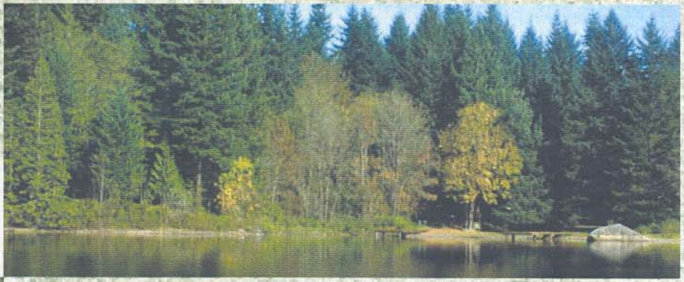
BEAVER LAKE MANAGEMENT PLAN UPDATE:

A Report on the Quality of Beaver Lake for 1996-2000

Final Report for the Beaver Lake Management District No. 1 and Washington State Department of Ecology



December 2000

KING COUNTY

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Beaver Lake Management Plan Update: A Report on the Quality of Beaver Lake for 1996-2000

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Beaver Lake Management District No. 1 and
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Prepared by:
Sharon Walton
Senior Limnologist
King County Water and Land Resource Division
201 South Jackson Street, Suite 600
Seattle, WA 98104
(206) 296-6519

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Many individuals contributed to the completion of this plan update including local Beaver Lake area residents. These residents, as members of the Beaver Lake Management District Advisory Board, met once a month between September 1996 through December 2000. During these regular meetings, the Board directed the work program for Beaver Lake Management District No. 1 and was instrumental in data collection and the development of the vision for the plan update. Below are the 11 residents who served terms on the six-member advisory board.

Advisory Board
Donna Carlson, Zone 1, 1996-1998, 1999-2000
Sharon Freechtle, Zone 2, 1996-1997
Vicky Giannelli, Zone 1, 1996-1998
Tom Harman, Zone 1, 1996-1997
Joe McConnell, Zone 1, 1998-2000
Al Sauerbrey, Zone 1, 1999-2000
Lisa Shank, Zone 2, 1998-2000
Ruth Shearer, Zone 1, 1996-1997
Sharon Steinbis, Zone 2, 1999-2000
Bob White, Zone 1, 1998-2000
Cory Wolfe, Zone 2, 1996-1998

Lake and stream monitoring and sample analysis was completed by both King County staff and Beaver Lake residents. Listed below are the individuals or groups who assisted in the collection or analysis of data for the lake management plan update.

Monitoring
Acar and Kazuko Bill, Beaver Lake residents
Donna Carlson, Beaver Lake resident
Wendy Cooke, Limnologist, WLR Division
David Funke, Engineer, WLR Division
Tom Harman, Beaver Lake resident
Al and Shirley Jokisch, Beaver Lake resident
Joe and Mary Lippi, Beaver Lake resident
Larry Miller, Beaver Lake resident
Ray Petit, Beaver Lake resident
Wally Prestbo, Beaver Lake resident
Catherine Rice and Bob White, Beaver Lake residents

Al Sauerbrey, Beaver Lake resident
Ruth and Jack Shearer, Beaver Lake residents

Sample Analysis
King County Environmental Laboratory
Maribeth Gibbons, Water Environmental Services, Inc.

A variety of people also contributed to the analysis of the lake and stream monitoring data and the update of the lake management plan. Below are the key individuals who assisted in these activities.

Data Reduction
Wendy Cooke, Limnologist, WLR Division
David Funke, Engineer, WLR Division

Hydrologic Modeling
David Hartley, Hydrologist, WLR Division

Lake Modeling and Restoration Analysis
Dave Cline, Tetra Tech, Inc-ISG
Harry Gibbons, Tetra Tech, Inc-ISG
Krey Price, Tetra Tech, Inc-ISG
Eugene Welch, Tetra Tech, Inc-ISG

Plankton Analysis
Maribeth Gibbons, Water Environmental Services, Inc.

Technical Writing
Sharon Walton, Senior Limnologist, WLR Division

Editing
Erin Gebert, Tetra Tech, Inc-ISG
Suzanne Rowe, Communication Specialist, WLR Division
Sharon Walton, Senior Limnologist, WLR Division

Executive Summary

Background

Beaver Lake is located in Sammamish, Washington, east of Lake Sammamish and north of Interstate-90. This area was formerly rural King County but has seen rapid development over the past decade. On August 31, 1999, the area incorporated, becoming the City of Sammamish.

In 1993, the *Beaver Lake Management Plan* (King County, 1993a) was completed. The plan characterized the lake's water quality as good and was earmarked as a pollution prevention plan. The plan provided a series of recommendations for mitigating surface water impacts associated with future land development.

During 1995, Lake Management District No. 1 was formed in the Beaver Lake watershed to implement a monitoring program and provide information on water quality issues to the Beaver Lake community. Revenues from the district combined with a federal grant funded a four-year monitoring program. This program was designed to detect water quality problems as land was developed and allow corrective actions to be implemented. This current report represents the culmination of this four-year monitoring program, updating the 1993 *Beaver Lake Management Plan.*

Land Use

Ongoing development of the watershed continues to be the primary threat to long-term preservation of lake water quality. In 1993, approximately 660 acres of the 1100-acre watershed was categorized in forested uses (King County, 1993a). In 2000, approximately 462 acres remain as forest while under maximum build-out about 235 acres will remain. Under build-out conditions, this additional lost of forest will result in a 64 percent reduction from 1993 forest levels.

Loss of forest affects the surrounding hydrology, delivering water more quickly to the lake and omitting the natural attenuation and treatment that previously occurred naturally. Without treatment, water from residential uses is substantially higher in nutrient levels and can contribute to the degradation of the upland wetlands and eventually the lake.

Current Lake Condition

Thus far, water quality remains good and relatively unchanged from levels documented with the *Beaver Lake Management Plan* (King County, 1993a). Because of the findings in the original plan, the most stringent stormwater treatment standard in King County was required in the Beaver Lake watershed for new development. This standard, in combination with preservation of wetland function, has been critical to maintaining good water quality in Beaver Lake.

As additional residential development continues, Beaver Lake remains vulnerable to a decline in water quality without ongoing preservation measures. Water quality modeling results for both lake basins show that phosphorus levels will increase in the lake under a build-out land use scenario. This increase in phosphorus is potentially larger and has a greater impact to the water quality of Beaver Lake 1 because of its lower assimilative capacity than the larger Beaver Lake 2.

Under the build-out land use scenario, a two-fold increase in phosphorus levels is predicted for Beaver Lake 1 in comparison to Beaver Lake 2. This predicted phosphorus increase strongly suggests that Beaver Lake 1 will be more vulnerable to added phosphorus than Beaver Lake 2.

Currently, Beaver Lake 1 has an average phosphorus concentration of about 19 μg/L and would be expected to increase to about 25 μg/L or about 32 percent under modeled build-out conditions. In Beaver Lake 2 (which naturally has lower phosphorus levels to begin with) phosphorus levels would be expected to increase only 2 to 3 μg/L to about 16 μg/L, an increase of 14 to 23 percent.

The shift in surface phosphorus concentrations in Beaver Lake 1 from 19 μg/L to 25 μg/L could noticeably alter lake water quality in the upper lake basin by increasing algal bloom frequency and further diminishing water clarity. In Beaver Lake 2, an increase of surface phosphorus concentrations of only 2 to 3 μg/L is within the current natural variation observed in the lake and may not result in a noticeable difference in water quality because of the greater assimilative capacity of the lake basin.

Discussion

Given the water quality vulnerability of Beaver Lake 1, the preservation of wetland ELS 21 function has been identified as critical to the ongoing preservation of the lake. Protection of this wetland and preservation of existing water quality functions should be given high priority because of the vital role the wetland plays in binding and recycling phosphorus prior to discharging surface flow to the lake.

Wetland ELS 21 currently receives only minor regulatory protection in comparison to wetland ELS 10 which is encompassed by the Hazel Wolf Wetland Preserve (which discharges to Beaver Lake 2). Further, wetland ELS 21 has already been impacted by the

Trossachs subdivision where two stormwater quality facilities have been placed along the southeastern and eastern edges of the wetland. To prevent further impacts to wetland ELS 21, efforts should be made to maximize preservation of open space around the wetland to ensure that wetland functions are not further degraded.

Beaver Lake also remains vulnerable to catastrophic events associated with new land development. Efforts should be made to avoid erosion of recently cleared lands and the mass movement of sediment to surrounding wetlands, streams, and ultimately the lake. Additionally, ongoing stormwater management (especially facility maintenance), local shoreline and watershed actions, and ongoing monitoring will remain important in the continued preservation of Beaver Lake water quality.

Recommendations

Beaver Lake water quality remains good but additional development of the watershed could cause degradation of water quality. To ensure the ongoing preservation of Beaver Lake, a series of recommendations have been made (Table ES-1). These recommendations are focused in five key areas: (1) wetland and resource land preservation, (2) future land development guidelines, (3) ongoing stormwater management, (4) local shoreline and watershed actions, and (5) ongoing monitoring.

Table ES-1: Management Recommendations

No.	Recommended Actions
	Wetland and Resource Land Preservation
R1	• Acquire Additional Open Space
R2	• Increase Wetland and Stream Buffer Size
R3	• Promote Long-term Land Conservation via Incentive Programs
	Future Land Development Guidelines
R4	• Enforce Seasonal Clearing and Grading Requirements
R5	• Enforce Temporary Erosion and Sediment Control Standards
	Ongoing Stormwater Management
R6	• Maintain AKART (all known, available, and reasonable methods of prevention, control, and treatment) Standard for New Development
R7	• Maintain Stormwater Facilities
	Local Shoreline and Watershed Actions
R8	• Restore Shoreline Vegetation
R9	• Reduce Lawn Size and Fertilizer Use
R10	• Maintain On-site Septic Systems
R11	• Reduce Phosphorus from Pet Waste, Car Washing, and Exposed Soil
	Ongoing Monitoring
R12	• Continue Lake and Stream Monitoring

Wetland and Resource Land Preservation

To ensure the protection of Beaver Lake 1 water quality, additional measures should be undertaken to preserve the function of wetland ELS 21. These measures include land acquisition, increased buffers, and land conservation around the wetland. Preservation of wetland ELS 21 directly contributes to the preservation of Beaver Lake 1 which, in turn, directly benefits Beaver Lake 2 which receives about 20 percent of its annual inflow from Beaver Lake 1 during a typical year.

Beaver Lake 2 already benefits from the preservation of wetland ELS 10 through the establishment of the Hazel Wolf Wetland Preserve but could benefit further from the addition of larger buffer requirements downstream. These larger buffers would protect the southern end of the wetland outside the preserve as well as the stream (tributary 0166d) which connects the preserve with Beaver Lake 2.

Future Land Development Guidelines

Beaver Lake remains vulnerable to catastrophic events that can occur during land development. These events are generally related to timing of land clearing and the level of temporary erosion and sediment control (TESC) measures that are in place. To ensure that Beaver Lake water quality is protected, seasonal clearing requirements should be adhered to and all construction sites stabilized with TESC measures by October 1 each year.

Stormwater Management

Critical to the ongoing preservation of Beaver Lake water quality is the continued application of the current water quality treatment standard for new development. For a build-out land use scenario, modeled water quality results show phosphorus levels will increase and continued removal of excess phosphorus from new development will help minimize future impacts to Beaver Lake water quality.

Regular maintenance of existing stormwater is also critical to ensuring maximum phosphorus removal occurs from residential runoff. It is recommended that the City of Sammamish establish a regular maintenance schedule for all facilities in the Beaver Lake watershed with sandfilters receiving extra attention given that this facility may be vulnerable to plugging over time.

Shoreline and Watershed Actions

Both lake and watershed residents have fundamental roles in preserving Beaver Lake water quality. By making environmentally sound landscaping choices, lake residents can minimize their impact to the lake. Shoreline residents can restore shoreline areas with native vegetation, reduce adjacent lawn sizes, and create buffers between homes and the lake. Similarly, watershed residents can minimize their fertilizer use, reduce lawn size, and develop lower maintenance landscapes. Other activities that can be undertaken by all watershed residents include maintaining on-site septic systems, properly disposing pet waste, using car wash facilities instead of washing cars in the driveway or street, and covering exposed soil with mulch to reduce erosion.

Monitoring

As further development of the watershed occurs, monitoring remains important as an early detection tool for identifying upland water quality problems. Beginning in 2001, a five-year lake and stream monitoring program is proposed that will continue the evaluation of the water quality entering Beaver Lake. This monitoring program would be funded through a second lake management district, which is currently in the formation stage under the direction of the City of Sammamish.

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Chapter 1: Introduction

Beaver Lake is located in Sammamish, Washington, east of Lake Sammamish and north of Interstate-90. This area was formerly rural King County but has seen rapid development over the past decade. On August 31, 1999, the area incorporated, becoming the City of Sammamish.

In this chapter, a brief project history is provided to document the involvement of local residents in the preservation efforts of Beaver Lake. This effort includes the formation of the first lake management district in King County. A brief description of the current project for updating the lake management plan is also provided.

History

The Beaver Lake community has a long history of local activism and has been a strong advocate for the preservation of the lake. Beginning with the development of the 1982 *East Sammamish Community Plan* (King County, 1982), substantial debate has occurred between policy makers and the local community regarding land use and the ultimate growth of the east King County.

By the late 1980s, Beaver Lake and the surrounding area's had seen rapid growth, raising concerns over the lag in public services including police, fire, roads, and schools (King County, 1992). In 1989, an update to the 1982 *East Sammamish Community Plan* was initiated to address these concerns. Meanwhile, residents of the Beaver Lake area began exploring options for specifically protecting Beaver Lake water quality.

In 1990, the Beaver Lake community worked with the King County Department of Public Works, Surface Water Management Division to develop a grant application for funding a lake management plan. This application was submitted to the Washington Department of Ecology Centennial Clean Water Fund grant program which awarded a grant to the County to develop a lake management plan for Beaver Lake. In 1991, a lake monitoring program was initiated and served as the basis for developing the lake management plan.

In 1993, the *Beaver Lake Management Plan* (King County, 1993a) was completed. The plan characterized the lake's water quality as good and was earmarked as a pollution prevention plan. The plan provided a comprehensive approach for mitigating surface water impacts associated with future land development. To preserve the lake's quality, several key recommendations were made including: (1) modification of existing King County stormwater treatment policy; (2) completion of a long-term monitoring program and watershed inventories; and (3) implementation of community education and involvement programs.

In 1994, the Metropolitan King County Council adopted the *Beaver Lake Management Plan* and established an 80 percent total phosphorus reduction goal for stormwater treatment facilities in the Beaver Lake watershed. To achieve this goal, all known, available, and reasonable methods of prevention, control, and treatment (AKART) was established as the Beaver Lake treatment standard through KCC 9.08 PUT8-7 (King County, 1995). As a condition to the County's adoption of this policy, the Beaver Lake community was required to form a lake management district to monitor water quality and evaluate the effectiveness of the plan's implementation.

During 1995, Lake Management District No. 1 was formed in the Beaver Lake watershed to implement a follow-up monitoring program and other plan recommendations. A Federal 319 nonpoint grant from the Washington Department of Ecology (WDOE), combined with revenues from the district, funded a four-year lake and stream monitoring program. This monitoring program was designed to detect water quality problems during land development and allow corrective actions to be implemented, minimizing the potential for long-term impacts to Beaver Lake.

Results from this monitoring program have been previously reported in annual progress reports to the WDOE (King County, 1998a; King County 1999a, and King County 2000a). Over the course of the four-year program, no major water quality problems were detected. This plan update represents the final report for the monitoring program and updates the recommendations from the 1993 *Beaver Lake Management Plan*.

Lake Management District

A lake management district (LMD) is a special purpose district which can be created by local property owners to fund a variety of lake protection or restoration measures including ongoing maintenance related activities. A district may be created for a period of up to 10 years with assessment rates imposed annually or as specified in the adopting resolution creating the district. The process for creating an LMD in King County (or by another legislative authority) is detailed in RCW 36.61 (Washington State, 2000).

The Beaver Lake Management District was formed by a public vote in 1995 to support the implementation of key recommendations from the *Beaver Lake Management Plan* (King County Ordinance No. 11956, 1995). These recommendations included four items: (1) erosion control inspection; (2) stormwater facility monitoring; (3) lake and watershed monitoring; and (4) a public involvement and education program.

In 1996, the King County Executive appointed six-members to the Beaver Lake Management District advisory board. The district's six-member board was comprised of four lakefront (Zone 1) property owners and two watershed (Zone 2) property owners (King County Ordinance No. 12209, 1996). Over the life of the district, 11 community members have been appointed by the King County Executive to oversee the management of the district's funds and associated work program. The district's authorization expires December 31, 2000.

The board was responsible for approving all expenditures and overseeing the completion of the district’s work program. At the board’s direction and based on available funds, the district’s work program focused on the completion of two items: (1) lake and watershed monitoring; and (2) a public involvement and education program. District funds were leverage and a grant obtained to partially fund the lake and watershed monitoring program.

Project Description

This plan update represents the culmination of a four-year monitoring program at Beaver Lake funded by Lake Management District No. 1 and the WDOE. This monitoring program was designed to evaluate the preservation of lake quality as watershed forested areas are developed for residential uses.

Since the completion of the *Beaver Lake Management Plan* (King County, 1993), three large subdivisions have been built in the watershed area resulting in a loss of 200 acres of forest in the 1184-acre watershed. In the near future, more residential development projects are slated that could result in an additional loss of 200 or more forested acres.

Through this plan update, the current quality of Beaver Lake is measured. This measurement serves as an indirect assessment of the effectiveness of water quality mitigation associated with recent residential development. This plan update also provides guidance for preserving Beaver Lake quality as new residential development continues in the watershed.

Chapter 2: Watershed Characteristics

The specific characteristics of the watershed, wetlands, lakes, and tributary streams are described for the Beaver Lake area in this chapter. Demographic and land use information has also been included here to provided context for the development of this plan update and serves as a basis for ongoing preservation efforts.

Watershed

Beaver Lake is located in Sammamish, Washington, at the top of the Sammamish plateau (Figure 1). The watershed is approximately 1,184 acres in size. Other features of the watershed include Beaver Lake Park, Hazel Wolf Wetland Preserve, and the Department of Fish and Wildlife boat launch (Figure 2).

Topographically, this area can be characterized as moderately sloping with a maximum elevation change of less than 200 feet from the watershed high point to the lake's surface (Figure 3). The watershed topography and surrounding geology was largely determined about 15,000 years ago during the Fraser glaciation. Soil deposits left during this period consist largely of glacial outwash and till. The surface soils are generally very thin providing minimal storage for surface waters once saturated. Interflow (shallow groundwater) contributes only two to five percent of the annual flows to the lake.

The year-round climate of the area is moderated by maritime air from the Pacific Ocean. Annual precipitation averages about 45 inches per year with the majority of rainfall occurring between October and March (King County, 1990b). While winters are cool and generally quite wet, summers are generally warm and dry with moderate day temperature and cooler overnight temperatures. Occasionally, temperatures will drop below freezing allowing snow to blanket the Beaver Lake area and ice to form on the lake.

Additional information on the geology, topography, and climate of the watershed is summarized in *Beaver Lake Management Plan* (King County, 1993a). More detailed information for the Sammamish plateau can be found in the *East Lake Sammamish Basin Conditions Report* (King County, 1990b).

Figure 1. Beaver Lake Location

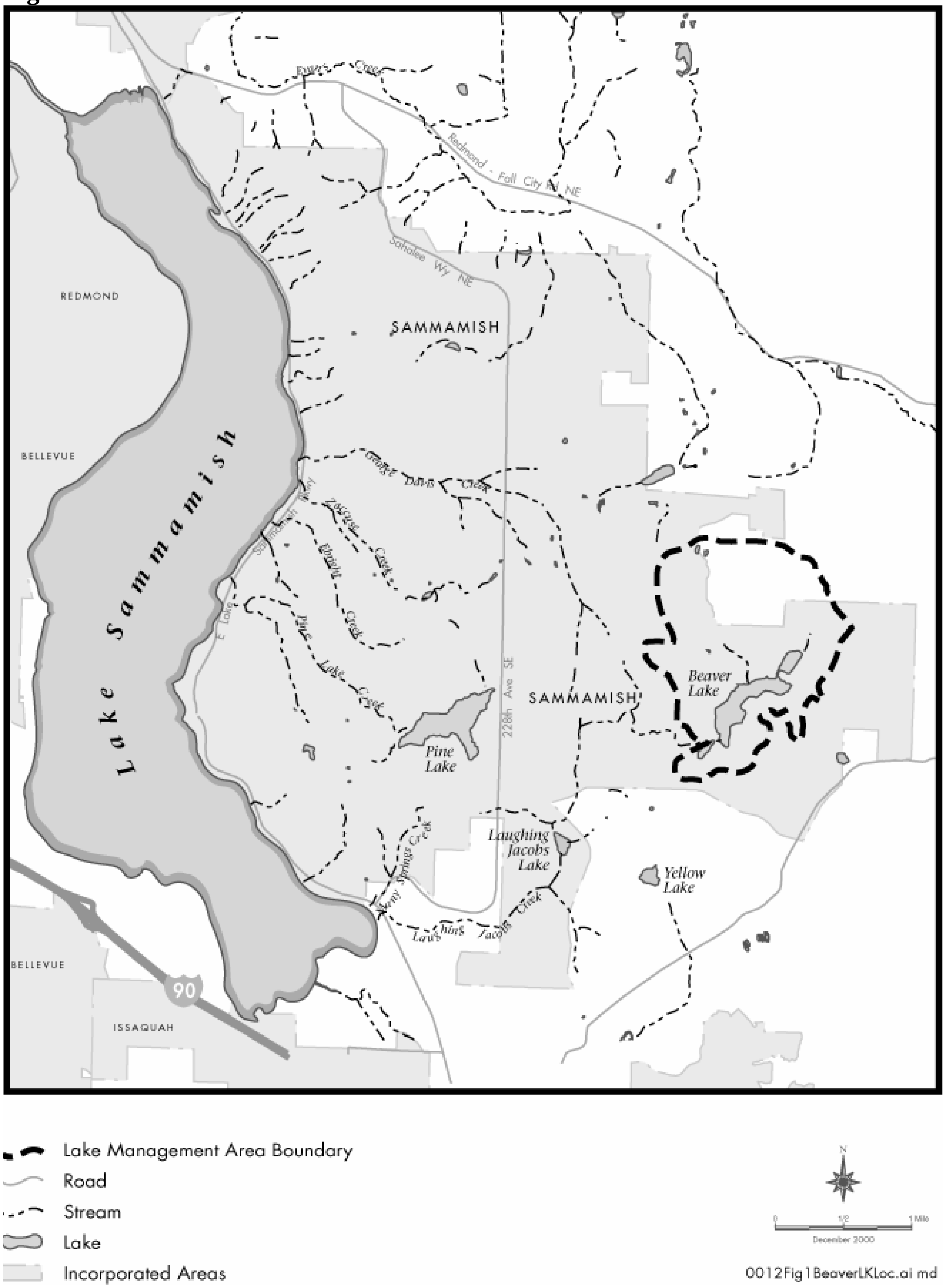


Figure 2. Major Watershed Features

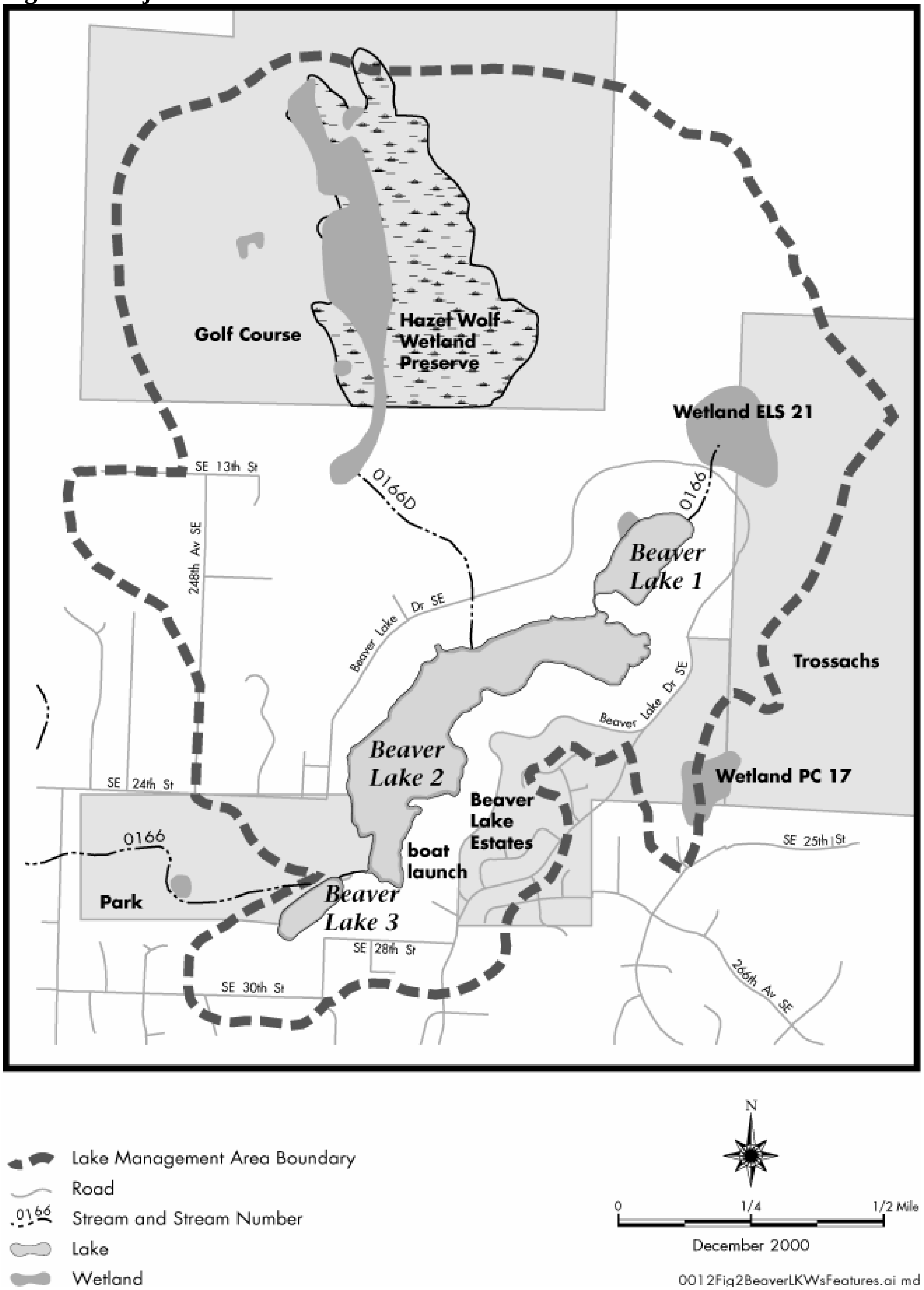
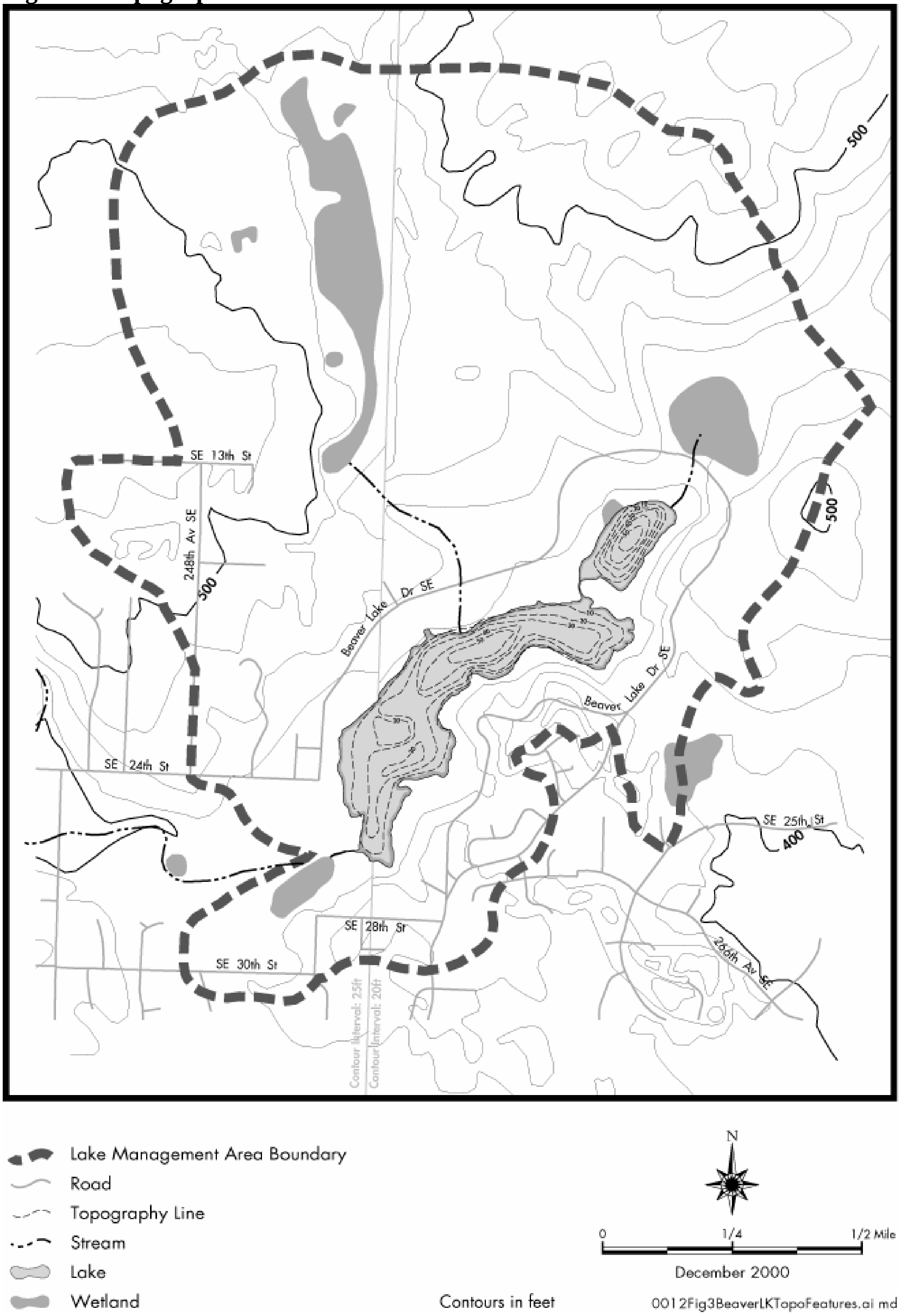


Figure 3. Topographic Features



Wetlands

The watershed includes four number 1-rated, unique, and outstanding wetlands: Hazel Wolf Wetland Preserve (Wetland ELS 10), East Lake Sammamish 21 (Wetland ELS 21), Patterson Creek 17 (Wetland PC17), and the combined Beaver Lake 1 and 2 system (Figure 2; King County, 1990a). Beaver Lake 3 is classified as number 2-rated, significant wetland.

Each of these wetlands help control the quality and quantity of water flowing to or through Beaver Lake and eventually to Lake Sammamish. Included in this section, is a brief description of Hazel Wolf Wetland Preserve, East Lake Sammamish 21, and Patterson Creek 17.

Hazel Wolf Wetland Preserve

The 116-acre Hazel Wolf Wetlands Preserve is one of the most pristine wetland-based wildlife refuges in King County and includes the 50-acre wetland, East Lake Sammamish 10, at it center. The wetland is home to nine different plant communities including bog vegetation and open water areas (King County, 1999b).

In 1995, this wetland area was preserved thanks to the cooperative efforts of concerned citizens, progressive corporations, county government, and a nonprofit environmental organization. The preserve was named for Hazel Wolf, a grassroots advocate, who invigorated the environmental community with her spirit and foresight.

The preserve hosts several different wetland and forest habitats. This varied landscape supports many of the area’s most beautiful and sensitive plants and wildlife. The preserve also links a network of protected habitats stretching from the Issaquah Alps to Lake Sammamish. Additionally, these wetlands help control the quality and quantity of water flowing through Beaver Lake and eventually to Lake Sammamish.

The wetland preserve hosts a wealth of animals. Bird life includes osprey, bald eagles, herons, hooded mergansers, pied-billed grebes, and wood ducks (Land Conservancy, 1999). The wetland also is home to a variety of frogs, salamanders, and newts as well as a diversity of mammals like beaver, muskrat, raccoon, squirrel, bear, deer, and mice (Weinmann and Richter, 1999).

The preserve was established to protect water quality and habitat functions. The site has been used historically by horseback riders and more recently by runners, cyclists, and hikers. As the population of the area grows, education of trail users becomes increasingly important in preserving the quality of the wetland and downstream Beaver Lake area.

The preserve is bounded on the east, north, and west sides by an 18-hole golf course and housing development. Numerous stormwater facilities discharge water that eventually drains to the preserve’s major wetland. Regular maintenance of these facilities will be essential to preserving the health of the wetland and Beaver Lake.

East Lake Sammamish 21

This 13-acre wetland has bog characteristics including peat soil, low phosphorus levels, and acidic pH (King County, 1999b). The wetland is characterized by a central area of sphagmum moss and shrubs typical of bogs. Two intermittent streams flow into the wetland. A single outlet located on the south end flows to Beaver Lake 1.

The eastern portion of the wetland abuts the Trossachs subdivision. Two stormwater facilities were built adjacent to the wetland. The northern most facility discharges to the wetland after being treated in a large wetpond and peat-sand filter stormwater system. The second facility discharges just south of the wetland outflow channel after first being treated in a large wetpond and sand filter stormwater system that flows into the northern tributary of Beaver Lake 1.

Patterson Creek 17

This three-acre wetland is classified as a true bog because it has no actual surface inflow channel. The wetland receives water from direct rainfall and surface runoff from the adjacent land. Outflow from the wetland occurs along the western edge and occasionally east when water levels become particularly high. The wetland is very similar to East Lake Sammamish 21 with a central mat of spaghnum moss (King County, 1999b). Eventually, the wetland will be surrounded by residential development.

Lakes

The lake consists of three interconnected water bodies: Beaver Lake 1, 2, and 3. Beaver Lake 1 is the northernmost lake body and at 13 acres, is about one-quarter the size of Beaver Lake 2 (Table 1). The lake has an average depth of 22 feet and maximum depth of 55 feet (Bortleson et al. 1976).

Beaver Lake 1 water quality is heavily influenced by wetland discharge to the lake from East Lake Sammamish 21. Beaver Lake 1 is noticeably darker in water color from humic matter leached from the wetland. The transparency is generally 1 to 2 meters in depth.

Table 1: Physical Characteristics of Beaver Lake

Element*	Beaver Lake 1	Beaver Lake 2	Beaver Lake 3
Surface Area	13 acres	61.5 acres	4 acres
Maximum Depth	55 feet	54 feet	na**
Average Depth	22 feet	21 feet	na
Lake Volume	271 acre-feet	1258 acre-feet	na
Altitude	407 feet	406 feet	na

* Data Sources: Bortleson et al. 1976; Appendix D; King County, 1990a
** na–data not available

Beaver Lake 2, at 62 acres, is the largest lake body comprising 82 percent of the total lake volume (Table 1). Beaver Lake 1 flows to Beaver Lake 2 which also receives wetland drainage from the Hazel Wolf Wetland Preserve. The water color of Beaver Lake 2 is noticeably lighter than Beaver Lake 1 with transparency ranging from 2-4 meters.

Beaver Lake 3 is four acres in size and has the lake outlet located on the western side of the lake. The lake is generally too shallow during the summer for regular water quality sampling. Aquatic vegetation dominates most of the surface area during the summer but generally the water level is high enough for small water craft to move between Beaver Lake 2 and Beaver Lake 3.

Streams

Flow to Beaver Lake is intermittent, occurring primarily from November through June via two unnamed tributaries (Figure 2). The northernmost tributary (0166) drains directly to Beaver Lake 1 from East Sammamish Wetland 21 and the adjacent Trossachs subdivision. The western tributary (0166D) drains directly to Beaver Lake 2, bypassing the upper lake basin (Figure 2). This lower tributary drains an area that includes the golf course and Hazel Wolf Wetland Preserve.

Outflow from the lake is also intermittent, generally occurring from late November through June. The lake outflows directly from the third lake basin (Beaver Lake 3) to Laughing Jacob's Creek which eventually discharges to Lake Sammamish. Limited flow to and from the three lakes results in a cumulative residence time (the average time required to completely renew a lake's water volume) of nearly two years.

Demographics

The Beaver Lake watershed is located largely within the newly incorporated City of Sammamish (Figure 1). The city incorporated on August 31, 1999, marking a change in the governing jurisdiction for the Beaver Lake area from King County to the city.

In the last decade, the population of the Sammamish area has grown 43 percent increasing from a base of 21,550 in 1990 to nearly, 31,000 in 2000 (King County, 2000b). Based on 1990 statistics, one-third of the area's population is under 17 and only four percent is over 65. The racial/ethnic make-up of the area is 94 percent Caucasian, one percent African American, three percent Asian, and two percent Hispanic.

In the immediate Beaver Lake watershed, there were approximately 215 households in 1991 (King County, 1993a). In 1996 (at the time of lake management district formation), approximately 420 households were present in the watershed. In 2000, approximately 540 households are in the watershed based on lake management district records. In the next several years, an additional 200 to 300 households could be added in the Beaver Lake area (City of Sammamish, 2000).

Land Use

The Beaver Lake area is designated for urban land use through the *East Sammamish Community Plan Update and Area Zoning* (King County, 1992) and the *King County Comprehensive Plan* (King County, 1994). During the early 1990s, the potential conversion of the forested watershed to urban residential densities (primarily three to eight units per acre) was the driving force behind the development of the *Beaver Lake Management Plan* (King County, 1993a) and the subsequent formation of Beaver Lake Management District No. 1.

The ongoing development of the watershed continues to be viewed by the local community as the primary threat to long-term preservation of lake water quality. In Table 2, land use is summarized for the year 2000 and for maximum build-out (future) under current zoning. Land use for these two scenarios is also illustrated in Figures 4 and 5.

In 1993, approximately 660 acres of the watershed was categorized in forested uses (King County, 1993a). In 2000, approximately 462 acres remain as forest while under maximum build-out about 235 acres will remain (Table 2). Under build-out conditions, this additional lost of forest will result in a 64 percent reduction from 1993 forest levels.

Table 2: Watershed Land Use Summary

Landuse Category	**Year 2000 (acres)**	**Build-out (acres)**	**Percent Change**
Forested	462	235	-49
Golf Course	121	121	0
Open Water	79	79	0
Roads/Right of Way	73	73	0
Wetland	62	62	0
Rural Residential, 1 du/2.5-10 acres	63	6	-91
Urban Residential, 1-3 du/2.5 acres	91	44	-51
Urban Residential, 1-3 du/acre	148	231	56
Urban Residential, 4-12 du/acre	85	333	292
Total Acres	1184	1184	

Figure 4. Beaver Lake Current Land Use

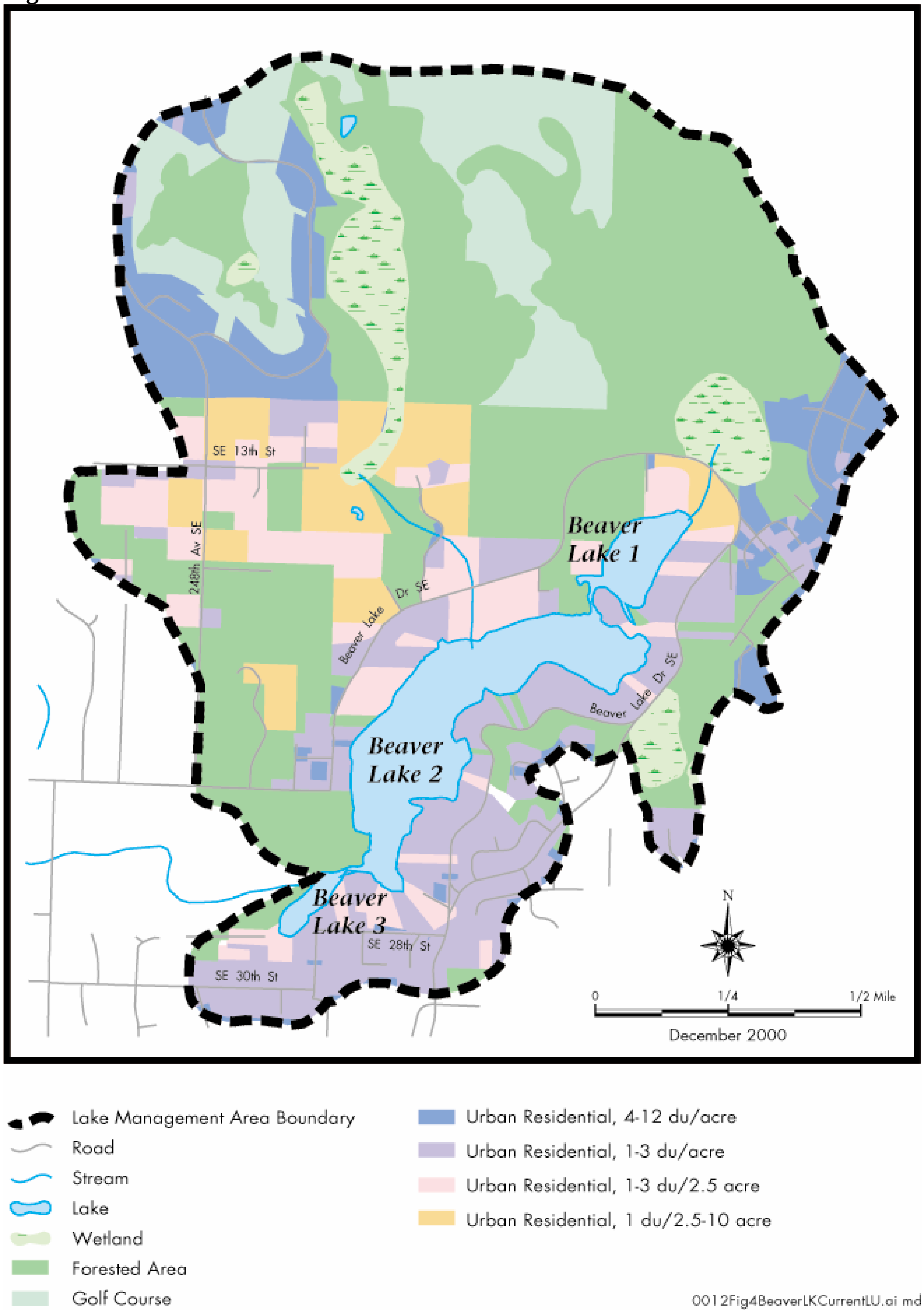
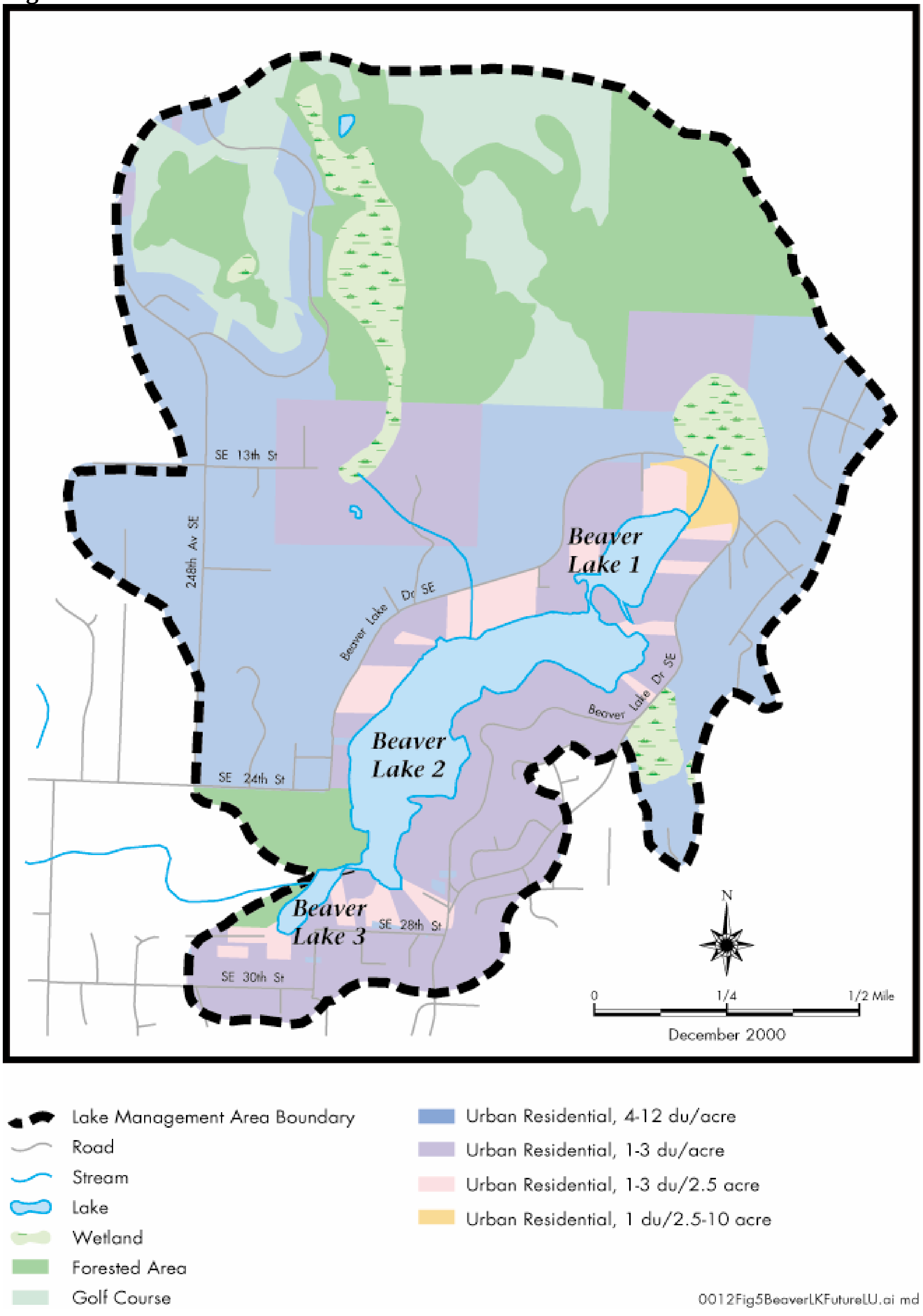


Figure 5. Beaver Lake Build-Out Land Use



Chapter 3: Monitoring Program

This Chapter provides an overview of the monitoring methods used to collect lake and stream information for Beaver Lake. A more complete description of sampling protocols and analytical methods can be found in the *Water Quality Monitoring Plan* for Beaver Lake (King County, 1996b) which was developed using the Washington State Department of Ecology guidelines for quality assurance plans (Ecology, 1991).

In summary, a four-year monitoring program was developed for the Beaver Lake area to collect information on the quality of the lake as watershed lands are converted from forested to residential uses. This monitoring program included both stream and lake monitoring elements. These elements are briefly described below beginning with sample site locations.

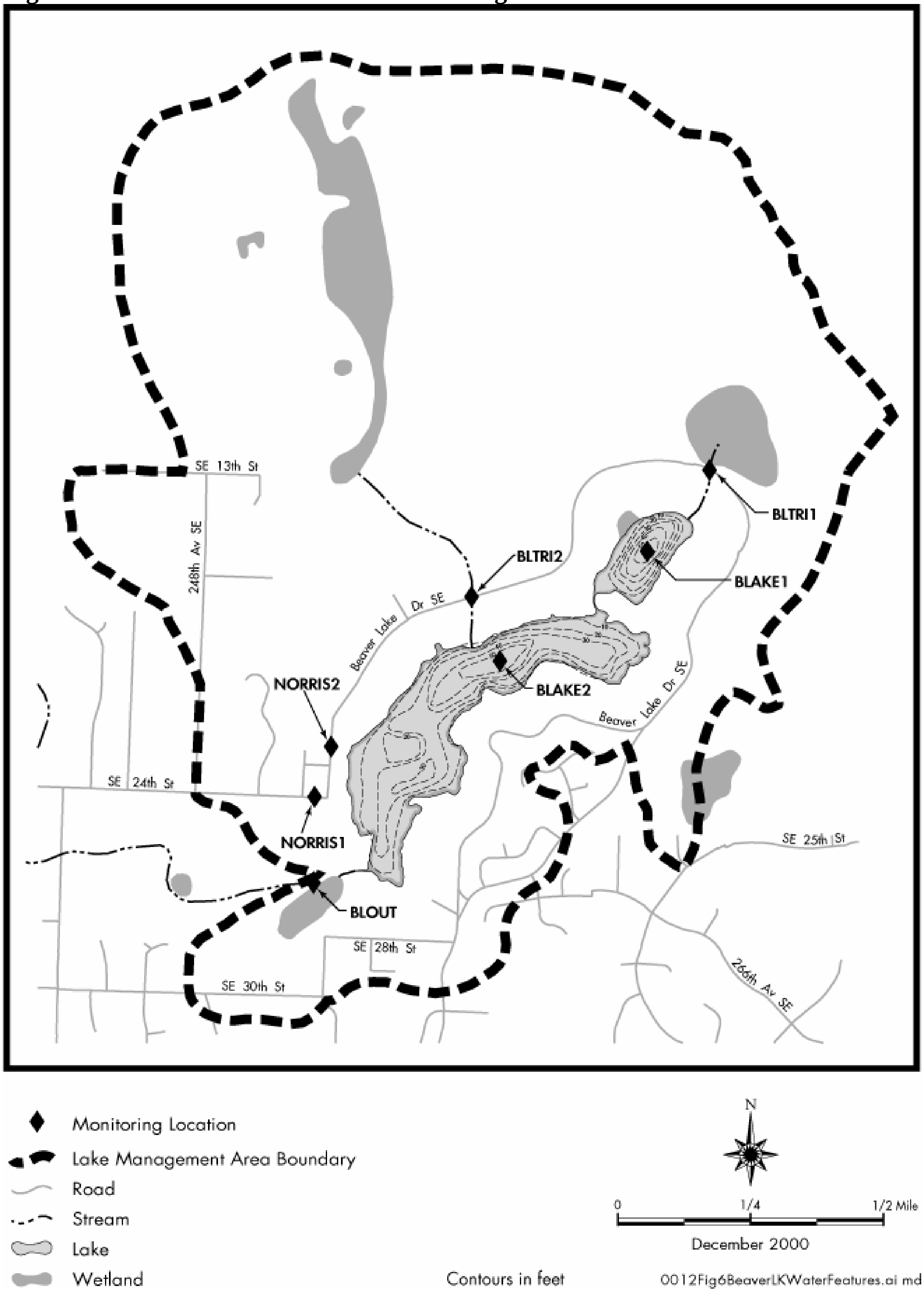
Sampling Sites

Beaver Lake consists of three interconnected bodies of water described as Beaver Lake 1, Beaver Lake 2, and Beaver Lake 3 (See Chapter 2, Figure 2). For the lake monitoring program, water quality in Beaver Lake 1 (BLAKE1) and Beaver Lake 2 (BLAKE2) were characterized only. Lake sampling locations for these two sites are shown in Figure 6.

