake, at the Daniels Creek inlet, includes a portion of Big Bear Creek Wetland 10, a class 1 wetland based on the King County Wetlands Inventory (1990). Snohomish County has identified an extensive wetland area of approximately 150 acres along Daniels Creek north of and including Crystal Lake. This wetland area is designated an environmentally sensitive area of importance by Snohomish County.

i. *Approximately how many people would reside or work in the completed project?*

Does not apply.

j. *Approximately how many people would the completed project displace?*

Does not apply.

k. *Proposed measures to avoid or reduce displacement impacts, if any:*

Does not apply.

l. *Proposed measures to ensure the proposal is compatible with existing and projected land uses and plans, if any:*

Does not apply.

9. Housing

a. *Approximately how many units would be provided, if any? Indicate whether high-, middle-, or low-income housing.*

Does not apply.

b. *Approximately how many units, if any, would be eliminated? Indicate whether high-, middle-, or low-income housing.*

Does not apply.

c. *Proposed measures to reduce or control housing impacts, if any:*

Does not apply.

10. Aesthetics

a. *What is the tallest height of any proposed structure(s), not including antennas? What is the principal exterior building material(s) proposed?*

Not applicable to the plan itself. The design for the compressor building has not been completed. It is expected that the structure will not exceed 12 feet in height. Standard materials (concrete, brick, and wood) will be used to construct the compressor building.

b. *What views in the immediate vicinity would be altered or obstructed?*

Does not apply.

c. *Proposed measures to reduce or control aesthetic impacts, if any:*

No aesthetic impacts are anticipated. If appropriate, landscaping will be incorporated into the final design for the compressor building site.

11. Light and Glare

a. *What type of light or glare will the proposal produce? What time of day would it mainly occur?*

Does not apply.

b. *Could light or glare from the finished project be a safety hazard or interfere with views?*

Does not apply.

c. *What existing off-site sources of light or glare may affect your proposal?*

Does not apply.

d. *Describe proposed measures to reduce or control light and glare impacts, if any:*

Does not apply.

12. Recreation

a. *What designated and informal recreational opportunities are in the immediate vicinity?*

Swimming, fishing, boating opportunities, and aesthetic enjoyment are available for the general public via Cottage Lake Park. Cottage Lake Park also provides other active and passive recreational opportunities including a swimming pool, open play meadows, a children's playground, basketball and tennis courts, and picnic shelters. People who live on the lake have direct access for swimming, fishing, boating, and aesthetic enjoyment.

b. *Would the proposed project displace any existing recreational uses? If so, describe.*

No displacement of existing recreational uses is expected. The Cottage Lake Management Plan is expected to enhance recreational uses of the lake by improving lake water quality and trophic status.

c. *Proposed measures to reduce or control impacts on recreation, including recreation opportunities to be provided by the project or applicant, if any:*

Does not apply.

13. Historic and Cultural Preservation

a. *Are there any places or objects listed on, or proposed for, national, state, or local preservation registers known to be on or next to the site? If so, generally describe.*

Does not apply.

b. *Generally describe any landmarks or evidence of historic, archaeological, scientific, or cultural importance known to be on or next to the site.*

Does not apply.

c. *Describe proposed measures to reduce or control impacts, if any:*

Does not apply.

14. Transportation

a. *Identify public streets and highways serving the site, and describe proposed access to the existing street system. Show on-site plans, if any.*

Access to Cottage Lake is via Woodinville-Duvall Road, which passes to the north of the lake. This road intersects Avondale Road, a major roadway extending north from the end of State Highway 520 (Figure 2-1). The entrance to Cottage Lake Park is on Woodinville-Duvall Road, approximately 1/2 mile west of the intersection of this road with Avondale Road. Other major roads around the lake are 185th Avenue NE on the west shore, 191st Avenue NE on the east shore, and NE 165th Street on the south shore.

b. *Is the site currently served by public transit? If not, what is the approximate distance to the nearest transit stop?*

Yes. Metro bus routes 251 and 311 serve the Cottage Lake area.

c. *How many parking spaces would the completed project have? How many would the project eliminate?*

Does not apply.

d. *Will the proposal require any new roads or streets, or improvements to existing roads or streets, not including driveways? If so, generally describe (indicate whether public or private).*

Does not apply.

e. *Will the project use (or occur in the immediate vicinity of) water, rail, or air transportation? If so, generally describe.*

Does not apply.

f. *How many vehicular trips per day would be generated by the completed project? If known, indicate when peak volumes would occur.*

Does not apply.

g. *Proposed measures to reduce or control transportation impacts, if any:*

Does not apply.

