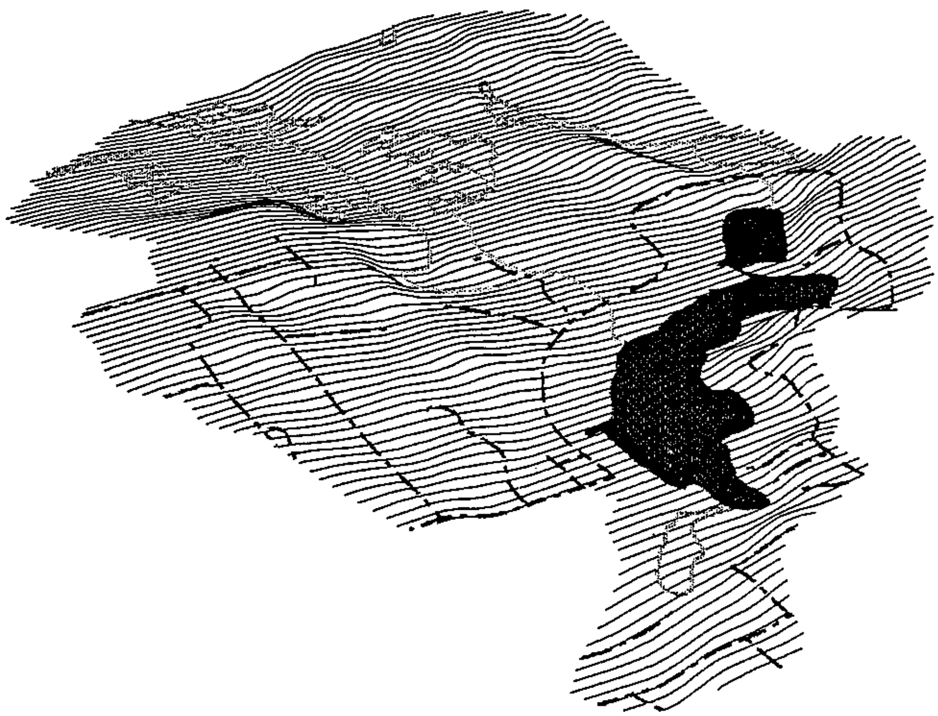
BEAVER LAKE

Management Plan



October 1993

King County Surface Water Management
Everyone lives downstream

WASHINGTON STATE DEPARTMENT OF ECOLOGY

ENTRANCO

BEAVER LAKE

MANAGEMENT PLAN

Grant No. TAX91110

Prepared for

King County Surface Water Management
Yesler Building Room 400
400 Yesler Way
Seattle, Washington
98104

Prepared by

ENTRANCO
10900 NE 8th Street, Suite 300
Bellevue, Washington 98004
(206) 454-5600

Funded by:

Washington State Department of Ecology
King County Surface Water Management Division
Municipality of Metropolitan Seattle,
Environmental Laboratory Division
Beaver Lake Community Club
Beaver Lake Protection Association

November 1993

ACKNOWLEDGMENTS

On behalf of the project team, appreciation is expressed to the following people who were instrumental in the successful completion of this project:

Sharon Walton - Project Manager, King County Surface Water Management
Allen Moore - Grant Officer, Washington State Department of Ecology

We would also like to thank the members of Beaver Lake Technical Advisory Committee for their interest and guidance in the direction of the project. The committee was composed of the following individuals:

Don Althauser - Senior Engineer, King County Surface Water Management
Tom Berteck - Road Standards Engineer, King County Department of Public Works
Robin Cole - Project Administrator, King County Parks, Planning, and Resource Development
Rick Cooper - Division Manager, Washington State Department of Natural Resources
Joanne Davis - Supervisor, Municipality of Metropolitan Seattle
Carol Flohr - Vice President, Beaver Lake Community Club
Tom Harman - Board Member, Beaver Lake Protection Association
Skip Holman - Vice President, Quadrant
Nancy Hopkins - Planner, King County Department of Development and Environmental Services
Anne Knapp - Planner, King County Planning and Community Development
Ron Little - General Manager, Sammamish Plateau Water and Sewer District
Mike Miller - Vice President, Pacific Properties
Allen Moore - Project Officer, Water Quality Financial Assistance Program, Washington State Department of Ecology
Bob Pfeifer - Fisheries Biologist, Washington State Department of Wildlife
Jim Sanders, Technical Development Engineer, King County Department of Development and Environmental Services
Jeff Stern - Program Analyst, King County Surface Water Management Division
Sharon Walton, Senior Limnologist - King County Surface Water Management Division

Thanks to the following volunteers who collected precipitation samples and lake level readings:

Carol Flohr and Steve Kipper - Precipitation
Tom Harmon - Lake level

This report was prepared by the following Entranco staff:

Dale Anderson, Project Manager
Jory Oppenheimer, Assistant Project Manager
David Morency
Michael Schwar
Ralph Nelson
Kellie McBee
Anne Hazel
Linda Budinich

Appreciation for their professional work is extended to:

Ken Ashley - fisheries studies
Sandy Lipovsky - benthic invertebrate analysis
Linda Sexton - Eastern Washington University - phytoplankton and zooplankton identification
Christine Eddy and Associates - groundwater analysis
Lee and Associates - development of the public access plan
Lin and Associates, in particular Lorin Reinelt - storm water monitoring and analysis
Metro Environmental Laboratory, in particular Jeff Droker - laboratory services
Aquatic Research Incorporated (ARI) - laboratory services

Gratitude is also due to the following firms for their cooperation in the use of water quality data and the use of their groundwater wells for sampling:

Pacific Properties
Terra Associates
W&H Pacific, Inc.
The Trossachs Group
Q-V Associates/Taiyo American Corporation

EXECUTIVE SUMMARY

INTRODUCTION

Beaver Lake, located within the East Lake Sammamish Plateau, is used for a variety of recreational activities including non-motorized boating, fishing, bird watching, and swimming. Although water quality problems in the lake have not been documented, lake residents are concerned about water quality problems due to watershed development.

Most of the watershed is currently undeveloped, consisting mainly of forests and wetlands. The existing watershed development is primarily single-family housing located along the lake's shoreline. Proposals to develop nearly one-half of the watershed were recently received by King County. Increased stormwater runoff from the proposed development may degrade the water quality of Beaver Lake unless sufficient control measures and management practices can be developed and implemented. Because the proposed development of the watershed is imminent, a lake management plan is needed now to prevent future degradation of lake water quality and correct any current problems.

OBJECTIVES

The main objectives of the Beaver Lake Phase 1 Lake Restoration Study were to assess the current water quality status of the lake, to identify and quantify sources of algal nutrients, to provide a restoration and management plan to prevent degradation of lake water quality, and to provide opportunities for the public to become involved in the future management of the lake.

To achieve these objectives, the lake was monitored from September 1991 through September 1992. Water quality samples were collected from the lake and inlet streams. Other elements of the monitoring program included mapping the lake's aquatic plants, groundwater sampling, surveys of nearshore pollution from septic systems, and stormwater sampling.

RESULTS OF THE MONITORING PROGRAM

Algal Nutrients/Algae Levels/Water Clarity

Phosphorus (P) was found to limit algal growth throughout the year. Sources of phosphorus to Beaver Lake are shown in **Figure S-1.**

The monitoring program provided information about the sources and quantified algal nutrients within the watershed and lake. About 75 percent of the phosphorus entering Beaver Lake was contributed from watershed sources. Of these watershed sources, stormwater and direct runoff were the largest, contributing 46 percent of phosphorus to the lake. Most of the phosphorus was delivered during the winter and spring when streamflows are higher. Because of the lack of watershed development, phosphorus in the watershed originates largely from natural sources, such as upstream wetlands.

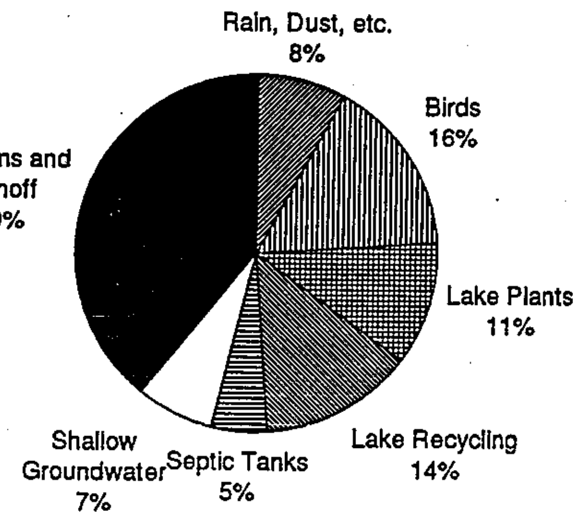


Figure S-1
Beaver Lake Annual Phosphorus Budget
(1992 Water Year)

Recycling of phosphorus within the lake, principally from the lake's sediments, represented a minor source of phosphorus to the lake annually.

Blue-green algae, a type of algae that is most often associated with nuisance conditions, formed a large part of the algal community throughout the year.

Color and pH

Beaver Lake is highly colored (tea color) due to wetland influences. Based on data collected during this study and results from other research on brown-water lakes, the high color and low pH do not reduce lake algal levels. Algal levels depend directly on phosphorus concentrations.

Dissolved Oxygen

Between April and November, Beaver Lake separated into distinct layers caused by temperature differences. The relatively warm and well-lit surface layer was about four meters (13 feet) deep. Within the deeper waters, oxygen was depleted by early June.

Assessment of fish distribution in late summer showed that fish were restricted to the oxygenated surface waters. Significant releases of phosphorus did not occur from the lake sediments during the summer, despite bottom waters being devoid of oxygen.

Bacteria

In-lake bacterial counts consistently were within the standards for lakes set by the Washington Department of Ecology. Both open-water and nearshore stations were safe for swimming and other contact recreational activities.

Aquatic Plants

Large aquatic plants (macrophytes) cover about 16 percent of the lake surface during the summer months, which is a moderately low density. The aquatic plants do not appear to be restricting recreational uses of the lake, with the possible exception of localized areas around certain docks.

Overall Lake Condition (Trophic State)

Based on the traditionally-used trophic parameters of total phosphorus, Secchi depth, and chlorophyll *a*, the condition of Beaver Lakes 1 and 2 can be classified as poor (high algal levels) and moderate (medium levels of algae), respectively. Because the watershed is largely forested, the existing conditions of Beaver Lakes 1 and 2 are the result of natural conditions.

RECOMMENDED LAKE AND WATERSHED MANAGEMENT PLAN

Based on the water quality monitoring program and watershed and lake predictions, watershed control methods were evaluated for their effectiveness to reduce phosphorus reaching Beaver Lake. In-lake control methods, such as lake aeration or alum treatments, are not recommended at this time. The responses of the lake to future land uses in the watershed and the installation of stormwater controls were predicted by the use of a computer model. Water quality predictions showed that great care is needed to allow watershed development while protecting Beaver Lake water quality. Following this analysis, a recommended lake and watershed management plan was developed (Table S-1) and is summarized below.

Watershed Controls

The focus of future lake and watershed management will be directed toward a non-degradation water quality policy. Existing and on-going State and local planning and regulatory programs have or will impose considerable precautionary measures (mitigation) for existing and potential future development in the watershed. In addition to the control measures that have already been required by these existing plans, ordinances and regulations, additional best management practices (BMPs) are recommended and summarized in **Table S-1**.

Table S-1
Summary of Lake and Watershed Recommendations

Recommendation	Lead Agency[a]	Cost[b]
Policy, Land Use, and Zoning		
BL-1 Beaver Lake Management Plan Adoption	KCSWM	N/A[c]
BL-2 Phosphorus Removal	KCSWM/ DDES	N/A[c]
BL-3 Lake Classification System	KCSWM	N/A[c]
Interim Monitoring		
BL-4 Interim Monitoring	BLPA/ BLCC	$5,000[d]
Long-term Monitoring		
BL-5 Construction Inspection, Technical Assistance, and Monitoring		$50,000
BL-6 Citizen Lake Monitoring	KCSWM/ METRO	$45,500
BL-7 Watershed Monitoring		
Streams	KCSWM	$40,000
Shallow Groundwater	KCSWM/ SKCDPH	$35,000
GIS Watershed Data Base Update	KCSWM	$20,000
Stormwater Treatment Performance	KCSWM	$34,000
BL-8 Inventories		
Existing On-Site Sewage Systems	SKCDPH	$14,500
Wetlands, Streams and Native Growth Protection Easements	DDES	$12,000
Stormwater Detention and Treatment Facilities	KCSWM	$12,000
Community Education and Involvement Programs		
BL-9 Beaver Lake Watershed Management Committee	KCSWM	$10,000
BL-10 Homeowner Education and Involvement Programs	KCSWM/ BLPA/ BLCC	$10,000

Continued on next page . . .

Recommendation	Lead Agency[a]	Cost[b]
BL-11 Homeowner BMPs		
Septic Tank and Drainfield Maintenance	SKCDPH	$1,000
Lawn Fertilization and Yard Maintenance	KCSWM	N/A[c]
Shoreline Revegetation	KCSWM	N/A[c]
Aquatic Plant Management	KCSWM	N/A[c]
Animal Waste Control	KCSWM	$10,000
Milfoil Prevention	KCSWM	$10,000
Low/No Phosphate House and Garden Products	KCSWM	N/A[c]
Household Hazardous Waste Disposal	KCSWD	N/A[c]
Community Meetings	KCSWM	$10,000
Modeling Analysis and Management Plan Update		
BL-12 Modeling Analysis	KCSWM	$40,000
BL-13 Beaver Lake Watershed Management Plan Update	KCSWM	$50,000
Watershed Management Contingency Plans		
BL-14 Contingency Stormwater Treatment		
Construction Practices	KCSWM	N/A[c]
Innovative Post Construction Treatment	KCSWM	N/A[c]
BL-15 Contingency Wastewater Management		
On-Site System Repair and Replacement	KCSWM/ SKCDPH	N/A[c]
Sewer Service Extension	KCSWM/ SKCDPH	N/A[c]
BL-16 In-Lake Contingency Plan	KCSWM	N/A[c]
Total Project Cost		$404,000

a. DDES - Department of Development and Environmental Services
KCSWM - King County Surface Water Management
KCSWD - King County Solid Waste Division
METRO - Municipality of Metropolitan Seattle
SKCDPH - Seattle-King County Department of Public Health
BLPA - Beaver Lake Protection Association
BLCC - Beaver Lake Community Club

b. All costs are estimated for a five-year period except for BL-4, which covers only one year.

c. Not applicable - costs will be covered by existing or future funding programs.

d. Not included in total cost because recommendation should be performed during the period of obtaining funding for the remaining recommendations.

The future water quality of the lake is dependent upon the density of new development, the effectiveness of stormwater and watershed controls, and the unique response of the lake to the changes in its watershed. In the event that the watershed controls summarized in **Table S-1** are found to be inadequate, future consideration to density controls as well as in-lake control measures should be considered as restorative measures to the lake quality.

In-Lake Control Measures

In the event that the application of source controls and structural best management practices in the watershed fail to achieve the lake management goal of non-degradation, the following in-lake control methods should be considered:

- Aluminum Sulfate Treatment
- Hypolimnetic Aeration
- Aquatic Plant Controls

Predicted Water Quality Benefits of Implementing Stormwater Controls

The predicted response of Beaver Lake to changes in watershed land use and the implementation of the stormwater controls is shown in **Figure S-2**:

- The amount of pollution (phosphorus loading), particularly in stormwater, is predicted to almost double without pollution controls. This will cause the lake to have poor water quality.
- The effectiveness of pollution controls is variable, depending on what is done and how good a job of installation and maintenance occurs.
- Careful monitoring of the watershed and lake is needed to decide if the pollution control measures are working or need improvements.

Schedule of the Recommended Plan

It is anticipated that the recommendations summarized in **Table S-1** will be implemented between 1993 and 2000, in the following tasks:

- Final Lake and Watershed Management Plan Approval — 1993
- LMD Formation and Ecology Grant Application — 1994
- BMP Implementation and Monitoring — 1995–2000

See Chapter 6 for a detailed management plan implementation schedule.

In addition, the Beaver Lake and Watershed Management Plan addresses the contingency measures identified in **Table S-1** that will be implemented if: (1) the need for such measures is demonstrated through citizen and watershed monitoring programs,

(2) affected agencies and organizations can agree on appropriate actions and funding mechanisms, and (3) environmental reviews and permit clearances can be obtained.

Funding for the Beaver Lake and Watershed Management Plan is available from the Washington Department of Ecology's Centennial Clean Water Grant, which currently provides a 50 percent matching fund. Following review and approval of the Beaver Lake and Watershed Management Plan, King County Surface Water Management plans to apply for Phase II funds through the Ecology Centennial Clean Water Lake Program for the watershed BMPs, totaling $404,000. The cost of many other BMP elements is assumed to be covered under other existing County programs. To cover local share of the grant, King County is proposing the formation of a Lake Management District.

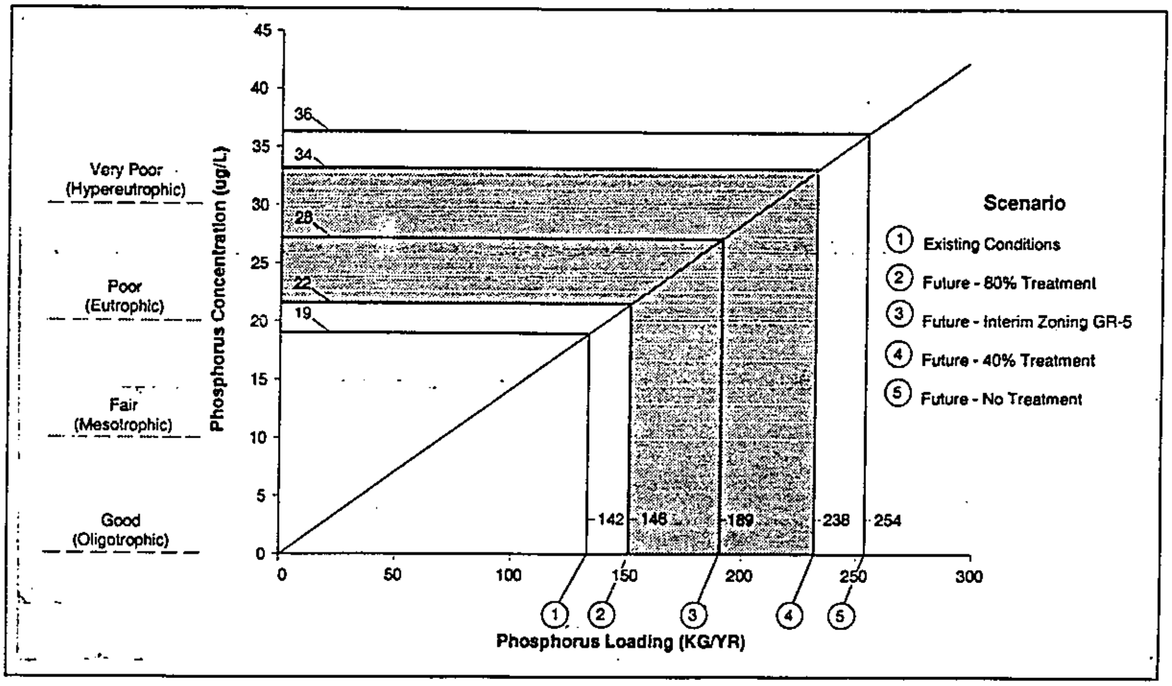


Figure S-2
Sensitivity of Beaver Lake to P Loading

CONTENTS

CONTENTS (Continued) **Page**

CONTENTS (Continued) — Page

FIGURES **Page**

FIGURES (Continued) **Page**

TABLES

1. INTRODUCTION

BASIS FOR THE STUDY

Beaver Lake is a 75-acre lake located approximately five miles northeast of Issaquah, Washington. Only 23 percent of the 1,041-acre drainage basin is currently developed. Beaver Lake has been classified by water quality agencies as mesotrophic (i.e., moderately productive), based on data collected between 1981 and 1989. The lake is heavily used for nonmotorized boating, fishing, and swimming.

Proposals to develop nearly one-half of the watershed are in the County's development review process. Increased runoff from the proposed watershed development may degrade the water quality of Beaver Lake unless appropriate pollution control measures and management practices are implemented. Because the proposed development of the watershed is imminent, a management plan is needed now to prevent future degradation of lake water quality and to correct any current problems.

There are no point sources of pollution within the Beaver Lake watershed (**King County SWM 1990a**) and, given the heavily forested watershed, nonpoint pollution is likely to be minor. However, the anticipated change in watershed land uses from primarily forested to residential could potentially degrade Beaver Lake's water quality (**King County SWM 1990a**). Nonpoint sources of pollution associated with residential development include construction activities, stormwater runoff, failing septic systems, improper pesticide/fertilizer applications, and household hazardous wastes. Nonpoint pollutants, such as sediments, nutrients, petroleum byproducts, pesticides, heavy metals, bacteria, and organics are typically related to residential development.

In addition to its effects on water quality, the projected land use changes potentially will modify the hydrology of the basin. The hydrologic impacts of watershed development include reducing groundwater recharge, stream base flows, wetland recharge, and groundwater availability for domestic supply (**King County SWM 1990a**). During the development phase of a watershed, construction activity typically results in increased sedimentation and nutrient release from exposed bare soil, unless mitigating measures, such as Best Management Practices (BMPs), are put in place and carefully maintained (**King County SWM 1990a**).

On-site sewage disposal does not currently represent a significant water quality threat within the East Lake Sammamish Basin, given the current failure rate of four percent (**King County SWM 1990a**). However, approximately 25 percent of the systems reviewed are over 20 years old. (The average life expectancy of an on-site sewage disposal system is from 20 to 40 years.) Therefore, failing on-site septic systems may pose a future water quality threat as the density and age of the systems increase.

GOALS AND OBJECTIVES OF THE PROJECT

Goals

Project goals were to:

- Assess water quality and the health of the lake
- Identify current problems and corresponding corrective measures
- Protect lake water quality
- Minimize watershed impacts which degrade water quality

Objectives

The specific objectives of the project are to:

- Conduct a Phase 1 lake restoration study of Beaver Lake, including a limnological monitoring program, to define the current biological, physical, and chemical conditions of the lake. A main focus of the Beaver Lake Phase 1 Restoration Study is lake eutrophication: greater levels of phosphorus loading resulting from the planned development of the watershed may degrade Beaver Lake's water quality by increasing algal blooms and decreasing oxygen for fish.

- Provide a restoration and management plan to prevent degradation of lake water quality and correct any current problems. The management plan will be based on results of the water quality monitoring program, predictions of future development in the watershed, and results from a computer model simulation of the watershed pollutant loading and lake water quality response. The lake water quality also will be used to predict the response of Beaver Lake to the application of restoration techniques.

- Provide information, education, and opportunities for public involvement to the technical advisory committee (TAC), watershed residents, users of the lake, and jurisdictional entities.

2. STUDY AREA DESCRIPTION

BEAVER LAKE CHARACTERISTICS

Beaver Lake is located approximately five miles east of Lake Sammamish on the plateau (**Figure 1**). The lake is primarily used for non-motorized boating (motorized boating is prohibited), fishing, bird watching, and swimming (**King County SWM 1990a**). The resident fish population includes large mouth bass, pumpkinseed sunfish, and rainbow and cutthroat trout. The Washington Department of Wildlife (Wildlife) regularly plants the lake with hatchery-reared rainbow trout (**King County SWM 1990a**). In 1989, Beaver Lake was planted with 7,000 rainbow trout of catchable size. (Refer to **Appendix A** for a listing of stocking records from 1980 to 1991 and creel survey records).

A seasonal Wildlife boat launch on the southeastern corner of the lake is currently the only public access point. (Refer to **Appendix B** for an inventory of existing and proposed access facilities for Beaver Lake. This inventory was conducted for the Beaver Lake Phase I Project to meet the grant requirements of the Centennial Clean Water Fund established by the Washington State Department of Ecology.) The 83-acre Beaver Lake Park, located on the southwestern shore, will soon provide a second public access point. The park has baseball diamonds, a play area, and a picnic area (**King County SWM 1990a**). Facilities along the waterside portion of the park (formerly occupied by Camp Cabrini) are being renovated. Upon completion, the park will provide facilities for special events, camping, boating, fishing, picnicking, and hiking (**The Portico Group 1987**).

WATERSHED CHARACTERISTICS

Community and Population

The East Lake Sammamish area (which includes the Beaver Lake and Pine Lake areas, Sahalee, Klahanie, and Grand Ridge) has one of the fastest rates of population growth in King County (**King County Parks, Planning, and Resources 1991**). Between 1980 and 1990, the population increased by 155 percent, from 12,300 to 31,300 people. The population of the East Lake Sammamish area is expected to increase by another 135 percent to 73,400 people by 2020. Currently, there are approximately 650 people living within the 1.63-square-mile Beaver Lake watershed, in 215 housing units (**King County Parks, Planning, and Resources 1991**).

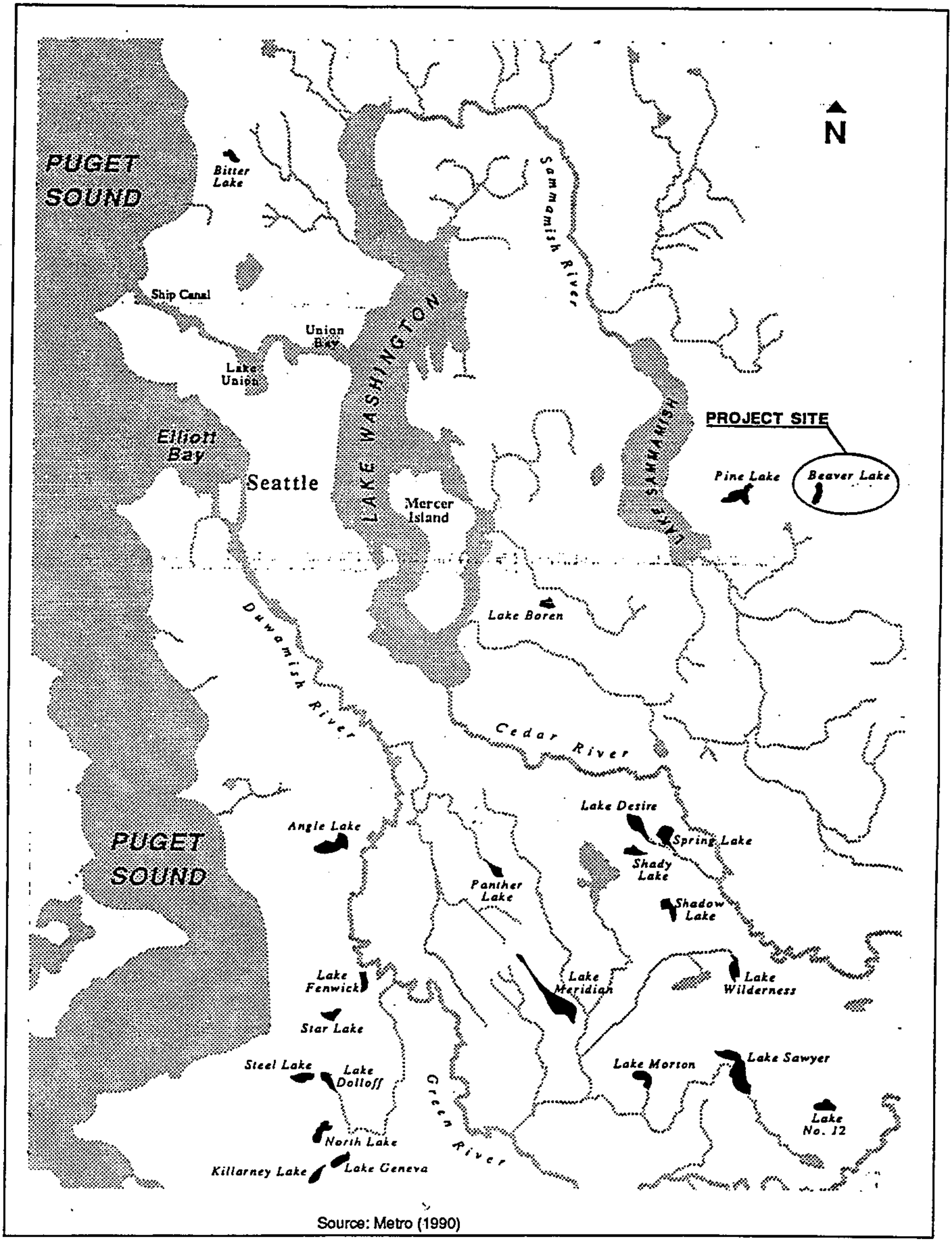


Figure 1
Project Vicinity

Existing and Future Land Use

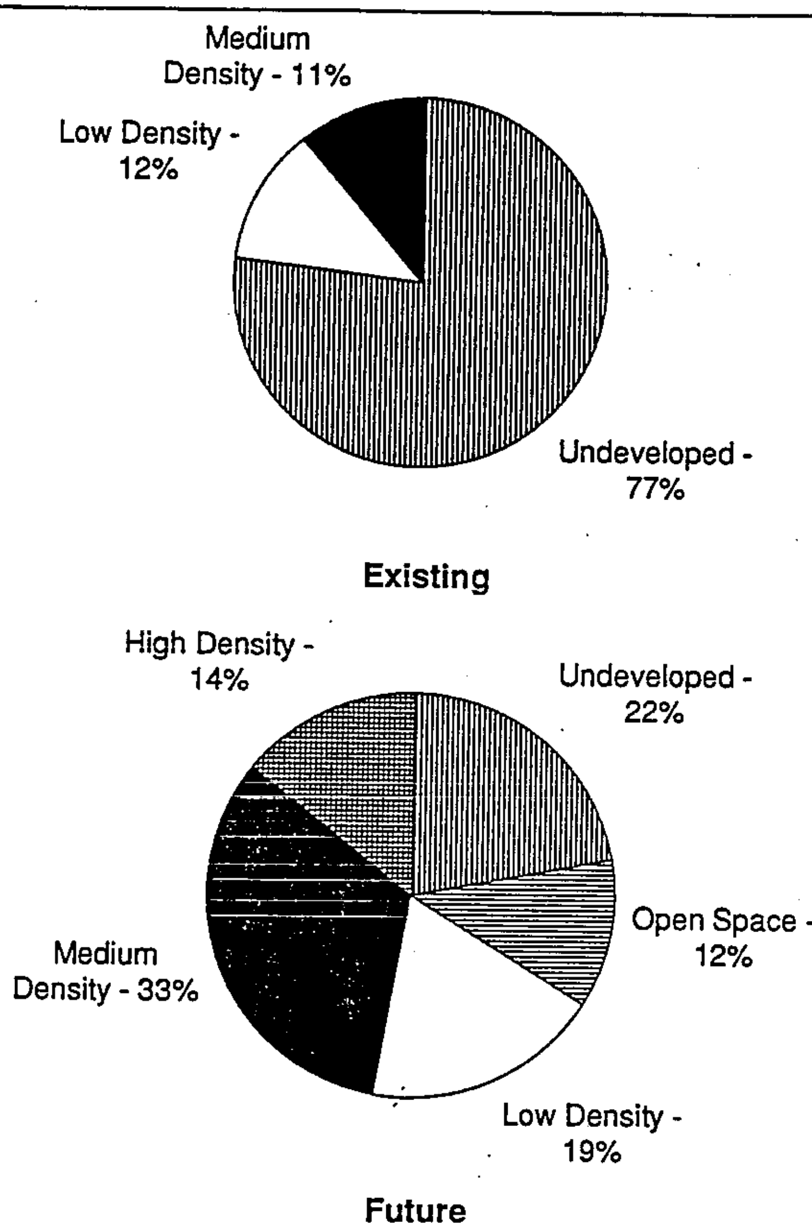
One of the most important issues of the Beaver Lake Restoration Study is the expected changes in land uses within the watershed. The proportion of existing and future land uses in the Beaver Lake watershed is shown in **Figure 2.** At present, the watershed is predominately undeveloped, consisting of second-growth forests and wetlands (**Figure 3**). The existing development consists of single-family housing, which is primarily located adjacent to the lake and to the west further upstream in the watershed. In the near future, it is expected that most of the watershed will be developed, primarily as low and medium residential density (**Figure 4**).

There are three major developments planned near Beaver Lake: the Beaverdam Property, the Beaver Lake Estates, and the Trossachs property. Each of these developments has a portion of its property located in the Beaver Lake watershed. The Beaverdam Property will be located northwest of Beaver Lake, and will have 114 single family residences and an 18-hole golf course. The Beaver Lake Estates is a 92-acre development, half of which will be developed, while the remaining half will be held in reserve for future development. Only a portion of this property drains to Beaver Lake. A total of 92 single family residences is planned when fully developed. The Trossachs property will include a residential development with approximately 52 homes within the Beaver Lake catchment (**Vasey Engineering Co., Inc. 1993**).

Additionally, part of the watershed now owned by the Washington State Department of Natural Resources (DNR) will likely be converted to low-density residential land use. The overall effect of these developments within the 1,041-acre watershed is to increase the number of dwelling units by more than six times, from 215 dwelling units to approximately 1,461 dwelling units. This represents an increase in residential density from approximately 1 dwelling unit per five acres (0.2 dwelling unit/acre) to approximately 1.4 dwelling units per acre.

Zoning and Land Use

Zoning within the Beaver Lake watershed is currently guided by the East Sammamish Community Plan and Area Zoning, which was adopted by the King County Council in 1982. Most of the watershed is zoned for Suburban Cluster (SC), one dwelling unit per acre. The two categories of SC are SC 9600 and SC 15000, with minimum lot sizes of 9,600 square feet and 15,000 square feet, respectively. The area immediately surrounding the lake is primarily zoned for Suburban Residential, which allows up to four dwelling units per acre. In March 1990, King County passed an interim zoning ordinance that changed the existing zoning from SC to Growth Reserve-5 (GR-5), one unit per five acres (**W & H Pacific 1991**). For the GR-5 classification, parcels greater than five acres may be subdivided with clustering of houses, provided that at least 75 percent of the parcel is maintained in reserve tracts suitable for future development.



Land use definitions:
Undeveloped - forested and wetlands
Open space - golf course and grass
Low density residential - 1 dwelling unit per acres or less
Medium residential - between 2 and 5 dwelling units per acre
High density residential - 6 or more dwelling units per acre
Source: **King County 1992a, King County 1992b, King County 1992c**

Figure 2
Changes in Land Use

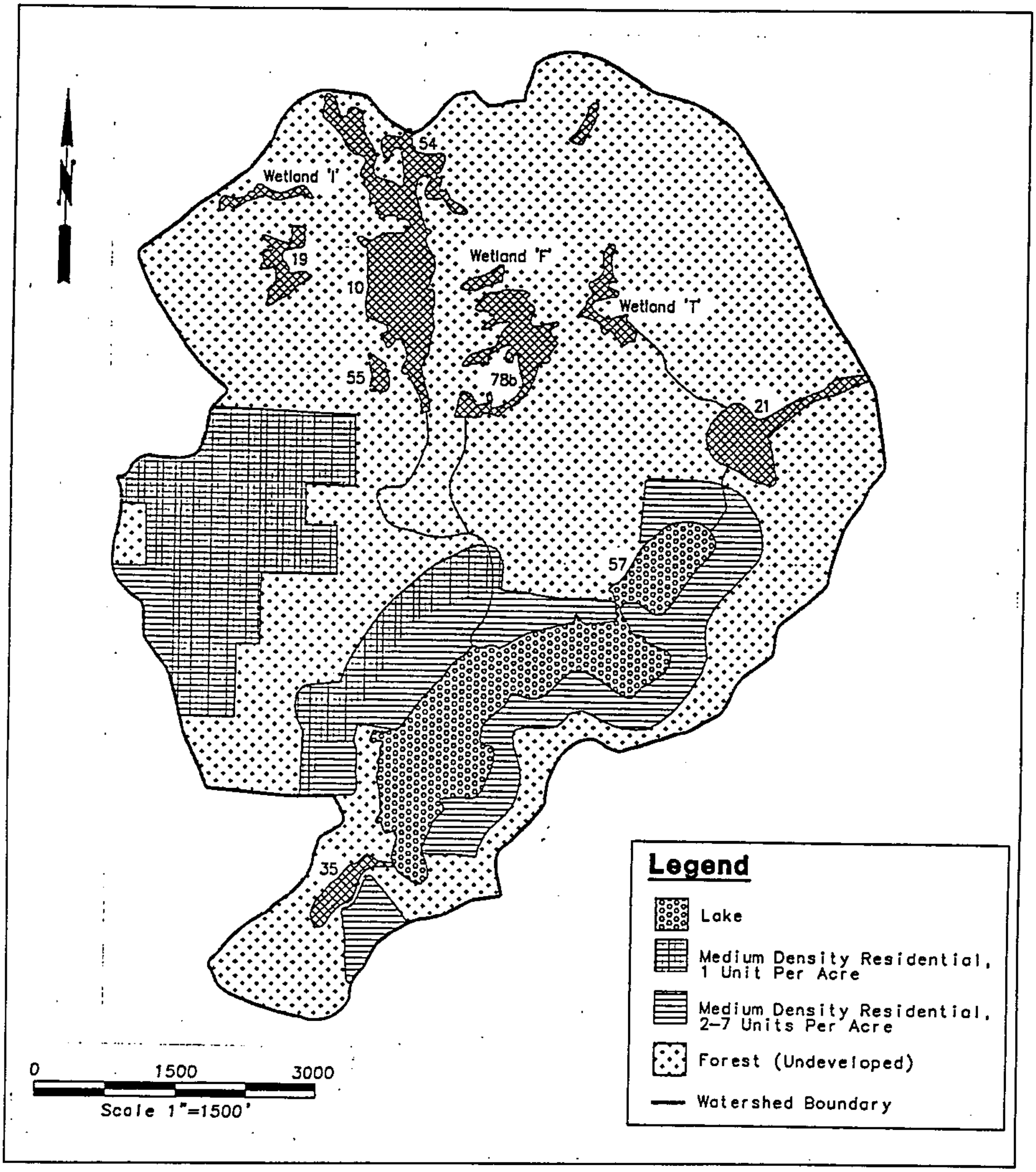


Figure 3
Existing Land Use in Beaver Lake's Watershed

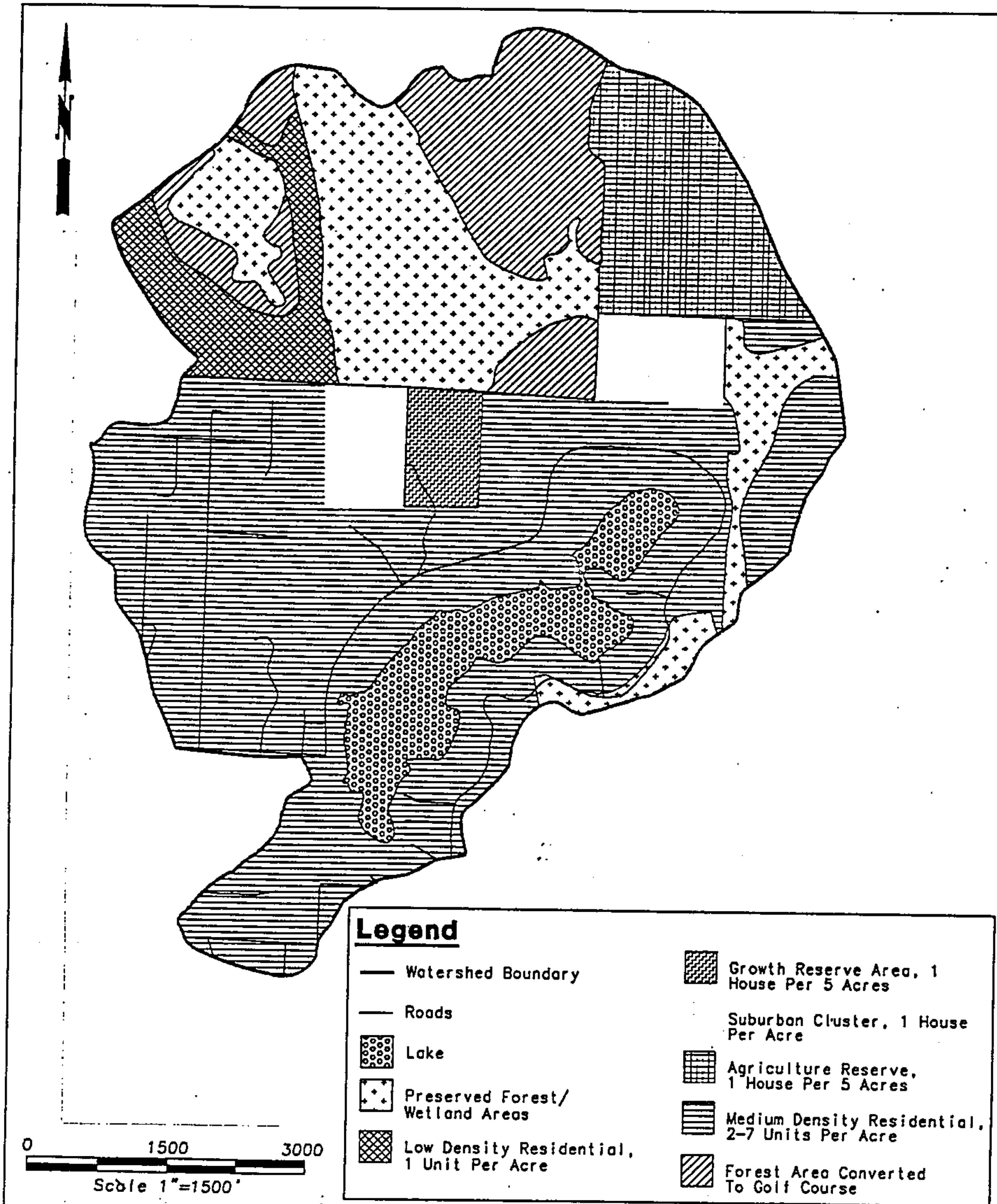


Figure 4
Future Land Use Within Beaver Lake's Watershed

Characteristic of the East Sammamish plateau, wetlands are an important part of the Beaver Lake watershed. There are eight identified wetlands within the basin (including the shoreline of Beaver Lake), comprising a total area of 67 acres (**Figure 3**). Wetlands 10 and 21, located upstream of Beaver Lake, are rated as Class 1 wetlands by the King County *Wetlands Inventory*, Volume 2 (**King County 1990b**). The shoreline of Beaver Lake is classified as a Class 1 wetland. (Refer to **Appendix C** for an assessment of wetlands within the Beaver Lake watershed.)

Geology

The geology of the East Lake Sammamish Basin, which includes the Beaver Lake watershed, was described in detail in the East Lake Sammamish Basin Conditions Report - Preliminary Analysis (**King County SWM 1990a**). The geology of the Beaver Lake area consists primarily of Pleistocene age deposits of the Vashon drift. This stade of the Fraser Glaciation originated in the mountains of British Columbia and climaxed approximately 15,000 years ago (**King County SWM 1990a**).

The glacial deposits in the Beaver Lake watershed consist of till and recessional stratified drift. The till is a light gray unsorted mixture of clay, sand, silt, and gravel. These deposits usually are not more than 150 feet deep. Although till is commonly referred to as hardpan, thin beds of perched water can occur within these deposits.