The lake has two primary inflows (tributary 0166 and tributary 0166D) and discharges to Laughing Jacobs Creek via an outlet channel (tributary 0166) located on the western-side of Beaver Lake 3 (see Chapter 2, Figure 2). Stream sampling locations for these sites (BLTRI1, BLTRI2, and BLOUT) are shown in Figure 6.

During 1998, two additional sampling sites (NORRIS1 and NORRIS2) were added to the stream monitoring program to characterize stormwater runoff from the forested Norris Estates property located west of Beaver Lake 2 (Figure 6). These sites are characterized by intermittent flow which occurs only during large storm events. During the two seasons when the Norris Estate sites were monitored, sufficient flow for sampling only occurred at NORRIS2 during one event in December 1999. Although flow occurred during other dates, flow was insufficient to collect a discrete water sample.

Figure 6. Watershed Features and Monitoring Locations



Lake Monitoring

The Beaver Lake Management District funded a comprehensive lake monitoring program that was conducted during October 1996 through September 1997 and again from October 1999 through Septermber 2000. This comprehensive program was complemented by a seasonal (May through October) lake monitoring program conducted by volunteers participating in the King County Department of Natural Resources Lake Stewardship Program.

The data collected through these two programs were used for different purposes. The comprehensive data collect by the management district was used for developing the lake nutrient budgets and assessing management strategies for the long-term protection of Beaver Lake. The data collected by volunteers provided a long-term record for evaluating seasonal trends in surface water quality in Beaver Lake. Results for both data collection efforts are reported in Chapter 5.

Management District Monitoring Program

Both lake sites (Figure 6) were monitored monthly for water quality during October 1996 through September 1997 and again from October 1999 through September 2000. These sites (BLAKE1 and BLAKE2) represent the deepest areas of the two lake basins. Water samples were collected for nutrient analysis from these sites at two meters intervals.

The sampling frequency and parameters measured are detailed in Table 3. A complete explanation of methods and quality assurance protocols can be found in the Water Quality Monitoring Plan (King County, 1996b).

Table 3: Management District Monitoring Program

Component	Sampling Frequency	Stations	Parameters
Lake	monthly	2 stations, deep spots, each 2 meters	pH, Conductivity, Total Phosphorus, Soluble Reactive Phosphorus
	July and August	2 stations, each two meters	Nitrite+Nitrate-Nitrogen, Ammonia, Total Nitrogen
	monthly	2 stations, water column composite (@0.5m, 1.5m, 2.5m, and 3.5m)	Chlorophyll *a*, Phaeophytin *a*, Phytoplankton species, biovolume, and identification
	monthly	2 stations, vertical tow 14m	Zooplankton species, enumeration, and identification
	monthly	1 station, surface only	Fecal Coliform
	monthly	2 stations, surface	Turbidity, Alkalinity, Color, Secchi depth
	monthly	2 stations, profile	Temperature, Dissolved Oxygen

Volunteer Monitoring Program

Since 1985, Beaver Lake water quality has been evaluated as part of the King County Lake Stewardship Program (prior to 1996, the METRO Small Lakes Program). Through this program, the physical (Level I) and chemical (Level II) characteristics are currently monitored on over 45 small lakes in King County. Volunteer data are reported by King County in annual lake monitoring reports (King County, 1999c).

For Level I, volunteers measure precipitation and lake level on a daily basis, and measure lake surface temperature and Secchi depth on a weekly basis. Lake level data from the Level I monitoring program was used to verify lake stage (level) simulations completed as part of the hydrologic analysis and subsequent water budget development for the lake.

For Level II, volunteers collect water samples biweekly from May through October for phosphorous, nitrogen, chlorophyll *a*, and algal analysis. Level II volunteers also measure Secchi depth and water temperature when collecting water samples.

For Level I and Level II monitoring methods, the sampling frequency, station location, and parameters monitored are summarized by component in Table 4. A complete description of methods and quality assurance protocols for Level I and II programs can be found in the *Sampling Manual for Lake Volunteers* (King County, 2000d).

Table 4: 2000 Volunteer Monitoring Program

Component	Sampling Frequency	Stations	Parameters
Lake (Level I)	Daily Year-round	1 station (Beaver Lake 2 only)	Lake level and Precipitation
	Weekly Year-round	1 station (Beaver Lake 2 only)	Color, Temperature, and Secchi depth
Lake (Level II)	Biweekly May-October	2 stations, surface (1m)	Total Phosphorus, Total Nitrogen, Chlorophyll *a*, Phaeophytin *a*, Phytoplankton species, Color, Temperature, and Secchi depth
	Monthly profile July and August	2 stations, surface, mid, and bottom depths	Same as biweekly parameters except no Chlorophyll *a*, Phaeophytin a, Phytoplankton species data for bottom depth sample

Stream Monitoring

Water quality was also evaluated through the management district stream monitoring program. This program includes the collection of baseflow and stormwater samples from the two tributaries to Beaver Lake, and when flow allowed, samples from two intermittent drainage that exit the Norris Estates property (Figure 6).

Stream flow to the lake is intermittent, flowing typically between November and June only. Manual grab sampling methods were used to collect both baseflow and storm flow, and inlet and outflow samples (King County, 1996b).

The two primary tributaries to the lake, BLTRI1 and BLRTI2, originate in wetland headwaters. BLTRI1 is the direct outflow from a 13-acre bog and discharges directly into Beaver Lake 1. BLTRI2 originates from a 31-acre open water wetland and flows about one quarter mile before entering Beaver Lake 2 (Figure 6). The two Norris discharges, NORRIS1 and NORRIS2, drain the eastern portion of the property and flow intermittently. During 1999, samples were not collected at the Norris sites due to inadequate flow.

Discharge

Gaging data was collected from the inflow tributaries (BLTRI1 and BLTRI2) and lake outlet (BLOUT) using 15-min stage recorders from November 1996, through September 2000. Data from each recorder was downloaded monthly and discharge determined using a rating curve developed for each site. Gaging data was used to determine mean annual daily discharge, mean daily discharge, and annual inflow loading, and to develop the water budget for the lakes.

Baseflow

When flow was present in the two stream channels, baseflow stream samples were collected on a monthly basis beginning November 1996 though June 1998 and then biweekly beginning November 1998 though June 2000. The water samples were analyzed for the parameters shown in Table 5. These parameters are similar to those collected during 1992. A complete description of stream sampling methods can be found in the *Water Quality Monitoring Plan* (King County, 1996b).

Table 5: 1996-2000 Stream Monitoring Program

Component	Sampling Frequency	Stations	Parameters
Inlets/Outlets	Monthly (11/96-6/98) and biweekly 11/98-6/00) discrete baseflow samples plus four composite stormwater samples/year	4 sites total: primary inflows (BLTRI1 and BLTRI2) plus 2 Norris Estate site tributaries (NORRIS1 and NORRIS2), added 11/98	Temperature, pH, Dissolved Oxygen, Conductivity, Total Phosphorus, Ortho-Phosphorus, Nitrite+Nitrate-Nitrogen, Ammonia, Total Nitrogen, Color, Turbidity, Total Suspended Solids, Fecal Coliform
Flow/Hydrology	Daily	Lake level Inflow and Outflow Rain Gauge	Volume Fluctuations Total Discharge Total Precipitation

Stormwater

Because of the moderating effects of upstream wetlands, the tributary streams to Beaver Lake generally have a slow response to precipitation events. Thus, characterizing “stormwater quality” was ultimately restricted to characterizing water quality during high flow events.

During these sampling events, high flow samples were composited from two to three individual grab samples taken over the course of an individual storm event. A storm event was generally defined as 0.5 inches of rainfall in a six-hour period or 1.0 inches of rain in a 24-hour period preceded by 60- to 72-hours of dry conditions (less than 0.25 inches per day). Volunteers assisted with high flow stormwater characterization by measuring stream height and assisting in the collection of individual grab samples over the course of the storm hydrograph.

Generally, four storm events were targeted for sampling each year. Because of the slow response of the tributaries to precipitation, typically two to three events were characterized each year. The only exception was in 1999, when five storms were characterized.

Chapter 4: Lake and Stream Quality

For Beaver Lake, water quality data are available from a variety of sources including the original *Beaver Lake Management Plan* (King County, 1993a) and from October 1996 through September 2000 monitoring program completed by the Beaver Lake Management District. Data are also available from the King County volunteer lake monitoring program. For Beaver Lake 2, a 16-year record is available for trophic state parameters.

In this section, lake water quality is discussed using data from both the Beaver Lake Management District and the King County volunteer monitoring programs. These data are compared with data collected for the 1993 *Beaver Lake Management Plan*. As part of the Beaver Lake Management District monitoring program, stream quality was also monitored and is discussed in a separate section in this chapter. Similarly, stream data are compared with available data from the 1993 *Beaver Lake Management Plan*.

Lake Water Quality

For select water quality parameters, average surface (0.5 meters) concentrations are shown in Table 6. Generally, surface water quality remains similar for the three water years (1992, 1997, and 2000).

Most freshwater lakes are phosphorus limited, that is, all other nutrients necessary for plant growth are in greater abundance. Over time, increases in phosphorus levels can contribute to the degradation of water quality in lakes.

For Beaver Lake, phosphorus has been identified as the limiting nutrient and thus, in order to preserve Beaver Lake water quality, has been the focus for control (King County 1993a). Fortunately, in both Beaver Lake 1 and Beaver Lake 2, phosphorus levels have remained at similar levels over the three water years. Although, higher surface concentrations were recorded for both lake basins during 1996-1997, precipitation was also above average (totaling 70 inches) resulting in an increase in surface runoff as well as phosphorus to the lakes.

In the section that follows, phosphorus as well as other water quality parameters are discussed in more depth for both lake basins. Complete data for the 1991-1992 year can be found in the *Beaver Lake Management Plan*, Technical Appendices (King County 1993b) while data for 1997 and 2000 water years can be found in Appendix A.

Table 6: Average Surface (0.5 meters) Concentrations for Select Water Quality Parameters

Parameter	Water Year*	Beaver Lake 1 (BLAKE1)			Beaver Lake 2 (BLAKE2)		
		Average	Min	Max	Average	Min	Max
Total Phosphorus (µg/L)	1992	28.4	10.0	40.0	19.3	11.0	32.0
	1997	30.6	14.5	47.5	21.2	9.0	42.8
	2000	23.3	12.2	37.4	15.9	10.1	33.0
Ortho-Phosphate (µg/L)	1992	8.6	5.0	29.0	6.5	5.0	15.0
	1997	13.7	6.9	30.4	7.0	3.5	12.3
	2000	6.0	1.0	19.4	2.6	1.0	6.1
Chlorophyll *a* (µg/L)	1992	10.8	0.3	44.0	3.9	0.9	11.0
	1997	7.5	0.4	23.2	10.4	2.5	35.2
	2000	5.1	0.1	20.8	5.5	0.6	13.7
Secchi Depth (m)	1992	1.3	0.90	2.00	2.5	2.00	3.60
	1997	1.8	1.75	1.75	2.3	2.25	2.25
	2000	1.8	1.25	2.50	2.8	2.25	3.50
Temperature (C)	1992	14.1	4.9	26.0	14.7	5.1	27.0
	1997	12.4	3.4	22.2	13.2	3.6	23.2
	2000	12.5	4	23.3	13.1	4.6	24.1
Dissolved Oxygen (mg/L)	1992	8.1	5.7	9.9	8.9	6.7	11.1
	1997	8.0	5.4	11.0	8.9	6.8	11.4
	2000	8.0	6.9	9.7	8.7	7.0	10.8
pH	1992	5.9	5.5	6.9	5.8	4.9	6.9
	1997	6.0	5.6	7.6	6.3	6.0	6.7
	2000	6.2	5.8	6.9	6.5	6.3	7.1
Conductivity (µmhos/cm)	1992	31	18	38	37	20	41
	1997	23	20	26	31	27	34
	2000	37	30	44	42	37	51
Alkalinity (mgCaCO³/L)	1992	5.1	3.0	10.0	7.8	6.0	11.0
	1997	7.0	4.6	10.6	9.1	6.1	11.3
	2000	9.2	7.7	10.8	10.9	9.8	12.0
Turbidity (NTU)	1992	0.6	0.3	1.1	0.5	0.3	0.9
	1997	1.3	0.6	2.8	1.0	0.6	1.6
	2000	1.1	0.5	2.4	0.9	0.5	1.4
Color (CPU)	1992	71	45	90	28	10	50
	1997	86	40	120	53	40	90
	2000	79	70	90	36	25	50
Bacteria (CFU/100ml)	1992	2	1	15	3	1	10
	1997	6	1	13	8	1	150
	2000	na**	na**	na**	6	1	18

* 1992-October 1991 to September 1992; 1997-October 1996 to September 1997; and 2000-October 1999 to September 2000.
**na-data not available.

Management District Monitoring Program

The monitoring program funded by the lake management district resulted in the collection of water quality data for October 1996 through September 1997 and again from October 1999 through September 2000. The data collected for these two time periods are compared with data collected previously (during October 1991-September 1992) for the1993 *Beaver Lake Management Plan*. In this section, physical parameters (temperature, water clarity, and color) are discussed first followed by chemical parameters (dissolved oxygen, conductivity, alkalinity, pH, phosphorus, nitrogen, and chlorophyll *a*) and then biological parameters (bacteria, phytoplankton, and zooplankton).

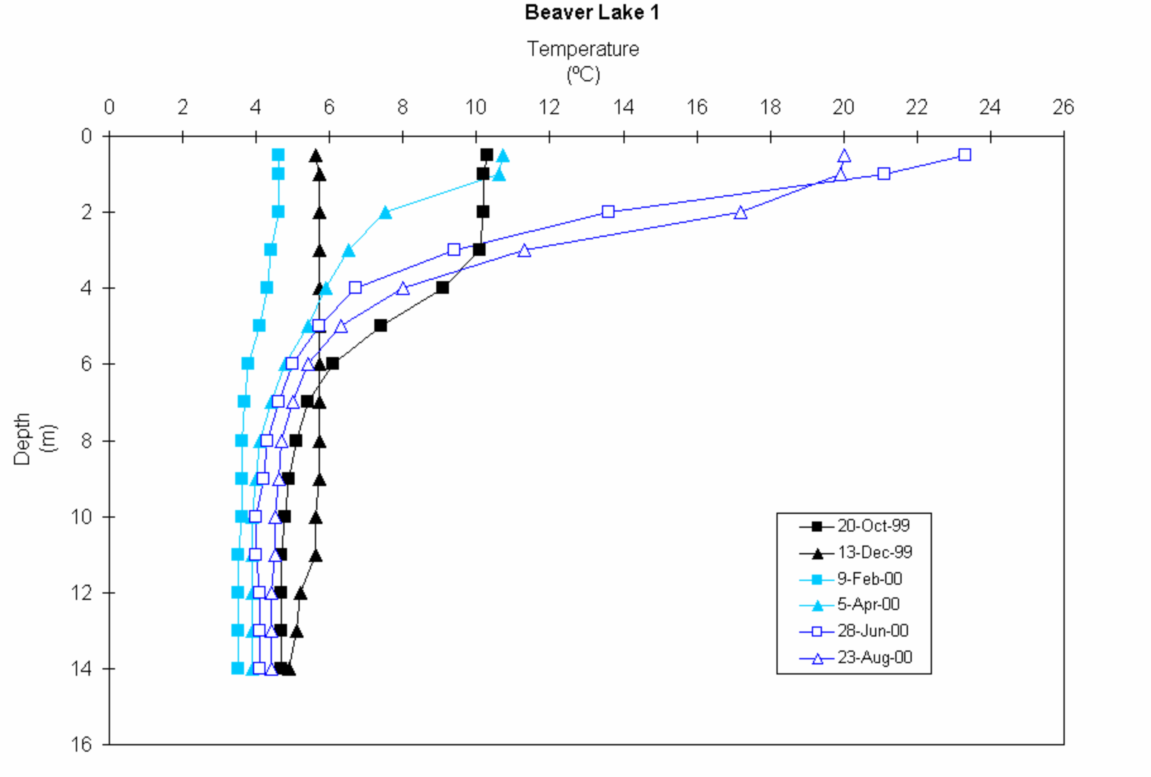
Temperature

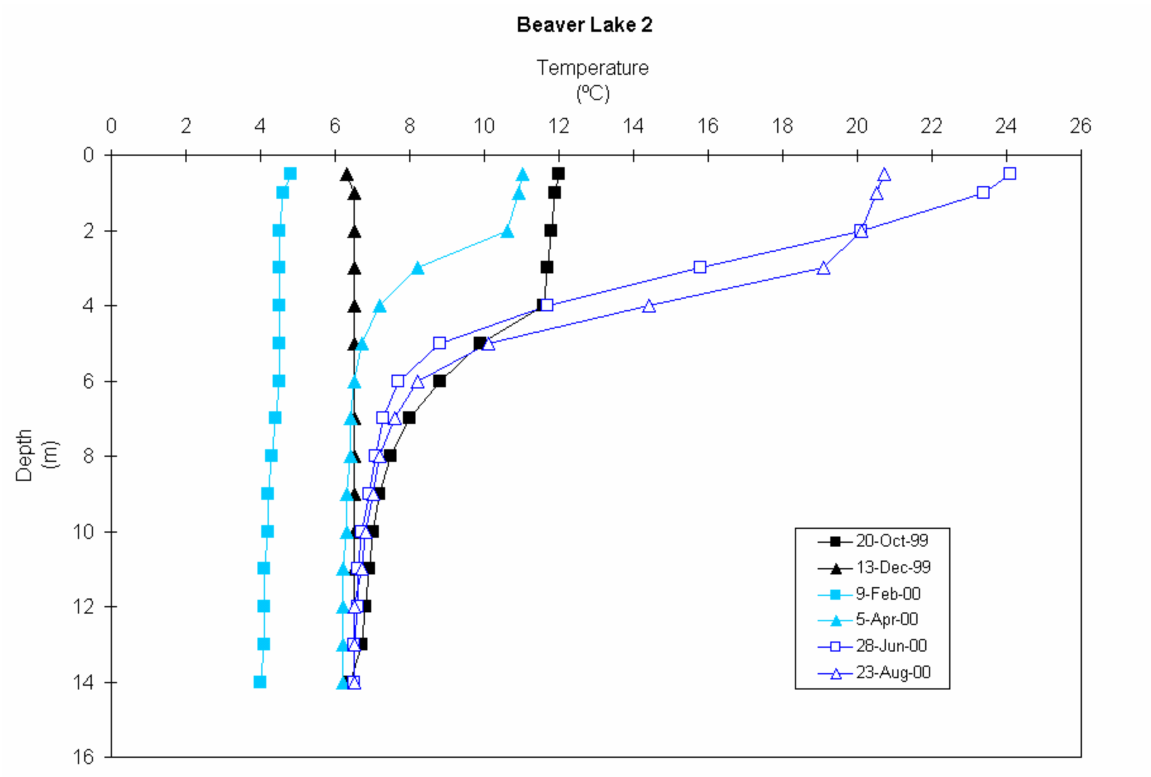
Water is densest at 4°C resulting in the formation of ice at a lake's surface rather at the lake bottom. This unique property of water is also important in the development of thermal stratification of lakes. Thermal stratification results in the separation of the lake water column into distinct temperature and chemical layers based on density differences of water along a temperature gradient. The typical stratification pattern results in water temperature being nearly uniform during the heart of winter followed by water column stratification beginning as early as March when sunlight starts significantly warming surface waters.

This warming continues through spring and summer resulting in the development of three distinct temperature layers: the epilimnion (upper), metalimnion (middle), and hypolimnion (lower). The middle layer is characterized by large temperature changes with increasing depth and serves to effectively isolate chemically the upper from the lower layer.

Typical temperature profiles for Beaver Lake are shown in Figure 7. For the 2000 water year, water temperature was nearly uniform on December 13, 1999 and February 9, 2000 for both lakes. Minimum temperatures of 4.0 °C at Beaver Lake 1 and 4.6°C at Beaver Lake 2 were observed on this February date. Maximum surface temperatures of 23.3 °C at Beaver Lake 1 and 24.1°C at Beaver Lake 2 were observed on June 28, 2000.

Figure 7. Temperature Profiles





Water Clarity and Color

Water clarity and color affect the depth to which light penetrates the water column. In turn, light is important factor for plant growth including both algae and rooted or floating aquatic plants. In addition to color, turbidity related to sediment, algae, or decaying organic matter affect water clarity.

In Beaver Lake, natural color plays an important role in water clarity. In Beaver Lake 1, Secchi depth (a measure of water clarity) averages less then 2.0 meters with a range of 1.25 to 2.5 meters in 2000 (Table 6). In Beaver Lake 2, water clarity is slightly better with an average of 2.8 meters and a range of 2.25 to 3.5 meters in 2000 (Table 6).

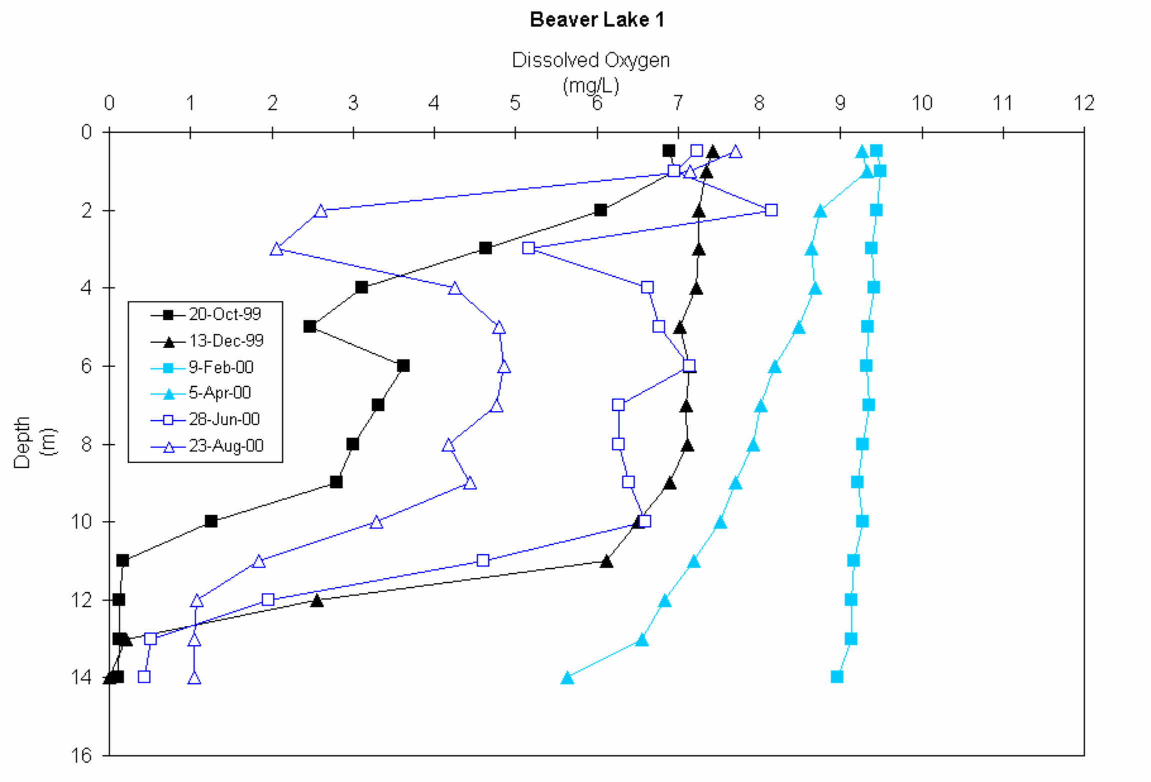
The low water clarity in both lakes is due in part to color. In Beaver Lake 1, average color values ranged from 71-86 Cobalt Platinum Units (CPU) for the three water years, while Beaver Lake 2 values ranged from 28-53 CPU. The higher color values in Beaver Lake 1 result in lower water clarity year-round. The source of color to both lakes originates in upstream wetlands which discharge organic matter and highly colored water to Beaver Lake. For Beaver Lake 1, the color values are higher because outflow from wetland ELS 21 enters the lake relatively undiluted while in inflow from the Hazel Wolf Wetland Preserve flows for about one-quarter of a mile, becoming diluted before entering Beaver Lake 2.

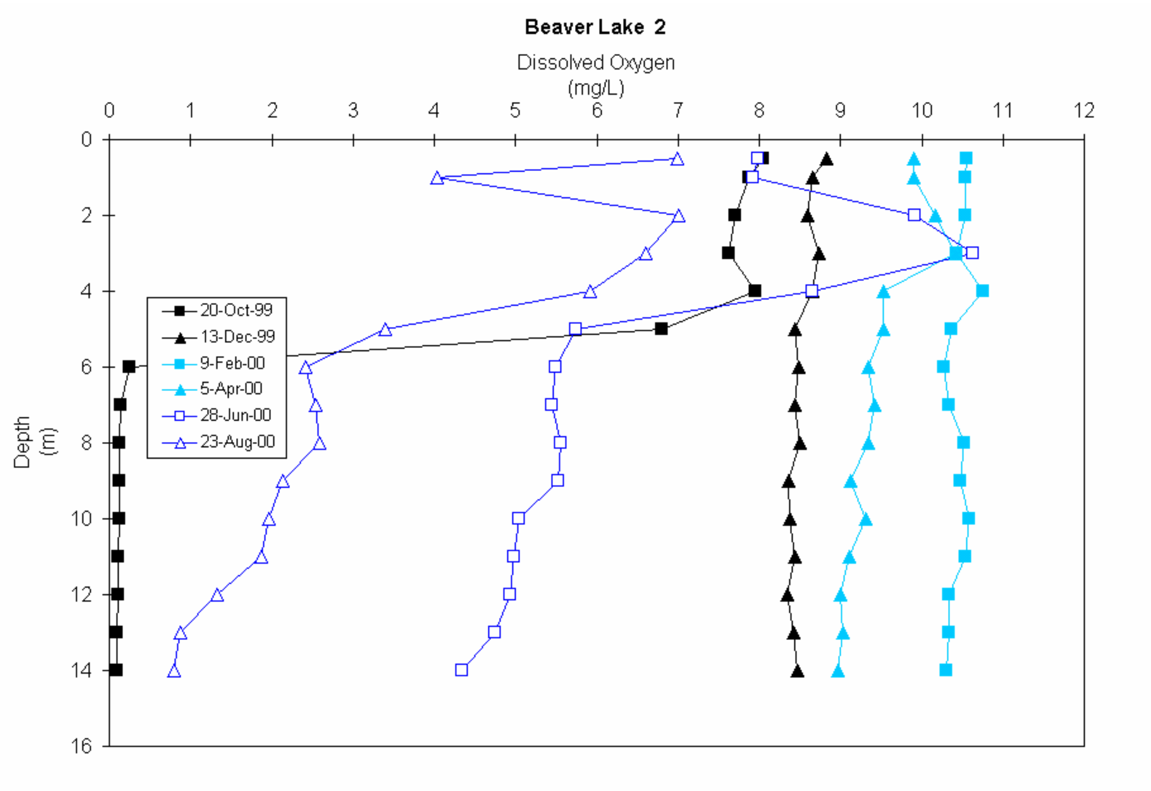
Dissolved Oxygen

Oxygen is important for supporting a variety of life forms as well as regulating chemical processes in the lake. Once the lake becomes stratified, oxygen levels begin dropping in the hypolimnion eventually dropping to near zero. This change in oxygen levels results in a change in phosphorus chemistry at the lake/sediment interface. Under oxygenated conditions, phosphorus remains in the sediment, under low oxygen conditions, phosphorus can be release to the hypolimnion, eventually becoming available for plant growth when lake mixing occurs in the fall.

In Beaver Lake, surface concentrations of oxygen are generally higher in Beaver Lake 2 in comparison to Beaver Lake 1 (Table 6). Actual stratification of the lake begins in March and becomes well established during April and May. After the thermocline sets-up at two to four meters (Figures 7 and 8), oxygen levels generally remain good in the hypolimnion through June before finally dropping off to their lowest values in October (Figure 8).

Figure 8. Oxygen Profiles





Conductivity, Alkalinity, and pH

Conductivity, alkalinity, and pH are routinely measured for lake water quality. Conductivity is a measure of the water's ability to conduct an electrical current and reflects the amount of dissolved ions in the water. Surrounding soils play an important role in determining a water body's conductivity.

In Beaver Lake, conductivity is generally less than 50 μmhos/cm. For most freshwaters, conductivity can range from 10 to 1,000 μmhos/cm (Chapman, 1992), placing Beaver Lake on the lower end.

Alkalinity is a measure of water's ability to neutralize hydrogen ions while pH is measure of the hydrogen ion concentration. Because pH plays an important role in many biological and chemical processes, alkalinity can have an important affect on the character of a lake and its ability to buffer chemical process and support a range of biological life.

In Beaver Lake 1, both pH and alkalinity levels are on average lower than those in Beaver Lake 2 (Table 6). Again, upstream wetlands heavily influence lake chemistry. In Beaver Lake 1, surface pH ranged from 5.8 to 6.9 and averaged 6.2 while alkalinity averaged 9.2 for 2000. For Beaver Lake 2, surface pH ranged from 6.3 to 7.1 and averaged 6.5 while alkalinity averaged 10.9 for 2000.

Nutrient Limitation

Most lake water quality problems are related to an excess of plant nutrients which results in nuisance plant growth either as algae or rooted aquatic plants. Prior to evaluating management options, the nutrient that limits plant growth is determined. Nitrogen and phosphorus are the major nutrients that are important to plant growth. Most often, phosphorus is limiting in freshwater environments resulting in a management focus of phosphorus load reduction.

When determining nutrient limitation, generally nitrogen to phosphorus ratios of surface water are examined. Ratios greater than 17:1 generally suggest that phosphorus limits algal growth (Carroll and Pelletier, 1991) while ratios less than 10:1 suggest nitrogen limitation. Previous data for Beaver Lake showed phosphorus was the limiting nutrient (King County, 1993a).

To confirm whether phosphorus levels continued to drive algal growth, limited nitrogen data were collected for July and August in 1997 and 2000. Based on this data, nitrogen to phosphorus ratios for Beaver Lake 1 ranged from 14:1 to 32:1 while in Beaver Lake 2 ratios ranged from 28:1 to 38:1. These ratios suggests that phosphorus continues to be the limiting nutrient for algal growth.

Phosphorus

Phosphorus is a common element found in soil, rock, plant and animal tissue, as well as in the atmosphere. All organisms rely on phosphorus to grow. In freshwater environments, phosphorus plays a particular role in plant growth providing a basis for the food chain that supports higher organisms like zooplankton and fish.

Phosphorus can be measured in a variety of forms. Most commonly, total phosphorus and ortho-phosphate. Total phosphorus represents both organic and inorganic forms of phosphorus while ortho-phosphate represents the dissolved fraction that is available for algal growth.

Both forms of phosphorus have been measured for the three water years. In Figure 9, monthly concentrations for total phosphorus are shown for both Beaver Lake 1 and Beaver Lake 2. From month to month, surface concentrations vary but generally peak during the winter months when surface inflow to the lake is prevalent.

Concentrations are typically higher in Beaver Lake 1 than in the larger Beaver Lake 2. During the most recent water year, total phosphorus surface concentrations have been lower than those observed during 1992 and 1997 (Table 7). Year-to-year variability in phosphorus concentration is partially attributed to accompanying precipitation levels. During wetter years, higher phosphorus concentrations are generally observed during the entire year for both lake basins.

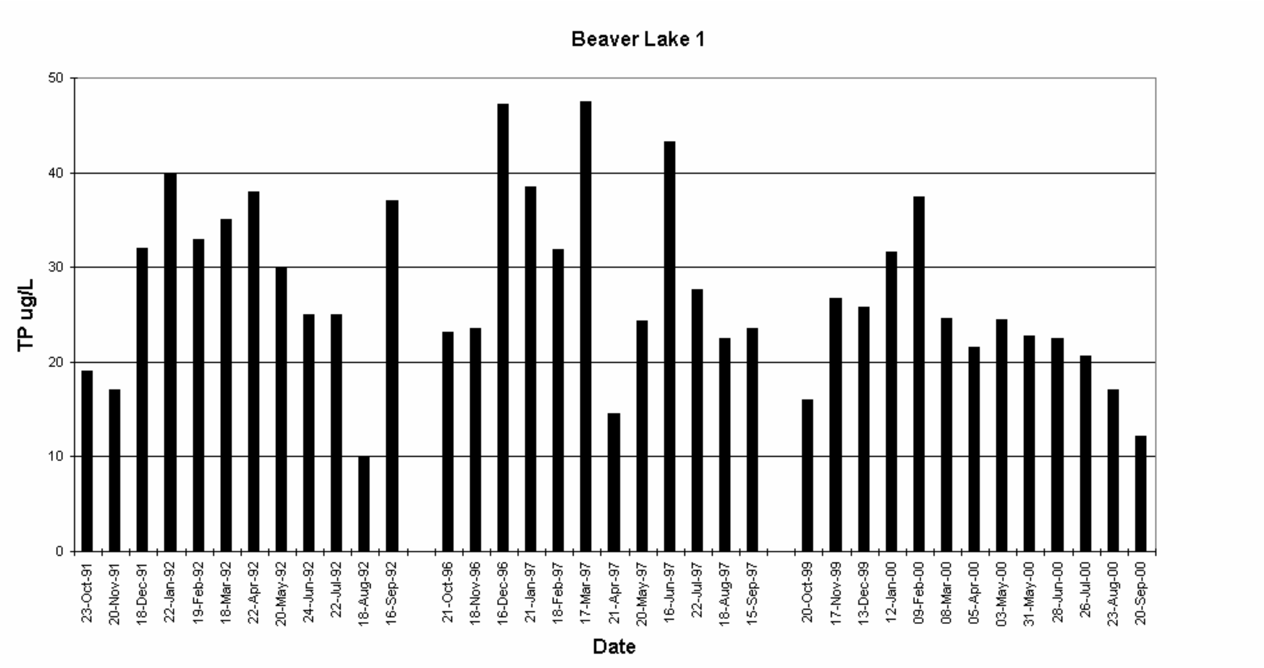
Table 7: Average Surface Total Phosphorus Concentrations for Three Water Years

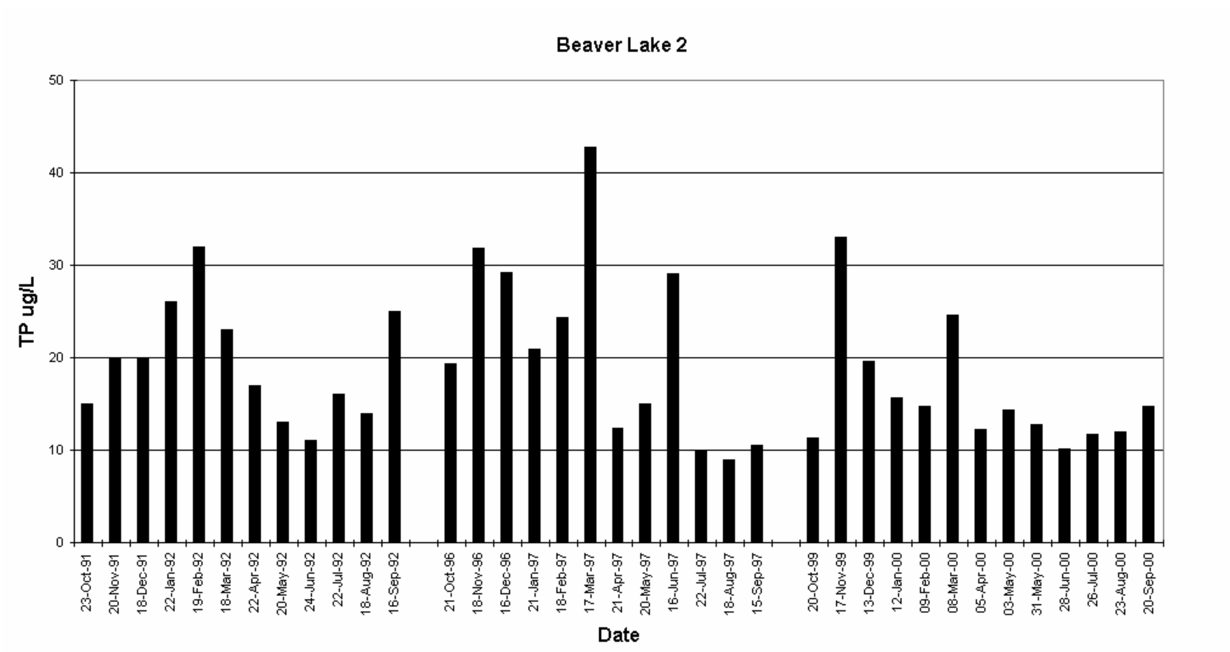
Water Year	Beaver Lake 1 Total Phosphorus (μg/L)	Beaver Lake 2 Total Phosphorus (μg/L)	Annual Rainfall @46U* (inches)	Annual Rainfall @MLU* (inches)	Annual Rainfall @Level I* (inches)
1992	28.4	19.3	45	not available	not available
1997	30.6	21.2	70	63	55
2000	23.3	15.9	not available	40	40

* The precipitation record for the Beaver Lake area was taken from site 46U (Black Nugget gauge) until midway through the 1999 water year when property access changed. Therefore, the precipitation record from MLU (Mystic Lake gauge) and the Beaver Lake2-Level I gage sites are also shown to allow comparison of annual rainfall levels with surface total phosphorus levels.

Phosphorus levels are generally stable from year to year when precipitation levels are similar. In turn, when phosphorus levels are higher, generally chlorophyll *a* levels (an indicator of algal abundance) are also elevated.

Figure 9. Total Phosphorus Annual Record for Three Water Years





Nitrogen

Nitrogen exists in several forms in the aquatic environment. These forms include nitrate+nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen, organic nitrogen, and elemental nitrogen. The dissolved forms of nitrogen are the most common forms used by algae and aquatic plants for growth and include nitrate-nitrogen and ammonia-nitrogen.

Limited nitrogen data was collected for Beaver Lake during the 1996-1997 and 1999-2000 water years because nitrogen does not limit algal growth in Beaver Lake. Total nitrogen, nitrate+nitrite-nitrogen, and ammonia nitrogen summer averages for July and August are summarized in Table 8. For the three water years, nitrogen values are fairly consistent for the three forms measured. Also, total nitrogen levels are consistently higher in Beaver Lake 1 than Beaver Lake 2.

Table 8: Average Summer (July and August) Surface Nitrogen Concentrations for Three Water Years

Water Year	Total Nitrogen (μg/L)	Nitrate+Nitrite-Nitrogen (μg/L)	Ammonia-Nitrogen (μg/L)
Beaver Lake 1			
1992	597	50	13
1997	533	25	24
2000	547	10	5
Beaver Lake 2			
1992	385	42	25
1997	331	25	26
2000	345	10	5

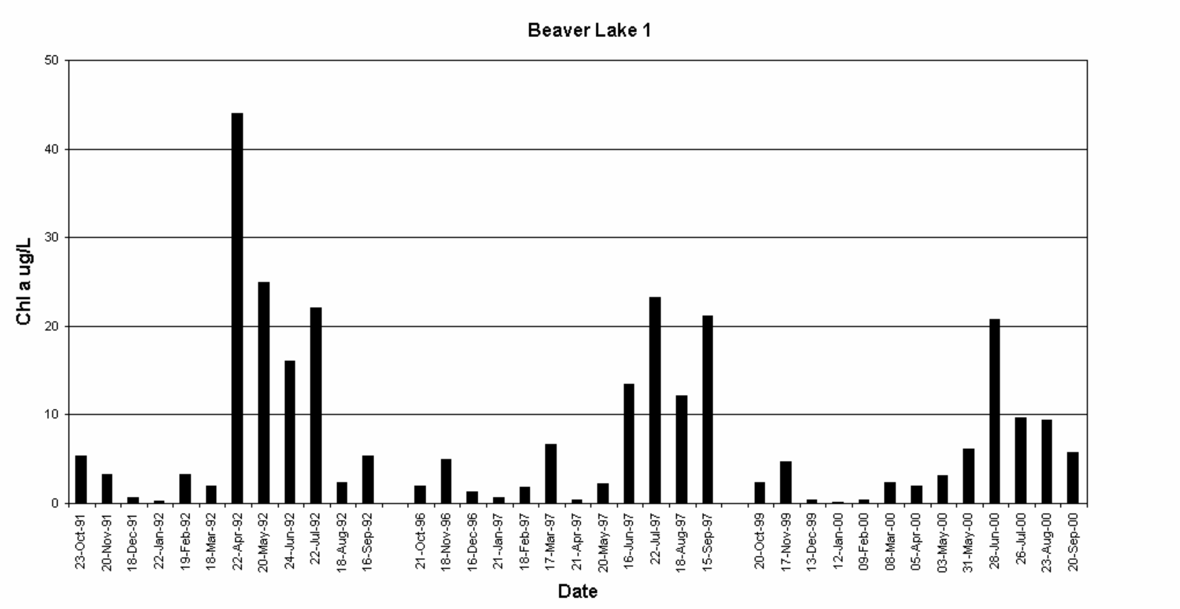
Chlorophyll a

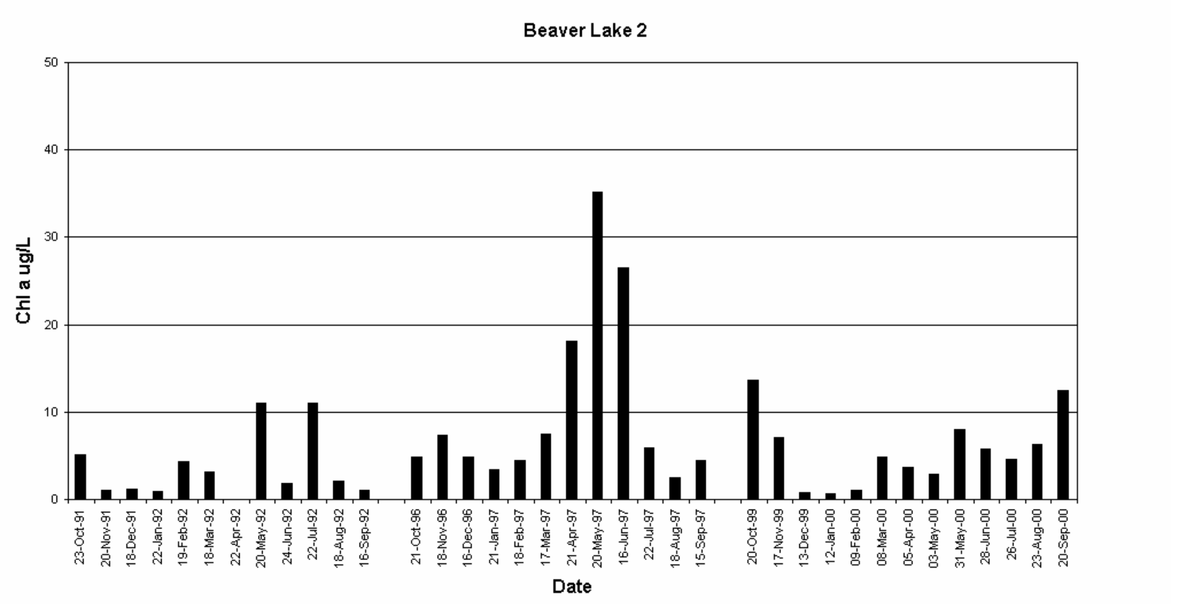
Chlorophyll *a* is one of the photosynthetic pigments found in algae. Measurement of this pigment is most frequently used to indicate the presence of algae in freshwater and characterize lake trophic state. The Carlson Tophic Index (1977) integrates values for Secchi depth, chlorophyll *a*, and total phosphorus to determine a lake's level of biological activity or trophic state. Generally, chlorophyll *a* values ranging from four to 10 μg/L are indicative of mesotrophic or good quality, while values greater than 10 μg/L are indicative of eutrophic or fairer quality. Concentrations exceeding 20 μg/L are generally indicative of bloom conditions.

In Figures 11 and 12, monthly chlorophyll *a* values are shown for Beaver Lake 1 and Beaver Lake 2 for the three water years. In Beaver Lake 1, chlorophyll *a* was highest in 1992, averaging 10.8 μg/L. In the two subsequent water years, chlorophyll *a* decline to 7.7 μg/L and 5.1 μg/L for 1997 and 2000, respectively and indicate more mesotrophic quality for Beaver Lake 1. During 1992, peak concentrations exceeded 20 μg/L on three occurrences while in subsequent years the frequency of these peaks declined (Figure 10).

In Beaver Lake 2, chlorophyll *a* was highest in 1997, averaging 10.4 μg/L. In the two other water years, chlorophyll *a* was lower, averaging 3.9 μg/L and 5.5 μg/L for 1992 and 2000 respectively and indicate mesotrophic quality for Beaver Lake 2. During 1997, peak concentrations exceeded 20 μg/L on two occurrences. In the remaining periods, no concentrations above 20 μg/L were observed and most concentrations were less than 10 μg/L (Figure 10).

Figure 10. Chlorophyll *a* Annual Record for Three Water Years





Bacteria

Fecal coliform bacteria originate in the intestinal tract of humans and other warm-blooded animals. This bacterium is not considered harmful to humans but is used to indicate possible bacterial contamination by sewage from on-site septic systems. Sewage is likely to contain a whole host of other bacteria that can be harmful to humans.

Fecal coliform counts at Beaver Lake continue to be low, averaging less than 10 CFU/100ml (Table 6). More localized shoreline sampling might indicate higher values but previous shoreline surveys did not indicate major problems with septic leakage (King County, 1993a).

Phytoplankton

Freshwater phytoplankton include a variety of algae, bacteria and infective stages of certain fungi and actinomycetes (Reynolds, 1984), but the algae are the most conspicuous and prominent group of phytoplankton. These microscopic, photosynthetic plants form the basic foundation of food production in a waterbody. Planktonic algae, along with bacteria, fungi, and fine organic matter, are directly grazed by higher organisms, primarily the zooplankton, which are consumed by other invertebrate and vertebrate (fish) predators.

Major groups of algae commonly occurring in a lake are the blue-green bacteria (Cyanobacteria), the green algae (Chlorophyta), the yellow-green/golden brown algae (Chrysophyta, diatom and non-diatom species), the dinoflagellates (Pyrrhophyta), euglenoids (Euglenophyta), and cryptomonads (Cryptophyta). The types and amount of algae present in a lake vary over the annual cycle and are dependent on a complex interaction of factors such as nutrient supply, light, temperature, sinking rates, and invertebrate grazing. The algae in a lake can be used as indicators of the overall nutrient status of the waterbody and the likelihood of nuisance algae blooms.

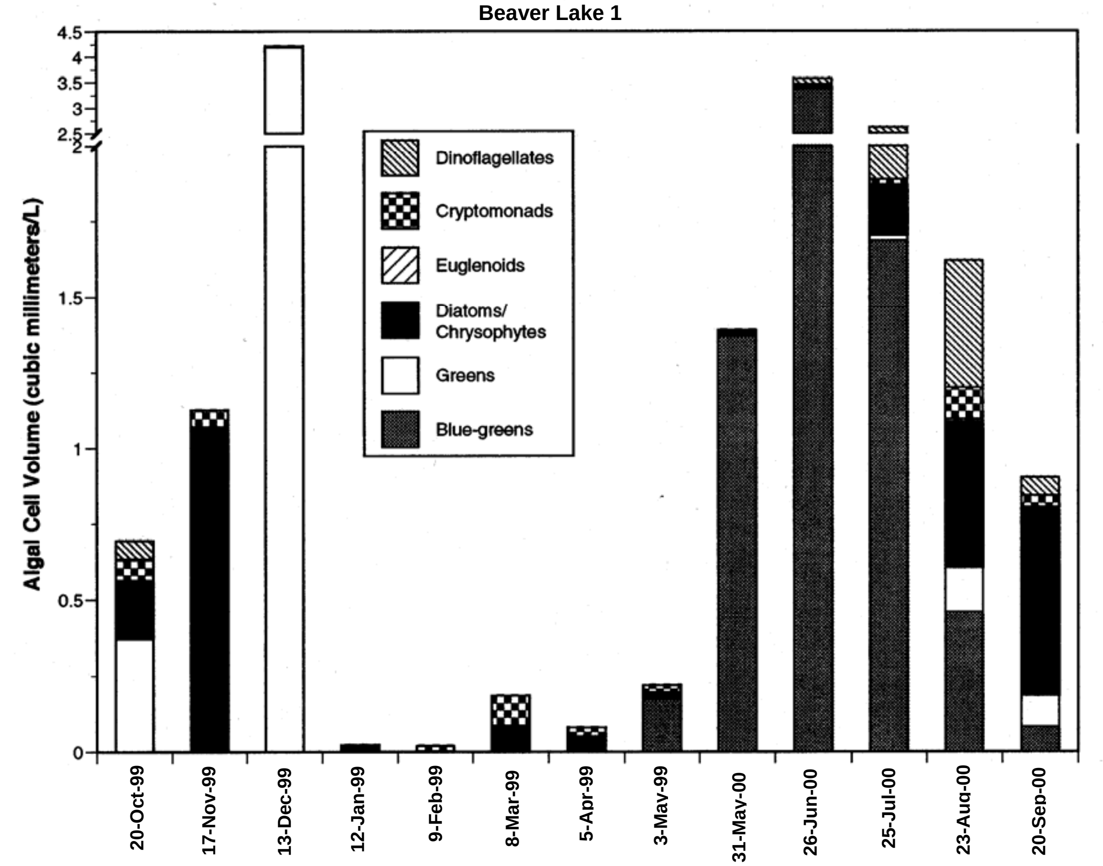
For Beaver Lake 1 and Beaver Lake 2, phytoplankton trends were analyzed for the 1997 and 2000 water years and compared with data collected for the *Beaver Lake Management Plan* (King County, 1993a). This section describes recent trends in phytoplankton biovolume only and summarizes overall phytoplankton community patterns for both lake basins. A complete analysis of phytoplankton data, including both cell density and biovolume trends, is reported in Appendix C.

Biovolume Trends

Overall phytoplankton biovolume trends, including timing and intensity of peaks, were distinctly different for each Beaver Lake basin during the 2000 water year (Figure 11). Also, with a few exceptions, trends in algal cell volume did not always follow cell density patterns in either lake basin during 2000 due to high numbers of small-sized organisms co-occurring with low numbers of larger organisms.

Algal cell volume measures generally coincided with corresponding chlorophyll *a* concentrations in both Beaver Lake basins during 2000 water year (Figure 12). Disparity between the two parameters occurred on a few dates when low densities of large spherical colonies of the green alga *Volvox sp.* were present. Presence of even a few of these large algal colonies dramatically skewed total cell volumes upward for that date, but were much less influential on chlorophyll *a* values.