15. Public Services

a. *Would the project result in an increased need for public services (for example: fire protection, police protection, health care, schools, other)? If so, generally describe.*

Does not apply.

b. *Proposed measures to reduce or control direct impacts on public services, if any:*

Does not apply.

16. Utilities

a. *Underline utilities currently available at the site: electricity, natural gas, water, refuse service, telephone, sanitary sewer, septic system, other.*

b. *Describe the utilities that are proposed for the project, the utility providing the service, and the general construction activities on the site or in the immediate vicinity that might be needed.*

Not applicable to the plan itself. The compressor building will need to have electrical lines connected to it.

C. SIGNATURE

The above answers are true and complete to the best of my knowledge. I understand that the lead agency is relying on them to make its decision.

Signature: Frances Solomon

Title: Senior Limnologist

Date Submitted: November 28, 1995

SUPPLEMENTAL SHEET FOR NONPROJECT ACTIONS

1. *How would the proposal be likely to increase discharge to water; emissions to air; production, storage, or release of toxic or hazardous substances; or production of noise?*

   This proposal will not result in any increases in these categories.

   Proposed measures to avoid or reduce such increases are: Does not apply.

2. *How would the proposal be likely to affect plants, animals, fish, or marine life?*

   This proposal is intended to improve the future environment for fish and other aquatic animals by providing a lake management plan to improve water quality in the lake and to prevent further degradation from new development in the watershed. The Cottage Lake Management Plan recommends actions for preventing and controlling infestations of noxious, non-native aquatic plants such as Eurasian watermilfoil and purple loosestrife. Removal of non-native aquatic plants makes way for native plants which provide valuable fish and wildlife habitat.

   Proposed measures to protect or conserve plants, animals, fish, or marine life are:

   The Cottage Lake Management Plan proposes watershed source control, in-lake restoration, aquatic plant management, and monitoring measures to improve water quality and protect or conserve native plants, fish, and other aquatic animals. Watershed source control measures reduce the amount of nutrients and contaminants entering the lake from external sources. These measures include stormwater treatment, forest retention, wetland restoration and native plant buffer maintenance, ditch maintenance, homeowner and business best management practices, agricultural best management practices, and enhanced on-site septic system maintenance. In-lake restoration measures reduce the release of phosphorus from lake sediments and decaying plants. An alum treatment and long-term hypolimnetic aeration are proposed. Aquatic plant management measures include milfoil prevention, purple loosestrife removal, and reduction in water lily density to improve lake access. A lake, watershed, fishery, and wetland monitoring program will evaluate the effectiveness of the other measures in the plan.

3. *How would the proposal be likely to deplete energy or natural resources?*

   This proposal will not deplete energy or natural resources. The in-lake aeration system would require only two 40 horsepower compressors, one for the aerators and one as backup.

   Proposed measures to protect or conserve energy and natural resources are: Does not apply.

SUPPLEMENTAL SHEET
FOR NONPROJECT ACTIONS

4. *How would the proposal be likely to use or affect environmentally sensitive areas or areas designated (or eligible or under study) for governmental protection; such as parks, wilderness, wild and scenic rivers, threatened or endangered species habitat, historic or cultural sites, wetlands, floodplains, or prime farmlands?*

   The Cottage Lake Management Plan contains recommendations for improving water quality in Cottage Lake and its tributaries. Hence, implementation of the plan would protect environmentally sensitive areas from degradation.

   Proposed measures to protect such resources or to avoid or reduce impacts are:

   Watershed source control measures will reduce the amount of nutrients and contaminants that enter Daniels Creek. Improving water quality in the Daniels Creek inlet will help to protect Daniels Creek as a Locally Significant Resource Area and Big Bear Creek No. 10 as a number one rated wetland.