The stratified drift is characterized by unsorted to well-sorted, light gray, stratified sand and gravel, with small amounts of silt and clay. These sediments are deposited from glacial collapse features, such as stagnant melting ice. Glacial features produced by the Vashon drift include kame terraces, kames, and eskers.

Topography

The overall relief of the East Lake Sammamish basin has typically less than 100 feet variation in elevation (**King County SWM 1990a**). The low gradient areas that developed beneath the ice sheet are represented by filled lakes and wetlands deposited as the ice was retreating from the region during glaciation (**King County SWM 1990a**). The topography of the Beaver Lake basin is typical of the east Lake Sammamish plateau, with gently rolling hills that rise to 600 feet above mean sea level.

Beaver Lake is located at an elevation of 406 feet; therefore, the maximum elevation difference is slightly less than 200 feet. Because of the moderate slopes, no erosion or landslide hazards have been identified in the Beaver Lake watershed. Due to the low gradient, however, poor drainage is common in many areas of the watershed.

Climate

Maritime air from the Pacific Ocean moderates temperatures and rainfall throughout the year in the Puget Sound region. The area around Beaver Lake receives approximately 45 inches of precipitation each year, with 75 percent falling between October and March (**King County SWM 1990a**).

3. STUDY METHODS

This chapter discusses the field methods used in this study. The routine monitoring program is described first, followed by the methods used for the special studies. Analytical laboratory methods and the laboratory performing each analysis are listed in **Appendix D.**

The water quality of Beaver Lake was monitored between September 1991 and September 1992. The monitoring program included the following elements:

- Routine lake and inlet stream sampling
- Stormwater monitoring of the inlet streams
- Lake sediment analysis
- Groundwater sampling
- Fisheries surveys
- Septic leachate shoreline surveys
- Aquatic plant (macrophyte) surveys

ROUTINE LIMNOLOGICAL MONITORING

The present water quality condition of Beaver Lake was assessed by a baseline limnological study in which biological (plants and animals), chemical (nutrients, oxygen, and conductivity), and physical (secchi, temperature, flow, and precipitation) variables were collected between September 1991 and September 1992. **Table 1** presents a summary of parameters sampled during the study. Routine monitoring station locations are shown in **Figure 5.** Monthly sampling was conducted from September 1991 to March 1992 and again in September 1992, and twice per month between April 1992 and August 1992 for in-lake water quality sampling.

Discrete samples were collected at two-meter intervals (0.5, 2, 4, 6, 8, 10, 12, and 14 meters) from the surface to the bottom at the deep stations in Beaver Lakes 1 and 2 using a Van Dorn Sampler. Light intensity readings were made at one-meter intervals to one percent of the surface light—the depth of the euphotic zone. Composite samples, representing the euphotic zone, were collected for chlorophyll *a* and phytoplankton. Four samples from the euphotic zone were composited, using a Van Dorn Sampler.

Table 1
Summary of Beaver Lake
Routine Limnological Monitoring Program

Station[a]	Depth (m)	Parameters[b]
Beaver Lakes:		
BLAKE1-0	0.5	1, 2
BLAKE1-2	2	1
BLAKE1-4	4	1
BLAKE1-6	6	1
BLAKE1-8	8	1
BLAKE1-10	10	1
BLAKE1-12	12	1
BLAKE1-14	14	1
BLAKE3[c]	Surface	1
Tributaries:		
BLTR 1	Surface	3
BLTR 2	Surface	3
BLOUT1	Surface	3

a. BLAKE1 refers to Beaver Lake 1 stations, while the number following the dash is the corresponding depth. Beaver Lake 2 stations were sampled at the same depths as Beaver Lake 1.

b. The Parameters are defined as follows:
1. TP, SRP, NO_2+NO_3, NH_3, TKN, pH, turbidity, temperature, dissolved oxygen, alkalinity, conductivity, (and sampled quarterly: SO_4, Ca, Na, Mg, K, Cl, Al, Fe, TSP).
2. Fecal coliform and color (surface grab); Zooplankton - bottom to surface hauls; Chlorophyll *a*, phytoplankton biomass - euphotic zone composites consisting of four discrete samples; and Secchi and euphotic depths.
3. Temperature, dissolved oxygen, conductivity, TP, SRP, NO_2+NO_3, NH_3, TKN, turbidity, alkalinity, TSS, fecal coliform bacteria, and flow.

c. Beaver Lake 3 was generally too shallow to sample - it was sampled seven times during the study.

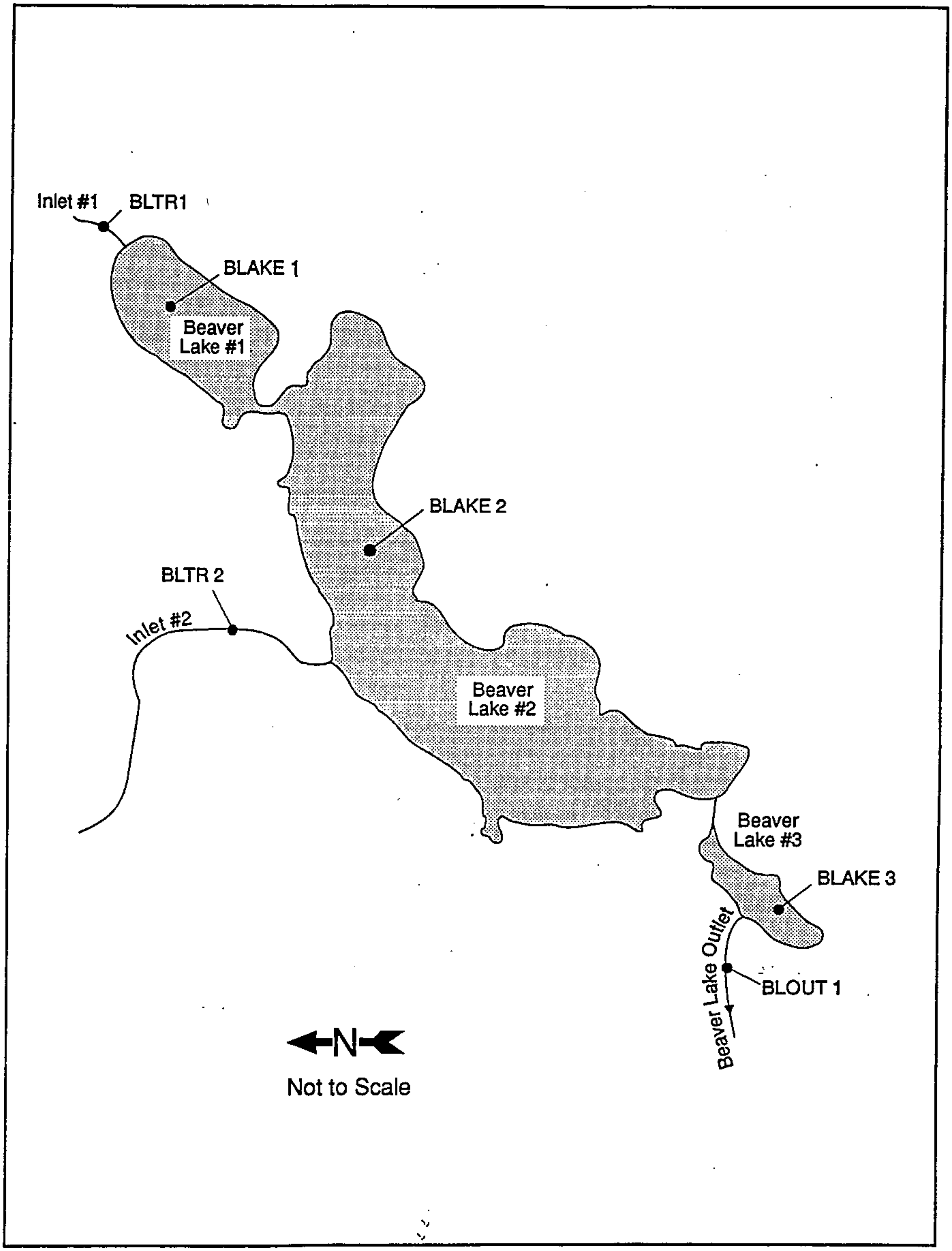


Figure 5
Routine Sampling Stations

The inlets, BLTR1 and BLTR2, and the outlet from Beaver Lake, BLOUT1, were sampled twice monthly between October and March and monthly between April and September. (Station locations are shown in **Figure 5** and the water quality parameters that were sampled are listed in **Table 1**.) The inlets flowed for only a portion of the study year, between December 1991 and June 1992. Instantaneous flow measurements were made using a Marsh-McBirney Model 265 Velocity Modified flow meter for each sampling event. Water level was continuously monitored at the outlet channel (BLOUT1) using a Leupold-Stevens Model F water level recorder. Lake level measurements were made by staff gauge readings at the Washington State Department of Wildlife Boat Launch. (Refer to Chapter 5 for the other components of the lake's water budget that were not routinely monitored, such as evaporation.)

The equipment used to measure conductivity, pH, temperature, dissolved oxygen, and euphotic zone depth is listed in **Appendix D**. Samples for nutrients were collected in acid-washed polyethylene bottles and stored in ice chests until analysis at the laboratory. A field replicate was taken on each sampling event for chlorophyll *a* and nutrients.

Phytoplankton samples were collected in 250 glass bottles and preserved with 5 ml of Lugol's solution. Phytoplankton samples were analyzed for species identification, enumeration, and biovolume. Zooplankton samples were bottom-to-surface hauls taken from each lake using a conical net (73 µm #20). Samples were preserved with 10 ml of formalin for every 250 ml of sample, and samples were identified for zooplankton species and density.

Benthic macroinvertebrates samples were collected every other month from three random stations in Beaver Lakes 1 and 2, using a Petite Ponar Grab. The benthic stations were sampled at depths of three to nine meters. Samples were sorted in the field, using two mesh screens (62-micron mesh size minimum), and preserved using alcohol. Samples were sorted for macroinvertebrate identification and abundance estimates.

TRIBUTARY STORMWATER MONITORING

The two inlets to Beaver Lake, BLTR1 and BLTR2, were sampled during three storms between January and April 1992. The samples collected during storms were used to characterize the existing water quality in the streams during high flows and to provide data for the development of the lake's nutrient budget.

The specific objectives of the stormwater monitoring were:

- Determine total phosphorus (TP) and soluble reactive phosphorus (SRP) event mean concentrations (EMC) for representative storms
- Compare the TP and SRP storm EMC data with other stormwater data
- Provide input data for the development of the lake response model

Storms greater than 0.5 inches in six hours or 1 inch in 24 hours were targeted. Samples were collected by the grab composite method. Under this method, a minimum of three grab samples (one each during the rising and falling limb of the storm hydrograph, and one near the peak) were composited to approximate a storm event mean concentration. This method was used to obtain representative storm samples at a lower cost compared to automatic flow-weighted sampling.

During each storm, field measurements were made for flow, temperature, dissolved oxygen, pH, and conductivity. All other water quality parameters were analyzed by the laboratories. After field sample collection, the samples were placed on ice in a cooler and returned to a laboratory at the end of the storm. Samples were composited, with the exception of fecal coliform, in the laboratory based on measured flow values. Fecal coliform samples were analyzed from individual grab samples taken on the rising limb of the hydrograph, typically the first sample.

For each sampled storm, flow measurements or V-notch weir measurements were made at each inlet sampling site. At BLTR1, this involved taking a height reading (h) at a 90° V-notch weir located at the sampling site (outlet of wetland ELS 21) (**Figure 3**). At BLTR2, cross-sectional flow measurements were made in the creek channel and at the pipe inlet during the time of sample collection. A Marsh McBirney flow meter was used to take velocity measurements. In addition, pipe depth measurements were taken at the inlet and outlet of the culverts during sample collection. The stormflow measurements at BLTR2 were used to develop an approximate stage discharge curve.

SEDIMENT ANALYSIS

The surface sediments of Beaver Lakes 1 and 2 were sampled in the summer of 1992 (to a depth of five cm) at ten deep-water locations using a Petite Ponar Grab. The purpose of the sediment sampling was to evaluate the potential for the lake sediments to release phosphorus. The sediment samples were analyzed for percent water, weight loss on ignition (total organic carbon), total phosphorus, nitrogen, aluminum, zinc, iron, lead, and separate fractions of phosphorus. Each sample was collected in glass jars and stored on ice in an ice chest until delivery to the laboratory, where samples were kept at four degrees Celsius until analysis. Samples were divided into two subsamples: one for total sediment analysis, and the other for the sequential extraction of the inorganic sediment phosphorus fractions.

A sequential extraction procedure of the inorganic sediment phosphorus fractions was conducted for each of the sediment samples. The sequential extraction procedure was performed by ARI using the modified procedure described in Hiltjes and Kijklema (1980). The extracting acids and corresponding phosphorus fractions are:

- NH_4Cl extractable P—this is loosely bound phosphorus that is easily released to the lake

- NaOH extractable P (iron and aluminum bound P)—this fraction is sensitive to changes in pH or redox conditions and will be released or sorbed accordingly
- HCl extractable P (calcium bound P)—this fraction is tightly bound and unavailable for release under most natural conditions
- Organic phosphorus—estimated by determining the difference between the sum of the three inorganic fractions and total phosphorus in the sediments

GROUNDWATER SAMPLING

Shallow groundwater samples were collected around the lake to characterize natural background concentrations and to provide data for the lake's water and nutrient budgets. Groundwater samples were collected quarterly from five domestic wells adjacent to Beaver Lake (**Appendix D**). (Note that two samples were collected at Well # 1 at depths of 103 feet and 140 feet, respectively. For more information on the procedures used for groundwater sampling, refer to the groundwater sampling plan in **Appendix D**.)

In addition to the groundwater sampling program, hydrogeologic data was examined to characterize the groundwater entering Beaver Lake. As part of this characterization, well log records were examined and the elevation of wells was determined.

The five wells were scheduled to be sampled in the quarterly monitoring program; however, in the first round of sampling, only Wells 3 and 4 were sampled due to equipment problems. Well 1 could not be sampled in July and September because it had been vandalized and Well 5 was dry in July and September.

Ground-water samples were analyzed in the field for temperature, pH, and conductivity. In addition, samples were analyzed for TP, SRP, nitrate nitrite nitrogen (NO_2+NO_3), ammonia nitrogen (NH_3), chloride, and Total Kjeldahl Nitrogen (TKN).

FISHERIES

Two gillnet surveys were performed in Beaver Lake to characterize the existing fish population. The first gillnet survey was conducted in spring 1992 (March 30–31), to represent conditions before stratification.. The second survey was performed during stratification in late summer 1992 (August 26–27).

For each survey, the sampled trout were analyzed for length, weight, age class, condition factor, and diversity. Four gillnets (two vertical nets and two horizontal nets) were set in the evening and removed on the following morning. The horizontal gillnets were used to characterize the type of fish found in Beaver Lake, while the vertical gill nets were used to document the vertical distribution of fish in the water column. Refer to **Appendix D** for specifications of net dimensions and soak times.

Fish samples collected from Beaver Lake were put on ice as soon as they were removed from the overnight gill net sets, and then taken to the boat launch area for processing. Fish samples were grouped by species and lengths. Lengths and weights were taken for each fish using a meter ruler and a postal scale. Scale samples were taken from rainbow trout for aging. Scales were taken from a standardized area on the left side of the fish, i.e., near the lateral line area below the dorsal fin. Fish age was determined by examining the scales under a dissecting microscope and observing the patterns of circuli. Stomachs from the rainbow trout collected in the spring and fall nettings were removed from the trout, wrapped in gauze cloth and preserved in a 10 percent formalin solution.

SEPTIC LEACHATE SURVEYS

The assessment of the contribution of on-site domestic wastewater systems to the pollution of Beaver Lake was based, in part, on two procedures: a comprehensive lake shoreline survey for shallow concentrated effluent plumes, and groundwater sampling of five wells along the lake's shoreline.

Septic surveys of the shorelines of Beaver Lakes 1 and 2 were conducted in early spring (March and April) and late summer (September) 1992 to represent wet and dry seasons, respectively. Shoreline septic leachate was surveyed using a K-V Associates Model 16 Septic Leachate Detector. The instrument is a hand-held flourometer indexed to the intermediate degradation products of human urine. It is secondarily sensitive to laundry whiteners. Under aerobic soil conditions these aromatic compounds are readily degraded by microbial action to non-flourescing carbon forms. However, under anaerobic saturated conditions of a failing septic drainfield, these compounds may travel intact for some distance and be detected by the flourometer as they break out at the shoreline **(Entranco 1989)**.

The surveys were accomplished by the operator sweeping the leachate detector along a narrow swath in front, while boating the shallow zone of the entire shoreline. The instrument continuously pumped lake water through the measurement cell and measured flourescence. When the unit showed a response, an effluent plume was suspected, and shoreline water quality samples were collected.

The instrument was set at a baseline with an open-water lake sample. For the Beaver Lake study, potential waste strength effluent plume was designated at a 0.1 percent urine solution. No manufacturer information is available regarding quantifiable detection limits of effluent study concentrations. However, based on an estimated 0.5 percent composition household wastewater from literature values **(Sigriest et al. 1978)**, the minimum detection level is expected to be at least as low 20 percent of a full strength effluent plume, and is likely much lower in the presence of laundry whiteners.

The flourometer provides only a qualitative indication of effluent plume presence; that is, positive signals require confirmation by collection and analysis of shoreline groundwater, surface water samples, or both. The water samples collected for each survey were analyzed for conductivity, chloride, ammonia-nitrogen, TKN, fecal coliform, SRP, nitrate+nitrite-nitrogen, and TP.

Macrophyte (Aquatic Plant) Sampling

The objectives of the macrophyte survey were to determine aquatic plant community composition, area distribution, and average phosphorus content of the macrophytes.

Aquatic plants in Beaver Lake were surveyed in September 1992. The entire nearshore area of Beaver Lakes 1 and 2 was visually inspected for the presence of emergent and submergent macrophytes. A rake sampler was used to determine the presence of submergent macrophytes below a depth of 3 feet. The rake sampler consisted of a weighted bow rake with a square foot area of 1/2-inch wire mesh for entangling macrophytes. Visual observations and rake samples were used for identifying macrophyte species and estimating the relative dominance of each species.

Ten areas were sampled for macrophytes for biomass and phosphorus content. Macrophyte samples were collected using the "half-barrel" method. The barrel sampler ($0.26m^2$) consisted of a one-third section of a 55-gallon drum with a nylon net attached to one end. Once the sampler was placed on the bottom, macrophytes were uprooted and pushed up into the net. The net was then twisted closed and brought to the surface. The macrophyte samples were gently rinsed in the lake, secured in labeled plastic bags, and stored on ice in a cooler.

4. LIMNOLOGICAL DESCRIPTION

MONITORING PROGRAM OBJECTIVES

The objectives of the Beaver Lake monitoring program were to:

- Characterize the existing limnology, including physical, chemical, and biological conditions, and define the current trophic state of Beaver Lake.
- Quantify the amount of nutrients entering Beaver Lake based on nutrient limitation analysis from various external sources in the watershed, including surface inflows, groundwater, and interflow. Quantify the release of nutrients from the lake sediments (internal loading).
- Compare water quality data collected in the current year with long-term data gathered by Metro.

A summary of selected water quality parameters sampled from Beaver Lake during the study year from September 1991 through September 1992 is presented in **Table 2.** The complete water quality database is presented in **Appendix E.**

LAKE PHYSICAL CONDITIONS

Water Temperature

The temperature-related characteristics of water have a large effect on the water quality and ecology of lakes. As water warms, it becomes less dense and floats on top of colder water. Unless there is enough wind to mix the water and therefore equalize the temperature of the lake, the water will tend to form two separate layers. This phenomenon is known as thermal stratification. After stratification starts, the upper layer, which is called the epilimnion, is warmed by sunlight, while the lower layer, which is called the hypolimnion, remains cool. Between these two layers is the metalimnion (or thermocline), which is marked by a rapid change in temperature from top to bottom. Because of the temperature difference, there is very little exchange of water between the epilimnion and the hypolimnion and, therefore, water quality can be very different in each layer.

Table 2
Summary of Selected Water Quality Variables
(± standard error)

	Units	Beaver Lake 1[a]	Beaver Lake 2[a]
Alkalinity	mg/l as $CaCO_3$	5 ± 0	8 ± 0.2
Conductivity	μmhos/cm	30 ± 1	36 ± 1
Total Nitrogen	μg/l	660 ± 31	510 ± 38
Dissolved Nitrogen	μg/l	95 ± 24	113 ± 24
Total Phosphorus	μg/l	28 ± 2	18 ± 2
Soluble Reactive Phosphorus	μg/l	7 ± 2	4 ± 1
Turbidity	NTU	0.5 ± 0.0	0.5 ± 0.0
pH[b]	s.u.	5.3–7.1	4.9–7.3
Color	PCU	72 ± 1	28 ± 1
Secchi	m	1.2 ± 0.9	2.4 ± 1.0
Chlorophyll *a*	μg/l	10.9 ± 1.1	4.2 ± 1.1
Fecal Coliform	(#/100 ml)[c]	2	2

Notes: Sampled in Beaver Lakes 1 and 2 during the study year, September 1991 through September 1992.

a. Values are average annual volume-weighted epilimnetic (usually to a depth of 4 meters) concentrations from 18 surveys at Beaver Lake 1 and 17 surveys at Beaver Lake 2.

b. pH values are annual ranges.

c. Fecal coliform values are geometric means.

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

The temperature profiles shown in **Figure 6** demonstrate the progression of thermal stratification in Beaver Lake 2 through the year. Beaver Lake 1 follows approximately the same pattern. Beaver Lake was completely mixed from late November 1991 until February 1992. The temperature in the lake was 5 to 9 degrees Celsius (40 to 48 degrees Fahrenheit) during the mixed period, with the coldest temperatures occurring in January. During the summer, the temperature in the epilimnion approached 22 degrees Celsius (72 degrees Fahrenheit), while the hypolimnion warmed to less than 8 degrees Celsius. The metalimnion was generally located between four and five meters (13 to 16 feet) in depth.

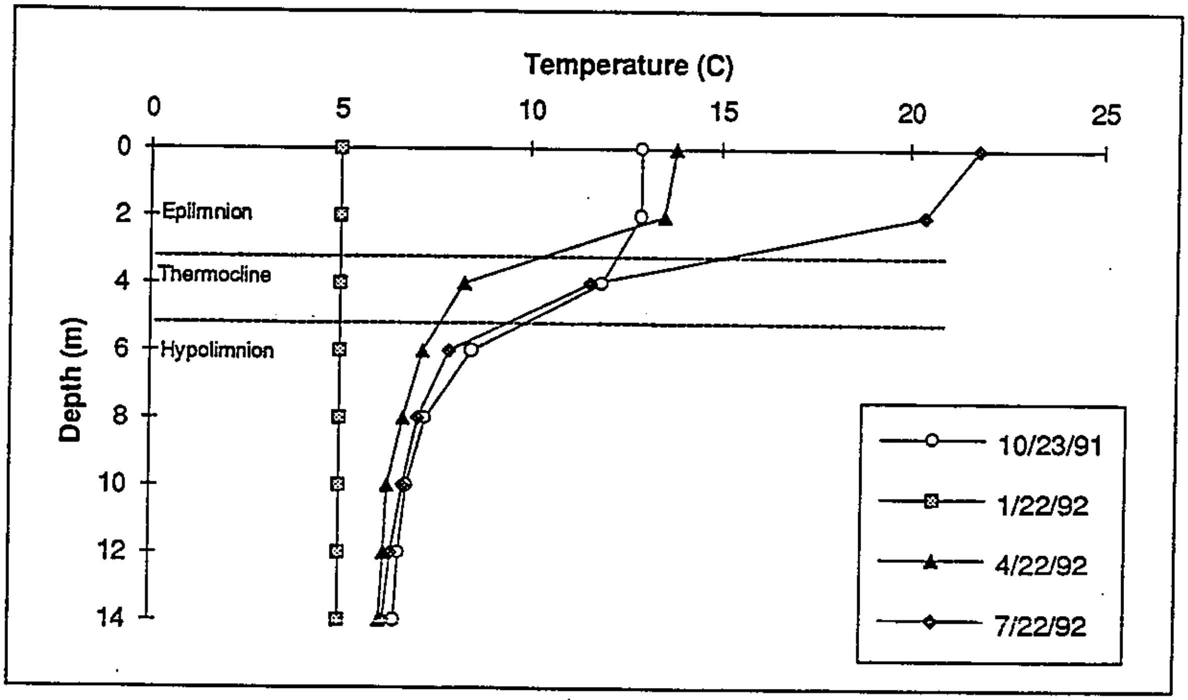


Figure 6
Beaver Lake 2 Temperature Profiles

The timing of seasonal stratification patterns in Beaver Lake 1 and Beaver Lake 2 were similar. The temperatures measured in Beaver Lake 1 were consistently lower than those in Beaver Lake 2, but the differences were not large.

Morphometry

The shape of a lake basin (morphometry) influences the lake's response to nutrients and potential pollutants entering it. For example, lakes that are relatively shallow are more likely to show water quality impacts from nutrient loading than deeper lakes.

Beaver Lake is separated by a narrow channel into two major subbasins, Beaver Lake 1 and Beaver Lake 2 (**Figure 5**). The channel nearly becomes dry by late summer. Each major basin is approximately the same depth, but with dissimilar shapes. Beaver Lake 1 is oval-shaped, while Beaver Lake 2 is significantly larger and much more elongated. Beaver Lake 2 contains 82 percent of Beaver Lake's total volume. Outflow from Beaver Lake 2 enters another channel at the southern end of the lake. Water from this channel enters a third and relatively minor basin, Beaver Lake 3. The outlet from Beaver Lake is located at the southwestern end of Beaver Lake 3 (**Figure 5**).

A summary of the physical characteristics of Beaver Lakes 1 and 2 is presented in **Table 3**. The bathymetry of both lakes is shown in the section on aquatic plants on page 54.

Table 3 Physical Characteristics of Beaver Lakes 1 and 2	Beaver Lake 1		Beaver Lake 2	
	English	Metric	English	Metric
Lake Surface Area	13 acres	5.24×10^4 m^2	61.5 acres	2.49×10^5 m^2
Maximum Depth	50 feet	15.2 m	50 feet	15.2 m
Mean Depth	21.0 feet	6.4 m	20.1 feet	6.14 m
Lake Volume	1.19×10^8 feet^3	3.34×10^5 m^3	5.48×10^8 feet^3	1.53×10^6 m^3
Shoreline Length	0.59 miles	0.95 km	2 miles	3.22 km
Altitude	407 feet	124.1 m	406 feet	123.8 m
Percent Hypolimnion Volume	50–55	---	50–55	---
Thermocline Depth	13 feet	4 m	13 feet	4 m

Source: **Bortleson et al. 1976**

The relationships between the lakes' volumes and areas with depths for each major basin are shown in **Figure 7**. This information indicates the proportion of a lake that is available for fish habitat or that is potentially without oxygen. The thermoclines in each basin were shallow—between four and five meters—through most of the stratified period. The hypolimnia in both basins of Beaver Lake are relatively large compared with other lakes of similar size, representing about one-half of the total lake volume in each basin. The large hypolimnia are due to the shallow depth of light penetration in the surface layer. The brown water color of Beaver Lake absorbs relatively more of the light compared with lakes that are less colored. As a result, the surface layers are warmer, while the hypolimnia are cooler. The source of Beaver Lake's color is dissolved humic substances from the wetlands in the watershed.

Water Clarity

Light is necessary for the growth of plants. The depth of sunlight penetration into a lake affects many important water quality factors, including the photosynthetic rate of algae and other aquatic plants, and the aesthetic quality of the water (**Thomann and Mueller 1987**). Absorption and scattering are the two principal mechanisms for reducing light in water. Suspended sediments in the water column mainly scatter light, while dissolved organic matter, which produces a brown color in water, absorbs light.

Table 4 presents a summary of the parameters that relate to water clarity and light transmittence in Beaver Lake during the summer recreational period. The levels of these variables were fairly constant throughout the study year.

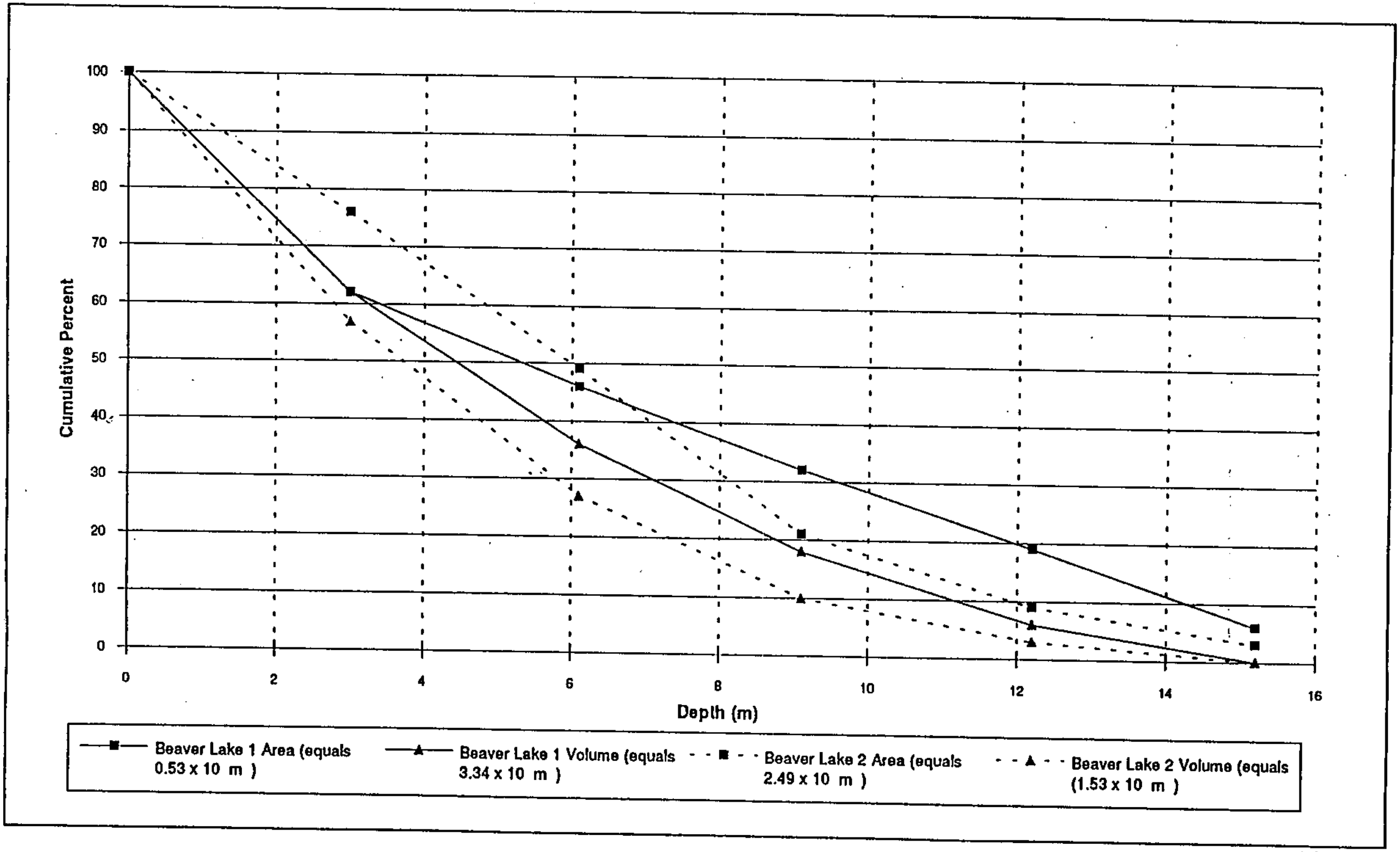


Figure 7
Depth/Volume and Depth/Area Curves

Table 4
Summary of the Variables Related to Water Transparency in Beaver Lake

	Average Summer Secchi Depth (m)	Average Summer Euphotic Depth (m)	Average Summer Color (PCU)[a]	Light Extinction (1/m)[b]
Beaver Lake 1	1.0	1.2	75	1.8
Beaver Lake 2	2.3	2.9	25	0.8

Note: Measured June - August 1992
a. Plantinum Cobalt Color Units
b. Based on an empirical estimate of 1.8/Secchi depth (Thomann and Mueller 1987)

Secchi Depth

Water transparency is most often measured in lakes by a Secchi disk. The depth at which this black and white disk can no longer be seen is referred to as the Secchi depth. Secchi depths not only provide information on the transparency of the water and the depth of light penetration, but also on trophic status, because the transparency of a lake often depends directly on the amount of algae suspended in the water (phytoplankton). The relationship between Secchi depth and algal biomass, as expressed in chlorophyll *a* concentrations, has been developed for a large number of lakes.

The monthly changes of Secchi depths in Beaver Lakes 1 and 2 are shown in **Figure 8.** Secchi depths were consistently higher in Beaver Lake 2 than in Beaver Lake 1. This is primarily due to the higher levels of color (and secondarily to higher levels of algae) in Beaver Lake 1. Secchi depths in Beaver Lake 1 and Beaver Lake 2 ranged from 0.9 to 2.0 meters (3 to 6.6 feet) and 1.9 to 3.6 meters (6.2 to 11.8 feet), respectively.

Although the brown water color in Beaver Lake reduces water transparency (for example, the highest Secchi depths in both basins occurred during the time of lowest color), there was not a significant correlation between Secchi depths and color (**Appendix E**). Additionally, there were no correlations between Secchi depth and other factors that reduce light in lakes, such as algal biomass or chlorophyll *a*—the peak in algae levels produced a negligible reduction in Secchi depths (**Appendix E**).

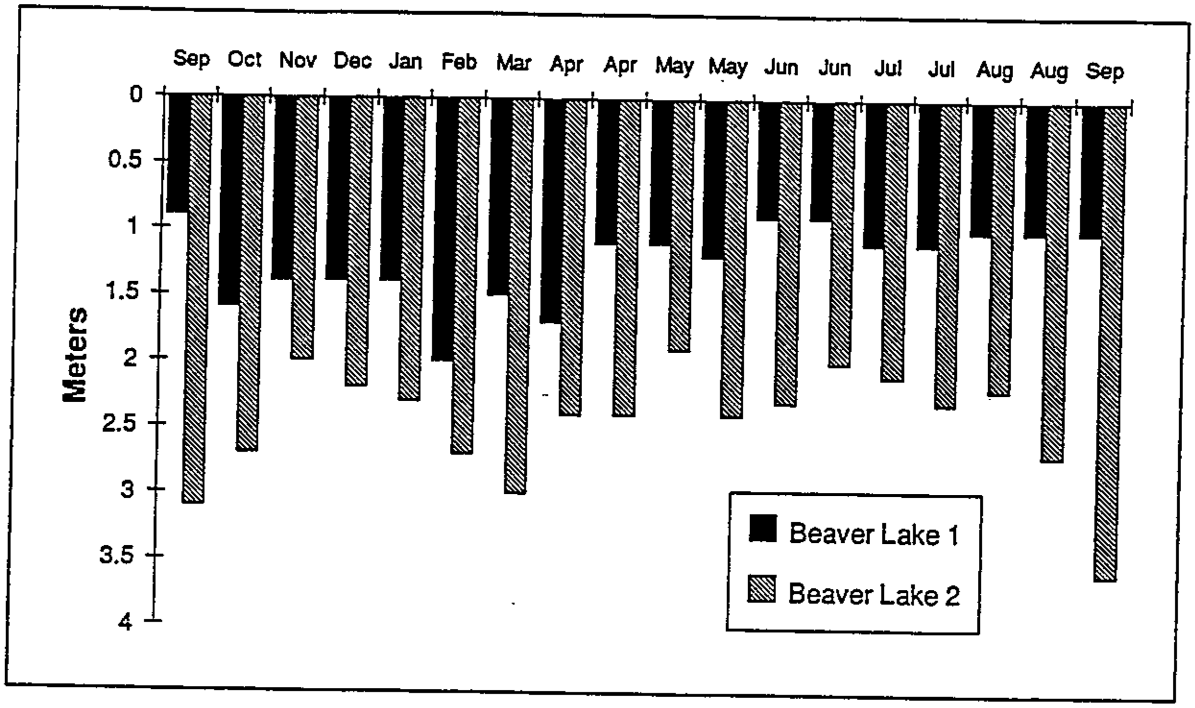


Figure 8
Secchi Depths
September 1991 through September 1992

Euphotic Zone

The depth in a lake at which one percent of the surface light remains is referred to as the euphotic zone. Below the euphotic zone, there is insufficient light to allow photosynthetic production by algae and aquatic plants. The euphotic depths in Beaver Lakes 1 and 2 ranged from 1.1 to 1.7 meters and 2.4 to 4.4 meters, respectively. Based on the euphotic zones and Secchi depths measured in the study, Secchi depths represented approximately 80 percent of the euphotic zone depth in both basins. Therefore, the euphotic zone roughly can be estimated by multiplying the Secchi depth by 1.2.

Color

Canfield et al. (1984) consider a water body "colored" if it has greater than 20 Platinum Cobalt Color Units (PCU). However, they caution that this is an arbitrary limit, and the effects of color on light penetration continuously increase as the color increases (**Cooke and Carlson 1989**). Beaver and Crisman (1991) considered a lake to be colored when it had greater than 75 PCU units. As shown in **Figure 9**, Beaver Lake 1 generally had two to three times the levels of color as Beaver Lake 2. On an annual basis, Beaver Lakes 1 and 2 averaged (± standard error) 72 (± 3) PCU and 28 (± 3) PCU, respectively. The difference in color is the result of relatively greater wetland drainage entering Beaver Lake 1.

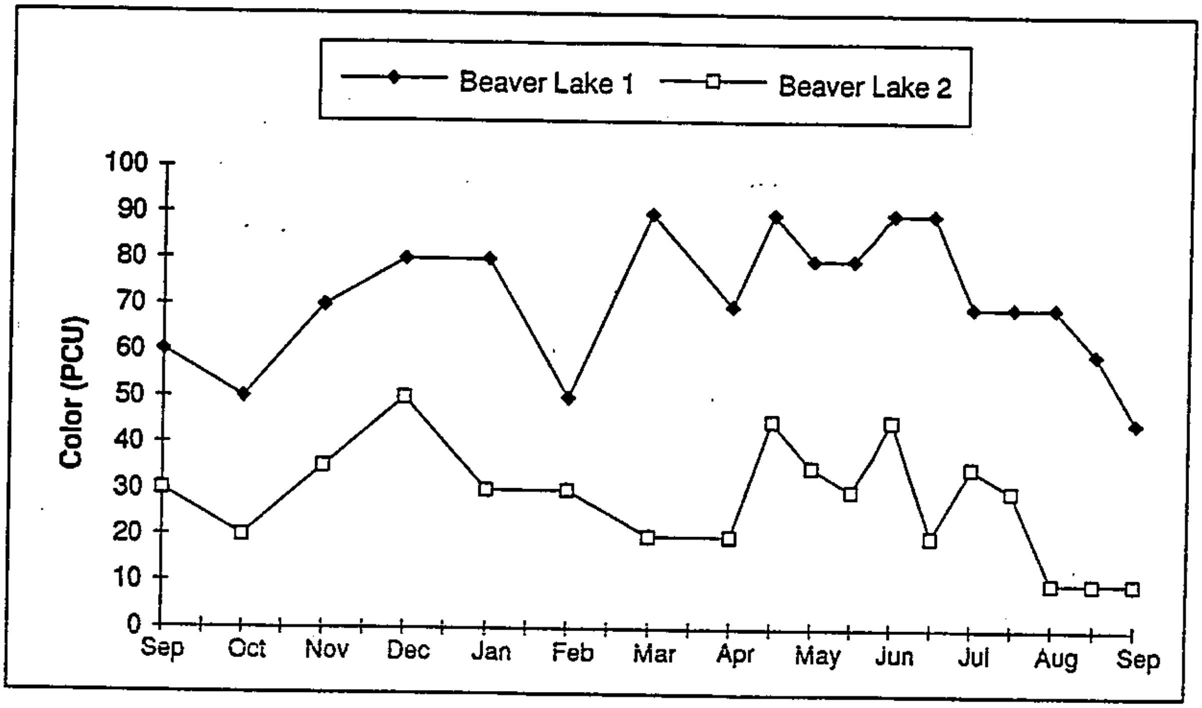


Figure 9
Temporal Pattern of Color
September 1991 through September 1992

Because certain algal species can grow under low light conditions, highly colored water in lakes does not necessarily result in low algal levels. Although organic color may limit the total biomass production, it apparently does not affect chlorophyll *a* concentrations (**Carlson 1992**). For example, highly colored Florida lakes (>75 PCU) were shown to produce high chlorophyll *a* concentrations (**Canfield and Hodgson 1983**). Under the conditions of moderate to high color, therefore, nutrient (phosphorus and nitrogen) concentrations control algal growth (**Carlson 1992**).

Other studies have found variable effects of high color on phytoplankton production (**Beaver and Crisman 1991; Canfield et al. 1984**). The complex interactions between humic material and nutrient forms also may regulate nutrient availability (**Beaver and Crisman 1991**).

In summary, it appears that color limits light penetration in Beaver Lakes 1 and 2, but color does not reduce algal chlorophyll *a* and biomass levels. For example, Beaver Lake 1 has much higher levels of color and algae. (The effects of color on Beaver Lake's trophic status is discussed on page 58.) The lake management implication is that nutrient control is a valid strategy for the regulation of algae levels in Beaver Lake.

Light Extinction

The rate at which light intensity is reduced with depth in the water column is referred to as the extinction coefficient. The higher the light extinction, the less light reaches lower waters. In Beaver Lake, as mentioned above, the vertical penetration of light appeared to be influenced more by the color of the water than by algal levels. The light extinction coefficient is high when there are no algae, indicating that the reduction of light in water is more likely caused by the other factors than algae, such as color.

LAKE CHEMICAL CONDITIONS

The water quality variables that describe the chemical characteristics of Beaver Lake's limnology are discussed in this section. The concentrations and seasonal patterns of various parameters are discussed.

Dissolved Oxygen

The level of dissolved oxygen (DO) in lakes determines the types of organisms which can survive in that environment. It also can affect natural chemical processes, such as the amount of nutrients released from the sediments of lakes. Anoxic conditions at the sediment surface usually increase the magnitude of sediment nutrient release. Oxygen is added to a lake from exposure to the air, and by the contribution of aquatic plants, through photosynthesis. Conversely, oxygen is removed from water by the respiration of aquatic organisms and plants, and the decomposition of organic matter in the water and sediments by bacteria.

Soon after Beaver Lake 2 becomes thermally stratified, oxygen levels in the hypolimnion fall to less than 2 mg/l (**Figure 10**). Beaver Lake 1 follows approximately the same pattern. These oxygen levels, which are called anoxic, are too low for fish and most animal life, and remain until the lake destratifies and mixes again in late fall.

Nutrient Limitation

A major focus of lake management is to control algae, because algal productivity directly and indirectly influences a range of other water quality characteristics in lakes (**OECD 1982**). Nitrogen (N) and phosphorus (P) are the major nutrients that limit algal growth in most lakes. Because phosphorus is typically in shorter supply than nitrogen, relative to the needs of algae, the management of lake eutrophication usually involves phosphorus control. Most lakes in the Puget Sound Region are phosphorus limited (**Gilliom 1981**).