Figure 11. Algal Cell Volume for 2000 Water Year



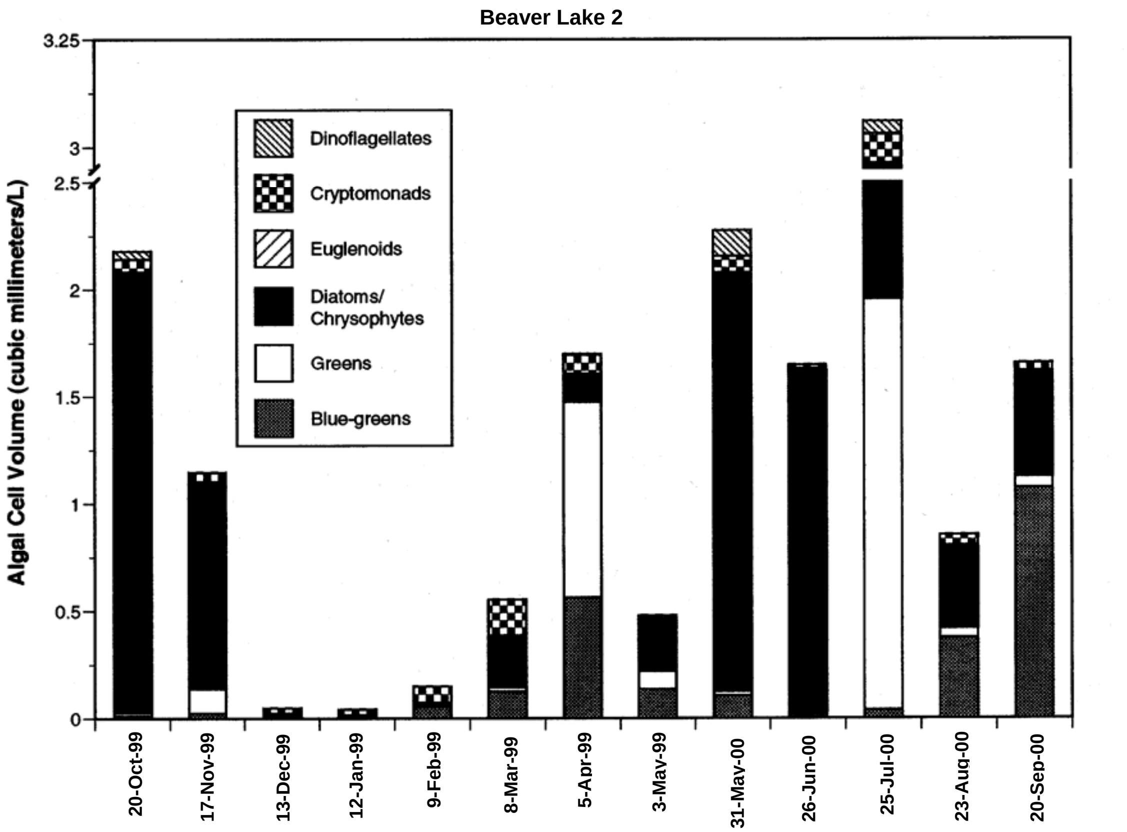
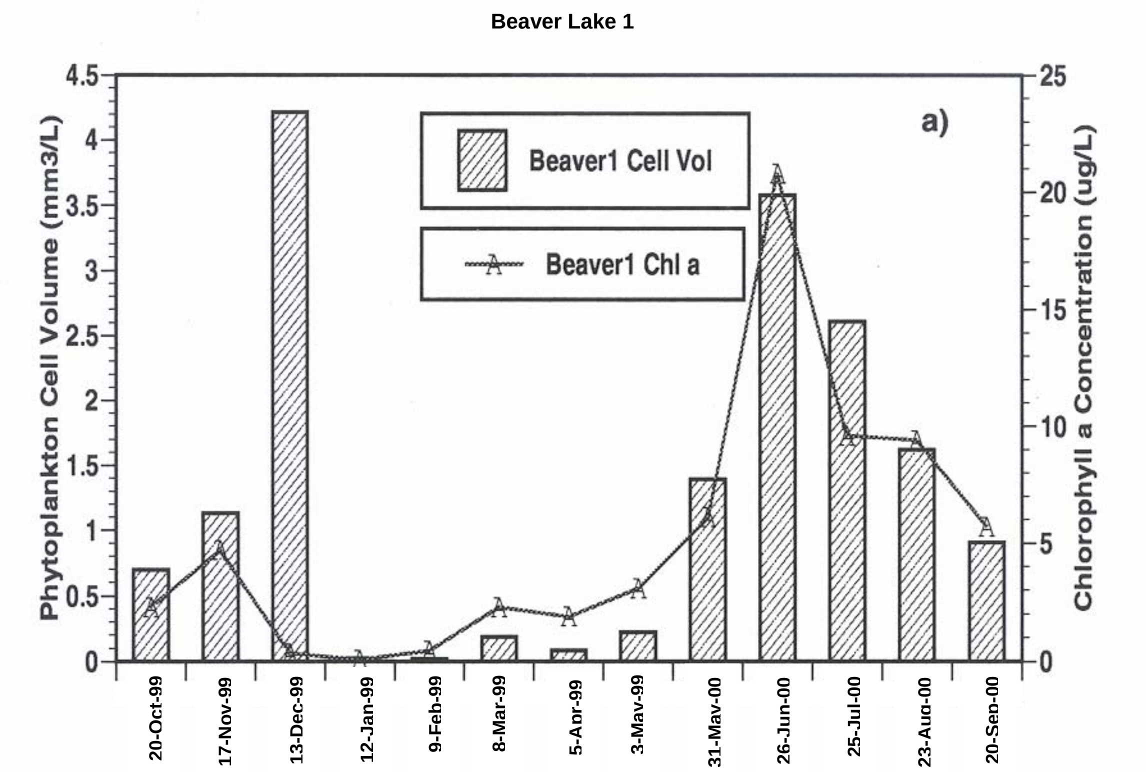
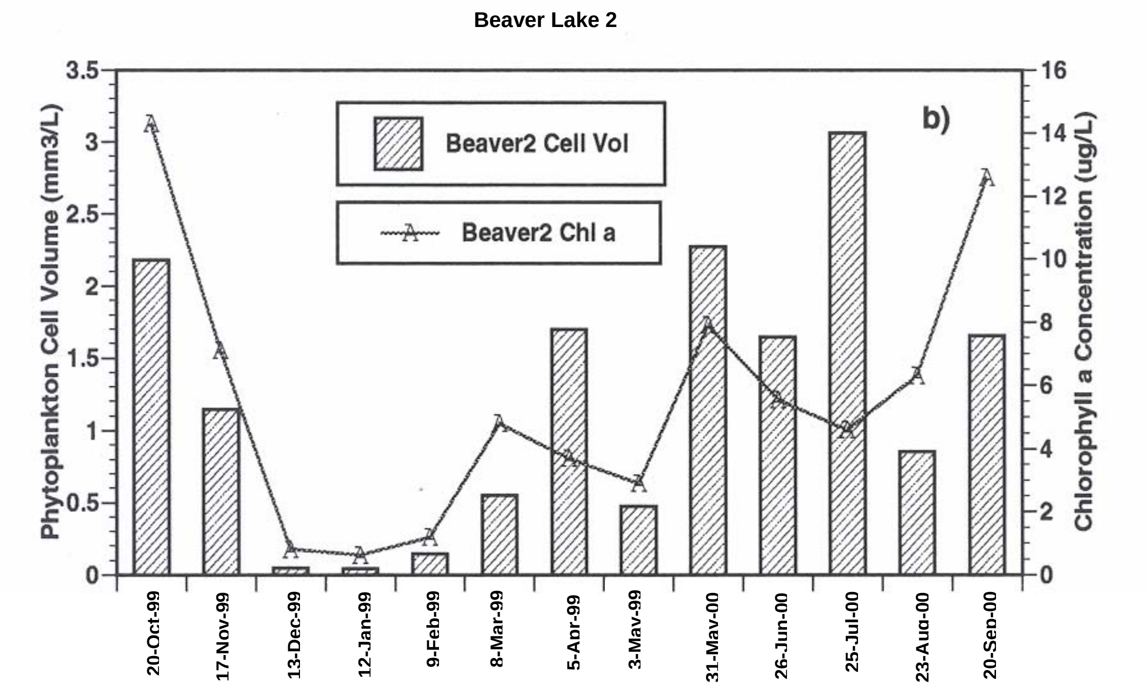


Figure 12. Beaver Lake Chlorophyll *a* versus Algal Cell Volume for 2000 Water Year





Community Patterns

In Table 9, average algal cell volume (physical quantity of algal matter) is presented for the growing season (April through September) and annual water year (October through September) for three Beaver Lake water years. Average algal cell volumes computed for the growing season for Beaver Lake 1 are fairly close between the three years, varying slightly from 1.5 to 2.1 mm^3/L. In contrast, growing season biovolume averages for the Beaver Lake 2 algal community show a greater fluctuation between the three years, ranging from 0.6 to over 3.3 mm^3/L. Yearly cell volume averages computed for all studies also show considerable variation in both basins from year to year.

Average chlorophyll *a* values were computed for the growing season and annual water year for the three Beaver Lake water years (Table 9). These values generally correlate with cell volume means, with the exception of the Beaver Lake 1 annual biovolume average for 1997. As with biovolume computations, chlorophyll *a* values for the growing season exceeded annual values, corresponding with higher biological activity during the growing season. Average chlorophyll *a* levels computed in Beaver Lake 1 during the 2000 were lower than comparative values in 1992 and 1997. Highest mean chlorophyll *a* levels (19.1 µg/L) occurred in Beaver Lake 1 during the 1992 water year and coincided with the unique occurrence of large numbers of the small euglenoid, *Eutreptia viridis*.

Table 9: Comparison of Growth Season and Annual Algal Cell Volume and Chlorophyll *a* for Three Water Years

Basin/Time Period	Cell Volume (mm^3/L)	Chlorophyll *a* (µg/L)
Beaver 1		
Growth Season		
4/92-9/92	2.10	19.1
4/97-9/97	2.02	12.0
4/00-9/00	1.49	8.1
Annual		
10/91-9/92	1.67	10.8
10/96-9/97	3.00*	7.5
10/99-9/00	1.28	5.1
Beaver 2		
Growth Season		
4/92-9/92	0.63	5.4
4/97-9/97	3.30*	15.5
4/00-9/00	1.67	6.2
Annual		
10/91-9/92	0.54	3.9
10/96-9/97	1.93	10.4
10/99-9/00	1.21	5.6

* Cell volumes reflect low numbers of very large spherical colonies of *Volvox sp* which effectively boosted total cell volume averages

For both Beaver Lake basins, the percent contributions by major algal groups are presented in Table 10 for three water years. No single algal group continuously dominated average cell volumes in either basin for one monitoring period to the next. Additionally, relative dominance by the major algal groups varied not only within each basin each year, but also between the two basins over the three years.

During the 1992 water year, euglenoids dominated total annual volumes within Beaver Lake 1 followed by the diatoms/yellow-brown, while in Beaver Lake 2 comparable biovolume measures were dominated by the blue-greens with the diatoms/yellow-brown and cryptomonads as secondary contributors. The chlorophytes (green algae) accounted for most of the annual cell volume measure in Beaver Lake 1 during 1997. During the same year, the green algae predominated to a lesser extent in Beaver Lake 2, followed by the dinoflagellates and cyanophytes. During the 2000 water year, blue-greens comprises the largest portion of total annual biovolume in Beaver Lake 1 with green algae next in importance. In Beaver Lake 2, the chrysophytes made up the greatest percentage of total volumes on an annual basis, followed by the green and blue-green groups.

Table 10: Percentage of Annual Biomass by Major Algal Groups by Water Year

Basin/Algal Group	1992	1997	2000
Beaver 1			
• Blue-greens	13	9	43
• Greens	3	62*	29
• Diatoms/yellow-brown	36	19	17
• Cryptomonads	5	1	3
• Dinoflagellates	2	8	8
• Euglenoids	41	0	<1
Beaver 2			
• Blue-greens	32	25	16
• Greens	8	38*	20
• Diatoms/yellow-brown	23	8	58
• Cryptomonads	23	3	5
• Dinoflagellates	9	26	1
• Euglenoids	5	0	<1

* Total percentage reflects cell volumes which reflects low densities of very large spherical colonies of *Volvox sp.*

Similarities and Distinguishing Characteristics

Major reoccurring features of the phytoplankton community are summarized for both basins and by each basin in Table 11. Based on cell density data, blue-greens dominated the phytoplankton community in both lake basins during the growing season

(Appendix C). The filamentous form, *Aphanizomenon flos-aquae*, has been the principal blue-green bacteria species represented in epilimnetic samples collected at both Beaver Lake Stations during the growing season.

Data from the three years also show a fairly close correspondence in both basins between algal biovolume (physical cell volume measurement) and chlorophyll *a* concentrations (a biochemical compound quantity), varying somewhat in relative quantities. Magnitude differences between the two distinct parameters for a specific sample date were most pronounced when small numbers of large colony-formers like the green alga, *Volvox sp*., were present in the epilimnetic community. The presence of this alga produce a pronounced upward skewing of physical biovolume estimates, but apparently had less affect on overall chlorophyll *a* concentrations.

Finally, a recurrent characteristic of the phytoplankton community was documented in both basins during the 1997 and 2000 water years that was significantly different from a condition described in 1992. Euglenoids dominated the Beaver Lake phytoplankton community, particularly in Beaver Lake 1, during the first half of the 1992 water year. Prominence of the euglenoids was the result of elevated numbers of *Eutreptia viridis*, which like other members of the Euglenaceae family thrives under conditions of optimal organic content. In contrast, the euglenoids made negligible contributions to phytoplankton cell volume and density measures in both basins during 1997 and 2000. The absence of this particular species during 1997 and 2000 water years (Table 11, both lakes) is interesting given the naturally high amount of organic matter associated with wetland inflows to the lake which probably supported the dominance of this species in 1992.

Table 11: Major Recurring Phytoplankton Patterns Over Three Water Years

Lake/Patterns	1992	1997	2000
Both Lakes			
• Blue-greens cell density dominate Apr.-Sep.	X	X	X
• Aphanizomenon flos-aquae primary blue-green	X	X	X
• Euglenoids biovolume dominant Sep.-Apr.	X	-	-
• Chlorophyll a corresponds with cell volume	X	X	X
Beaver Lake 1			
• Aphanizomenon flos-aquae present only during growing season	X	X	X
• Blue-green cell volume dominant May-July	X	X	X
• Cell volume/density peaks in June or July	X	X	X
• Blue-greens absent from winter samples	X	X	X
• Yellow-brown cell volume dominant fall	X	X	X
Beaver Lake 2			
• Blue-greens present throughout year	X	X	X
• Blue-green cell density peaks in April	X	X	X
• Yellow-brown cell volume/density dominant briefly in fall	X	X	X

There were several features of the phytoplankton community distinct to each Beaver Lake basin that recurred over the three years. In Beaver Lake 1 the filamentous blue-green species, *Aphanizomenon flos-aquae*, was prominent in the phytoplankton community only during the growing season. The blue-green bacteria group typically dominated biovolume measures from May through July in Beaver Lake 1, reflecting high densities of this blue-green species. Algal biovolume and density peaks were regularly observed in Beaver Lake 1 in either June or July, also resulting from peaking populations of *Aphanizomenon.*

In striking contrast was a consistent lack of blue-green representation in samples from Beaver Lake 1 during the winter season. In fact, a more prolonged absence of blue-green members from the phytoplankton community extended from the fall through winter during the 1997 and 2000 water years. Another regular feature of the Beaver Lake 1 phytoplankton community was domination of cell volumes by non-diatom chrysophytes, mainly *Dinobryon* and *Mallomonas* spp., during late summer/early fall period.

In Beaver Lake 2, the blue-green group (including the dominant species, *Aphanizomenon flos-aquae*) made substantial contributions to phytoplankton community throughout most of the year, unlike the group's more limited presence in Beaver Lake 1 samples during the growing season. Results from 1997 and 2000 water years reveal occurrence of an early growing season density peak in April varying in magnitude, but dominated by the blue-green, *Aphanizomenon flos-aquae*. In all three years, the non-diatom chrysophyte group, represented primarily by *Dinobryon* spp., typically dominated Beaver Lake 2 biovolume measures for a short time during the fall season.

Zooplankton

The zooplankton are microscopic aquatic animals adapted to planktonic life in the water. Major invertebrate groups typically represented in the freshwater zooplankton are the small-bodied rotifers (Phylum Rotifera) and two crustacean groups (Phylum Arthropoda, Subphylum Crustacea), the cladocerans and copepods, the latter consisting of filter-feeding calanoids and raptorial cyclopoids. The insect family Chaoboridae (Phylum Arthropoda, Subphylum Uniramia) is sometimes represented in the zooplankton. During portions of the year, the presence of this family is marked by the occurrence of phantom midge larvae in the upper water column.

Zooplankton organisms feed upon planktonic algae, bacteria, small organic particles and other zooplankton suspended in the water column. Under certain conditions, zooplankton groups can be a significant part of nutrient recycling within the aquatic system. Large daphnid cladocerans are highly opportunistic filter-feeders that are efficient grazers of small algae and bacteria. The cladoceran group can form an important food source for invertebrate predators as well as planktivorous fish. Copepods also can be significant primary and secondary consumers as well as a food source for higher invertebrate and fish predators.

Even the rotifers play an important role in the aquatic food web, offering a food store for aquatic invertebrates, which in turn are consumed by higher order invertebrate predators and planktivorous fish. Interestingly, rotifers may be consumed directly by many adult planktivorous fish and can be a highly nutritious dietary component of certain larval fish. Thus, the zooplankton provide an important link between the primary producers (algae) and higher order consumers (larger invertebrates and fish) in an aquatic system. Furthermore, the occurrence of certain groups or species of zooplankton, called indicator organisms, can signal either the existence of detrimental water quality conditions or presence of high quality conditions.

For Beaver Lake 1 and Beaver Lake 2, zooplankton trends were analyzed for the 1997 and 2000 water years and compared with data collected for the *Beaver Lake Management Plan* (King County, 1993a). This section describes recent trends in zooplankton biomass and summarizes community trends for both lake basins. A complete analysis of zooplankton data is reported, including density and biomass trends, in Appendix C.

Biomass Trends

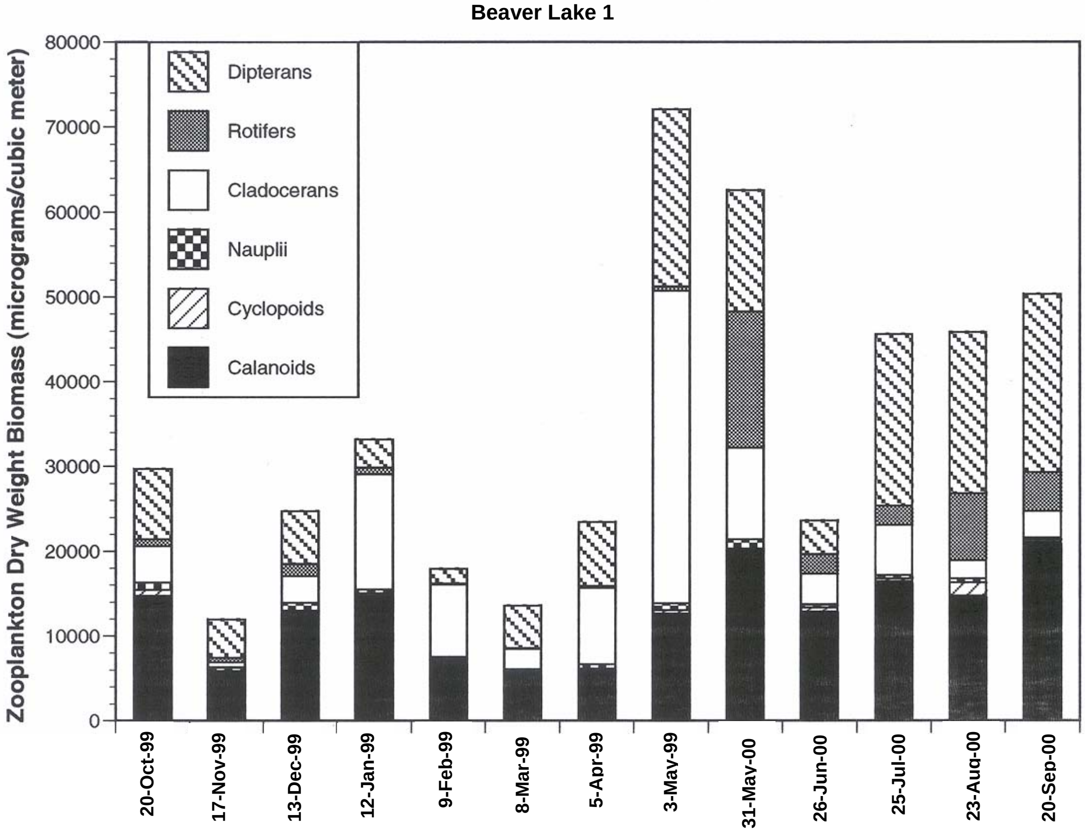
Zooplankton sample biomass patterns differed somewhat between the two Beaver Lake stations during the 2000 water year (Figure 13). These differences were largely the result of variances in relative biomass contributions by predaceous dipteran larvae and filter-feeding cladocerans and calanoid copepods throughout the annual cycle. The data show more substantial contributions to dry weight measures by the calanoid and dipteran groups in Beaver Lake 1 than in Beaver Lake 2 over the course of the recent monitoring year.

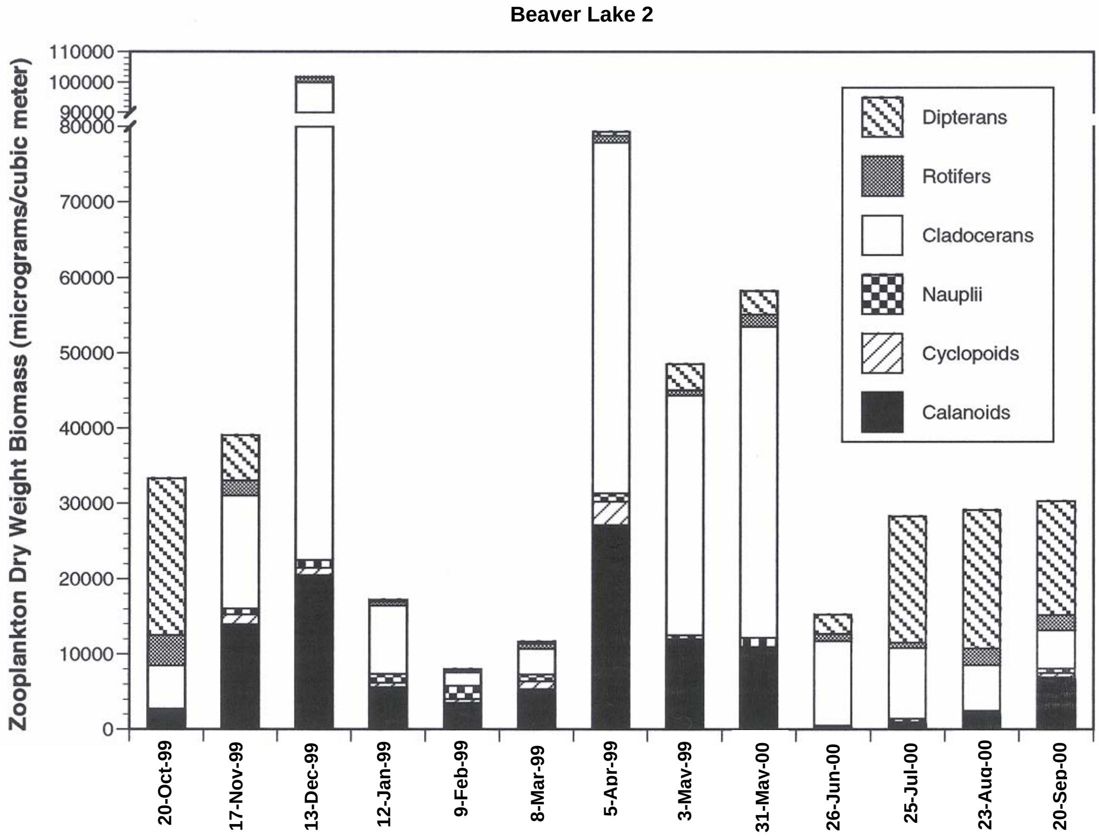
In contrast, the herbivorous cladocerans were more significant contributors to zooplankton biomass measures in Beaver Lake 2 relative to Beaver Lake 1 (Figure 13). The cyclopoid copepod and rotifer groups contributed little to overall zooplankton dry weight measures during the 2000 water year in either lake basin. Zooplankton biomass data from the 1997 water year revealed similar group dominance and annual biomass patterns in each basin as documented for the current study year.

The 2000 water year data show that the number, timing, and intensity of zooplankton dry weight biomass peaks differed between the two lake basins. Whereas Beaver Lake 1 demonstrated a single zooplankton biomass peak in early May, two biomass peaks were documented in Beaver Lake 2, a primary maximum in mid-December and a secondary peak in early April (Figure 13). Both Beaver Lake 2 peaks exceeded the sole Beaver Lake 1 peak. Similarly, a single spring biomass peak was observed in Beaver Lake 1 zooplankton community in 1997, although the magnitude of the peak (142,000 ug/m3) was nearly double that of 2000 (72,000 ug/m3). During the 1997 water year, the zooplankton assemblage in Beaver Lake 2 demonstrated a single maximum in June of 107,000 ug/m3 as opposed to the two peaks in the 2000 water year, occurring in December (101,667 ug/m3) and in April (79,380 ug/m3).

Zooplankton biomass patterns did not generally follow density patterns over the same time span in either Beaver Lake basin during the 2000 water year (Appendix C). In fact, major contributions to community biomass by the crustacean and dipteran groups was in stark contrast to overwhelming density dominance by the Rotifera in both Beaver 1 and Beaver 2 during this time period. Even when organism densities were high, the small-bodied rotifers composed only a small portion of zooplankton biomass on each sample date, a disparity that was especially evident when other groups with larger organisms were represented in the sample community.

Figure 13. Zooplankton Dry Weight Biomass for the 2000 Water Year





Community Patterns

In Table 12, average zooplankton density and biomass values are shown for Beaver Lake 1 and Beaver Lake 2. For all three water years, the zooplankton community in Beaver Lake 2 exhibited higher yearly average densities than did the Beaver Lake 1 community. For 2000, average organism densities within both basins were less than comparative measures in 1997, but substantially more than in the 1992 water year.

Table 12: Comparison of Zooplankton Mean Density and Biomass for Three Water Years

Lake/Measure	1992	1997	2000
Beaver Lake 1			
• Mean Density (organisms/L)	10.9	49.2	40.0
• Biomass (μg/L, dry weight)	*	39.0	35.0
Beaver Lake 2			
• Mean Density (organisms/L)	13.2	57.8	40.3
• Biomass (μg/L, dry weight)	*	44.0	38.5

* Zooplankton biomass estimates were not conducted in 1991-1992.

During both 1997 and 2000 water years, mean annual biomass measures computed for Beaver Lake 2 were somewhat higher than comparative values for Beaver Lake 1. Furthermore, average dry weight biomass levels within both basins in 2000 were somewhat less than comparative measures in 1997. Within a lake system, annual variations in zooplankton community measures are to be expected as resident groups and individual species respond to constantly changing factors affecting nutrition, reproduction, competition, and predation.

While between-basin and between-year differences in mean annual biomass of the Beaver Lake zooplankton assemblages appear to be similar to those just described for average annual densities, these two quantitative plankton parameters were controlled by completely different zooplankton groups in the Beaver Lake basins. Whereas the small-bodied rotifers dominated zooplankton densities during the three years, zooplankton biomass measures in both basins were largely driven by presence of large-bodied crustacean groups and predaceous dipteran larvae. In Table 13, relative contributions of the major zooplankton are listed which illustrates this biomass relationship.

On an annual basis, the filter-feeding crustacean and predaceous dipteran groups composed the largest percentages of total dry weight biomass estimates in the two Beaver Lake basins during 1997 and 2000 water years (Table 13). Relative group contributions to total yearly biomass measures differed between the two basins for both years. Also, dipteran larvae and calanoid copepods composed larger percentages of yearly dry weight totals in Beaver Lake 1 relative to those computed in Beaver Lake 2. In contrast, the cladocerans made more substantial contributions to annual biomass totals in

Beaver Lake 2 than in Beaver Lake 1 during both years. Cyclopoid copepod and rotifer groups contributed little to annual zooplankton biomass totals in either basin during the two studies.

Table 13: Percentage of Total Annual Biomass by Major Zooplankton Group for Two Water Years

Basin/Zooplankton Group	1997*	2000*
Beaver Lake 1		
• Cladocerans	31	23
• Calanoid Copepods	23	36
• Cyclopoid Copepods	<1	1
• Copepode Nauplii	2	2
• Rotifers	5	8
• Dipteran Larve	38	30
Beaver Lake 2		
• Cladocerans	43	53
• Calanoid Copepods	26	22
• Cyclopoid Copepods	3	2
• Copepode Nauplii	5	2
• Rotifers	6	4
• Dipteran Larve	17	17

* Biomass data was not collected in 1991-1992.

Compared to other small, productive, western lowland lakes (e.g., Phantom Lake), average zooplankton density and biomass levels in Beaver Lake appear to be on the low to moderate side. This consequence reflects smaller numbers of larger-bodied crustacean zooplankton (daphnids, calanoid copepods) and higher relative densities of small plankters (rotifers, and to a lesser extent, copepod immatures and small non-daphnid cladocerans) in the Beaver Lake zooplankton community (Table 14).

Smaller zooplankters often prevail under environmental conditions that may be less than optimal for survival of larger crustaceans, such as, low dissolved oxygen, high temperatures, low pH, cyano-bacteria dominance of phytoplankton, and increased presence of potential predators (e.g., dipteran larvae). In fact, summer depression in daphnid populations during conditions of reduced water quality and increased potential predation (spring time trout introduction and increasing invertebrate populations) has been regularly documented in both Beaver Lake basins in all three water years. These factors, as well as presence of additional minute food sources, including bacteria, organic and detrital matter associated with cyanophyte blooms and/or with wetland and surface drainage, may be giving the competitive advantage to the opportunistic rotifer group for much of the year in the Beaver Lake system.

Table 14: Major Recurring Zooplankton Patterns Over Three Water Years

Patterns	1992	1997	2000
Both Basins			
• Rotifer group density domination throughout year	X	X	X
• Crustacean and dipteran groups dominate annual biomass		X	X
• Summer decline in *Daphnia* spp. populations	X	X	X
• Biomass patterns do not correspond to density patterns		X	X
• Presence of eutrophic indicator organisms (*Trichocerca cylindrica*, *T. pusilla*, and *Pompholyx sulcata*)	X	X	X
Beaver Lake 1			
• Dipterans more significant contributor to annual biomass		X	X
Beaver Lake 2			
• Higher annual average densities and biomass	X	X	X
• Cladocerans more significant contributor to annual biomass		X	X

Indicator Species

In 1997 and 2000 water years, several rotifer species occurred in the Beaver Lake zooplankton community that are indicative of more productive lake conditions. *Pompholyx sulcata*, *Trichocerca cylindrica* and *T. pusilla* are indicators of or associated with eutrophic waters (Stemberger, 1979). *Pompholyx sulcata* often appears in eutrophic embayments and is regarded as a useful indicator of eutrophy in the Great Lakes; this species grazes minute detrital and bacterial particles. Additional discussion of the occurrence of these species can be found in Appendix C. Interestingly, indicator species of both genera, *Pompholyx* and *Trichocerca*, were represented in Beaver Lake samples during the 1997 water year, which coincided with some of the highest yearly TSI values recorded over the past 10-15 years in Beaver Lake. Future plankton work could focus on potential relationships between occurrence of indicator organisms like these and elevated TSI values.

Volunteer Lake Monitoring Program

The Level II monitoring data is used to characterize a lake's trophic status. Trophic state is calculated using Robert Carlson's (1977) numerical trophic state index (TSI). The index is based on the summer mean of three commonly measured lake parameters: Secchi depth, total phosphorus, and chlorophyll *a*.

Using the TSI, lake data can be transformed to a common scale and comparisons in quality made over time. Index values between 40 and 50 indicated mesotrophic or good water quality conditions while values greater than 50 indicated eutrophic or fair water quality conditions. For Beaver Lake 1 and Beaver Lake 2, trends for TSI are discussed in this section.

Beaver Lake 1

Beaver Lake 1 has limited TSI data because it was not included in the original 1985 small lakes volunteer monitoring program (METRO, 1986). In Table 15, average TSI values for 1997 through 2000 are compared with past data collected for the 1993 *Beaver Lake Management Plan* (1992 water year). The 2000 TSI value remains similar to the 1998 and 1999 levels. Lower summer chlorophyll *a* values for the past three years relative to the 1992 and 1997 measured chlorophyll *a* values continue to contribute to a lower TSI average for the most recent time periods (Table 15).

Beaver Lake 2

For Beaver Lake 2, a 16-year TSI record from 1985 through 2000 is available (Table 15). Between 1985 and 1989, the TSI ratings for Beaver Lake 2 ranged from 41 to 43 and averaged 42. Between 1991 and 1995, the trophic status value ranged from 44 to 47 and averaged 46. Similarly, between 1996 and 2000, the trophic status value ranged from 43 to 49 and averaged 46.

As noted in previous reports (King County, 1998a; King County, 1999a; King County, 2000a; and King County, 2000c), Beaver Lake 2 has shifted from the lower end of the mesotrophic range to the middle of the range during the past decade. Most of the upward shift in TSI during the 1990s can be attributed to a decrease in water clarity as measured by Secchi depth (Table 15). During 1997 and 1998, chlorophyll *a* concentrations were much higher in September and October, increasing summer average values and further elevating the TSI values for Beaver Lake 2 (Table 15).

In 1999, chlorophyll *a* and total phosphorus concentrations were markedly lower resulting in a several point drop in TSI value from the previous highs of 1997 and 1998. In 2000, water clarity improve 0.3 meters on average and total phosphorus levels reached a new minimum of 10 μg/L for the May through October sampling period (Table 15).

Table 15: Beaver Lake 1 and 2 Summer (May-October) Trophic State Index (TSI) Summary

Lake/ Year	Depth	No. of Samples	Secchi (meter)	Chl *a** (µg/l)	TP* (µg/L)		TSI Secchi	TSI Chl *a**	TSI TP*	TSI Avg.
Beaver 1										
1992	0.5**	9	1.0	17.0	23		60	58	49	56
1997	1	12	1.4	16.0	32		56	58	54	56
1998	1	13	1.4	5.9	27		55	48	52	52
1999	1	13	1.4	7.9	20		55	51	48	51
2000	1	13	1.3	6.8	24		57	49	50	52
Beaver 2										
1985	1	12	3.7	4.1	14		41	44	42	42
1986	1	12	3.9	3.3	13		41	42	41	41
1987	1	12	3.8	3.4	16		41	43	44	43
1988	1	10	3.1	2.5	15		43	39	43	42
1989	1	10	2.9	2.1	16		45	38	45	42
1990	No data									
1991	1	12	2.2	2.4	15		49	39	44	44
1992	0.5**	9	2.4	6.6	13		47	49	42	46
1993	1	10	2.3	3.6	23		48	43	49	47
1994	CS***	6	2.8	3.5	23		45	43	49	46
1995	CS***	11	2.9	4.9	18		44	46	46	46
1996	1	9	2.6	4.3	21		46	45	48	46
1997	1	12	2.5	10.1	20		47	53	47	49
1998	1	13	2.3	11.5	14		48	55	43	48
1999	1	13	2.4	6.1	13		47	48	41	45
2000	1	13	2.8	4.6	10		45	46	37	43
min		6	2.2	2.1	10		41	38	37	41
max		13	3.9	11.5	23		49	55	49	49
mean		10.9	2.9	4.9	16		45	45	44	45

* Chl *a*-chlorophyll *a* and TP-total phosphorus

** Data from 1991-92 management plan.

*** Samples were composited from 1 meter and at the Secchi depth.

Stream Water Quality

Both baseflow and stormflow was characterized for the two tributaries that drain to Beaver Lake. Baseflow is the relatively constant flow found in the stream during the wet season and is due to the draining of water from soil storage. Stormflow is the streamflow that occurs due to storm water runoff into the stream system over and above the base flow volume.

In this section, flow, baseflow quality, and stormwater quality monitoring results are summarized for the two main tributaries to Beaver Lake. Annual precipitation and phosphorus loading totals are also summarized here.

Annual Discharge

Beaver Lake has two main inflows (BLTRI1 and BLTRI2) and a single outlet (BLOUT). Generally, the direct surface flow (BLTRI1) entering Beaver Lake 1 is about half of the flow (BLTRI2) that enters the larger Beaver Lake 2 (Table 16). During this four-year monitoring period, outflow from the lake ranged from 30 to 90 percent higher than the combined inflows to the lake reflecting relative differences in annual precipitation and other onflow and outflow components to and from the lake.

Table 16: Mean Annual Daily Discharge for Lake Inflows and Outlet in Cubic Feet per Second (cfs)

Water Year	BLTRI1 cfs	BLTRI2 cfs	BLOUT cfs
1997	0.63	1.11	3.3
1998	0.38	0.64	1.3
1999	0.52	1.14	2.5
2000	0.48	1.0	1.9

Baseflow

For baseflow samples, average total phosphorus, total suspended solids, and turbidity values are provided in Table 17 for the 1992, 1997, 1998, 1999, and 2000 water years. Overall, values for these three parameters continue to remain low or are similar (or lower) to values recorded in 1992.

Table 17: Baseflow Stream Water Quality Comparison

Parameter	BLTRI1			BLTRI2		
	Total Samples	**Average Conc.**	**Trend**	**Total Samples**	**Average Conc.**	**Trend**
Total Phosphorus (µg/L)						
1992	11	43		12	40	
1997	8	39	⇔	8	37	⇔
1998	6	35	⇔	7	22	⇓
1999	14	20	⇓	14	16	⇓
2000	18	37	⇑	18	22	⇔
Total Suspended Solids (mg/L)						
1992						
1997	8	1.6	⇔	8	1.6	⇔
1998	6	1.4	⇔	7	1.6	⇔
1999	14	1.8	⇔	14	1.1	⇔
2000	18	2.1	⇔	18	2.2	⇔
Turbidity (NTU)						
1992	11	1.7		12	1.8	
1997	8	2.9	⇔	8	1.4	⇔
1998	6	3.1	⇔	7	1.5	⇔
1999	14	2.4	⇔	14	1.7	⇔
2000	18	2.5	⇔	18	2.3	⇔

* Trend is a qualitative comparison of 1992 vs. 1997, 1998, 1999, and 2000 water year data with ⇔ indicating no change, ⇑ indicating an increase in value and ⇓ indicating a decrease in value.

Stormwater

For stormwater samples, average values for total phosphorus, total suspended solids, and turbidity are provided in Table 18. Although the sample sizes are small, the samples appear fairly representative of high flow events for Beaver Lake (Figure 18 and 19). During the past two years, stormwater phosphorus concentrations appear to be lower. Overall, stormwater quality has varied only slightly from baseflow conditions, suggesting that the quality of stormwater entering Beaver Lake is generally good.

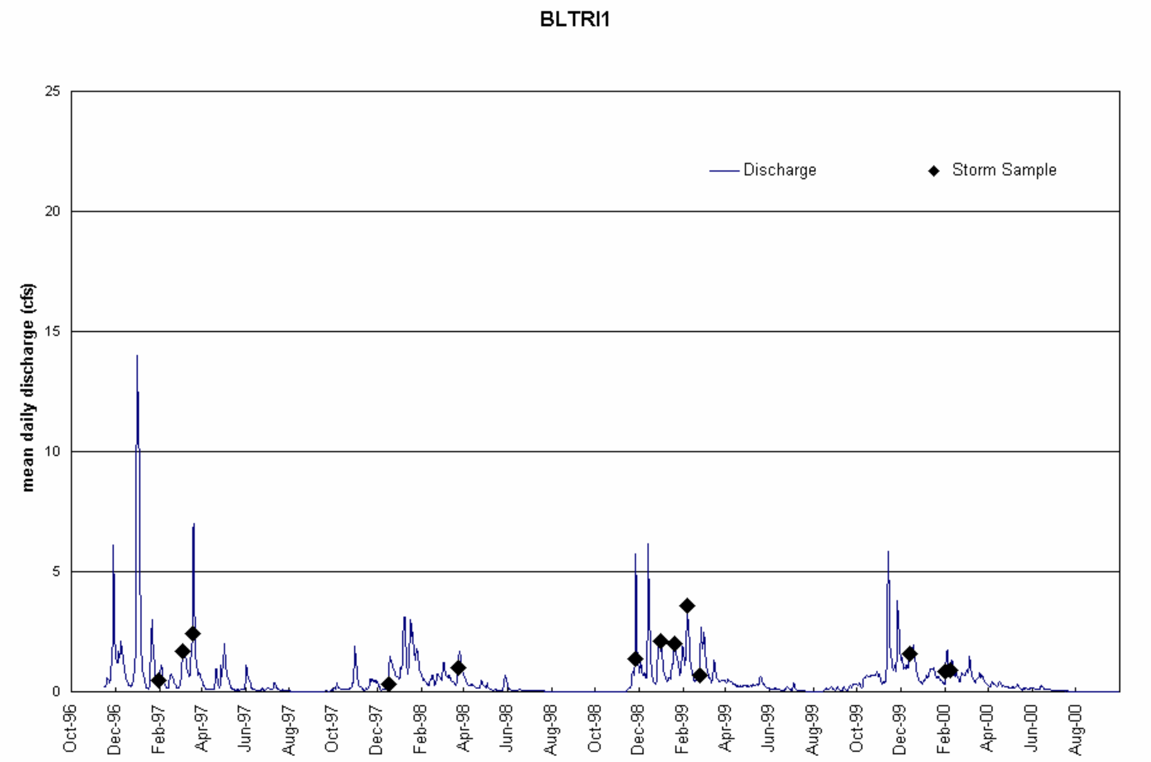
Table 18: Stormwater Stream Water Quality Comparison

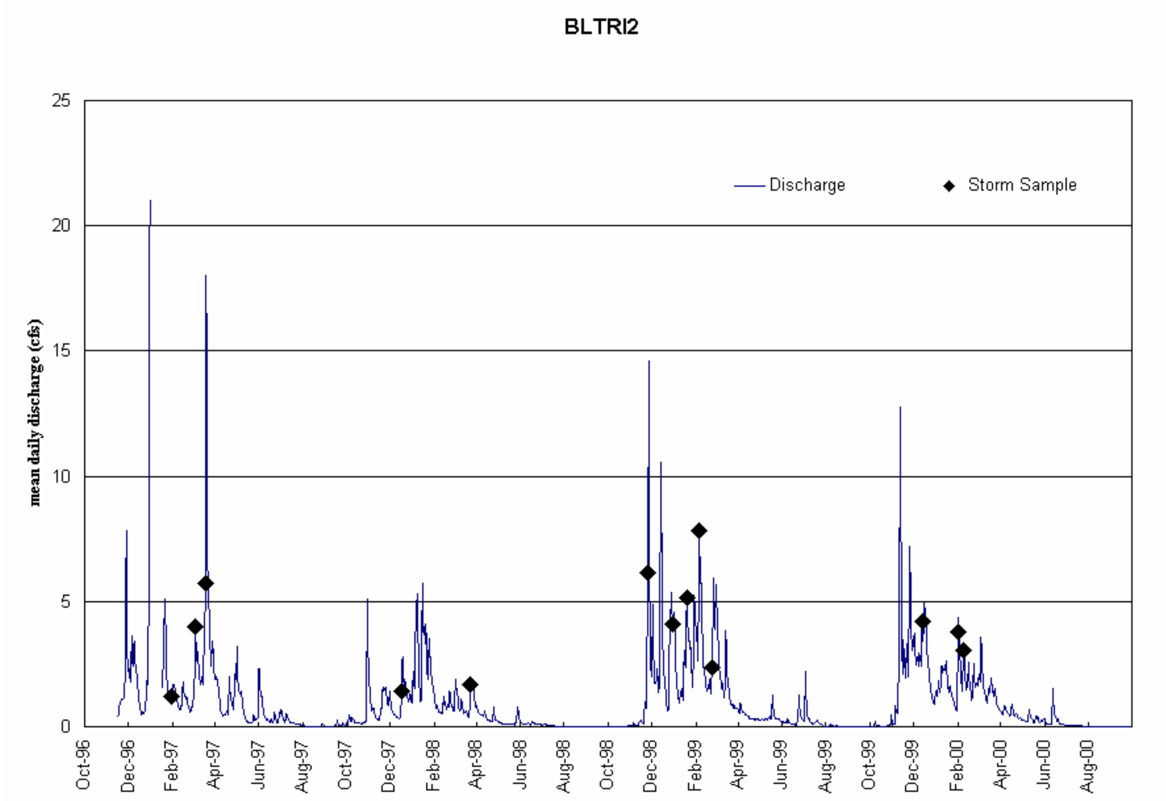
Parameter	BLTRI 1			BLTRI 2		
	Total Samples	**Average Conc.**	**Trend**	**Total Samples**	**Average Conc.**	**Trend**
Total Phosphorus (μg/L)						
1992	3	52		3	57	
1997	3	21	⇓	3	41	⇓
1998	2	41	⇓	2	43	⇓
1999	5	23	⇓	5	21	⇓
2000	3	23	⇔	3	28	⇔
Total Suspended Solids (mg/L)						
1992	3	0.9		3	7.8	
1997	3	0.6	⇔	3	1.7	⇓
1998	2	1.4	⇔	2	9.7	⇑
1999	5	0.3	⇔	5	2.3	⇓
2000	3	0.9	⇔	3	9.2	⇑
Turbidity (NTU)						
1992	3	2.7		3	7.4	
1997	3	1.1	⇔	3	1.4	⇓
1998	2	3.5	⇔	2	3.3	⇓
1999	5	1.6	⇔	5	2.0	⇓
2000	3	2.2	⇔	3	4.9	⇔

* Trend is a qualitative comparison of 1992 vs. 1997, 1998, 1999, and 2000 water year data with ⇔ indicating no change, ⇑ indicating an increase in value and ⇓ indicating a decrease in value.

Figure 14 illustrates mean annual discharge and storm sample dates. Samples from stormflow (highflow) events were fairly well characterized over the four-year water years between 1996 and 2000. Again, discharge for BLTRI1 is about half of that contributed by BLTRI2.

Figure 14. Stream Flow Record Versus Storm Samples





Precipitation and Loading

Annual precipitation totals have varied significantly for the four water years where stream data was collected (Table 19). During the 1992 and 1998 water years, 45 inches and 42 inches of rainfall were recorded, respectively, while in the 1997 water year, 70 inches of rainfall was recorded at the Black Nugget gauge site (46U). In 1999, data from this gauge site was no longer available. Subsequently, rainfall data from a nearby site (Mystic Lake, MLU) was used as well as data from the Level I lake volunteer monitor.

Although the precipitation totals are different between the three gauges (Table 19), the general pattern between water years can be determined. The 1999 water year was somewhat wetter than 1998. However, loading from the two tributaries to Beaver Lake remained relatively the same (Table 19).

For 1992, 1998, and 1999 water years, phosphorus loading remained fairly similar each year despite some variation in rainfall totals (Table 19). With the near record rainfall totals observed in 1997, phosphorus loading levels were dramatically higher to the lake. In 2000, loading from BLTRI1 was somewhat higher than previous years with similar precipitation levels.

Table 19: Inflow Phosphorus Loading Summary

Water Year	Annual Rainfall @46U* (inches)	Annual Rainfall @MLU* (inches)	Annual Rainfall @Level I (inches)	Stream BLTRI1 (Kg TP/year)	Stream BLTRI2 (Kg TP/year)
1992	45	na**	na**	8.2	13.0
1997	70	63	55	18.2	34.8
1998	42	33	37	8.5	11.4
1999	na**	55	51	6.8	15.1
2000	na**	40	46	10.6	15.9

* The precipitation record for the Beaver Lake area was taken from site 46U (Black Nugget gauge) until midway through the 1999 water year when property access changed. Therefore, the precipitation record from MLU (Mystic Lake gauge) and the Beaver Lake2-Level I gage sites are also shown to allow comparison of annual rainfall levels with surface total phosphorus levels.

** na-not available

Chapter 5: Data Analysis

This chapter briefly describes the methods used to analyze land use, develop the water and nutrient budgets, and complete water quality modeling. Subsequent results for land use, water budget, nutrient budget, and water quality modeling analyses are also described here.

Information contained in this chapter was developed from separate reports on hydrology (land use and water budget), nutrient budgets, and lake modeling. These reports can be found in Appendices D, E, and F.

Land Use

A Geographic Information System (GIS) database of current land use (as of February 2000) was determined using King County Assessor's data and interpretation of 1998 air-orthophotos (Colleen Rasmussen, personal communication, May, 2000). Residential uses were classified by dwelling units per acre into four classes which were reflected in the hydrologic model by varying the percentages of "effective" impervious area (Table 20).

Table 20: Cover Assumptions for Residential Classes in the Beaver Lake Watershed

Residential Classes	Percent Effective Impervious	Percent Grass
Rural Residential, 1 du/2.5-10 acres	4	96
Urban Residential, 1-3 du/2.5 acres	7	93
Urban Residential, 1-3 du/acre	10	90
Urban Residential, 4-12 du/acre	25	75

The land use information was combined with a surficial geology map to create a land cover/geology map layer of the basin. Then, the impervious area assumptions listed in Table 20 were used to determine hydrologic response unit (HRU) acreages for the basin (Table 21).

Table 21: Comparison of 1993 and Updated Soil-Cover Complex Acreages

Hydrologic Response Unit (HRU)	1993 Model (acres)	2000 Update (acres)	Difference (acres)
Forest, Till	356	219	-137
Grass, Till	101	235	134
Forest, Outwash	365	236	-129
Grass, Outwash	120	254	134
Wetland	42	92	50
Effective Impervious	24	81	57
Open Water	76	67	-9
Total	1084	1184	100

Since 1993 *Beaver Lake Management Plan*, development has reduced forest acerage while increasing grass and impervious acerage within the watershed. An apparent increase in wetland and a loss of open water appears to have occurred between the 1993 and 2000 land use analyses. These discrepancies are anomalies caused by differences in methods of land cover analysis rather than actual changes in basin land cover. The more recent GIS analysis indicates that watershed area is 100 acres more than was assumed in the 1993 plan.