5. *How would the proposal be likely to affect land and shoreline use, including whether it would allow or encourage land or shorelines uses incompatible with existing plans?*

   Implementation of the recommendations in the Cottage Lake Management Plan would reduce the discharge of nutrients and contaminants to Cottage Lake from the Cottage Lake shoreline and from land in the Cottage Lake watershed. The proposal would not allow or encourage land or shoreline uses incompatible with existing plans.

   Proposed measures to avoid or reduce shoreline and land use impacts are: Does not apply.

6. *How would the proposal be likely to increase demands on transportation or public services and utilities?*

   This proposal will not increase demands on transportation, public services or utilities.

   Proposed measures to reduce or respond to such demand(s) are: Does not apply.

7. *Identify, if possible, whether the proposal may conflict with local, state, or federal laws or requirements for the protection of the environment.*

   This proposal will increase compliance with local, state, and federal environmental laws and ordinances.

cause of degradation. C) The recommended policies reduce future loading of phosphorus.

X			If so, is county government the most appropriate organization to address this need?
			For both policy recommendations, the County is the most appropriate public body to address these needs since it defines land use and stormwater management policy for the Cottage Lake watershed.
		X	2. **ECONOMY AND JOB GROWTH**: Has the economic impact of the proposed regulation been reviewed to ensure it will not have a long-term adverse impact on the economy and job growth in King County?
			None of the proposed policy additions or changes would be expected to have an economic impact.
X			3. **PURPOSE**: Is the purpose of the proposed ordinance clear?
			This ordinance directs the Department of Natural Resources to adopt the Cottage Lake Management Plan as an administrative rule. The purpose of the administrative rule would be to designate the Cottage Lake watershed as a special management area for phosphorus loading control and to establish a procedure for evaluating drainage plans and related material for development applications for conformance with watershed stormwater treatment goals.
X			Are the steps for implementation clear?
			Implementation of the above recommendations will be consistent with K.C.C. 9.080.040 and 9.08.120. and are already well defined in development review procedures.
X			4. **EVALUATION**: Does the proposed ordinance identify specific measurable outcomes that the proposed regulation should achieve?
			Evaluation is an integral portion of the implementation of the management plan and will measure both policy and non-policy elements. Within the management plan, existing water quality has been well documented. This will serve as a baseline from which policy implementation will be evaluated for its success or failure. The evaluation process will include ongoing water quality and watershed monitoring.

(CONTINUED)

$1000. These costs are consistent with those associated with the lake protection standard in the SWM Design Manual update.

X			Has the cost of not adopting the proposed regulation been considered?

A cost/benefit analysis was completed for the implementation of the **Lake Desire** management plan. The results of the analysis indicates that the loss in cumulative shoreline property values between the no action and plan implementation scenarios ranged from $187,000 after one year to $9,000,000 in the year 2006. Thus, a financial benefit (increase in property value above inflation) could be attributed to plan implementation. Conversely, a financial cost (loss of property value) could be attributed to non-implementation. Property value losses not only impact County residents, but also the County's ability to collect tax revenues.

X			Do the benefits of the proposed regulations outweigh the costs?

The overall benefit of good water quality is difficult to quantify watershed-wide. For the purpose of this plan, the benefits of water quality were correlated to shoreline property values to assess the cost/benefit of plan implementation. This did not directly include the implementation costs associated with stormwater treatment. Those who own shoreline property and use the public park, however, would argue that the benefits of maintaining good watershed and lake quality through added stormwater treatment outweigh the cost to new development.

X			7. **VOLUNTARY COMPLIANCE**: Does the proposed ordinance inspire voluntary compliance?

The policy elements inspire voluntary compliance to the extent that the inclusion of sensitive lake protection water quality elements in site drainage design facilitates the approval of new development proposals in the watershed and the meeting of the Bear Creek Community Plan goals for water quality and resource protection.

X			8. **CLARITY**: Is the proposed ordinance written clearly and concisely, without ambiguities?

Yes, and the subsequent administrative rule will be written clearly, concisely, and without ambiguities.

X			9. **CONSISTENCY**: Is the proposed regulation consistent with existing federal, state and local statutes?

The proposed policy elements are consistent with existing, federal, state and local statues. Proposed state water quality standards for lakes may make implementation of plans such as these a requirement for highly eutrophic lakes.

a:96-2:mi17