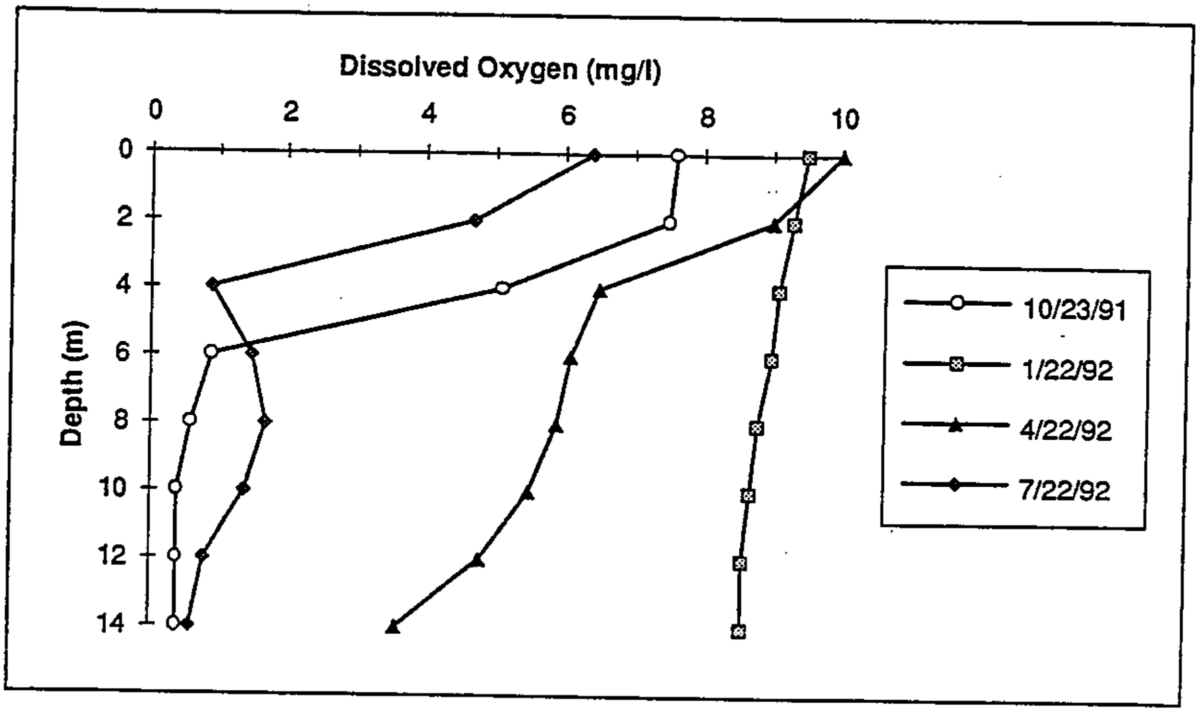


Figure 10
Beaver Lake 2 Dissolved Oxygen Profiles

Ratios of total nitrogen to total phosphorus (TN:TP) within the epilimnion (surface waters) greater than 17:1 usually indicate that the growth of algae in a lake is limited by phosphorus (**Cooke and Carlson 1989; Carroll and Pelleteir 1991**). Similarly, TN:TP ratios less than 10:1 generally indicate nitrogen limitation (**Carroll and Pelleteir 1991**).

The average annual and summer (June through August) volume-weighted epilimnetic TN:TP in Beaver Lakes 1 and 2 indicates that algae are limited by phosphorus concentrations (**Table 5**). The seasonal progression of TN:TP ratios indicate that phosphorus consistently limits algal growth in Beaver Lake (**Figure 11**).

Table 5
Ratios of Epilimnetic Total Nitrogen to Total Phosphorus

TN:TP	Beaver Lake 1	Beaver Lake 2
Annual Mean	26:1 (± 2)[a]	34:1 (± 4)[a]
Summer Mean[b]	34:1	48:1
Minimum	16:1	18:1

Note: TN:TP ratios greater than 17:1 generally indicate phosphorus limitation.
a. Numbers in parentheses are standard errors.
b. Summer: June–August.

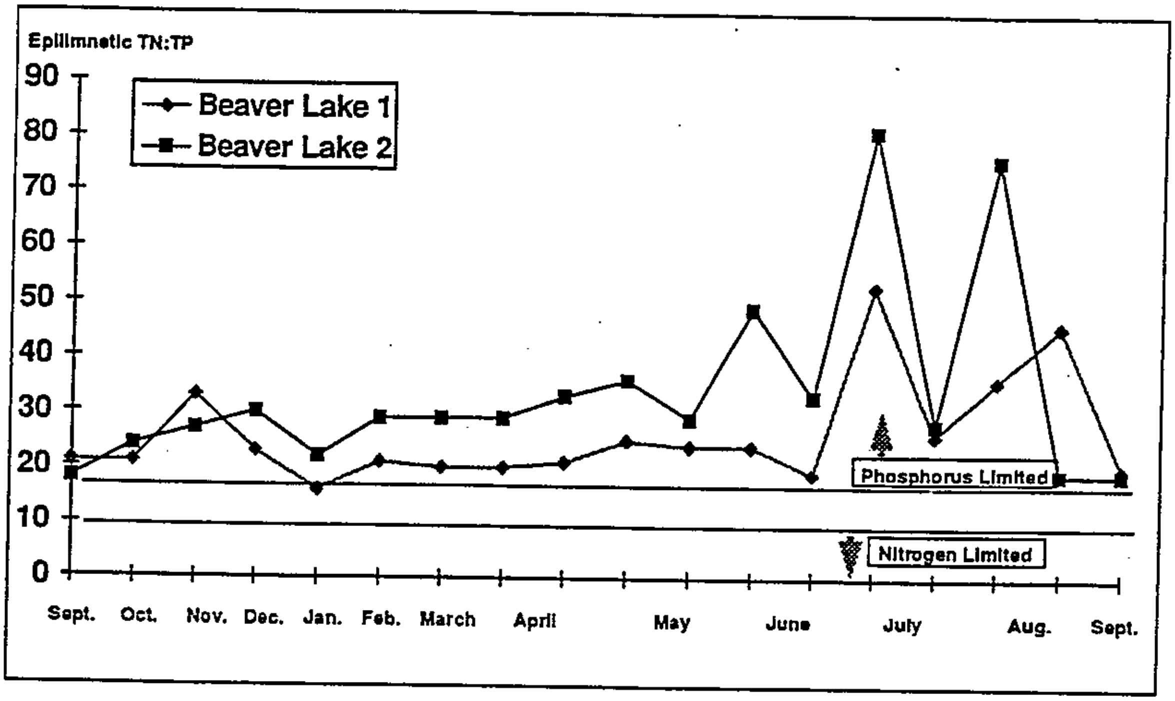


Figure 11
Seasonal Progression of TN:TP Ratios
September 1991 through September 1992

Because algal growth in Beaver Lake is limited by phosphorus concentrations, the nutrient budget, as discussed in Chapter 5, focuses on the sources and sinks of phosphorus. Therefore, for the control of algae in Beaver Lake, it is unnecessary to develop a separate nutrient budget and lake water quality model for nitrogen.

Phosphorus

As indicated by the above discussion on nutrient limitation, levels of phosphorus control algae in Beaver Lake. **Table 6** shows the relationship between the levels of phosphorus and lake water quality. Artificial increases in the concentration of phosphorus due to human activities in the watershed are the principal cause of eutrophication (**Chapman 1992**).

The two forms of phosphorus sampled in Beaver Lake during the study were total phosphorus (TP) and soluble reactive phosphorus (SRP). Total phosphorus includes organically combined phosphorus and all phosphates, while SRP is roughly equal to the amount of phosphorus that is readily available for algal uptake.

Table 6
General Relationship Between Phosphorus Concentrations and Lake Water Quality

Trophic Classification	TP Concentration µg/l	Group Characteristics
Oligotrophic	0 to 10	Low algal productivity; high suitability for all recreational uses. Algal blooms are rare and the water is extremely clear, with a Secchi disk transparency that is usually 5 m or greater. Summer chlorophyll *a* concentrations generally average less than 3 µg/l.
Mesotrophic	10 to 20	Moderate algal productivity; generally compatible with all recreational uses. Algal blooms are occasional, but generally of low to moderate intensity. Oxygen depletion is common in the bottom waters, and cold water fisheries may be endangered in some shallow lakes. In many lakes, however, the fishery may be enhanced by the increased productivity. Secchi disk transparency is usually 3 to 5 m, and chlorophyll *a* averages 2 to 6 µg/l in most lakes.
Eutrophic	20 to 30	Moderately high algal productivity; still compatible with most recreational uses, but algal blooms are more frequent and intense, and oxygen depletion is more serious. This can increase fisheries problems, though productivity may still be enhanced. Water is often somewhat murky and Secchi disk transparency is usually 2 to 4 m. Chlorophyll *a* usually averages 4 to 12 µg/l.
Eutrophic to Hypereutrophic	Greater than 30	High algal productivity; lake suitability for most recreational uses is often impaired by frequent and intense algal blooms, which may form floating scums. The water often takes on a "pea soup" color and is extremely murky. Fish kills may be common because of depleted oxygen, especially in shallow lakes. Secchi disk transparency is generally less than 3 m, and chlorophyll *a* concentration is usually greater than 10 µg/l.

Source: Modified from Gilliom (1984)

Volume-weighted concentrations of TP are summarized in **Table 7** and the temporal pattern of phosphorus is shown in **Figure 12.** The seasonal progression of phosphorus concentrations were similar in both basins of Beaver Lake; however, Beaver Lake 1 phosphorus levels were generally 10 to 20 µg/l higher than Beaver Lake 2.

Table 7
Summary of Volume-Weighted Mean Total Phosphorus Concentrations
(± standard error)

Mean	**Beaver Lake 1** µg P/l	**Beaver Lake 2** µg P/l
Annual		
Epilimnetic	28 (± 2)	18 (± 2)
Hypolimnetic	43 (± 4)	22 (± 2)
Whole-lake	36 (± 2)	20 (± 1)
Summer (June - August)		
Epilimnetic	22	11
Hypolimnetic	43	19
Whole-lake	34	13

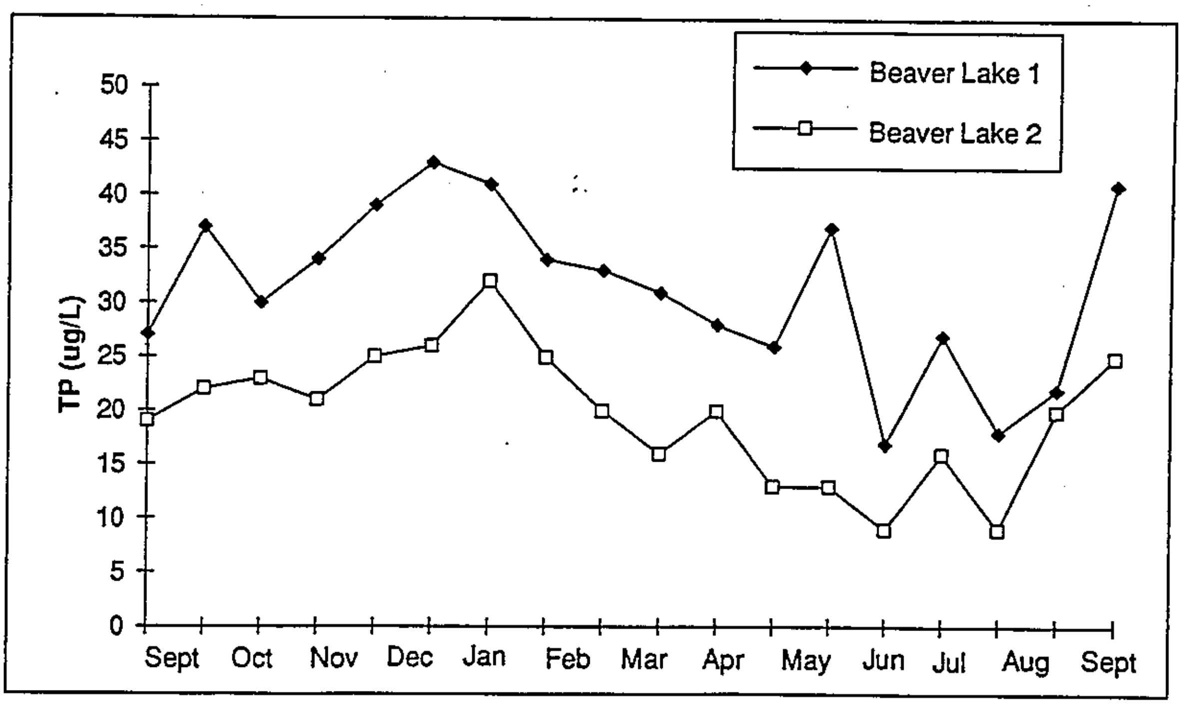


Figure 12
Volume-Weighted Total Phosphorus
September 1991 through September 1992

Beaver Lake 1

Volume-weighted, whole-lake TP levels in Beaver Lake 1 ranged from 20 to 50 µg/l, with an annual mean of 36 ± 2 µg/l during the study year (**Table 7**). Volume-weighted, whole lake-SRP concentrations ranged from 5 to 24 µg/l, with an annual mean of 12 ± 1 µg/l.

Concentrations of epilimnetic TP were highest during the spring, corresponding to the algal bloom at this time (**Figure 13**). Epilimnetic TP levels were relatively low during late fall in 1991 and decreased in mid-summer 1992—a common pattern in small lakes in this area.

Based on hypolimnetic phosphorus concentrations, the release of phosphorus from the sediments is delayed until late summer, despite anoxic conditions beginning in late spring (**Figure 13**). Phosphorus is usually released from the lake sediments under anaerobic conditions. (The cause of the delay in phosphorus release is discussed in the section on sediment chemistry.)

As shown in **Figure 13**, epilimnetic and hypolimnetic phosphorus concentrations were similar (except mid-May) through the onset of stratification (early April 1992) until early August. At this time hypolimnetic concentrations increased, while epilimnetic levels were stable. A similar pattern of elevated hypolimnetic concentrations occurred at the beginning of the study, from late summer until turnover in November 1991.

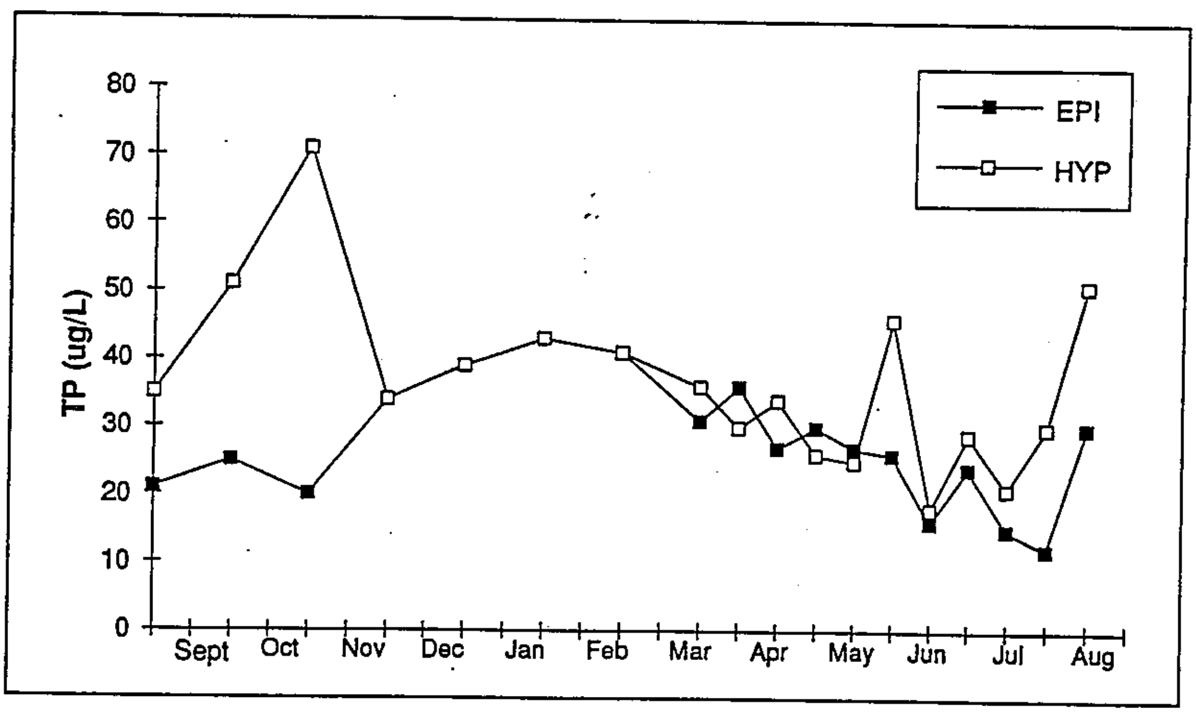


Figure 13
Beaver Lake 1 Volume-Weighted Total Phosphorus
September 1991 through September 1992

Beaver Lake 2

Although concentrations were lower in Beaver Lake 2, the seasonal pattern of phosphorus concentrations were similar to Beaver Lake 1 (**Figure 14**). Volume-weighted, whole-lake TP levels in Beaver Lake 2 ranged from 10 to 32 µg/l, with an annual mean of 20 ± 1 µg/l during the study year. Volume-weighted, whole-lake SRP concentrations ranged from 3 to 11 µg/l, with an annual mean of 5 ± 1 µg/l.

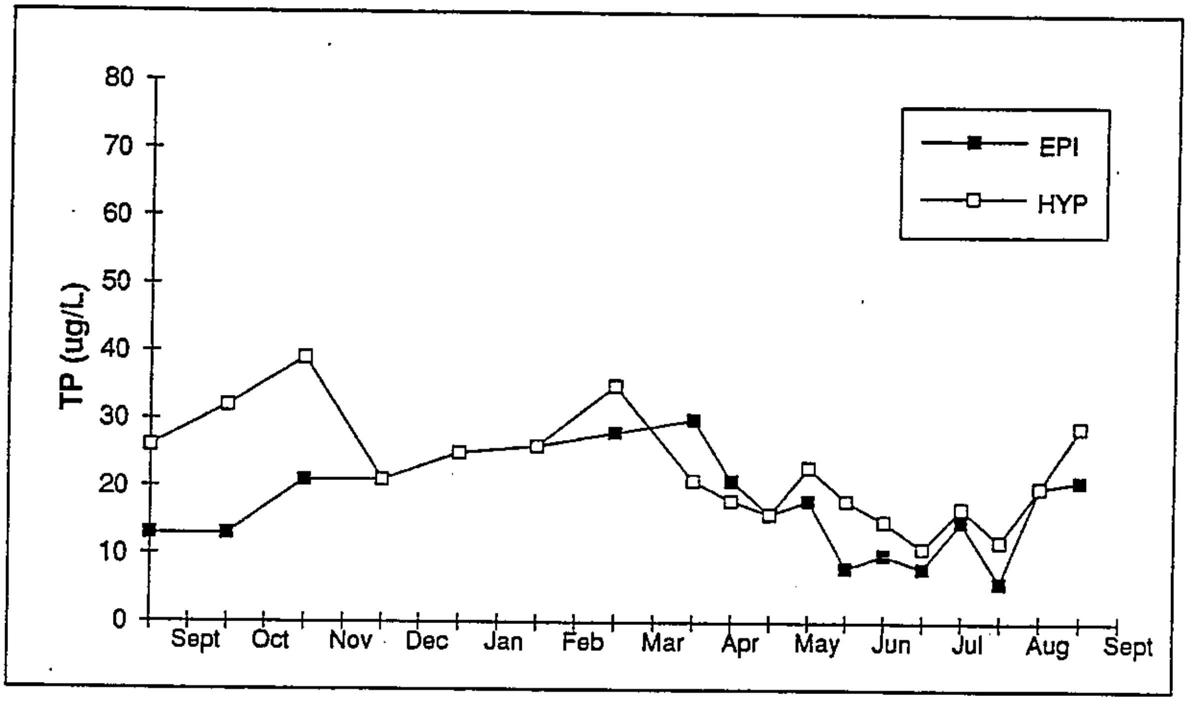


Figure 14
Beaver Lake 2 Volume-Weighted Total Phosphorus
September 1991 through September 1992

As with Beaver Lake 1, concentrations of epilimnetic TP were highest during the spring and reached a minimum during mid-summer (**Figure 14**). Total phosphorus levels within the epilimnion ranged from 11 µg/l to 42 µg/l, with a summer volume-weighted mean of 19 µg/l.

Hypolimnetic TP concentrations were generally similar to epilimnetic concentrations and showed a similar seasonal pattern to Beaver Lake 1—an increase in late fall 1991 and again in August 1992, and relatively low concentrations in mid-summer. Hypolimnetic phosphorus concentrations were relatively low, given the extended period of anoxia and the moderate levels of phosphorus in the epilimnion. Again, this indicates low sediment release of phosphorus. The maximum hypolimnetic concentrations of TP and SRP during the stratified period were 42 µg/l and 13 µg/l.

Nitrogen

Three forms of nitrogen were monitored in this study: ammonia-nitrogen (NH_3-N), nitrate+nitrite-nitrogen (NO_3+NO_2-N), and TKN. The dissolved inorganic forms of nitrogen (DIN), ammonia and nitrate plus nitrite, are readily available for plant growth.

Ammonia-nitrogen concentrations typically increase in the hypolimnion during stratification as a result of nitrification and the release of this soluble form of nitrogen from sediments. This pattern occurred in Beaver Lake 1, but was delayed until late summer, and was relatively minor.

High levels of un-ionized ammonia are toxic to freshwater life. Ammonia toxicity is not a problem in lakes with a pH below eight and ammonia-nitrogen concentration less than 1,000 µg/l. Levels of ammonia-nitrogen were low in Beaver Lake, averaging 45 ± 8 µg/l and 25 ± 4 µg/l in Beaver Lakes 1 and 2, respectively. It is unlikely, therefore, that chronic or acute levels of un-ionized ammonia are present in Beaver Lake.

Nitrate levels typically decrease in the lower waters of a lake during summer as dissolved oxygen concentrations decline and nitrogen remains in the reduced form of ammonia. If nitrate is not fully depleted in the sediment pore water, it may restrict the release of phosphorus from the sediments (**Harper 1992**). In both basins of Beaver Lake, nitrate levels declined during the summer, but did not become depleted in the hypolimnion. This may be another reason for the delayed release of phosphorus in Beaver Lake.

Concentrations of DIN peaked in winter to nearly 400 µg/l in both lakes, and declined to less than 50 µg/l through most of the summer. This is a common pattern in lakes, as ammonia and nitrate progressively decline in the epilimnion through uptake by algae during the growing season (**Harper 1992**). The volume-weighted epilimnetic mean DIN concentrations were 95 ± 24 µg/l and 113 ± 24 µg/l for Beaver Lakes 1 and 2. Similarly, the average DIN summer growing season epilimnetic concentrations decreased to 39 µg/l and 41 µg/l for Beaver Lakes 1 and 2.

The volume-weighted whole-lake mean annual TN (the sum of TKN and NO_3+NO_2) concentrations were relatively high: 659 ± 31 µg/l and 526 ± 37 µg/l for Beaver Lakes 1 and 2, respectively. Total nitrogen concentrations generally ranged between 400 µg/l and 800 µg/l in both lakes. The highest TN concentrations occurred during the late winter due to surface runoff entering the lake at this time. Total nitrogen values decreased in summer due to algal uptake and sedimentation to the lake bottom (**Carrol and Pelletier 1991**). As with phosphorus, TN concentrations were slightly higher in Beaver Lake 1.

Conductivity

Conductivity is a measure of a waters' ability to conduct an electrical current, and is an indicator of the amount of dissolved ions in the water. Conductivity of most freshwaters range form 10 to 1,000 µmhos/cm (**Chapman 1992**). The conductivity of a lake depends heavily on the type of soil and precipitation within the watershed. Beaver Lake had relatively low conductivity levels, even for Western Washington lakes. Conductivity (at 25°C) in Beaver Lakes 1 and 2, ranged from 16 to 43 µmhos/cm during the monitoring year. Through much of the study, conductivity in Beaver Lake 1 varied between 30 and 35 µmhos/cm. Beaver Lake 2 had slightly higher conductivities, generally between 35 and 40 µmhos/cm.

Alkalinity and pH

Alkalinity is a measure of a waters' capacity to neutralize hydrogen ions. The degree of alkalinity affects the ability of water to buffer or minimize changes in the lake pH. Because the pH of water affects many chemical and biological reactions, alkalinity can play an important role in the character of a lake. Alkalinities are generally low in Western Washington lakes, due to the lack of sedimentary carbonate (**Carrol and Pelletier 1991**).

Similar to conductivity, total alkalinity in Beaver Lake was low, ranging between 3 mg/l as $CaCO_3$ in Beaver Lake 1 to 11 mg/l as $CaCO_3$ in Beaver Lake 2. Waters of low alkalinity (<24 mg/l as $CaCO_3$) have a low buffering capacity, and can therefore be susceptible to alterations in pH (**Chapman 1992**). The low pH of organic acids from the wetlands within the Beaver Lake watershed may reduce the alkalinity levels in Beaver Lake, by effectively titrating the lake with organic acids (**Anderson and Welch 1991**).

Development may increase alkalinity through the leaching of cations from greater areas of concrete and the disturbance of the soil horizon, which in turn releases cations (**S. Abella, personal communication**). Long-term gradual increases in alkalinity are occurring in Lake Washington, and may be caused by increased development in the watershed (**Edmondson 1990**).

The pH of most natural waters is between 6.0 and 8.5, although lower values can occur in dilute waters high in organic content, such as Beaver Lake. Similar to nearby Pine Lake, the range of pH in Beaver Lake was slightly acidic, ranging from 4.8 to 7.2 in Beaver Lake 1 and 5.5 and 7.2 in Beaver Lake 2 (**Appendix E, Table 1**). The slightly acidic water in this area is due to the wetland drainage, which contributes humic acids (**Anderson and Welch 1991**). In general, pH values were highest in the surface waters due to the photosynthetic activity of algae in the epilimnion. (Refer to the trophic state section of this report for a discussion of the importance of pH in Beaver Lake as a controlling factor for algae.)

Sediment Chemistry

Sediments represent a significant source of phosphorus in many lakes. The capacity of the sediments of a lake to release or retain phosphorus depends on sediment chemistry, including the sediment's ability to bind phosphorus; the extent to which sediments are saturated with phosphorus, and the length of anoxia during the stratified period.

The top five centimeters of the sediments from Beaver Lakes 1 and 2 were sampled at ten random locations (five stations at each lake). The results of the surface sediment phosphorus fractionation are presented in **Table 8**.

Table 8
Sediment Phosphorus Fractionation Results

		Inorganic P			
	Total Bound P	Loosely Bound	Iron+Al Bound	Tightly Bound	Organic[a] P
Beaver Lake 1	1,068	24 (2 ± 2)[b]	208 (19 ± 2)[b]	5 (0.5 ± 0.1)[b]	838 (79 ± 4)[b]
Beaver Lake 2	1,427	21 (1 ± 1)[b]	539 (38 ± 11)[b]	7 (0.5 ± 0.2)[b]	865 (61 ± 12)[b]
Beaver Lake Average		(2)	(28)	(1)	(70)
Mean from other studies[c]	1,693	(3)	(11)	(49)	(31)
Range from other studies[c]	662–4,700	5–76 (1–7)	13–380 (1–27)	4–2,550 (11–79)	110–1,600 (10–57)

Notes: Values in mg/kg of dry-weight
Percent of total in parentheses
Results from ten station in Beaver Lakes 1 and 2 and comparison with other studies

a. Organic P is calculated by the difference between inorganic P and Total Bound P. This fraction includes organic bound plus that contained in minerals such as feldspars.

b. Standard error

c. Revised from **Bostrom et al. 1982.** Number of samples equals 14.

In this study, the following four fractions of sediment phosphorus were measured:

- **Loosely-bound phosphorus** (NH_4-Cl extractable-P): The fraction of phosphorus that is easily released into the lake.
- **Iron and aluminum-bound phosphorus** (NaOH extractable-P): The fraction of phosphorus that is sensitive to changes in pH or redox conditions in the sediment. This form of phosphorus becomes released under low redox environments, a typical condition found in the summer stratified period.
- **Calcium-bound phosphorus** (HCl extractable-P): The fraction of phosphorus that is tightly bound and unavailable for release under most conditions.
- **Organic-bound phosphorus**: the remaining form of phosphorus, which is highly refractory and rarely constitutes a source of phosphorus to lake water.

These fractions represent the progressive ability of phosphorus to be released by a lake's sediments. The first two fractions, which are inorganic, are those that are most easily used by algae and bacteria and therefore, most often increase lake productivity. Lakes most prone to high rates of internal phosphorus loading will be alkaline with sediments characterized by high concentrations of iron-bound phosphorus, and low concentrations of organic matter (**Ostrofsky et al. 1989**).

Phosphorus bound to inorganic species often constitutes the dominant portion of lake sediments. The exceptions are from highly organic sediments characterized as iron-rich peat (**Bostrom et al. 1982**). The role of organic matter (i.e., humic compounds) for the sorption of phosphorus, must be strongly emphasized in Beaver Lake. The sorption of phosphorus to humic substances is probably indirect, and in most cases, the result of a binding of phosphate to iron (III) associated with humic complexes, referred to as humic-iron-phosphate complexes (**Bostrom et al. 1982**). In other words, organic matter does not bind phosphate, but the adsorption of P is entirely dependent on the amount of associated metals such as iron and aluminum.

According to Bostrom et al. (1982):

> Since humic material has a strong tendency to chelate iron... the sediments of brown water lakes have a high capacity to retain phosphorus...humic-phosphate complexes are highly refractory...phosphate sorbed in humic-iron complexes should not be released as easily as phosphate sorbed to iron hydroxides when the redox potential is low.

In summary, Beaver Lake has a large proportion of the sediment phosphorus bound to organic matter (between 61 and 79 percent of the total sediment bound phosphorus), which reduces the amount of phosphorus released into the water.

Tributary Water Quality

Water quality within the main tributaries to Beaver Lake was evaluated using samples collected during routine monitoring and three storms. The amount of phosphorus entering Beaver Lake from each tributary (phosphorus loading) is discussed as part of the phosphorus budget development in Chapter 5.

Both tributaries drain through wetlands before they enter Beaver Lake. The tributary to Beaver Lake 1, BLTR 1, enters the lake from a forested drainage basin and wetland ELS 21 (**Figure 3**). BLTR 2 enters the north end of Beaver Lake 2 from wetland ELS 10 (**Figure 3**). The drainage basin of BLTR 2 is primarily forested, except for low-density residential near the southwest end of the subbasin. The drainage areas of BLTR 1 and BLTR 2 are 195 acres and 266 acres, respectively.

Routine Sampling

Average concentrations of selected water quality variables from the inlets are presented in **Table 9**. Refer to **Appendix E, Table 1** for the complete water quality database.

The water quality of the two inlets entering Beaver Lake reflect the primarily forested conditions of the watershed and drainage through the wetlands ELS 21 and ELS 10. Water quality variables, which generally increase with urbanization, such as turbidity, fecal coliform bacteria and nitrogen, were low in the tributaries. The geometric means of fecal coliform from the two inlets were well below the State Class AA standard of 50 org/100 ml. However, one of the nine samples collected from each inlet exceeded 100 org/100 ml, exceeding the State Class AA standard.

The influence of the tributaries on the water quality of Beaver Lake 1 and Beaver Lake 2 is shown by comparing average concentrations in these streams with each lake basin. (Refer to **Table 2** for a summary of water quality data from each lake). That is, the water quality of each lake is significantly different because of the distinct characteristics of the inlets and their drainages. For example, BLTR 1 has lower alkalinity, conductivity, and pH than BLTR 2. BLTR 1 has lower dissolved oxygen concentrations, probably because of the greater proportion of the wetland drainage in its catchment.

Total phosphorus concentrations from the tributaries were similar, averaging approximately 40 µg/l. The maximum TP concentration was 85 µg/l, but the phosphorus levels were fairly constant through the study. Although this phosphorus concentration is higher than typical forested conditions, it is much less than the phosphorus levels measured in the wetlands draining to Pine Lake, which averaged more than 150 µg/l (**Anderson and Welch 1991**). The Beaver Lake 1 Tributary had a greater proportion of phosphorus in the soluble form than that draining to Beaver Lake 2 (35 percent vs. 12 percent), which is the form of phosphorus that is readily used by algae. However, this is significantly less than the Pine Lake wetland, in which 90 percent was in the soluble form (**Anderson and Welch 1991**).

Table 9
Average Concentrations of Water Quality Variables Sampled in the Two Inlets to Beaver Lake

Variable	Units	Sampling Location[a] BLTR 1	BLTR 2
Alkalinity	mg/l as $CaCO_3$	3 ± 0	8 ± 1
Conductivity	μmhos/cm	29 ± 1	41 ± 2
Dissolved Oxygen	mg/l	4.4 ± 0.3	9.3 ± 0.5
Total Nitrogen	μg/l	781 ± 58	1,029 ± 74
Dissolved Nitrogen	μg/l	169 ± 43	418 ± 86
Total Phosphorus	μg/l	43 ± 4	40 ± 6
SRP	μg/l	15 ± 2	5 ± 1
Turbidity	NTU	1.7 ± 0.3	1.8 ± 0.4
pH[b]	s.u.[c]	4.4–6.2	5.6–6.8
Fecal Coliform	(#/100 ml)[d]	5 (1–180)	6 (1–590)
Temperature	(C)	7.1 ± 0.9	10.0 ± 1.5
Flow	(cfs)	0.5 ± 0.1	0.9 ± 0.3

Note: Routine sampling period: December 1991–July 1992.
a. Refer to **Figure 4** for station locations.
b. pH values listed are ranges.
c. Standard units
d. Fecal coliform values are geometric means, ranges are listed in parentheses.

Stormwater Sampling

The two inlets to Beaver Lake were sampled during three storms between January and April 1992 to collect data to characterize the water quality of high tributary flows **(Appendix E, Table 4)**.

The water quality varied only slightly between samples collected during storms and low flow periods (represented by routine sampling). This is a common phenomenon in undeveloped watersheds, and reflects the slow water runoff response of the watershed and its wetlands draining to the lake.

Values of stormwater phosphorus sampled from the two tributaries are summarized in **Table 10**. Concentrations from local storm data are listed for comparison purposes.

Total phosphorus concentrations varied from 35 to 98 µg/l over the three storm events, which is slightly higher than concentrations measured during the routine sampling and in similar local studies for small forested catchments (**Reinhelt et al. 1990, Metro 1990, Beak Consultants 1992**). Again, the slightly higher phosphorus concentrations in the inlets are due to the two major wetlands (ELS 10 and 21) directly upstream for both sampling stations. As with TP, the mean SRP values were slightly higher during storms—29 µg/l and 14 µg/l at BLTR 1 and BLTR 2, respectively. The phosphorus concentrations, however, were much lower than storm TP concentrations observed in nearby urban areas.

Table 10
Phosphorus Concentrations in the Inlets to Beaver Lake During Storm Sampling in Comparison with Local Stormwater Data

Site	Predominant Land Use	Average TP (µg/l)	Average SRP (µg/l)
BLTR 1	Forest	52 (47–60)	29 (14–28)
BLTR 2	Forest	57 (35–98)	14 (10–17)
Patterson Creek[a]	Forest	28 (7–57)	9 (2–47)
Middle Green[b]	Forest	26 (9–50)	–
Cedar Creek[b]	Mixed	34 (20–70)	–
Bellevue Creek[a]	Urban	171 (45–490)	38 (7–134)
Kelsey Creek[b]	Urban	106 (76–147)	–
Juanita Creek[b]	Urban	160 (52–325)	–
Bellevue Creek[c]	Urban	260 (2–3,600)	–
NURP[c]	Urban	460	–

a. Source: Puget Sound Wetland Study
b. Source: Metro; January 9, 1990 storm data removed from analysis.
c. National Urban Runoff Program; primarily storm drain data.

Turbidity values met the state water quality standard for Class AA streams (WAC 173-201), with the exception of the largest storm at BLTR 2, which reached 15 NTU. Turbidities are expected to be low because of the moderate slopes in the watershed and the small amount of development.

Fecal coliform concentrations were highly variable, ranging from 2 to greater than 1,900 organisms/100 ml. Geometric means of the three storms for fecal coliform were 22 and 149 org/100 ml for BLTR 1 and BLTR 2, respectively. (Note: the geometric mean of stormwater values for BLTR 1 exceeds the state standard for Class AA streams of

50 org/100 ml and both stream's stormwater values exceeded the Class AA criterion of not more than 10 percent of the samples exceeding 100 org/100 ml. This was, however, based on only three stormwater samples from each tributary.)

The flow rates during the monitored storms varied from about 0.6 to 1.6 cubic feet per second (cfs) at BLTR 2 and from 0.1 to 0.5 cfs at BLTR 1. In general, the response time of BLTR 2 was faster than BLTR 1, probably due to the greater forest coverage and relative wetland storage potential in the BLTR 1 catchment.

In summary, results of the storm sampling indicate that TP concentrations in stormwater entering Beaver Lake are slightly higher than other comparable forested creeks in the region, largely as a result of the wetland drainage. However, P concentrations are much lower than those measured in wetland drainage from Pine Lake or from creeks in urbanized catchments. The other principle effects of the watershed wetlands on tributary water quality include lowering of both pH and DO concentrations.

Groundwater Quality

Quarterly water quality sampling results of five wells in proximity to Beaver Lake are sampled and are presented in **Appendix E, Table 5.**

Comparison of groundwater elevations in these wells to the lake elevations suggests that shallow aquifer water flows into the lake in the vicinity of Well 3 and out of the lake in the vicinity of Wells 2 and 4. This flow pattern was consistent throughout the year. However, without a detailed hydrogeological study of the area, the quantity of groundwater flow reaching the lake (if any) cannot be determined with monitoring results. For this study, a modeling approach is used to estimate groundwater flows.

High groundwater concentrations of nitrate and phosphorus have been measured by other studies within the general area around Beaver Lake, but were not measured during this study. High nitrate concentrations (above the drinking water standard of 10,000 µg/l) were recently measured from groundwater sampling conducted by Terra Associates (**C. Lee, personal communication**). The maximum groundwater nitrate concentration, measured at GW-4, was 630 µg/l, which is slightly higher than tributary nitrate levels. Sources of high nitrate to groundwater include septic system wastewater, fertilizers, and fixation by certain vegetation, such as alders.

Although phosphorus, as measured by SRP, was generally higher in the groundwater than in the lake water, they were less than or equal to phosphorus levels in the inlets. Similarly, high SRP concentrations (a geometric mean of 206 µg/l) were recently measured from groundwater samples in the Patterson Creek catchment (**L. Reinhelt, personal communication**). The maximum concentration of SRP measured in the Beaver Lake study was much lower (93 µg/l) and the geometric mean was 22 µg/l (14 samples).

Although the total phosphorus concentrations measured from the groundwater wells were occasionally high (>100 µg/l), high turbidity within groundwater samples can contaminate samples and, when interpreted as groundwater values, can cause an overestimate of the amount of phosphorus that moves through the ground. The soluble form of phosphorus, SRP, gives a better estimate of the movement of phosphorus through the soil and the levels of phosphorus that may reach a lake.

Results of Septic Survey

Conditions that prevent or interfere with proper function of septic systems include unsuitable soils, high water tables, the occurrence of soil fissues that allow rapid movement of effluent (**Chapman 1992**), and steep slopes, as well as system undersizing or improper use. Many of these soil conditions can occur around lakes (**Olem and Flock 1990**). Water quality parameters that are potential indicators of septic tank effluent are high concentrations of nitrate, chloride, or fecal coliform. Nitrate in soils is dissolved in interstitial soil water, so it is easily leached by rainfall. An indication of possible septic system failure would be relatively high nitrate and chloride concentrations in groundwater samples. (As discussed above, groundwater sampling did not indicate excessive concentrations of these parameters).

In addition to the health effects, the primary concern of septic discharge to the lake is its contribution to in-lake phosphorus concentrations. An intensive study of septic tank phosphorus loading to Pine Lake indicated that movement of more than one percent of septic effluent phosphorus loading to the lake was rare (**Gilliom and Patmont 1983**). (The low rate of phosphorus loading is due to the ability of soils to adsorb phosphorus). The loading of phosphorus to the lake was probably associated with only a few old systems where soils are saturated during the winter.

To assess the impacts of nearshore septic tanks on the water quality of Beaver Lake 1 and Beaver Lake 2, two surveys to detect septic leachate were conducted in the winter and summer (refer to **Appendix E, Table 6** for the nearshore water quality data collected during the surveys). The summer survey was conducted to represent the time of heavy recreational use and the period when the dilution of septic effluent would be minimal. Conversely, the winter survey was performed when soils were saturated and septic systems were considered most likely to fail.

The purpose of the surveys was to document the occurrence of large-scale sources of septic failures, rather than to quantify the septic tank loading to the lake. The leachate survey was conducted by operating a septic leachate detector within shallow water along the lake shorelines. Nearshore water quality samples were collected to corroborate measurable responses by the detector and to characterize nearshore water quality.

In general, the shoreline septic survey did not show any conclusive evidence of a concentrated effluent plume entering Beaver Lake. During the summer survey there were two measurable responses directly offshore of two older homes, along the southeast shore of the lake. However, samples collected at these locations (sample numbers 4 and 5, **Appendix E, Table 6**) did not confirm septic tank effluent. The remainder of the shorelines of Beaver Lakes 1 and 2 showed no indication of large-scale effluent failure from septic tanks.

Absence of a verifiable plume does not necessarily indicate that drainage from septic systems is not entering the lake; rather, it suggests a lack of a concentrated, large-scale problem resulting from lakeshore septic tank failure. Septic system wastewater may still be entering the lake, but at a lower concentration than the detection level of the instrument, or septic wastewater may be discharging into a deeper portion of the lake.

LAKE BIOLOGICAL CHARACTERISTICS

This section describes the characteristics of Beaver Lake's biological community. Topics include fisheries, phytoplankton, zooplankton, aquatic plants, benthic macroinvertebrates, and bacteria. Data collected on these biological elements are provided in **Appendix F** and **Appendix E, Table 1**.

Fisheries

Historical Data

Beaver Lake's fish community was evaluated through a review of historical data and by gill net sampling in Beaver Lake 2. The historical records indicate a variety of fish species have been found in Beaver Lake (**Table 11**). The lake has been stocked with kokanee (*Oncorhynchus nerka*), and cutthroat trout (*Oncorhynchus clarki*). Cutthroat trout are native to Beaver Lake. The lake was chemically treated with rotenone in 1953 as part of a fisheries management program. This treatment apparently removed spiny rays for many years.