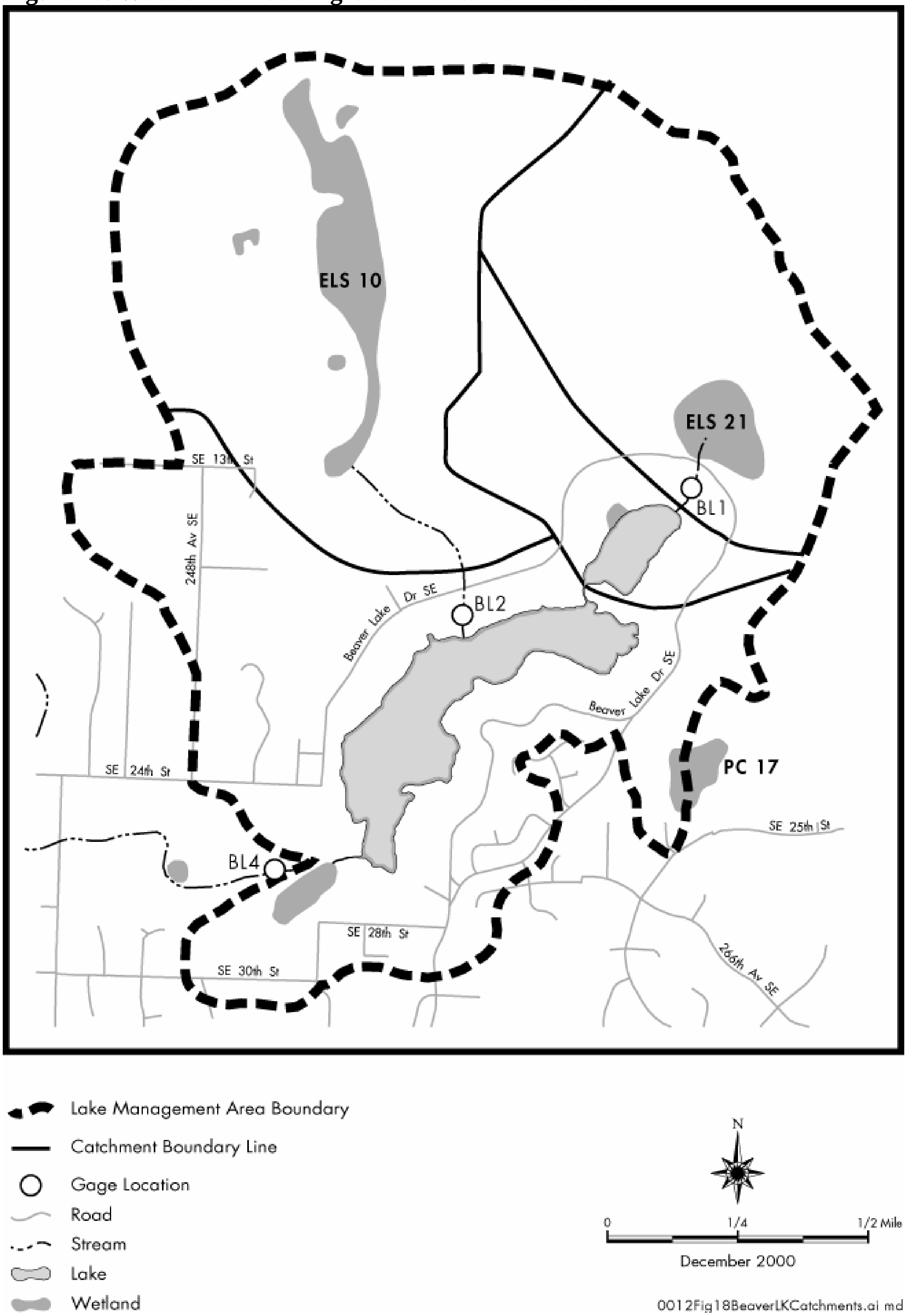
Water Budget

Gaging, lake level, and current land use data were used to update the Beaver Lake watershed Hydrologic Simulation Program-Fortran (HSPF) model. This model was originally developed as part of the East Lake Sammamish basin analysis (King County, 1990b) and was used in developing the 1992 lake water budget for the *Beaver Lake Management Plan* (King County, 1993a).

For the 1992 HSPF model, the lake was modeled as a single basin. In developing the water budgets for 1997 and 2000 water years, the HSPF model was modified and the "lake" modeled as two separate lake basins (Beaver Lake 1 and Beaver Lake 2). To complete this modification, the watershed (and associated land use) was divided into separate catchments draining to the two lake basins (Figure 15).

In creating the 1997 and 2000 water budgets for Beaver Lake, several steps were taken. These steps included evaluating and updating of the 1992 model, recalibration of the updated model, and verification of lake level simulations by the model.

Figure 15. Watershed Modeling Catchments Delineations



1992 Model Evaluation and Update

The HRU (land use/cover) changes from Table 21 were incorporated into the Beaver Lake 1992 HSPF model. For this initial evaluation, no changes were made to the hydrologic and hydraulic parameters or routing assumptions for the 1992 water budget model. To test the 1992 calibration and assumptions, the updated model was operated using precipitation data from the King County precipitation gage at nearby Mystic Lake.

Simulated flows at gages BL1, BL2, and BL4 (Figure 15) were compared to gage records of mean daily flows for the period of October 1, 1998 through April 25, 2000. As shown, BL1 is on the stream that connects drainage from Wetland ELS 21 to the upper-most cell of Beaver Lake, BL2 is on the stream that connects Hazel Wolf Wetland Preserve (Wetland ELS 10) to the middle and largest cell of the lake, and BL4 gages the outlet of the lake.

The results of this initial simulation are summarized using total volume error and mean daily error (Table 22). The results of this simulation show that the updated 1992 HSPF model consistently underestimated (negative values) total volumes at all three gage sites.

Table 22: Check of 1993 Calibration with Updated Land Use/Cover

Catchment	Total Volume Error*	Mean Daily Error**
BL1	-31 percent	84 percent
BL2	-42 percent	82 percent
BL4	-19 percent	51 percent

* Total volume error represents the difference between the total volume of flow simulated and the total volume gaged over the entire period from 10/97-4/00.

** Mean daily error represents the root mean square error of daily mean values as a percentage of the gaged root mean square flow.

Mean daily error is an aggregate measure of how well the model matches gaged flows on a daily basis. A value of zero percent represents a perfect match of simulated flows to gaged flows. A value of 100 percent means errors are approximately as large as the flows themselves, suggesting a poor match. Combined, the two error statistics indicate that the updated 1992 HSPF model is significantly biased toward underestimating discharge and with generally large errors on a daily basis.

Re-calibration of Updated Model

Because of these errors, recalibration of the 1992 HSPF model was performed and the 2000 HSPF model was developed. The assumptions and adjustments to flow routing in the recalibrated model can be found in Appendix D.

After recalibating the 2000 HSPF model, both the total volume error and the mean daily error were reduced from those calculated for the updated 1992 HSPF model. Re-calibration nearly eliminated the total volume error at all three gages and reduced the average error in daily mean flows compared to the 1992 HSPF model with updated land use (Table 23).

Table 23: Re-Calibrated 2000 HSPF Model Error Improvement

Catchment	Total Volume Error*	Mean Daily Error**
BL1	1 percent	74 percent
BL2	-7 percent	69 percent
BL4	1 percent	36 percent

* Total volume error represents the difference between the total volume of flow simulated and the total volume gaged over the entire period from 10/97-4/00.

** Mean daily error represents the root mean square error of daily mean values as a percentage of the gaged root mean square flow.

Lake Level Simulation

The Level I volunteer lake monitor has measured daily water levels at the lake since October 1993 (Figure 16). Using this water level data, the 2000 HSPF model's performance was evaluated for its ability to simulate fluctuations in lake level.

For water years 1998, 1999, and 2000, comparisons of simulated lake stages using the updated 1992 model and the re-calibrated 2000 model were made (Figure 17). As shown in Figure 17, both the updated 1992 (thin line) and the re-calibrated 2000 model (thick line) do a fairly good job of tracking the observed seasonal variations in lake stages (line with plus signs) of Beaver Lake.

Overall, the re-calibration of the Beaver Lake basin model can only be judged fair in its ability to match measured daily mean discharges and Beaver Lake levels. In spite of the mediocre performance of the calibrated model, the 2000 HSPF model represents an improvement over the updated 1992 HSPF model because of greatly improved matching of lake inflow and outflow volumes.

Figure 16. Lake Level Record for Beaver Lake 2

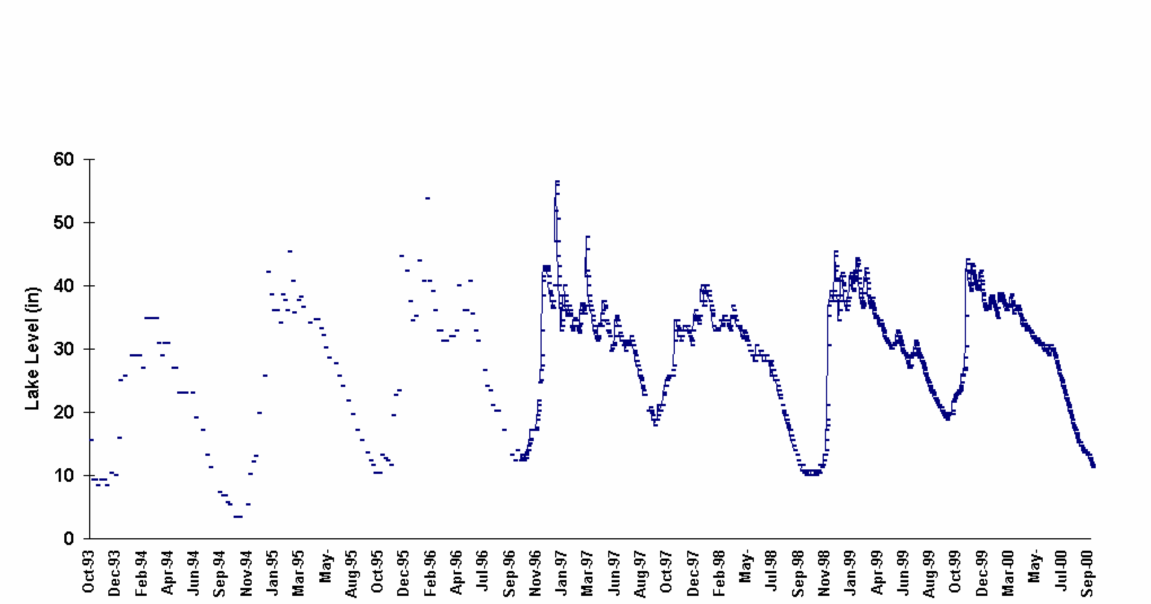
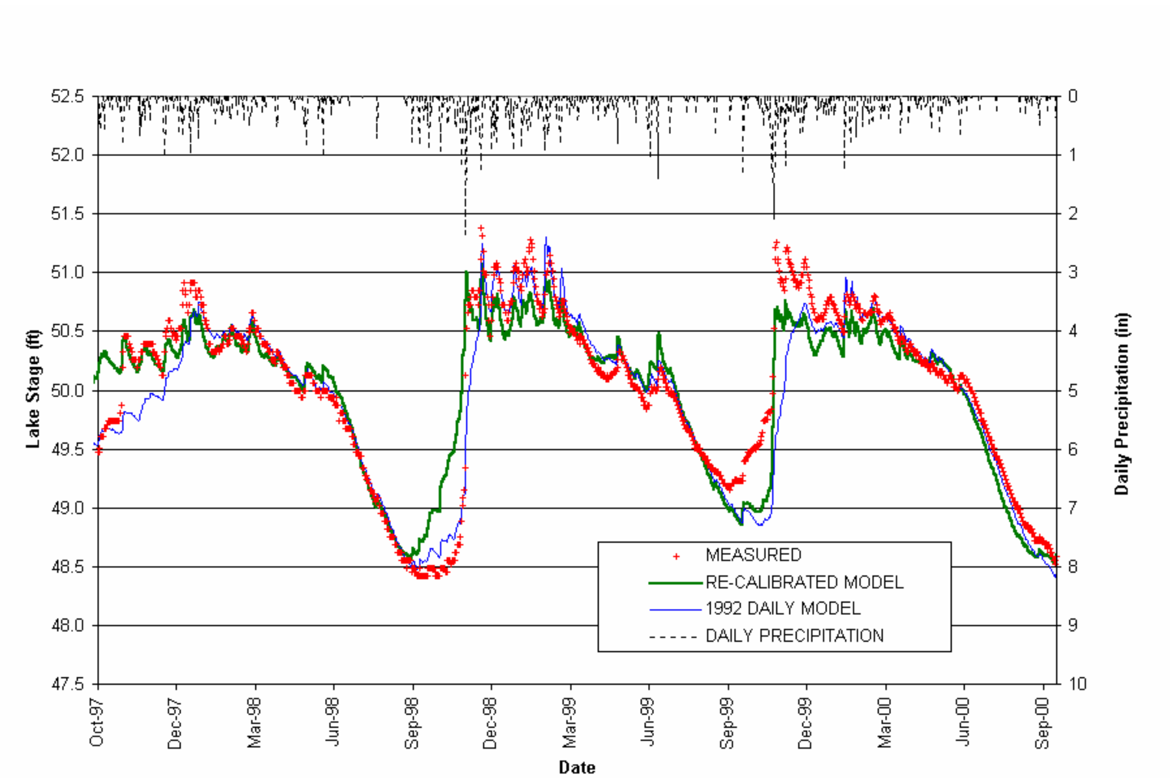


Figure 17. Gaged Lake Levels versus Model Lake Levels



Results

In this section, water budgets for both Beaver Lake 1 and Beaver Lake 2 are presented for the 1997 and 2000 water years. Water budgets were also developed for current (2000) land use and build-out (future) land use scenarios. Water budget information for these scenarios are also presented here. All water budget information was developed from the actual flow and lake level data and the subsequent hydrologic simulation discussed in the previous section.

1997 and 2000 Water Years

For both 1997 and 2000, annual inflows and outflows estimates are summarized in Table 25. These estimates were derived from actual gage data and HSPF modeling of 1997 and 2000 watershed conditions.

In 1997, precipitation levels were substantially higher than in 2000 resulting in larger observed inflow and outflow total volumes. These larger volumes are also reflected in the volume difference between inflows and outflows. For Beaver Lake 1, this difference was 7.61 acre-feet in 1997 and –4.17 acre-feet in 2000. For Beaver Lake 2, this difference was 37.26 acre-feet in 1997 and –41.27 acre-feet in 2000 (Table 25).

During 1997, this positive difference is reflected in slightly higher lake levels over the course of the year relative to the lake level at the beginning of the water year while a negative difference reflects slightly lower lake levels over the course of the year relative to the lake level at the beginning of the water year. This difference in relative lake level is illustrated in Figure 17.

Table 25: Modeled 1997 and 2000 Annual Water Budget by Inflows and Outflows for Beaver Lake 1 and Beaver Lake 2

	Beaver Lake 1		**Beaver Lake 2**	
	1997 (acre-feet)	**2000 (acre-feet)**	**1997 (acre-feet)**	**2000 (acre-feet)**
Inflows				
Rainfall	64.46	42.46	304.94	204.46
Tributary Inflow	448.40	429.52	1036.29	786.63
Lake Inflow			670.71	507.79
Surface Runoff	30.07	15.36	258.84	146.66
Interflow	17.20	11.01	151.18	104.27
Groundwater	205.92	134.18	622.71	638.78
Total	**766.06**	**632.53**	**3044.66**	**2388.6**
Outflows				
Outflow	670.71	507.79	2066.74	1583.67
Evaporation	25.50	24.5	120.65	126.54
Percolation	62.24	104.41	820.02	719.65
Total	**758.45**	**636.7**	**3007.40**	**2429.87**
Difference	**7.61**	**-4.17**	**37.26**	**-41.27**

Current and Build-out Conditions

In preparation for water quality modeling analysis, water budgets were also developed for both current and build-out land uses for a typical water year (Appendix D). For both current and build-out land use scenarios, annual inflows and outflows estimates are summarized in Table 26.

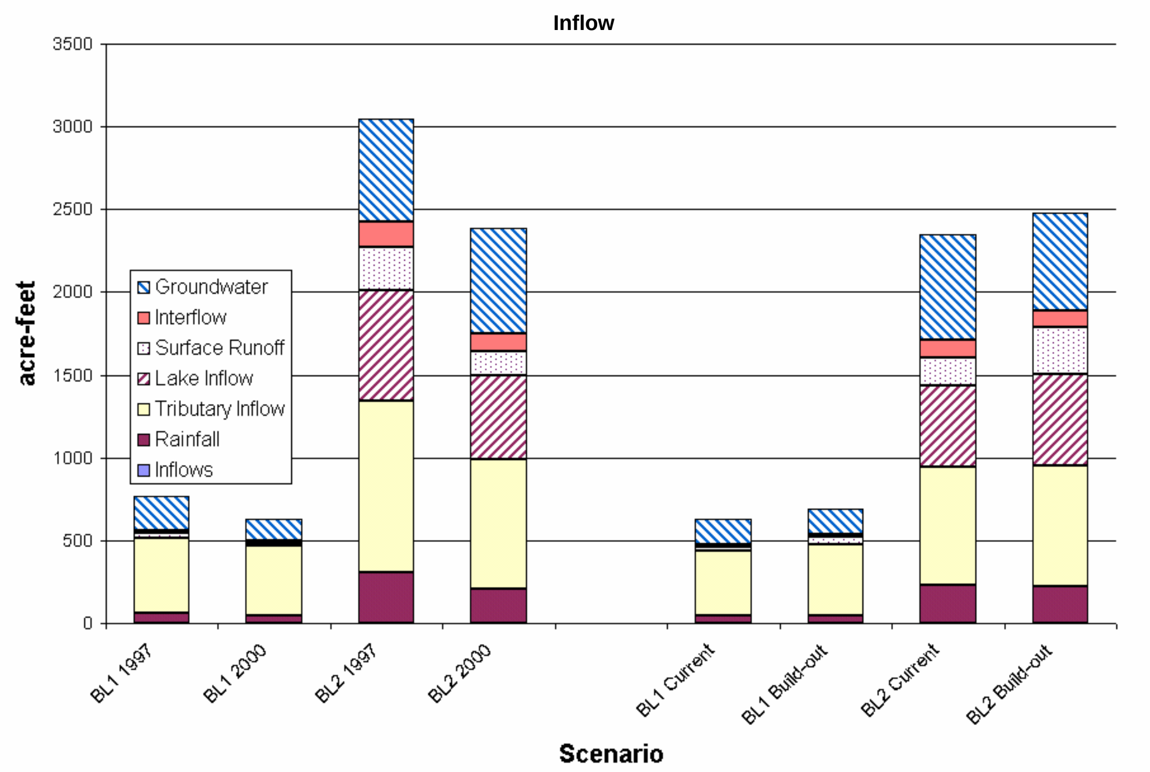
For both scenarios, precipitation levels are constant. Thus, the increase in flow volumes in the build-out scenario reflects the change in land use from forested to residential uses. For Beaver Lake 1, inflow volume increases from 628.15 acre-feet to 687.51 acre-feet, a nine percent volume increase spread over the water year. For Beaver Lake 2, inflow volume increases from 2345.19 acre-feet to 2482.68 acre-feet, a six percent volume increase spread over the water year.

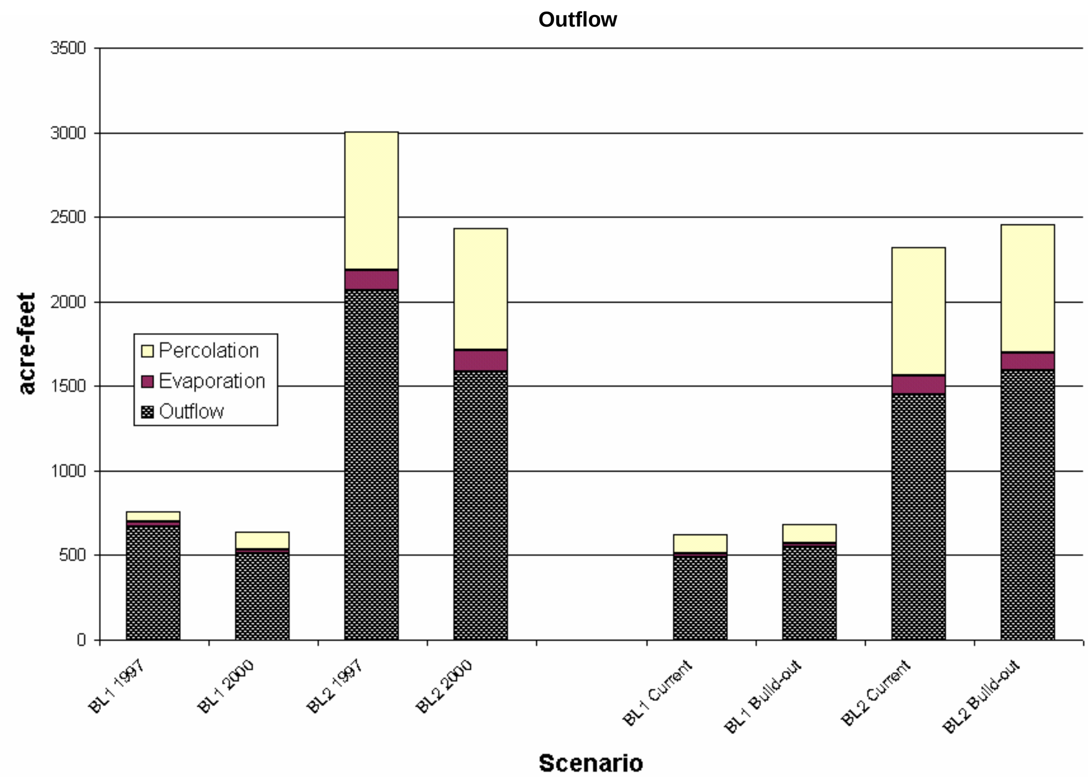
The current and build-out estimates for the typical precipitation year are also compared with 1997 and 2000 inflow and outflow components in Figure 18. The modeled budget for the typical year with current land use has similar volumes to the estimated historical volumes in water year 2000 but much lower ones than the 1997 historical volumes. This results from the fact that total measured precipitation in water year 2000 was very close to long term average or typical precipitation levels while in 1997 precipitation levels were much higher than average.

Table 26: Modeled Current and Build-out Annual Water Budget by Inflows and Outflows for Beaver Lake 1 and Beaver Lake 2

	Beaver Lake 1 Current (acre-feet)	Beaver Lake 1 Build-out (acre-feet)	Beaver Lake 2 Current (acre-feet)	Beaver Lake 2 Build-out (acre-feet)
Inflows				
Rainfall	48.65	47.9	227.55	223.48
Tributary Inflow	392.05	426.6	715.41	731.13
Lake Inflow			490.52	551.26
Surface Runoff	19.89	49.38	171.38	285.29
Interflow	12.23	13.36	106.62	96.07
Groundwater	155.33	150.27	633.71	595.46
Total	**628.15**	**687.51**	**2345.19**	**2482.68**
Outflows				
Outflow	490.52	551.26	1450.41	1589.98
Evaporation	23.14	22.61	109.21	106.53
Percolation	109.47	108.93	760.86	763.09
Total	**623.12**	**682.80**	**2320.47**	**2459.60**
Difference	**5.02**	**4.71**	**24.72**	**23.08**

Figure 18. Modeled Inflow (a) and Outflow (b) Water Budgets for 1997, 2000, Current, and Build-out Scenarios for Beaver Lake 1 (BL1) and Beaver Lake 2 (BL2)





Nutrient Budget

Prior to developing a nutrient budget for any lake, the limiting nutrient must be determined. For freshwater, phosphorus is generally the nutrient of interest because it is more limited relative to nitrogen and other elements needed for algal growth. Previously, phosphorus has been determined as the limiting nutrient for algal growth in Beaver Lake (King County, 1993a) and was again confirmed to be the limiting nutrient based on data for the 1997 and 2000 water years. Thus, in this section, the nutrient budget analysis is limited to the discussion of phosphorus.

For the 1993 *Beaver Lake Management Plan*, the nutrient budget was developed for a "single lake basin" and represented the combination of nutrient sources to both Beaver Lake 1 and Beaver Lake 2. For this management plan update, Beaver Lake's nutrient budget is separated for the two lake basins. This separation allows for better definition of the chemical differences between the two basins and analysis of potential trophic response to changes in nutrient loading.

This section briefly describes the methods and assumptions used to develop the phosphorus (total phosphorus) nutrient budget for Beaver Lake 1 and Beaver Lake 2. A complete account of the methods and assumptions can be found in Appendix E.

Volumetric Weighted Averages

Volumetric phosphorus averages were determined for both stratified and unstratifed time periods. The stratified period extended from March through November in both lakes for both the 1997 and 2000 water years. During the stratified period, volumetric averages were calculated for both the epilimnion (upper water layer) and hypolimnion (lower water layer). The depth of the epilimnion was calculated to the depth of the thermocline, which is defined as the largest change in temperature throughout the water column.

December through February was considered the unstratified period, during which the lake basins were considered to mix from the surface to the bottom of the lakes. Only whole-lake volumetric phosphorus averages were calculated during this period.

Phosphorus Inputs

Eight inputs were included in the phosphorus budget based on the hydrologic budget: (1) tributary baseflow; (2) tributary runoff; (3) interflow; (4)-onsite treatment or septic sources; (5) atmospheric deposition (precipitation/air); (6) groundwater; (7) overland runoff; and (8) internal recycling. Inputs from waterfowl and decomposition of macrophytes were not included because there was limited data available and neither factor is likely to be a major contributor to the phosphorus budget for this lake system.

Net internal loading from bottom sediment was calculated as residual (R) remaining in the model when inputs (I) were balanced against outputs (O) with positive values representing net internal loading and negative values representing net sedimentation and ΔTP is the change in phosphorus in the lake:

$$-I + O + \Delta TP = -R$$

Waterfowl and Macrophytes

Although phosphorus input from waterfowl was estimated to be 16 percent of the annual load to the lake in the 1993 study (King County, 1993a), this source was not included directly in the current nutrient budget. While the resident waterfowl population was probably similar in 1993, 1997 and 2000 for each lake, data were not available regarding usage.

Moreover, waterfowl fecal matter contains only a small soluble fraction of phosphorus rendering it largely unavailable for algal growth in the lake. By ignoring the waterfowl component, the net effect of waterfowl in the phosphorus budget was to include it as a part of internal loading. Given the absence of waterfowl data, less error is assumed in the phosphorus budget since the waterfowl contribution is treated as part of internal loading rather than listed as a distinct component.

Similarly, the addition of phosphorus from aquatic plants in the fall is partly offset by the limited availability of this phosphorus at the time of plant die back and its uptake by attached algae and fungi growing on the plants. In lakes with substantial littoral area volume relative to open water volume, the positive effect of aquatic plants on the nutrient budget can be pronounced. This positive effect was observed in shallow Lake Wingra in Wisconsin (Smith and Adams, 1986). However, for Beaver Lake, the littoral area volume represents a small fraction of the total lake volume resulting in negligible phosphorus from aquatic plant decay.

Even in shallow lakes, macrophytes may represent more of a net sink than source such that phosphorus concentrations in dense weed beds are less than in open water (Welch et al., 1994). In addition, at the time of phosphorus release by the plants (mid to late summer and early fall), a measurable increase in phosphorus concentration and chlorophyll *a* should occur in the lake, if indeed the phosphorus release amounted to as much as 11 percent as estimated in the 1993 *Beaver Lake Management Plan*. Such increases in epilimnetic phosphorus were not observed in 1997 or 2000 which supports the current assumptions use to develop the 1997 and 2000 nutrient budgets.

Tributary Sources

Phosphorus loading from tributary sources was determined by splitting tributary phosphorus concentrations into baseflow and stormflow. The baseflow was estimated at 5 cfs for Beaver Lake Tributary 1 (BLTRI1), and 10 cfs for Beaver Lake Tributary 2 (BLTRI2). Baseflow phosphorus concentrations were approximated using the standard monthly data, and storm event concentrations were used for the stormflow period.

Interflow

Interflow phosphorus loading was determined by multiplying the interflow volume by the tributary ortho-phosphate concentrations from monthly stream data.

Septic Systems

Estimations of phosphorus loading from on-site septic systems (tanks and drain fields) was based on a similar approach used in the 1993 study. Nine out of 215 drain fields in the Beaver Lake watershed were considered to be failing in 1992. This same number of failing systems was used in this analysis and assumed to represent all the phosphorus from this source. The remaining 206 were assumed to be operating efficiently with no loss of phosphorus to the lake. The daily phosphorus loading of 0.01 kg/day per system was used and is based on assuming 2.5 persons/household and 4 g TP/day-person (USEPA, 1980).

Leaching from the estimated failing drain fields to the lake was assumed to occur during November through May, the wet period for soils, and entered the lake in proportion to interflow volume. Therefore, the total mass entering the lake during that seven-month period was 18.9 kg. Assuming 25 percent retention in the settling tank, the total lost was 14.2 kg. Divided between the two basins based on number of residences observed in the 1990s, resulted in 2.8 and 11.4 kg for Beaver Lake 1 and Beaver Lake 2, respectively. The loading was distributed volumetrically as a function of tributary interflow from BLTR1 and BLTR2.

Atmospheric

Atmospheric deposition from both dryfall and precipitation adds phosphorus to the surface of the lake. For precipitation, concentration of 27 μg TP/L was assumed for the lake and was distributed according to each lake basin's surface area.

Groundwater

Phosphorus loading from the groundwater was estimated by using the monthly ortho-phosphate concentrations measured in the BLTR1 and BLTR2 tributaries multiplied by the monthly groundwater flow into the each lake basin.

Overland Runoff

Phosphorus loading from overland flow was determined by multiplying tributary phosphorus concentrations during stormflow events by overland runoff volumes determined by hydrologic model.

Internal Recycling

Internal loading of phosphorus in each lake basin was assigned to the positive residual in the phosphorus mass balance. That quantity was therefore equated to the net gain (load) of phosphorus from the sediments to the overlying water.

Phosphorus outputs

Phosphorus losses from the lake included: (1) surface outflow, (2)-groundwater discharge, and (3) sedimentation. The phosphorus loss from Beaver Lake 1 through its outlet to Beaver Lake 2 was the same as the phosphorus loading from Beaver Lake 1 to Beaver Lake 2. Phosphorus leaving Beaver Lake 1 and entering Beaver Lake 2 was determined by multiplying the phosphorus concentrations from the surface of the epilimnion in Beaver Lake 1 by the estimated flow through the channel that connects Beaver Lake 1 to Beaver Lake 2.

Groundwater percolation losses of phosphorus used the hypolimnetic ortho-phosphate concentrations during the stratified period and volume weighted average ortho-phosphate during the unstratified period, multiplied by the volume of groundwater lost from the lake.

Sedimentation loss of phosphorus in each lake basin was assigned to the negative residual in the phosphorus mass balance. That quantity was therefore equated to the net loss (settling) of phosphorus to the sediments.

Results

This section presents nutrient budgets for both Beaver Lake 1 and Beaver Lake 2 for the 1997 and 2000 water years. Phosphorus budget information is represented by major loading sources and losses. A comprehensive discussion of the phosphorus budgets is found in Appendix E.

Beaver Lake 1

For 1997 and 2000, the annual phosphorus budgets are summarized in Table 24. In the 1997 water year, the phosphorus loading to Beaver Lake 1 was 49.7 kg and the total outflow and sedimentation loss was 47.4 kg. External loading was 36.4 kg and net internal loading was 13.3 kg.

In the 2000 water year, the phosphorus loading to Beaver Lake 1 was 29.3 kg and the total outflow and sedimentation loss was 29.5 kg. External loading was 24.1 kg and internal loading was 5.2 kg in 2000.

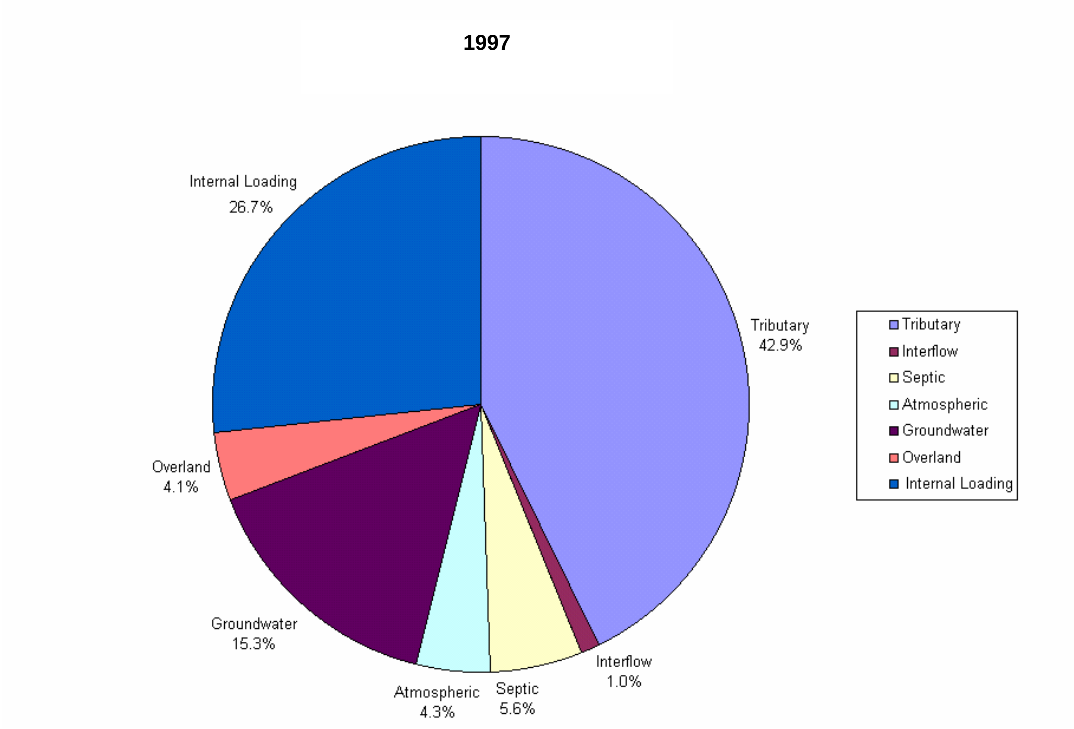
The significant difference in the phosphorus budgets from the two years was the loading increase due to greater precipitation in 1997 versus 2000. Loading from the inlet, groundwater, and overland runoff, as well as atmospheric loading were the direct result of increased precipitation. As will be shown in the modeling section, the higher internal loading observed in 1997 over 2000 was due to much higher sediment release rates in 1997.

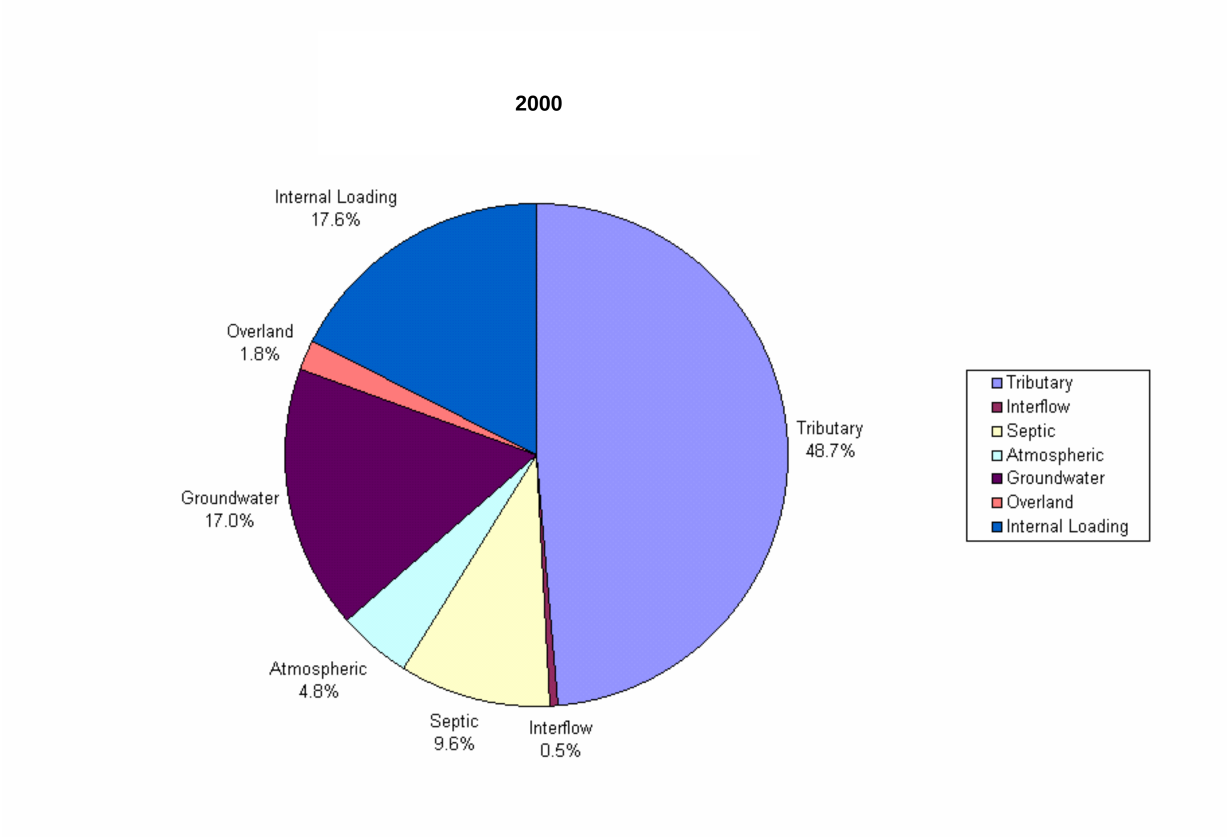
Table 24: Beaver Lake 1 Phosphorus Nutrient Budget For Water Years 1997 and 2000

	1997 Mass (kilogram)	2000 Mass (kilogram)
Loading Parameter		
Tributary 1 Baseflow	10.7	7.8
Tributary Runoff	10.6	6.5
Interflow	0.5	0.1
Septic Interflow	2.8	2.8
Atmospheric	2.1	1.4
Groundwater	7.6	5.0
Overland Runoff	2.0	0.5
Internal Loading	13.3	5.2
Total Loading	**49.7**	**29.3**
Loss Parameter		
Surface Outflow	30.3	17.0
Groundwater Discharge	1.2	2.0
Sedimentation	16.0	10.5
Total Losses	**47.4**	**29.5**
Increase or decrease in storage	2.3	-0.2

The tributary input (from both baseflow and runoff) was clearly the most significant source of phosphorus to Beaver Lake 1 in both years. For the 1997 and 2000 water years, the percent contribution to the total load for each source to Beaver Lake 1 is illustrated in Figure 19, respectively.

Figure 19. Beaver Lake 1 Annual Total Phosphorus Inputs by Category for 1997 and 2000 Water Years





Beaver Lake 2

For 1997 and 2000, the annual phosphorus budgets are summarized in Table 25. In the 1997 water year, the phosphorus loading to Beaver Lake 2 was 216.4 kg and total outflow and sedimentation loss was 220.5 kg. For 1997, the total external loading was 140.1 kg and internal loading was 76.3 kg.

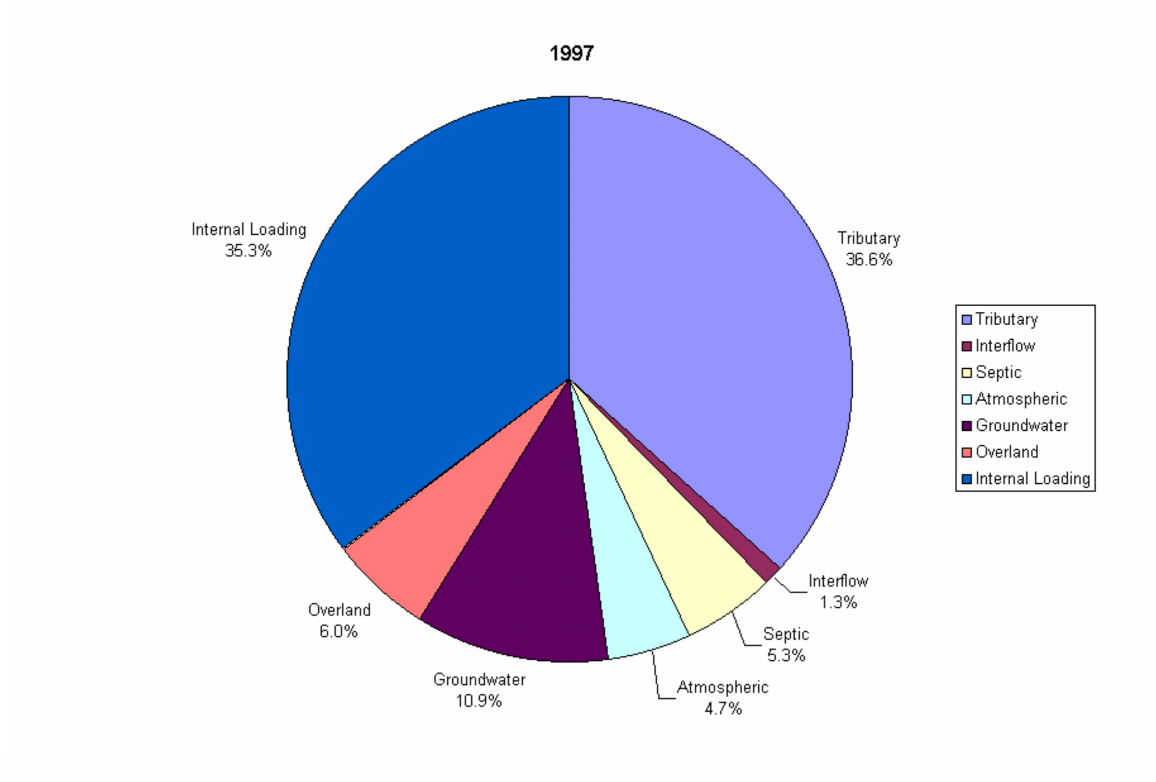
In the 2000 water year, phosphorus loading to Beaver Lake 2 was 101.7 kg and total outflow and sedimentation was 89.3 kg. External loading was 84.9 kg and internal loading was 16.8 kg in 2000. As with Beaver Lake 1, external loading to Beaver Lake 2 was related to the amount of precipitation and flow.

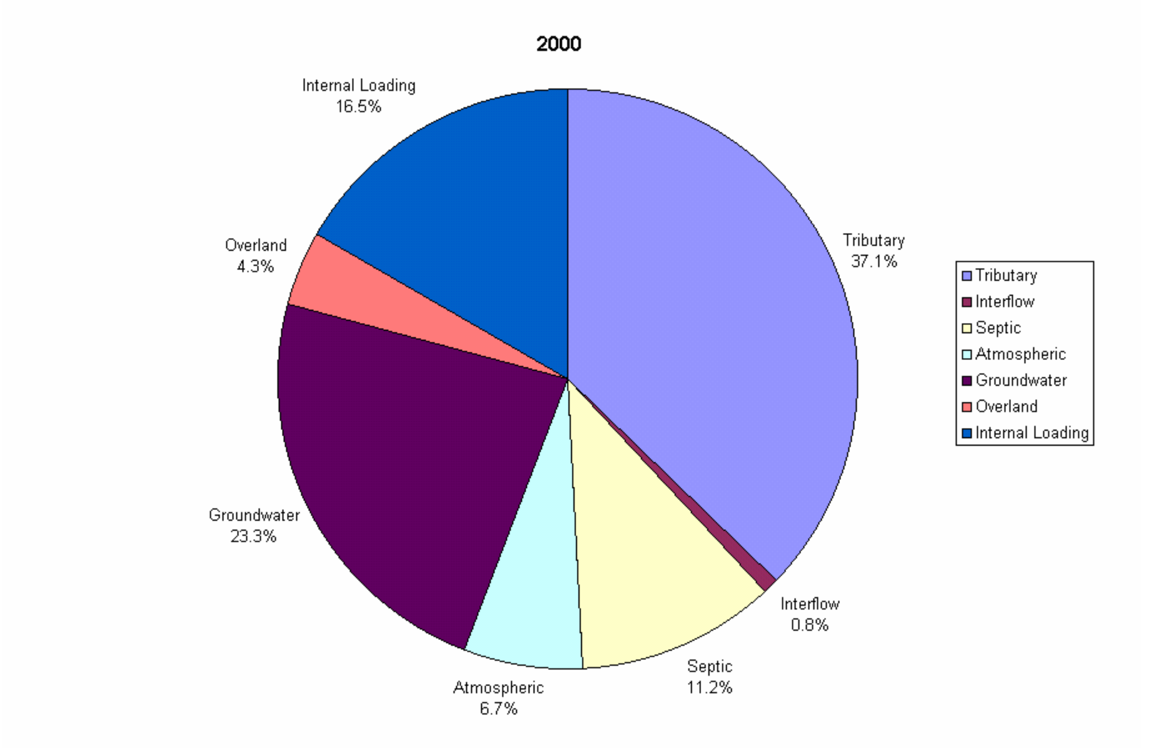
Table 25: Beaver Lake 2 Phosphorus Nutrient Budget for Water Years 1997 and 2000

	1997 Mass (kilogram)	**2000 Mass (kilogram)**
Loading Parameter		
Beaver Lake 1 Outflow	30.3	17.0
Tributary 2 Baseflow	14.7	7.4
Tributary 2 Runoff	34.3	13.4
Interflow from Beaver Lake 1	0.4	0.2
Interflow	2.3	0.7
Septic Interflow	11.4	11.4
Atmospheric	10.2	6.8
Groundwater	23.6	23.6
Overland Runoff	12.9	4.4
Internal Loading	76.3	16.8
Total Loading	**216.4**	**101.7**
Loss Parameter		
Surface Outflow	75.7	35.0
Groundwater Discharge	26.4	2.9
Sedimentation	118.4	51.4
Total Losses	**220.5**	**89.3**
Increase or decrease in storage)	-4.1	12.3

The tributary input (from both baseflow and runoff) and outflow from Beaver Lake 1 were clearly the most significant sources of phosphorus to Beaver Lake 2 in both years. For the 1997 and 2000 water years, the percent of the total input load for each source to Beaver Lake 2 is illustrated in Figure 20, respectively.

Figure 20. Beaver Lake 2 Annual Total Phosphorus Inputs by Category for 1997 and 2000 Water Years





Water Quality Modeling

This section briefly describes the methods and assumptions used to develop the water quality model for Beaver Lake 1 and Beaver Lake 2. A complete account of the methods and assumptions can be found in Appendix F.

Methods

Phosphorus was simulated in Beaver lakes 1 and 2 using a non-steady state model with one layer during the non-stratified period and two layers during the stratified period. The non-stratified period was defined as December through February while the stratified period was defined as March through November with the epilimnion (upper layer) and hypolimnion (lower layer) modeled separately. This approach allows prediction of the effects of changes in external phosphorus loading due to watershed changes as well as changes in internal loading (release of phosphorus from bottom sediments) during the summer, which is generally the period of greatest water quality interest.

Changes in external loading were estimated by using land use, phosphorus yield coefficients (runoff coefficients). Land use coefficients developed for the Lake Sammamish watershed were used as a guide for Beaver Lake values but individual coefficients were developed for the separate watersheds (of Beaver Lake 1 and Beaver Lake 2) due to differences in phosphorus transport behavior in the two basins. Appropriate coefficients were developed by calibration against the measured loading to Beaver Lake 1 and Beaver Lake 2. Appendix F includes a discussion of the land use coefficients used for Beaver Lake 1 and Beaver Lake 2 and how they were developed.

The model was calibrated against measured phosphorus concentrations in each lake for both years. Results for the 2000 water year with relatively normal precipitation are shown along with those for the 1997 high-precipitation year in Appendix F.

Results

The build-out land use scenario that was modeled will apparently have a larger effect in Beaver Lake 1 than in Beaver Lake 2 (Figure 21). Summer total phosphorus increase is predicted to be almost two fold greater in Beaver Lake 1 than Beaver Lake 2. Beaver Lake 1 has a phosphorus concentration currently ranging from 18 to 32 μg/L which would be expected to increase to about 28 to 37 μg/L or about 32 percent under build-out conditions. Because Beaver Lake 2 has lower total phosphorus levels to begin with, total phosphorus levels would be expected to increase between 2 to 3 μg/L to about 16 to 17 μg/L, an increase of 18 percent. Based on these modeling results, Beaver Lake 1 can be considered more sensitive to increasing activity in the watershed in spite of higher land-use phosphorus yield coefficients determined for Beaver Lake 2.

The range in Algal biomass, as chlorophyll *a*, was predicted to also increase about two fold more in Beaver Lake 1 than Beaver Lake 2 (Figure 22). That is consistent with predicted phosphorus changes because the predictive relationship between chlorophyll *a* and phosphorus includes data from both lakes. The expected decrease in transparency, although more in Beaver Lake 1 than Beaver Lake 2, was less than the change in chlorophyll *a* because color in the lakes masks the effect of algal biomass on water clarity.

In addition, algae produce more chlorophyll per unit phosphorus in colored lakes than in clear lakes which results in higher concentrations of chlorophyll in colored systems like Beaver Lake. The effect that chlorophyll concentrations has on water transparency is less in Beaver Lake than in clear water lakes due to the higher cellular chlorophyll concentration loading to high chlorophyll concentrations but not directly proportional to increase in turbidity.

Figure 21. Summer Mean Phosphorus Concentration Range Predicted in Beaver Lakes 1 & Beaver Lake 2 for Current and Build-Out Land Use Levels Based on Models Calibrated for 1997 and 2000 Water Years

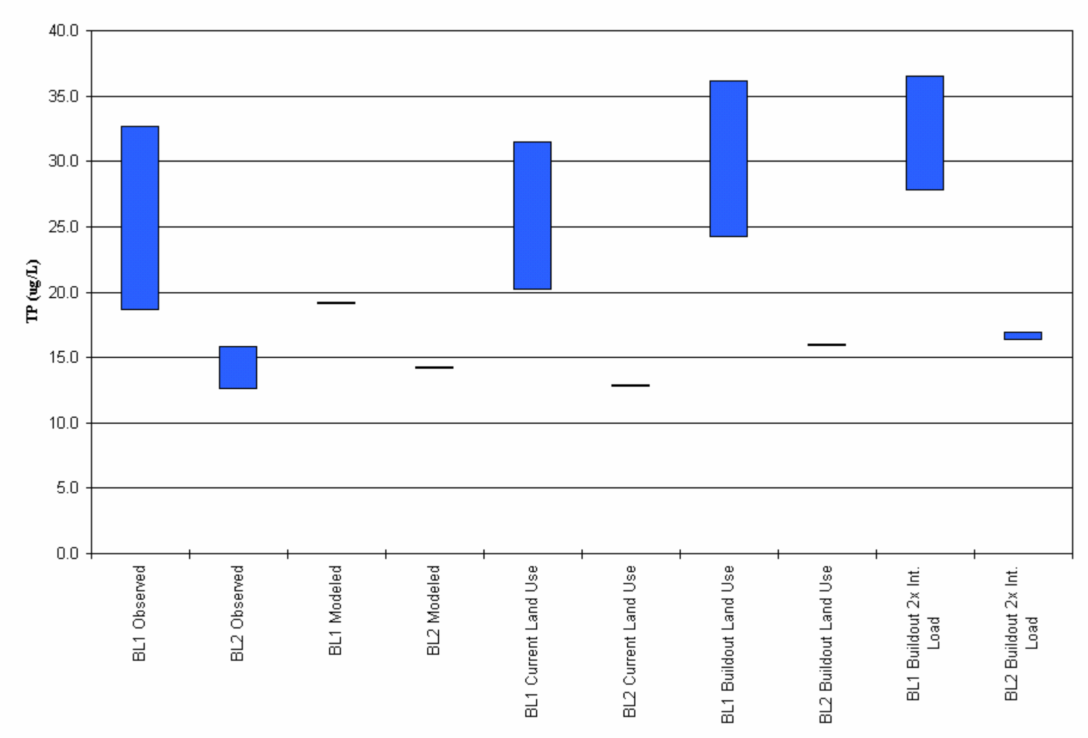
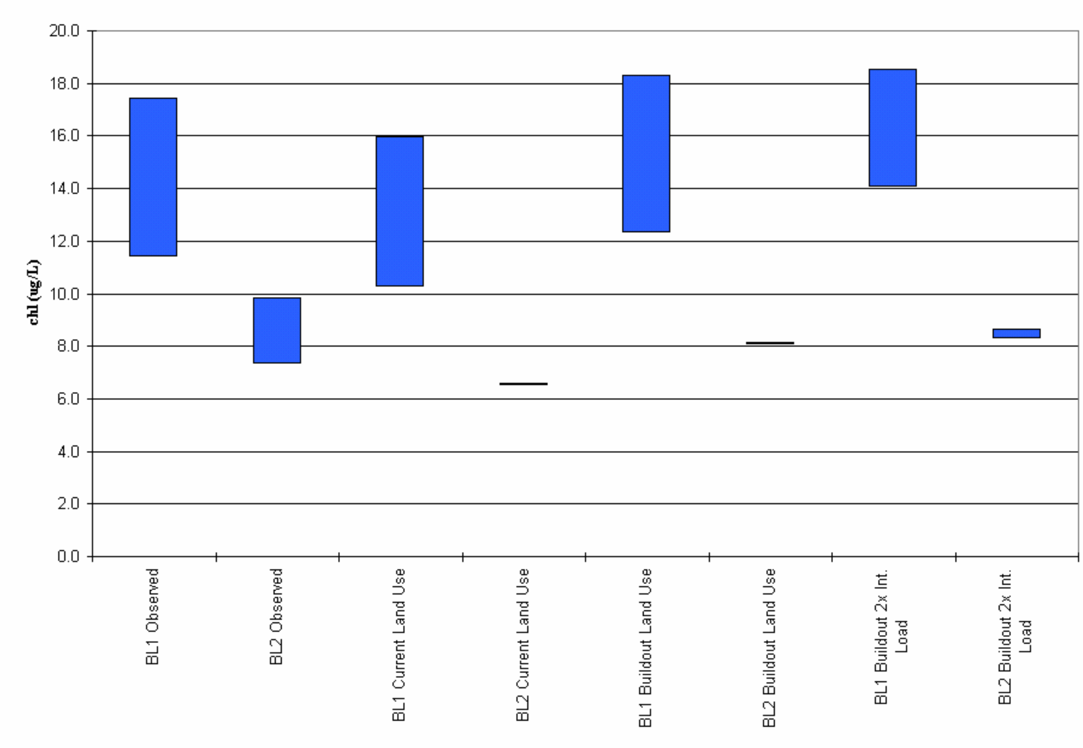


Figure 22. Predicted Chlorophyll Concentration Range for Beaver Lakes 1 & Beaver Lake 2 for Current and Future Land Use Based on Phosphorus Models Calibrated for 1997 and 2000 Water Years



Internal Loading Impacts

Summer phosphorus levels are predicted to increase by about 4 μg/L with additional watershed development. This increase would be slightly greater if internal loading also increased. An increase in internal loading is possible because increased phosphorus loading would tend to increase sediment phosphorus concentrations and greater algal biomass to compose in bottom water could ultimately result in more area of the hypolimnetic bottom being overlain with anoxic (no oxygen) water. That condition would produce more internal loading even if the phosphorus release rate from sediment did not increase. At this time, there are no documented cases where increased external phosphorus loading due to runoff from urban development directly lead to increased sediment phosphorus content. Nevertheless, the possibility exists, as illustrated in other lakes following increases in external loading. Increased internal loading and its long-term persistence has been a common occurrence in lakes receiving increased loading from sewage effluent.

The predictions for the two water years in each lake may represent a range of possible responses based on a high and medium precipitation years. The high precipitation year (1997) produced higher loading with a slightly higher (~3 μg/L) lake concentration in Beaver Lake 2 and much higher concentrations in Beaver Lake 1 (14μg/L, see Figure 21). The much higher concentration in Beaver Lake 1 in 1997 was probably due to a much higher internal loading during the summer of 1997 than in 2000. Hypolimnetic phosphorus concentrations reached almost 60 μg/L in 1997 while they ranged from only 20 to 30 μg/L in 2000 (see Appendix F). Why internal loading was so different is unclear, but such a difference was real and must be considered in predicting lake response to additional watershed development.

Difference Between Lakes

Even with year to year variation in internal loading, why Beaver Lake 1 has higher phosphorus and algal biomass (chlorophyll *a*) than Beaver Lake 2 normally is not entirely clear. The lakes' depths and other morphometric characteristics, such as the fraction of volume below some depth, are very similar. Therefore, no physical reason readily supports a difference in observed productivity levels.

Usually, measured sediment phosphorus release rate is even greater (about three fold) in Beaver Lake 2 than Beaver Lake 1 (see Appendix F). One difference is that base inflow phosphorus concentrations are greater to Beaver Lake 1 than Beaver Lake 2, in spite of apparent lower phosphorus yields per unit area in Beaver Lake 1's watershed, so there is apparently a difference in how the incoming phosphorus mass is diluted during low flow to Beaver Lake 1.

Also, comparison of measured and predicted phosphorus concentrations in the epilimnia of Beaver Lake 1 and Beaver Lake 2 shows that phosphorus drops more throughout the summer in Beaver Lake 2 than Beaver Lake 1, suggesting that even though sediment phosphorus release rates are usually less in Beaver Lake 1 than Beaver Lake 2, there is more hypolimnetic phosphorus reaching the surface layer. The higher sediment release rate in 1997 was apparently what accounted for keeping epilimnetic phosphorus concentrations higher in late summer 1997. Regardless of why Beaver Lake 1 is more productive and sensitive to changes in the watershed, that fact must be considered in managing the two lakes and their separate watersheds.

Conclusions

Based on observed data and the model predictions, it appears that the water quality in both lakes has not changed greatly from previous conditions. The year-to-year variations in water quality and algal biomass growth are more related to changes in annual precipitation than specific external loading increases. The model reinforces the observation by many that Beaver Lake 1 is more sensitive or less resilient than Beaver Lake 2. That is, relatively high algal biomass (chlorophyll *a*) is likely to occur more often in Beaver Lake 1 than Beaver Lake 2 if added external loading is superimposed on that existing condition. What this means is that the maintenance of buffers around the wetlands and stream corridors is important for the greatest long-term environmental stability of the lake. It also implies that aggressive management and source controls for stormwater are needed as land is converted from forest to urban development.

Chapter 6: Recommendations

Summary

Beaver Lake water quality has benefited from nearly a decade of planning and implementation activities which have focused on the assessment of water quality problems and the preservation of area land and water resources. These past planning efforts include the *Beaver Lake Management Plan* (King County, 1993a), the *East Lake Sammamish Basin and Nonpoint Action Plan* (King County, 1994b) and the *Lake Sammamish Water Quality Management Project* (King County, 1998b).

Through these plans and associated recommendations, Beaver Lake has benefited from more stringent water quality treatment standards for new development (*Beaver Lake Management Plan),* more vigilant temporary erosion and sediment control (*Lake Sammamish Water Quality Management Project*), seasonal clearing and grading restrictions (*East Lake Sammamish Basin and Nonpoint Action Plan,* BW-26*),* and designation of wetland management areas (*East Lake Sammamish Basin and Nonpoint Action Plan,* BW-5 and LJ-3*).* Beaver Lake will continue to benefit from the recommendations provided in this management plan update as well as past planning efforts.

In this chapter, key findings associated with the 1996-2000 Beaver Lake Management District monitoring program are presented. Based on these findings, 12 management actions are recommended. Through implementation of these actions, preservation of Beaver Lake water quality will continue, ensuring future generations the same enjoyment currently experienced by area residents.

Key Findings

Thus far, water quality remains good and relatively unchanged from levels documented with the *Beaver Lake Management Plan* (King County, 1993a). Because of the findings in the original plan, the most stringent stormwater treatment standard in King County was required in the Beaver Lake watershed for new development. This standard, in combination with preservation of wetland function, has been critical to maintaining good water quality in Beaver Lake.

As additional residential development continues, Beaver Lake remains vulnerable to a decline in water quality without ongoing preservation measures. Water quality modeling results for both lake basins show that phosphorus levels will increase in the lake under a build-out land use scenario. This increase in phosphorus is potentially larger and has a greater impact to the water quality of Beaver Lake 1 because of its lower assimilative capacity than the larger Beaver Lake 2.

Under the build-out land use scenario, a two-fold increase in phosphorus levels is predicted for Beaver Lake 1 in comparison to Beaver Lake 2. This predicted phosphorus increase strongly suggests that Beaver Lake 1 will be more vulnerable to added phosphorus than Beaver Lake 2.

Currently, Beaver Lake 1 has an average phosphorus concentration of about 19 μg/L and would be expected to increase to about 25 μg/L or about 32 percent under modeled build-out conditions. In Beaver Lake 2 (which naturally has lower phosphorus levels to begin with) phosphorus levels would be expected to increase only 2 to 3 μg/L to about 16 μg/L, an increase of 14 to 23 percent.

The shift in surface phosphorus concentrations in Beaver Lake 1 from 19 μg/L to 25 μg/L could noticeably alter lake water quality in the upper lake basin by increasing algal bloom frequency and further diminishing water clarity. In Beaver Lake 2, an increase of surface phosphorus concentrations of only 2 to 3 μg/L is within the current natural variation observed in the lake and may not result in a noticeable difference in water quality because of the greater assimilative capacity of the lake basin.

Given the water quality vulnerability of Beaver Lake 1, the preservation of wetland ELS 21 function has been identified as critical to the ongoing preservation of the lake. Protection of this wetland and preservation of existing water quality functions should be given high priority because of the vital role the wetland plays in binding and recycling phosphorus prior to discharging surface flow to the lake.

Wetland ELS 21 currently receives only minor regulatory protection in comparison to wetland ELS 10 which is encompassed by the Hazel Wolf Wetland Preserve (which discharges to Beaver Lake 2). Further, wetland ELS 21 has already been impacted by the Trossachs subdivision where two stormwater quality facilities have been placed along the southeastern and eastern edges of the wetland. To prevent further impacts to wetland ELS 21, efforts should be made to maximize preservation of open space around the wetland to ensure that wetland functions are not further degraded.

Beaver Lake also remains vulnerable to catastrophic events associated with new land development. Efforts should be made to avoid erosion of recently cleared lands and the mass movement of sediment to surrounding wetlands, streams, and ultimately the lake. Additionally, ongoing stormwater management (especially facility maintenance), local shoreline and watershed actions, and ongoing monitoring will remain important in the continued preservation of Beaver Lake water quality.

Management Recommendations

Beaver Lake water quality remains good but additional development of the watershed could cause degradation of water quality. To ensure the ongoing preservation of Beaver Lake, a series of recommendations are made in this section. These recommendations are focused in five key areas: (1) wetland and resource land preservation, (2) future land development guidelines, (3) ongoing stormwater management, (4) local shoreline and watershed actions, and (5) ongoing monitoring. The recommendations associated with these areas are summarized in Table 26.

Table 26: Management Recommendations

No.	Recommended Actions
	Wetland and Resource Land Preservation
R1	• Acquire Additional Open Space
R2	• Increase Wetland and Stream Buffer Size
R3	• Promote Long-term Land Conservation via Incentive Programs
	Future Land Development Guidelines
R4	• Enforce Seasonal Clearing and Grading Requirements
R5	• Enforce Temporary Erosion and Sediment Control Standards
	Ongoing Stormwater Management
R6	• Maintain AKART (all known, available, and reasonable methods of prevention, control, and treatment) Standard for New Development
R7	• Maintain Stormwater Facilities
	Local Shoreline and Watershed Actions
R8	• Restore Shoreline Vegetation
R9	• Reduce Lawn Size and Fertilizer Use
R10	• Maintain On-site Septic Systems
R11	• Reduce Phosphorus from Pet Waste, Car Washing, and Exposed Soil
	Ongoing Monitoring
R12	• Continue Lake and Stream Monitoring

Wetland and Resource Land Preservation

To ensure the protection of Beaver Lake 1 water quality, additional measures should be undertaken to preserve the water quality function associated with wetland ELS 21. The importance of this wetland in Beaver Lake water quality has been previously documented (King County, 1993a) and was discussed at length during plat approval hearings for the Trossachs subdivision. As a condition of development, the Trossachs subdivision was required to amend their sandfilter treatment system with peat to ensure that wetland ELS 21 would not be adversely impacted by stormwater discharges from upland treatment ponds.

Amendments alone, however, are not be enough to ensure the preservation of wetland ELS 21. Specific measures must be undertaken to protect and preserve the water quality functions naturally present with wetland ELS 21. These measures include land acquisition, establishment of larger stream and wetland buffers, and the encouragement of surrounding property owners to consider long-term land conservation.

R1: Acquire Additional Open Space

Open space acquisition should be targeted for the parcels which include or are located immediately adjacent to wetland ELS 21. South of section 36, two 15-acre parcels abut and/or include wetland ELS 21 and should be targeted for acquisition. Smaller parcels to the east and south are also important to acquire or be placed in long-term conservation.

To the south west of wetland 21, efforts are already underway to complete public acquisition of 57 acres located on the northern end of Beaver Lake. Initiated by the community, this acquisition is well underway with the support of the City of Sammamish and an award of a 1.5 million-dollar state grant. The 57-acre area includes 19 acres directly on the lake and an additional 38 acres north of Beaver Lake Drive which abutts the Hazel Wolf Wetland Preserve. If acquisition is successful, the land would remain largely undeveloped and also contribute to the preservation of Beaver Lake.

R2: Increase Wetland and Stream Buffer Size

Buffer requirements for wetlands and streams depend upon how the water feature is classified. For example, Class 1 wetlands require 100-foot buffers while Class 2 and 3 wetlands require 50 and 25-foot buffers, respectively (K.C.C. 21A.24.320, King County, 1993c). Similarly, Class 1 streams and Class 2 streams with salmonids require a 100-foot buffer otherwise Class 2 streams and Class 3 streams require 50-foot and 25-foot buffers, respectively (K.C.C. 21A.24.360, King County, 1993c).

Currently, wetlands ELS 10 (Hazel Wolf Wetland Preserve), ELS 21, and ELS 57 (Beaver Lake 1 and Beaver Lake 2) are Class 1 wetlands while ELS 35 (Beaver Lake 3) is a Class 2 wetland. Existing buffer requirements should be enforced and expansion of buffers requirements considered on a case by case basis. For ELS 21, a specific buffer expansion of 100 percent (an increase from 100 feet to 200 feet) should be consider by the City of Sammamish to preserve the water quality functions associated with the wetland.

Beaver Lake 2 water quality will benefit directly from the preservation of Beaver Lake 1 which provides about 20 percent of the annual inflow to Beaver Lake 2 during a typical year. Moreover, Beaver Lake 2 already benefits from the preservation of wetland ELS 10 through the establishment of the Hazel Wolf Wetland Preserve but could benefit further by increasing the 100-foot buffer requirements to 200-feet for the wetland area outside of the preserve. This larger buffer would protect the southern end of the wetland outside the preserve.

Tributaries 0166 and 0166D are the outlets for wetlands ELS 21 and ELS 10, respectively. Currently, these unclassified streams do not have specific buffer requirements. As a general rule, however, unclassified streams require a 100-foot buffer unless affected property owners have collected additional information regarding fish usage that demonstrates lesser buffer distances are appropriate. In establishing buffers specifically for these two tributaries, the City of Sammamish should consider the importance of maintaining intact streams systems between the adjoining wetlands and Beaver Lake and apply the most protective buffers to the two streams.

R3: Promote Long-term Land Conservation via Incentive Programs

Land conservation can be secured by other means besides outright acquisition. Interested property owners can participate in a variety of resource incentive protection programs. Examples of these programs include the current use and open space taxation programs which are based on property tax reduction in exchange for long-term land conservation.

In the Beaver Lake area, several property owners already participate in these programs, receiving a significant property tax reduction as an incentive to participate. Existing program participants' experience with these programs, along with other information about these programs, should be distributed to watershed property owners.

Future Land Development Guidelines

Beaver Lake remains vulnerable to catastrophic events that can occur during land development. These events are generally related to timing of land clearing and the level of temporary erosion and sediment control (TESC) measures that are in place. To ensure that Beaver Lake water quality is protected, seasonal clearing requirements should be adhered to and all construction sites should be stabilized with appropriate TESC measures by October 1 of each year.

By limiting the clearing of a site to the dry season and ensuring that exposed land is properly mulched and other TESC measures are in place, catastrophic events can more likely be avoided. Preserving the quality of upland wetlands and tributary areas to Beaver Lake remains essential to protecting water quality function. Once sediment has been mobilized from a site, it generally finds a new home in lower lying areas such as a neighboring stream, wetland, or lake shoreline. Preventing this mobilization in the first place can only be done with foresight and planning and requires regular inspection and enforcement of specific development conditions by the City of Sammamish or its current designee.

R4: Enforce Seasonal Clearing and Grading Requirements

The *East Lake Sammamish Basin and Nonpoint Action Plan* (King County, 1994b) recommended seasonal clearing limits as stated in BW-26 Seasonal Clearing and Grading Limts:

During the periods from October 1 to March 31, bare ground associate with clearing, grading, utility installation, building construction, and other development activity should be covered or revegetated in accordance with the King County Surface Water Design Manual. This limitation may be waived outside of the designated Wetland Management Areas and the Pine Lake and Beaver Lake watersheds, however, if the property owner implements erosion control measures that meet the following conditions:

1. No significant runoff leaves the construction site; and
2. The erosion and sediment control measures shown on an approve plan, or alternative best management practices as approved or required by the inspector or the Department of Development and Environmental Services (DDES), are installed and maintained throughout the course of construction.

The enforcement of these seasonal clearing and grading limits are now under the jurisdiction of the City of Sammamish and should be enforced in the Beaver Lake watershed. The city should exercise extreme caution in granting any waiver from these requirements. If a waiver is requested, the city should as a minimum require: (1) performance of a site inspection by a qualified water quality engineer to ensure erosion and sediment control measures have been properly implemented by October 1 of each water year (and that no mass movement of sediment or silt-laden water will occur) and (2) completion of regular temporary erosion and sediment control inspection by a qualified water quality engineer to ensure ongoing site compliance.

R5: Enforce Temporary Erosion and Sediment Control Standards

The temporary erosion and sediment control (TESC) program was originally recommended as part of the *Lake Sammamish Water Quality Management Project* (METRO, 1989) and then implemented by King County in 1995 and 1996 as a pilot project (King County, 1998b) using grant funds. The pilot project consisted of a dedicated full-time TESC inspector for the unincorporated areas of the Lake Sammamish watershed, including Beaver Lake. This inspection program has been carried out in subsequent years through various funding sources.

Beaver Lake has benefited directly from this program as the Plateau County Golf Course, Beaver Lake Estates, and Trossachs subdivisions were developed. As additional watershed development occurs, TESC inspection remains critical to ensuring compliance with erosion and sediment control measures. The City of Sammamish should continue funding of dedicated TESC inspector in the Beaver Lake watershed.

Stormwater Management

Successful stormwater management is essential to the ongoing preservation of Beaver Lake. Thus far, stormwater treatment measures appear to be working and no change in lake water quality has occurred. In order to ensure that good water quality is maintained, the AKART stormwater treatment standard must be applied to new development and regular maintenance of established stormwater facilities must occur.

R6: Maintain AKART Standard for New Development

Beaver Lake has benefited from a more restrictive water quality treatment standard which was adopted in 1995 by King County and was subsequently adopted by the City of Sammamish when the area incorporated in 1999. This treatment standard focuses on the removal of phosphorus, the nutrient most likely to cause degradation of water quality in Beaver Lake. Per Public Rule PUT 8-7 KCC 9.08, section 6.4.1, the standard states:

> The proposed stormwater facilities shall be designed to remove 80 percent of all new total phosphorus loading on an annual basis due to new development (and associated stormwater discharges) in the Beaver Lake Watershed where feasible or utilize AKART if unfeasible.

Per Public Rule PUT 8-7 KCC 9.08, section 5.1, AKART is defined as:

> …all known, available, and reasonable methods of prevention, control, and treatment.

The implementation of this standard has typically consisted of a large wetpond in combination with a large sand filter treatment system per King County Surface Water Design Manual, (King County, 1998c). Other treatment methods can be employed to meet the 80 percent total phosphorus removal goal.

Critical to the ongoing preservation of Beaver Lake water quality is the continued application of this water quality treatment standard to new development. For a build-out land use scenario, modeled water quality results show phosphorus levels will increase. Continued removal of excess phosphorus from new development will help minimize future impacts to Beaver Lake water quality.

R7: Maintain Stormwater Facilities

For the Beaver Lake watershed, regular maintenance of existing stormwater is critical to ensuring maximum phosphorus removal occurs from residential runoff. The City of Sammamish should establish a regular maintenance schedule for all facilities in the watershed. All facilities should be inspected prior to the fall and maintenance needs identified. Sandfilters should receive extra maintenance attention since these systems are new and may be vulnerable to plugging once they come on line.

Additionally, a second facility inspection should occur during the wet season to evaluate the water quantity and quality functioning of the facility. A qualified water quality engineer should complete this second inspection to ensure the facility is meeting the intended water quality and quantity design objectives.

Shoreline and Watershed Actions

Undoubtedly, residents living along the shores of Beaver Lake have the most direct impact on the immediate water quality of the lake depending on how their yards are maintained and the degree of shoreline alteration that has occurred. Additionally, watershed residents also have a fundamental role in preserving Beaver Lake water quality. Below are a series of actions directed at both shoreline and watershed residents that if implemented, can play an important role in the long-term preservation of Beaver Lake water quality.

R8: Restore Shoreline Vegetation

Over time, the Beaver Lake shoreline has been substantially altered and vegetation removed as residents have built docks, imported gravel for beaches, and developed lawns and gardens along the shoreline. Residents can minimize their impact to the lake by restoring the shoreline with native vegetation, reducing lawn sizes, and creating a buffer between their homes and the lake. Landscape designs are available that both preserve views and maintain access to the lake but provide a modest amount of vegetation along the shoreline, ensuring that water quality is enhanced rather than hindered by adjacent property development.

R9: Reduce Fertilizer Use and Lawn Size

Watershed residents have an important role in protecting Beaver Lake water quality by making environmentally sound landscaping choices. During the summer months, Beaver Lake receives no surface flow from the watershed when algae and lake plants are actively growing. Direct runoff from lawn watering, especially along shoreline properties, can reach the lake and be a significant source of nutrients to actively growing aquatic plants. Properly applying, reducing, or eliminating fertilizer use (which stimulates growth of both lake and land plants) can locally decrease water quality impacts.

Overall, lawns traditionally require more maintenance and chemical use. Reducing lawn size and developing drought tolerant and native plants can significantly reduce both maintenance and chemical needs. By making changes in lawn size and incorporating other vegetation choices, the cumulative water quality impacts associated with residential land use can be profoundly reduced.

R10: Maintain On-site Septic Systems

Poorly maintained on-site septic systems can also impact water quality. Residents should know the location of their system and have it regularly inspected, pumping full tanks as needed. Drainfield areas should also be maintained in grass only and compaction of the area avoided.

R11: Reduce Phosphorus from Pet Waste, Car Washing, and Exposed Soil

Pet ownership is quite popular in the Beaver Lake area. Based on a recent survey, approximately 74 percent of households in the area are dog or cat owners (King County, 1998c). Proper disposal of pet waste (as well waste from larger animals like horses) is important in preventing the pollutants (phosphorus, nitrogen, and bacteria) associated with this waste from moving to the lake via surface water runoff. Pet waste should be collected and disposed of as sewage or wrapped securely in a plastic bag prior to throwing it in the garbage.

Equally important is the reduction of phosphorus from car washing activities and erosion of exposed soil in residents' yards. Generally, cars should be washed at car wash facilities instead of in the driveway or street to avoid runoff of soapy water to the lake. If a suitable grassy site is available where no runoff will occur, cars may be safely washed at home. Additionally, exposed soil should be covered with mulch or revegetated to reduce erosion of soil particles to the lake.

Monitoring

Monitoring is a critical tool for detecting water quality problems early-on and addressing problems sooner rather than later. During the past five years, the Beaver Lake community (through the Beaver Lake Management District) has made a significant investment in monitoring the quality of the water entering the lake and the water in the lake itself. This monitoring has been performed to ensure that the stormwater treatment standards established through the *Beaver Lake Management Plan* were adequately protecting Beaver Lake. Thus far, these standards in combination with other phosphorus reduction efforts have resulted stable water quality in Beaver Lake.

As further development of the watershed occurs, monitoring remains important as an early detection tool for identifying upland water quality problems. Monitoring the tributaries that enter Beaver Lake provides pulse points on the quality of upstream wetland. If the function of these wetlands can be preserved, the future water quality of the lake will likely be protected from major degradation. Conversely, if the wetlands become substantially degraded, water quality in Beaver Lake can be expected to decline.

R12: Continue Lake and Stream Monitoring

Beginning in 2001, a five-year lake and stream monitoring program is proposed that will continue the evaluation of the water quality entering Beaver Lake. The proposed monitoring program is similar to the one described in Chapter 3 except whole lake monitoring is proposed to occur only during the 2005 water year. This monitoring program would be funded through a second lake management district, which is currently in the formation stage under the direction of the City of Sammamish.

If additional funding is available, the monitoring program should be expanded to monitor outflows from the Trossachs subdivision which enter wetland ELS 21 and golf course stormwater facilities which enter wetland ELS 19. As a minimum, the condition of these facilities should be qualitatively assessed and regular monitoring of pH, temperature, conductivity, and dissolved oxygen incorporated into the stream monitoring program.

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Appendix A

Lake Data Parameters [1]

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
21-Oct-96																
BLAKE1	0.5	5.90	9.5	25	1.75			23.1	10.9				6.2	0.6 B[4]	90	9
	2	6.00	9.5	25				22.6	9.9							
	4	5.60	8.4	26				28.3	12.7							
	6	5.40	5.1	28				30.8	12.5							
	8	5.40	4.3	27				33.5	20.8							
	10	5.40	4.1	31				56.7	37.9							
	12	5.60	4.1	32				173.0	144.0							
	14	5.70	4.1	34				269.0	230.0							
	comp.[2]					1.9	3.2									
BLAKE2	0.5	6.20	10.6	34	2.25			19.3	5.8				10.0	0.8 B	70	12
	2	6.20	10.6	30				16.7	6.9							
	4	6.20	10.6	34				13.7	6.3							
	6	5.80	9.2	41				29.0	12.9							
	8	5.80	7.1	42				31.5	17.3							
	10	5.90	6.5	44				55.7	32.4							
	12	6.00	6.3	45				76.8	56.0							
	14	6.10	6.2	47				97.1	74.3							
	comp.					4.9	3.9									
BLAKE1-DUP[3]	0.5	5.80	9.5	25		2.1	3	20.2	10.5				6.3	0.8 B	90	
18-Nov-96																
BLAKE1	0.5	6.10	7.1	24	1.75			23.5	11.3				10.6	0.8 B	40	11
	2	6.00	7.1	27				34.2	16.7							
	4	5.80	7.1	27				25.3	30.3							
	6	5.38	5.5	29				26.8	8.5							
	8	5.40	4.4	30				30.3	7.6							
	10	5.41	4.1	32				75.6	25.2							
	12	5.70	4.1	37				108.0	56.7							
	14	5.82	4.1	40				114.0	71.8							
	comp.					4.9 B	3.6									
BLAKE2	0.5	6.20	8.0	33	2.25			31.8	9.1				6.1	1.3	90	42
	2	6.10	8.0	32				25.3	13.2							
	4	6.10	8.0	32				26.8	10.0							
	6	6.10	8.0	32				48.1	15.8							
	8	6.15	7.9	32				58.3	23.6							
	10	5.90	6.8	42				71.8	56.0							
	12	6.15	6.4	44				210.0	149.0							
	14	6.20	6.3	44				290.0	196.0							
	comp.					7.4 B	1.9									
BLAKE1-DUP	14	5.78	4.1	40		7.8 B	2.2	261.0	206.0				12.0	4.0	120	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO^3/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
16-Dec-96																
	0.5	5.80	4.1	24	1.75			47.2	30.4				5.9	1.6	80	3
	2	5.40	4.1	24				54.6	24.6							
	4	5.40	4.1	24				50.3	27.6							
	6	5.40	4.1	24				47.1	29.3							
BLAKE1	8	5.40	4.1	26				50.6	33.4							
	10	5.40	4.1	24				52.0	29.0							
	12	5.40	4.1	24				51.4	30.0							
	14	5.50	4.1	24				52.3	27.5							
	comp.					1.3	1.7									
	0.5	6.10	4.7	33	2.25			29.2	9.2				9.9	1.1	60	2
	2	6.00	4.7	33				31.0	9.2							
	4	5.90	4.7	33				31.6	7.8							
	6	6.00	4.7	33				29.0	7.6							
BLAKE2	8	6.00	4.7	33				30.9	7.6							
	10	6.00	4.7	33				28.6	9.2							
	12	6.00	4.7	33				30.8	7.8							
	14	6.00	4.7	33				35.3	8.7							
	comp.					4.9	1.0									
BLAKE2-DUP	2	6.00	4.7	33		5.0	1.0	34.6	9.5				9.8	1.0	70	
21-Jan-97																
	0.5	5.65	3.4	26	2.25			38.5	22.3				4.6	1.1	80	3
	2	5.30	3.4	26				27.8	21.0							
	4	5.30	3.5	26				26.5	20.8							
	6	5.35	3.4	26				32.5	23.4							
BLAKE1	8	5.30	3.4	26				32.0	24.0							
	10	5.25	3.4	28				33.7	26.2							
	12	5.25	3.3	30				35.7	27.8							
	14	5.30	3.3	26				34.8	30.4							
	comp.					0.67	1									
	0.5	6.00	3.6	31	2.75			20.9	12.3				7.6	1.0	50	1
	2	6.00	3.6	31				20.3	12.1							
	4	6.00	3.6	31				20.6	12.2							
	6	5.90	3.5	31				18.6	13.1							
BLAKE2	8	6.00	3.5	31				17.7	13.4							
	10	5.90	3.5	31				20.0	13.7							
	12	5.90	3.5	31				20.5	12.9							
	14	5.90	3.5	31				22.3	12.5							
	comp.					3.4	0.66									
BLAKE1-DUP	0.5	5.30	3.4	26		0.47	0.7	32.7	22.8				4.3	1.2	70	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
18-Feb-97																
BLAKE1	0.5	7.60	4.7	25	2.25			31.9	19.1				4.9	0.9 B	70	9
	2	5.90	4.7	20				31.6	18.0							
	4	5.60	4.9	20				33.7	18.4							
	6	5.60	4.3	19				34.2	19.7							
	8	5.50	3.9	21				36.6	18.9							
	10	5.50	3.8	19				27.8	19.0							
	12	5.50	3.6	19				33.5	20.5							
	14	5.50	3.6	21				35.4	22.1							
	comp.					1.8	1.1									
BLAKE2	0.5	6.10	5.0	30	2.75			24.3	7.5				7.8	0.7 B	50	7
	2	6.10	4.8	30				24.3	7.3							
	4	6.20	4.7	30				25.9	8.2							
	6	6.20	4.6	30				26.0	8.0							
	8	6.20	4.6	30				18.5	7.0							
	10	6.20	4.5	30				17.2	7.9							
	12	6.20	4.5	28				22.8	7.5							
	14	6.20	4.5	28				22.2	7.2							
	comp.					4.5	1.1									
BLAKE2-DUP	0.5	6.10	5.0	30		3.5	1.1	20.5	6.80				7.9	0.6 B	50	
17-Mar-97																
BLAKE1	0.5	6.10	6.4	26	1.75			47.5	10.0				6.3	2.8	80	13
	2	5.90	5.5	26				38.4	11.9							
	4	5.70	5.4	25				39.8	11.7							
	6	5.70	5.3	25				26.4	15.3							
	8	5.50	4.9	25				37.4	18.6							
	10	5.40	4.4	24				34.9	24.4							
	12	5.40	4.2	26				40.0	22.2							
	14	5.40	4.1	26				49.0	25.3							
	comp.					6.6	2.9									
BLAKE2	0.5	6.50	6.4	32	2.75			42.8	3.7 B				8.5	1.4	50	5
	2	6.60	6.1	32				35.1	3.2 B							
	4	6.40	6.1	31				31.6	3.2 B							
	6	6.30	6.0	31				32.9	4.1 B							
	8	6.30	5.9	31				31.3	3.2 B							
	10	6.30	5.7	31				29.6	3.3 B							
	12	6.40	5.7	31				31.8	4.7 B							
	14	6.30	5.7	31				31.9	5.0							
	comp.					7.5	1.6									
BLAKE1-DUP		5.70	6.2	24		7.1	2	37.9	12.1				5.4	1.3	80	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mg$CaCO^3$/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
21-Apr-97																
	0.5	6.30	12.4	20	2.00			14.5	9.8				5.6	1.1	80	7
	2	6.30	11.0	19				12.3	9.4							
	4	6.00	6.7	18				24.8	12.6							
	6	6.10	5.6	18				25.3	13.5							
BLAKE1	8	5.80	4.8	19				21.9	24.8							
	10	5.80	4.5	19				25.0	30.1							
	12	5.80	4.3	18				32.7	34.3							
	14	5.70	4.3	21				48.8	40.3							
	comp.					0.39	2									
	0.5	6.50	14.8	27	2.25			12.4	4.4 B				8.2	1.6	50	4
	2	6.70	11.8	28				14.0	3.6 B							
	4	6.50	8.2	29				14.1	5.0							
	6	6.50	7.4	28				33.4	5.4							
BLAKE2	8	6.40	7.3	28				21.9	4.9 B							
	10	6.40	7.2	28				11.8	5.6							
	12	6.40	7.1	28				11.8	6.5							
	14	6.30	7.0	28				16.5	7.3							
	comp.					18.1	2.6									
BLAKE1-DUP	0.5	6.30	12.3	21		0.2	2.1	52.3	11.2				5.7	1.1	80	
19-May-97																
	0.5	5.60	19.6	22	1.50			24.3	10.0				6.8	1.0	110	1
	2	5.35	11.5	20				17.2	9.6							
	4	5.15	6.9	21				18.3	14.5							
	6	5.15	5.8	20				26.1	17.3							
BLAKE1	8	4.90	5.0	19				31.9	25.2							
	10	4.95	4.6	20				43.9	31.0							
	12	5.05	4.4	23				51.9	39.3							
	14	5.10	4.4	24				64.0	55.7							
	comp.					2.2	0.77									
	0.5	6.3	20.4	30	2.00			15.0	7.7				9.1	0.6 B	50	3
	2	6.4	19.0	30				17.1	7.1							
	4	6.0	9.3	31				35.9	10.3							
	6	5.6	7.7	29				17.8	9.2							
BLAKE2	8	5.7	7.5	29				16.6	8.1							
	10	5.6	7.2	28				23.7	10.1							
	12	5.6	7.1	28				24.5	13.3							
	14	5.5	7.1	27				26.7	17.9							
	comp.					35.2	1.5									
BLAKE1-DUP	0.5	5.70	19.8	22		2.5	0.67	30.9	11.5				6.9	0.7 B	110	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO^3/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
16-Jun-97																
	0.5	6.5	19.7	23	1.25			43.2	14.3				7.6	1.7	100	3
	2	5.9	13.3	24				66.3	31.0							
	4	5.9	7.4	22				42.6	9.0							
	6	5.9	5.7	23				34.1	8.1							
BLAKE1	8	5.8	5.0	24				35.9	10.5							
	10	5.8	4.8	24				40.8	11.6							
	12	5.7	4.5	24				67.9	37.0							
	14	5.7	4.4	26				11.2	73.6							
	comp.					13.4	6.7									
	0.5	6.5	20.1	31	2.75			29.1	9.8				9.7	0.7 B	50	9
	2	6.9	19.7	31				35.9	8.1							
	4	6.2	10.9	34				42.5	4.8 B							
	6	6.1	8.2	32				33.3	7.3							
BLAKE2	8	6.2	7.6	30				31.0	5.3							
	10	6.2	7.3	31				39.4	8.0							
	12	6.2	7.1	31				45.2	12.3							
	14	6.2	7.1	33				48.5	16.4							
	comp.					26.5	0.92									
BLAKE1-DUP		6.5	19.8	23		15.1	3.2	48.5	12.9				7.5	1.9	100	
21-Jul-97																
	0.5	6.1	22.0	21	1.25			27.7	8.1	748	25 A[5]	24 B	8.0	1.4	80	7
	2	5.6	15.2	22				39.5	10.0	688	25 A	24 B				
	4	5.5	8.0	19				16.7	6.0	339	25 A	26 B				
	6	5.6	6.1	17				15.5	7.2	422	102	27 B				
BLAKE1	8	5.5	5.0	19				23.1	11.7	493	153	24 B				
	10	5.3	4.7	19				45.6	27.2	579	201	36 B				
	12	5.7	4.6	20				79.5	54.4	583	124	74.5				
	14	5.8	4.5	24				135.0	85.7	640	25 A	188				
	comp.					23.2	4.1									
	0.5	6.7	22.8	27	2.50			10.0	3.9 B	380	25 A	30 B	10.2	1.4	40	14
	2	6.7	22.7	27				12.0	4.4 B	400	25 A	26 B				
	4	6.2	12.2	29				32.8	3.6 B	435	25 A	27 B				
	6	5.9	8.4	29				12.7	4.5 B	478	141	38 B				
BLAKE2	8	5.9	7.8	28				12.8	6.5	450	167	45.2				
	10	5.9	7.5	28				21.7	7.7	459	209	35 B				
	12	5.9	7.2	28				29.3	14.2	463	223	28 B				
	14	5.9	7.1	30				39.0	16.3	515	221	27 B				
	comp.					5.9	1.5									
BLAKE2-DUP	0.5	6.7	22.8	27		5.7	1.4	8.6 B	4.6 B	346	25 A	10 A	10.2	1.3	40	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
18-Aug-97																
BLAKE1	0.5	6.1	22.2	21	1.25			22.5	6.9	318	25 A	24 B	9.0	0.7 B	120	13
	2	5.6	16.4	24				30.3	6.5	388	25 A	25 B				
	4	5.6	8.3	22				26.0	5.7	236	25 A	10 A				
	6	5.7	5.8	20				22.8	9.9	349	94 B	21 B				
	8	5.7	5.0	19				32.0	16.4	404	149	41.4				
	10	5.7	4.7	19				65.8	37.3	197	155	79.2				
	12	5.8	4.6	22				115.0	63.3	242	25 A	120				
	14	6.0	4.5	27				202.0	140.0	417	25 A	311				
	comp.					12.1	6.4									
BLAKE2	0.5	6.3	23.2	31	2.50			9.0 B	3.5 B	282	25 A	21 B	11.3	0.8 B	40	150
	2	6.5	23.2	30				7.7 B	3.8 B	334	25 A	23 B				
	4	6.0	13.2	31				23.9	4.3 B	263	25 A	10 A				
	6	6.0	8.5	30				20.3	5.0	257	79 B	10 A				
	8	6.1	7.7	29				19.4	6.0	394	168	B B				
	10	6.2	7.4	30				33.3	8.8	324	145	32				
	12	6.2	7.2	31				41.3	11.1	281	148	43.5				
	14	6.3	7.0	31				69.2	18.7	376	25 A	97				
	comp.					2.5	2.6				25 A	10 A				
BLAKE2-DUP	0.5	6.4	23.2	31		4.3	0.37	11.5	5.8	315			10.8	0.8 B	30	
15-Sep-97																
BLAKE1	0.5	6.4	17.7	21	1.25			23.6	11.3				8.7	1.4	100	8
	2	5.8	16.6	22				27.2	14.0							
	4	5.7	8.3	17				23.3	10.9							
	6	5.7	5.9	17				20.7	16.0							
	8	5.8	5.0	19				47.7	40.8							
	10	5.7	4.8	19				56.6	46.0							
	12	5.9	4.6	22				131.0	106.0							
	14	6.0	4.6	24				172.0	149.0							
	comp.					21.1	6.9									
BLAKE2	0.5	6.5	18.6	30	2.50			10.5	7.1				10.9	0.6 B	40	7
	2	6.5	18.5	30				8.4 B	5.5							
	4	5.9	14.2	34				10.5	10.3							
	6	5.9	8.9	31				18.1	10.9							
	8	6.0	7.8	30				15.2	10.7							
	10	6.1	7.4	31				37.4	26.7							
	12	6.2	7.2	33				53.2	31.5							
	14	6.3	7.1	40				67.8	61.6							
	comp.					4.5	1.5									
BLAKE2-DUP	0.5	6.5	18.5	30		4.7	1.1	12.8	5.0				12.8	0.7 B	40	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
20-Oct-99																
BLAKE1	0.5	6.6	10	44	2.25			16.0	2.2 B				10.8	0.6 B	80	
	2	6.4	10	44				13.1	1.0 A							
	4	6.1	10	44				14.8	4.2 B							
	6	5.9	6	40				11.5	0.5 B							
	8	5.9	5	41				18.0	8.7							
	10	5.9	5	40				33.9	23.6							
	12	6.1	5	43				78.8	52.8							
	14	6.4	5	51				167.0	159.0							
	comp.					2.3	0.79									
BLAKE2	0.5	6.8	12	39	3.50			11.3	3.1 B				11.5	0.9 B	30	1
	2	7.0	12	40				10.9	1.0 A							
	4	6.8	12	40				10.2	1.0 A							
	6	6.8	10	41				14.8	2.0 B							
	8	6.3	8	44				15.6	3.8 B							
	10	6.3	7	44				26.5	7.7							
	12	6.3	7	45				28.4	10.0							
	14	6.5	7	53				43.8	43.3							
	comp.					13.7	0.38 B									
BLAKE2-DUP	0.5					14.9	0.15 A	19.7	3.3 B				10.7	1.0 B	90	
17-Nov-99																
BLAKE1	0.5	6.3	9	39	1.50			26.7	3.4 B				9.7	2.4	90	
	2	6.3	9	40				27.7	3.6 B							
	4	6.4	8	41				24.1	3.8 B							
	6	6.3	7	40				22.4	4.8 B							
	8	5.9	5	31				22.9	13.0							
	10	5.9	5	31				41.3	28.8							
	12	6.1	5	35				111.0	76.8							
	14	6.1	5	36				125.0	111.0							
	comp.					4.7	1.5									
BLAKE2	0.5	6.3	9	39	2.75			33.0	1.0 A				11.1	1.1	40	9
	2	6.6	9	42				15.1	1.0 A							
	4	6.6	9	41				13.8	1.0 A							
	6	6.6	9	41				18.1	2.5 B							
	8	6.5	9	41				14.8	2.7 B							
	10	6.3	8	42				22.9	4.8 B							
	12	6.2	7	46				41.2	14.3							
	14	6.5	7	54				62.3	52.3							
	comp.					7.1	2.1									
BLAKE2-DUP	0.5	6.5	9	41				14.4	2.1 B				11.3	0.9 B	40	2

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
13-Dec-99																
	0.5	6.3	6	39	1.50			25.8	12.0				9.4	1.0 B	80	
	2	6.6	6	39				26.6	13.1							
	4	6.6	6	39				26.0	12.4							
	6	6.5	6	39				25.8	12.8							
BLAKE1	8	6.9	6	39				28.3	13.9							
	10	6.9	6	39				29.5	15.7							
	12	6.7	5	39				43.2	25.7							
	14	6.5	5	41				148.0	108.0							
	comp.					0.34	0.73									
	0.5	6.5	6	43	2.50			19.6	5.9				11.5	1.4	40	2
	2	6.7	7	42				18.0	5.0 B							
	4	6.9	7	44				16.5	4.9 B							
	6	6.9	7	44				17.4	4.8 B							
BLAKE2	8	7.0	7	44				18.8	5.1							
	10	6.9	7	41				21.6	4.9 B							
	12	6.9	7	42				17.0	5.0 B							
	14	6.9	7	42				16.8	4.8 B							
	comp.					0.82	0.41									
BLAKE1-DUP	0.5	6.6	6	39		0.45	0.64	26.5	12.3				9.4	0.9 B	90	14
12-Jan-00																
	0.5	5.9	4	40	2.00			31.6	19.4				9.4	1.0 B	80	
	2	5.9	4	40				32.6	19.4							
	4	5.9	4	42				32.5	18.4							
	6	5.9	4	40				43.6	19.3							
BLAKE1	8	5.9	4	42				33.6	19.6							
	10	5.9	4	42				32.5	19.7							
	12	5.9	4	46				33.9	19.8							
	14	5.9	4	42				34.8	19.8							
	comp.					0.08 A	0.15 A									
	0.5	6.3	5	46	2.50			15.7	6.1				11.2	0.9 B	50	2
	2	6.3	5	48				16.8	5.7							
	4	6.7	5	48				16.3	5.7							
	6	6.4	5	48				26.4	5.7							
BLAKE2	8	6.4	5	48				15.3	5.1							
	10	6.4	5	48				15.6	5.3							
	12	6.3	5	46				16.7	5.4							
	14	6.4	5	46				17.2	5.5							
	comp.					0.63	0.5 B									
BLAKE1-DUP	0.5	5.9	6	40		0.08 A	0.15 A	35.0	18.8				9.4	1.0 B	90	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
9-Feb-00																
BLAKE1	0.5		5	35	2.00			37.4	16.6				9.2	1.2	80	
	2		5	33				29.7	16.7							
	4		4	34				28.9	17.2							
	6		4	34				33.6	20.9							
	8		4	34				30.0	18.2							
	10		4	34				29.9	18.8							
	12		4	34				31.0	18.5							
	14		4	33				33.1	17.3							
	comp.					0.45	0.15 A									
BLAKE2	0.5		5	40	3.00			14.8	5.1				11.0	0.7 B	45	5
	2		5	38				14.5	4.8 B							
	4		5	38				14.1	4.8 B							
	6		5	38				13.6	4.9 B							
	8		4	38				14.0	4.9 B							
	10		4	38				14.5	5.1							
	12		4	39				14.4	5.2							
	14		4	40				14.0	5.2							
	comp.					1.1	0.46 B									
BLAKE2-DUP	0.5		5	40		1.3	0.42 B	13.9	4.8 B				11.1	1.7	40	
8-Mar-00																
BLAKE1	0.5	6.5	6	30	2.00			24.6	8.8				7.7	1.2	80	
	2	6.9	5	31				25.3	10.9							
	4	6.9	5	31				28.9	14.4							
	6	6.9	4	32				30.5	16.0							
	8	6.9	4	32				32.3	17.0							
	10	6.9	4	32				32.0	17.7							
	12	7.0	4	32				32.1	18.4							
	14	7.0	4	32				39.4	19.4							
	comp.					2.3	0.15 A									
BLAKE2	0.5	7.1	6	38	2.50			24.6	2.5 B				10.3	0.7 B	40	4
	2	7.1	6	39				16.4	2.2 B							
	4	7.1	5	37				13.9	2.8 B							
	6	7.1	5	38				14.0	3.5 B							
	8	7.1	5	36				13.2	3.7 B							
	10	7.2	5	36				13.5	4.3 B							
	12	7.1	5	37				15.1	4.7 B							
	14	7.2	5	37				15.2	4.8 B							
	comp.					4.8	0.32 B									
BLAKE1-DUP	0.5	7.0	7	30		2.4	0.41 B	24.1	9.5				8.0	1.0 B	70	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO^3/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
5-Apr-00																
	0.5	6.3	11	35	2.00			21.5	3.3 B				7.9 B	0.9 B	80	
	2	6.5	8	34				24.3	10.8							
	4	6.7	6	35				23.5	10.3							
	6	6.8	5	35				27.6	14.4							
BLAKE1	8	6.8	4	35				30.3	16.6							
	10	6.8	4	35				33.3	17.5							
	12	6.8	4	35				36.0	18.0							
	14	6.8	4	35				35.5	19.7							
	comp.					1.9	0.66									
	0.5	6.6	11	42	3.00			12.3	2.4 B				9.8 B	0.7 B	40	4
	2	6.8	11	42				14.3	2.9 B							
	4	6.8	7	44				13.1	2.1 B							
	6	6.8	7	45				10.7	2.1 B							
BLAKE2	8	6.9	6	45				11.1	2.1 B							
	10	7.0	6	44				11.6	2.3 B							
	12	7.0	6	44				11.9	3.1 B							
	14	7.0	6	44												
	comp.					3.7	0.15 A									
BLAKE-DUP	0.5	6.5	11	35				19.0	3.0 B				7.9 B	0.8 B	70	
3-May-00																
	0.5	6.1	15	34	1.75			24.5	2.9 B				8.5 B	0.8 B	80	
	2	6.3	11	34				18.7	2.5 B							
	4	6.2	6	32				23.1	10.3							
	6	6.1	5	33				27.0	15.5							
BLAKE1	8	6.1	4	32				33.1	18.5							
	10	6.0	4	32				34.5	19.5							
	12	6.0	4	32				104.0	20.1							
	14	5.7	4	32				50.3	26.8							
	comp.					3.1	0.93									
	0.5	6.4	15	51	2.50			14.3	2.4 B				9.8 B	0.5 B	40	1
	2	6.8	14	53				15.6	1.0 A							
	4	6.8	8	58				13.2	1.0 A							
	6	6.5	7	58				12.7	2.1 B							
BLAKE2	8	6.5	7	60				11.9	2.1 B							
	10	6.5	7	59				12.8	2.7 B							
	12	6.4	6	61				16.9	4.8 B							
	14	6.4	6	61				17.9	6.5 B							
	comp.					2.9	0.92									
BLAKE1-DUP	0.5	6.5	15	34		3.6	0.82	23.3	2.2 B				8.5 B	0.8 B	80	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO^3/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
31-May-00																
	0.5	6.0	15	34	1.50			22.7	2.8 B				8.7 B	2.2 B	80	
	2	6.0	12	36				21.7	2.8 B							
	4	6.0	6	33				14.2	5.1							
	6	5.6	5	33				25.3	15.6							
BLAKE1	8	5.6	4	34				30.0	19.8							
	10	5.5	4	34				29.8	21.0							
	12	5.5	4	34				35.1	24.4							
	14	5.4	4	35				64.8	38.9							
	comp.					6.1	1.2									
	0.5	6.3	16	37	2.50			12.8	1.0 A				10.8	1.1	35	5
	2	6.7	16	38				10.9	D							
	4	6.6	10	43				11.0	1.0 A							
	6	6.4	7	41				10.4	2.9 B							
BLAKE2	8	6.0	7	41				10.0	2.6 B							
	10	6.0	7	41				11.1	2.8 B							
	12	6.0	6	41				11.8	3.1 B							
	14	5.9	6	41				14.3	3.9 B							
	comp.					8	0.79									
BLAKE2-DUP	0.5	6.6	16	38		7.8	1.2	9.9 B	2.4 B				110.7	1.1 B	35	
28-Jun-00																
	0.5	6.7	23	36	1.50			22.5	3.1 B				8.7 B	0.8 B	80	
	2	6.6	14	37				26.4	3.8 B							
	4	6.3	7	36				12.7	3.2 B							
	6	6.2	5	39				22.6	10.4							
BLAKE1	8	6.4	4	38				33.3	19.6							
	10	6.1	4	37				34.5	21.3							
	12	6.1	4	34				47.7	31.2							
	14	6.1	4	35				84.7	46.2							
	comp.					20.8	2.3									
	0.5	6.7	24	41	2.25			10.1	1.0 A				10.7	0.8 B	30	18
	2	7.0	20	43				11.7	1.0 A							
	4	6.9	12	44				11.6	2.2 B							
	6	6.7	8	44				11.0	2.4 B							
BLAKE2	8	6.4	7	45				12.3	2.4 B							
	10	6.4	7	44				12.6	2.8 B							
	12	6.4	7	45				13.0	2.8 B							
	14	6.7	7	60				16.3	3.3 B							
	comp.					5.8	0.44 B									
BLAKE2-DUP	0.5		24			5.3	0.63	8.4 B	1.0 A				10.4	0.7 B	30	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO^3/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
26-Jul-00																
	0.5	6.4	21	35	1.25			20.6	1.0 A	544	10 A	5 A	9.1 B	0.9 B	80	
	2	6.3	15	37				30.8	1.0 A	668	10 A	5 A				
	4	6.0	7	37				14.3	2.2 B	497	138	13 B				
	6	6.0	5	36				15.0	4.4 B	533	197	5 A				
BLAKE1	8	6.0	5	37				25.9	13.6	563	216	5 A				
	10	6.0	4	35				36.6	22.6	596	235	10 B				
	12	5.9	4	35				52.8	33.9	629	235	5 A				
	14	5.9	4	37				106.0	58.5	671	69.2	114				
	comp.					9.6	0.68									
	0.5	6.3	21	43	3.00			11.7	1.0 A	331	10 A	5 A	11.0	0.6 B	25	5
	2	6.7	21	43				10.2	1.0 A	325	10 A	5 A				
	4	6.8	13	46				14.8	1.0 A	336	10 A	5 A				
	6	6.6	8	45				12.4	1.0 A	473	159	5 A				
BLAKE2	8	6.3	7	45				12.2	1.0 A	509	216	5 A				
	10	6.3	7	45				16.5	2.2 B	532	204	20 B				
	12	6.3	7	45				16.3	2.6 B	531	224	13 B				
	14	6.3	6	45				21.8	4.3 B	562	209	39.9				
	comp.					4.6	0.4 B									
BLAKE1-DUP	0.5	6.5	21	35		8.8	1.5	18.1	1.0 A	530	10 A	5 A	9.1 B	1.0 B	70	
23-Aug-00																
	0.5	5.8	20	43	1.50			17.1	1.0 A	549	10 A	5 A	9.8 B	0.8 B	70	
	2	6.3	17	42				25.0	1.0 A	632	10 A	5 A				
	4	6.0	8	44				14.4	2.1 B	488	137	5 A				
	6	6.0	5	37				13.9	2.9 B	555	187	5 A				
BLAKE1	8	6.0	5	35				28.0	13.9	655	213	10 B				
	10	6.0	5	35				38.4	23.9	604	222	11 B				
	12	5.9	4	35				66.4	42.8	645	173	34.9				
	14	5.9	4	40				162.0	121.0	786	10 A	277				
	comp.					9.4	1.7									
	0.5	6.3	21	44	3.50			12.0	1.0 A	358	10 A	5 A	11.6	0.6 B	25	4
	2	6.4	20	44				15.0	1.0 A	398	10 A	5 A				
	4	6.7	14	47				17.8	1.0 A	340	10 A	5 A				
	6	6.5	8	45				19.8	1.0 A	427	131	5 A				
BLAKE2	8	6.3	8	44				14.6	2.1 B	484	193	5 A				
	10	6.2	7	45				18.1	3.6 B	518	194	27.9				
	12	6.2	7	45				108.0	4.4 B	892	203	34.5				
	14	6.2	7	45				40.7	9.1 B	646	145	120				
	comp.					6.3	0.15 A									
BLAKE1-DUP	0.5	6.0	20	43		9.5	2	19.6	1.0 A	534	10 A	5 A	9.8 B	0.6 B	70	

Lake Data Parameters

Sample Location	Depth (m)	pH	Temp. (C)	Cond (µmhos/cm)	Trans (m)	Chl *a* (µg/L)	Phaeo (µg/L)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	Fecals (CFU/100ml)
20-Sep-00																
	0.5	6.9	19	36	2.50			12.2	1.0 A				10.5	0.5 B	70	
	2	6.7	16	37				11.5	1.0 A							
	4	6.5	8	35				12.5	2.3 B							
	6	6.2	6	34				12.4	3.8 B							
BLAKE1	8	6.1	5	35				23.7	12.7							
	10	6.1	5	35				36.2	24.3							
	12	6.0	5	33				66.7	44.2							
	14	6.1	5	40				164.0	131.0							
	comp.					5.7	1.5									
	0.5	6.5	19	41	3.50			14.8	1.0 A				12.0	1.1	25	17
	2	6.9	18	42				18.2	1.0 A							
	4	6.8	15	43				11.6	1.0 A							
	6	6.4	9	42				12.9	2.4 B							
BLAKE2	8	6.3	8	44				13.5	3.0 B							
	10	6.2	7	45				21.6	6.4							
	12	6.2	7	45				32.8	7.5							
	14	6.2	7	47				43.7	15.3							
	comp.					12.5	0.15 A									
BLAKE2-DUP	0.5	6.5	19	41		12.7	0.42 B	9.3 B	1.0 A				12.1	0.7 B	25	

1. Temp = temperature, Cond = Conductivity, Trans = transparency, Chl a = Chlorophyll a, Phaeo = Phaeophyton, TP = Total Phosphorus, SRP = Soluble Reactive Phosphorus, TN = Total Nitrogen, NO_3+NO_2 = Nitrate+Nitrite, NH_4 + Ammonia, Alk = Alkalinity, Turb = Turbidity

2. comp = composite from 0.5, 1.5, 2.5, and 3.5 meters (Chl a, phaeophytin, and phytoplankton).