Table 11
Fish Species in Beaver Lake

Common Name	Scientific name	Confirmed from Gill Net Sampling
Rainbow Trout	*Oncorhynchus mykiss*	Yes
Largemouth Bass	*Micropterus salmoides*	Yes
Yellow Perch	*Perca flavescens*	No
Brown Bullhead	*Ictalurus nebulosus*	No
Pumpkinseed	*Lepomis gibbosus*	Yes
Kokanee	*Oncorhynchus nerka*	No
Cutthroat Trout	*Oncorhynchus clarki*	No

The existing fish community in Beaver Lake is a mixed assemblage of naturally reproducing spiny rays and annually stocked populations of rainbow trout. This type of mixed species assemblage is typical of mesotrophic lakes, which favor bass and perch species. Given the difficulty of maintaining a trout monoculture, the lake will probably remain as a mixed spiny ray-salmonid fishery for the near future.

Gill Net Survey Results

Gill net surveys were conducted before stratification (March 30-31, 1992), and during the stratified period (August 26–27, 1992). Data collected during the surveys are presented in **Appendix F.** The gill net surveys were used to characterize the existing fish community in Beaver Lake 2 through the analysis of fish condition factor and fish diet.

The fish condition factor is used as an index of "fatness" or "well-being" in fish, and may provide a useful comparison of individual fish weights relative to length. However, the index may be affected by two sources of variability: differences among individuals of a given length, and any change in relative weight that is a normal consequence of growth in species (**Ricker 1971**).

The condition factor of rainbow trout caught in the gill nets placed in Beaver Lake indicate that the fish are in good shape, and the trout do not appear to be limited by food. This is based on a relatively small sample size (**Appendix F**). Although the condition factor of stocked rainbow trout is good, the fish are confined to a narrow zone in the lower epilimnion, between 2 and 3 meters, during late summer. Fish were limited between the high epilimnetic water temperatures (greater than 21 degrees Celsius) and low hypolimnetic dissolved oxygen concentrations (less than 0.9 degrees mg/l). Any further widening or overlap of these two layers may result in a summer kill to the extent that no habitable area for trout would remain.

Trout in Beaver Lake feed mainly on the larvae and pupae of the phantom midge *Chaoborus* sp., based on an analysis of the stomach content of the trout caught during the August 1992 sampling gill net survey. *Chaoborus* larvae usually occur in the limnetic zones of lakes where they feed on zooplankton. Additionally, the stomach analyses data suggest the rainbow trout foraged at dusk and/or dawn. Although trout can briefly enter anoxic water to search for prey, anoxic conditions in the hypolimnion reduce the ability of rainbow trout to forage in these lower waters. Therefore, it appears that the trout fed on *Chaoborus* sp. in the epilimnion when there was sufficient light for predation, and when the *Chaoborus* sp. were higher in the water column.

Phytoplankton

Phytoplankton are the small suspended algae of lakes and include both free swimming forms that do not colonize, such as euglenoids, and colonial forms. Algae are easily carried in the water by currents and wind and tend to float near the water surface. The

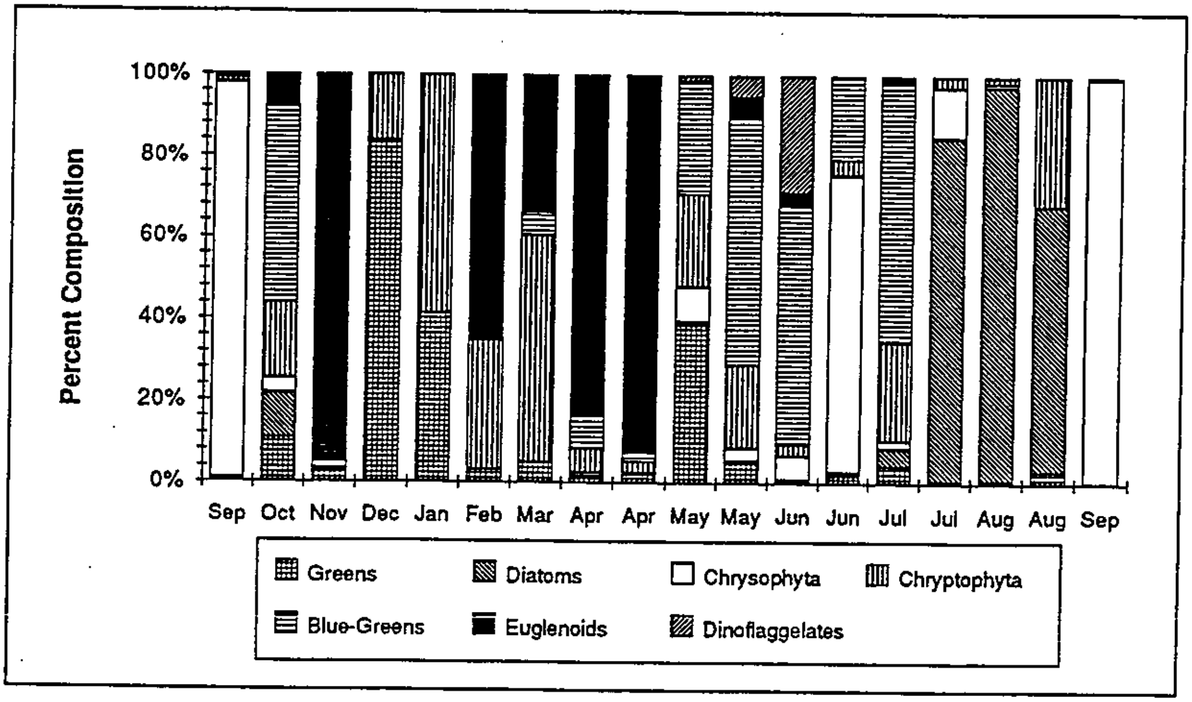


Figure 15
Beaver Lake 1 Phytoplankton Composition
September 1991 through September 1992

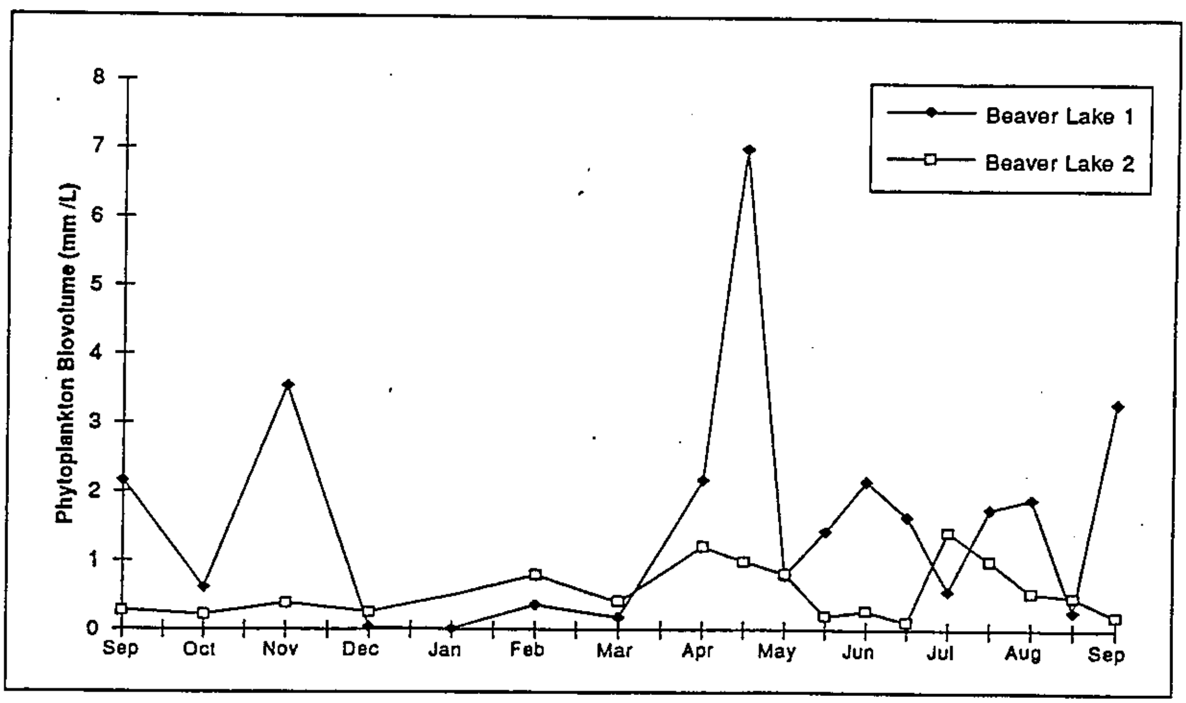


Figure 16
Beaver Lake Phytoplankton Biovolume
September 1991 through September 1992

In addition to the direct measurements of biomass levels derived from cell volume counts, the abundance of algae in Beaver Lake was estimated by chlorophyll *a* concentrations. In general, chlorophyll *a* concentrations in Beaver Lake 1 reflect the high phosphorus levels, and do not appear to be limited by the high colored conditions of the water. The annual and summer chlorophyll *a* concentrations in Beaver Lake 1 were 10.9 µg/l and 15.2 µg/l, respectively. Chlorophyll *a* concentrations were low until the early April bloom of *E. viridis*, at which time chlorophyll *a* concentrations rapidly increased to 44 µg/l (**Figure 17**). Typical of bloom conditions, chlorophyll *a* levels significantly decreased two weeks later. High chlorophyll *a* levels persisted through the summer.

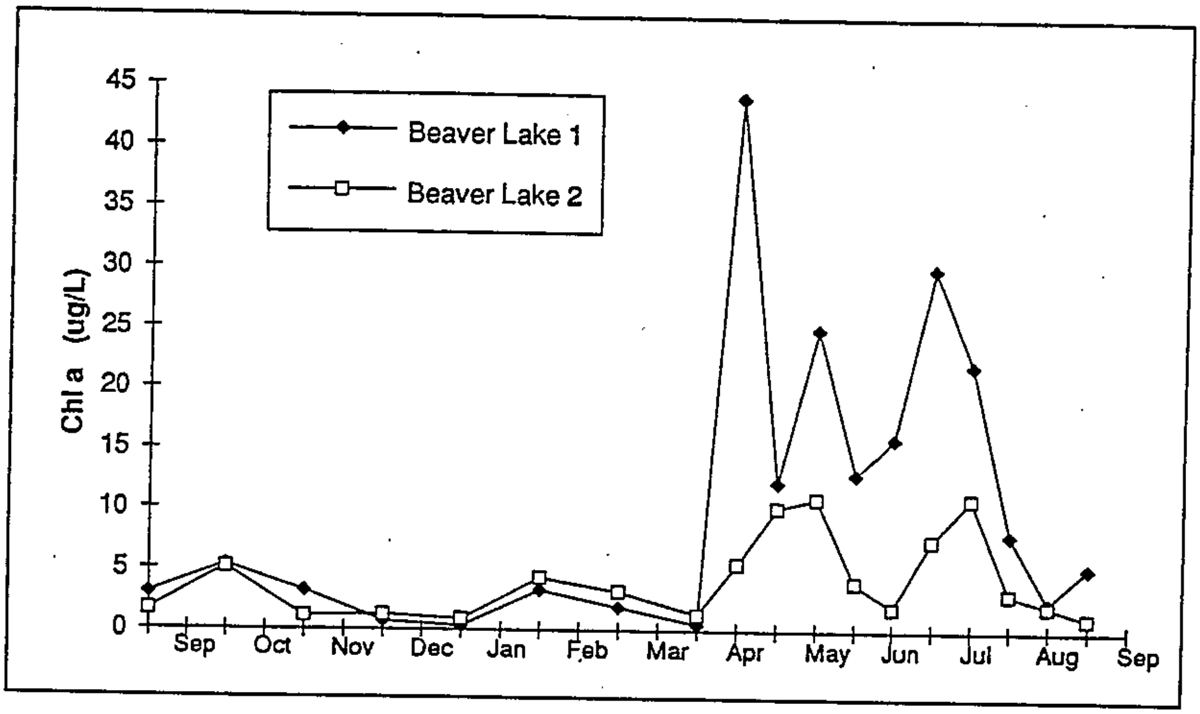


Figure 17
Beaver Lake Chlorophyll *a* Concentrations
September 1991 through September 1992

Beaver Lake 2

In contrast to Beaver Lake 1, Beaver Lake 2 had a relatively small proportion of euglenoids through most of the year, a much higher proportion of blue-greens, fewer periods of complete dominance by a single algal group, and, on an annual basis, much lower levels of algae.

Blue-green algae, primarily *A. flos-aquae*, were a significant portion of the algal community through most of the year and were dominant during the winter (**Figure 18**). *A. flos-aquae* can form large colonies on the surface (they have psuedovacuoles which give the plant great buoyancy) which look like small grass clippings in the water. Golden-browns and chryptophyta (*Chyrptomonas* sp. and *Rhidomanos* sp.) were the next most dominant algal group in Beaver Lake 2. *E. viridis* was absent, or comprised less than five percent of the algal community in Beaver Lake 2, through most of the study year.

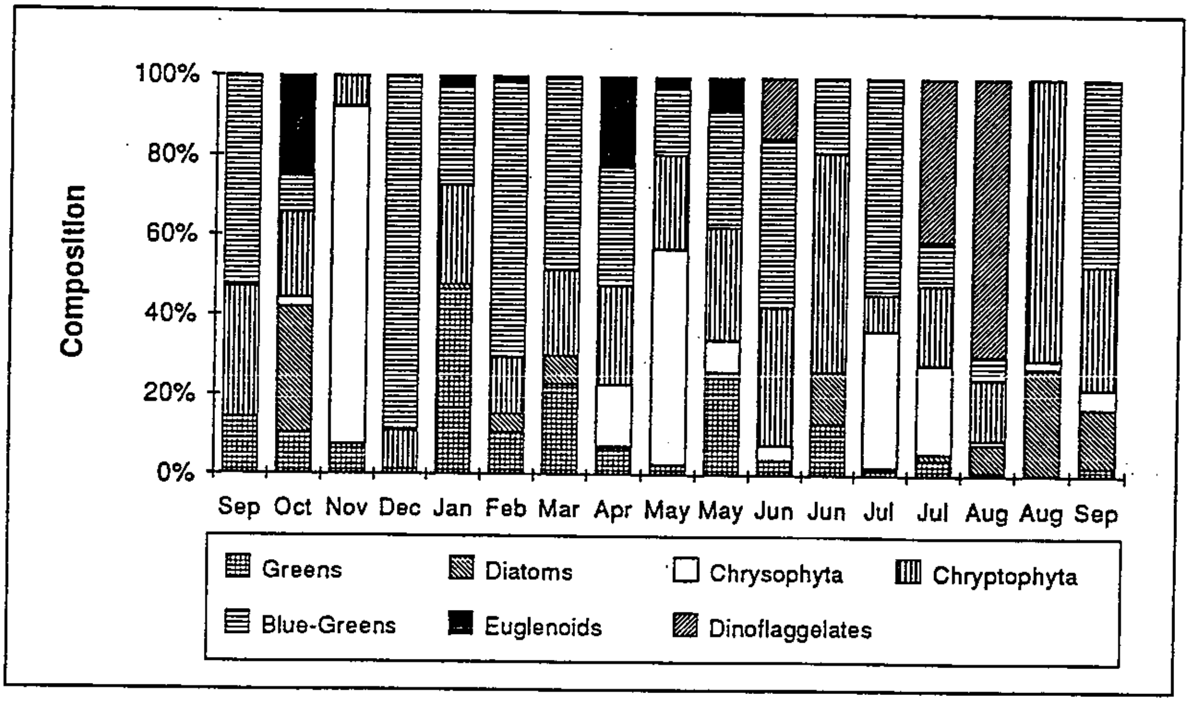


Figure 18
Beaver Lake 2 Phytoplankton Composition
September 1991 through September 1992

Phytoplankton biovolumes in Beaver Lake 2 fluctuated to a much smaller degree than in Beaver Lake 1 (**Figure 16**). Additionally, biovolumes were much lower in Beaver Lake 2, averaging 0.6 mm^3/L in the summer, as compared with 1.7 mm^3/L in Beaver Lake 1 during the same period. The largest algal biovolume measured in Beaver Lake 2, 1.4 mm^3/L, occurred in early July 1992, in which blue-greens and golden-browns codominated.

Corresponding to the lower biovolumes, the chlorophyll *a* values for Beaver Lake 2 were less than those for Beaver Lake 1 (**Figure 17**). Chlorophyll *a* concentrations ranged from 0.9 to 11 µg/l, compared with a 0.3 to 44 µg/l in Beaver Lake 1. Levels were similar in both basins of Beaver Lake from September 1991 until early April 1992, the time of the *E. viridis* bloom in Beaver Lake 1. Chlorophyll *a* levels in Beaver Lake 2 were consistently lower than in Beaver Lake 1 from early April until late summer. The two peaks in Beaver Lake 2 occurred during times when several algal groups were present.

Before the project began, citizens expressed concern regarding high levels of attached algae (periphyton) growing in the nearshore areas. As a result, the shoreline was visually inspected for periphyton on several occasions during the routine monitoring and the aquatic plant survey. Only minimal levels of periphyton were observed during the study year.

Zooplankton

Zooplankton are tiny aquatic animals which are found suspended in the water column of lakes. Zooplankton play an important role in lakes, because they eat algae, and in turn are eaten by fish. The quality of water also can be assessed by the numbers and species present. Generally, the presence of larger algal grazers such as *Daphnia* species indicate less nutrient-rich waters, whereas, smaller species such as rotifers are typical of more nutrient-rich waters.

The zooplankton community in Beaver Lake was dominated by rotifers, which is a common phenomenon in Pacific Northwest lakes. (Zooplankton data, consisting of species composition and density, collected during the study are listed in **Appendix F, Table 2**). Two orders of rotifers were found - Flosculariaceae and Ploima. Representing a small portion (less that 25 percent each) were Cladocera and Copepoda. Despite similar community compositions (**Figures 19 and 20**), seasonal dynamics differed between Beaver Lakes 1 and 2.

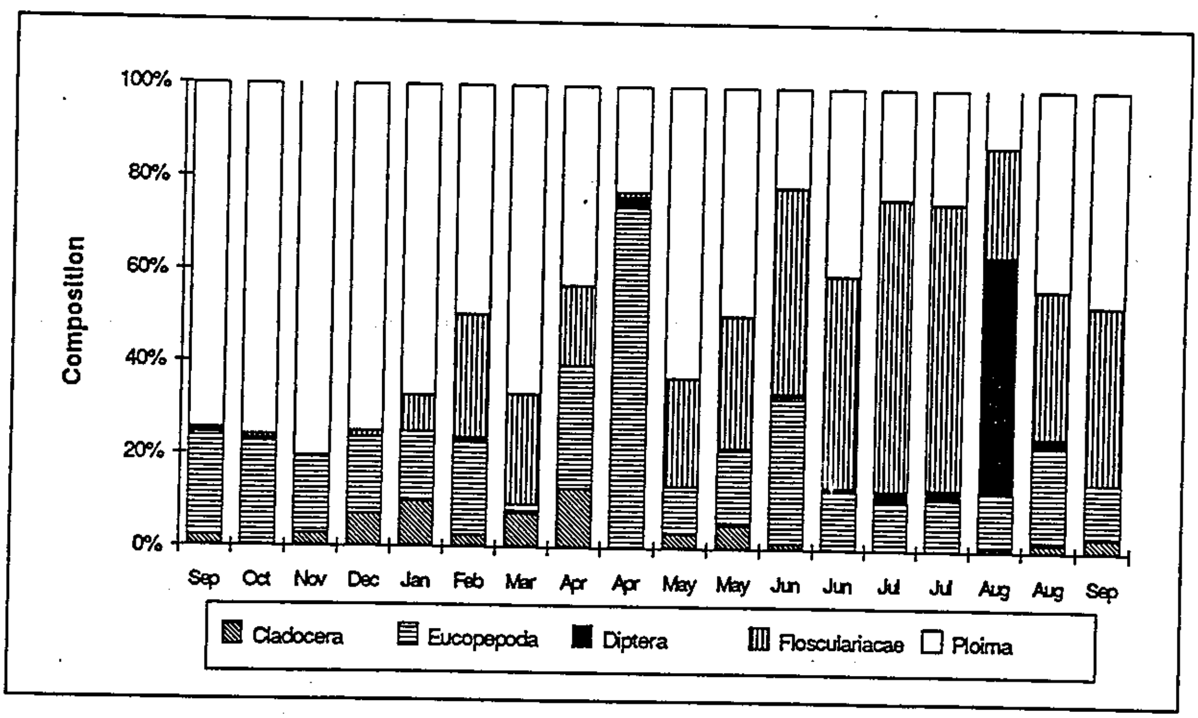


Figure 19
Beaver Lake 1 Zooplankton Composition
September 1991 through September 1992

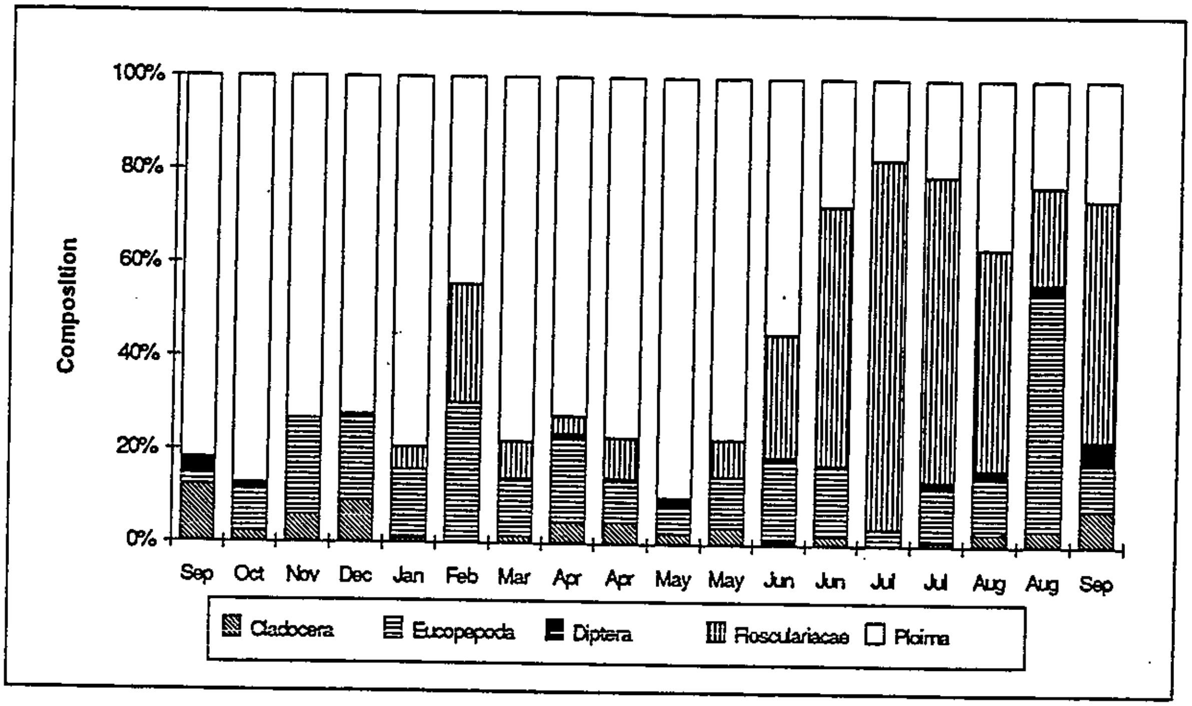


Figure 20
Beaver Lake 2 Zooplankton Composition
September 1991 through September 1992

Zooplankton densities were initially low in Beaver Lake 1, but rose to a peak in November 1991 due to a rapid and large increase in the rotifer population (**Figure 21**). Rotifers also contributed significantly to another density peak in January 1992; however, an increase in numbers was seen for all groups. Densities remained fairly constant until June 1992 when a second peak occurred, again, due to a proliferation of rotifers. Generally, density peaks corresponded to periods when greens (*Chlorphyta*) constituted a greater portion of the phytoplankton. This probably reflects feeding selectivity, as green algae has been found to produce more favorable growth rates than blue-green algae and some diatoms (**Wetzel 1983**).

In Beaver Lake 2, zooplankton densities fluctuated without experiencing any major peaks (**Figure 21**). Generally, zooplankton numbers increased when greens and diatoms were the predominant algal groups, and fell with increases in blue-greens.

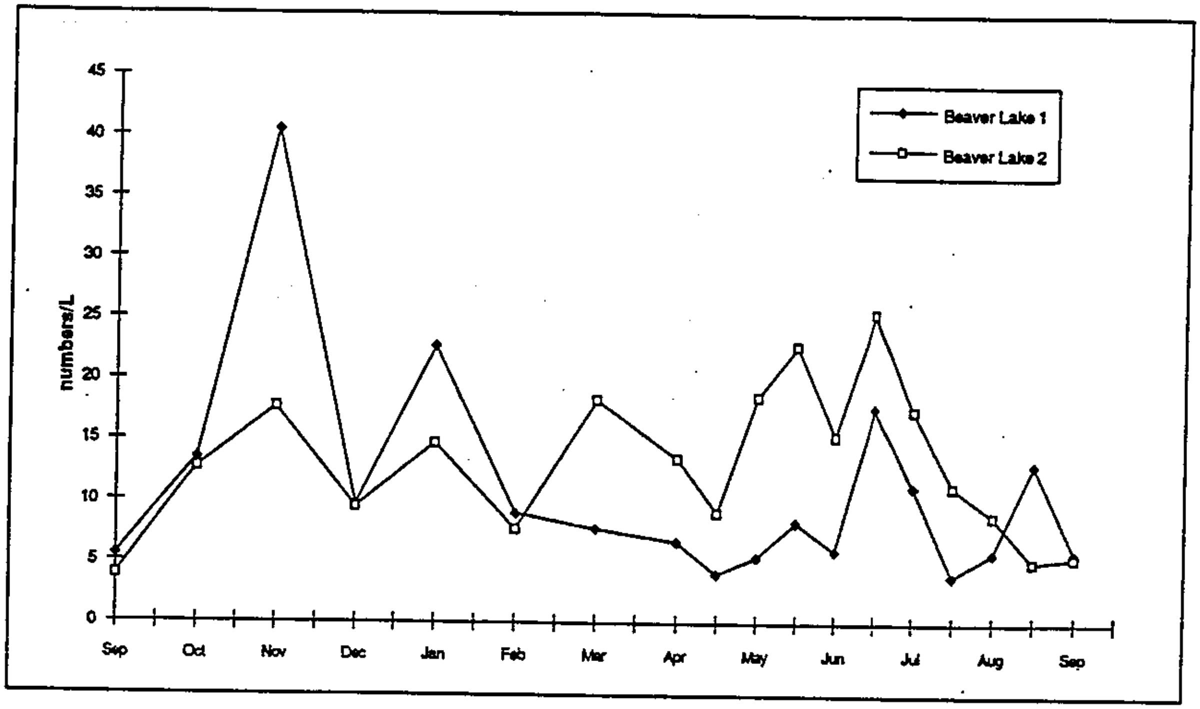


Figure 21
Beaver Lake Zooplankton Density
September 1991 through September 1992

Aquatic Plant Community (Macrophytes)

Aquatic macrophytes are large rooted or floating plants located along the nearshore and the marsh areas of lake. Macrophytes are adapted for growing totally or partially submerged in water. In most cases, macrophytes are a usual component in lakes, and they serve as habitat for fish, waterfowl and benthic invertebrates (bottom-dwelling organisms). Most rooted macrophytes obtain their nutrients from the bottom sediments rather than the water, and are restricted by light penetration **(Olem and Flock 1990)**.

The advantages of removing macrophytes from a lake for aesthetic reasons (e.g. unsightliness or interfering with water activities) must be weighed against the useful functions that these plants provide. For example, algae blooms have occurred in lakes following removal of macrophytes **(Cooke et al. 1986)**.

A survey of the aquatic plant community of Beaver Lake was conducted in August 1992 to coincide with the peak of the growing season. (**Appendix F, Table 4** presents raw data from the aquatic plant survey). Approximately 12 acres, or 16 percent, of the lake surface area (Beaver Lakes 1 and 2) are covered by macrophytes. This is a moderately low level of coverage, compared with other similarly sized lakes in this region. (For phytoplankton community consists of many groups of algae that have different biological, chemical, and physical requirements. Typically, several algal species coexist in a lake at the same time. Seasonal changes in environmental factors, primarily nutrient availability, and secondarily temperature and light, produce temporal changes in algae abundance and dominance (**Wetzel 1983**). Like all other plants, phytoplankton are able to produce organic matter through the process of photosynthesis.

A major symptom of eutrophication is a lake with high levels of algae. When conditions for growth are ideal (warm, lighted, nutrient-rich water), algae can multiply rapidly and reach very high densities ("blooms") in a few days (**Olem and Flock 1990**). These blooms can color the water green, brown, or reddish brown, depending on the type of algae present. Conspicuous features of algal blooms are decreases in water clarity and low dissolved oxygen (DO) in the lake's bottom waters.

Phytoplankton production is controlled primarily by water temperature, light availability, nutrient availability, residence time, and plant consumption by animals (**Olem and Flock 1990**). When light is adequate for photosynthesis, the availability of nutrients usually control phytoplankton productivity (**Olem and Flock 1990**).

Blue-green algae, which can form blooms (scums) on the surface, are most often associated with eutrophication (**Smith 1990**). "The abundance of blue-green algae is readily observable because many of them are buoyant and cause surface scums. Thus, "the fraction of blue-greens in the total biovolume... has real meaning for recreational users"" (**Welch 1989**). The summer biomass of blue-green algae depends most heavily on the epilimnetic concentrations of phosphorus (**Smith 1990**). Blue-greens (and euglenoids) are able to position themselves near the water surface.

Phytoplankton biomass is typically higher in the spring and early summer, due to warmer temperatures and relatively high levels of nutrients. Algae levels usually decline to a mid-summer low and increase in the late summer and fall when water column mixing increases the supply of nutrients (**Olem and Flock 1990**). Algal production and biomass are usually low in the winter because of cool water temperatures and low light levels. A common seasonal pattern for lakes in the Puget Sound region is the dominance of diatoms in spring, blue-greens in summer, and greens in the fall.

The algae community in Beaver Lake was analyzed by its composition, abundance, and seasonal dynamics. (Refer to **Appendix F, Table 1** for a complete list of algal abundance and composition). The seven major groups of algae found in Beaver Lake and their relative dominance are listed in **Table 12.** As shown in the table, the algal composition in Beaver Lake 1 and Beaver Lake 2 were quite different.

Table 12 Major Algal Groups in Beaver Lake and Their Relative Dominance		
	Percentage of Total Annual Biomass	
Algal Groups	Beaver Lake 1	Beaver Lake 2
Greens (*Chlorphyta*)	3	8
Diatoms (*Bacillariophyta*)	12	4
Golden-browns (*Chrysophyta*)	24	19
Blue-greens (*Cyanophyta*)	13	32
Cryptophyta	5	23
Euglenophyta	41	5
Dinoflagellates (*Pyrrhophyta*)	2	9

Beaver Lake 1

The most striking feature of the phytoplankton community in Beaver Lake 1 is the dominance of euglenoids, primarily *Eutreptia viridis* (**Table 12**). Euglenoids are commonly found in waters that are rich in organic matter (Wetzel 1983). In the case of Beaver Lake 1, the high levels of organic matter originate from the wetlands and other wet areas draining to the lake.

On an annual basis, the golden-browns were the next most abundant group, primarily *Dinobyron sertularia*. Blue-greens represented a relatively low amount of biomass in comparison with other eutrophic lakes. Two commonly found blue-greens, *Anabaena* sp. and *Aphanizomenon flos-aquae*, were the codominant blue-green species in Beaver Lake 1. Only one species of diatom was present in significant levels—*Cyclotella* sp.

Figure 15 presents the changes in the relative composition of the major phytoplankton groups in Beaver Lake 1 through the study year. *D. sertularia* initially dominated the algal community in September 1991. This was followed by a complete shift to *E. viridis* in November. Greens dominated in winter, although biomass levels were very low during this period. A usual pattern of dominance by *E. viridis* occurs in the late winter and spring. Blue-greens constituted a significant portion of the algal community by early May, and maintain codominance through early July. By late July, diatoms make up most of the algal community, an unusual time for this group to become dominant. Finally, *D. sertularia* dominated the algal community in September, as it did one year earlier.

Beaver Lake 1 experienced three peaks in algal levels, in which biomass volumes exceeded 3 mm^3/L (**Figure 16**). The first two algal blooms were the result of peaks in *E. viridis* in November 1991 and April 1992. The greatest algal biomass measured in Beaver Lake 1, 7 mm^3/L, occurred during the spring bloom of *E. viridis*. The final peak of algal levels occurred as a result of the rapid increase in *D. sertularia* in September 1992.

comparison, macrophyte coverage in Lake Fenwick is 36 percent [**Entranco 1991**].) Macrophyte coverage was relatively greater in Beaver Lake 1 than in Beaver Lake 2.

Fourteen species from eleven genera were identified during the survey (**Table 13**). Stands of floating-leaved water lilies and water shield dominated the areal coverage. Interspersed among them were beds of submerged macrophytes, such as pondweed (*Potamogeton* sp.). Most plant growth was limited to depths less than 10 feet and all surveyed growth was found within the 20-foot depth (**Figure 22**). The majority of macrophytes occurred in Beaver Lake 1 and at both ends of Beaver Lake 2. The dominant species were *Nymphea odorata, Brasenia schreberi* and *Nuphar* sp. The remaining species were *Myriophyllum* sp. (a native watermilfoil species) and *Fontinalis* sp., with only a few individual plants evident.

Table 13
Beaver Lake Macrophyte Species List
1992

Species	Common Name
Brasenia schrberi	Water shield
Ceratophyllum demersum	Coontail
Fontinalis sp.	Aquatic moss
Elodea canadensis	Common waterweed
Isotes bolanderi	Quillwort fern
Myriophyllum sp.	Milfoil
Nitella sp.	Nitella
Nuphar sp.	Water-lily
Nymphea odorata	Water-lily
Potamogeton berchtoldii	Pondweed
Potamogeton angustifolius	Pondweed
Potamogeton natans	Pondweed
Potamogeton robinsii	Pondweed
Utricularia vulgaris	Common Bladderwort

The average dry-weight biomass of ten macrophyte samples collected from Beaver Lake was 58 g and the average phosphorus content was 2.3 mg/g on a dry-weight basis. (The contribution of macrophytes to the phosphorus budget is addressed in Chapter 5.)

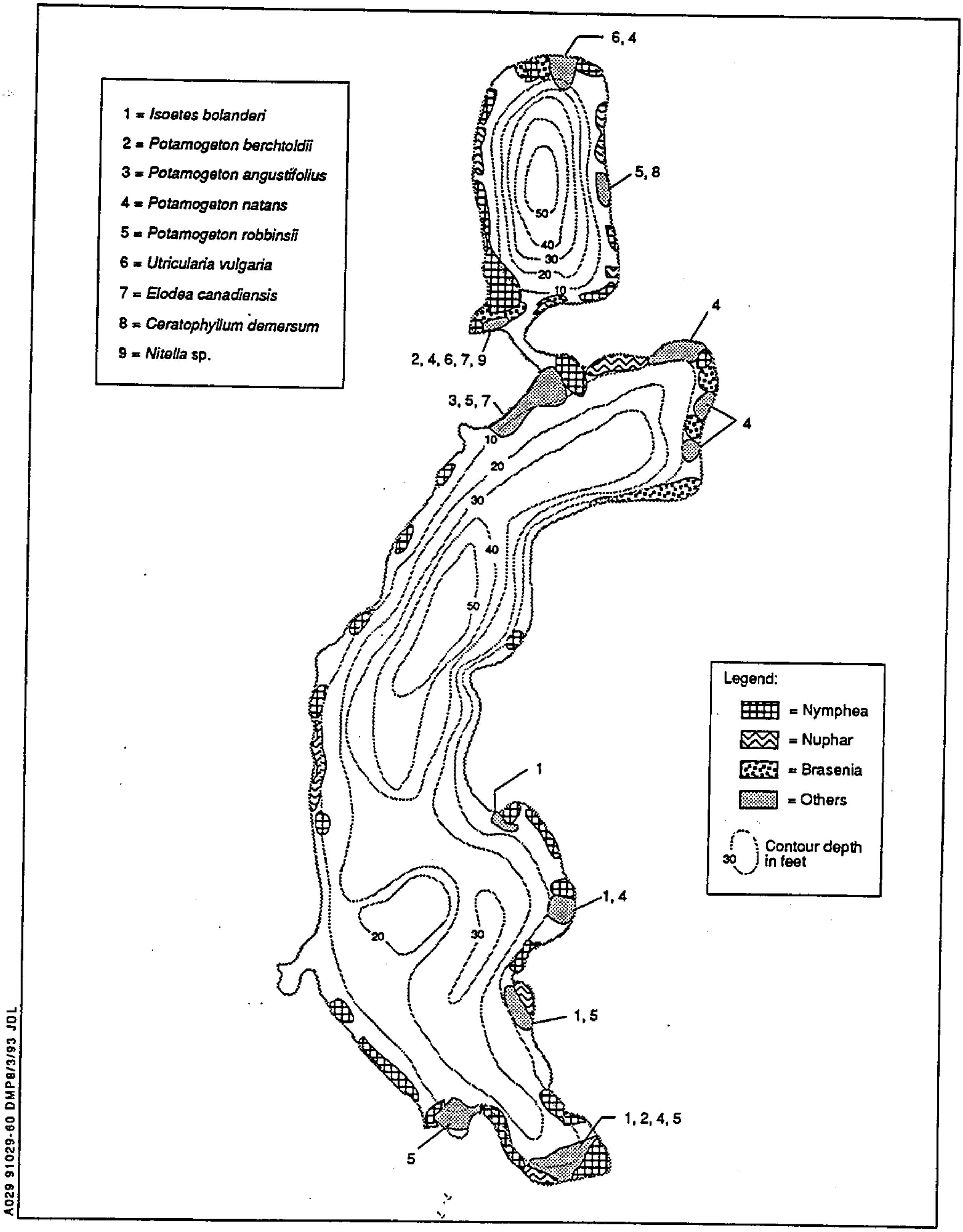


Figure 22
Beaver Lake Macrophyte Survey

The following factors restrict macrophyte growth in many areas of Beaver Lake:

- Steep shoreline - Steep-sided lakes support a much smaller development of common nuisance weeds because most of the sediments are too deep for adequate light (**Olem and Flock 1990**).
- Highly organic sediments - When the sediments are either highly organic or inorganic (sand), macrophyte growth may be poor because it is more difficult for roots to obtain nutrients in these sediment types (**Olem and Flock 1990**).
- Low light penetration due to the highly colored water - Light is generally regarded as the prime determinant of the maximum depth to which aquatic plants with submergent leaves can grow. Based on an empirical equation using Secchi depth developed from lakes in Wisconsin (**Canfield et al. 1985**) the maximum depth of submergent colonizable habitat in Beaver Lakes 1 and 2 would be about two meters (6.6 feet) and 3.7 meters (12.0 feet), respectively.

Benthic Macroinvertebrates

Benthic macroinvertebrates are organisms that grow in or on the bottom sediments in lakes. The benthic community is occasionally used as an indicator of water quality, with some species being more tolerant of poor water quality than others. For example, some organisms, such as mayflies, are intolerant of low dissolved oxygen and toxic pollution, while others (e.g., Oligochaetes and some Chironomids) are more resilient. *Chironomidae* and *Oligochaeta* are frequently used as indicator organisms for pollution assessment.

Most freshwater lakes have the highest densities and diversities of benthic macroinvertebrates in the nearshore zone (where the water is shallow enough to allow growth of aquatic vegetation). It is here that habitat and food resources are most suitable and nearshore macrophytes provide refuge from predators. Benthic macroinvertebrates are generally poor swimmers and have difficulty escaping from predators in the deeper, less vegetated zones (**Thorp and Covich 1991**).

The benthic stations in Beaver Lake were sampled at depths of 3–9 meters, which is within the depth that provides suitable habitat. **Appendix F, Table 4** lists the number per square meter of each taxa recovered by station and sampling date.

Low to moderate numbers of benthic macroinvertebrates—168 to 3,626/m^2—were collected from Beaver Lake. Two species of *Diptera* were dominant—*Chaoborus* sp. (phantom midges) and *Chironomus* sp. (midge flies) (**Figure 23**). *Chaoborus* sp. larvae usually spend most of the day in deeper water and move to the surface at night. Thus, they may be under-represented in a daytime benthic sample. The second dominant taxon, *Chironomus* sp., is among the most common benthic macroinvertebrates in freshwater habitats (**Oliver and Roussel 1983**) and are known for their tolerance of organic enrichment (**Klots 1966**).

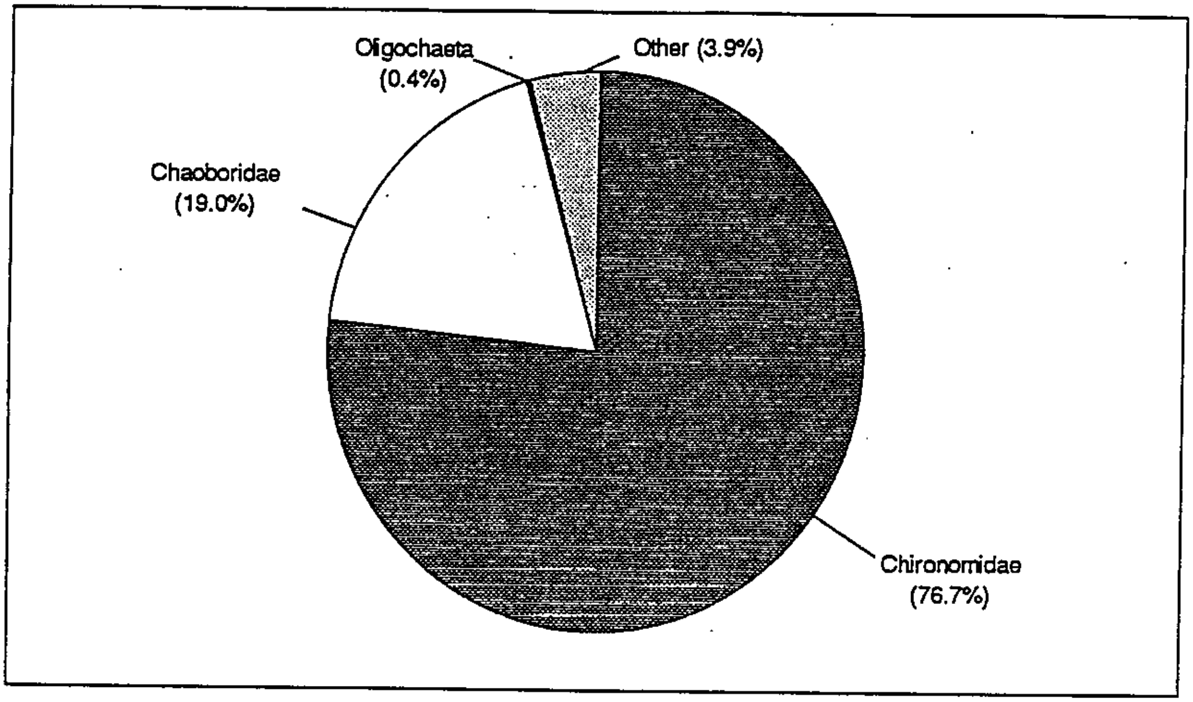


Figure 23
Beaver Lake Benthic Macroinvertebrate Composition

One oligochaete was found in Beaver Lake and, combined with the low counts of *Chironomidae*, the benthic invertebrate data does not suggest major water quality problems in Beaver Lake.