3. DUP = duplicate sample applies to depth listed except Chl a, phaeophytin, and phytoplankton which are duplicates of the composite

4. Code A=Less than Method Detection Limit; B=Less than Reporting Detection Limit. All codes are to right of applicable cell.

5. When note coded A, a value mid-way between zero and the Method Detection Limit is used for calculations. For 1997: NO_2+NO_3, A=25µg/L; NH_4, A=10.0µg/L, TSS, A=0.25mg/L. For 2000: SRP, A=1.0µg/L; NO_2+NO_3, A=10µg/L; NH_4, A=5.0µg/L; TSS, A=0.25mg/L

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	Depth (m)	Temp[1] (C)	DO[2] (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
21-Oct-96							
2:30 PM	0.5	9.5	6.96	10:58 AM	0.5	10.6	7.40
2:33 PM	1	9.5	7.01	10:59 AM	1	10.6	7.37
2:35 PM	2	9.5	6.90	11:01 AM	2	10.6	7.47
2:37 PM	3	9.4	6.80	11:02 AM	3	10.6	7.51
2:40 PM	4	8.4	2.25	11:03 AM	4	10.6	7.46
2:45 PM	5	6.3	2.17	11:04 AM	5	10.6	7.33
2:47 PM	6	5.1	3.07	11:06 AM	6	9.2	0.25
2:49 PM	7	4.6	2.90	11:08 AM	7	7.7	0.21
2:50 PM	8	4.3	2.31	11:09 AM	8	7.1	0.22
2:52 PM	9	4.2	0.73	11:11 AM	9	6.8	0.21
2:53 PM	10	4.1	0.35	11:12 AM	10	6.5	0.21
2:54 PM	11	4.1	0.34	11:13 AM	11	6.4	0.21
2:56 PM	12	4.1	0.32	11:15 AM	12	6.3	0.22
2:58 PM	13	4.1	0.32	11:16 AM	13	6.2	0.23
2:51 PM	14	4.1	0.31	11:17 AM	14	6.2	0.22
	0.5-DUP[3]	9.5	6.93				
28-Oct-96							
11:15 AM	0.5	9.6	7.96	10:37 AM	0.5	10.3	7.93
11:16 AM	1	9.5	7.79	10:40 AM	1	10.3	7.93
11:18 AM	2	9.3	7.42	10:41 AM	2	10.2	7.59
11:20 AM	3	9.0	7.30	10:43 AM	3	10.1	7.51
11:22 AM	4	8.8	6.90	10:45 AM	4	10.1	7.82
11:25 AM	5	6.9	1.65	10:48 AM	5	10.1	7.80
11:26 AM	6	5.1	2.54	10:51 AM	6	9.9	7.06
11:28 AM	7	4.6	2.87	10:53 AM	7	8.0	0.35
11:29 AM	8	4.3	2.10	10:55 AM	8	7.3	0.20
11:31 AM	9	4.2	0.91	10:57 AM	9	7.0	0.19
11:33 AM	10	4.1	0.35	10:59 AM	10	6.6	0.18
11:31 AM	11	4.1	0.32	11:00 AM	11	6.3	0.19
11:36 AM	12	4.1	0.29	11:03 AM	12	6.2	0.19
11:37 AM	13	4.1	0.29	11:05 AM	13	6.2	0.19
11:39 AM	14	4.1	0.28	11:07 AM	14	6.0	0.18
11:41 AM	5-DUP	6.2	1.86				
4-Nov-96							
12:25 PM	0.5	8.2	7.40	11:25 AM	0.5	9.1	7.73
12:28 PM	1	8.2	7.38	11:28 AM	1	9.1	7.53
12:31 PM	2	8.1	7.19	11:32 AM	2	9.0	7.40
12:35 PM	3	8.1	7.13	11:35 AM	3	9.0	7.34
12:37 PM	4	7.9	6.24	11:40 AM	4	9.0	7.34
12:40 PM	5	7.0	1.48	11:44 AM	5	9.0	7.39
12:44 PM	6	5.3	2.70	11:48 AM	6	9.0	7.22
12:46 PM	7	4.5	2.60	11:52 AM	7	9.0	7.20
12:48 PM	8	4.3	1.37	11:55 AM	8	7.5	0.07
12:50 PM	9	4.1	0.23	11:57 AM	9	6.8	0.06
12:51 PM	10	4.1	0.10	11:28 AM	10	6.6	0.05
12:52 PM	11	4.1	0.09	12:00 PM	11	6.4	0.05
12:54 PM	12	4.1	0.09	12:01 PM	12	6.3	0.05
12:55 PM	13	4.1	0.08	12:02 PM	13	6.2	0.05
12:27 PM	14	4.1	0.08	12:03 PM	14	6.2	0.04
1:00 PM	5-DUP	7.0	2.20				

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
11-Nov-96							
11:35 AM	0.5	8.3	7.94	10:23 AM	0.5	8.9	7.96
11:40 AM	1	8.2	8.00	10:28 AM	1	8.8	7.74
11:48 AM	2	7.9	7.99	10:33 PM	2	8.8	7.59
11:44 AM	3	7.8	7.72	10:35 PM	3	8.6	7.50
11:45 AM	4	7.6	7.50	10:38 PM	4	8.6	7.20
11:46 AM	5	7.3	6.10	10:46 AM	5	8.6	7.00
11:50 AM	6	5.2	2.44	10:50 AM	6	8.5	6.75
11:52 AM	7	4.7	2.60	10:55 AM	7	8.5	6.63
11:54 AM	8	4.4	1.90	10:58 AM	8	8.2	5.40
11:55 AM	9	4.2	0.30	11:02 AM	9	7.1	0.15
11:56 AM	10	4.1	0.16	11:05 AM	10	6.7	0.10
11:57 AM	11	4.1	0.12	11:06 AM	11	6.4	0.07
11:58 AM	12	4.1	0.10	11:07 AM	12	6.3	0.06
11:59 AM	13	4.1	0.10	11:08 AM	13	6.3	0.06
12:00 PM	14	4.1	0.08	11:09 AM	14	6.2	0.06
					0.5-DUP	8.8	7.95
18-Nov-96							
12:36 PM	0.5	7.1	8.23	10:30 AM	0.5	8.0	7.65
12:38 PM	1	7.1	8.12		1	8.0	7.57
12:41 PM	2	7.1	8.12		2	8.0	7.50
12:42 PM	3	7.1	7.94		3	8.0	7.47
12:45 PM	4	7.1	7.88		4	8.0	7.48
12:47 PM	5	6.9	7.81		5	8.0	7.56
12:48 PM	6	5.5	2.45		6	8.0	7.41
12:50 PM	7	4.8	2.35		7	8.0	7.35
12:52 PM	8	4.4	1.28		8	7.9	7.18
12:54 PM	9	4.2	0.24		9	7.5	3.50
12:55 PM	10	4.1	0.14		10	6.8	0.16
12:56 PM	11	4.1	0.11		11	6.5	0.10
12:54 PM	12	4.1	0.13		12	6.4	0.09
12:58 PM	13	4.1	0.12		13	6.3	0.09
12:59 PM	14	4.1	0.11		14	6.3	0.08
1:01 PM	14-DUP	4.1	0.20				
25-Nov-96							
10:05 AM	0.5	4.8	7.20	10:55 AM	0.5	6.0	6.90
10:07 AM	1	4.8	7.03	10:57 AM	1	6.0	6.90
10:08 AM	2	4.8	7.03	10:58 AM	2	5.9	6.82
10:12 AM	3	4.8	6.98	11:00 AM	3	5.9	6.80
10:15 AM	4	4.8	6.85	11:02 AM	4	5.9	6.75
10:18 AM	5	4.7	6.87	11:04 AM	5	5.9	6.68
10:20 AM	6	4.7	6.87	11:06 AM	6	5.9	6.74
10:22 AM	7	4.7	5.46	11:08 AM	7	5.9	6.71
10:24 AM	8	4.4	2.87	11:12 AM	8	5.9	6.80
10:26 AM	9	4.3	0.92	11:14 AM	9	5.9	6.79
10:28 AM	10	4.2	0.13	11:17 AM	10	5.9	6.50
10:29 AM	11	4.1	0.07	11:19 AM	11	5.9	6.50
10:30 AM	12	4.1	0.06	11:22 AM	12	5.9	6.60
10:31 AM	13	4.1	0.04	11:25 AM	13	5.9	6.60
10:32 AM	14	4.1	0.04	11:27 AM	14	5.9	6.81
10:35 AM	4-DUP	4.7	7.00	11:30 AM	14-DUP	5.9	6.65

Lake Temperature and Dissolved Oxygen Profile Data

	BLAKE1				BLAKE2			
	Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
3-Dec-96								
	1:35 PM	0.5	4.9	6.88	12:32 PM	0.5	5.7	8.36
	1:37 PM	1	4.8	6.74	12:35 PM	1	5.7	8.20
	1:38 PM	2	4.7	6.62	12:37 PM	2	5.6	8.20
	1:40 PM	3	4.7	6.56	12:40 PM	3	5.6	8.20
	1:43 PM	4	4.7	6.56	12:42 PM	4	5.6	8.18
	1:45 PM	5	4.7	6.58	12:44 PM	5	5.6	8.19
	1:47 PM	6	4.7	6.55	12:45 PM	6	5.6	8.18
	1:48 PM	7	4.7	6.59	12:48 PM	7	5.6	8.18
	1:50 PM	8	4.7	6.50	12:52 PM	8	5.6	8.15
	1:52 PM	9	4.7	6.38	12:56 PM	9	5.6	8.26
	1:54 PM	10	4.7	6.36	12:59 PM	10	5.6	8.20
	1:56 PM	11	4.6	5.08	1:02 PM	11	5.6	8.20
	1:07 PM	12	4.6	4.25	1:03 PM	12	5.6	8.23
	2:00 PM	13	4.3	0.14	1:04 PM	13	5.6	8.19
	2:02 PM	14	4.2	0.10	1:06 PM	14	5.6	8.18
	2:10 PM	12-DUP	4.6	3.97	1:12 PM	7-DUP	5.6	8.19
9-Dec-96								
	11:13 AM	0.5	4.4	7.19				
	11:18 AM	1	4.3	7.18				
	11:20 AM	2	4.3	6.95				
	11:22 AM	3	4.3	7.05				
	11:25 AM	4	4.3	7.07				
	11:28 AM	5	4.3	7.10				
	11:30 AM	6	4.3	7.09				
	11:32 AM	7	4.3	7.10				
	11:34 AM	8	4.3	7.08				
	11:35 AM	9	4.3	7.06				
	11:36 AM	10	4.3	7.17				
	11:36 AM	11	4.3	7.21				
	11:37 AM	12	4.3	7.10				
	11:39 AM	13	4.2	7.09				
	11:41 AM	14	4.2	7.15				
	11:44 AM	2-DUP	4.3	7.03				
16-Dec-96								
	9:32 AM	0.5	4.1	7.64	10:55 AM	0.5	4.7	9.56
	9:34 AM	1	4.1	7.52	10:56 AM	1	4.7	9.55
	9:35 AM	2	4.1	7.49	10:57 AM	2	4.7	9.34
	9:36 AM	3	4.1	7.49	10:58 AM	3	4.7	9.36
	9:37 AM	4	4.1	7.47	11:00 AM	4	4.7	9.35
	9:39 AM	5	4.1	7.44	11:02 AM	5	4.7	9.33
	9:41 AM	6	4.1	7.44	11:05 AM	6	4.7	9.31
	9:42 AM	7	4.1	7.44	11:07 AM	7	4.7	9.31
	9:45 AM	8	4.1	7.44	11:10 AM	8	4.7	9.31
	9:47 AM	9	4.1	7.39	11:12 AM	9	4.7	9.36
	9:49 AM	10	4.1	7.40	11:15 AM	10	4.7	9.29
	9:51 AM	11	4.1	7.39	11:18 AM	11	4.7	9.39
	9:53 AM	12	4.1	7.44	11:21 AM	12	4.7	9.21
	9:55 AM	13	4.1	7.36	11:24 AM	13	4.7	9.23
	9:57 AM	14	4.1	7.39	11:26 AM	14	4.7	9.38
						2-DUP	4.7	9.38

Lake Temperature and Dissolved Oxygen Profile Data

	BLAKE1				BLAKE2			
	Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
21-Jan-97								
	9:26 AM	0.5	3.4	9.22	10:55 AM	0.5	3.6	10.63
	9:28 AM	1	3.4	9.16	10:57 AM	1	3.6	10.49
	9:30 AM	2	3.4	9.02	10:59 AM	2	3.6	10.49
	9:33 AM	3	3.7	8.99	11:02 AM	3	3.6	10.60
	9:35 AM	4	3.5	8.90	11:05 AM	4	3.6	10.54
	9:37 AM	5	3.4	8.44	11:07 AM	5	3.6	10.54
	9:40 AM	6	3.4	8.47	11:09 AM	6	3.5	10.44
	9:43 AM	7	3.4	8.31	11:12 AM	7	3.5	10.34
	9:45 AM	8	3.4	8.10	11:17 AM	8	3.5	10.49
	9:47 AM	9	3.4	8.06	11:16 AM	9	3.5	10.54
	9:49 AM	10	3.4	7.96	11:18 AM	10	3.5	10.54
	9:52 AM	11	3.4	7.90	11:20 AM	11	3.4	10.57
	9:55 AM	12	3.3	7.53	11:22 AM	12	3.5	10.20
	9:58 AM	13	3.3	7.45	11:24 AM	13	3.5	10.11
	10:02 AM	14	3.3	7.19	11:26 AM	14	3.5	9.92
	10:05 AM	0.5-DUP	3.4	9.21				
18-Feb-97								
	9:03 AM	0.5	4.7	8.37	10:24 AM	0.5	5.0	9.80
	9:05 AM	1	4.7	8.15	10:25 AM	1	4.9	9.72
	9:08 AM	2	4.7	8.13	10:28 AM	2	4.8	9.81
	9:10 AM	3	4.7	8.23	10:30 AM	3	4.8	9.81
	9:12 AM	4	4.6	8.28	10:32 AM	4	4.7	9.70
	9:17 AM	5	4.3	8.10	10:34 AM	5	4.6	9.69
	9:20 AM	6	4.3	8.00	10:37 AM	6	4.6	9.61
	9:22 AM	7	4.1	7.97	10:40 AM	7	4.6	9.60
	9:25 AM	8	3.9	7.82	10:43 AM	8	4.6	9.50
	9:28 AM	9	3.8	7.81	10:45 AM	9	4.6	9.51
	9:32 AM	10	3.8	7.65	10:47 AM	10	4.5	9.51
	9:35 AM	11	3.7	7.62	10:52 AM	11	4.5	9.69
	9:37 AM	12	3.6	7.59	10:55 AM	12	4.5	9.69
	9:39 AM	13	3.6	7.46	10:58 AM	13	4.5	9.49
	9:41 AM	14	3.6	7.34	11:00 AM	14	4.5	9.49
					11:05 AM	0.5-DUP	5.0	9.72
17-Mar-97								
	9:45 AM	0.5	6.4	11.04	11:15 AM	0.5	6.4	11.37
		1	5.9	10.73		1	6.3	11.50
		2	5.5	10.62		2	6.1	11.71
		3	5.4	10.71		3	6.1	11.55
		4	5.4	10.50		4	6.1	11.50
		5	5.3	10.67		5	6.1	11.70
		6	5.3	10.34		6	6.0	11.59
		7	5.2	10.35		7	5.9	11.46
		8	4.9	9.89		8	5.9	11.24
		9	4.7	9.60		9	5.9	11.39
		10	4.4	9.06		10	5.7	11.35
		11	4.3	8.75		11	5.7	11.18
		12	4.2	8.56		12	5.7	10.64
		13	4.2	8.09		13	5.7	11.36
		14	4.1	8.36		14	5.7	11.37
		0.5-DUP	6.2	11.23				

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
21-Apr-97							
9:40 AM	0.5	12.4	9.10	11:12 AM	0.5	14.8	10.78
9:44 AM	1	12.2	8.96	11:14 AM	1	13.8	10.65
10:00 AM	2	11.0	8.14	11:16 AM	2	11.8	10.40
10:05 AM	3	7.4	8.25	11:40 AM	3	9.7	10.59
10:08 AM	4	6.7	8.20	11:45 AM	4	8.2	9.32
10:12 AM	5	6.2	8.35	11:46 AM	5	7.6	9.26
10:13 AM	6	5.6	8.50	11:47 AM	6	7.4	9.12
10:20 AM	7	5.2	8.33	11:49 AM	7	7.3	9.03
10:23 AM	8	4.8	7.45	11:50 AM	8	7.3	8.66
10:25 AM	9	4.7	7.05	11:53 AM	9	7.2	8.80
10:30 AM	10	4.5	6.39	11:56 AM	10	7.2	8.71
10:33 AM	11	4.4	6.28	12:00 PM	11	7.1	8.69
10:35 AM	12	4.3	6.20	12:02 PM	12	7.1	8.65
10:38 AM	13	4.3	5.27	12:05 PM	13	7.1	8.59
10:40 AM	14	4.3	4.78	12:07 PM	14	7.0	8.58
	0.5-DUP	12.3	8.92				
19-May-97							
10:00 AM	0.5	19.6	7.25	11:45 AM	0.5	20.4	8.75
	1	18.7	6.80		1	20.4	8.60
	2	11.5	6.40		2	19.0	9.20
	3	8.5	6.75		3	13.0	12.50
	4	6.9	7.65		4	9.3	5.90
	5	6.3	7.60		5	8.2	4.95
	6	5.8	7.52		6	7.7	5.35
	7	5.2	7.05		7	7.6	6.03
	8	5.0	7.08		8	7.5	6.50
	9	4.8	5.70		9	7.3	6.30
	10	4.6	5.44		10	7.2	6.20
	11	4.5	4.86		11	7.1	6.02
	12	4.4	4.50		12	7.1	6.08
	13	4.4	3.10		13	7.1	5.80
	14	4.4	2.15		14	7.1	5.20
	0.5-DUP	19.8	7.29		0.5-DUP	20.4	8.60
16-Jun-97							
9:23 AM	0.5	19.7	8.48	10:40 AM	0.5	20.1	9.14
9:25 AM	1	19.3	7.24	10:42 AM	1	20.0	9.29
9:27 AM	2	13.3	3.47	10:45 AM	2	19.7	9.29
9:30 AM	3	10.2	3.95	10:48 AM	3	14.4	10.31
9:35 AM	4	7.4	5.57	10:50 AM	4	10.9	1.91
9:36 AM	5	6.3	6.80	10:53 AM	5	8.9	1.59
9:38 AM	6	5.7	6.80	10:54 AM	6	8.2	2.43
9:41 AM	7	5.2	6.26	10:56 AM	7	7.8	3.02
9:43 AM	8	5.0	6.19	10:59 AM	8	7.6	4.32
9:45 AM	9	4.9	5.91	11:01 AM	9	7.4	4.31
9:47 AM	10	4.8	5.41	11:01 AM	10	7.3	3.80
9:50 AM	11	4.6	5.01	11:06 AM	11	7.2	3.60
9:52 AM	12	4.5	3.96	11:08 AM	12	7.1	3.66
9:55 AM	13	4.5	2.72	11:10 AM	13	7.1	3.55
9:58 AM	14	4.4	0.30	11:12 AM	14	7.1	3.15
10:02 AM	0.5-DUP	19.8	8.15		0.5-DUP	20.0	9.14

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
21-Jul-97							
10:00 AM	0.5	22.0	7.35	11:45 AM	0.5	22.8	7.71
	1	20.9	6.70		1	22.8	7.65
	2	15.2	0.32		2	22.7	7.54
	3	10.8	1.36		3	16.2	6.60
	4	8.0	2.97		4	12.2	0.12
	5	6.7	3.88		5	9.4	0.16
	6	6.1	4.54		6	8.4	0.54
	7	5.4	4.36		7	8.0	0.44
	8	5.0	3.45		8	7.8	1.36
	9	4.8	2.98		9	7.6	1.36
	10	4.7	1.50		10	7.5	1.27
	11	4.6	0.16		11	7.3	1.04
	12	4.6	0.08		12	7.2	0.91
	13	4.5	0.06		13	7.1	0.59
	14	4.5	0.05		14	7.1	0.29
					0.5-DUP	22.8	7.40
18-Aug-97							
9:35 AM	0.5	22.2	5.38	11:04 AM	0.5	23.2	6.77
9:38 AM	1	22.2	5.34	11:06 AM	1	23.2	6.68
9:41 AM	2	16.4	0.16	11:08 AM	2	23.2	6.58
9:44 AM	3	10.5	0.04	11:10 AM	3	17.4	3.94
9:47 AM	4	8.3	1.12	11:12 AM	4	13.2	0.12
9:49 AM	5	6.6	2.37	11:14 AM	5	9.7	0.05
9:51 AM	6	5.8	2.53	11:15 AM	6	8.5	0.05
9:52 AM	7	5.3	1.60	11:16 AM	7	8.1	0.03
9:55 AM	8	5.0	2.10	11:14 AM	8	7.7	0.04
9:58 AM	9	4.9	1.03	11:18 AM	9	7.5	0.03
10:01 AM	10	4.7	0.10	11:19 AM	10	7.4	0.02
10:03 AM	11	4.6	0.04	11:20 AM	11	7.3	0.02
10:04 AM	12	4.6	0.03	11:21 AM	12	7.2	0.02
10:05 AM	13	4.6	0.03	11:22 AM	13	7.1	0.01
10:06 AM	14	4.5	0.03	11:23 AM	14	7.0	0.01
					0.5-DUP	23.2	6.58
15-Sep-97							
10:00 AM	0.5	17.7	7.40	11:45 AM	0.5	18.6	7.50
	1	17.6	7.20		1	18.6	7.58
	2	16.6	0.42		2	18.5	7.54
	3	11.6	0.17		3	18.3	7.15
	4	8.3	0.51		4	14.2	0.21
	5	6.7	1.33		5	10.6	0.22
	6	5.9	1.45		6	8.9	0.30
	7	5.3	1.09		7	8.2	0.32
	8	5.0	0.58		8	7.8	0.36
	9	4.9	0.19		9	7.6	0.40
	10	4.8	0.16		10	7.4	0.44
	11	4.7	0.16		11	7.3	0.44
	12	4.6	0.15		12	7.2	0.51
	13	4.6	0.15		13	7.1	0.52
	14	4.6	0.15		14	7.1	0.47
					0.5-DUP	18.5	7.86

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
20-Oct-99							
9:47 AM	0.5	10.3	6.90	11:42 AM	0.5	12.0	8.05
9:50 AM	1	10.2	6.96	11:46 AM	1	11.9	7.87
9:53 AM	2	10.2	6.06	11:50 AM	2	11.8	7.70
10:06 AM	3	10.1	4.64	11:52 AM	3	11.7	7.63
10:02 AM	4	9.1	3.12	11:54 AM	4	11.6	7.95
10:00 AM	5	7.4	2.48	11:57 AM	5	9.9	6.80
10:16 AM	6	6.1	3.63	12:00 PM	6	8.8	0.25
10:19 AM	7	5.4	3.31	12:02 PM	7	8.0	0.14
10:28 AM	8	5.1	3.00	12:03 PM	8	7.5	0.13
10:31 AM	9	4.9	2.80	12:04 PM	9	7.2	0.12
10:36 AM	10	4.8	1.26	12:06 PM	10	7.0	0.12
10:40 AM	11	4.7	0.17	12:08 PM	11	6.9	0.11
10:45 AM	12	4.7	0.12	12:10 PM	12	6.8	0.11
10:45 AM	13	4.7	0.12	12:12 PM	13	6.7	0.10
10:50 AM	14	4.7	0.11	12:13 PM	14	6.4	0.09
				12:16 PM	9-DUP	7.4	0.11
17-Nov-99							
9:25 AM	0.5	8.6	7.86	10:37 AM	0.5	9.2	8.25
9:27 AM	1	8.6	7.63	10:38 AM	1	9.1	8.12
9:29 AM	2	8.5	7.62	10:40 AM	2	9.1	7.95
9:32 AM	3	8.1	7.05	10:42 AM	3	9.1	7.70
9:32 AM	4	7.6	6.79	10:46 AM	4	9.1	7.70
9:36 AM	5	7.5	6.07	10:50 AM	5	9.0	7.37
9:39 AM	6	7.1	5.70	10:52 AM	6	9.0	7.13
9:41 AM	7	6.0	2.78	10:54 AM	7	8.9	6.92
9:43 AM	8	5.3	2.20	10:55 AM	8	8.9	9.74
9:46 AM	9	5.1	1.71	10:59 AM	9	8.8	9.01
9:50 AM	10	4.9	0.27	11:01 AM	10	8.1	2.14
9:52 AM	11	4.9	0.05	11:03 AM	11	7.5	0.05
9:54 AM	12	4.8	0.02	11:05 AM	12	7.0	0.00
9:55 AM	13	4.8	0.00	11:07 AM	13	6.9	0.00
9:57 AM	14	4.8	0.00	11:09 AM	14	6.9	0.00
				11:11 AM	4-DUP	9.2	8.00
13-Dec-99							
9:25 AM	0.5	5.6	7.42	10:47 AM	0.5	6.3	8.82
9:28 AM	1	5.7	7.34	10:52 AM	1	6.5	8.65
9:30 AM	2	5.7	7.26	10:56 AM	2	6.5	8.59
9:34 AM	3	5.7	7.25	10:58 AM	3	6.5	8.73
9:36 AM	4	5.7	7.22	11:00 AM	4	6.5	8.65
9:38 AM	5	5.7	7.02	11:02 AM	5	6.5	8.43
9:40 AM	6	5.7	7.14	11:04 AM	6	6.5	8.49
9:42 AM	7	5.7	7.10	11:06 AM	7	6.5	8.43
9:45 AM	8	5.7	7.11	11:08 AM	8	6.5	8.50
9:47 AM	9	5.7	6.89	11:11 AM	9	6.5	8.36
9:50 AM	10	5.6	6.50	11:13 AM	10	6.5	8.37
9:52 AM	11	5.6	6.11	11:15 AM	11	6.5	8.44
9:54 AM	12	5.2	2.56	11:17 AM	12	6.5	8.35
9:57 AM	13	5.1	0.20	11:20 AM	13	6.5	8.42
9:58 AM	14	4.9	0.00	11:22 AM	14	6.5	8.47
10:02 AM	4-DUP	5.7	7.12				

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	**Depth** (m)	**Temp** (C)	**DO** (mg/L)	**Time**	**Depth** (m)	**Temp** (C)	**DO** (mg/L)
12-Jan-00							
10:16 AM	0.5	4.0	7.81	11:44 AM	0.5	4.6	9.73
10:20 AM	1	4.1	7.90	11:46 AM	1	4.6	9.84
12:00 AM	2	4.2	8.00	11:48 AM	2	4.6	9.93
10:00 AM	3	4.2	8.00	11:50 AM	3	4.6	9.68
12:00 AM	4	4.2	7.93	11:52 AM	4	4.6	9.80
10:32 AM	5	4.2	8.19	11:54 AM	5	4.6	9.49
10:36 AM	6	4.2	7.96	11:58 AM	6	4.6	9.57
10:38 AM	7	4.2	7.98	12:05 PM	7	4.6	9.44
10:40 AM	8	4.2	7.97	12:08 PM	8	4.6	9.46
10:42 AM	9	4.2	7.98	12:14 PM	9	4.6	9.56
10:46 AM	10	4.2	7.89	12:17 PM	10	4.6	9.52
10:48 AM	11	4.2	7.90	12:20 PM	11	4.6	9.50
10:51 AM	12	4.2	7.98	12:22 PM	12	4.6	9.38
10:54 AM	13	4.2	7.97	12:24 PM	13	4.6	9.39
10:56 AM	14	4.2	7.83	12:25 PM	14	4.6	9.41
10:59 AM	0.5-DUP	4.2	7.92				
9-Feb-00							
9:40 AM	0.5	4.6	9.45	11:08 AM	0.5	4.8	10.55
	1	4.6	9.50	11:11 AM	1	4.6	10.54
	2	4.6	9.44	11:15 AM	2	4.5	10.54
	3	4.4	9.38	11:19 AM	3	4.5	10.43
	4	4.3	9.42	11:25 AM	4	4.5	10.75
	5	4.1	9.34	11:29 AM	5	4.5	10.36
	6	3.8	9.32	11:33 AM	6	4.5	10.27
	7	3.7	9.35	11:38 AM	7	4.4	10.34
	8	3.6	9.27	11:43 AM	8	4.3	10.52
	9	3.6	9.22	11:47 AM	9	4.2	10.48
	10	3.6	9.27	11:54 AM	10	4.2	10.58
	11	3.5	9.17	11:54 AM	11	4.1	10.53
	12	3.5	9.14	11:57 AM	12	4.1	10.33
	13	3.5	9.13	11:58 AM	13	4.1	10.33
	14	3.5	8.97	12:00 PM	14	4.0	10.30
				12:04 PM	0.5-DUP	4.8	10.55
8-Mar-00							
9:42 AM	0.5	6.3	9.73	11:09 AM	0.5	6.3	10.80
9:45 AM	1	6.1	9.68	11:12 AM	1	6.1	10.69
9:48 AM	2	5.4	9.18	11:15 AM	2	5.8	10.56
9:50 AM	3	4.9	9.10	11:19 AM	3	5.7	10.35
9:52 AM	4	4.9	9.03	11:19 AM	4	5.5	10.16
9:57 AM	5	4.3	8.94	11:21 AM	5	5.2	10.02
10:00 AM	6	4.0	8.89	11:22 AM	6	5.1	10.00
10:02 AM	7	4.0	8.84	11:24 AM	7	5.1	10.00
10:05 AM	8	3.9	8.63	11:26 AM	8	4.8	9.97
10:08 AM	9	3.8	8.44	11:28 AM	9	4.8	9.91
10:10 AM	10	3.7	8.08	11:30 AM	10	4.7	9.81
10:12 AM	11	3.7	8.06	11:31 AM	11	4.6	9.78
10:13 AM	12	3.7	7.78	11:32 AM	12	4.6	9.60
10:14 AM	13	3.7	7.40	11:35 AM	13	4.6	9.60
10:15 AM	14	3.7	6.98	11:37 AM	14	4.6	9.19
10:22 AM	0.5-DUP	6.5	9.17				

Lake Temperature and Dissolved Oxygen Profile Data

	BLAKE1			BLAKE2			
Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
5-Apr-00							
9:24 AM	0.5	10.7	9.26	10:45 AM	0.5	11.0	9.90
9:33 AM	1	10.6	9.33	10:48 AM	1	10.9	9.90
9:36 AM	2	7.5	8.75	10:51 AM	2	10.6	10.16
9:38 AM	3	6.5	8.64	10:53 AM	3	8.2	10.41
9:40 AM	4	5.9	8.68	10:56 AM	4	7.2	9.52
9:42 AM	5	5.4	8.49	10:58 AM	5	6.7	9.52
9:45 AM	6	4.8	8.19	11:00 AM	6	6.5	9.34
9:47 AM	7	4.4	8.01	11:02 AM	7	6.4	9.42
9:49 AM	8	4.1	7.92	11:04 AM	8	6.4	9.34
9:51 AM	9	4.0	7.70	11:07 AM	9	6.3	9.12
9:53 AM	10	3.9	7.51	11:09 AM	10	6.3	9.30
9:55 AM	11	3.9	7.19	11:12 AM	11	6.2	9.11
9:57 AM	12	3.9	6.83	11:14 AM	12	6.2	9.00
9:59 AM	13	3.9	6.55	11:16 AM	13	6.2	9.03
10:02 AM	14	3.9	5.63	11:18 AM	14	6.2	8.96
10:07 AM	0.5-DUP	10.5	9.25				
3-May-00							
9:50 AM	0.5	15.0	8.20	11:15 AM	0.5	15.0	8.84
9:52 AM	1	14.3	8.50	11:18 AM	1	13.5	8.84
9:56 PM	2	11.0	6.77	11:20 AM	2	13.5	9.15
9:58 AM	3	6.9	7.73	11:23 AM	3	12.5	8.95
10:00 AM	4	5.8	7.92	11:25 AM	4	8.3	8.25
10:03 AM	5	5.1	7.75	11:27 AM	5	7.1	8.07
10:05 AM	6	4.8	7.77	11:29 AM	6	6.9	7.89
10:07 AM	7	4.3	6.94	11:31 AM	7	6.8	7.76
10:09 AM	8	4.2	6.92	11:33 AM	8	6.7	8.09
10:12 AM	9	4.0	7.10	11:35 AM	9	6.6	8.09
10:14 AM	10	3.9	7.33	11:38 AM	10	6.5	7.91
10:16 AM	11	3.9	7.17	11:40 AM	11	6.3	7.55
10:18 AM	12	3.9	5.54	11:42 AM	12	6.3	7.53
10:20 AM	13	3.9	4.20	11:44 AM	13	6.2	7.38
10:22 AM	14	3.9	3.80	11:46 AM	14	6.2	7.33
10:26 AM	0.5-DUP	15.0	8.50				
31-May-00							
9:53 AM	0.5	15.3	7.65	11:10 AM	0.5	16.0	8.59
9:55 AM	1	15.3	7.77	11:12 AM	1	16.0	8.88
9:57 AM	2	12.3	5.85	11:14 AM	2	15.9	8.75
9:59 AM	3	8.5	6.39	11:16 AM	3	13.4	8.41
10:00 AM	4	6.4	7.02	11:18 AM	4	9.8	6.96
10:08 AM	5	5.5	6.86	11:20 AM	5	8.0	6.33
10:10 AM	6	4.8	6.90	11:22 AM	6	7.2	6.34
10:12 AM	7	4.5	6.90	11:24 AM	7	7.0	6.32
10:14 AM	8	4.2	6.34	11:25 AM	8	6.8	6.58
10:16 AM	9	4.1	6.56	11:27 AM	9	6.6	6.54
10:18 AM	10	3.9	6.90	11:29 AM	10	6.5	6.40
10:20 AM	11	3.9	6.75	11:30 AM	11	6.4	6.11
10:22 AM	12	3.9	4.64	11:32 AM	12	6.3	6.01
10:26 AM	13	4.0	2.64	11:34 AM	13	6.3	5.92
10:25 AM	14	4.0	0.85	11:35 AM	14	6.3	5.61
				11:37 AM	0.5-DUP	15.9	8.72

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	Depth (m)	Temp (C)	DO (mg/L)	Time	Depth (m)	Temp (C)	DO (mg/L)
28-Jun-00							
9:40 AM	0.5	23.3	7.24	10:57 AM	0.5	24.1	7.98
9:44 AM	1	21.1	6.96	10:59 AM	1	23.4	7.92
9:46 AM	2	13.6	8.15	11:01 AM	2	20.1	9.92
9:48 AM	3	9.4	5.16	11:03 AM	3	15.8	10.63
9:50 AM	4	6.7	6.63	11:05 AM	4	11.7	8.65
9:53 AM	5	5.7	6.77	11:07 AM	5	8.8	5.75
9:55 AM	6	5.0	7.14	11:08 AM	6	7.7	5.50
9:57 AM	7	4.6	6.28	11:10 AM	7	7.3	5.44
9:59 AM	8	4.3	6.27	11:12 AM	8	7.1	5.56
10:01 AM	9	4.2	6.40	11:13 AM	9	6.9	5.53
10:04 AM	10	4.0	6.60	11:14 AM	10	6.7	5.05
10:07 AM	11	4.0	4.60	11:15 AM	11	6.6	4.98
10:12 AM	12	4.1	1.96	11:16 AM	12	6.6	4.93
10:14 AM	13	4.1	0.51	11:17 AM	13	6.5	4.74
10:15 AM	14	4.1	0.44	11:18 AM	14	6.5	4.35
				11:21 AM	0.5-DUP	23.7	7.78
26-Jul-00							
10:48 AM	0.5	20.7	6.93	12:18 PM	0.5	21.4	7.34
10:52 AM	1	20.6	6.77	12:20 PM	1	21.4	7.31
10:55 AM	2	14.6	2.22	12:22 PM	2	21.3	7.32
10:58 AM	3	10.4	2.66	12:24 PM	3	18.1	8.74
10:59 AM	4	7.1	4.74	12:26 PM	4	12.7	6.92
11:01 AM	5	5.8	4.90	12:29 PM	5	9.4	7.84
11:04 AM	6	5.1	5.37	12:30 PM	6	8.1	3.80
11:05 AM	7	4.7	5.40	12:32 PM	7	7.4	3.66
11:09 AM	8	4.5	5.51	12:33 PM	8	7.1	3.45
11:10 AM	9	4.3	5.53	12:34 PM	9	6.8	3.20
11:12 AM	10	4.2	4.80	12:35 PM	10	6.7	2.91
11:14 AM	11	4.1	3.61	12:37 PM	11	6.5	2.91
11:16 AM	12	4.1	1.61	12:41 PM	12	6.5	2.72
11:24 AM	13	4.1	0.50	12:43 PM	13	6.4	2.26
11:25 AM	14	4.1	0.56	12:45 PM	14	6.4	1.80
11:29 AM	0.5-DUP	20.9	6.75				
23-Aug-00							
9:28 AM	0.5	20.0	7.71	10:40 AM	0.5	20.7	6.99
9:29 AM	1	19.9	7.15	10:42 AM	1	20.5	4.03
9:32 AM	2	17.2	2.60	10:43 AM	2	20.1	7.01
9:34 AM	3	11.3	2.05	10:45 AM	3	19.1	6.60
9:36 AM	4	8.0	4.25	10:46 AM	4	14.4	5.91
9:40 AM	5	6.3	4.80	10:47 AM	5	10.1	3.40
9:41 AM	6	5.4	4.85	10:49 AM	6	8.2	2.42
9:43 AM	7	5.0	4.77	10:50 AM	7	7.6	2.54
9:46 AM	8	4.7	4.17	12:00 AM	8	7.2	2.58
9:48 AM	9	4.6	4.44	10:53 AM	9	7.0	2.14
9:49 AM	10	4.5	3.29	10:54 AM	10	6.8	1.96
9:51 AM	11	4.5	1.84	10:55 AM	11	6.7	1.87
9:57 AM	12	4.4	1.08	10:56 AM	12	6.5	1.33
9:58 AM	13	4.4	1.05	10:57 AM	13	6.5	0.87
9:59 AM	14	4.4	1.05	10:58 AM	14	6.5	0.80
10:03 AM	0.5-DUP	19.7	5.40				

Lake Temperature and Dissolved Oxygen Profile Data

BLAKE1				BLAKE2			
Time	**Depth** (m)	**Temp** (C)	**DO** (mg/L)	**Time**	**Depth** (m)	**Temp** (C)	**DO** (mg/L)
20-Sep-00							
9:25 AM	0.5	18.5	7.30	10:47 AM	0.5	18.7	7.78
9:30 AM	1	18.4	7.19	10:51 AM	1	18.7	8.10
9:34 AM	2	15.8	5.25	10:55 AM	2	17.9	8.03
9:37 AM	3	12.5	0.63	11:00 AM	3	16.8	7.12
9:40 AM	4	8.3	3.53	11:02 AM	4	15.1	4.15
9:44 AM	5	6.4	4.46	11:04 AM	5	11.2	1.12
9:46 AM	6	5.5	4.43	11:06 AM	6	9.2	0.87
9:48 AM	7	5.1	4.14	11:08 AM	7	8.0	1.23
9:50 AM	8	4.9	3.46	11:10 AM	8	7.6	1.16
9:55 AM	9	4.7	3.26	11:12 AM	9	7.2	0.90
9:57 AM	10	4.6	2.13	11:14 AM	10	7.1	0.88
10:01 AM	11	4.6	1.09	11:17 AM	11	6.9	0.80
10:04 AM	12	4.5	0.90	11:20 AM	12	6.8	0.77
10:07 AM	13	4.5	0.86	11:22 AM	13	6.7	0.76
10:10 AM	14	4.5	0.85	11:24 AM	14	6.7	0.75
				11:29 AM	0.5-DUP	18.8	7.15

1. Temp = temperature
2. DO = Dissolved Oxygen
3. DUP = duplicate sample.

Appendix B

Baseline Stream Data Parameters [1]

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
18-Nov-96														
BLTRI1		5.5	3.6	35	50.2	43.3	610	25 A[3]	10.0 A	4.5	2.0	140	0.9 B	10
BLTRI2		6.0	9.8	46	52.6	21.2	752	254	10.0 A	10.5	1.3	120	1.4	50
BLTRI1 -DUP[2]					38.1	14.6	619	25 A[4]	10.0 A	5.0	1.5	140	1.4	20
16-Dec-96														
BLTRI1		5.2	3.4	20	30.7	14.6	436	101	41.5 B	4.2	1.1	90	0.5 B	10
BLTRI2		5.9	10.7	34	27.5	11.2	694	409	45.0	8.7	1.4	70	0.6 B	12
BLOUT		6.1	9.7	30	30.6	6.1	520	149	74.7	10.1	1.3	60	1.3	13
BLTRI2-DUP		5.8	11.1	42	27.6	10.7	682	414	36.0 B	8.7	2.2	70	1.3	6
21-Jan-97														
BLTRI1		5.4	8.0	19	18.0	12.8	813	536	20.0 B	0.0	1.2	80	0.25 A	31
BLTRI2	6.66	5.6	11.6	32	14.8	10.2	683	432	24.0 B	6.7	1.1	60	1.3	14
BLOUT	18.95	5.9	11.2	27	25.6	12.3	621	293	55.2	7.7	1.6	60	1.0	10
BLOUT-DUP		5.9	11.2	29	20.5	10.9	627	291	56.6	7.7	1.4	60	0.9 B	14
18-Feb-97														
BLTRI1	22.58	5.3	3.8	23	14.4	16.1	238	65 B	40.5	4.7	0.7 B	70	0.9 B	77
BLTRI2	6.09	6.0	10.4	33	21.0	5.7	430	136	31.0 B	9.7	0.5 B	50	0.7 B	11
BLOUT	18.58	6.3	11.1	30	28.6	5.0	588	279	39.0 B	7.9	0.7 B	50	1.0 B	20
BLTRI1-DUP		5.2	4.1	20	26.4	16.1	410	89 B	37.0 B	4.7	0.8 B	80	0.6 B	78
17-Mar-97														
BLTRI1	22.78	5.6	7.7	21	37.5	12.2	617	70 B	29.0 B	4.8	1.4	60	0.25 A	47
BLTRI2	6.4	6.1	11.1	31	48.4	8.0	301	129	44.1	9.0	1.5	60	1.1	8
BLOUT	18.78	6.3	11.4	30	40.4	5.1	598	240	30.0 B	8.2	1.8	50	2.7	28
BLTRI2-DUP		6.1	11.1	30	34.6	7.1	416	125	93.7	8.9	1.2	60	1.2	13
21-Apr-97														
BLTRI1	22.7	6.0	5.6	21	20.3	12.1	436	25 A	34.0 B	5.5	1.8	80	0.7 B	48
BLTRI2	6.14	6.3	9.6	25	22.0	4.8 B	510	72 B	44.1	10.2	1.5	70	2.4	44
BLOUT	18.65		9.2	28	21.2	4.7 B	480	94 B	40.0 B	8.4	1.2	50	0.8 B	30
BLOUT-DUP			9.1	28	13.6	3.4 B	444	102	31.0 B	8.5	1.0	50	0.8 B	13

Baseline Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
19-May-97														
BLTRI1	22.3		0.8	20	105.0	63.1	826	25 A	43.2	7.8	0.7 B	200	1.0 B	N/A
BLTRI2	5.79		5.3	34	54.4	25.6	633	162	81.3	13.9	2.1	80	2.8	5
BLOUT	18.4	6.1	6.4	32	20.0	8.5	337	25 A	55.2	9.4	1.0 B	50	0.7 B	N/A
BLTRI1-DUP			0.7	21	98.8	64.2	828	25 A	53.2	7.7	1.1	240	0.9 B	16
16-Jun-97														
BLTRI1	22.2	5.5	0.1	28	204.0	81.1	152	25 A	32.0 B	9.8	14.0	240	8.6	5
BLTRI2	5.8	6.6	8.1	35	56.3	17.6	1500	140	50.9	14.6	1.7	70	2.4	23
BLOUT	18.41	6.3	6.8	28	36.1	56.9	1230	25 A	22.0 B	9.6	1.2	50	1.3	43
BLTRI2-DUP		6.4	8.1	35	58.7	15.9	888	143	43.2	14.8	2.1	70	2.1	39
20-Oct-97														
BLTRI1	low flow													
BLTRI2	5.81	6.2	8.8	41	25.1	17.1	429	162	40.1	14.9	1.0 B	60	1.8	14
BLTRI2-DUP		6.2	8.7	41	24.9	17.2	436	160	40.2	15.2	1.3	60	1.0 B	10
17-Nov-97														
BLTRI1	22.37	5.4	1.9	37	63.3	36.6	850	25 A	43.5	8.2	5.9	280	2.7	25
BLTRI2	6.01	6.2	9.5	48	22.8	10.8	565	206	38.0 B	15.4	2.7	60	1.9	14
BLTRI1-DUP		5.3	1.9	37	61.3	39.6	860	F	F	8.8	5.6	280	2.5	7
15-Dec-97														
BLTRI1	22.25	5.0	2.3	31	41.9	86.3	591	25 A	45.6	7.3	3.2	200	1.0 B	6
BLTRI2	5.93	6.3	10.5	46	18.4	10.6	589	261	48.7	13.2	1.4	50	1.1	3
BLTRI1-DUP		4.9	2.2	31	40.1	31.5	591	25 A	60.0	6.4	3.0	200	1.0 B	5
20-Jan-98														
BLTRI1	22.79	5.8	6.2	28	8.6	8.4	699	545	26.0 B	4.1	2.4	50	0.25 A	5
BLTRI2	6.43	6.7	11.5	42	20.9	7.2	566	411	28.0 B	9.6	1.1	40	1.1	5
BLTRI2-DUP		6.7	11.5	42	18.7	5.8	533	411	27.0 B	9.6	0.9 B	50	1.1	6
17-Feb-98														
BLTRI1	22.48	5.8	4.3	30	27.8	6.6	463	25 A	10.0 A	6.3	2.7	100	0.9 B	28
BLTRI2	6.01	6.6	11.8	43	19.9	3.4 B	468	242	10.0 A	12.4	0.9 B	50	1.2	18
BLTRI2-DUP		6.6	11.8	43	18.8	3.4 B	492	247	10.0 A	12.2	0.9 B	40	0.8 B	29