In summary, the benthic macroinvertebrates of a typical Pacific Northwest freshwater lake were recovered from Beaver Lake. The taxa and numbers described are not indicative of an overly enriched sediment environment.

Fecal Coliform Bacteria

Fecal coliform bacteria originate in the intestinal tract of humans and other warm-blooded animals. Fecal coliform bacteria are used to indicate potential contamination from sewage and other sources of fecal material, such as bird and pet waste, and are used in water quality studies as indicators of pathogens. The most common water-borne bacterial pathogens include *Salmonella*, *Shigella*, and *Escherichia coli* (Chapman 1992). Fecal coliform organisms reach lakes via stormwater runoff, waterfowl, and septic wastewaters. The presence of high counts of fecal coliform bacteria may indicate the possibility of other microorganisms that can cause human illness.

Fecal coliform levels in Beaver Lake were evaluated by two separate monitoring elements:

1. Routine lake monitoring at the surface stations in Beaver Lakes 1 and 2 (**Figure 5**). A total of 35 samples were collected during the year-long study.

2. Nearshore samples collected during the two septic surveys. Nine nearshore samples were taken during the winter and summer septic surveys (station locations are shown in **Appendix E**).

The bacterial data for the open lake stations and the shoreline sampling stations are summarized in **Table 14** and are presented in **Appendix E, Tables 1 and 6**.

Table 14
Summary of Beaver Lake Fecal Coliform Data

	Beaver Lake 1	Beaver Lake 2	Beaver Lake Both Basins
Open Water Station			
Annual Geometric Mean	2	2	
Summer Geometric Mean	2	2	
Maximum	15	10	
Number of samples	18	17	
Nearshore Samples			
Winter Survey Geometric Mean			3
Winter Maximum			570
Summer Survey Geometric Mean			4
Summer Maximum			16

Notes: Collected at the deep water and nearshore stations during the monitoring year.
The Washington State Department of Ecology Standard for the Lakes Classification is a geometric mean of the samples not to exceed 50 org/100 ml and not more than 10 percent of the samples exceeding 100 org/100 ml (**Ecology 1992a**).

Open Water

The geometric mean of the open water stations (Beaver Lakes 1 and 2) was 2 org/100 ml, well below the state standard of 50 org/100 ml (WAC 173-201-045). The data indicate that, from a public health perspective, the lake is safe for contact recreation such as swimming.

Nearshore

Nearshore fecal coliform samples similarly indicate that nearshore water quality is meeting the Lake Class State Standard. One sample had a high value (570 org/100 ml) during the March survey, but the remaining eight samples were below 3 org/100 ml.

TROPHIC STATE

The most common way lakes are classified is by their trophic state, which defines a lake in relation to the degree of biological productivity. High levels of algae, plant nutrients, and organic matter and low water clarity characterize a lake that is eutrophic. Lakes with low nutrients and algae and clear water are classified as oligotrophic. Mesotrophic lakes have water quality characteristics that are between these two classifications (Refer to **Table 6** for a summary of the general lake characteristics of each of these classifications). Eutrophication is a natural process that can be greatly accelerated by human activities in the watershed.

Three parameters are typically used to classify lakes into these trophic states:

1) Chlorophyll *a* - an indicator of algal biomass
2) Total phosphorus - a nutrient that usually limits algal growth in freshwaters
3) Secchi depths

The comparison of Beaver Lake with typically used trophic criteria is presented in **Table 15**. Beaver Lake 1 can be classified as eutrophic, while Beaver Lake 2 is mesotrophic. It should be remembered that the trophic state of Beaver Lake is largely due to natural conditions, because of the lack of sources of pollution in the watershed. The trophic state is really a continuum of states; however, lakes are generally grouped into the three lake categories for management purposes.

Generally, chlorophyll *a* concentrations give the most accurate classification of trophic state (**Carlson 1992; Jones and Lee 1982**). Because of the highly colored water, Secchi depths should not be used to estimate the trophic state of Beaver Lake. However, both phosphorus concentrations and chlorophyll *a* can be used to classify its trophic state. In addition to the traditionally-used trophic parameters, the presence of blue-greens through most of the year and the extended period of hypolimnetic anoxia indicate nutrient-rich systems.

Before the project began, it was thought that the relatively high water color and low pH would limit algal biomass in Beaver Lake. That is, algae would respond less to given amounts of phosphorus because other factors would be limiting algal growth. Color reduces light levels in the lake by reducing light penetration. The pH of water can limit algal production through: direct suppression of algal productivity; indirect toxic effects of metals, such as aluminum; and reduction in the amount of available nutrients (**Carlson 1992**). The results of this study indicate that algae respond primarily to nutrient concentrations, regardless of the levels of color and pH.

Table 15
Annual and Summer Means of Beaver Lake Trophic Parameters in Comparison with Trophic State Criteria and Other Lakes in King County

	Chl *a* (µg/l)	TP (µg/l)	Secchi (m)	TSI[a]	Result
Trophic Classification					
Oligotrophic	<4	<10	>4	<40	
Mesotrophic	4–10	10–20	2–4	40–50	
Eutrophic	>10	>20	<2	>50	
Beaver Lake 1					
Annual	10.9	28	1.2		Eutrophic
Summer	15.2	20	1		Eutrophic
Annual TSI	54	52	57		Eutrophic
Summer TSI	57	47	60		Eutrophic
Beaver Lake 2					
Annual	4.2	18	2.5		Mesotrophic
Summer	4.9	11	2.3		Mesotrophic
Annual TSI	45	46	47		Mesotrophic
Summer TSI[a]	46	39	48		Mesotrophic
Average of 24 King County Lakes	3.4	22	3.5		
Pine Lake					
Annual	–	24	3.7		Mesotrophic
Summer	3	–	–		

a. Trophic State Index

The Trophic State Index (TSI) classification scheme uses algal biomass as the basis for trophic state classification, which can be independently measured by chlorophyll *a*, Secchi depth and TP. The TSI can be used to identify situations where nutrients are not limiting plant biomass, such as light limitation or low pH. The three index variables (TP, chl *a*, and Secchi) are interrelated by linear regression models, and should produce nearly the same TSI value for a given combination of variable values (**Carlson 1992**). For example, if the TSI calculated from phosphorus levels is greater than the TSI calculated from chlorophyll *a* and Secchi depth, then some other factor is limiting algal biomass. This relationship does *not* occur in Beaver Lakes 1 and 2—the TSI for chlorophyll *a* is usually greater than the TSI for phosphorus (**Table 15**). An unexpected result of the study is the generally good agreement between phosphorus levels and chlorophyll *a* concentrations, as indicated by similar TSI values between these parameters.

Algae concentrations were generally high in Beaver Lake 1, despite the somewhat high color. According to Carlson (1992), "Eutrophic situations (TSI(Chl)>50) occur only at lower color (less than 100 PCU) values. It is possible that color might affect transparency, but algal chlorophyll *a* is responding to low concentrations of nutrients rather than light limitation".

In general, studies of other brown-water humic lakes which receive wetland drainage suggest that acidity and color may affect algal productivity (the rate at which algae grow), but biomass is limited by nutrients (**Arvola et al. 1990; Carlson 1992; Kerekes et al. 1990; Beaver and Crisman 1991**). In other words, acidity does not affect the trophic response of a lake. Kerekes (1989) suggest that overall biological production in acidic lakes may remain high if the nutrient supply remains high. This does not mean that acidity does not influence individual species or groups of species. (**Kerekes et al. 1990**). Within many humic lakes, algae migrate vertically in the water column (such as euglenoids), enabling them to maximize production without inhibition by prolonged light intensity (**Ilmavirta 1982**). The seasonal successions of species are rapid and distinct. Additionally, as discussed earlier, dissolved organic color was found to affect transparency, but not algal biomass (**Carlson 1992**).

Comparison with Other Small Lakes in King County

Another way in which the condition of Beaver Lake can be evaluated is to compare these trophic parameters with other lakes in this area (**Table 15**). Based on 1989 data from 24 similarly sized lakes in King County, including Beaver Lake, the conditions of Beaver Lake 2 was classified as mesotrophic (**Brenner and Maguire 1990**). Chlorophyll *a* concentrations were higher, whereas phosphorus and Secchi depths were generally lower than the other lakes in the county. Of the 24 King County lakes sampled in 1989, Beaver Lake had the highest average summer temperature (**Brenner and Maguire 1990**), likely due to the dark brown water color, which absorbs more light.

Comparison with Historical Data Collected at Beaver Lake 2

Water quality data has been collected for several years by Metro as part of its small lakes monitoring program. The data collected includes the three principal indicators related to lake eutrophication: total phosphorus, chlorophyll *a*, and measurements of water transparency (Secchi depths).

Metro began water quality sampling of Beaver Lake 2 in 1972. The monitoring continued until the end of 1973, and began again in 1983. Sampling has continued on a yearly basis since 1983. Based on comparison of surface samples, total phosphorus and chlorophyll *a* data indicate that the trophic state of Beaver Lake 2 has not substantially changed over the last ten years (**Figures 24 and 25**). (Historical annual ranges and means are listed in **Appendix A, Table 2**.) This is not surprising, given the relatively small change in land uses within the watershed during this period.

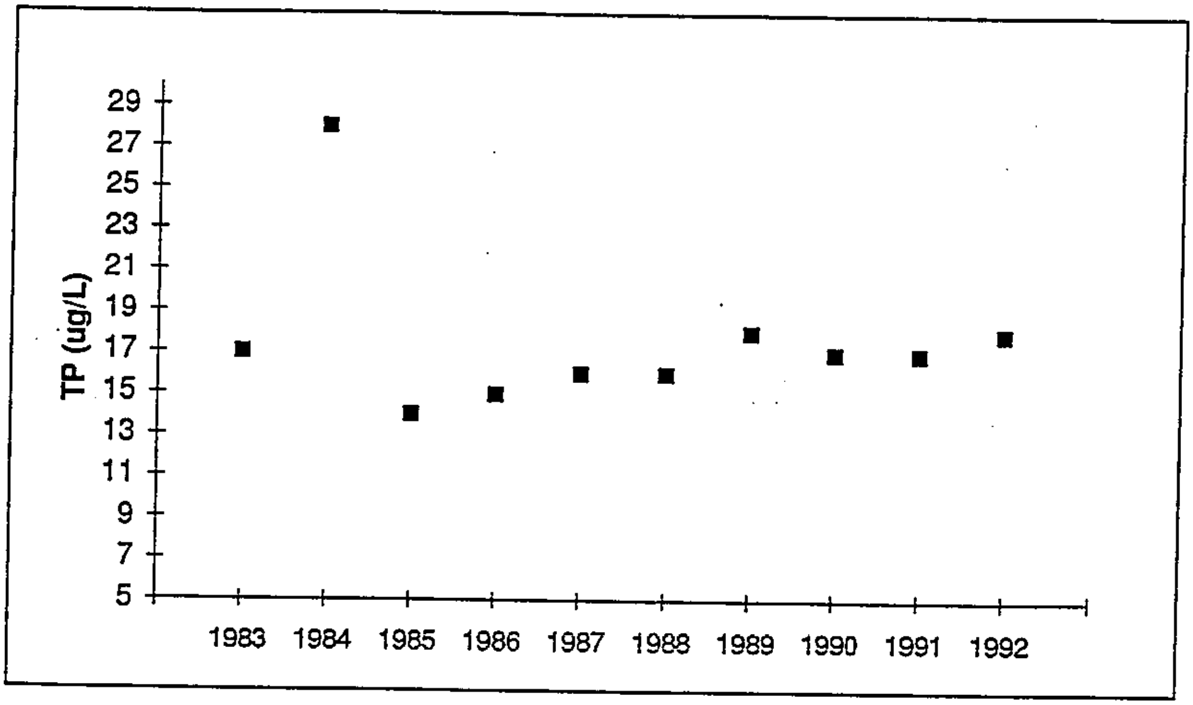


Figure 24
Beaver Lake 2 Average Annual TP
Source: Metro 1983-1991

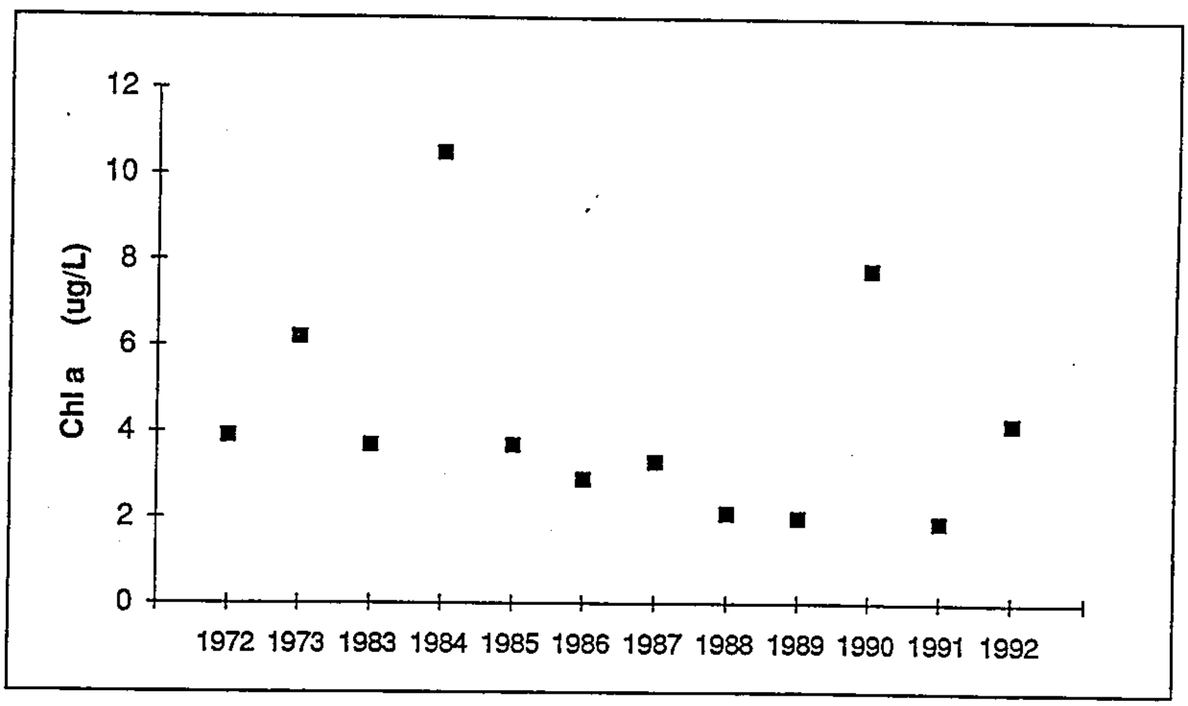


Figure 25
Beaver Lake 2 Average Summer Chlorophyll *a*
Source: Metro 1983-1991

LIMNOLOGICAL SUMMARY

Based on the water quality sampling program conducted in Beaver Lake during the study year—September 1991 to September 1992—the following observations can be made:

- Many of the water quality variables were significantly different in Beaver Lake 1 and Beaver Lake 2.

- Beaver Lake stratifies between late March and November 1991, with dissolved oxygen depletion occurring in the hypolimnion in June. The hypolimnion occupies approximately one-half of the lake volume, a relatively large amount compared with lakes of similar shape. The low dissolved oxygen levels in the bottom may restrict fish habitat, but do not necessarily increase the amount of P released from the lake sediments.

- The volume-weighted whole-lake TP concentrations in Beaver Lakes 1 and 2 ranged from 20 to 50 µg/l and 10 to 32 µg/l, respectively. Annual means ranged from 20 µg/l in Beaver Lake 1 to 36 µg/l in Beaver Lake 2. Total phosphorus levels within the epilimnion during the summer growing period averaged 22 µg/l and 11 µg/l, respectively.

- Aquatic macrophytes occupy about 16 percent of the lake surface area in the summer, indicating moderately low coverage. The aquatic plants are primarily restricted by the low penetration of light and the steep slope in most areas of the shoreline.

- The existing fish community in Beaver Lake is a mixed assemblage of naturally-reproducing spiny rays and annually-stocked populations of rainbow trout.

- The algal community was dominated by a euglenoid in Beaver Lake 1, a type of algae that is found in waters rich in organic matter. Blue-green algae occurred in both lakes, but Beaver Lake 2 had a relatively high proportion. Chlorophyll *a* concentrations—an indicator of algal biomass—peaked during the spring due to the bloom of euglenoids in Beaver Lake 1. High chlorophyll *a* levels persisted throughout the summer growing season, particularly in Beaver Lake 1.

- Open water and nearshore fecal coliform samples collected during the study year showed no evidence of fecal contamination.

- Based on the traditionally-used trophic parameters of total phosphorus, Secchi depth, and chlorophyll *a*, Beaver Lakes 1 and 2 would be classified as eutrophic and mesotrophic, respectively. Other indications of nutrient enriched environments, such as the large percentage of blue-greens, occurred in both lakes.

- Based on data collected during the study and results from other brown-water humic lakes, low pH and high color in the water (as in Beaver Lake) does not reduce algal biomass or chlorophyll *a* concentrations. The biomass responds directly as a result of the nutrient concentrations.

- Septic surveys conducted of the nearshore homes around Beaver Lake during the summer and winter generally did not indicate large-scale failure of nearshore septic systems.

- Comparisons with historical data collected by Metro from Beaver Lake 2 indicated that the trophic state of Beaver Lake has remained essentially unchanged over the last ten years.

- The growth of algae in Beaver Lake is limited by phosphorus concentrations in the water column, based on the ratios of nitrogen to phosphorus. The average annual TN:TP ratios in Beaver Lake 1 and Beaver Lake 2 were 26:1 and 34:1, respectively. TN:TP ratios above 17:1 usually indicate phosphorus limitation.

- Before the project began, citizens expressed concern regarding high levels of attached algae (periphyton) growing in the nearshore areas. As a result, the shoreline was visually inspected for periphyton on several occasions during the routine monitoring and the aquatic plant survey. Only minimal levels of periphyton were observed during the study year.

5. WATER AND NUTRIENT BUDGETS AND DEVELOPMENT OF THE LAKE RESPONSE MODEL

This chapter describes the methods used to develop hydrologic and phosphorus budgets for Beaver Lake, the methods used to develop and calibrate a dynamic lake response model, and the results of the water and nutrient budgets.

Hydrologic budgets are developed for lakes to estimate the amount and seasonal changes of water inflows and outflows. The purpose of phosphorus budgets is to identify the major sources of the phosphorus to a lake. Phosphorus can originate from the watershed or within the lake through release from the lake's sediments and other mechanisms. Finally, a dynamic lake response model is used to simulate the response of a lake to changes in phosphorus loading associated with the application of restoration measures or changes in watershed land use.

HYDROLOGIC BUDGET

This section describes the methods, assumptions, and results in the development of a hydrologic budget for Beaver Lake.

Methods and Assumptions

The U.S. Environmental Protection Agency (EPA) hydrologic model, Hydrologic Simulation Program - Fortran (HSPF), was used to develop the water budget for Beaver Lake. The model simulates daily totals of direct runoff (surface runoff and interflow) and direct precipitation (rain falling on the lake surface) entering the lake. The major components of the HSPF model are shown in **Figure 26**. Various rainfall-runoff relationships are represented in the model, providing a means to continuously predict changes in the moisture stored within the watershed, as well as the amount of runoff generated by surface and subsurface flow. Surface flow is that portion of the rainfall that runs directly off either pervious or impervious land surface, rather than rainfall that either infiltrates into the soil or evaporates. Subsurface flow includes interflow (shallow lateral groundwater flow that commonly occurs in the soil mantle above relatively impermeable till or hardpan layers) and deeper groundwater flow.

The initial model used to simulate the lake's water budget was the HSPF model calibrated by King County SWM to the Laughing Jacobs subbasin as part of their basin planning process. This HSPF model had to be recalibrated because lake levels recorded in this study were not adequately simulated by the prior model. It is important to match lake levels because lake stage measurements are made throughout the year (as opposed to streams, which are dry in early summer) from which to make comparisons.

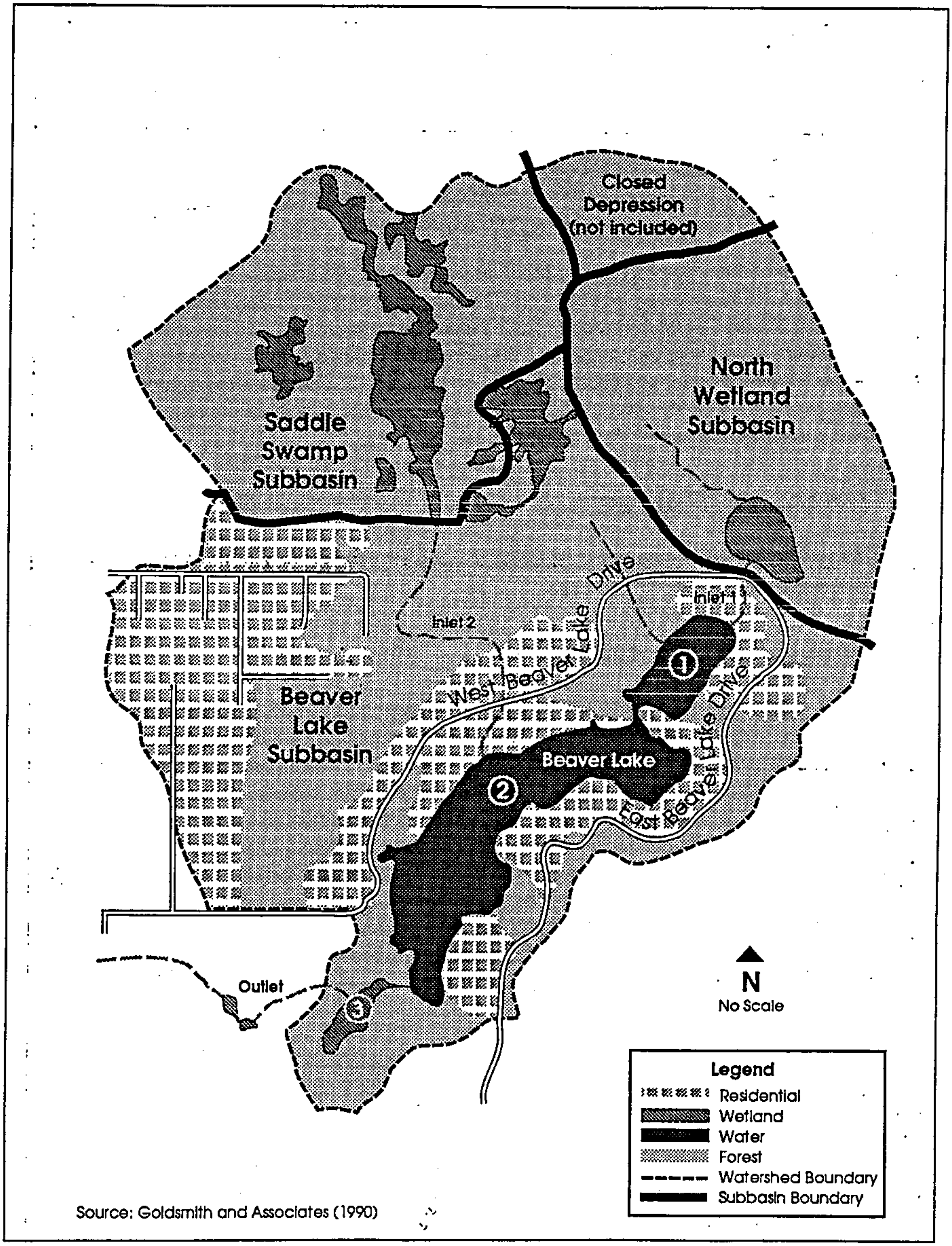


Figure 27
Subbasin Boundaries

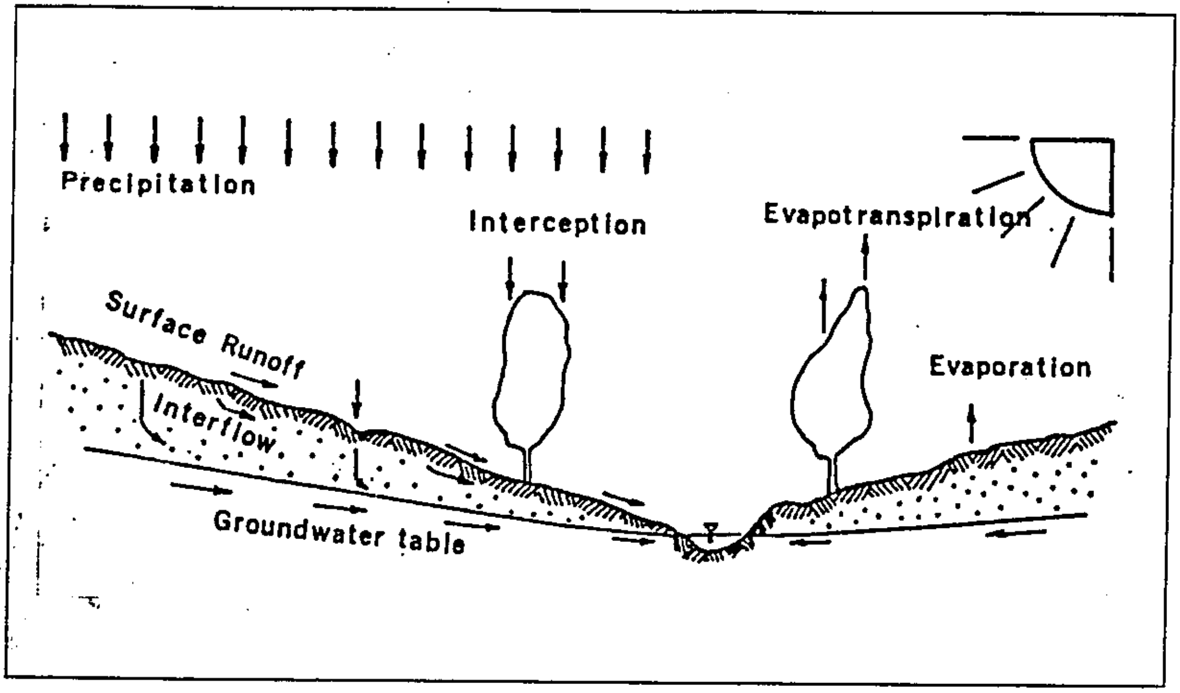


Figure 26
Components of the Hydrologic Cycle
Included in the HSPF Model

To match the observed lake levels, the SWM model was recalibrated by taking the following steps:

1. Subdividing the watershed into three subbasins (**Figure 27**) based on Goldsmith and Associates (1990) to increase the hydrological resolution of the model. These subbasins were:

   - Saddle Swamp Subbasin (266 acres), which includes the Saddle Swamp wetlands and its outlet station

   - North Wetland Subbasin (195 acres), the area contributing to the large wetland north of Beaver Lake 1

   - Beaver Lake Subbasin (580 acres), the remainder of the watershed

2. Incorporating data from the Beaverdam Master Drainage Plan (MDP) (**Goldsmith and Associates 1990**) and the North Wetlands Subbasin (Northwest Hydraulic Consultants, Inc.) to reflect the influence of the two large upstream wetlands.

3. Removing approximately 20 acres from the original HSPF model because this area was a closed depression that did not drain to the lake.

4. Using rainfall data from a gauge closer to Beaver Lake (at Klahanie).
5. Increasing groundwater outflow from the lake from 0.24 cfs to 0.30 cfs, and increasing surface and interflow runoff generated to the lake. The assumption for deep groundwater flow remained unchanged from the original SWM model—it was assumed that surface runoff and interflow enter the lake and the lake drains to a deep aquifer, but deep groundwater does not enter the lake. This assumption matched our conceptual understanding of lake/groundwater interactions developed during the study.

To calibrate to the measured lake levels in the summer, groundwater outflow from the lake to deep groundwater and active groundwater had to be increased because the lake level drops faster than can be accounted for by losses through evaporation. Therefore, it is assumed in the model that both active groundwater and deep groundwater drain away from Beaver Lake, rather than into the lake.

For hydrologic modeling conducted for the Beaverdam property, active groundwater was assumed to be connected to (draining to) upstream wetlands, ELS-10 and ELS-21. It was presumably connected to simulate water levels in the wetlands. It is possible that the wetlands in the watershed occur because of perched water tables, and that the impermeable layers occur at a higher elevation than the lake. In such cases, active groundwater would enter the upstream wetlands, becoming surface flow which then drains into Beaver Lake.

Some limitations of the HSPF watershed hydrologic model (and the lake response model) as presently configured are:

- Water flow and phosphorus loading from individual developments cannot be simulated. The model does, however, simulate cumulative effects for watershed development, which are important for development of a lake management plan.
- Despite differences in water quality between Beaver Lakes 1 and 2, the HSPF model treats the inflows as draining to one receiving water, due to a lack of detailed hydrologic data for each lake. The lake model was therefore calibrated by comparing volume-weighted lake concentrations from Beaver Lakes 1 and 2 to model simulations. By combining the two basins of Beaver Lake, the lake model overpredicts phosphorus levels for Beaver Lake 2 and underpredicts phosphorus levels for Beaver Lake 1. Beaver Lake 2 provides the most beneficial uses, since it represents 83 percent of the total surface area of both lakes. Therefore, basing the lake management strategy on the combined model predictions provides a conservative approach to protecting lake water quality. The present model configuration provides a valid basis for predicting the relative effects of watershed development on lake quality and thus is a viable tool to use to establish a lake management strategy.

- Groundwater data is lacking to completely verify the assumptions used. The conceptual understanding of groundwater relationships in this area matches our model configuration.

- The model was calibrated to the data collected during the study year. The certainty of the model predictions could be improved by model verification, which is the application of the model to another year in which conditions are different, such as under a heavy rainfall year. The basic model verification would require a minimum of an additional year of data. However, as shown by the generally stable concentrations of phosphorus (and chlorophyll *a*) from year to year (**Figures 24 and 25**), it is not anticipated that changes to the lake during a wet or dry year would substantially change the trophic state of the lake. Part of this dampening of yearly variations is due to the relatively long retention time of Beaver Lake—almost two years.

- The lake response model developed for Beaver Lake is a physically-based model that simulates phosphorus levels in the lake. Algal levels are not directly modeled. The assumption in using the model is that phosphorus concentrations directly control the growth of algae in Beaver Lake, and therefore, changes in phosphorus concentrations can be used to estimate the sensitivity of the lake. Future work could involve simulation of algae levels in Beaver Lake by developing a phytoplankton-eutrophication model which includes the effects of light and temperature. One other approach for future work is to estimate modeling error for this type of model by conducting a sensitivity analysis on the model parameters. This would help to determine the relative importance of separate phosphorus components (e.g., waterfowl, septic loading, settling velocity), and the factors that affect phosphorus concentrations in the lake.

Land use, slope, and soil information were obtained from the King County SWM delineation (**King County SWM 1992a, 1992b**). The land use represented in the model is 77 percent undeveloped (forested or wetlands) with the remaining land covered by grass or impervious surfaces (**Figure 27**). The watershed has till-derived and outwash soils. The subbasin drainage boundaries (with the exception of the closed depression) were obtained from a drainage map prepared by Goldsmith and Associates (**1990**) for the Beaverdam Property.

Meteorological data used in the model calibration included measurements made during the monitoring period. Rainfall was recorded at Klahanie, located approximately 0.5 miles from Beaver Lake (King County SWM, provisional data). The total rainfall recorded for the 1992 water year was 41.9 inches at Klahanie. For comparison, rainfall recorded at SeaTac International Airport during the 1992 water year was approximately 20 percent lower (34.3 inches) than the long-term average rainfall. During the study year, the late fall and winter were very dry, while the summer had nearly normal rainfall (**Figure 28**).

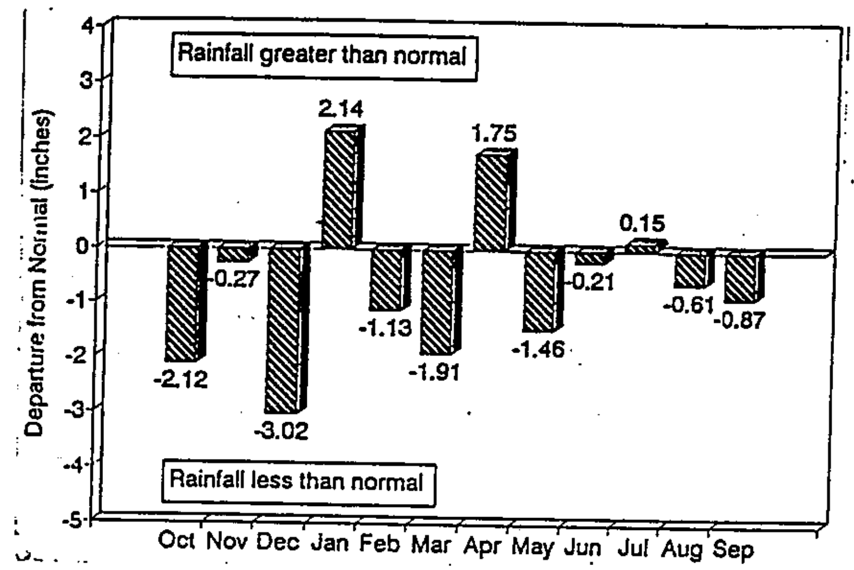


Figure 28
Rainfall at SeaTac International Airport - 1992 Water Year vs. 30-Year Average

Pan evaporation data was collected by Washington State University at the extension office in Puyallup, Washington between October 1991 and April 1992, and in Bellingham, Washington between May and June, 1992. August and September 1992 were modeled using 1991 data. Pan evaporation data was multiplied by 0.75 to estimate lake evaporation.

Results

The simulation of Beaver Lake water levels using the calibrated HSPF model is presented in **Figure 29**. The model simulates approximately a 3-foot difference in lake levels over the 1992 water year. Below a lake elevation of 50 feet, there is no surface outflow from the lake.

Figure 30 presents a monthly summary of simulated inflows to Beaver Lake for the 1992 water year. Seventy-eight percent of the total annual simulated inflow to Beaver Lake occurs between December and April. Actual surface inflow to the lake occurred between mid-December 1991 and early June 1992. Total annual inflow to the lake during the 1992 water year was 936 acre-feet. Assuming a lake volume of 1,779 acre-feet, Beaver Lake has a fairly long retention time of 1.9 years (and conversely, a slow flushing rate of 0.5 $year^{-1}$). In general, the longer the retention time, the more susceptible the water is to phosphorus loading.

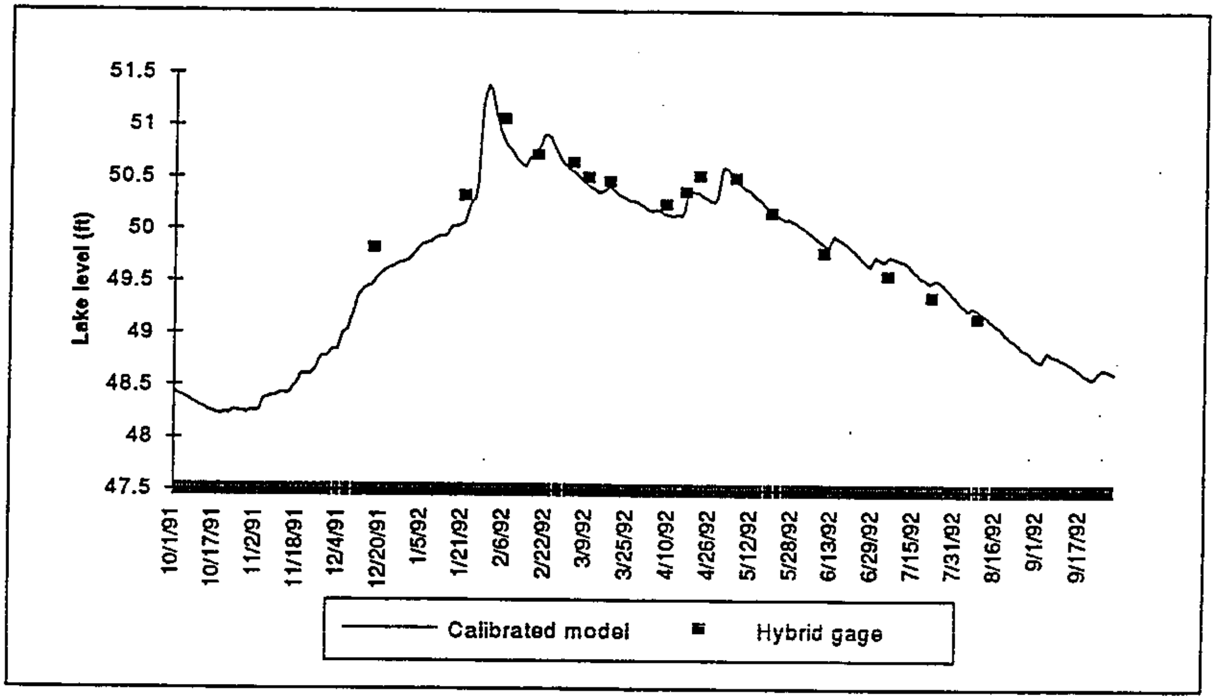


Figure 29
Comparison of Recorded and Simulated Lake Stage Data

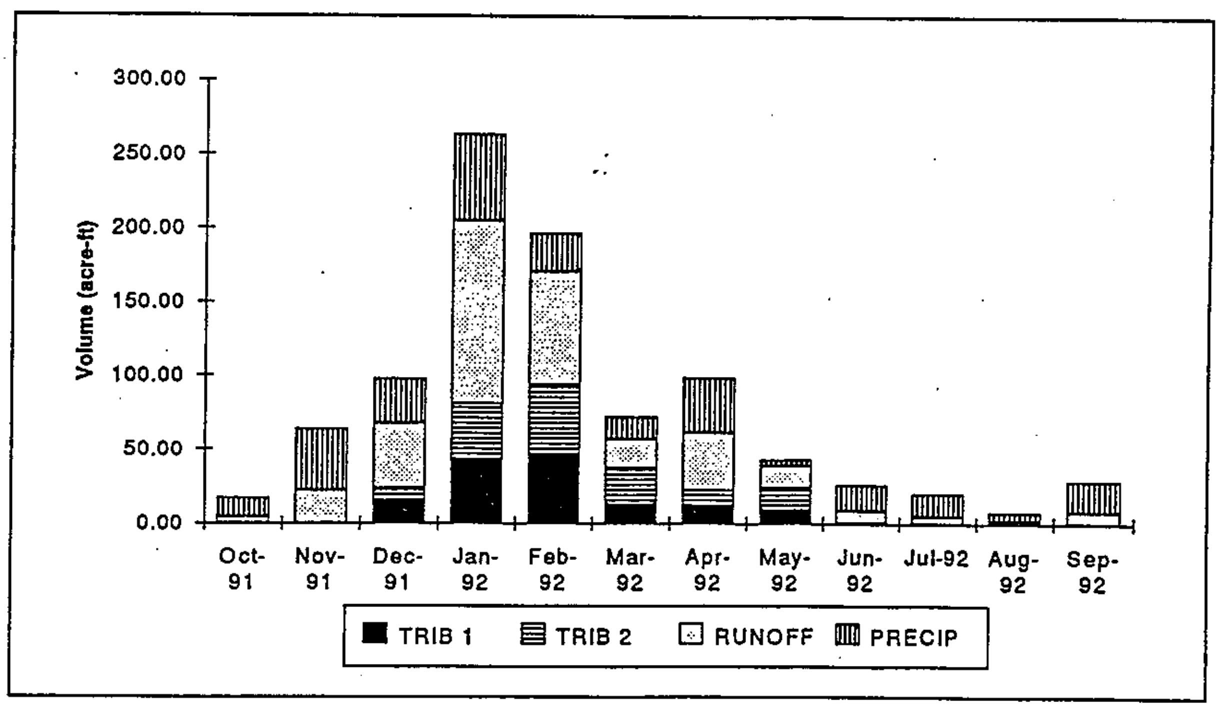


Figure 30
Annual Water Budget (Inflows) by Volume

The proportion of modeled annual inflow that each component contributes is summarized in **Figure 31**. The two main inlets deliver about the same amount of flow, and in total, account for 31 percent of the water entering the lake.

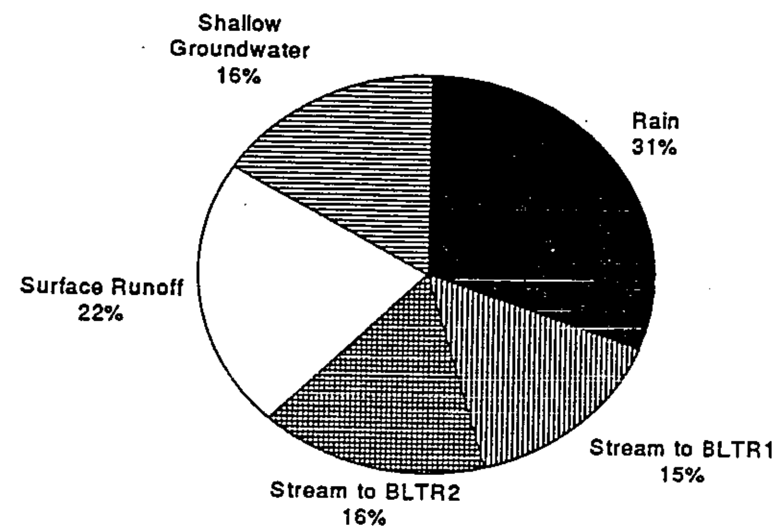


Figure 31
Annual Water Budget (Inflows) by Type

Figure 32 shows the modeled monthly amounts of water outflow or losses from Beaver Lake. The lake level dropped below the outlet between October and late December 1991, and again from June to September 1992. Thus, outflows from the lake during much of the year are limited to evaporation and groundwater discharge.

The relative percentages of annual modeled discharges/loss from Beaver Lake are shown in **Figure 33**. Outflows through the lake outlet channel represent about one-half of the losses from the lake on an annual basis.

PHOSPHORUS BUDGET AND LAKE RESPONSE MODEL

A phosphorus budget was developed to determine the origin and fate of phosphorus in Beaver Lake. As described in Chapter 4, phosphorus is the nutrient that limits algal growth in Beaver Lake, and is usually the most controllable nutrient for lake restoration alternatives. This section describes the methods and assumptions used to develop the phosphorus budget and the lake response model, the phosphorus budget results, and lake response model calibration.

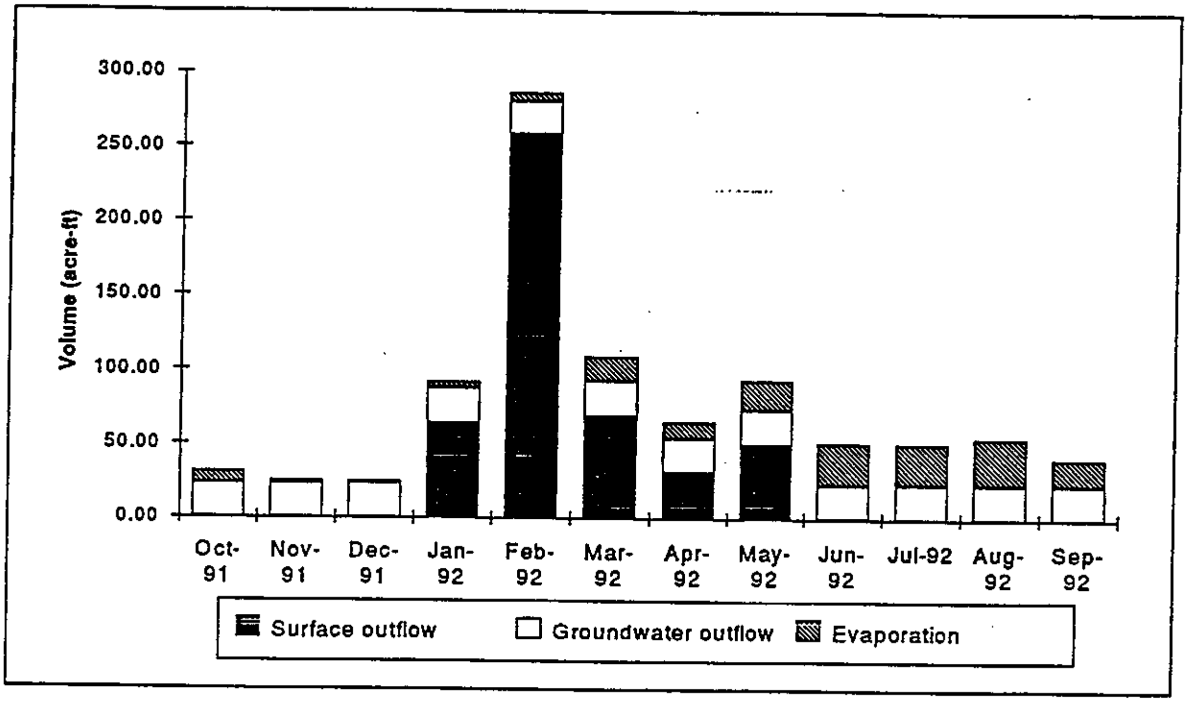


Figure 32
Annual Water Budget (Outflows) by Volume

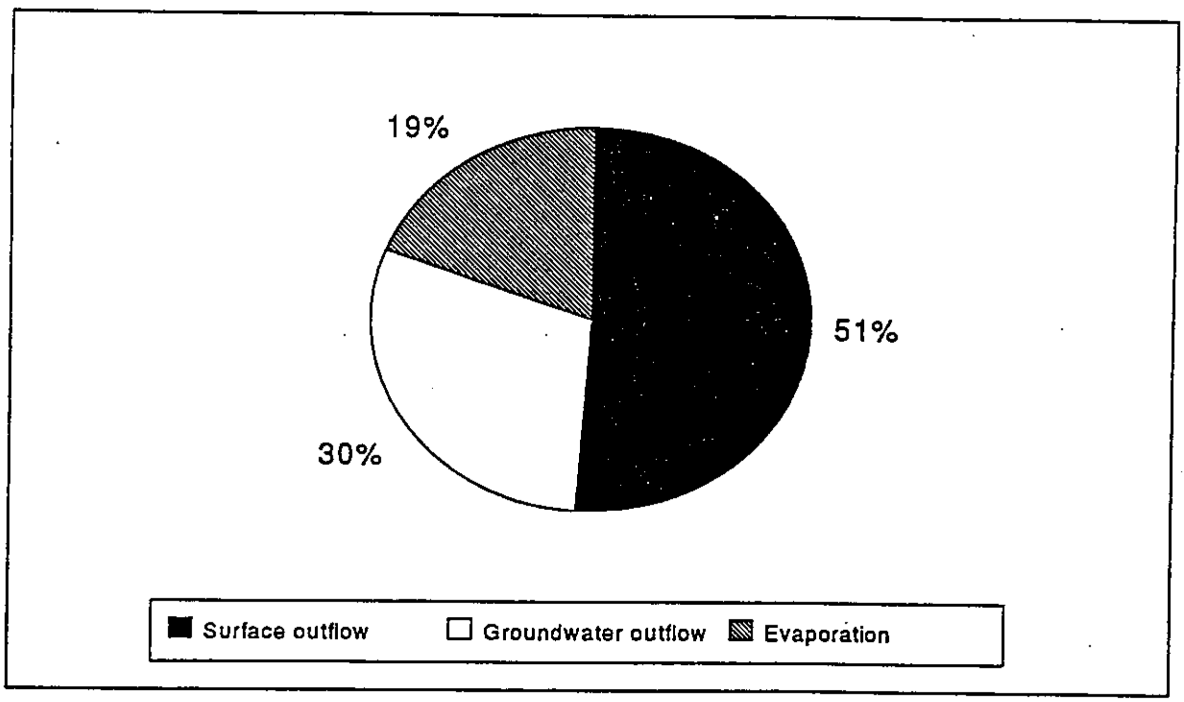


Figure 33
Annual Water Budget (Outflows) by Type

Methods and Assumptions

The phosphorus budget was developed by combining the calibrated HSPF runoff model with phosphorus concentrations measured during the study year. For those sources of phosphorus not directly measured, such as waterfowl, loading estimates were based on data from other studies.

Following the development of the phosphorus budget, a mass-balance numerical model—the lake response model—was calibrated to volume-weighted phosphorus concentrations in Beaver Lake. The model conducts a daily mass-balance calculation of volume-weighted phosphorus concentrations in the lake using the continuous hydrologic output from the HSPF model and various phosphorus concentrations for the different components in the HSPF model. For phosphorus modeling purposes, Beaver Lakes 1 and 2 were combined into one body of water on the basis of volume. Beaver Lake 2 represents the majority of the combined lake volume—about 82 percent.

Sources of Phosphorus

Watershed and in-lake sources of phosphorus to Beaver Lake included in the lake response model were:

- Tributary areas (surface runoff and interflow)
- Septic tanks
- Waterfowl
- Atmospheric deposition (dryfall and precipitation)
- Macrophytes
- Lake sediment release and diffusion across the thermocline.

Tributary Areas

Phosphorus concentrations measured in the two inlets during routine and storm flow sampling were used to estimate watershed phosphorus loading. Watershed sources of phosphorus include interflow from the pervious areas, and direct surface runoff from impervious areas and pervious areas (i.e., forest, wetlands, and grass). Volume-weighted phosphorus concentrations were used for the different runoff components, so that the combined sources simulated the measured phosphorus concentrations in the inlets. The modeled phosphorus concentration for surface runoff from forested areas was 52 μg/l, based on the monitoring result's average stormflow phosphorus concentrations. Interflow from the forested areas was modeled to equal the phosphorus concentrations measured in the tributaries under non-storm events—39 μg/l. Phosphorus concentrations modeled from impervious surfaces were assumed to be 236 μg/l, based on data collected in Bellevue from urban land uses (Pitt and Bissionette 1984). These three components accounted for 85 percent of the estimated direct runoff phosphorus loading.

For the remaining direct runoff components—grassy and wetland areas—phosphorus concentrations of 50 µg/l and 70 µg/l were assumed, while interflow P concentration from these components was assumed to be 40 µg/l.

The interflow phosphorus concentration was based on the phosphorus concentration measured in the tributaries during non-storm (baseflow) periods. The assumption is that the source of water in the tributaries is fed solely by interflow during baseflow periods. Therefore, the phosphorus concentration measured in tributaries during baseflow periods represents the levels found in interflow phosphorus concentration.

Higher total phosphorus concentrations were measured in shallow groundwater samples collected for the Beaverdam property. However, this data showed considerable variability. Additionally, groundwater SRP concentrations were similar to those measured in this study (generally between 20 and 40 µg/l). As mentioned in Chapter 4, SRP is a better estimator of phosphorus movement through soils than TP. For modeling purposes, therefore, SRP was assumed to be equal to total phosphorus concentrations in the groundwater.

Septic Tanks

Phosphorus loadings were estimated for the 215 septic tanks located within the Beaver Lake watershed. A daily phosphorus loading into each of the 206 properly operating septic systems (a failure rate of 4 percent was assumed) was estimated to be 0.01 kg TP day^{-1}, based on a per capita waste generation of 4 grams/day (**US EPA 1980**) and an average occupancy rate of 2.5 people per household. A septic system failure rate of four percent was based on the surveyed failure rates in the East Lake Sammamish Plateau (**King County SWM 1990a**). The nine septic systems with failing drainfields were assumed to remove only 25 percent of the phosphorus.

Phosphorus removal by septic systems was assumed to be 25 percent at the settling tank, and 94 percent of the remaining phosphorus by the drainfield. This is the equivalent of a net phosphorus removal rate of 95.5 percent. In a study of phosphorus loading from septic systems from nearby Pine Lake, it was found that phosphorus transport from newer systems was usually less than 1 percent (**Gilliom and Patmont 1983**). Removal of more than 95 percent of phosphorus from wastewater is common after the water passes through a few meters of soil. In the acidic soils, typical of the Puget Sound region, most phosphorus is probably absorbed by exchangeable and amorphous forms of aluminum and iron (**Gilliom and Patmont 1983**). In a similar study of near-shore septic systems around Lake Sawyer, the average removal efficiency of the systems was 94 percent (**Hart Crowser 1990**).

The proportion of phosphorus released from septic systems which eventually reaches the lake was assumed to be proportional to the interflow generated. Septic tank leachate was assumed to either evaporate, discharge to groundwater, or enter the interflow which returns to the lake. From June to October, interflow is dominated by evaporation, so that phosphorus would not reach the lake during this period. The percentages of water which becomes interflow for November–February and March–May varied between 32 percent and 64 percent, so these percentages of the phosphorus generated were assumed to reach the lake.

Waterfowl

In the absence of actual bird counts, it was assumed that phosphorus loading by birds represents a constant year-round loading. A resident population of 83 birds was assumed with an average daily phosphorus loading of 0.00075 kg/bird/day (**Uttormark et al. 1974**). The assumption of year-round loading is valid because a relatively constant number of birds use the lake, although the species change. The number of birds assumed in the model may be overestimated because more recent estimates are in the range of 40 to 50 birds (**C. Flohr, personal communication**).

Atmospheric Deposition (Dryfall and Precipitation)

Both wet (rainfall) and dry fallout onto the surface of a lake add nutrients directly to a waterbody (**Ryding and Rast 1989**). This represents atmospheric sources of phosphorus falling directly on the surface of Beaver Lake. A constant atmospheric contribution including dryfall and precipitation of 3.9×10^{-4} kg acre^{-1} day^{-1} (± 42 percent) phosphorus acre^{-1} day^{-1} was assumed (**Reckhow and Chapra 1983**). Similar rates of atmospheric deposition have been found for Pine Lake: 3.0×10^{-4} kg acre^{-1} day^{-1} (**Pelletier 1985**) and for other studies: 2.2×10^{-4} kg acre^{-1} day^{-1} (**Gilliom 1981**).

Macrophytes

Predicted phosphorus loading from macrophytes was based on a biomass survey completed during the study, and on assumptions about decay and phosphorus release. It was estimated that 8,100 dry weight kg of macrophytes were within the lake. A total phosphorus content of 0.23 percent of dry weight plant biomass was assumed, based on the average of ten samples taken during the study. It was also assumed that during decomposition, 80 percent of biomass phosphorus would be mineralized by bacteria and thus potentially available for algal uptake. The macrophyte biomass phosphorus release was assumed to be long-term, occurring over the late summer and fall (**Carpenter 1980**).

Sediment Release and Diffusion Across the Thermocline

Aerobic sediment release was assumed to be negligible. The sediment release rate under anaerobic conditions was calculated as a linear rate corresponding to the net increase in hypolimnetic phosphorus concentrations between July and September (1.8 mg m^{-2} d^{-1}). The delayed release of phosphorus from the lake sediments following the onset of anaerobic conditions within the hypolimnion is likely due to the large fraction of organic-bound phosphorus in Beaver Lake's sediments. Sediments with humic matter have a strong tendency to chelate iron, which, in turn, have a high capacity to retain phosphorus and make it less likely to be released (**Bostrom et al. 1982**).

The amount of phosphorus in the hypolimnion that can become available for primary production in the overlying waters of the epilimnion is largely controlled by the rate of diffusion across the thermocline. The transfer of phosphorus across the thermocline was determined by calculating a heat exchange coefficient based on the apparent heat transfer—the change in temperature in the hypolimnion over time—from the epilimnion to the hypolimnion during the stratified period. The calculated rate, 0.0036 m day^{-1}, is low. The mass transfer across the thermocline was calculated as the product of the exchange coefficient, the thermocline surface area, and the difference in phosphorus concentrations between the epilimnion and the hypolimnion (**Reckhow and Chapra 1983**).

Phosphorus Losses

Losses of phosphorus from Beaver Lake are through:

- Surface outflow
- Groundwater discharge
- Sedimentation to the lake bottom

Surface Outflow

The loss of phosphorus from the surface outflow was estimated as the product of the volume-weighted epilimnion phosphorus concentrations and the modeled lake outflow. This calculation assumes that the phosphorus concentration in the epilimnion is equal to the phosphorus concentration in the outflow.

Groundwater Discharge

Phosphorus export associated with groundwater discharge from the lake was estimated as the product of the groundwater discharge volume and the volume-weighted hypolimnetic phosphorus concentration. During the non-stratified periods, the hypolimnetic phosphorus concentration was equal to the whole-lake average phosphorus concentration.

Sedimentation

Because the loss of phosphorus from the water column to the sediments is difficult to measure, it was determined by a combination of literature values and phosphorus model calibration steps. The sedimentation rate is the primary calibration parameter of the lake model.

Initial settling rates were based on literature values reported by Reckhow and Chapra (1983), with settling velocities ranging between 0.05 and 0.6 meters day^{-1}. During the calibration of the lake model, a constant settling velocity of 0.015 meters day^{-1} was found to simulate the observed phosphorus changes during the unstratified period (November 22 through March 15). During the stratified period, velocities of 0.060 and 0.075 meters day^{-1} were used to model the epilimnion and hypolimnion, respectively.

The settling velocity in Beaver Lake may be lower than the typical ranges, because a larger proportion of the phosphorus is in the dissolved form, which does not settle to the bottom.

Results

The monthly phosphorus budget for Beaver Lake is provided in **Figure 34.** Internal sources of phosphorus include sediment release, diffusion across the thermocline from the hypolimnion to the epilimnion, hypolimnetic phosphorus during overturn, and macrophyte decay. External sources include direct runoff, septic tanks, waterfowl, and dust and rain falling onto the lake surface. Seasonally, the majority of the annual phosphorus loading occurs during the winter, coinciding with the period of highest inflows of direct runoff. During the late summer, the relative importance of external sources decline and internal loadings increase.

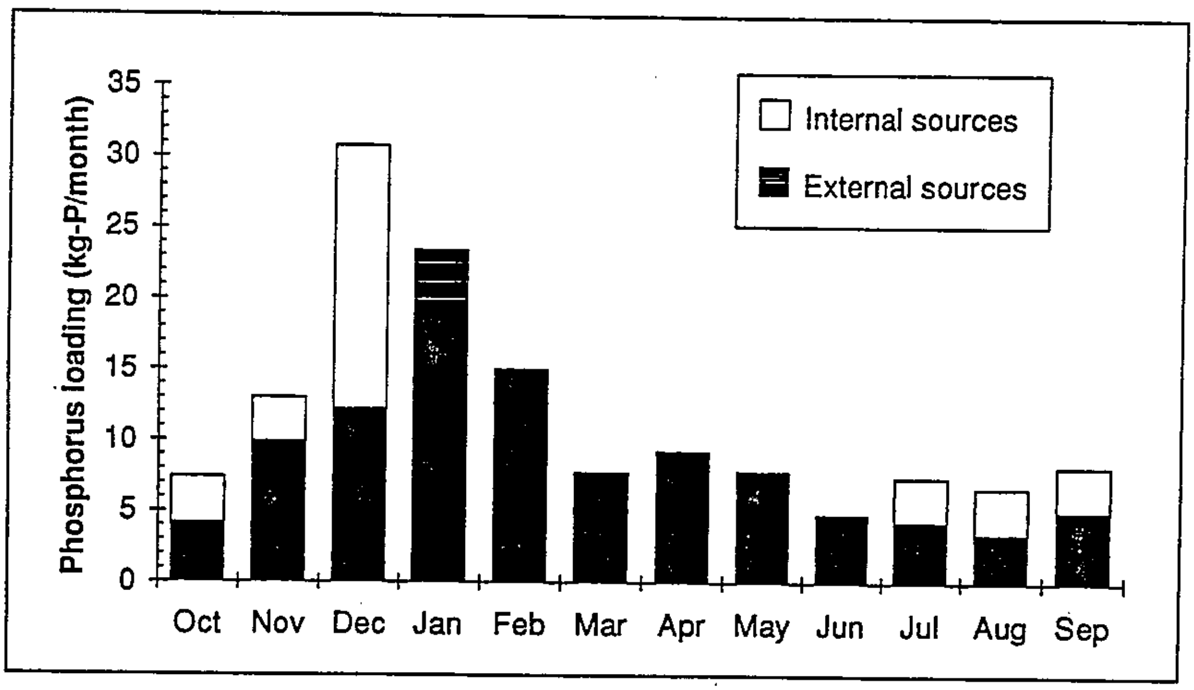


Figure 34
Beaver Lake Total Phosphorus Loading
October 1991 - September 1992

Figures 35 and **36** present the simulated contribution of phosphorus sources during the stratified and non-stratified period. The proportion that each source contributes to the annual phosphorus budget is shown schematically in **Figure 37.** The total amount of phosphorus supplied or recycled within the lake during the 1992 water year is estimated to be 142 kg. Of this total, 25 percent originates within the lake and 75 percent (106 kg) is attributed to external sources. Of the external sources, direct runoff contributed the greatest amount, accounting for 46 percent of the annual phosphorus budget.

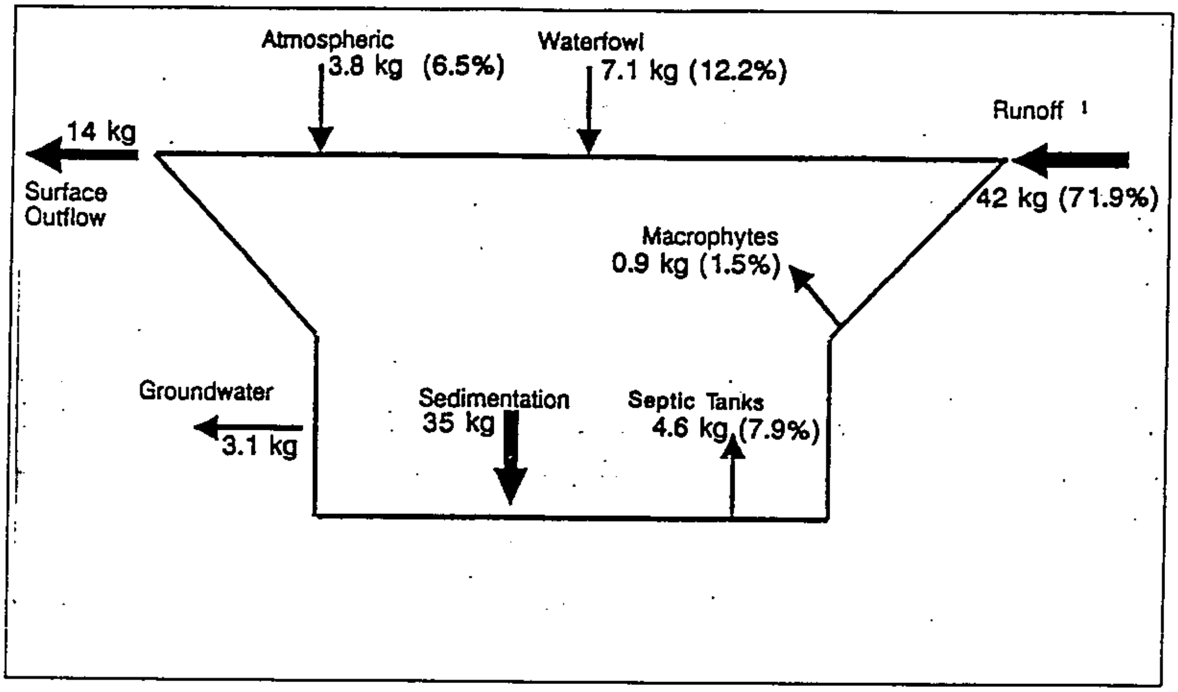
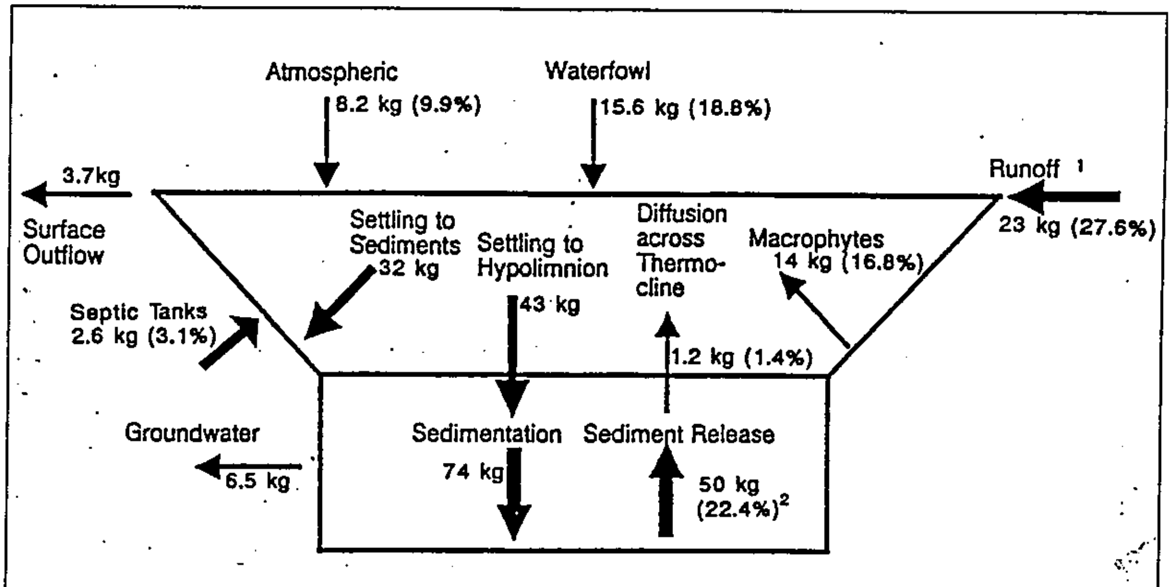


Figure 35
Schematic Representation of Phosphorus Budget during the Non-Stratified Period (Nov. 21 - Mar. 15)



Note: Numbers in parentheses represent percentage of total P loading
(1) Includes surface runoff and interflow
(2) The amount of P represents a net release over the stratified period

Figure 36
Schematic Representation of Phosphorus Budget during the Stratified Period (Mar. 16 - Nov. 20)

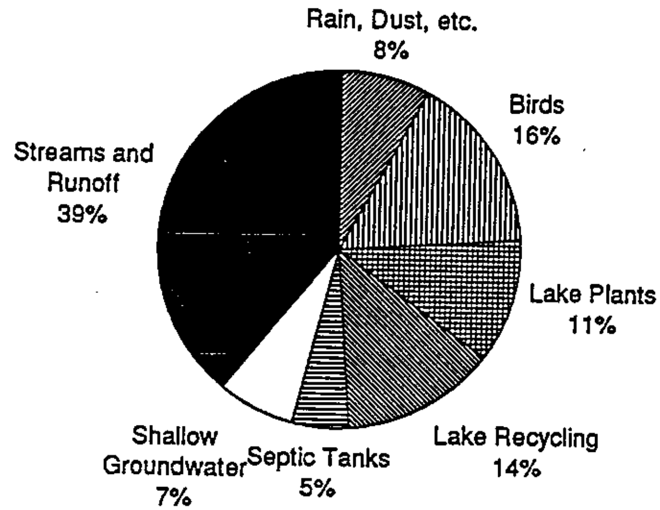


Figure 37
Beaver Lake Annual Phosphorus Budget
(October 1991– September 1992)

On the basis of watershed loading, simulated phosphorus input from the drainage basin equals 0.102 kg P acre^{-1}-yr. This rate represents twice the background loading rate (0.049 kg P acre^{-1}-yr) for many lakes in the Puget Sound Region (**Gilliom 1981**). Because most of the watershed is undeveloped, relatively high background phosphorus concentrations in the watershed are likely the result of natural sources, such as wetland drainage. For example, in the nearby Pine Lake watershed, the average phosphorus concentration draining the wetlands was 160 µg/l (**Metro 1981**).

Figures 38 through **40** compare the predicted (based on the calibrated lake model) and observed in-lake phosphorus concentrations for the study year. On average, the model predicted an annual whole-lake, volume-weighted total phosphorus concentration of 25 µg/l, which matched the measured value. The model predicted an average summer concentration of 19 µg/l, slightly less than the observed value of 21 µg/l.

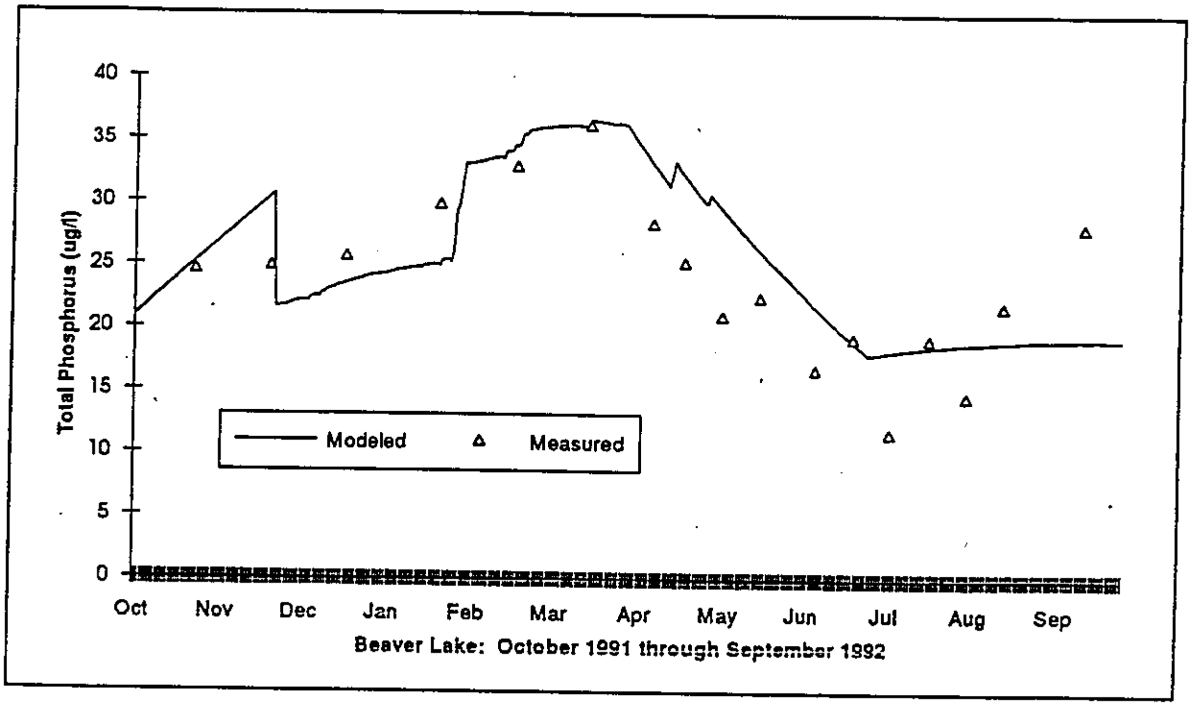


Figure 38
Whole-lake, Volume-Weighted TP Concentrations

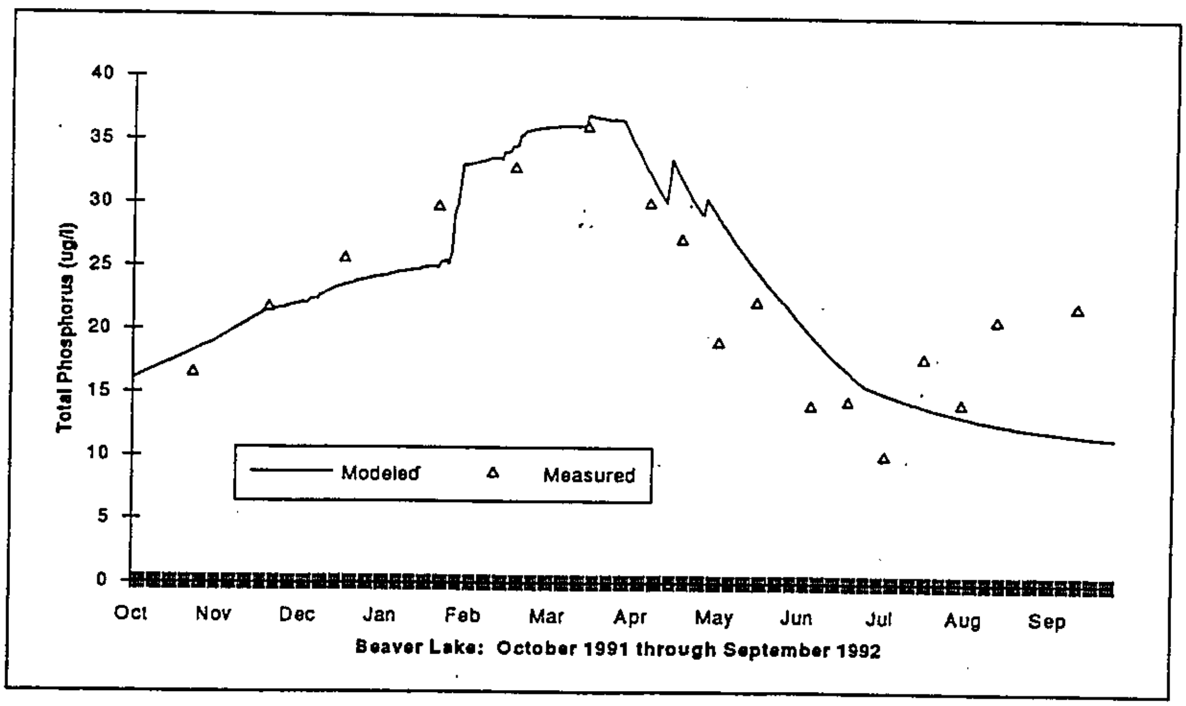


Figure 39
Volume-Weighted TP Concentrations in the Epilimnion

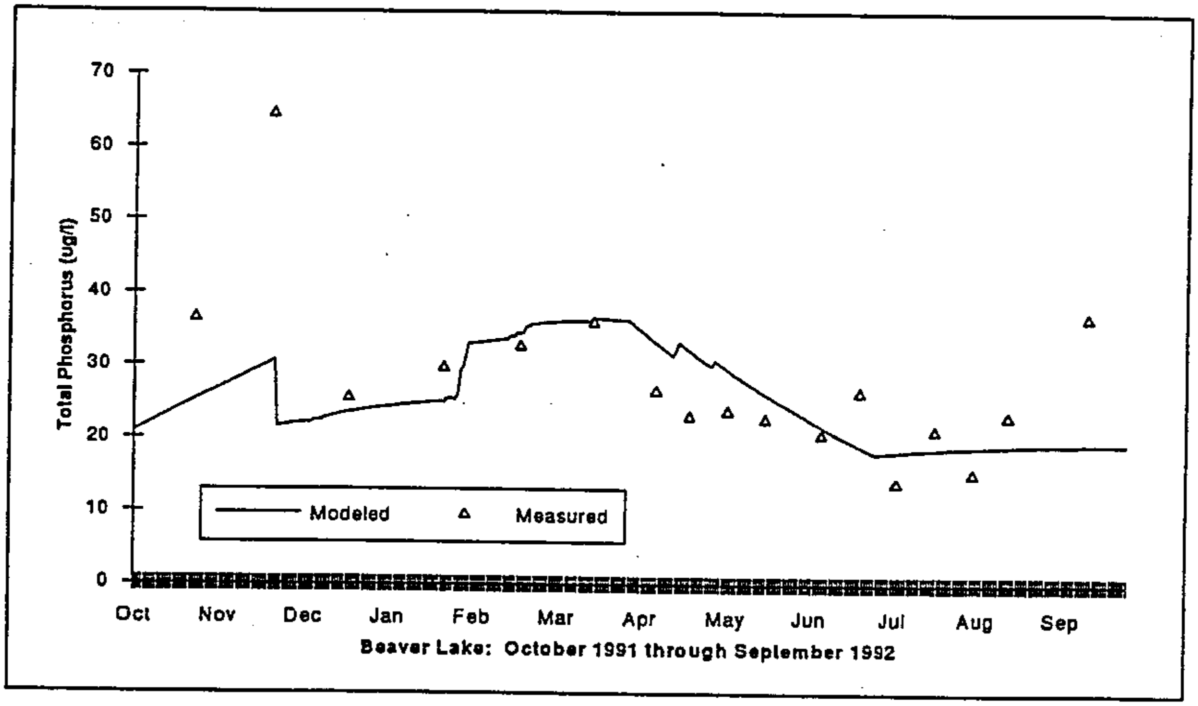


Figure 40
Volume-Weighted TP Concentrations in the Hypolimnion

SUMMARY

Hydrologic Budget

The HSPF model calibrated specifically for Beaver Lake indicated that the two inlets each contributed approximately 15 percent of the annual inflow to the lake. Surface flow from the two tributaries occurred between December 1991 and the end of May 1992. The largest source of water to Beaver Lake is direct runoff, contributing 38 percent of the annual inflow (**Figure 31**; sum of surface runoff and shallow groundwater). Direct runoff includes flow from impervious areas, pervious areas (forest, grass, and wetlands), and interflow (shallow lateral groundwater flow).

The amount of water entering the lake during the 1992 water year was 936 acre-feet. Based on this inflow amount, the retention time of Beaver Lake is fairly long—1.9 years.

Surface outflow from Beaver Lake occurred from late December 1991 through May 1992. Water loss from the outflow represented approximately one-half of the loss of water from the lake. The other losses of water included evaporation (19 percent) and groundwater discharge (30 percent).

Phosphorus Budget

A phosphorus budget was developed for Beaver Lake using water flows from the calibrated HSPF model in conjunction with average phosphorus concentrations measured during the study. The major components of the phosphorus budget were measured during the study; however, a few components (such as waterfowl) were estimated based on literature values.

The annual phosphorus loading to Beaver Lake was 142 kg year^{-1}, with 75 percent (106 kg) originating from external sources. Of the external sources, direct runoff—including tributary inlet base flows, stormflows, and shallow groundwater—represented the largest source (46 percent) of phosphorus to the lake. This phosphorus loading amount represents about twice the level of background (undeveloped) loading found in many lakes in the Puget Sound Region. Because more than 80 percent of the Beaver Lake watershed is undeveloped, it is likely that the higher levels of phosphorus are due to natural sources, such as the major wetlands draining into the two inlets. The inlets had approximately the same phosphorus concentrations—40 µg/l during non-storm flows and 52 µg/l during stormflows.

The release of phosphorus from the lake sediments is relatively minor in Beaver Lake, despite an extended anoxic period. Annually, the sediments contribute 20 kg (14 percent of the annual phosphorus load) of phosphorus to the water column. The low sediment phosphorus release is due to the very high fraction of organically-bound phosphorus in the sediments, which tend to bind phosphorus with iron compounds.

The amount of phosphorus entering the surface waters from the lower waters (from diffusion) during the stratified period is also relatively small. This is primarily due to the strong stratification. Seasonally, most of the phosphorus loading (58 percent) occurs during the four-month period between November and February. This is a common pattern for lakes in the Puget Sound region.

Phosphorus loading from the septic systems in the watershed are estimated to represent only about five percent of the total annual phosphorus load. This estimate was based on the number of dwelling units in the watershed, using an assumed treatment efficiency of 95.5 percent and an assumed failure rate of four percent. The low failure was corroborated by the two septic leachate surveys performed during the study. In the nearby Pine Lake watershed, phosphorus treatment efficiency was determined to be greater than 99 percent for newer systems.

Lake Response Model

A numerical mass-balance phosphorus model—the lake response model—was developed for Beaver Lake. The model was calibrated by comparing model simulations of phosphorus concentrations in Beaver Lake with phosphorus levels measured during the study year. The calibrated lake model predicted a volume-weighted mean phosphorus concentration of 25 μg/l, matching the phosphorus concentration measured during the study.

In Chapter 7, the calibrated model is used to predict the response of Beaver Lake to changes in phosphorus loading associated with increased development in the watershed and the use of stormwater controls. The lake response determines how sensitive a lake is to land use changes in the watershed or other factors that affect phosphorus loading to the lake.

Implications for Modeling and Management

For the improvement or protection of Beaver Lake, phosphorus controls should focus on watershed sources. In-lake restoration measures could be used to meet other objectives, such as increasing fisheries habitat in the lake. The potential internal sources of phosphorus, such as sediment release and the decay of macrophytes, are relatively minor when compared with phosphorus loading from direct runoff.

6. LAKE AND WATERSHED MANAGEMENT PLAN

CONDITIONS SUMMARY

Under existing conditions, 77 percent of the watershed is composed of undeveloped forest and wetland areas. The remaining 23 percent consists of single-family residential uses including 215 dwellings. These residential land uses contributed approximately five percent of the total annual phosphorus loading to the lake. This five percent is attributed primarily to septic/tank drainfield leachate, but may also involve other nonpoint sources, such as lawn fertilizer and pet wastes. The remaining 95 percent consists of direct precipitation (8 percent), waterfowl (16 percent), aquatic plants (11 percent), lake sediments (14 percent), and streamflow/runoff (46 percent). The combination of internal and external phosphorus loads, totaling 142 kg P/year, results in in-lake concentrations of 36 µg/L for Beaver Lake 1 and 20 µg/L for Beaver Lake 2. The volume-weighted concentration for both basins combined is 23 µg/L.

The monitoring results indicate that Beaver Lake 1 is eutrophic and that Beaver Lake 2 is mesotrophic. In addition, both lake basins experience hypolimnetic oxygen depletion and high surface water temperatures. Together these conditions limit the depth of rainbow trout habitat to two to three meters during July and August. However, because of heavy fishing, there may be few trout left in the lake this late in the summer. Therefore, this condition may not have much impact on the trout fishery. In addition, both basins support moderate populations of non-nuisance aquatic plants. Fecal coliform levels in both lake basins are well below the State Lake Class standard and there are no existing public health concerns.

Despite the eutrophic status of Beaver Lake 1 and the hypolimnetic oxygen depletion in both lake basins, King County SWM, the Entranco team, and representatives of the Beaver Lake community have come to the conclusion that existing water quality represents the natural state for Beaver Lake. Only minor impacts can be attributed to the limited existing residential development in the watershed. Therefore, no in-lake restoration measures are recommended at the present time.

With expected residential development in the watershed, there is a significant potential for future increases in phosphorus loading to the lake and a corresponding potential for declining lake water quality. Watershed model predictions indicate that future phosphorus loading could increase to as much as 254 kg P/year (a 73 percent increase) in the absence of appropriate stormwater treatment. However, with treatment of stormwater, preservation of wetland chemistry, hydrology, and buffers, and public education, phosphorus loading is expected to range from 146 to 228 kg P/year, depending on variations in source loading, effectiveness of stormwater treatment (refer to **Table 17** and **Figures 43** and **44** of Chapter 7), density of development, and wetland preservation. If future loading can be restricted to about 146 kg P/year, lake water quality should remain largely unchanged. However, given the uncertainty associated with future predictions, there is a need for appropriate land use controls, best management practices, careful monitoring, and contingency planning, as described further in this chapter.

LAKE AND WATERSHED MANAGEMENT GOALS

The focus of future lake and watershed management should be directed by the antidegradation water quality policy of the Water Quality Standards for Surface Waters of the State of Washington:

> **WAC 173-201A-070 - Antidegradation.** The antidegradation policy of the State of Washington, as generally guided by chapter 90.48 RCW, Water Pollution Control Act, and chapter 90.54 RCW, Water Resources Act of 1971, is stated as follows:
>
> (1) Existing beneficial uses shall be maintained and protected and no further degradation which would interfere with or become injurious to existing beneficial uses shall be allowed.
>
> (2) Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria.
>
> (3) Water quality shall be maintained and protected in waters designated as outstanding resource waters in WAC 173-201A-080.
>
> (4) Whenever waters are of a higher quality than the criteria as signed for said waters, the existing water quality shall be protected and pollution of said waters which should reduce the existing quality shall not be allowed, except in those instances where:
>
> (a) It is clear, after satisfactory public participation and intergovernmental coordination, that overriding considerations of the public interest will be served;
>
> (b) All wastes and other materials and substances discharged into said waters shall be provided with all known, available, and reasonable methods of prevention, control, and treatment by new and existing point sources before discharge. All activities which result in the pollution of waters from nonpoint sources shall be provided with all known, available, and reasonable best management practices; and
>
> (c) When the lowering of water quality in high quality waters is authorized, the lower water quality shall still be of high enough quality to fully support all existing beneficial uses.
>
> (5) Short-term modification of water quality may be permitted as conditioned by WAC 173-201A-110.

Beaver Lake is sensitive to potential increases in phosphorus and other pollutant loading from existing and proposed residential development in the watershed. Therefore, this lake management plan establishes a non-degradation policy which is interpreted in the context of the following specific goals:

GOAL NUMBER 1 - PRESERVE TROPHIC STATUS: There should be no significant increase in the annual external phosphorus load to Beaver Lake and the present trophic status of each lake basin should be maintained.

Discussion: No residential or other development should be allowed, individually or cumulatively, to cause any increase in annual external phosphorus loading to the lake unless it can be demonstrated that "all known, available, and reasonable best management practices" (WAC 17-3-201A-070) have been applied. These best management practices (BMPs) may include the application of innovative structural and nonstructural technology for control of erosion/sedimentation, post-development stormwater runoff, and/or septic tank leachate, or any other nonpoint sources of phosphorus loading. Confirmation of this goal will be provided by appropriate stream, groundwater, and lake water quality monitoring as required by King County (see recommendations BL-5, BL-6, and BL-7) and by site inspections and maintenance of drainage facilities and on-site wastewater disposal systems.

GOAL NUMBER 2 - PRESERVE PUBLIC HEALTH STATUS: There should be no significant increase in the concentration of fecal coliform bacteria in Beaver Lake.

Discussion: Under existing conditions, fecal coliform levels in Beaver Lake are well below the State Lake Class Standard (geometric mean equal to or less than 50 organisms per 100 ml and not more than ten percent of samples exceeding 100 organisms per 100 ml). Therefore, "all known, available, and reasonable best management practices" should be used to reduce any additional fecal coliform bacterial loading to Beaver Lake from septic tank/drainfield systems, birds, animals, and/or stormwater runoff. Confirmation of this goal should be provided by appropriate stream, groundwater and lake water quality monitoring (see recommendations BL-5, BL-6, and BL-7) and by site inspection of drainage facilities and on-site wastewater disposal systems. If appropriate BMPs have been implemented and any violations of the State Lake Class standards still occur, then King County SWM and other affected departments and agencies, in cooperation with the Beaver Lake community, should consider the feasibility of contingency watershed pollution control measures (recommendations BL-14 and BL-15).