Baseline Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
16-Mar-98														
BLTRI1	22.42	5.9	3.8	26	15.9	11.0	429	25 A	10.0 A	9.1	2.3	50	0.5 B	260
BLTRI2	6.03	6.5	10.4	43	14.6	3.4 B	555	232	10.0 A	14.0	1.8	30	2.5	41
BLTRI1-DUP		5.9	3.8	26	24.3	11.4	483	25 A	22.0 B	7.8	2.4	50	0.6 B	210
20-Apr-98														
BLTRI1	22.31	5.9	3.0	26	54.9	11.7	668	25 A	10.0 A	7.9	2.0	60	3.0	4
BLTRI2	5.85	6.9	10.2	44	29.3	2.4 B	558	202	28.0 B	14.4	1.6	20	1.7	15
BLTRI1-DUP		5.9	3.1	28	51.5	11.9	657	25 A	10.0 A	7.8	2.3	80	2.6	8
23-Nov-98														
BLTRI1	22.68	5.4	3.8	58	28.3	6.0	793	158	5.0 A	3.7	2.1	120	0.25 A	29
BLTRI2	6.01	6.3	9.0	48	26.2	5.8	1110	609	5.0 A	4.3	1.5	110	0.6 B	17
BLTRI2-DUP		6.3	9.0	48	26.1	5.9	1090	606	5.0 A	6.3	1.4	110	0.6 B	19
7-Dec-98														
BLTRI1	22.65	5.3	5.1	32	15.1	4.3 B	588	192	10.0 B	4.4	1.5	100	0.7 B	230
BLTRI2	6.31	6.0	10.5	45	15.3	3.9 B	899	529	16.0 B	9.0	1.3	80	0.25 A	25
BLTRI1-DUP		5.4	5.1	34	14.3	4.3 B	555	179	5.0 A	5.5	1.3	100	0.25 A	220
21-Dec-98														
BLTRI1	22.51	5.7	4.4	36	16.0	5.1	655	193	15.0 B	5.3	2.9	110	0.25 A	3
BLTRI2	6.14	6.5	12.9	53	10.2	3.6 B	933	715	35.9	10.1	1.8	60	0.25 A	4
BLTRI2-DUP		6.5	12.8	50	10.5	3.0 B	988	670	29.4	9.9	1.3	50	0.25 A	5
4-Jan-99														
BLTRI1	22.68	5.7	6.5	29	10.3	3.4 B	643	328	10.0 B	4.2	1.1	80	0.25 A	6
BLTRI2	6.24	6.5	11.7	36	9.2 B	2.9 B	824	585	16.0 B	9.3	1.4	60	0.5 B	1
BLTRI2-DUP		6.5	11.7	38	9.6 B	2.9 B	857	586	17.0 B	9.2	1.5	60	0.25 A	5
19-Jan-99														
BLTRI1	22.95	5.8	7.9		13.3	5.1	566	264	5.0 A	4.0	1.2	60	1.5	31
BLTRI2	6.7	6.5	10.9		12.7	3.6 B	649	341	18.0 B	9.2	1.4	50	0.7 B	22
BLTRI1-DUP		5.7	7.7		13.9	5.0	540	262	12.0 B	3.7	1.6	50	0.25 A	27

Baseline Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
1-Feb-99														
BLTRI1	22.89	5.8	7.7	24	11.7	3.9 B	553	251	5.0 A	3.8	1.3	60	0.25 A	80
BLTRI2	6.5	6.5	11.3	42	11.9	3.0 B	742	448	11.0 B	9.5	1.0 B	50	0.25 A	3
BLTRI2-DUP		6.6	11.3	42	11.9	2.9 B	738	440	10.0 B	9.6	1.4	40	0.25 A	4
16-Feb-99														
BLTRI1	22.5	5.9	6.6	25	15.5	6.4	466	84.1	19.0 B	5.9	2.9	80	0.25 A	22
BLTRI2	6.14	6.6	11.4	42	10.9	3.4 B	750	459	11.0 B	9.8	1.6	30	0.25 A	5
BLTRI2-DUP		6.6	11.4	42	11.0	3.3 B	731	460	11.0 B	9.6	1.6	30	0.25 A	8
1-Mar-99														
BLTRI1	23.01	6.0	7.9	24	12.9	4.40 B	424	146	12.0 B	4.9	3.1	40	0.25 A	80
BLTRI2	6.69	6.7	10.8	38	14.7	5.47	560	268	53.1	9.6	2.0	50	1.8	17
BLTRI2-DUP		6.7	10.8		14.1	2.80 B	559	268	12.0 B	9.7	2.5	40	1.8	12
15-Mar-99														
BLTRI1	22.81	5.9	7.0	24	13.0	3.8 B	385	85.9	5.0 A	4.9	1.7	60	0.25 A	22
BLTRI2	6.35	6.2	10.4	38	16.8	2.4 B	473	191	5.0 A	10.4	1.9	40	2.3	7
BLTRI1-DUP		5.8	7.1	24	12.8	3.8 B	386	84.9	5.0 A	5.3	1.7	40	0.25 A	23
29-Mar-99														
BLTRI1	22.48	5.9	7.3	24	16.1	3.8 B	408	10 A	5.0 A	5.7	1.9	90	2.0	4
BLTRI2	6.02	6.5	11.8	42	15.4	1.0 A	479	185	5.0 A	11.8	1.4	40	1.1	6
BLTRI2-DUP		6.5	11.8	42	17.1	1.0 A	516	185	5.0 A	11.7	1.7	40	1.2	5
12-Apr-99														
BLTRI1	22.37	5.7	5.4	25	22.5	4.8 B	515	10 A	14.0 B	6.5	1.4	140	0.25 A	2
BLTRI2	5.93	6.5	10.6	42	18.4	2.1 B	465	154	14.0 B	12.1	1.8	50	1.9	15
BLTRI2-DUP		6.6	10.6	42	20.8	2.2 B	482	151	14.0 B	13.4	2.2	40	3.0	15
26-Apr-99														
BLTRI1	22.29	5.8	3.5	28	31.5	8.9	731	10 A	11.0 B	6.8	1.5	170	0.6 B	3
BLTRI2	5.88	6.4	10.6	45	27.4	3.9 B	567	131	22.6	15.1	2.7	50	2.2	58
BLTRI2-DUP		6.4	10.7	45	28.5	4.1 B	591	132	24.3	15.0	2.6	50	1.8	48

Baseline Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
10-May-99														
BLTRI1	22.31	5.9	5.3	26	25.5	5.8	624	10 A	5.0 A	7.5	1.4	150	0.25 A	2
BLTRI2	5.87	6.9	10.8	42	28.7	4.2	547	91.2	14.0 B	14.4	2.8	60	2.5	45
BLTRI1-DUP		5.9	5.3	26	24.8	5.4	590	10 A	5.0 A	6.9	1.3	170	0.25 A	1
20-Oct-99														
BLTRI1	22.56	6.6	5.4	71	11.3	4.7	170	10 A	5.0 A	26.2	0.8 B	50	0.25 A	12
BLTRI2	low flow													
BLTRI1-DUP		6.6	5.4	72	11.9	5.6	177	10 A	5.0 A	25.9	0.9 B	40	0.25 A	13
3-Nov-99														
BLTRI1	22.45	7.8	1.6	49	32.5	6.2	626	10 A	5.0 A	18.2	1.6	160	0.25 A	9
BLTRI2	low flow													
BLTRI1-DUP		7.8	1.6	49	30.9	5.9	587	10 A	5.0 A	18.0	1.3	180	0.25 A	14
17-Nov-99														
BLTRI1	22.84	5.7	3.1	43	18.8	6.9	407	10 A	5.0 A	11.2	3.2	100	0.25 A	11
BLTRI2		6.3	8.3	53	19.4	4.2 B	695	26.6	5.0 A	11.7	1.5	80	0.25 A	14
BLOUT		6.5	8.0	38	15.5	2.1 B	709	47.2	23.9	11.3	1.2	40	1.4	2
BLTRI2-DUP		6.3	8.3	53	27.9	3.9 B	542	26.3	5.0 A	11.6	1.5	80	0.6 B	20
1-Dec-99														
BLTRI1	22.8	5.8	4.5	33	17.9	5.9	449	71	5.0 A	9.4	1.9	80	0.5 B	12
BLTRI2		6.5	9.9	48	14.0	3.9 B	633	311	15.0 B	12.2	0.7 B	70	0.6 B	43
BLTRI2-DUP		6.5	10.0	48	13.9	4.0 B	645	316	16.0 B	12.3	1.0 B	70	0.6 B	56
13-Dec-99														
BLTRI1	22.87	6.5	6.2	34	16.5	5.4	497	151	5.0 A	8.2	1.2	70	0.9 B	90
BLTRI2		6.9	10.2	45	14.2	4.0 B	596	273	22.3	12.7	0.8 B	60	1.1	15
NORRIS2		6.3	7.8	38	5.3	1.0 A	1690	1610	5.0 A	4.0	0.7 B	10 B	1.3	5
BLOUT		6.9	8.9	49	17.2	3.8 B	498	158	50.2	11.5	1.5	50	1.9	14
BLTRI2-DUP		6.8	10.2	45	14.4	3.6 B	594	263	22.1	12.5	1.0 B	70	1.3	21

Baseline Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
29-Dec-99														
BLTRI1	22.41	5.8	3.0	51	18.7	6.1	473	24 B	20.7	11.5	1.5	130	0.25 A	7
BLTRI2		6.3	11.1	53	11.3	3.3 B	690	430	46.8	13.6	1.3	40	0.7 B	4
BLTRI1-DUP		5.6	3.0	51	21.0	6.1	464	10 A	22.0	11.4	1.3	100	0.25 A	5
12-Jan-00														
BLTRI1	22.66	5.7	8.2	41	15.7	5.4	478	148	11.0 B	8.4	1.7	60	0.5 B	65
BLTRI2		6.3	11.7	53	14.0	4.4 B	554	230	26.8	13.6	1.3	50	1.1	5
BLOUT		6.4	10.3	47	16.8	4.9 B	566	200	46.7	11.1	1.5	40	1.7	16
BLTRI2-DUP		6.3	11.7	53	13.8	3.8 B	550	238	26.1	13.6	1.5	50	1.5	10
26-Jan-00														
BLTRI1	22.48	5.4	4.9	30	42.7	6.9	742	48.4	21.3	9.3	9.1	90	18.6	12
BLTRI2		6.2	12.0	47	12.3	4.5 B	631	313	19.0 B	13.5	0.9 B	40	0.25 A	5
BLTRI1-DUP		5.4	4.9	30	39.4	7.1	714	45.4	21.0	9.1	8.4	90	18.8	14
9-Feb-00														
BLTRI1	22.79		7.7	29	18.6	8.0	497	167	17.0 B	8.1	2.6	65	1.6	44
BLTRI2			10.3	44	15.9	3.4 B	540	221	16.0 B	13.4	1.7	40	1.4	25
NORRIS2			8.3	35	2.5 A	2.2 B	1430	1280	5.0 A	4.4	0.3 A	10	0.25 A	3
BLOUT			10.7	34	16.7	3.7 B	564	243	13.0 B	11.0	1.8	50	2.0	13
BLTRI2-DUP			10.3	44	16.0	3.5 B	516	223	16.0 B	13.4	2.1	45	1.2	16
23-Feb-00														
BLTRI1	22.63	6.1	6.8	31	20.1	8.8	415	80.3	22.4	8.9	1.9	60	0.7 B	47
BLTRI2		6.7	10.9	36	23.8	3.9 B	554	184	21.7	13.6	3.5	45	5.7	29
BLTRI1-DUP		5.9	6.8	31	21.6	8.3	395	77.2	21.7	8.7	1.9	65	0.25 A	54
8-Mar-00														
BLTRI1	22.61	7.0	6.1	30	15.2	6.3	556	111	16.0 B	7.7	1.8	55	0.25 A	17
BLTRI2		7.1	10.7	45	14.5	3.3 B	541	261	14.0 B	13.1	1.1	40	1.3	10
BLOUT		7.1	10.9	40	16.2	2.0 B	552	202	5.0 A	10.0	1.0 B	35	1.5	20
BLTRI2-DUP		7.1	10.7	45	18.3	3.2 B	455	262	14.0 B	13.1	1.1	35	1.1	4

Baseline Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
22-Mar-00														
BLTRI1	22.56	5.7	6.3	31	23.6	8.7	374	25 B	16.0 B	8.2 B	1.9	70	0.7 B	10
BLTRI2		6.4	10.7	46	30.9	4.3 B	574	230	17.0 B	12.2	6.3	55	4.2	26
BLTRI2-DUP		6.3	10.6	46	32.0	4.3 B	544	232	17.0 B	12.3	6.3	55	4.6	24
5-Apr-00														
BLTRI1	22.49	6.8	6.3	30	42.9	11.8	603	10 A	20.0 B	8.5 B	4.8	80	5.4	25
BLTRI2		7.0	10.7	43	23.2	3.4 B	575	180	18.0 B	13.5	2.2	45	2.3	90
BLOUT		7.0	9.1	40	32.3	1.0 A	659	150	34.0	9.9 B	1.0 B	45	1.9	26
BLTRI2-DUP		7.0	10.7	43	22.6	3.4 B	601	181	18.0 B	13.6	2.0	45	2.2	64
19-Apr-00														
BLTRI1	22.4	5.7	3.1	35	45.8	18.7	553	10 A	14.0 B	10.2	2.1	120	1.2 B	6
BLTRI2		6.6	9.5	52	31.8	5.0	548	144	23.1	15.8	3.9	45	4.6	35
BLTRI2-DUP		6.5	9.6	52	32.5	4.8 B	581	145	24.0	15.7	3.9	45	4.5	30
3-May-00														
BLTRI1	22.33	5.9	2.4	53	88.4	49.6	803	10 A	29.4	11.1	1.8	170	1.4	27
BLTRI2		6.6	9.2	67	33.2	57.4	562	135	27.8	16.4	2.8	50	3.1	76
BLOUT		6.6	8.3	51	20.9	1.0 A	427	61	20.5	9.7 B	0.6 B	40	0.6 B	25
BLTRI1-DUP		5.9	2.4	53	89.9	50.5	806	10 A	29.5	11.1	1.8	170	1.4	35
17-May-00														
BLTRI1	22.3	5.5	1.4	38	95.5	55.1	919	10 A	34.0	10.8	2.8	210	3.2	14
BLTRI2		6.3	8.8	50	33.3	6.4	596	149	33.4	16.0	3.5	60	2.7	41
BLTRI2-DUP		6.3	8.8	50	31.1	6.3	592	148	35.3	15.9	3.3	50	2.7	44
31-May-00														
BLTRI1	22.38	5.6	2.2	32	67.9	37.3	831	10 A	43.8	10.2	2.1	180	0.9 B	30
BLTRI2		6.1	9.0	43	26.6	5.2	560	137	36.2	15.8	3.0	55	2.4	160
BLOUT		5.9	6.5	39	15.4	2.9 B	499	10 A	31.8	10.1	0.6 B	35	0.25 A	13
BLTRI1-DUP		5.6	2.2	32	64.6	37.3	755	10 A	44.1	10.2	2.1	180	0.9 B	33

Baseline Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
14-Jun-00														
BLTRI1	22.41	5.7	2.0	40	79.3	38.9	771	10 A	25.4	11.8	2.2	120	0.8 B	24
BLTRI2		6.6	8.6	44	35.6	4.1 B	657	72.5	29.3	13.9	2.5	60	3.8	120
BLTRI2-DUP		6.6	8.6	44	34.5	4.2 B	685	73.5	30.4	13.7	2.4	60	4.1	140

1. Temp = temperature, Cond = Conductivity, Trans = transparency,TP = Total Phosphorus, SRP = Soluble Reactive Phosphorus, TN = Total Nitrogen, NO_3+NO_2 = Nitrate+Nitrite, NH_4 + Ammonia, Alk = Alkalinity, Turb = Turbidity, TSS = Total Suspended Solids.

2. DUP = duplicate sample.

3. Code A=Less than Method Detection Limit; B=Less than Reporting Detection Limit; F=No value reported. All codes are to right of applicable cell.

4. When coded A, mid-value between zero and the Method Detection Limit is used for calculations. For 1997: NO_2+NO_3, A=25µg/L; NH_4, A=10.0µg/L; Turb, A=0.25NTU; TSS, A=0.25mg/L. For 2000: SRP, A=1.0µg/L; NO_2+NO_3, A=10µg/L; NH_4, A=5.0µg/L; Turb, A=0.25NTU;TSS, A=0.25mg/L

Storm Stream Data Parameters [1]

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mg$CaCO^3$/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
30-Jan-97														
BLTRI1		5.6	5.5	17	25.1	16.6	472	149	43.5	4.4	0.9 B[2]	60	0.25 A[3]	58
BLTRI2	6.2	6.0	10.8	25	20.8	10.3	560	363	37.0 B	8.2	1.2	60	0.6 B	29
4-Mar-97														
BLTRI1	22.85	5.8	8.6	21	19.0	17.5	434	147	49.4	4.2	1.1	60	0.7 B	180
BLTRI2	6.5	6.3	11.8	24	21.5	15.5	390	150	45.9	8.7	0.7 B	60	1.3	12
18-Mar-97														
BLTRI1	23	5.2	8.5	18	17.8	13.0	446	149	38.0 B	4.5	1.4	60	0.8 B	38
BLTRI2	6.9	6.0	10.4	22	80.5	9.6	513	156	36.0 B	8.0	2.2	60	3.3	73
16-Dec-97														
BLTRI1	22.37	5.2	4.2	30	46.6	34.7	670	25 A	24.0 B	6.8	4.4	240	1.9	9
BLTRI2	6.15	6.1	10.6	44	67.2	25.5	806	327	33.0 B	11.6	4.5	80	12.3	100
23-Mar-98														
BLTRI1	22.69	6.0	4.8	25	35.0	7.8	517	88 B	10.0 A	7.0	2.5	40	0.9 B	53
BLTRI2	6.22	6.8	9.4	39	17.9	2.3 B	651	192	27.0 B	12.7	2.1	20	7.0	54
25-Nov-98														
BLTRI1	22.8	5.4	5.6	53	23.9	5.7	605	48.9	A	3.9	2.4	140	0.25 A	74
BLTRI2	6.65	6.2	9.6	45	41.2	8.0	1070	459	15.0 B	8.6	3.7	150	4.4	270
30-Dec-98														
BLTRI1	22.99	5.6	6.0	41	50.9	12.3	618	366	A	3.5	1.0 B	60	0.25 A	23
BLTRI2	6.63	6.5	10.5	42	12.5	3.7	759	498	A	8.8	0.9 B	50	0.25 A	16
18-Jan-99														
BLTRI1	22.83	5.8	7.9		14.4	5.1	537	199	A	4.3	1.4	60	0.25 A	46
BLTRI2	6.65	6.5	11.1		15.1	3.7 B	662	359	15.0 B	9.9	1.3	50	0.8 B	13

Storm Stream Data Parameters

Sample Location	Gauge (ft)	pH	Temp. (C)	Cond (µmhos/cm)	TP (µg/L)	SRP (µg/L)	TN (µg/L)	NO_3+NO_2 (µg/L)	NH_4 (µg/L)	Alk (mgCaCO³/L)	Turb (NTU)	Color (CPU)	TSS (mg/L)	Fecals (CFU/100ml)
5-Feb-99														
BLTRI1	23.2	6.0	9.4	24	12.6	4.2 B	588	247	15.0 B	3.5	1.2	50	0.25 A	57
BLTRI2	6.95	6.5	11.5	37	17.7	6.2	618	327	22.3	8.1	2.5	40	3.9	25
23-Feb-99														
BLTRI1	22.85	5.8	9.1	23	14.6	5.7	371	122	12.0	4.2	1.8	60	0.25 A	160
BLTRI2	6.82	6.5	11.3	37	16.3	3.4	555	220	12.0	9.1	1.8	50	2.3	25
13-Dec-99														
BLTRI1	22.87	6.5	6.2	34	17.1	5.5	507	145	5.0 A	8.2	1.2	80	0.5 B	110
BLTRI2	15.21	6.8	10.2	45	14.4	3.1 B	607	270	21.4	12.4	1.0	60	1.20	18
NORRIS2		6.3	7.7	36	6.2 B	1.0 A	1750	1640	5.0 A	4.1	0.3 A	10	1.20	12
1-Feb-00														
BLTRI1	22.73	5.6	8.2	28	27.6	11.6	470	51.1	30.9	8.4	3.4	80	1.60	60
BLTRI2	15.84	6.2	11.3	39	49.4	6.5	859	307	30.5	12.0	11.0	55	22.8	60
8-Feb-00														
BLTI1	22.64	5.6	6.0	31	23.7	9.1	432	55.7	26.6	9.2	2.1	80	0.69 B	47
BLTRI2	15.45	6.2	10.7	41	21.1	4.6 B	635	274	21.7	12.6	2.6	50	3.5	63

1. Temp = temperature, Cond = Conductivity, Trans = transparency,TP = Total Phosphorus, SRP = Soluble Reactive Phosphorus, TN = Total Nitrogen, NO_3+NO_2 = Nitrate+Nitrite, NH_4 + Ammonia, Alk = Alkalinity, Turb = Turbidity, TSS = Total Suspended Solids.

2. Code A=Less than Method Detection Limit; B=Less than Reporting Detection Limit. All codes are to right of applicable cell.

3. When coded A, mid-value between zero and the Method Detection Limit is used for calculations. For 1997: NO_2+NO_3, A=25µg/L; NH_4, A=10.0µg/L; Turb, A=0.25NTU; TSS, A=0.25mg/L. For 2000: SRP, A=1.0µg/L; NO_2+NO_3, A=10µg/L; NH_4, A=5.0µg/L; Turb, A=0.25NTU;TSS, A=0.25mg/L

Appendix C

Beaver Lake Phytoplankton Community Composition

1999-2000 Annual Patterns

This section discusses annual phytoplankton community trends within the two Beaver Lake basins in terms of organism density, biovolume, and changes in major species as part of the 1999-2000 Phase II study. Phytoplankton data analyses are based on composite (surface to 3.5 m) sample collections made from two lake stations (Station 1 and Station 2, representing Basin 1 and Basin 2, respectively) over thirteen dates from October, 1999 through September, 2000. Individual phytoplankton data tables were generated for each sample date of the study and are contained in the Appendices. Additionally, the Phase II project included measurement of other selected chemical and physical parameters in Beaver Lake as part of the expanded citizen lake monitoring program during the same 1999-2000 water year time period. References to certain of these auxiliary physical and chemical data are made in this section where appropriate to further describe certain aspects of the plankton data. Phytoplankton data obtained from the current monitoring study is also compared to similar data collected during the 1996-1997 water year of the Phase II Project (King County, 1997) and the 1991-1992 water year of the Phase I monitoring investigation (King County, 1993). Phytoplankton sampling methods used in the Phase I study differed slightly from that employed in both Phase II studies. Depth of composite sample collection in both basins was set at 0-3.5m in the Phase II studies, whereas in the Phase I study this depth varied in each basin on each date according to secchi depth/euphotic zone relationships.

Phytoplankton: Definition and Measurement

Freshwater phytoplankton include a variety of algae, bacteria and infective stages of certain fungi and actinomycetes (Reynolds, 1984), but the algae are the most conspicuous and prominent group of phytoplankton. These microscopic, photosynthetic plants form the basic foundation of food production in a waterbody. Planktonic algae along with bacteria, fungi and fine organic matter, are directly grazed by higher organisms, primarily the zooplankton, which are consumed by other invertebrate and vertebrate (fish) predators.

Major groups of algae commonly occurring in a lake are the blue-green bacteria (**Cyanobacteria**), the green algae (**Chlorophyta**), the yellow-green/golden brown algae (**Chrysophyta**, diatom and non-diatom species), the dinoflagellates (**Pyrrhophyta**), euglenoids (**Euglenophyta**), and cryptomonads (**Cryptophyta**). The types and amount of algae present in a lake vary over the annual cycle, and are dependent on a complex interaction of factors such as nutrient supply, light, temperature, sinking rates, and invertebrate grazing. The algae in a lake can be used as indicators of the overall nutrient status of the waterbody, and the likelihood of nuisance algae blooms. Certain algae, such as some forms of blue-green algae (a.k.a., cyanobacteria), are characteristic of nutrient enrichment. Filamentous blue-greens, like *Aphanizomenon flos-aquae*, can regulate their buoyancy in response to light and nutrients, and can outcompete diatom and green algae when dissolved nutrients are in high supply but at low concentrations (Welch, 1980). Under optimal growth conditions, these highly competitive, opportunistic forms can proliferate rapidly, forming dense populations or "blooms" in the water column, that often appear as green scums.

The *quantity, density or abundance* of algae present in freshwaters is commonly measured in terms of numbers of cells (for unicellular forms) or numbers of colony aggregates per unit volume of water. While measuring numbers of organisms is useful for determining relative occurrence of different algal types, numbers alone do not indicate the *amount of biological matter* in the water. Biovolume is a quantitative measure of the mass of algal cells. Total biovolume of algal organisms equals the total number of algae forms times average cell volume (based on geometric shape) per unit volume of water.

Phytoplankton Cell Density Trends

Figures 1 and 2 present algal cell densities (cells/ml) by major group in Beaver Lake samples collected at Station 1 and Station 2, respectively, on thirteen dates from October, 1999 through September, 2000. {**NOTE:** On some of the sample dates, **very low algal group densities** may not show up on the graph as distinctly as higher algal group densities because of the great disparity between high and low measures}.

Inspection of these data reveal marked differences in algal cell density patterns between the two Beaver Lake stations during 1999-2000 water year study period. During the fall, 1999-winter, 2000 span of the study, algal sample densities were generally higher in Beaver Lake 2 than Beaver Lake 1. The reverse was true during the spring-summer, 2000 seasons, when phytoplankton sample data from Basin 1 typically showed greater cell counts relative to those measured in Basin 2. Furthermore, the quantity, timing and intensity of sample cell density peaks differed within the two lake basins, as did relative algal group composition and dominance over the twelve month period of the current study.

Beaver Lake Basin 1

During the fall, 1999-winter, 2000 span of the study, the phytoplankton community of Beaver Lake 1 shifted from low densities dominated by cryptomonads and non-diatom chrysophytes to elevated spring-summer populations of cyanobacteria. Basin 1 phytoplankton exhibited a single sample density peak of 28,661 cells/ml that occurred on June 28, which was almost entirely composed of the filamentous cyanobacteria, *Aphanizomenon flos-aquae.* The sample density maximum recorded on the late June date, reflecting the *Aphanizomenon* bloom, was the largest measured during the 1999-2000 study period and corresponded to an epilimnetic chlorophyll *a* concentration of 20.8 μg/L that was the study high as well. Also, a low secchi depth measure of 1.5 m was obtained on this date, consistent with the historical occurrence of generally poor water transparency during the growth season in Basin 1.

Beaver Lake Basin 2

The predominantly non-diatom chrysophyte-cyanobacteria assemblage characterizing the Beaver Lake 2 algal community in the first half of the study year transitioned to higher, but fluctuating, densities of a cyanophyte dominated assemblage later in the study. In contrast to the single, study high Basin 1 peak, the algal community of Basin 2 demonstrated lower, tri-modal density maxima, with the smallest maximum recorded on October 20, mainly resulting from a fall pulse in the colonial chrysophyte, *Dinobryon sociale*. A secondary peak occurred on April 5, 2000 (5,187 cells/ml) with the primary peak on September 20, 2000 (9,951 cells/ml), which was the second highest peak of the entire study. The two growth season density maxima in Beaver 2 were the result of elevated populations of the blue-green species, *Aphanizomenon flos-aquae*, also the peak dominant form found in Basin 1.

Interestingly, the two algal density peaks in Basin 2 occurring at the fall endpoint dates of the study corresponded with highest chlorophyll *a* values (13.7 ug/L on October, 20; 12.5 ug/L on September 20) recorded in Basin 2.

Sample population density patterns, including number and timing of peaks in each basin of the current study are generally comparable to that reported in Beaver Lake during the 1996-1997 water year investigation (King County, 1997). However, sample populations in Basin 1 did reveal a dramatic crash by mid-August, 1997 that was unlike the more gradual decline and restructuring of the algal community observed in the current study. The magnitude of relative maxima also showed between-study year differences. Specifically, the late June Basin 1 peak (28,661 cells/ml) in the current study was 25% higher than the comparative late July, 1997 study level (22,880 cells/ml), both of which reflected surging populations of *Aphanizomenon flos-aquae*. In both studies, Basin 2 phytoplankton exhibited tri-modal density maxima, but the occurrence of the primary peak differed. The principal peak (33,000 cells/ml) in the 1996-1997 study occurred in April, which was the study high, as opposed to the late September, 2000 primary maximum (9,951 cells/ml), which was not the study high. Both of these Basin 2 peaks were almost exclusively due to blooms of the cyanophyte, *Aphanizomenon flos-aquae*.

Algal Group Contributions

The **Cyanophyta (blue-green bacteria)** dominated the epilimnetic phytoplankton community (>50% composition of total sample cell counts) at both Beaver Lake stations during the April-September, 2000 growth season. This predominance was more pronounced in Beaver 1, where the cyanophyte (blue-green bacteria) group exhibited a classic growth curve, with a single sample population peak occurring on June 28, which coincided with the overall phytoplankton density high for the study. During this six month period, the filamentous form, *Aphanizomenon flos-aquae*, was the principal blue-green species represented in the epilimnetic samples collected at Station 1. The 1996-1997 study also revealed cyanobacteria group dominance over other algal groups during the latter half of the water year in Basin 1. Interestingly, the cyanophyte group was not detected in any of the composited samples collected within the Station 1 epilimnion in the first half of the study period from October, 1999 through March, 2000. Absence of blue greens from epilimnetic composite samples in Beaver 1 during a similar fall-winter season period was also a feature of the 1996-1997 study. Furthermore, cyanophytes did not appear in samples from Beaver 1 during the winter season of 1991-1992 of the Phase I study .

The cyanophyte group was present in the phytoplankton sample community within Basin 2 throughout most of the twelve month 1999-2000 water year period, unlike the group's more limited representation in Basin 1 samples during the last six months of the study. The cyanobacteria within Basin 2 showed a dominance of the phytoplankton community over the year 2000 growth season similar to that observed within Basin 1. However, the group revealed greater fluctuations in sample population growth patterns over the same time frame, demonstrating two smaller population peaks compared to the single maximum at Station 1 that was the study period high. Epilimnetic cyanophyte populations in Basin 2 peaked in early April, experienced a dramatic crash by late June, with numbers again surging to highest levels by late September study end. As was found in Station 1, the dominant cyanophyte composing the density highs measured at Station 2 was *Aphanizomenon flos-aquae*. *Coelosphaerium Naegelianum*, a common colonial form, appeared regularly at low densities in Station 2 samples during the annual study. This species became the predominant cyanophyte within Basin 2 when *Aphanizomenon* populations (and overall cyanophyte group numbers) were low, particularly in the period from October, 1999 through January, 2000, and again from late May through July, 2000. The presence of the blue-green bacteria group throughout most of the study year and prevalence of *Aphanizomenon flos-aquae* were also features of the Beaver Lake 2 phytoplankton sample community during both the 1996-1997 and 1991-1992 study years.

The **Chrysophyta** was the next most important contributor to phytoplankton community density, persisting in low numbers throughout the current twelve month study period at both Beaver Lake stations. The group's presence was more conspicuous within the Basin 2 sample phytoplankton community than the Basin 1 algal assemblage. Interestingly, the non-diatom species generally dominated group cell densities at both lake stations over the course of the 1999-2000 study. The non-diatom Chrysophyta was the overwhelming sample density dominant at Station 2 on both the October and November, 1999 sample dates, making up 79% and 54% of total sample density, respectively. This was due to a surge beginning in October of populations of the colonial non-diatom, *Dinobryon sociale. Dinobryon sociale* is a common plankton species that thrives in hard-water habitats, and can produce taste and odor problems in lakes at elevated concentrations. This species exhibited a sample density peak of 2250 cells/ml and biovolume peak of 2.0 mm3/L on the late October, 1999 date before experiencing a dramatic population crash by mid-December. The 1996-1997 study also noted a conspicuous presence of *Dinobryon sociale* populations in the Basin 2 algal community from October to December, but at lower densities. Additionally, this earlier study showed surging numbers of *Dinobryon* and domination of Basin 1 community density by mid September, 1997, a condition not observed during the present study in Beaver 1.

The **Bacillariophyta (diatom group)** was a minor density component of the Beaver Lake phytoplankton community, contributing significantly to sample numbers on only one occasion in the current study. At Station 2, the diatoms accounted for 79% of total sample cell counts on June 28 due to small numbers of the colonial, star-shaped diatom, *Asterionella formosa* and unicellular forms of the centric diatom, *Cyclotella* spp. This date also marked the growth season density low in the epilimnetic phytoplankton assemblage in Basin 2, corresponding to a disappearance from the upper water column of the previously dominant cyanophyte, *Aphanizomenon flos-aquae*. Of note too was the uniform occurrence of very low concentrations of TP (mean=12.3 ug/L) measured throughout the water column at Station 2 on the late June date. During the 1996-1997 water year chrysophyte diatoms also maintained low background populations at both stations, contributing very little to overall sample cell densities.

The **Cryptophyta** exhibited cell density trends similar to that of the Chrysophyta, namely, persistence of low background populations throughout the twelve month period in Basin 2, and prevalence in the community that was more conspicuous within the first half of the 1999-2000 water year in Basin 1, when overall algal densities were at a fall-winter season low. In fact, the cryptomonads overwhelmingly dominated sample cell density measures throughout the October, 1999-March, 2000 period in Basin 1. The common, dimunitive form, *Rhodomonas* sp., followed by *Cryptomonas* spp., were the numerical group dominants at both lake stations during this time. Cryptomonad population trends observed in both basins in the current study are analogous to those documented during the 1996-1997 water year.

In terms of cell density, the **Chlorophyta (green algae)** group was a minor component of the Beaver Lake phytoplankton community within both lake basins, maintaining low numbers during the current twelve month study period. The largest contribution made by the green algae to total cell count measures were found in samples collected at Station 2 only in early May and late July 2000, due to the presence of small, colonial forms. Interestingly, these time periods coincided with depressed populations of blue-green bacteria. **Euglenophyta (euglenoids) and Pyrrhophyta (dinoflagellates)** composed an even smaller percentage of phytoplankton sample cell counts at both lake stations throughout the twelve month interval of the present investigation. Similar numerical trends in these three algal groups were documented in both lake basins during the 1996-1997 water year study.

Algal Cell Volume Patterns

Figures 3 and 4 present algal cell volume (cubic microns/ml) by major group in Beaver Lake samples collected at Station 1 and Station 2 on thirteen dates from October, 1999 through September, 2000. {**NOTE:** On some of the sample dates, **very low algal group cell volumes** may not show up on the graph as distinctly as higher algal group cell volumes because of the great disparity between high and low measures}.

Overall phytoplankton biovolume trends, including timing and intensity of peaks, were distinctly different for each Beaver Lake Basin during the 1999-2000 study year. Also, with a few exceptions, trends in algal cell volume did not always follow cell density patterns in either lake basin during the twelve month span of the current investigation. This was mostly due to small-sized density dominants co-occurring with low numbers of larger organisms.

Algal cell volume measures generally coincided with corresponding chlorophyll *a* (chl *a*) concentrations in both Beaver Lake basins (Figure 5) over the annual cycle of the current Phase II study, varying somewhat in overall magnitude. Disparity between the two parameters occurred on a few dates when low densities of large spherical colonies of the green alga, *Volvox* sp., penetrated the epilimnetic phytoplankton community of Beaver Lake. Presence of even a few of these robust algal colonies/ml had the effect of dramatically skewing total cell volumes upward for that date, but apparently having much less influence on chl *a* levels (see discussion below of December 13 sample data in Basin 1).

Beaver Lake Basin 1

The sample phytoplankton community characterizing Beaver Lake Basin 1 demonstrated two clear biovolume peaks during the 1999-2000 water year. The first and largest of the study (4.2 mm^3/L) occurred on December 13, due almost exclusively to very low numbers (1 colony/ml) of the green alga, *Volvox* sp., which can form large, hollow, spherical colonies. Interestingly, this was a seasonal low point in sample cell numbers, a time at which small cryptomonad flagellates dominated. The early winter biovolume high in Basin 1 coincided with very low chl *a* concentrations of 0.34 ug/L (Figure 5) and reduced secchi depth levels (1.5 m). This phenomenon illustrates how the presence of a few large-celled organisms, like *Volvox*, may have more of an effect on physical water quality conditions in this basin, skewing biovolume measures to the very high side, and perhaps contributing to low water transparency. A second biovolume high of 3.6 mm^3/L was measured on June 28, which as noted above, corresponded both to an epilimnetic chl *a* peak (Figure 5) and to the sample algal density peak in that basin (Figure 1). This maximum was the result of greatly elevated populations (28,600 cells/ml) of the cyanophyte, *Aphanizomenon flos-aquae*, which accounted for 99.8% of total sample cell volume computed on that date.

Total biovolume trends in Basin 1, as well as timing of peak occurrences and algal group dominants at those times, were comparable to those recorded for the 1996-1997 water year. However, the magnitude of peak volumes were significantly greater in the earlier water year study (23.7 mm^3/L on 11/96; 6.3 mm^3/L on 7/97) due to the presence of more larger-bodied phytoplankton forms. For example, *Volvox* colonies appearing in the November samples were larger, and the robust dinoflagellate, *Ceratium hirundinella,* co-dominated with cyanophytes on the July date, skewing biovolume measures upwards. Algal cell volume trends in Basin 1 documented during the 1991-1992 Phase I study were in striking contrast to both of these later Phase II investigations. Of note was the prominence of the Euglenophyta group throughout the first half of the Phase I study year, as well as the occurrence of three primary peaks (November, April, September), the first two of which were dominated by the euglenoid species, *Eutreptia viridis*. Interestingly, this small euglenoid was not observed in epilimnetic samples collected from either basin during both Phase II investigations.

Beaver Lake Basin 2

During the first half of the study year, the phytoplankton community in Basin 2 demonstrated cell volume patterns that followed cell density patterns, a condition unlike that observed in Basin 1. A biovolume peak of 2.2 mm^3/L (and correlative density and chl *a* peaks) was recorded on October 20, 1999, that was the result of a population pulse in the colonial non-diatom chrysophyte, *Dinobryon sociale*. Continued low cell volumes and densities during the winter, 1999-2000 season gave way to marked fluctuations in phytoplankton biovolumes for the last six months of the water year, as different algal groups traded off in dominance. The primary biovolume high occurred on July 25 in Basin 2 due to the presence of small numbers of the large colonial green alga, *Volvox* sp. At the time of both biovolume peaks in Basin 2, water transparency was also relatively high with secchi depth measures varying from 3.0 to 3.5 m. Of note is that the timing of the cell volume maximum coincided with a mid-summer dip in algal cell densities and lower chlorophyll *a* levels (4.6 ug/L) in the basin. This phenomenon is somewhat reminiscent of the fall, 1999 biovolume peak measured in Basin 1 that also reflected small numbers of *Volvox* sp. occurring during a winter population density and chl *a* low (see above discussion). Except for a similar winter season low, total biovolume trends in Basin 2 for the current year study were not highly comparable to those recorded for the 1996-1997 water year. The number, timing and magnitude of phytoplankton biovolume peaks differed between the two study years in this basin. The earlier study showed only one clear maximum of 13.4 mm^3/L in April, with biovolumes tailing off dramatically for the remainder of the year 1997 growth season. The two studies do share the similarity that both growth season biovolume highs were dominated by the large green algal species, *Volvox*. In contrast, results of the 1991-1992 study demonstrated lower annual algal biovolumes with greater dominance by blue-greens in Beaver 2 than either of the later studies.

Algal Group Contributions

Review of these data also show variable dominance of phytoplankton biovolume measures by the major algal groups over the 1999-2000 water year that was different for each Beaver Lake basin. The **Chrysophyta** group (diatoms and non-diatoms) as a whole was a conspicuous member of the Beaver Lake plankton community, particularly within Basin 2.

The **non-diatom chrysophytes** were important contributors to sample cell volumes of both stations at the start of the investigation in October, 1999 and again by late August to September, 2000. However, at these two water year endpoints, chrysophyte influence on biovolume measures was due to small pulses in different species within each basin. Whereas the unicellular flagellates, *Mallomonas* spp., dominated Station 1 sample biovolume at these times, the prevalent non-diatom form accounting for the majority of the Station 2 sample algal biovolume was the colonial species, *Dinobryon sociale*. In fact high numbers of the latter species contributed significantly to concurrent phytoplankton community peaks in both density and biovolume measured at Station 2 on the October 20 date. Furthermore, the highest chlorophyll *a* levels in Basin 2 also occurred at the two endpoints of the study when *Dinobryon* was prominent. Non-diatom chrysophyte group influence on phytoplankton cell volumes was more similar between the two study years in Basin 2, where *D. sociale* was an important biovolume contributor. In contrast, relative to the current study year, the non-diatom chrysophytes were more prevalent contributors to Beaver 1 cell volume measures during both the 1996-1997 and 1991-1992 water year studies, with *D. sociale* becoming the biovolume dominant in September of both years in that basin.

The **diatom chrysophytes** contributed very little to sample biovolume measures at both lake stations during the 1999-2000 water year, with one exception. Unicellular centric diatoms, represented by species of *Cyclotella*, overwhelmingly dominated cell biovolumes in Station 2 samples from May 31 through June, 1999. This occurrence corresponded to an early summer, 2000 trough in algal density, reflecting plunging populations of the blue-green dominant, *Aphanizomenon flos-aquae*, from the upper water column. Like the current study, diatoms contributed little to overall sample cell volumes in Basin 1 for most of the 1991-1992 study year, becoming important contributors only during July-August, 1992. Diatoms were observed to be minor components of the Beaver Lake phytoplankton community in both basins during the 1996-1997 water year.

Results of the current study show the **blue-green bacteria** group composing the Beaver 1 phytoplankton assemblage dominated biovolume measures only from May through July, coinciding with peak densities of *Aphanizomenon flos-aquae*. A similar trend of short cyanophyte biovolume dominance over the late spring-early summer period in Beaver 1 was also a feature of the earlier 1991-1992 Phase I and 1996-1997 Phase II studies. As noted above, the blue-greens prevailed as density dominants in Beaver 2 throughout most of the 1999-2000 water year time period. But, because of their small cell size, they composed only a small percentage of total biovolume during this time when other algal groups with larger-sized representatives were present in the community. The blue-green bacteria group was a biovolume dominant in Beaver 2 only at the end of the current study in late September, due to very high densities of filamentous *Aphanizomenon flos-aquae*. In contrast to the present study year, the cyanophytes were more persistent contributors to overall cell volumes within Basin 2 for most of the 1996-1997 water year, as well as the 1991-1992 study year.

As discussed earlier, **green algae** were significant contributors to sample cell volume measures on only a few occasions in both Beaver Lake basins during the 1999-2000 study. Chlorophyte biovolume dominance occurred in December, 1999 in Basin 1, and in July, 2000 in Basin 2, the latter following a dramatic drop in epilimnetic populations of the blue-green species, *Aphanizomemon flos-aquae*. Both of these occasions of predominance by green algae came at times of overall low algal densities and chlorophyll *a* levels. Chlorophytes also made sporadic contributions to sample biovolumes, particularly in Beaver 2, mainly during winter and spring seasons of both the 1996-1997 and 1991-1992 study years.

The **cryptomonads** and **dinoflagellate** groups generally composed very low percentages of sample algal biovolumes over the current twelve month time frame in both Beaver Lake basins. However, dinoflagellates did make an important contribution to sample cell volumes measured in Beaver 1 in late August, 2000 with the occurrence of small numbers of large-celled *Ceratium hirundinella*. This common dinoflagellate contributed substantially to cell volumes in Basin 1 during a similar time period in both prior Beaver Lake studies. In contrast to current study conditions, *Ceratium* composed a substantial portion of algal cell volumes of the Basin 2 community during most of the 1996-1997 water year.

Euglenoids contributed very little to sample cell volumes in both Beaver Lake basins during the 1999-2000 water year. Minimal presence of the euglenoid group in the current as well as in 1996-1997 water year studies is in stark contrast to the striking dominance of the Beaver 1 phytoplankton community by the euglenoid, *Eutreptia viridis*, during the early half of the 1991-1992 study year. Surging populations of this small euglenoid accounted for most of the volume peaks recorded in November, 1991 and April, 1992 in Basin 1. Interestingly, this organism composed a much smaller percentage of total algal cell volumes in Basin 2 during the same study year.

Summary of Phytoplankton Community Patterns

The following summarizes important features of the Beaver Lake phytoplankton community (cell densities, cell volumes and chlorophyll *a* levels) obtained from the current Phase II investigation (1999-2000 water year) as compared with the two historical Phase I (1991-1992 water year) and Phase II (1996-1997 water year) studies. Inspection of data from all three investigations also revealed ***similarities within both basins*** consistently observed over the three studies, as well as ***characteristics distinctive within each separate basin*** that recurred over the three study years.

Phytoplankton Cell Density, Cell Volume and Chlorophyll *a*

Table 1 presents average algal cell density (numbers of organisms) measured over typical growth season (April through September) and annual water year (October through September) time periods for the 1996-1997 and 1999-2000 Beaver Lake monitoring studies. Algal cell count data were not included in the taxonomic sample analyses of the 1991-1992 Beaver Lake Phase I study results. Both years of the Phase II studies show average algal cell densities were greater over the April through September growth season than over the annual cycle. This condition reflects typical occurrence of elevated populations of the blue-green species *Aphanizomenon flos-aquae* during the growth season. Of note is that in the current study Basin 1 cell count averages were higher than comparative phytoplankton cell densities computed in Basin 2, while the opposite situation was true in the earlier Phase II study. Annual variations in phytoplankton community measures within a lake system are natural as resident groups and individual species respond to a constantly changing complex of physical, chemical and biological conditions within the lake as well as from watershed influences. Nevertheless, average cell densities computed for these two studies are still relatively high, and any disparity between years just reflects differences in population dynamics of the cyano-bacteria group that numerically dominated phytoplankton communities in each basin during the two study years.

Table 1. Comparison of Algal Cell Density Average Measures (No./ml) in Beaver Lake from 1996-1997 Phase II, and 1999-2000 Phase II Studies.

Basin/Time Period	Cell Density (No./ml)		Cell Density (No./ml)
Beaver 1		**Beaver 2**	
Growth Season		**Growth Season**	
4/97-9/97	5,379	4/97-9/97	7,961
4/00-9/00	8,834	4/00-9/00	3,586
Annual		**Annual**	
10/96-9/97	2,748	10/96-9/97	4,696
10/99-9/00	4,828	10/99-9/00	2,528

Table 2 presents average algal cell volume (physical quantity of algal matter) measured over typical growth season (April through September) and annual water year (October throughSeptember) time periods for the three Beaver Lake monitoring studies. Average algal cell volumes computed over the growth season in Basin 1 are fairly close between the three water year studies, varying slightly from 1.5 to 2.0 mm^3/L. In contrast, growth season biovolume averages for the Basin 2 algal community show a greater fluctuation between the three study years, ranging from 0.6 to over 3.3 mm^3/L. Yearly cell volume averages computed for all studies also show considerable variation in both basins from year to year. It is noteworthy that the annual cell volume average computed for the Basin 1 phytoplankton community during the 1996-1997 water year study was influenced by the presence of very low numbers of very large spherical colonies of the green alga, *Volvox* sp. in the November, 1996 sample. This occurrence had the effect of boosting total cell volumes for that date to 23.7 mm3/L, the highest value measured for all three studies. Penetration of the summer algal community of Basin 2 by small numbers of robust *Volvox* colonies had a similar, but less extensive, amplifying effect on growth season computation of average cell volume. In other words, this alga was more conspicuous in the epilimnetic algal community in Beaver Lake during the 1996-1997 study period than it was in other years.

Average chlorophyll *a* (chl *a*) values similarly computed over the growth season and annual period for the three Beaver Lake studies (Table 2) generally corresponded to correlative cell volume means, with the exception of the Basin 1 annual biovolume average as previously noted. As with mean cell density and biovolume computations, growth season measures for chl *a* exceeded values computed over the annual time frame, corresponding with typically higher biological activity during the spring-summer cycle. Average chl *a* levels computed in Basin 1 during the current water year were lower than comparative measures in both of the corresponding 1991-1992 and 1996-1997 values. Highest mean chl *a* levels (19.1 μg/L) occurred in Basin 1 during the 1991-1992 water year, coinciding with the unique occurrence of highly elevated populations of the small euglenoid, *Eutreptia viridis*.

Table 2. Comparison of Average Measures of Beaver Lake Algal Cell Volume (mm3/L) and Chlorophyll a (ug/L) from 1991-1992 Phase I, 1996-1997 Phase II, and 1999-2000 Phase II Studies.

	Parameter	
Basin/Time Period	Cell Volume (mm3/L)	Chl a (ug/L)
BEAVER 1		
Growth Season		
4/92-9/92	2.10	19.1
4/97-9/97	2.02	12.0
4/00-9/00	1.49	8.1
Annual		
10/91-9/92	1.67	10.8
10/96-9/97	3.00*	7.5
10/99-9/00	1.28	5.1
BEAVER 2		
Growth Season		
4/92-9/92	0.63	5.4
4/97-9/97	3.30*	15.5
4/00-9/00	1.67	6.2
Annual		
10/91-9/92	0.54	3.9
10/96-9/97	1.93	10.4
10/99-9/00	1.21	5.6

*NOTE: Cell volumes reflect very low densities of very large spherical colonies of Volvox sp.

Table 3 presents percentage contributions of the six principle algal groups to total annual biovolumes within the two Beaver Lake basins for the three water year studies. Unlike phytoplankton ***cell density*** patterns in both Beaver Lake basins which were influenced mainly by population dynamics of predominating cyano-bacteria for much of the year, there was not one algal group that continuously dominated average annual ***cell volumes*** in either basin for the three years of investigation. Furthermore, relative dominance of total annual cell volumes by the major algal groups varied not only within each basin each year, but also between the two basins over the three study years. During the 1991-1992 study year, euglenoids dominated total annual volumes within Basin 1 followed by the chrysophytes, while in Basin 2 comparable biovolume measures were dominated by the cyano-bacteria with the chrysophytes and cryptomonads as secondary contributors. The chlorophytes (green algae) accounted for most of the annual cell volume measure in Basin 1 during the 1996-1997 Phase II study (see earlier discussion of *Volvox* sp.). During the same year the green algae predominated to a lesser extent in Basin 2, followed by the dinoflagellates and cyanophytes. The current 1999-2000 water year study revealed the cyano-bacteria comprising the largest portion of total annual biovolume in Basin 1 with green algae next in importance. In Basin 2 of thsi same water year, the chrysophytes made up the greatest percentage of total volumes on an annual basis, followed by the green and blue-green groups.

Table 3. Percentage of Total Annual Biomass by Major Algal Groups in Beaver Lake Basins during Phase I, Phase II, and Current Phase II Studies.

Basin/Time Period	Study: Phase I (1991-1992)	Phase II (1996-1997)	Phase II (1999-2000)
Beaver 1			
Blue-greens	13	9	43
Greens	3	62*	29
Diatoms/yelow-browns	36	19	17
Cryptomonads	5	1	3
Dinoflagellates	2	8	8
Euglenoids	41	0	<1
Beaver 2			
Blue-greens	32	25	16
Greens	8	38*	20
Diatoms/yelow-browns	23	8	58
Cryptomonads	23	3	5
Dinoflagellates	9	26	1
Euglenoids	5	0	<1

**NOTE: Cell volumes reflect very low densities of very large spherical colonies of Volvox sp.

Phytoplankton Community Similarities Between Both Basins

Major recurring features of the Beaver Lake phytoplankton community observed over the 1991-1992, 1996-1997, and 1999-2000 water year studies are described below and summarized in Table 4.