GOAL NUMBER 3 - PREVENT NUISANCE AQUATIC PLANT INFESTATION: Introduction of nuisance aquatic plants to Beaver Lake should be prevented.

Discussion: In recent years the nuisance aquatic plant Eurasian watermilfoil has infested Long Lake in Thurston County and Silver Lake in Snohomish County, and has resulted in adverse impacts to recreational uses and overall lake ecology. Similar adverse impacts have occurred in Lake Washington. Once introduced, eradication can be very costly. Estimated first-year costs of a five-year program for attempted eradication of twenty acres of milfoil at Silver Lake have been estimated at $288,000 (KCM 1992). Therefore, every effort should be made to prevent colonization of Beaver Lake by Eurasian watermilfoil. Prevention should involve a combination of surveillance monitoring and public education as described further in this report.

GOAL NUMBER 4 - PRESERVE THE BEAVER LAKE FISHERY: The water quality of Beaver Lake should be managed in such a manner as to continue to support a viable mixed fishery.

Discussion: Beaver Lake is stocked annually with rainbow trout by the Department of Wildlife. The lake also supports largemouth bass and pumpkin seed sunfish. High summer surface water temperatures and anoxic hypolimnetic conditions limit suitable summer habitat for cold water species (trout) to a relatively narrow zone about two to three meters below the surface. Although the number of fish affected could be quite small at this time of year, any worsening of current conditions could result in further oxygen depletion and increased potential for fish kills. This could occur if there is any substantial increase in external phosphorus loading and/or total organic carbon resulting from future residential development in the watershed. Increased phosphorus can lead to increased algal growth and result in increased oxygen demand on decomposition. Increased total organic carbon loading from the watershed could also result in increased oxygen demand during subsequent decomposition in the lake. Therefore, "all known, available and reasonable best management practices" should be employed to prevent such impact. Confirmation of this goal should be provided by appropriate stream, groundwater and lake monitoring as required by King County SWM (see recommendations BL-5, BL-6, and BL-7). If watershed control measures prove ineffective, in-lake contingency measures may be evaluated for implementation at a later date.

GOAL NUMBER 5 - EDUCATE AND INVOLVE THE BEAVER LAKE COMMUNITY: The local community, in cooperation with King County, Metro, the Seattle-King County Department of Public Health, Washington Lake Protection Association, and the Washington State Departments of Health, Ecology, and Wildlife, should develop and implement a program to educate and involve existing and future residents of the watershed regarding wise lake and watershed management practices at the individual household level.

Discussion: Effective resource management requires the cooperative efforts of informed citizens and government representatives. This requires a dedicated source of funding. Forming a Lake Management District is one approach. The intent of this goal is to provide lakeshore and watershed residents with the information they need to understand their impacts on lake water quality, both individually and cumulatively, and implement best management practices (BMPs). The further intent of this goal is to actively involve the citizenry in resource stewardship whether through monitoring, clean-up efforts, inventory work, community education, or related projects.

MANAGEMENT APPROACH

The overall management approach for Beaver Lake is based on the following:

- Existing water quality is still acceptable and supports the various beneficial uses desired by the community. These beneficial uses include aesthetics, fishing, swimming, boating, and waterfront property values. Since existing beneficial uses are presently supported, no in-lake restoration measures are recommended at the present time.

- Despite the suitability of existing water quality, modeling of future conditions indicates sizable potential risk of water quality degradation associated with water shed development. Therefore, water quality management over the next five years should focus on:

  - Modification of King County policy—modified stormwater treatment requirements in the watershed, a county-wide lake classification system, and plan adoption (refer to recommendations BL-1, BL-2, and BL-3)

  - Implementation of interim (prior to Lake Management District formation) and long-term monitoring programs and inventories (refer to recommendations BL 4 through BL-8) to evaluate stormwater treatment and other water quality mitigation measures imposed by the County on vested development projects in the watershed

  - Implementation of community education and involvement programs (refer to recommendations BL-9 through BL-11)

  - Reassessment of the lake response model and lake/watershed management plan at the end of five years (refer to recommendations BL-12 and BL-13

  - In the event that lake quality degradation occurs after the management plan has been implemented, additional watershed controls, including contingency stormwater treatment (BL-14), contingency wastewater management (BL-15), and future density reductions as well as in-lake control measures (BL-16) should be considered. Density reductions would apply only to unvested property within the watershed.

Plan implementation is predicated upon approval of a Centennial Clean Water Fund grant request from the Washington State Department of Ecology and formation of a Lake

Management District (LMD) for grant matching funds. If grant funding cannot be obtained or if the community fails to approve the LMD, plan implementation may not be realized.

LAKE AND WATERSHED RECOMMENDATIONS

The following discussion addresses recommendations that apply specifically to Beaver Lake and its watershed. It should be noted that existing or on-going State and local planning and regulatory programs have or may impose considerable mitigation for existing and potential future development in the watershed in addition to the measures discussed in this chapter. Some of the more important planning and regulatory programs that will serve to control potential water quality impacts to Beaver Lake include:

- The East Lake Sammamish Basin and Nonpoint Action Plan (**King County SWM 1992a and 1992b**—summarized in **Appendix G**)
- The King County Sensitive Areas Ordinance - protecting streams, wetlands, and other resources
- SEPA review and mitigation measures for new residential development, including requirements for erosion/sedimentation during construction and stormwater detention and treatment following construction, consistent with the King County Surface Water Design Manual
- The County's new Water Quality Ordinance No. 10636, which gives the County the authority to prevent contamination of ground and surface waters in a manner consistent with state and federal regulations
- The provisions of the East King County Groundwater Management Plan
- The land use policies and regulations of the East Sammamish Community Plan

In addition to the control measures that have already been imposed by these existing plans, ordinances, and regulations, King County SWM proposes the lake and watershed management recommendations summarized in **Table 16**. Each of these BMPs is described in the remainder of this chapter.

Table 16
Summary of Lake and Watershed Recommendations

Recommendation	Lead Agency[a]	Cost[b]
Policy, Land Use, and Zoning		
BL-1 Beaver Lake Management Plan Adoption	KCSWM	N/A[c]
BL-2 Phosphorus Removal	KCSWM/ DDES	N/A[c]
BL-3 Lake Classification System	KCSWM	N/A[c]
Interim Monitoring		
BL-4 Interim Monitoring	BLPA/ BLCC	$5,000[d]
Long-term Monitoring		
BL-5 Construction Inspection, Technical Assistance, and Monitoring		$50,000
BL-6 Citizen Lake Monitoring	KCSWM/ METRO	$45,500
BL-7 Watershed Monitoring		
Streams	KCSWM	$40,000
Shallow Groundwater	KCSWM/ SKCDPH	$35,000
GIS Watershed Data Base Update	KCSWM	$20,000
Stormwater Treatment Performance	KCSWM	$34,000
BL-8 Inventories		
Existing On-Site Sewage Systems	SKCDPH	$14,500
Wetlands, Streams and Native Growth Protection Easements	DDES	$12,000
Stormwater Detention and Treatment Facilities	KCSWM	$12,000
Community Education and Involvement Programs		
BL-9 Beaver Lake Watershed Management Committee	KCSWM	$10,000
BL-10 Homeowner Education and Involvement Programs	KCSWM/ BLPA/ BLCC	$10,000

Continued on next page . . .

Recommendation	Lead Agency[a]	Cost[b]
BL-11 Homeowner BMPs		
Septic Tank and Drainfield Maintenance	SKCDPH	$1,000
Lawn Fertilization and Yard Maintenance	KCSWM	N/A[c]
Shoreline Revegetation	KCSWM	N/A[c]
Aquatic Plant Management	KCSWM	N/A[c]
Animal Waste Control	KCSWM	$10,000
Milfoil Prevention	KCSWM	$10,000
Low/No Phosphate House and Garden Products	KCSWM	N/A[c]
Household Hazardous Waste Disposal	KCSWD	N/A[c]
Community Meetings	KCSWM	$10,000
Modeling Analysis and Management Plan Update		
BL-12 Modeling Analysis	KCSWM	$40,000
BL-13 Beaver Lake Watershed Management Plan Update	KCSWM	$50,000
Watershed Management Contingency Plans		
BL-14 Contingency Stormwater Treatment		
Construction Practices	KCSWM	N/A[c]
Innovative Post Construction Treatment	KCSWM	N/A[c]
BL-15 Contingency Wastewater Management		
On-Site System Repair and Replacement	KCSWM/ SKCDPH	N/A[c]
Sewer Service Extension	KCSWM/ SKCDPH	N/A[c]
BL-16 In-Lake Contingency Plan	KCSWM	N/A[c]
Total Project Cost		$404,000

a. DDES - Department of Development and Environmental Services
KCSWM - King County Surface Water Management
KCSWD - King County Solid Waste Division
METRO - Municipality of Metropolitan Seattle
SKCDPH - Seattle-King County Department of Public Health
BLPA - Beaver Lake Protection Association
BLCC - Beaver Lake Community Club

b. All costs are estimated for a five-year period except for BL-4, which covers only one year.

c. Not applicable - costs will be covered by existing or future funding programs.

d. Not included in total cost because recommendation should be performed during the period of obtaining funding for the remaining recommendations.

Recommendations

Policy, Land Use, and Zoning

BL-1 Management Plan Adoption - *King County SWM should pursue incorporation of the Beaver Lake Management Plan by reference into the East Lake Sammamish Basin and Nonpoint Action Plan. Separate adoption of the Beaver Lake Plan by the King County Council should also be pursued.*

The Beaver Lake Management Plan should be incorporated as part of the East Lake Sammamish Basin and Nonpoint Action Plan through the establishment of a specific recommendation in the basin and nonpoint action plan. Establishment of this recommendation should include review and approval of the Beaver Lake Management Plan by the Issaquah/East Lake Sammamish Watershed Management Committee (a committee which oversees the development of the basin and nonpoint action plan).

The funding of the Beaver Lake Management Plan should remain independent of the basin/nonpoint action plan. Moreover, individual adoption of the lake management plan by Council should be pursued upon completion of the plan.

BL-2 Phosphorus Removal - *An 80 percent reduction of total phosphorus (above background levels) should be established as a stormwater treatment goal for all future development. AKART or "all known, available, and reasonable methods of prevention, control, and treatment" for phosphorus control should be employed as the standard to achieve this goal.*

Future phosphorus loading to Beaver Lake is predicted to be 254 kg/yr without stormwater controls. Under current conditions, annual loading is 142 kg/yr. If 80 percent (or more) of the total phosphorus associated with stormwater runoff from new development can be removed prior to entering Beaver Lake, it is predicted that annual loading to the lake will increase to only 146 kg/yr. This level of phosphorus increase would not be expected to cause a significant change in the lake's trophic status (see Chapter 7).

It is important to recognize that the value of 80 percent represents a goal for phosphorus load reduction. Since current stormwater treatment technology is limited (in terms of achieving treatment efficiencies which would meet the treatment goal for phosphorus), the standard which has been set for treatment efficiency is AKART.

Table 17 illustrates various treatment efficiencies for a variety of stormwater treatment technologies. In some potential loading scenarios, an efficiency of 80 or more is needed to meet the treatment goal and preserve Beaver Lake water quality. In such a loading scenario, treatment options are very limited. However, if source control can be implemented prior to treatment, treatment efficiencies needed would be lowered and thus the loading goal met. For example, let's examine three loading scenarios:

Example 1	Example 2	Example 3
C: 150	C: 50	C: 50
F: 250	F: 250	F: 150
G: 80%	G: 80%	G: 80%
E_n: 32%	E_n: 64%	E_n: 53%

where C=current loading from a site, F=future loading from a site, G=the phosphorus load reduction goal, and $E_n = [(F-C) \times G]/F$ or the needed treatment efficiency to meet the loading goal.

In the first example, numerous treatment options from **Table 17** could be used to meet the loading reduction goal of 80 percent. In the second example, infiltration remains as the only single stormwater treatment option which will achieve the efficiency needed (or better) to meet the loading reduction goal. In the third example, the future loading is significantly less than in the second example and thus a lower treatment efficiency is needed to meet the loading reduction goal.

Potentially, other treatment combinations (in series wetpond or constructed wetland in combination with biofiltration and sand filters) or new technologies (such as alum treatment and new filtration media) may be used to achieve the loading reduction goal of 80 percent. All treatment strategies should be monitored post-construction to verify their effectiveness in meeting the treatment goal for the Beaver Lake Watershed.

Table 17
Potential Efficiency of Treatment Best Management Practices

BMP	35 Percent Total Phosphorus	50 Percent Total Phosphorus	80 Percent Total Phosphorus
Infiltration (in loam soils)	yes	yes	yes
Wetpond	yes	yes?	no
Wet Vault	yes?	no	no
Constructed Wetland	yes	yes?	no
Biofilter	yes	no	no
Extended Detention	yes?	no	no
Sand Filter	yes	yes?	no

Source: "The selection and sizing of treatment BMPs in new developments to achieve water quality objectives" an issue paper prepared by Gary R. Minton, Resource Planning Associates for KCSWM, 1993.

BL-3 Lake Classification System - *King County SWM should work with Ecology and other King County departments to develop a county-wide lake classification system. The purpose of this classification system would be to distinguish lakes from wetlands and to identify authorized lake management policies and practices. This could involve a subsequent amendment to the Sensitive Areas Ordinance (SAO) to include lakes as a protected sensitive area category.*

Interim Monitoring

BL-4 Interim Monitoring - *King County should work with the Beaver Lake Community Club and the Beaver Lake Protection Association to obtain funding for one year of interim water quality monitoring and inspection.*

One year of interim funding is needed for monitoring of Beaver Lake and its surface water tributaries prior to the time that a Lake Management District is formed and the management plan is successfully funded. The existing Lake Sammamish site inspector should be directly involved in the inspection of all new construction sites in the Beaver Lake watershed which are also tributary to Lake Sammamish. Interim monitoring and inspection should include the following elements:

- Performance of visual inspections of streams, wetlands, and any construction sites
- Continued Metro small lakes monitoring
- Implementation of citizen lake monitoring as described under BL-6
- Collection of monthly grab samples for 12 months at two stream inlets for total suspended solids, total organic carbon, and total phosphorus
- Collection of storm runoff samples at each of the two stream inlets during three storm events for total suspended solids, total organic carbon, and total phosphorus

Long-Term Monitoring

BL-5 Construction Inspection, Technical Assistance, and Monitoring - *King County should provide increased construction inspection, technical assistance, and monitoring surveillance before, during, and after the construction period for all new development in the watershed.*

King County SWM should conduct a water quality seminar and site visit for drainage engineers, contractors, private construction inspectors, and King County inspectors prior to construction. All technical assistance and educational activities should be coordinated at the preconstruction meeting. This would involve representatives from the King County

Department of Development and Environmental Services Environmental Education and Land Use Inspection Sections, King County SWM, and Seattle-King County Department of Public Health. The seminar would include a presentation by a representative of the King County SWM Lake Stewardship Program to discuss the water quality sensitivity of Beaver Lake and streams and wetlands in the watershed.

The Lake Sammamish water quality inspector (per the SWM and DDES memorandum of understanding) should include as part of his/her duties a site visit to all new sites led by the developer's drainage engineer to point out clearing limits, proposed erosion control facilities, and site-sensitive features (streams, wetlands, native growth protection easements, areas of steep slope or otherwise high erosion potential). Special attention would be directed to ensuring that no proposed drainage infiltration facility is used as a temporary sedimentation control facility (unless safeguards are in place to protect the infiltration area), and that its infiltration capability is not reduced by clearing, grading, or other use of heavy equipment within the infiltration area. Any adjustments necessary to the erosion/sedimentation control plan following the site visit would be documented and provided to appropriate King County staff, the contractor(s), and construction inspector(s).

During storm events, the Lake Sammamish water quality inspector would visit the construction site to observe the performance of erosion/sedimentation control facilities and to measure the quality of streamflow entering and leaving the construction site. The inspector should notify appropriate DDES and SWM staff of any water quality problems related to overflow or outflow from stormwater treatment facilities that ultimately discharges to Beaver Lake by surface flow. This will allow coordination with monitoring efforts at the point of discharge to the lake. Additionally, all stormwater discharges should be monitored for: instantaneous discharge (Q), turbidity and total suspended solids.

The frequency of violations of the Class AA water quality standards (WAC 173-201A 030 and 120[2]) for turbidity should be documented by the inspector for use in assessing interim water quality impacts to the lake as related to erosion/sedimentation control practices. The frequency should be evaluated based on visual observations and field turbidity measurements. All violation of required erosion/sedimentation control practices should be recorded and reported to the contractor and construction inspector immediately, so that corrective action could be taken immediately. The Lake Sammamish water quality inspector should work directly with the contractor and other site inspectors to rectify all erosion control practices which are failing to properly control on-site erosion.

Finally, the frequency of violations of Class AA turbidity standards and violations of required erosion/sedimentation control practices should be reported in the quarterly status report to the Beaver Lake Watershed Management Committee (BLWMC) (see recommendation BL-9). This report should be prepared by the Lake Sammamish water quality inspector.

BL-6 Citizen Lake Monitoring - *King County and Metro should establish an expanded citizens' lake monitoring program with the Beaver Lake Community Club and Beaver Lake Protection Association.*

The 1996 and 1999 citizen monitoring program for Beaver Lake should be expanded to include the collection of samples to be tested for fecal coliform bacteria, soluble reactive phosphorus, total phosphorus, chlorophyll a, ammonia nitrogen, nitrate plus nitrite nitrogen, total nitrogen, turbidity, alkalinity, color, zooplankton, phytoplankton, conductivity, pH, Secchi disk, and temperature and dissolved oxygen profiles.

Two surface open water stations—one in the middle of Beaver Lake 1 and one in the middle of Beaver Lake 2 (**Figure 5**)—would be sampled monthly during 1996 and 1999. Samples for the three forms of nitrogen would be collected only during July and August. Temperature and dissolved oxygen profiles would be collected during each monitoring trip. In addition, temperature and dissolved oxygen profiles would be collected weekly from April through July. In addition, bacterial monitoring will involve collecting one shoreline sample per month in each lake basin. This is because past experience has shown that the lakeshore environment is usually more susceptible to fecal coliform contamination than the open lake, and because this is the area where most contact recreation is likely to take place. In addition, citizen monitors would be trained to identify and look for Eurasian watermilfoil and other undesirable plant species. If they are unsure of identification, they could bring a sample to King County staff for positive identification.

One or two dedicated residents would be trained to perform this kind of monitoring with only four to eight hours of instruction. The confidence and skills of the citizen monitors is likely to be enhanced if a qualified water quality field person joins the citizen monitors during the first two or three sampling trips. This would include assistance with sample bottle pick up and delivery to the laboratory, calibration of field equipment, and filling out field note sheets. If citizens provide the field monitoring labor, the remaining tasks would involve (1) quality review of the data, (2) computer data management, (3) simple statistical analysis and data reduction, and (4) preparation of quarterly and annual reports of the results. The remaining tasks could be performed through the King County Lake Stewardship Program. For 1995, 1997, and 1998, the current Metro small lakes monitoring program for Beaver Lake should be continued.

Phosphorus, chlorophyll a, and Secchi disk data would be compared with data collected during this study (see **Appendix E**). Significant differences would be defined using standard t-tests at the five percent confidence interval. If significant increases were observed, an evaluation of steam inflows and in-lake data would be performed to determine if observed increases were due to increases in internal or external loading. Depending on the results of this evaluation, contingency watershed pollution control or in-lake measures could be considered for implementation.

Dissolved oxygen profile data would also be used to calculate oxygen depletion rates in the hypolimnion. If oxygen depletion rates increase over time, implementation of additional watershed or in-lake contingency measures (especially hypolimnetic aeration) could be further evaluated.

These efforts would be coordinated with BW-59 (Water Quality Monitoring), BW-35 (basin steward), BW-52 (Annual Report) of the East Lake Sammamish Basin and Nonpoint Action Plan, and results would be reported to the WIC (BW-21) and the proposed BLWMC (BW-21a) (see **Appendix G**). The results of the citizen monitoring program would be reviewed quarterly to determine if any significant shifts from historical water quality trends take place.

BL-7 Watershed Monitoring - *King County should establish a watershed monitoring program to include streams and shallow groundwater, GIS tracking, and stormwater treatment performance.*

In addition to the citizens' and construction monitoring plans described above, to be initiated as soon as possible, King County should routinely monitor groundwater and stormwater.

The primary purpose of watershed monitoring should be to confirm that no significant increase in phosphorus, fecal coliform bacteria, or total organic carbon loading occurs in the three tributary streams or groundwater system. Monitoring would also demonstrate the effectiveness of stormwater treatment facilities. (See **Figure 5** for location of sampling stations.) Recommended monitoring approaches for both objectives would be as follows:

Streams. Water level readings and eight grab samples annually would be collected at two stations (BLTR 1 and BLTR 2) plus composite storm samples would be collected for four storms per year for the following parameters: soluble reactive phosphorus, total phosphorus, nitrate plus nitrite, ammonia, turbidity, total suspended solids, fecal coliform bacteria, temperature, dissolved oxygen, and total organic carbon. Stream monitoring would occur between 1995–1999. Stream monitoring could also be triggered by notification from DDES to KCSWM that construction inspection (BL-5) has found water quality problems in the Beaver Lake watershed.

If upstream construction site monitoring of turbidity confirms water quality problems, field inspection and sampling of downstream areas should determine if direct surface water flows are impacting the lake. If upstream problems are confirmed, inlets to Beaver Lake should be monitored for instantaneous discharge (Q), turbidity, total suspended solids, soluble reactive phosphorus, and total phosphorus. Inlet stream data (e.g. total phosphorus) should then be compared to data collected in this study. A simple application of the standard t-test at the five percent confidence interval would allow data comparison.

Data evaluation would be performed by the King County SWM Lake Stewardship Program. Storm and non-storm stream quality data would be compared to corresponding data from this study (refer to **Appendix E**) and with results from interim monitoring. Significant differences would be defined using the standard t-test at the five percent confidence inter val. If significant differences are observed, erosion/sedimentation control and stormwater detention/treatment facilities would be inspected and monitored (if necessary—see stormwater treatment performance under recommendation BL-7) to determine if control measures are performing satisfactorily. Depending on the outcome of this assessment, modifications to erosion/sedimentation control or stormwater detention/treatment facilities could be recommended. In addition, significant increases in stream phosphorus or total organic carbon loading could result in a recommendation to implement contingency watershed pollution control measures (refer to recommendations BL-14 and BL-15) or in-lake contingency measures (BL-16).

Shallow Groundwater. The Seattle-King County Department of Public Health, through an interlocal agreement with King County SWM, would install and monitor shallow groundwater near the lakeshore of Beaver Lake. This monitoring would characterize shallow groundwater quality at the point of entry to the lake.

While upper watershed monitoring wells already in place may indicate potential future groundwater impacts resulting from new development in the upper watershed, any pollutants measured in these more remote groundwater monitoring wells could be filtered out prior to entry to Beaver Lake. The proposed near-shore wells would assist in measuring any change in quality at the lake edge.

Six shallow groundwater monitoring stations would be installed near the shoreline edge. These monitoring stations would be approximately ten feet in depth. Groundwater quality would be characterized by collecting composite samples for these parameters: soluble reactive phosphorus, total phosphorus, nitrate plus nitrite, ammonia, turbidity, total suspended solids, fecal coliform bacteria, temperature, dissolved oxygen, total organic carbon, and chloride. Sample collection would occur during 1995 and 1999. In 1995 and 1999, samples would be taken four times during the year. In 1996-1998, samples would be taken once a year.

Two of the six shallow groundwater wells should be located in areas where there is no suspected on-site wastewater influence. The remaining wells should be located between existing septic tank/drainfield systems and the lake shoreline, if possible. Since these all would be new monitoring wells, they should be installed as soon as possible and monitored prior to the onset of major new construction in the watershed, if possible.

GIS Watershed Data Base Update. Entranco, working with KCSWM, established a GIS data base as a pilot project for Beaver Lake. Existing and future GIS watershed land use maps were produced to depict anticipated watershed changes. These were used for water quality modeling.

This recommendation includes updating the GIS data base to allow tracking of watershed changes and to establish a permanent data base for Beaver Lake water quality information.

Stormwater Treatment Performance. In addition to the stream and groundwater monitoring described above, stormwater treatment performance monitoring could also be needed. This monitoring would only be implemented if other monitoring programs demonstrated violation of turbidity, phosphorus, total organic carbon, or fecal coliform criteria consistent with State Water Quality Standards and/or the water quality goals stated at the beginning of this chapter. In that case, additional treatment performance monitoring would be implemented for one or more stormwater treatment facilities, wetlands, or golf course irrigation ponds in the watershed. A total of $34,000 should be allocated to perform monitoring during this period (BL-7).

Land developers are already required to monitor the effectiveness of stormwater detention/treatment facilities for two years following construction. Any monitoring of such facilities by King County SWM would supplement this effort upon expiration of the developer's monitoring commitment, if needed.

The basic monitoring approach would be to obtain composite (automated) water samples upstream and downstream of a particular water treatment facility during at least three storm events to determine treatment effectiveness and to assess the need for application of contingency stormwater treatment modifications (see BL-14 in the Contingency Stormwater Treatment section).

Parameters would include soluble reactive phosphorus, total phosphorus, nitrate plus nitrite, ammonia, turbidity, total suspended solids, fecal coliform bacteria, and total organic carbon. During monitoring events, dissolved oxygen, pH, conductivity, and temperature should be measured in situ when possible. Two facilities per year would be monitored and three storm composite samples would be collected for each facility at upstream and downstream monitoring stations. To the extent possible, performance monitoring of stormwater facilities should be incorporated into the King County SWM BMP monitoring program.

BL-8 Inventories and Inspections - *King County should conduct inventories of existing on-site septic tank/drainfield systems; wetlands, streams, and native growth protection easements; and inspections of stormwater detention and treatment facilities as discussed below.*

Existing On-Site Sewage Systems (Septic Tank/Drainfield Systems.) Contingent upon funding, existing on-site sewage systems should be inventoried by the Seattle-King County Department of Public Health during 1995. A data file would be established for each existing residence in the watershed, including information about estimated wastewater loading (based on number of bedrooms, etc.), and size, location, age, maintenance, and design of sewage systems. It is anticipated that most of this information could be obtained from existing as-built records and interviews of property owners. This inventory would include an inspection for any evidence of failure with appropriate recommendations for maintenance or corrective action as needed. This could involve pumping, repair, or system replacement, as appropriate. A work plan would be included as part of the annual report to the BLWMC, if continuing projects are indicated. Homeowners would be given copies of the information obtained, along with educational materials regarding proper care and maintenance of their on-site sewage systems. This inventory work would be coordinated with BW-58, BW-18, and BW-31 of the East Lake Sammamish Basin and Nonpoint Action Plan (see **Appendix G**).

Wetlands, Streams, and Native Growth Protection Easements. King County SWM and King County DDES and local volunteers should make an annual inventory of these resources to identify any damage and to make recommendations for restoration, if needed. Specific attention should be paid to potential impacts due to erosion/ sedimentation (failing drainage facilities, road erosion, construction site erosion, etc.) and potential water quality impacts in the vicinity of the proposed equestrian/pedestrian trail system. Any repair, restoration, or maintenance needs would be identified in an annual work plan and included in the annual report to the BLWMC. This should also be coordinated with BW-56 of the East Lake Sammamish Basin and Nonpoint Action Plan (see **Appendix G**).

Stormwater Detention/Treatment Facilities. Inspection and maintenance of all future facilities should occur annually to determine if they are operating properly and if any maintenance is needed. Present development proposals include 18 biofiltration swales, three infiltration swales, one sedimentation basin, two dry detention ponds, one irrigation reservoir, 11 wet detention ponds, and two infiltration ponds. Any repair and/or maintenance work would be identified in an annual work plan and included in the annual report to the BLWMC. This work could be coordinated with BW-41 of the East Lake Sammamish Basin and Nonpoint Action Plan (see **Appendix G**).

Community Education and Involvement Programs

BL-9 Beaver Lake Watershed Management Committee - *The existing Beaver Lake Technical Advisory Committee should be expanded by King County SWM to form the Beaver Lake Watershed Management Committee.*

The BLWMC would have functions similar to the East Lake Sammamish Watershed Implementation Committee (WIC), but specific to the Beaver Lake watershed. The main focus of the BLWMC during the next five years would be to ensure that mitigating measures described in EIS documents, various permits, and hearing examiner conditions of approval, would be properly implemented for new construction in the watershed. Regular meetings would be held to discuss the effectiveness of erosion/sedimentation control measures and any modifications warranted subsequent to field inspection and monitoring. Representatives from King County DDES, Development Inspection Unit, King Conservation District, Seattle-King County Department of Public Health, and the East Lake Sammamish basin steward, as well as construction contractors and inspectors, would be added to the BLWMC.

As the watershed continues to develop, the BLWMC also would meet to evaluate whether both structural and non-structural BMPs are implemented, including appropriate operation and maintenance functions for stormwater detention/treatment facilities and the proposed Beaverdam Golf Course Management Plan. The BLWMC would also track water quality in Beaver Lake, tributary streams, and groundwater to assess if and when supplemental watershed or in-lake treatment measures might be warranted. They would also interface with the public during any lake/watershed plan updates.

BL-10 Homeowner Education/Involvement Programs - *Workshops handbooks, and videos should be used by King County and other organizations to convey homeowner BMPs (BL-11) to existing and future residents in the watershed.*

The County should use existing educational materials to promote lake and watershed protection. All programs should be consistent with the Lake Sammamish residential education program. The County should specifically assist the Beaver Lake Community Club in the development of their residential BMP handbook which is currently being funded by the Surface Water Management Division's Community Action Grant program. The County should also serve as an assistant to the community for establishing work shops which promote the education of residents and the implementation of homeowner best management practices which achieve lake and watershed protection.

BL-11 Homeowner Best Management Practices (BMPs) - *A variety of homeowner BMPs should be conveyed by King County to existing and future watershed residents, as discussed below.*

Septic tank and drainfield maintenance. Contingent upon funding, the Seattle-King County Department of Public Health should conduct a periodic (once in 1995 and 1998) on-site sewage system inspection and maintenance workshop for the Beaver Lake community. The workshop should be requested by and coordinated through the Beaver Lake Community Club and the Beaver Lake Protection Association. Citizens also should be informed about proper care of their on-site sewage systems and what to do in the event that failure is suspected or known.

Periodic septic tank pumping should be performed and evidence of failure should be reported to the Seattle-King County Department of Public Health. Periodically, a "septic tank pump out week" should be organized by the Beaver Lake Community Club and Beaver Lake Protection Association. The community should give consideration to the possibility of contacting a private septage company to arrange for discounted group pump-out charges.

Lawn fertilization and yard maintenance. Residents should adopt alternatives to standard lawn and yard maintenance practices which would result in a reduction of the transport of fertilizer, pesticides, and yard waste material to Beaver Lake. These alternatives include omitting purchase and application of commercial yard maintenance chemicals, the use of organic slow release fertilizers (if used), proper timing and application (i.e., localized application) of all organic fertilizers (if used), lawn size reduction or replacement, regular thatching or aeration of lawns if retained, incorporation of native plants into shoreline and yard landscaping, and soil enhancement through mulching and composting. Integrated pest management techniques are strongly encouraged over calendar-style applications of pesticides to control pests. Residents are encouraged to contact organizations like the Washington Toxics Coalition and Seattle Tilth for less toxic alternatives for lawn and yard maintenance practices in the Beaver Lake watershed.

Shoreline revegetation. Shoreline residents should consider and pursue volunteer revegetation of their shoreline with native plantings. King County SWM has an ongoing native plant salvage and revegetation program and is available for consultation to individual property owners and the Beaver Lake Community Club and the Beaver Lake Protection Association.

Aquatic plant management. Limited aquatic plant control by individual property owners should be permitted to maintain access to the lake and to prevent health and safety threats. The Beaver Lake Community Club and Beaver Lake Protection Association should pursue a lake-wide permit from the Department of Development and Environmental Services for limited hand pulling or hand-harvesting and bottom barrier use in the control of aquatic plants (see **Appendix H** for more information).

Animal waste control (waterfowl, pet wastes, and hobby farms). Waterfowl feeding should be prohibited at Beaver Lake. Signs prohibiting feeding and detailing the effect of animal waste on water quality should be illustrated on signs posted at the park and boat launch.

Pet wastes from dogs or other domesticated animals should be disposed of properly or composted. Dog runs and other animal keeping facilities should be built as far from receiving waters as possible, and site drainage should be routed so they do not pass through areas of animal waste accumulation. In addition, signs should be posted regarding leash and pooper scooper laws.

Animal waste accumulations on pedestrian and equestrian trails is a particular concern, especially in the vicinity of wetlands and stream crossings. Therefore, homeowner's associations and King County should assume responsibility for educating trail users on proper animal waste disposal practices.

Milfoil prevention. Warning signs at the Beaver Lake County Park and the Washington State Department of Wildlife boat launch area are recommended. Educational materials showing what Eurasian watermilfoil looks like and how to inspect boat and trailer equipment for undesirable plant fragments should be provided at the park and boat launch. Educational brochures should be included in the citizens' BMP handbook. These should be updated annually through the King County SWM Lake Stewardship Program and sent out with Community Club notices.

Bright, colorful stickers, that could be placed on boats and trailers as a reminder to check for and remove any milfoil fragments that are found on the vehicle, boat, trailer, motor, oars, or fishing gear, should be provided by the community during the first four weekends of fishing season. King County and citizen monitoring staff should also perform a periodic inspection of the lake to look for any evidence of noxious plant outbreaks.

Use of low and/or no phosphate household and garden products. Volunteer use by watershed residents of low and/or non-phosphate products and organic forms of phosphate-based fertilizers should be encouraged.

Household hazardous waste disposal. Education of watershed residents encouraging them to reduce the generation of hazardous waste using alternatives to and/or decreasing the use of products which result in hazardous waste, as well as education on proper disposal of hazardous waste, is recommended. The Beaver Lake Community Club, Beaver Lake Protection Association, and King County Solid Waste Division should be encouraged to promote an annual household hazardous waste clean-up day in the watershed.

Community Meetings. Annual community meetings should be held in the Beaver Lake area to report on the status of monitoring results and any implications for watershed management activities and/or in-lake contingency measures. In the event that modifications to the lake/watershed management plan are needed, several community meetings could be required to communicate information including costs, effectiveness, and environmental considerations. Therefore, it is proposed that the County and community plan for a total of eight community meetings over the next five years.

Lake Analysis and Management Plan Update

BL-12 Modeling Analysis - *King County SWM should conduct updated watershed/lake modeling analyses to validate the model and to make new loading and lake condition forecasts.*

After five years, King County SWM should conduct modeling analyses to update land use, water budget, nutrient budget, and lake trophic response analyses. Updated modeling would focus on phosphorus loading, assuming that trophic status is primarily con trolled by phosphorus levels. The updated model would be calibrated against field monitoring data and revised projections of future lake quality would be made.

BL-13 Beaver Lake Watershed Management Plan Update - *The Beaver Lake Management Plan should be reviewed thoroughly at least once every five years (or more frequently if compelling reasons exist) and updated by King County SWM if needed.*

If lake and watershed monitoring and/or the updated modeling analysis indicate that any of the water quality goals are not being met or are not likely to be met by the lake and watershed controls in place at that time, then King County SWM should initiate a process for reviewing and updating the Beaver Lake and Watershed Management Plan. The planning process should include the public, watershed land owners, and any affected agencies, and should consider amendments that would make it possible to achieve the water quality goals stated in this plan.

CONTINGENCY WATERSHED POLLUTION CONTROL MEASURES

BL-14 Contingency Stormwater Treatment - *King County should implement contingency measures to control nonpoint sources of pollution from site development construction or post-construction stormwater runoff as warranted by monitoring and inspection.*

Because of the sensitivity of Beaver Lake to increased phosphorus, bacteria, and total organic carbon loading, existing County erosion/sedimentation control and post-construction stormwater quality treatment practices may not be sufficient to meet the water quality goals stated at the beginning of this chapter. Therefore, additional innovative practices may be necessary, if monitoring results indicate that water quality standards and criteria are not being met.

Construction Practices. If excessive pollutant loading is contributed to either of the two tributary streams entering Beaver Lake during the construction phase, immediate action should be taken to correct any problem conditions. Emergency response should be coordinated between the King County Department of Development and Environmental Services Inspection Unit, SWM Drainage Investigation and Regulation Unit, the Lake Sammamish Inspector, and the East Lake Sammamish basin steward.

In addition, a special meeting of the BLWMC should be called. The purpose of the meeting would be to consider improvements and modifications to the erosion/sedimentation control plan(s) that could mitigate observed water quality impacts. Since the concern at Beaver Lake involves the control of phosphorus, bacteria, and total organic carbon, it should be clear that construction runoff management in the watershed could involve more than measures to simply control erosion and sedimentation alone. In the event that problems do arise, the following construction control options should be considered in order of priority listed:

- Review the King County Surface Water Design Manual (**King County 1990c**) and the Stormwater Management Manual for the Puget Sound Basin (**Ecology 1992b**) to consider the application of any standard erosion/sediment control measures that have not previously been included in the erosion/sedimentation control plan for the site in question.

- Consult with King County SWM regarding new and or experimental erosion/sediment control measures for potential application in the Beaver Lake watershed

- Consider the potential effectiveness and feasibility of imposing more stringent construction timing limits to limit runoff impacts. This might be particularly appropriate for any construction work scheduled in and around drainage courses, wet lands, and streams.

- Consider the feasibility of routing runoff through temporary soil infiltration trenches, using imported soil material in a designed fill/underdrain facility.

- Consider the feasibility of pumping site runoff from temporary erosion control ponds to undisturbed forest areas to allow additional soil infiltration and treatment prior to discharge from the site. If performed, discharge into forested soil areas should be done in areas of low gradient. In addition, some kind of manifold distribution and rock splash pads should be used, if appropriate.

- Consider mulching cleared areas and exposed soils with chipped/shredded vegetation, removed during clearing, for enhanced erosion control.

Innovative Post-Construction Stormwater Treatment. Under post-construction conditions, it is expected that stormwater treatment measures constructed by developers, in combination with existing natural downstream wetland treatment, will be sufficient to meet the Beaver Lake Watershed goals presented at the beginning of this chapter. However, if monitoring results indicate otherwise, then King County SWM and the BLWMC should conduct performance monitoring to identify facilities that are not providing good treatment and consider the application of innovative stormwater treatment measures presently being tested by the Lake Sammamish Project Management Committee (PMC) and others.

The City of Bellevue (one of the PMC members) is taking the lead in evaluating the effectiveness of designed media stormwater infiltration using bench scale and full scale test approaches. One of the proposed test media is a combination of leaf compost, sand, and limestone. Other unspecified media will also be tested. The Lake Sammamish Project Management Committee and the City of Redmond (one of the PMC members) will also be testing the feasibility of using alum blocks as a low-cost, low-maintenance approach for phosphorus removal in biofiltration swales. One possible de sign approach has already been proposed for Sammamish Park Place, Phase II by Harding Lawson Associates (refer to **Appendix I**). King County, the City of Issaquah, and the City of Bellevue will also be testing the feasibility of liquid alum dosing into underground storage tanks, vaults, catch basins, or other drainage detention and conveyance systems.

BL-15 Contingency Wastewater Management - *King County and other affected parties should consider alternative on-site wastewater designs or extension of sewers, in the event that monitoring results indicate violation of either water quality standards or water shed goals resulting from conventional on-site wastewater disposal systems.*

The approach to on-site wastewater management in the watershed should involve monitoring evaluation in a manner similar to that proposed for stormwater runoff. It is proposed by the developers that Beaver Lake Estates, Brighton's Landing, and Belvedere Park will be served by sewer service extension, while the Beaverdam project will use septic tank/drainfield systems. With respect to sewer service, there is little potential impact to Beaver Lake since wastewater would all be conveyed outside the watershed for treatment. Therefore, the main focus of future monitoring would be to assess the impact of failing septic tank/drainfield systems for existing shoreline development and new residential units in the Beaverdam development project.

On-site System Repair and Replacement. If on-site septic system failure surveys or any of the water quality monitoring data indicate failure of one or more systems, the Seattle-King County Department of Public Health should be requested to contact the affected property owner for consultation regarding repair or replacement options. In some situations, repair may simply involve septic tank pump-out. In other cases, new septic tanks and/or drainfields may have to be constructed in reserve areas. In the case of existing older home sites (typically located on shoreline property), where on-site systems may have been designed and constructed prior to current design and construction standards, site dimensions could preclude the construction of new septic tank/drainfield facilities. Under these conditions, the feasibility of pumping septic tank effluent to an undeveloped lot upslope from the lakeshore should be explored. If soil conditions permit, the possibility of a community drainfield approach should be evaluated, if there are multiple failures in proximity. Another possibility would be to consider the implementation of innovative and alternative on-site system designs.

Sewer Service Extension. If serious water quality problems arise with the use of on-site wastewater disposal systems, and if repair/replacement options do not prove to be feasible because of site constraints or low cost-effectiveness, the feasibility of extending sewer service into areas presently lacking sewer service should be examined. This should be considered for the future, while recognizing that sewer service extension could increase land use densities in the watershed, potentially increasing nonpoint pollution originating from stormwater runoff.

IN-LAKE CONTINGENCY PLAN

BL-16 In-Lake Contingency Plan - *In the event that the application of source controls and structural BMPs in the watershed fail to maintain lake management goals for trophic status, fisheries, or aquatic plant control, the following in-lake control methods should be reviewed by King County SWM, the State Departments of Ecology and Wildlife, and the BLWMC to determine the feasibility of implementation:*

Aluminum Sulfate Treatment - This lake restoration technique is used to limit internal sediment phosphorus release. This technique may be desirable if long-term increases in external loading or changes in other limnological conditions result in an increase in internal phosphorus loading to Beaver Lake. This technique could also be used as mitigation to reverse short-term increases in lake phosphorus concentrations, should these occur as a result of construction runoff. Also, if lake water quality begins to deteriorate, it may be worthwhile to compare the cost-effectiveness of aluminum sulfate treatment as a means of internal phosphorus control against the cost effectiveness of additional water shed controls (refer to **Appendix J** for more information).

Hypolimnetic Aeration - This technique is primarily used to ensure adequate oxygen supply to the fishery. Trout habitat in Beaver Lake is currently limited in summer due to high temperatures at the surface and insufficient dissolved oxygen in the bottom waters. Coldwater fish are generally limited to the area of lakes that are cooler than 21 degrees Centigrade and have dissolved oxygen concentrations greater than 3 mg/L (**Van Velson 1986**). Using these criteria for Beaver Lake 2, there is no available fish habitat during August. Above a depth of two meters, the surface waters are too warm to support the coldwater fisheries. Similarly, below a depth of two meters there is insufficient oxygen. Any increase in algae levels, as a result of the contingency measures not working, would extend the period in which the lake could not support trout habitat.

Aquatic Plant Controls - The most likely reason for intensive aquatic plant control would probably be associated with infestation by Eurasian watermilfoil or Brazilian elodea. If aquatic plant growth gets out of control it can interfere with a variety of beneficial uses. Several alternative plant control techniques are discussed in **Appendix H**, including bottom barriers, diver hand pulling or dredging, grass carp, and herbicides.

IMPLEMENTATION PLAN

It is anticipated that the recommendations addressed in this chapter and summarized in **Table 16** would be implemented in 1995–2000 in the following sequence:

Final Lake and Watershed Management Plan Approval	1993
Lake Management District (LMD)	1994
Formation and Ecology Grant Application	1994
Plan Implementation and Monitoring	1995–2000

In addition, the Beaver Lake and Watershed Management Plan addresses contingency measures that only would be implemented if the need for such measures is demonstrated through citizen and watershed monitoring programs, affected agencies and organizations can agree on appropriate actions and funding mechanisms, and appropriate environmental reviews and permit clearances can be obtained. These measures are:

- Contingency stormwater treatment during construction
- Innovative post-construction stormwater treatment

- Contingency wastewater management
- In-lake aluminum sulfate treatment
- Hypolimnetic aeration
- Aquatic plant control.

Funding

Grants

There are four kinds of grant programs available that could be pursued for funding assistance on recommended best management practices and/or future contingency measures:

Ecology's Centennial Clean Water Fund (CCWF) Freshwater Activities. This is the most likely source of funding for implementation of watershed BMPs and any future contingency work, except for aquatic weed control. Applicants must be sponsored by a unit of local government such as King County, have an Ecology-approved Phase I lake management plan (such as this document) for Phase II (implementation) and must compete with other state and local agencies annually for limited funds. If approved, CCWF grants will cover 50 percent of eligible project costs.

Ecology's Centennial Clean Water Nonpoint Source Control Program. This program will cover any structural or non-structural watershed BMPs with a 50 percent funding match. However, it would not cover any in-lake contingency restoration measures or aquatic plant control efforts. Other criteria are the same as those for the Centennial Clean Water Fund Lake Program.

Ecology's Aquatic Weeds Management Fund. This is a new program for the control of aquatic weeds that interfere with fish populations, reduce habitat for desirable plant and wildlife species, or interfere with public recreational opportunities. The funding contribution is 75 percent, which must go to a unit of local government. The program includes special consideration for removal of early infestations of invasive, non-native freshwater aquatic weeds.

The Clean Lakes Program of the United States Environmental Protection Agency (US EPA). Some funding is also available for lake restoration projects through the US EPA. Grant matches are 50 percent for Phase II projects. Ecology usually works with local units of government to compete with other applicants in US EPA Region X, which includes the states of Washington, Oregon, Idaho and Alaska. Based on Ecology policy, combined state and federal grant assistance cannot exceed 75 percent. Following review and approval of this lake/watershed management plan, King County SWM plans to make application for Phase II funds through the CCWF grant program for the following activities/costs:

BL-5	Construction Inspection and Monitoring	50,000
BL-6	Citizen Lake Monitoring	45,500
BL-7	Watershed monitoring (five years)	129,000
BL-8	Inventories	38,500
BL-9	Beaver Lake Watershed Management Committee	10,000
BL-10	Homeowner Education and Involvement Programs	10,000
BL-11	Homeowner BMPs	31,000
BL-12	Modeling update	40,000
BL-13	Management Plan Update	50,000
Total Phase II Project Budget		**$404,000**
Ecology Grant Share		$202,000
Local Share		$202,000

The cost of all other BMP elements is assumed to be covered under other existing County programs or born by private developers and homeowners. These costs do not include the cost of any watershed or in-lake contingency measures. If needed, cost estimates for these activities would be prepared at some future date and included as a supplement to the proposed Ecology Lake Program grant. If needed, another lake management district process would also be required (see below).

Lake Management District

King County is proposing the formation of a Lake Management District to cover the local share of the grant. The Revised Code of Washington 36.61 outlines the procedure for forming a lake management district (see **Appendix K**) and is summarized below. Lake management districts can be formed to raise revenue for the purpose of improving or maintaining the quality of a lake or lakes. The procedure for district formation requires that local property owners initiate the process by petition or that local government initiate the process by resolution. In either case, the petition or resolution must set forth the following:

- The nature of the lake improvement or maintenance activity proposed
- The amount of money proposed to be raised
- Whether assessments will be annual, one-time payment, or combination
- The amount of annual assessment and revenue bonds, if desired
- The number of years for the duration of the district (up to ten)
- The proposed boundaries of the district

This information is included in a public notice, and a public hearing is held to provide an opportunity for the county legislative authority to hear testimony for and against the pro posed district. The State Departments of Wildlife and Ecology are also notified and given the opportunity to comment on the formation of the district. Subsequent to the hearing, the county may modify the boundaries or change the proposed scope of work and assessments in accordance with procedures set forth in the RCW. If the County finds that it is in the interest of the public to form a district, a ballot is sent to each property owner in the proposed district including the information above as well as the estimated assessment for each parcel of land. Various methods for calculating special assessments are covered under RCW 36.61.160. Assessments must be in accordance with the benefit conferred on each property. Each property owner's vote is weighted to give one vote for every dollar of assessment and a simple majority is required to form the district. If approved by such a ballot, district formation can be appealed by filing a lawsuit no later than forty days after a notice has been published ordering the formation of the district.

If there are no appeals, the County is then required to prepare a special assessment roll and to submit a public notice of another public hearing for the purpose of hearing objections regarding any special assessments and, following the hearing, may adjust special assessments as the County deems appropriate and in accordance with the RCW. The County is then required to pass a resolution confirming the special assessment role and to notify each property owner of their individual assessment. This action can also be appealed within ten days of the resolution. If there are no appeals, the County Treasurer is then required to publish a notice that the special assessments have been confirmed and will be collected.

Although the specific nature of the proposed district will be developed by the County in accordance with the provisions of the RCW as summarized above, the following is presented to give the reader an indication of the potential financial implications.

- It is proposed that the district boundaries encompass the entire watershed and include two zones—one zone including parcels with lakefront property that would collectively be assessed 75 percent of the total assessment, and one zone including all other property in the watershed that would collectively be assessed 25 percent of the assessment. This assumes that the greatest benefit would accrue to waterfront parcels, but that benefit would also accrue to other properties in the watershed via the public access afforded through the Department of Wildlife boat launch and Beaver Lake Park.

- It is proposed that the district be established for a period of five years and that the total assessment include the $202,000 local share, plus an additional $50,000 to match grant funds for feasibility studies for any contingency work that may be deemed desirable by the community and could be sponsored by the County over the duration of the district. Therefore, the total proposed assessment would be $189,000 for Zone One and $63,000 for Zone Two.

- It is further proposed that assessments be collected every year for five years. The total annual assessment for Zone One is $37,800 and the total annual assessment for Zone Two is $12,600. It is further proposed that the assessment for each parcel be calculated as the percentage of the individual property assessment divided by the total assessed value of all properties within each zone. A rough estimate of the individual property assessments can be obtained by dividing the total annual assessments by the number of properties in each zone. For example, we have estimated that there are 253 zone 1 lots and that the annual cost per lot would be $149, or approximately $13 per month per lot.

If an LMD cannot be formed, there will be no local funding for this management plan and only those few elements that correspond with existing agency programs will be implemented.

Preliminary Schedule

It is assumed that this report should be reviewed and approved during 1993. Following report approval, King County SWM should initiate the process for forming a Lake Management District and should also apply to Ecology for a Phase II Centennial Clean Water Grant to cover 50 percent of the cost of recommended Phase II efforts. It is anticipated that the LMD and grant application/approval process should take about one year. This assumes that the LMD is approved and that grant application is approved by Ecology. Monitoring and other BMP practices should be implemented during the following five years. A preliminary detailed schedule of implementation and monitoring activities is shown in **Figure 41**.

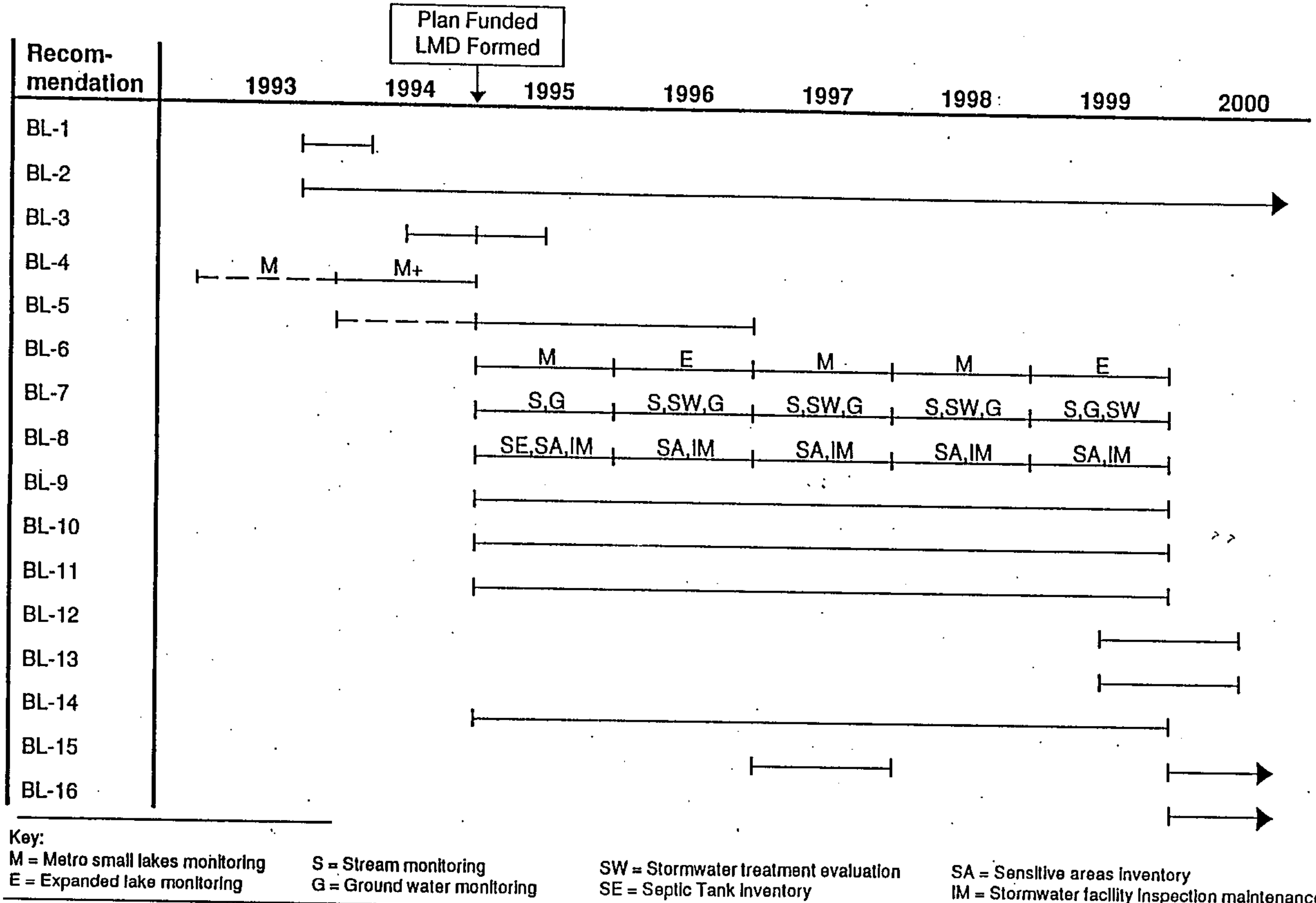


Figure 41
Beaver Lake Management Plan Implementation Schedule

7. LAKE MODEL PREDICTIONS

The calibrated lake water quality response model discussed in Chapter 5 is used to determine the sensitivity of Beaver Lake to phosphorus loading from changes in watershed land use. Along with the water and phosphorus budgets, these model predictions form the basis of the lake and watershed recommendations provided in Chapter 6.

As shown in **Figure 2**, the Beaver Lake watershed will be converted from primarily undeveloped to residential development in the near future. The purpose of this modeling is to predict the water quality of Beaver Lake once the watershed becomes fully developed and to evaluate the water pollution control effectiveness of stormwater measures that may be implemented under the fully developed conditions. Specifically, the lake response model predicts the future trophic state of Beaver Lake assuming a completely developed watershed. The following five cases were modeled:

1. Existing conditions
2. Watershed buildout with stormwater controls assuming low phosphorus loading and high treatment effectiveness of stormwater
3. Future watershed conditions with Interim Zoning GR-5
4. Watershed buildout with stormwater controls assuming high phosphorus loading and low treatment effectiveness of stormwater
5. Watershed buildout without stormwater controls

Cases two and four were simulated because of the variability in factors that will influence phosphorus levels in the future, including:

- The water pollution control effectiveness of stormwater measures
- The proportion of the watershed that will have sewers
- Future phosphorus concentrations from the open space areas, such as golf courses
- The effects of high phosphorus concentrations within the deep groundwater which may be used for domestic purposes and golf course irrigation

By combining high phosphorus concentrations with low stormwater treatment and low phosphorus loading with high stormwater treatment, the range of phosphorus loading simulated should bracket the actual range of future phosphorus loading to the lake.

To control stormwater runoff, new developments in the watershed (Beaverdam, Beaver Lake Estates, and Trossachs property) plan to use a combination of infiltration basins, wet detention ponds, constructed wetlands, and biofiltration swales. Based on a review of case study literature, these stormwater control methods provide wide ranges of phosphorus treatment, generally varying between 20 and 90 percent as measured by percent influent phosphorus reduction (Strecker et al. 1990; Ecology 1992c; Schueler 1987; Welch et al. 1988). The variables that affect treatment efficiency of these stormwater control techniques include the ratio of treatment facility area to tributary watershed area, watershed characteristics, pollutant concentrations in the inflow, pond depths and volumes, hydraulic residence time, and the presence or absence of vegetation (Entranco 1992).

Although the treatment effectiveness of the stormwater controls is generally between 20 and 90 percent, two values of treatment effectiveness, 40 percent and 80 percent, were assumed for the model simulations of future conditions.

The methods and assumptions for each of the model simulations are described below. The results of the modeling simulations follow this discussion. Refer to Chapter 5 for the methods and assumptions used to develop the model, which was calibrated to existing conditions. For the model simulations, the major factors that may change from existing to future conditions are:

- Number of homes in the watershed
- Number of septic systems
- Percent of phosphorus treated in stormwater controls
- Phosphorus concentrations in open spaces, (e.g., golf courses)
- Phosphorus concentration from developed areas which contain effective impervious areas (EIA)

EXISTING CONDITIONS

- Number of homes in the watershed: 215
- Number of septic systems: 215 (9 failing)
- Percent of phosphorus treated in stormwater controls: 0 (no stormwater controls are installed)
- Phosphorus concentrations in open spaces: N/A (there are currently no open space areas)
- Phosphorus concentration from effective impervious areas (EIA): 236 μg/l, based on values for stormwater data collected from Bellevue (refer to Chapter 5)

METHODS AND ASSUMPTIONS FOR MODEL SIMULATIONS OF FUTURE CONDITIONS

Watershed Buildout With Stormwater Controls Assuming Low Phosphorus Loading and High Stormwater Treatment

- Number of homes in the watershed: 1,725.
- Number of septic systems: 265 (11 failing). It is assumed that most of the watershed will have sewers, with the exception of the Beaverdam property, which will remain without sewer service.
- Percent of phosphorus treated in stormwater: 80. It should be noted that this is a very optimistic level of treatment.
- Phosphorus concentration in open spaces: 50 µg/l. No increases in phosphorus loading is expected from grassed areas, and that treatment cannot reduce phosphorus below the existing levels.
- Volume-weighted phosphorus concentration in runoff from effective impervious surface area: 94 µg/l. Approximately 25 percent of the EIA within the watershed occurs on existing land uses and will not receive stormwater treatment. The volume-weighted phosphorus concentration from this portion is 59 µg/l (236 µg/l × 25 percent). For the remaining EIA, 80 percent treatment is assumed. Therefore, the volume-weighted concentration is equal to 35 µg/l (236 µg/l × 75 percent × 20 percent). These two volume-weighted values are summed to equal the average phosphorus concentration from EIA of 94 µg/l.

Future Watershed Conditions With Interim Zoning GR-5

- Number of homes in the watershed: 446, based on the densities assumed from the three planned developments in the watershed (Beaverdam, Beaver Lake Estates, and Trossachs property), with development in the nonvested property (e.g., the land owned by the DNR) limited to GR-5 (one unit per five acres) (King County 1992a; King County 1992b; King County 1992c). This assumes four percent EIA for the interim zoning area.
- Number of septic systems: 446 (18 failing). It is assumed that the watershed will remain without sewer service. Phosphorus loading from septic systems is estimated by assumed typical loading rates per septic tank and treatment efficiencies. Therefore, phosphorus loading to the lake increases as the number of septic systems increase. As with existing conditions, a failure rate of four percent is assumed.

- Percent of phosphorus treated in stormwater: 0. It is assumed that no stormwater controls will be implemented for this modeling case.

- Phosphorus concentration in open spaces: 100 µg/l. Phosphorus levels may increase because of greater use of fertilizer in golf courses or the use of deep groundwater for irrigation or domestic water use.

- Phosphorus concentration in runoff from effective impervious surface area: 236 µg/l (as described above for existing conditions).

Watershed Buildout With Stormwater Controls Assuming High Phosphorus Loading and Low Stormwater Treatment

- Number of homes in the watershed: 1,725.

- Number septic systems: 1,725 (69 failing). It is assumed that the watershed will remain without sewer service.

- Percent of phosphorus treated in stormwater: 40. This represents the percent reduction in phosphorus concentration draining each subbasin. The treatment applies only to future development.

- Phosphorus concentration in open spaces: 100 µg/l.

- Volume-weighted phosphorus concentrations in runoff from effective impervious surface area: 165 µg/l. As above, 59 µg/l originates from existing development, and 106 µg/l associated with new development. Therefore the assumed volume weighted concentration is equal to 165 µg/l (236 µg/l × 75 percent × 60 percent).

Watershed Buildout without Stormwater Controls

- Number of homes in the watershed: 446 based on the densities assumed from the three planned developments in the watershed (Beaverdam, Beaver Lake Estates, and Trossachs property), with development in the nonvested property (e.g., the land owned by the DNR) limited to GR-5 (one unit per five acres) (King County 1992a; King County 1992b; King County 1992c). This assumes four percent EIA for interim zoning area.

- Number of septic systems: 446 (18 failing). It is assumed that the watershed will remain without sewer service. Phosphorus loading from septic systems is estimated by assumed typical loading rates per septic tank and treatment efficiencies. Therefore, phosphorus loading to the lake increases as the number of septic systems increase. As with existing conditions, a failure rate of four percent is assumed.

- Percent of phosphorus treated in stormwater: 0. It is assumed that no stormwater controls will be implemented for this modeling case.

- Phosphorus concentration in open spaces: 100 µg/l. Phosphorus levels may increase because of greater use of fertilizer in golf courses or the use of deep groundwater for irrigation or domestic water use.

- Phosphorus concentration in runoff from effective impervious surface area: 236 µg/l (as described above for existing conditions).

MODELING RESULTS OF FUTURE CONDITIONS

The results of the model simulations for future conditions are presented in **Table 18**, and the sensitivity of Beaver Lake to increase phosphorus loads (based on the model simulations) is shown in **Figure 42**. It should be noted that, for the future model scenarios, it was assumed that the internal phosphorus loading rate would remain unchanged from existing conditions. If internal loading increases as a result of prolonged increases in external loading, then the water quality of Beaver Lake would decrease at a faster rate than modeled.

Table 18
Response of Beaver Lake to Variations in Phosphorus Loading

Scenario	Phosphorus: Annual Loading (kg P/year)	Phosphorus: Annual Epilimnetic (µg/l)	Phosphorus: Summer Epilimnetic (µg/l)	Epilimnetic Summer Chlorophyll *a* (µg/l)
Existing conditions	142	19	17	5.2
Future assuming low phosphorus loading and high stormwater treatment	146	22	14	6.4
Future conditions with interim GR-5 zoning	189	28	18	9.1
Future assuming high phosphorus loading and low stormwater treatment	238	34	22	12.1
Future conditions without stormwater controls	254	36	23	13.1

Note: Based on an empirical relationship of ug chl *a* L^{-1} equals (0.073) $(P)^{1.449}$ **(Dillon and Rigler 1974)**

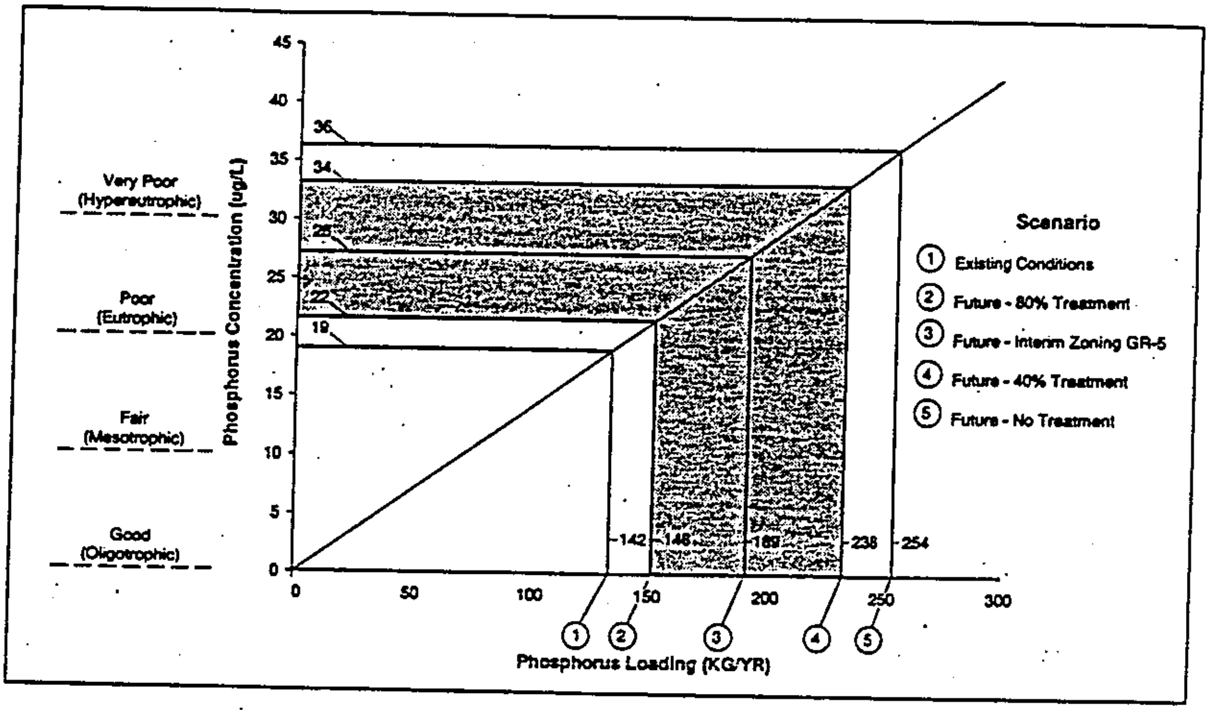


Figure 42
Sensitivity of Beaver Lake to P Loading

Watershed Buildout With Stormwater Controls Assuming Low Phosphorus Loading and High Stormwater Treatment

As shown in **Figure 42** and **Table 17**, under the most optimistic levels of treatment, it is expected that the phosphorus concentrations and algae levels will be similar to those observed in existing conditions. Note that this level of treatment is fairly high for stormwater controls in this area.

Future Watershed Conditions With Interim Zoning GR-5

The interim GR-5 zoning (see recommendation BL-2) with no other controls would result in an annual loading of phosphorus of 189 kgP/year (**Table 17**). This amounts to a 26 percent reduction from the Watershed Buildout Without Stormwater Controls scenario, due to lower septic and stormwater inputs.

Watershed Buildout With Stormwater Controls Assuming High Phosphorus Loading and Low Stormwater Treatment

Estimated increases in external loading under a fully developed watershed could result in P concentrations within the lake that are similar to unmitigated conditions. At the worst, average annual and summer epilimnetic phosphorus concentrations would increase by about 75 percent and 25 percent, respectively.

Watershed Buildout Without Stormwater Controls

Without stormwater controls, phosphorus loading to Beaver Lake is expected to increase by over 75 percent under a completely developed watershed (Table 17). As shown in **Figure 43**, the increase in loading is primarily due to greater loading from stormwater and septic tank systems, which increase from five percent to 21.7 percent. (Refer to **Figure 37**, page 80 for existing phosphorus loading.) As a result of this increased loading, average annual epilimnetic phosphorus concentrations would be expected to increase by 89 percent (Table 17). Because most of the stormwater enters during the winter, summer increase in phosphorus is expected to be only 35 percent, assuming no change in internal loading rates. In other words, most of the increase in annual average epilimnetic phosphorus concentrations is due to the much higher levels of winter loading from stormwater. Average summer epilimnetic phosphorus concentrations in Beaver Lake will increase about 35 percent above existing levels, from 17 µg/l to 23 µg/l. Based on the annual epilimnetic phosphorus concentration, chlorophyll *a* would be expected to increase to 13.1 µg/l, which is more than a two-fold increase above current conditions.

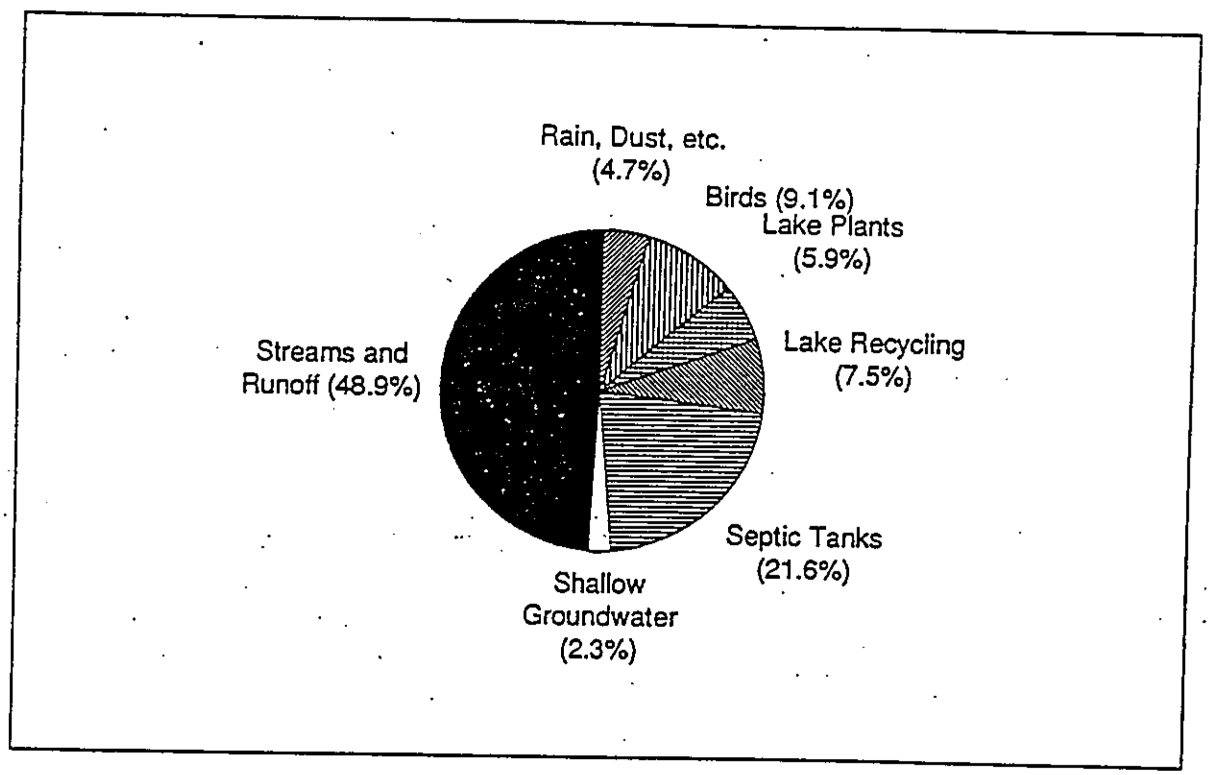


Figure 43
Future Phosphorus Loading Without Stormwater Controls

Despite the relatively low increase in summer-time loading to Beaver Lake, the water quality of the lake would decrease because of 1) the presence of blue-green algae through much of the year (wintertime blue green algal blooms are not uncommon in eutrophic lakes in this area), 2) spring and early summer chlorophyll *a* levels would be expected to increase by an estimated 150 percent, and 3) spring-time algal blooms of the euglenoid may significantly increase with the much higher levels of winter phosphorous in the lake.

SUMMARY

In summary, under conditions of a fully developed watershed, the phosphorus concentrations and algal levels in Beaver Lake are predicted to range from levels that are similar to existing conditions, based on optimistic levels of stormwater treatment, to dramatically higher levels on an annual basis, despite stormwater controls. As shown by Figure 43 the effectiveness of installation of stormwater controls under the fully developed watershed is uncertain. These results support the need to monitor Beaver Lake and its tributaries, and the effectiveness of stormwater control measures as the watershed becomes developed.

REFERENCES

Anderson, C. W. and E.B. Welch

1991 Pine Lake Response to Diversion of Wetland Phosphorus. Department of Civil Engineering, University of Washington. Water Resources Series Technical Report No. 127. Seattle, Washington.

Arvola, L. T,R. Metsala, A. Simila, and M. Rask

1990 Phyto- and Zooplankton in relation to water pH and humic content in small lakes in southern Finland. *Intern. Vereinig. fuer Theorest. Angewand. Limnol.* 24:688-692.

Ashley, K.I.

1987 Artificial Circulation in British Columbia: Review and Evaluation. Fisheries Technical Circular 78. Province of British Columbia, Ministry of Environment.

Beak Consultants, Inc.

1992 Master Drainage Plan for the Beaverdam Property, King County, Washington. Appendix A1 (Water Quality) and A1 [sic] (Fisheries). Prepared for King County Surface Water Management.

Beaver, J.R. and T.L. Crisman

1991 Importance of latitude and organic color on phytoplankton primary productivity in Florida lakes. *Can. J. Fish. Aquat. Sci.* 48:1145-1150.

Bortleson, G.C., N.P. Dion, J.B. McConnell, and L.M. Nelson

1976 Reconnaissance Data on Lakes in Washington. Washington Department of Ecology *Water Supply Bulletin.*

Bostrom, B., M. Jansson, and C. Forsberg.

1982 Phosphorus release from lake sediments. *Arch. Hydrobiol. Beih.* 18:5-59.

Brenner, R.N. and B. McGuire

1990 Status of Water Quality in Small Lakes. Seattle - King County Region: 1989 Survey. Prepared for Municipality of Metropolitan Seattle (Metro).

Canfield, D.E. and L.M. Hodgson

1983 Prediction of Secchi disc depths in Florida lakes: impact of algal biomass and organic color. *Hydrobilogia.* 99:51-60.

Canfield, D.E., K.A. Langeland, S.B. Linda, and W.T. Haller

1985 Relations between water transparency and maximum depth of macrophyte colonization in lakes. J. *Aquat. Plant Manage.* 23:25-8.

Canfield, D.E., S.B. Linda, and L.M Hodgson

1984 Relations between color and some limnological characteristics of Florida lakes. *Water Res. Bull.* 20:323-329.

Carlson, R.E.

1992 Expanding the Trophic State Concept to Identify Non-nutrient Limited Lakes and Reservoirs. In Enhancing the States' Lake Management Programs - monitoring and lake impact assessment. pp 59-72. U.S. Environmental Protection Agency, Washington, D.C.

Carpenter, S.R.

1980 Enrichment of Lake Wingra, Wisconsin, by Submersed Macrophyte Decay. *Ecology*, 6(5):1145-1155.

Carroll, J.V. and G.J. Pelletier

1991 Diagnostic Study of Lake Sawyer. Washington State Department of Ecology. Surface Waters Investigations Section.

Chapman, D.

1992 *Water Quality Assessments - A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring.* Champman and Hall, New York.

Cooke, G.D. and R.G. Carlson

1989 Reservoir Management for Water Quality and THM control. AWWA Research Foundation. Denver, CO.

Cooke, G.D., E.B. Welch, S.H. Peterson, and P.R. Newroth

1986 *Lake and Reservoir Restoration.* Butterworth Publishers.

Dillion, P.J. and F.H. Rigler

1974 The phosphorus - chlorophyle relationship in lakes. *Limnology and Oceanography* 19:767-773.

Ecology - see Washington State Department of Ecology

Edmondson, W.T.

1990 Lake Washington entered a new state in 1988. *Verh. Internat. Verein. Limnol.* 24:428-430.

Entranco

1989 Deer Lake Shoreline Wastewater System Evaluation. Septic Leachate Survey. Kirkland, Washington. Prepared for Public Utility District No. 1, Stevens County, Washington, and Eastern Washington University, Cheney, Washington.

1990 Final Report - Phase I Diagnostic and Feasibility Analysis - Winchester Lake. Prepared for Idaho Department of Health and Welfare Division of Environmental Quality and U.S. Environmental Protection Agency Region 10.

1991 Lake Fenwick Restoration Study. Prepared for the City of Kent.

1992a Garrison Creek Wetland/Erosion Control Facilities. Final Report. Prepared for the City of Kent. City of Kent Engineering Department. Bellevue, Washington

1992b Beaver Lake Technical Memorandum, Task 1 - Background Data Collection. Prepared for King County Surface Water Management.

Fast, A.W.

1973 Effects of Artificial Hypolimnion Aeration on Rainbow Trout. (Salmo Gairdneri Richardson.) Depth distribution. *Trans. Amer. Fish Soc.* 4:715–722

Ferris Company, The

1992 Beaverdam - Draft Environmental Impact Statement.

Gilliom, R.J.

1981 Estimation of Background Loadings and Concentrations of Phosphorus for Lakes in the Puget Sound Region, Washington. *Water Resources Research* 17(2):410-420.

1984 Tools for Assessing Lake Eutrophication in the Puget Sound Region, Washington. In *Lake and Reservoir Management.* North American Lake Management Society. EPA 440/5/84-001.

Gilliom, R.J. and C.R. Patmont

1983 Lake Phosphorus Loading From Septic Systems by Seasonally Perched Groundwater. *JWPF* 55(10):1297-1307.

Goldsmith and Associates

1990 Ground Water Hydrology Study Map. The Beaverdam Property. Existing Conditions. Prepared for Quadrant Corporation and Taiyo-American Corporation.

Granberg, K. and H. Harjula

1982 Nutrient dependence of phytoplankton production in brown-water lakes with special reference to Lake Paijanne. *Hydrobiologia* 86:129-132.

Harding Lawson Associates

1990

Harper, D.

1992 *Eutrophication of Freshwaters, Principles, Problems, and Restoration.* Chapman & Hall. New York.

Hart Crowser

1990 Lake Sawyer Hydrogeologic Study; Black Diamond, Washington. Prepared for Washington State Department of Ecology.

Hiltjes, A.H.M., and L. Kijklema

1980 Fractionation of Inorganic Phosphates in Calcareous Sediments. *J. Environ. Qual.* 9:405–407.

Ilmavirta, V.

1982 Dynamics of phytoplankton in Finnish lakes. *Hydrobiologia* 86(1&2):11–20.

James, B.R., M.C. Rabenhorst, and G.A. Frigon

1992 Phosphorus Sorption by Peat and Sand Amended with Iron Oxides or Steel Wool. *Water Environment Research.* Volume 64, Number 5.

Jones, R.A. and G.F. Lee

1982 Recent advances in assessing impact of phosphorus loads on eutrophication-related water quality. *Water Research.* 16(5):503-515.

KCM

1992 Silver Lake Milfoil Control Predesign Report.

Kerekes, J.J., A.C. Blouin, and S.T. Beauchamp

1989 Characteristics of 3 acidic lakes in Kejimkujik National Park, Nova Scotia. *Archives of Environmental Contamination and Toxicology.* Volume 18, Page 183-200.

1990 Trophic response to phosphorus in acidic and non-acidic lakes in Nova Scotia, Canada. *Hydrobiologia* 191:105-110

King County

1990 *Wetlands Inventory.* Volume 2. King County Environmental Division.

1992a East Sammamish Community Plan Update and Area Zoning. King County Planning and Community Development Division. July 1992.

1992b Final Environmental Impact Statement for Beaver Lake Estates. King County Environmental Division Building and Land Development Division.

1992c Draft Environmental Impact Statement Working Papers and Appendices for the Trossachs, Brightons Landing and Belvedare Park. King County Department of Development and Environmental Services - Environmental Division.

King County Surface Water Management (King County SWM)

1990a East Lake Sammamish Basin Conditions Report - Preliminary Analysis.

1990b *Surface Water Design Manual.*

1992a Draft Basin and Nonpoint Action Plan. East Lake Sammamish Basin.

1992b WMC - Proposed Basin and Nonpoint Action Plan. East Lake Sammamish Basin.

Klots, E.B.

1966 *The New Field Book of Freshwater Life*. G.P. Putnam's Sons. New York.

Metro - See Municipality of Metropolitan Seattle.

Municipality of Metropolitan Seattle (Metro)

1981 Pine Lake Restoration Analysis. Final Report. December 1981.

1990 Quality of Local Lakes and Streams 1989-1990 Update. Water Resources Section. Water Pollution Control Department.

Newroth

1990 Prevention of the Spread of Eurasian Water Milfoil. Proceedings of a National Conference on Enhancing the State's Lake and Wetland Management Programs.

Olem, H. and G. Flock (eds.)

1990 *Lake and Reservoir Restoration Guidance Manual.* 2nd Edition. EPA 440/4-90-006. Prep. by North American Lake Management Society for U.S. EPA. Washington, D.C.

Oliver, D.R. and M.E. Roussel

1983 The Genera of Larval Midges of Canada Diptera: Chironomidae. Part 11 of *The Insects and Arachnids of Canada*. Research Branch. Agric. Can. Publ. 1746.

Organization for Economic Cooperation and Development (OECD)

1982 Eutrophication of waters: Monitoring, assessment and control. Final report. OECD Cooperative Program on Monitoring of Inland Waters (Eutrophication Control), Environmental Directorate, OECD. Paris 154 pp.

Ostrofsky, M.L., D.A. Osborne, and T.J. Zebulske

1989 Relationship between anaerobic sediment phosphorus release rates and sedimentary phosphorus species. *Canadian J. Fish. Aquat. Sci.* 46:416-419.

Pelletier, G.J.

1985 The phosphorus loading and sedimentation history for Pine Lake, Washington. M.S. Thesis, Dept. of Civil Engr. University of Washington. Seattle, Washington.

Pitt, R. and P. Bissionette

1984 Bellevue Urban Runoff Program Summary Report.

Portico Group, The

1987 Beaver Lake Park Final Master Plan Executive Summary. Prepared for King County Department of Parks, Planning, and Resources. Seattle, Washington.

Reckhow, K.H. and S.C. Chapra

1983 *Engineering Approaches for Lake Management. Volume 1: Data analysis and empirical modeling.* Butterworth Publishing.

Reinhelt, L., R. Homer, and H. Wittgren

1990 Removal of Sediments and Nutrients in Palustrine Wetlands Receiving Runoff from Urban and Nonurban Watersheds.

Ricker, W.E.

1971 Methods for assessment of fish production in freshwaters. *IBP Handbook No. 3.* Second Edition. Blackwell Scientific Publications. Oxford, England.

Ryding, S. and W. Rast

1989 *The Control of Eutrophication of Lakes and Reservoirs.* Man and the Biosphere Series, Vol. 1.314 pp. UNESCO and Parthenon Publishing Group. Paris.

Schueler, T.R.

1987 Controlling Urban Runoff: A Practical Manual for Planning and Design of Urban BMPs. Metropolitan Washington Council of Governments. Washington, DC.

Sigriest, R.L., T. Woltanski, and L.E. Waldorf

1978 Water Conservation and Wastewater Disposal. In *National Home Sewage Disposal Symposium.* ASAE. pp. 121–136.

Smith, Val

1990 Effects of Nutrients and Non-algal Turbidity on Blue-green Algal Biomass in four North Carolina Reservoirs. In *Lake and Reservoir Management.* 6(2):125–131.

Strecker, E.W., G.E. Palhegyi, and E.D. Driscoll

1990 The Use of Wetlands for Control of Urban Runoff Pollution in the USA. Fifth International Conference on Urban Storm Drainage.

Thomann, R.V. and J.A. Mueller

1987 *Principles of Surface Water Quality Modeling and Control.* Harper & Row Publishers, Inc., New York.

Thorp, J.H. and A.P. Covich (eds.)

1991 *Ecology and Classification of North American Freshwater Invertebrates.* Acad. Press, Inc.

U.S. Environmental Protection Agency (US EPA)

1980 Design Manual for Onsite Wastewater Treatment and Disposal Systems. Office of Water Program Operations. Washington, D.C.

Uttormark, P.D., J.D. Chapin, and K.M Green

1974 Estimating Nutrient Loadings of Lakes from Non-point Sources. EPA 66/3-74-020.

Van Velson, R.C.

1986 Techniques for Measuring Summer Trout Habitat in Coolwater Reservoirs of Colorado. Colorado Department of Natural Resources. Division of Wildlife. Fishery Information Leaflet 38.

Vasey Engineering Co., Inc.

1993 Storm Water Impacts from the Trossachs to Beaver Lake and Wetland ELS 21. Technical Memorandum.

W & H Pacific, Inc.

1991 Preliminary Draft Environmental Impact Statement. Working papers and appendices for Beaver Lake Estates.

1992a Final Environmental Impact Statement, Beaver Lake Estates.

1992b Working Draft Environmental Impact Statement - Trossachs. Belvedere Park, Brighton's Landing.

Washington On-Site Sewerage Association (WOSSA)

1992 "Pollution Solutions?" Glendon Reactor.

Washington State Department of Ecology (Ecology)

1992a Water quality standards for water of the State of Washington. Washington Administrative Code, Chapter 173-201, 11/25/92. Washington State Department of Ecology.

1992b Stormwater Management Manual for the Puget Sound Basin.

1992c Aquatic Plants Management Program for Washington State - Final Supplemental Environmental Impact Statement. Volumes 1 and 2.

Washington State Department of Health

1991 Understanding and Caring for your Septic Tank System. DOH Publication 334-009 (1/91).

Welch, B.

1989 Building Lake Protection Strategies into State Lake Management Programs. National Conference on Enhancing States' Lake Management Programs.

Welch, E.B., J.S. Oppenheimer, R.R. Horner, and D.E. Spyridakis

1988 Silver Lake Water Quality, Nutrient Loading, and Management. University of Washington, Department of Civil Engineering. *Water Resources Series Technical Report* 106.

Wetzel, R.G.

1983 *Limnology*. 2nd Edition. Saunders College Publishing, New York, N.Y.

PERSONAL COMMUNICATION

Abella, Sally. University of Washington, Department of Zoology. January 15, 1993.

Flohr, Carol. Beaver Lake Community Club. April 9, 1993.

Lee, Chuck. Terrera and Associates. December 7, 1992.

McKee, Kim. Washington State Department of Ecology. 1990.

Reinhelt, Lorin. King County Surface Water Management. April 1, 1993.

Welch, Dr. Eugene. University of Washington, Department of Civil Engineering. March 1993.