The Cyano-bacteria dominated the epilimnetic phytoplankton community in both Beaver Lake basins during the April-September growth season. Cell density predominance of the blue-green bacteria over other algal groups during this six month period (>50% composition of total cell counts for each sample date) was directly comparable between the two Phase II studies, and is strongly inferred by cyano-bacteria dominance of cell volumes reported by the Phase I study over this same time frame (cell counts not given). The filamentous form, *Aphanizomenon flos-aquae*, has been the principal blue-green bacteria species represented in epilimnetic samples collected at both Beaver Lake Stations during the growth season.

Data from the three studies also show a fairly close correspondence in both basins between algal biovolume (a physical cell volume measurement expressed as mm^3/L) and chl *a* concentrations (a biochemical compound quantity given as $\mu g/L$), varying somewhat in relative quantities. Magnitude differences between the two distinct parameters for a specific sample date were most pronounced when small numbers of large colony-formers like the green alga, *Volvox* sp., were present in the epilimnetic community, producing a pronounced upward skewing of physical biovolume estimates, but apparently having less effect on overall chlorophyll *a* concentrations.

Finally, a recurrent characteristic of the phytoplankton community was documented in both basins during the two Phase II studies that was significantly different from a condition described in the early Phase I study. The Euglenophyta dominated the Beaver Lake phytoplankton community, particularly in Basin 1, during the first half of the 1991-1992 water year study. Prominence of the euglenoids was the result of elevated numbers of *Eutreptia viridis*, which like other members of the Euglenaceae family thrives under conditions

Table 4. Major Recurring Features of the Beaver Lake Phytoplankton Community Observed during the Phase I (1991-1992), Phase II (1996-1997) and Current Phase II (1999-2000) Studies

	Study Year		
Unique Feature	**1991-1992**	**1996-1997**	**1999-2000**
Both Basins			
• Cyanobacteria group density domination Apr-Sep	X	X	X*
• *Aphanizomenon flos-aquae* primary blue-green species	X	X	X
• Euglenoid group biovolume dominance Sep-Apr	X	--	--
• Chl *a* pattern generally corresponds to cell volume pattern	X	X	X
Basin 1			
• *A. flos-aquae* present only during growth season	X	X	X
• Cyano-bacteria group biovolume domination May-Jul	X	X	X
• Algal biovolume/density peaks in Jun or Jul dominated by cyanobacteria	X	X	X
• Cyano-bacteria absent from winter epilimnetic samples	X	X	X
• Chrysophyte (*Dinobryon*/*Mallomonas*) biovolume domination late summer/fall	X	X	X
Basin 2			
• Cyano-bacteria (*A. flos-aquae*) present throughout study	X	X	X
• Early growth Season(Apr) Cyanobacteria density peak	X	X	X
• Chrysophyte (*Dinobryon* spp.) brief fall biovolume dominance	X	X	X
• Chrysophyte (*Dinobryon* spp.) brief fall density dominance	X*	X	X

* NOTE: 1991-92 cell density data not given; condition strongly inferred from cell volume data

of optimal organic content. In contrast, the euglenoids made negligible contributions to phytoplankton cell volume and density measures in both basins during the 1996-1997 and 1999-2000 water year studies. That this particular species has not been detected in epilimnetic samples from two recent water year studies is a noteworthy characteristic of the Beaver Lake algal community.

Phytoplankton Community Similarities Distinct to Each Basin

Basin 1

There were several features of the phytoplankton community distinct to each Beaver Lake basin that recurred over the three study years. In Basin 1 the filamentous cyano-bacteria species, *Aphanizomenon flos-aquae*, was prominent in the epilimnetic phytoplankton community only during the growth season months. The blue-green bacteria group typically dominated biovolume measures from May through July in Basin 1, reflecting high densities of this cyanophyte species. Algal biovolume and density peaks were regularly observed in Basin 1 in either June or July, also resulting from peaking populations of *Aphanizomenon.* In striking contrast was a consistent lack of cyano-bacteria group representation in epilimnetic composite samples from Basin 1 during the winter season period. Furthermore, both Phase II studies reported a more prolonged absence of cyanophyte members from the epilimnetic community of Basin 1 extending from fall through winter. Another regular feature of the Basin 1 phytoplankton community was domination of cell volumes by non-diatom chrysophytes, mainly *Dinobryon* and *Mallomonas* spp., during late summer/early fall period.

Basin 2

The cyanophyte group, including the dominant species, *Aphanizomenon flos-aquae*, made substantial contributions to phytoplankton sample community densities within Basin 2 throughout most of the twelve month water year period, unlike the group's more limited presence in Basin 1 samples during the growth season. Results of both Phase II studies reveal occurrence of an early growth season density peak in April varying in magnitude, but dominated by the cyano-bacterial form, *Aphanizomenon flos-aquae*. In all three study years, the **non-diatom chrysophyte** group, represented primarily by *Dinobryon* spp., typically dominated Basin 2 biovolume measures for a short time during the fall season. Additionally, the latter Phase II investigations reported substantial contributions by non-diatom chrysophytes, (again *Dinobryon* spp.) to sample population densities coincident with biovolume predominance during the same fall season.

Beaver Lake Zooplankton Community Composition

1999-2000 Annual Patterns

This section discusses annual zooplankton community trends within the two Beaver Lake basins in terms of organism density, biomass, and changes in major species as part of the 1999-2000 Phase II study. Zooplankton data analyses are based on sample collections consisting of a single 14 meter vertical net tow made at each of two lake stations (Station 1 and Station 2, representing Basin 1 and Basin 2, respectively) over thirteen dates from October, 1999 through September, 2000. The measure of abundance of each species both numerically and in terms of dry weight (biomass) represents a water column average, based on a vertical cylinder of water through which the plankton net is pulled from lake bottom to surface. Individual zooplankton data tables were generated for each sample date of the study and are contained in the Appendices. Additionally, the Phase II project included measurement of other selected biological, chemical and physical parameters in Beaver Lake, including lake phytoplankton, as part of the expanded citizen lake monitoring program during the same 1999-2000 water year time period. References to certain of these auxiliary biological, physical, and chemical data are made in this section where appropriate to further describe certain aspects of the zooplankton data. Zooplankton measures obtained from the current monitoring study is also compared to similar data collected during the 1996-1997 water year of the Phase II Project (King County, 1997) and the 1991-1992 water year of the Phase I monitoring investigation (King County, 1993).

Zooplankton: Definition and Measurement

The zooplankton are microscopic aquatic animals adapted to planktonic life in the water. Major invertebrate groups typically represented in the freshwater zooplankton are the small-bodied **rotifers** (Phylum Rotifera), and two crustacean groups (Phylum Arthropoda, Subphylum Crustacea), the **cladocerans** and **copepods**, the latter consisting of filter-feeding ***calanoids*** and raptorial ***cyclopoids***). The insect family **Chaoboridae** (Phylum Arthropoda, Subphylum Uniramia) is sometimes represented in the zooplankton with the occurrence of phantom midge larvae in the upper water column of some lakes during certain times of the year.

Zooplankton organisms feed upon planktonic algae, bacteria, small organic particles and other zooplankton suspended in the water column. Under certain conditions, zooplankton groups can be a very significant part of nutrient recycling within the aquatic system. Large daphnid cladocerans are highly opportunistic filter-feeders that are efficient grazers of small algae and bacteria. The cladoceran group can form an important food source for invertebrate predators as well as for visual vertebrate predators (e.g., planktivorous fish). Copepods also can be significant primary and secondary consumers, and a food source for higher invertebrate and fish predators. Even the rotifers play an important role in the aquatic food web, offering a food store for aquatic invertebrates, which in turn are consumed by higher order invertebrate predators and planktivorous fish. Interestingly, rotifers may be consumed directly by many adult planktivorous fish, and can be a highly nutritious dietary component of certain larval fish. Thus, the zooplankton provide an important link between the primary producers (algae) and higher order consumers in an aquatic system. Furthermore, the occurrence of certain groups or species of zooplankton, called **indicator organisms**, can signal either the existence of detrimental water quality conditions or presence of high quality conditions. For example, the small rotifer species, *Anuraeopsis fissa*, is considered to be a eutrophic indicator species.

The *quantity, density or abundance* of zooplankton present in freshwaters is commonly measured in terms of numbers of organisms per unit volume of water. While measuring numbers of organisms is useful for determining relative occurrence of different zooplankton types, numbers alone do not indicate the ***amount of biological matter*** in the water. Biomass is a quantitative measure of the mass of zooplankter cells, and is presented as either wet or dry weight. Zooplankton biomass (micrograms per cubic meter of water volume, *dry weight*) is typically estimated for each organism species according to published literature values that relate organism length (average) to dry weight. Such length to dry weight relationships were used to calculate zooplankter biomass values for the 1996-1997 Phase II and the current Phase II study. Taxonomic assessment of zooplankton samples from the 1991-1992 Phase I study reported organism densities (numbers/L) and percent community composition, but did not include zooplankton biomass estimates.

Zooplankton Density Trends

Figures 6 and 7 present zooplankton densities (organisms/m^3) by major group in Beaver Lake samples collected at Station 1 and Station 2, respectively, on thirteen dates from October, 1999 through September, 2000. With one exception, all major groups of zooplankton were represented in samples collected from both basins of Beaver Lake during this twelve month period. Adult and copepodid life forms of the predaceous cyclopoid **copepods** did not appear in the sample tows collected on two dates in May in Basin 2 only.

Inspection of these data reveal similar zooplankton group community composition in both Beaver Lake basins for the entire 1999-2000 study period. Except for peak occurrences, zooplankton sample densities measured in Beaver 1 and Beaver 2 were generally below 50,000 organisms/m^3 (50 organisms/L) during the current study. The **rotifer** group dominated zooplankton density throughout the Phase II study period in both lake basins, a condition often documented in lowland lakes in the Pacific Northwest. Copepod immatures, the **nauplii**, appeared a distant second in terms of overall density contributions, maintaining low background populations in both Beaver Lake basins during the current water year period. The **calanoid copepods**, the **cladocerans**, and the **cyclopoid copepods** followed the nauplii in order of group density importance in the two Beaver Lake basins in the 1999-2000 study. **Dipteran** immatures, represented by the genus *Chaoborus* spp., occurred in small numbers over most of the present study year in both basins, and made more significant contributions to zooplankton biomass measures, especially in Basin 1. The earlier Phase II (1996-1997 water year) and Phase I (1991-1992 water year) studies also reported rotifer domination of zooplankton communities in both Beaver Lake basins, as well as secondary importance of the naupliar group, followed by the crustacean and dipteran groups.

There were also marked differences in zooplankton total density patterns between the two Beaver Lake stations during the current water year time frame. These differences were largely the result of seasonal dynamics within the rotifer group as various species traded off in numerical dominance throughout the annual cycle. During the fall, 1999-winter, 2000 span of the study, zooplankton sample densities were generally higher in Beaver Lake 2 than in Beaver Lake 1. The reverse was true during the spring-summer, 2000 seasons, when zooplankton sample data from Basin 1 typically showed greater organism numbers relative to those measured in Basin 2. Current study data showed that the timing and intensity of sample organism abundance peaks differed within the two lake basins, as well. Whereas Beaver 1 demonstrated highest zooplankton numbers (82,889 organisms/m^3) in late August, 2000 at study end, peak densities in Basin 2 (91,749 organisms/m^3) were recorded earlier in mid-November, 1999.

The principal zooplankton species documented during the current water year study were also found during both earlier Phase I (1991-1992) and Phase II (1996-1997) investigations of Beaver Lake. However, overall zooplankton abundances in the current study were generally lower than corresponding levels documented in 1996-1997 in both basins, with the exception of the early fall seasons in both study years. In contrast, current study densities in both basins were higher than comparative measures obtained during the 1991-1992 investigation. While density patterns and peak occurrences were comparable within Basin 2 in both Phase II investigations, Basin 1 zooplankton assemblages differed markedly in these measures between these two study years, particularly in the presence of a prominent April, 1997 peak in the common rotifer species, *Conochilus* and *Conochiloides*, that was not demonstrated in the 1999-2000 water year study. The current study density trends were somewhat more comparable to those recorded during the 1991-1992 water year study.

Beaver Lake 1

At the time of the October, 1999 sampling date (start of the 1999-2000 water year), the rotifer-dominated zooplankton community in Basin 1 demonstrated slightly elevated population densities averaging 46,000 organisms/m3 (46 organisms/L) that were sustained over the autumn-early winter seasons. During this initial four month period, a succession of common rotifer species assumed the position of Basin 1 community density dominant. The soft-bodied form, *Conochilus unicornis* (Order Flosculariacea), was the principal zooplankton species in samples collected at project start-up in late October. This species abruptly declined by mid-November as populations of the long-spined loricate (rigid cuticle), *Kellicottia bostoniensis* (Order Ploima) surged and became the next predominant zooplankter in the Beaver 1 zooplankton community. This species of *Kellicottia* continued to maintain high densities for several months in Basin 1, appearing as a density co-dominant, first with *Conochilus* which had rebounded by the mid-December sampling date, and then with another soft-bodied form, *Conochiloides* sp. (Order Flosculariacea) by mid-January.

In-situ and laboratory measurements of water quality parameters over this four month span show progressive disruption of stratified conditions was occurring in the lake, with the lake water column becoming completely mixed by the mid-January date. While algal populations were at a study low at this time, consisting mostly of small edible flagellates (cryptomonads and chrysomonads), other minute food sources, such as bacteria and organic particulates were probably available as a result of lake overturn, increased wetland inputs, and surface runoff. The likely occurrence of these food sources is supported by the prevalence of the above-referenced rotifer species, which are sedimentary suspension feeders (create currents with anterior cilia to sweep food into mouthparts), that typically feed indiscriminately on detritus and other fine particulates.

Zooplankton sample populations, including the Rotifera, dipped to very low levels during the remainder of the winter season and into early spring, 2000 in Basin 1. The common species, *Keratella cochlearis*, became the predominant rotifer form in early March, responding most likely to a concurrent pulse in algal populations primarily composed of small cryptomonads and chrysomonads that are readily grazed by this organism. Of note, however, was the appearance of the rotifers and copepod nauplii (immatures) as density co-dominants in the early April sample community, the only exception to complete density dominance by the Rotifera during this study. At this time of seasonal transition and increased lake mixing, field measurements of water quality parameters confirmed initial warming of the upper waters was occurring as well as deterioration of isothermal conditions within the water column.

The month of May revealed rising numbers in all the major zooplankton groups, particularly in the juvenile crustacean and dipteran forms, as the lake basin volume continued to mix and turn over, fed by seasonal runoff. At this time a small short-lived pulse was observed in populations of the large cladoceran, *Daphnia pulex/pulicaria* group, with densities dropping dramatically for the remainder of the study. Many of these spring season daphnids exhibited dorsal thickening and spine formation, a morphological defense mechanism against tactile invertebrate predators such as larval *Chaoborus* spp., which penetrated the zooplankton community in increasing numbers throughout the growth season. However, by early May the rotifer group also returned as the sole density dominant of the Basin 1 zooplankton community. Rotifer densities remained elevated for the rest of the study as well, exhibiting a primary basin peak of 82,889 organisms/m3 (83 organisms/L) on August 23.

Of note was the dominating presence of highly elevated populations of the cyano-bacteria, *Aphanizomenon flos-aquae*, within the phytoplankton community during this entire last half of the water year. *Conochilus unicornis*, which readily grazes bacteria and detritus, persisted as the principal rotifer species in the Beaver 1 zooplankton community during the *Aphanizomenon* bloom from early May through late August. This species dropped in numbers by study end in late September to a position of co-dominance with rebounding populations of *Kellicottia bostoniensis*. Surging numbers of *Kellicottia,* as well as a small pulse in all life forms of *Hesperodiaptomus franciscanus* (a large calanoid copepod) corresponded to rapidly declining populations of *Aphanizomenon* and restructuring of the algal community with inclusion of flagellates, such as *Mallomonas, Cryptomonas,* and *Ceratium* spp., that dominated cell volumes during August and September.

Beaver Lake 2

The Basin 2 sample zooplankton assemblage exhibited similar density domination by the Rotifera throughout the 1999-2000 water year as was documented in Basin 1. However, the crustacean groups, particularly the cladocerans and the copepod nauplii, made a relatively greater contribution to overall abundances during much of the study period. From project onset in October through January, the Beaver 2 zooplankton community maintained elevated densities, an occurrence similar to the Basin 1 community pattern. Unlike the late summer, 2000 peak measured in Basin 1, the sole zooplankton population maximum in Basin 2 of 91,749 organisms/m^3 occurred early in the study on 11/17/99, and was the largest for the entire study year. *Kellicottia bostoniensis*, the dominant species on this density peak date in Basin 2, exhibited populations twice that measured on the same date in Basin 1, where it also predominated.

The rotifer *Keratella cochlearis* was a conspicuous member of the Basin 2 zooplankton community throughout all but the summer season of the 1999-2000 water year. As the October sample community dominant, *Keratella* lost its pre-eminent position over the next few months, first to exploding populations of *Kellicottia bostoniensis,* which composed the density high in November, and then to the *Conochilus/Conochiloides* group in December. As was observed in Basin 1, this was a period of physical, chemical and biological flux due to seasonal turn over, with the basin water column becoming completely mixed by the mid-January date. *K. cochlearis* continued to maintain high background populations in Basin 2 throughout the first four months even when not in dominance, and persisted as density dominant during the winter and spring seasons as well. This species is a cold stenotherm and is an effective grazer of particles less than 12 microns, particularly detritus, bacteria, cryptomonads and chrysomonads. During the same late fall through spring period, the nauplii group (immature copepods) also exhibited moderate, but steady, numbers that were significantly greater than those measured over the same time frame in Basin 1. Proliferation of these small herbivores suggests that, in addition to low levels of small flagellates in the *Aphanizomenon*-dominated algal community during this time, other minute food sources (bacteria, detritus) also appeared to be in adequate supply. Furthermore, these rotifers were apparently not experiencing much predation by larger invertebrates at this time.

It is noteworthy that cladocerans, particularly larger daphnids, demonstrated sporadic population pulses in Basin 2 during the winter-spring seasons that were more pronounced than documented in Basin 1 at a corresponding time. For example, juveniles (<1.5 mm) of the common form, *Daphnia rosea*, appeared in large numbers in the zooplankton community sampled in mid December, contributing significantly to overall biomass measures as well. At this time the basin was experiencing the latter stages of fall turnover, and followed a pulse in small, non-diatom chrysophytes (mostly *Dinobryon sociale*), suggesting ample food reserves were most likely present. In addition, occurrence of these small *Daphnia* (many showing neck spines as a typical defensive response to invertebrate predators) coincided with declining numbers of predaceous larval chaoborids. A similar surge in opportunistic daphnids (mainly larger, spined *D. pulex*) extended from early April into May at a time of spring mixing and turnover, but also coinciding with a spring *Aphanizomenon flos-aquae* bloom in the phytoplankton community. Of note is that during the month of May three different diaptomid genera commonly found in Pacific Northwest waters represented the calanoid group in the Basin 2 zooplankton community. These were the cold stenotherm, *Skistodiaptomus oregonensis*, the robust-bodied *Hesperodiaptomus franciscanus*, and *Onychodiaptomus hesperus*. Coexistence of these different sized diaptomid species within the basin at this time may be the result of several interacting mechanisms, such as differential food niche and habitat partitioning, and successful predator avoidance.

During the summer months, the sample zooplankton community in Basin 2 exhibited lower density levels relative to those measured during the same time frame in Basin 1. A zooplankton abundance minimum was recorded in Beaver 2 on June 28, which corresponded to a phytoplankton density low as well as conditions of strong thermal stratification present within both basins. Zooplankton numbers in Basin 2 bounced slightly upwards during the remainder of the summer, with the rotifers comprising a hefty 85-95% of sample population densities. The advancing summer season saw explosive growth in the cyanophyte, *Aphanizomenon flos-aquae*, which accounted for a basin density peak on September 20. The zooplankton community at this time was dominated by members of closely related rotifer genera, *Conochiloides* and *Conochilus,* which typically feed on bacteria, detritus and other very fine particulates. Larger crustaceans (particularly *Diaptomus* and *Daphnia* spp.) revealed very low summer populations, a common phenomenon in temperate lakes related to dwindling food reserves, increased invertebrate (e.g., *Chaoborus* sp. immatures) and vertebrate (fish) predation, and loss of refuge (increasing temperatures, reduced dissolved oxygen levels). Interestingly, the large calanoid copepod, *Epischura nevadensis* (average body length=2.1 mm), appeared in very low numbers in the Beaver Lake 2 zooplankton community in October, 1999 and from July through September, 2000. Low densities of this omnivorous calanoid were present only in the Basin 2 sample collected during April, 1997 in the earlier 1996-1997 water year study.

Zooplankton Biomass Trends

Figures 8 and 9 present zooplankton biomass (ug/m^{3,} dry weight) by major group in Beaver Lake 1 and 2 in samples samples collected at Station 1 and Station 2, respectively, on thirteen dates from October, 1999 through September, 2000.

Zooplankton sample biomass patterns differed somewhat between the two Beaver Lake stations during the current water year time frame. These differences were largely the result of variances in relative biomass contributions by predaceous dipteran larvae and filter-feeding cladocerans and calanoid copepods throughout the annual cycle. The data show more substantial contributions to dry weight measures by the calanoid and dipteran groups in Basin 1 than in Basin 2 over the course of the current twelve month study. In contrast, the herbivorous cladocerans were more significant contributors to zooplankton biomass measures in Basin 2 relative to Basin 1 conditions over the current water year. The cyclopoid copepod and rotifer groups contributed little to overall zooplankton dry weight measures during the 1999-2000 water year in either lake basin. Zooplankton biomass data from the 1996-1997 water year study revealed similar group dominance and annual biomass patterns in each basin as documented for the current study year.

The 1999-2000 study data showed that the number, timing, and intensity of zooplankton dry weight biomass peaks differed between the two lake basins, as well. Whereas Beaver 1 demonstrated a single zooplankton biomass peak in early May, two biomass peaks were documented in Beaver 2, a primary maximum in mid December and a secondary peak in early April, both of which exceeded the sole Beaver 1 maximum. A single spring biomass peak was similarly observed in Basin 1 zooplankton community in the earlier Phase II study, although the magnitude of the peak (142,000 ug/m^3) was nearly double that of the current study (72,000 ug/m^3). During the 1996-1997 water year, the zooplankton assemblage in Beaver 2 demonstrated a single maximum in June of 107,000 ug/m^3 as opposed to the two peaks in the current study, occurring in December (101,667 ug/m^3) and in April (79,380 ug/m^3).

Zooplankton biomass patterns did not generally follow density patterns over the same time span in either Beaver Lake basin during the 1999-2000 water year study. In fact, major contributions to community biomass by the crustacean and dipteran groups was in stark contrast to overwhelming density dominance by the Rotifera in both Beaver 1 and Beaver 2 during this time period. Even when organism densities were high, the small-bodied rotifers composed only a small portion of zooplankton biomass on each sample date, a disparity that was especially evident when other groups with larger organisms were represented in the sample community. A similar body-size relationship between density and mass was also demonstrated in the Beaver Lake phytoplankton with the domination of cell volumes by low numbers of larger-bodied non-cyanophyte alga appearing during blooms of small-celled cyano-bacteria (See Phytoplankton Community Patterns).

Beaver Lake 1

Review of the data show that zooplankton biomass measures in Basin 1 were dominated by filter-feeding crustacean and predatory dipteran groups during the 1999-2000 water year. In particular, the calanoid copepods maintained low but relatively stable populations throughout the course of the study, making substantial contributions to sample zooplankton biomass measures in Basin 1 during the entire twelve month span of the current study. The large-bodied form, *Hesperodiaptomus franciscanus*, was the predominant form in this basin, with adults and copepodids (older juveniles) composing the bulk of the group's dry weight measures. Dipteran immatures, represented by the genus *Chaoborus* sp., occurred in small numbers throughout the study year within Basin 1, but were significant contributors to zooplankton sample biomass, particularly during the growth season. The herbivorous cladocerans maintained consistently low populations and biomass levels over the study year, with *Daphnia pulex* and *D. rosea* accounting for most of the cladoceran group biomass from project start-up in October through May, giving way to the smaller forms, like *Holopedium gibberum*, during the summer season until project end in late September. As noted above, the Rotifera, despite consistently high densities, generally provided minimal contributions to zooplankton dry weight measures in either basin during the current study. However, the group composed a substantial portion (26%) of Basin 1 sample community biomass on a single study date, May 31, due to a population surge in *Conochilus unicornis* (an effective bacteria/detritus grazer). Review of field chemistry data on this date suggest that the lake basin appeared to be in the final stages of spring turnover preceding onset of summer stratification.

The zooplankton community representing Beaver Lake 1 demonstrated a single peak in sample biomass of 72,109 μg/m3 (72.1 μg/L) on May 3 due to small concurrent pulses in populations of cladoceran *Daphnia pulex*, the dipteran *Chaoborus* spp., and calanoid copepod *Hesperodiaptomus franciscanus*. This was the only date in the study during which the cladocerans dominated zooplankton dry weight measures (51%) in Basin 1. While the other two major zooplankton groups sustained high biomass levels through the remaining summer months, the pulse in populations of *Daphnia pulex* was short-lived, and cladoceran group density and biomass contributions declined to very low levels thereafter.

Summertime loss of daphnids from Beaver Lake (documented in both basins during this study), a common occurrence in temperate stratified lakes, may have been the result of a combination of factors. Coincident with the summer depression of daphnids, the dipteran group penetrated the zooplankton community in increasing numbers and contributed substantially to overall biomass measures from May through project end in October. Diptera, represented by transparent, large-bodied larvae of *Chaoborus* sp. (phantom midge), often prey on daphnid and copepod crustaceans. The summer months of low crustacean densities were also characterized by successive blooms of filamentous blue-green algae and a paucity of non-blue-green algal species that are better food sources. Also, summer water quality conditions were poorer than at other times of the year. Water column chemistry measurements show dissolved oxygen concentrations were severely depressed below 2 m

(6.5 ft depth) from July through September in Beaver 1, a condition that may have limited potential refuge for and survival of more sensitive daphnids. During the summer months, the cladoceran group was composed of low numbers of smaller-sized herbivores, *Holopedium gibberum* and *Diaphanosoma brachyurum*, which often prevail under environmental conditions that are more stressful to larger crustaceans.

Beaver Lake 2

Zooplankton biomass measures in Beaver 2 were dominated by the same filter-feeding crustacean and predatory dipteran groups as was observed in Beaver 1 during the 1999-2000 water year. However, in Basin 2 the herbivorous cladocerans were more significant contributors to zooplankton biomass measures during the study year, followed by the calanoids and dipterans, a reversal of biomass dominance trends observed in Basin 1.

Two biomass maxima, one in the fall and the other in the spring, were evident in the Beaver Lake 2 zooplankton community during the twelve month period of the current study. The largest biomass maximum (101,667 $\mu g/m^3$) occurred in mid-December, 1999 due to peaking numbers of the cladoceran, *Daphnia rosea*, particularly juveniles (<1.5 mm). The basin volume appeared to be well-oxygenated and in the latter stages of fall turnover at this time, and followed a pulse in small, non-diatom chrysophytes (mostly *Dinobryon sociale*), suggesting ample food reserves were most likely present. In addition, rising numbers of these *Daphnia* (many showing neck spines as a typical defensive response to invertebrate predators) coincided with declining numbers of predaceous larval chaoborids (probably entering winter diapause period) over the same October to December period.

Sample zooplankton biomass levels dropped to a winter season low extending through March, before climbing to a secondary biomass maxima of 79,380 ug/m^3 in early April. This spring time peak reflected surging populations of opportunistic daphnids (mainly larger, spined *D. pulex*) and to a lesser extent adult and later instars of the robust calanoid copepod *Hesperodiaptomus franciscanus*. Cladocerans (*D. pulex* and later *Holopedium gibberum*) continued to dominate community biomass measures into the month of May at a time of increased vernal temperatures and water column mixing, but also coinciding with a spring *Aphanizomenon flos-aquae* bloom in the phytoplankton community.

By late June, zooplankton biomass demonstrated a significant drop which was sustained through the summer mainly due to a dramatic decline in the cladoceran (primarily daphnid component) and calanoid copepod groups, which persisted for both groups through the summer. While a similar summer depression in daphnid density and biomass was apparent in the Basin 1 zooplankton community, the calanoids in Basin 1 demonstrated more stable biomass patterns during the entire twelve month study. A zooplankton abundance minimum was also recorded in Beaver 2 on June 28, which corresponded to a phytoplankton density low as well as conditions of strong thermal stratification and high temperatures in the upper water column present within both basins. It is noteworthy that during this time of summer depression in the crustacean groups, a common phenomenon in temperate lakes related to dwindling food reserves, loss of refuge (increasing temperatures, reduced dissolved oxygen levels), and increased predation, the dipteran group, represented by *Chaoborus* sp. immatures, maintained stable populations over the summer much as in Basin 1, dominating sample zooplankton biomass.

Summary of Zooplankton Community Patterns

The following summarizes important features of the Beaver Lake zoplankton community (organism densities, dry weight biomass) obtained from the current monitoring investigation (1999-2000 water year) as compared with the two historical Phase I (1991-1992 water year) and Phase II (1996-1997 water year) studies. Inspection of data from all three investigations also revealed ***similarities within both basins*** consistently observed over the three studies, as well as ***characteristics distinctive within each separate basin*** that recurred over the three study years.

Zooplankton Density and Biomass

Table 5 presents average zooplankton density (organisms/L) and biomass (μg/L, dry weight) measured over the water year period of October through September for the three Beaver Lake monitoring studies. Zooplankton biomass estimates were not included in taxonomic sample analyses of the 1991-1992 Beaver Lake Phase I study. In all three studies the zooplankton sample community in Basin 2 exhibited higher yearly average densities than than did the Basin 1 community. Average organism densities within both basins of the current study were somewhat less than comparative measures in the earlier Phase II study, but substantially more than the Phase I study results. During both Phase II studies, mean annual biomass measures computed for the Basin 2 zooplankton community were somewhat higher than comparative values for the Basin 1 community. Furthermore, average dry weight biomass levels within both basins of the current Phase II study were somewhat less than comparative measures in the earlier Phase II study. Certainly, annual variations in zooplankton community measures within a lake system are to be expected as resident groups and individual species respond to a constantly changing complex of biotic and abiotic factors within the lake affecting nutrition, reproduction, competition, and predation.

Table 5. Comparison of Mean Density (Organisms/L) and Biomass (ug/L, Dry Weight) of Beaver Lake Zooplankton from Phase I, Phase II, and Current Monitoring Studies.

Basin/Time Period	Study: Phase I (1991-92)	Phase II (1996-97)	Current (1999-2000)
Beaver 1			
Mean Density	10.9	49.2	40.0
Mean Biomass	*	39.0	35.0
Beaver 2			
Mean Density	13.2	57.8	40.3
Mean Biomass	*	44.0	38.5

* NOTE: Zooplankton biomass estimates not included in Phase I study.

While between-basin and between-year differences in mean annual ***biomass*** of the Beaver Lake zooplankton assemblages appear to be similar to those just described for average annual ***densities***, these two quantitative plankton parameters were controlled by completely different zooplankton groups in the Beaver Lake Basins. Whereas the small-bodied **rotifers** dominated zooplankton densities during these three studies, zooplankton biomass measures in both Beaver Lake basins were largely driven by presence of large-bodied **crustacean** groups and predaceous **dipteran larvae**.

This relationship is illustrated in Table 6, which lists relative contributions of the major zooplankton groups to total annual biomass estimates in each Beaver Lake basin for the two Phase II investigations. Zooplankton dry weight biomass values were not included in the Phase I study. On an annual basis, the filter-feeding crustacean and predaceous dipteran groups composed the largest percentages of total dry weight biomass estimates in the two Beaver Lake basins during both Phase II studies. Relative group contributions to total yearly biomass measures differed between the two basins for both study periods. Dipteran larvae and calanoid copepods composed larger percentages of yearly dry weight totals in Basin 1 relative to those computed in Basin 2 during both water years. In contrast, the cladocerans made more substantial contributions to biomass totals in Basin 2 than in Basin 1 over the annual cycle of both Phase II studies. Cyclopoid copepod and rotifer groups contributed little to annual zooplankton biomass totals in either basin during the two studies.

Table 6. Percentage of Total Annual Biomass by Major Zooplankton Groups in Beaver Lake Basin 1 and Basin 2 during Phase II and Current Phase II Studies.

	Study	
Basin/Time Period	**Phase II (1996-1997)**	**Current (1999-2000)**
Beaver 1		
Cladocerans	31	23
Calanoid Copepods	23	36
Cyclopoid Copepods	<1	1
Copepod Nauplii	2	2
Rotifers	5	8
Dipteran Larvae	38	30
Beaver 2		
Cladocerans	43	53
Calanoid Copepods	26	22
Cyclopoid Copepods	3	2
Copepod Nauplii	5	2
Rotifers	6	4
Dipteran Larvae	17	17

It is important to note that, compared to other small, productive, western lowland lakes (e.g., Phantom Lake), average zooplankton density and biomass levels in Beaver Lake appear to be on the low to moderate side. This consequence reflects smaller numbers of larger-bodied crustacean zooplankton (daphnids, calanoid copepods) and higher relative densities of small plankters (rotifers, and to a lesser extent, copepod immatures and small non-daphnid cladocerans) in the Beaver Lake zooplankton community. Smaller zooplankters often prevail under environmental conditions that may be less than optimal for survival of larger crustaceans, such as, low dissolved oxygen, high temperatures, low pH, cyano-bacteria dominance of phytoplankton, and increased presence of potential predators (e.g., dipteran larvae). In fact, summer depression in daphnid populations during conditions of reduced water quality and increased potential predation (spring time trout introduction and increasing invertebrate populations) has been regularly documented in both Beaver Lake basins in all three study years. These factors, as well as presence of additional minute food sources, including bacteria, organic and detrital matter associated with cyanophyte blooms and/or with wetland and surface drainage, may be giving the competitive advantage to the opportunistic rotifer group for much of the year in the Beaver Lake system.

Indicator Species

Several rotifer species occurred in the Beaver Lake zooplankton community during both Phase II Studies that are indicative of more productive lake conditions. *Pompholyx sulcata*, *Trichocerca cylindrica* and *T. pusilla* are indicators of or associated with eutrophic waters (Stemberger, 1979). *Pompholyx sulcata* often appears in eutrophic embayments and is regarded as a useful indicator of eutrophy in the Great Lakes; this species grazes minute detrital and bacterial particles. *Pompholyx* was found in both Beaver Lake basin samples from October 1996 through February, 1997, and again in May, 1997. However, this species was detected only in the Basin 2 sample collected in November, 1999 of the current Phase II study. *Pompholyx sulcata* was not recorded in Beaver Lake samples obtained during the 1991-1992 Phase I study. *Trichocerca cylindrica* appeared in Beaver Lake samples in both basins from late May through September, 2000 of the current study year. *T. cylindrica* was similarly identified in Beaver Lake samples collected from June through September, 1997 of the earlier Phase II study. *T. cylindrica* was not observed in samples from either lake basin during the Phase I study. However, *T. pusilla* occurred sporadically in samples taken from both lake basins during the summer season of the 1991-1992 Phase I investigation, but was not detected in either Phase II investigation. It is noteworthy that indicator species of both genera, *Pompholyx* and *Trichocerca*, were represented in Beaver Lake samples during the 1996-1997 water year, which coincided with some of the highest yearly TSI values recorded as part of the extensive data base developed over the past 10-15 years in Beaver Lake. A potential relationship between occurrence of indicator organisms like these and elevated TSI values in Beaver Lake may be an area for future work.

Zooplankton Community Basin Similarities

Major recurring features of the Beaver Lake zooplankton community observed over the Phase I (1991-1992 water year) and two Phase II (1996-1997 and 1999-2000 water year) studies are summarized from the above discussion in Table 7.

Table 7. Major Recurring Features of the Beaver Lake Zooplankton Community Observed during the Phase I (1991-1992), Phase II (1996-1997) and Current Phase II (1999-2000) Studies

	Study Year		
Unique Feature	**1991-1992**	**1996-1997**	**1999-2000**
Both Basins			
• Rotifer group density domination throughout year	X	X	X
• Crustacean and dipteran groups dominate annual biomass		X	X
• Summer decline in *Daphnia* spp. populations	X	X	X
• Biomass patterns do not correspond to density patterns		X	X
• Presence of eutrophic indicator organisms (*Trichocerca cylindrica*, *T. pusilla*, and *Pompholyx sulcata*)	X	X	X
Basin 1			

• Dipterans more significant contributor to annual biomass		X	X
Basin 2			
• Higher annual average densities and biomass	X	X	X
• Cladocerans more significant contributor to annual biomass		X	X

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Appendix D

Memorandum

To: **Sharon Walton, Senior Limnologist**

From: David Hartley, Senior Watershed Hydrologist, King County DNR-WLRD

Date: December, 2000

Re: Simulated Daily Flow Data for Beaver Lake Phosphorus Model

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Simulation of Hydrologic Components for Daily Phosphorus Model of Beaver Lake

Introduction

This report documents the approach taken to simulating one year of typical, daily hydrologic inputs and outputs from Beaver Lake. It includes an explanation of how typical conditions were defined and a description of the simulated water balance components of for upper and lower (BL1 and BL2) cells of the lake.

Typical Daily Values

Typical daily values of water balance components of the two lake cells were determined using the re-calibrated HSPF model that reflects land use during 1999 and 2000. It was assumed that typical values of the water balance components would be generated using a typical precipitation record. An examination of recent years of record at the NWS gage at Landsburg shows that 1995 was a typical water year based on total monthly precipitation with only the month of May registering a total that was more than one standard deviation less than the long term monthly mean. The King County record at the Mystic Lake (MLU) rain gage is consistent with the 1995 Landsburg record in this respect. The MLU record began in water year 1995 and also exhibits a low May total precipitation value compared to the May values from 1996 through 1999. Consequently, it was decided to increase hourly precipitation values recorded at MLU during May 1995 by 50% and use these values with the remainder of unmodified recorded values for 1995 to represent typical rainfall conditions. This modification of the 1995 record results in a year of precipitation where all monthly totals are estimated to be within 1.0 standard deviation of the long term mean, and where the total annual precipitation is estimated to be within 5% of the long term annual mean. Simulated daily water balance components for this modified 1995 water year are assumed to represent typical conditions at Beaver Lake.

A GIS database of current land use (as of 2/2000) was determined using King County Assessor's data and interpretation of 1998 air-orthophotos (personal communication, Colleen Rasmussen, KC-DNR-WLR-GIS). Residential uses were classified by dwelling units per acre and into 4 classes which in turn were reflected in the updated model by varying percentages of "effective" impervious area as shown below:

Table 1. Cover Assumptions for Residential Classes in the Beaver Lake Basin

RESIDENTIAL CLASSES	% EFFECTIVE IMPERVIOUS	%GRASS
Rural Residential, 1 du/2.5-10 acres	4	96
Urban Residential, 1-3 du/2.5 acres	7	93
Urban Residential, 1-3 du/acre	10	90
Urban Residential, 4-12 du/acre	25	75

The land use information was combined with a surficial geology map to create a land use/cover-geology map layer of the basin. The impervious area assumptions in Table 1 were then used to help calculate hydrologic response unit (HRU) acreages for the basin as summarized in Table 2.

Table 2. Comparison of 1993 and Updated Soil-Cover Complex Acreages

HRU	1993 MODEL (ACRES)	1999 UPDATE (ACRES)	DIFFERENCE (ACRES)
FOREST, TILL	356	219	-137
GRASS, TILL	101	235	134
FOREST, OUTWASH	365	236	-120
GRASS, OUTWASH	120	254	134
WETLAND	42	92	50
EFFECTIVE IMPERVIOUS	24	81	57
OPEN WATER	76	67	-10
TOTAL ALL CLASSES	1084	1184	100

As might be expected, since 1993 development has reduced forest cover while increasing grass and impervious areas within the basin. The table also shows an apparent increase in wetland and a loss of open water. These are probably anomalies caused by differences in methods of land cover interpretation rather than actual changes in basin land cover. The more recent GIS analysis does indicate that basin drainage area is 100 acres more than was assumed in the 1993 plan.

Check of 1993 Model

The HRU (land use/cover) changes from Table 2 were incorporated into the 1993 model. No changes were made to the hydrologic and hydraulic parameters or routing assumptions of the management plan model. To test the 1993 calibration and assumptions, the updated model was operated using precipitation data from the King County gage at nearby Mystic Lake. Simulated flows at gages BL1, BL2, and BL4 (see Figure 1) were compared to gage records of mean daily flows for the period of 10/1/98 through 4/25/00. As shown, BL1 is on the stream that connects drainage from North Wetland (ELS-21) to the upper-most cell of Beaver Lake, BL2 is on the stream that connects Saddle Swamp (ELS-10) to the middle and largest cell of the lake, and BL4 gages the outlet of the lake.

Table 3. Check of 1993 Calibration with Updated Land Use/Cover

CATCHMENT	TOTAL VOLUME ERROR	MEAN DAILY ERROR
BL1	-31%	84%
BL2	-42%	82%
BL4	-19%	51%

Results of the simulation are summarized in Table 3. The second column represents the difference between the total volume of flow simulated and the total volume gaged over the entire period from 10/97-4/00 at each site. As shown, the model consistently and substantially under-estimated (negative values) volumes at all three sites. The third column represents the root mean square error of daily mean values as a percentage of the gaged root mean square flow. It is an aggregate measure of how well the model matches gaged flows on a daily basis- and is always a positive number. A value of 0% represents a perfect match of simulated flows to gaged flows. A value of 100% means that the RMS of the daily deviations (positive or negative) is equal to the RMS of the daily gaged flows- or that errors are approximately as large as the flows themselves, suggesting a poor match.

Together, the two error statistics indicate that the updated 1993 model is significantly biased toward underestimating discharge and with generally large errors on a daily basis.

Re-calibration of the Beaver Lake Model

Based on the relatively poor performance of the updated 1993 model, the Beaver Lake HSPF model was re-calibrated using the following adjustments to flow routing and parameters:

1. The simulation time step was changed from 24-hr to 1-hr
2. Active groundwater was returned to all routing reaches. In the 1993 model, it was assumed that none of the pervious HRUs contributed any groundwater to wetlands or stream channels.
3. Maximum percolation loss from North Wetland, Saddle Swamp, and Beaver Lake had been 0.30 cfs for all three reaches. These values were changed to 0.22, 0.25 and 1.40 cfs respectively to better calibrate the model to gage data.
4. To better calibrate the model to gage data, minor changes to HRU parameters were made as shown in Table 4.
5. The flow routing table representing Beaver Lake was adjusted based on bathymetry information and on a correlation between observed lake stage and gaged outflow at BL-4 as shown in Figure 2.

Table 4. Adjustments to HSPF HRU (PERLUND) Parameters

HRU*	INFILT* (IN/HR)		LZSN* (IN)		INTFW *(-)		IRC* (1/DAY)	
	1993	RE-CAL	1993	RE-CAL	1993	RE-CAL	1993	RE-CAL
FOREST, TILL	0.030	0.040	3.00	4.50	8.5	12.0	0.75	0.70
GRASS, TILL	0.015	0.015	3.00	4.50	8.5	12.0	0.75	0.70
FOREST, OUTWASH	1.00	1.00	3.00	4.50	0.0	0.0	-	-
GRASS, OUTWASH	0.40	0.40	5.00	4.50	0.0	0.0	-	-

* per Bicknell, B.R., et.al., 1993: HRU-hydrologic response unit; INFILT-infiltration rate; LZSN-lower zone storage nominal; INTFW-interflow coefficient; and IRC interflow recession coefficient.

Results of Re-Calibration-Comparison with Gaged Flows

The adjustments outlined above resulted in the error statistics shown in Table 5. As shown in Table 5, re-calibration has nearly eliminated the total volume error at all three gages and has also reduced the average error in daily mean flows compared to the 1993 model with updated land use.

Table 5. Check of Re-Calibration Improvement

GAGE SITE	TOTAL VOLUME ERROR		MEAN DAILY ERROR	
	Re-Calibrated Model	Updated 1993 Model	Re-Calibrated Model	Updated 1993 Model
BL1	1%	-31%	74%	84%
BL2	-7%	-42%	69%	82%
BL4	1%	-19%	36%	51%

<u>Check of Lake Stage Simulations</u>

Another check on the model's performance is its ability to simulate fluctuations in lake stage. Volunteers have monitored daily water levels at the lake since October 1993. Observations have generally been made in the morning. Comparisons of simulated lake stages using the 1993 model with updated land use and the re-calibrated model are shown in Figures 3 for water years 1998-2000. In this figure, a lake elevation of 50.0 feet corresponds to the point below which the outlet channel goes dry at flow station BL-4. As shown in Figure 3, both the 1993 (thin line) and the re-calibrated model (thick line) do a fairly good job of tracking the observed seasonal variations in lake stages (plus sign) of Beaver Lake. The root mean square error of the 9 AM daily lake level over the period from 10/1/97 to 9/30/00 is approximately .26 feet for the re-calibrated model and 0.25 feet for the updated 1993 model. Relative to a nominal zero-flow elevation of 50.00 feet, the range of gaged values over this same period is from 48.31 feet to 51.85 feet or 3.54 feet.

Table 6. Check of Re-Calibration, lake levels

ROOT MEANS SQUARE ERROR (FT)	
Re-Calibrated Model	Updated 1993 Model
.26	.25

<u>Summary of Re-Calibration Results</u>

Overall, the re-calibration of the Beaver Lake basin model can only be judged "fair" in its ability to match measured daily mean discharges and Beaver Lake levels. In spite of the mediocre performance of the calibrated model, it represents an improvement over the original (1993) lake management plan model with updated land use because of greatly improved lake inflow and outflow volumes.

Modeling of Future Hydrologic Response

A future conditions HSPF model was developed to estimate hydrologic conditions at build-out. This future scenario is based on an assumption of maximum development consistent with zoning, plans, and regulations that apply within the basin. The main land cover changes that occur under these assumptions are the conversion of existing forest-covered land to impervious and grass (or other developed landscape) areas. Table 7 provides a summary of the hydrologic soil-cover complex acreages under future build-out conditions. The 1999 acreages are also included for comparison purposes.

Table 7. Comparison Current (1999) and Build-out Soil-Cover Complex Acreages

HRU	1999 (ACRES)	BUILD-OUT (ACRES)	CHANGE (ACRES)
FOREST, TILL	219	137	-82
GRASS, TILL	235	290	55
FOREST, OUTWASH	236	91	-145
GRASS, OUTWASH	254	361	107
WETLAND	92	92	0
EFFECTIVE IMPERVIOUS	81	145	64
OPEN WATER	67	67	0
TOTAL ALL CLASSES	1184	1184	0

1997 and 2000 Water Budgets

For 1997, weekly inflows and outflows estimates are summarized for Beaver Lake 1 and 2 in Tables 8 and 9. These estimates were derived from actual gage data and HSPF modeling of 1997 watershed conditions. Similarly, these estimates were made using 2000 data which are summarized for Beaver Lake 1 and 2 in Tables 10 and 11.

For both 1997 and 2000 water budgets, a consistent balance has been achieved. Because of the presence of data gaps and spotty consistency of the data for both years, substantial effort was required to balance both the water year 1997 and water year 2000 budgets. In balancing the individual budgets, the following hierarchy was applied: (1) volunteer water level information reflecting the lake level and storage volume were assumed correct and were not altered; (2) A regression relationship based on 1999 BL-4 data and monitored lake levels was used to fill the missing data for BL-4 in water year 2000; (3) up to 10 percent adjustments in BL-1 and BL-2 volumes were applied to make the balance work; and (4) no back flow was allowed from Beaver Lake 2 to Beaver Lake1.

Current and Build-out Water Budgets

In preparation for water quality modeling analysis, water budgets were also developed for both current and build-out land uses for a typical water year. Tables 12 and 13 illustrate weekly water budget information for a typical year based on current land use. Finally, Tables 14 and 15 summarize weekly water budget information for a typical year based on build-out land use. The typical water year budget for current conditions budgets and the actual water year 2000 budget are very similar since rainfall patterns during water year 2000 were close to typical patterns used in developing the current and build-out water budgets.

Figure 1. Catchments and Gage Locations

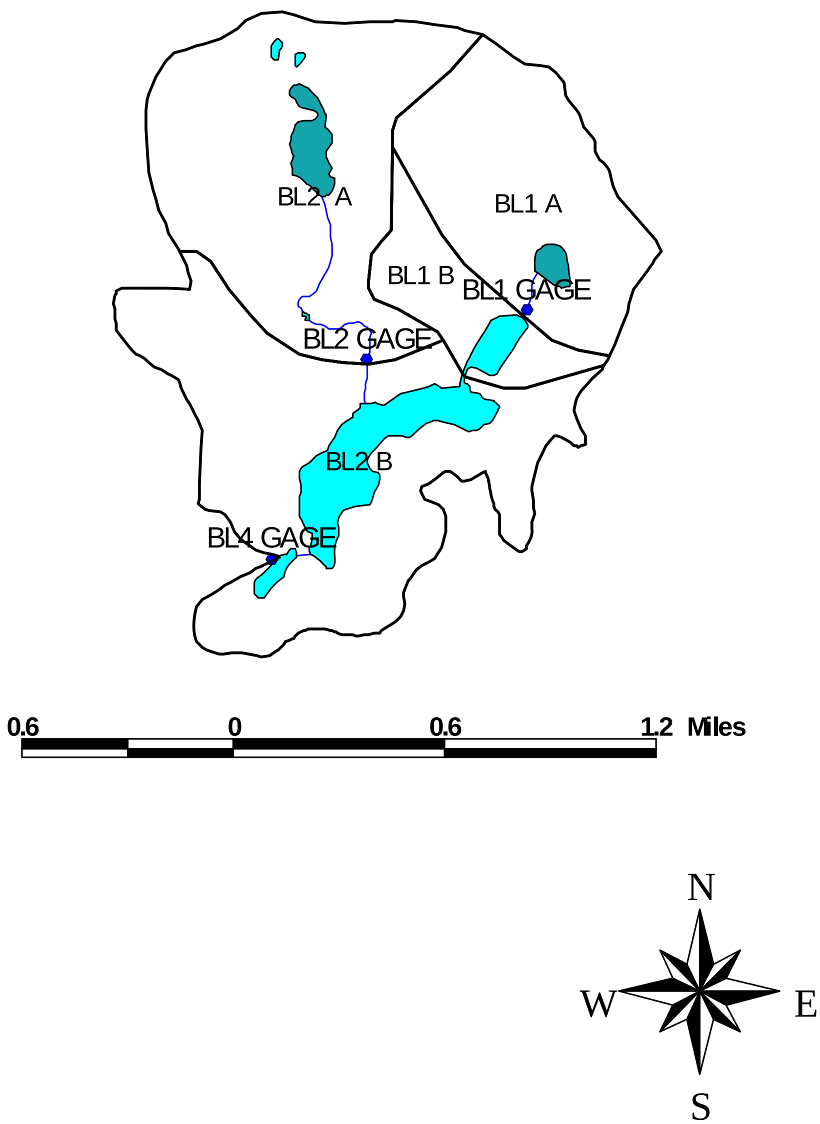


FIG 2. GAGED BEAVER LAKE OUTLET DISCHARGE VERSUS GAGED LAKE STAGE
(BOTH READINGS DAILY AT 9 AM)
STAGE CORRESPONDS TO FTABLE IN HSPF MODEL

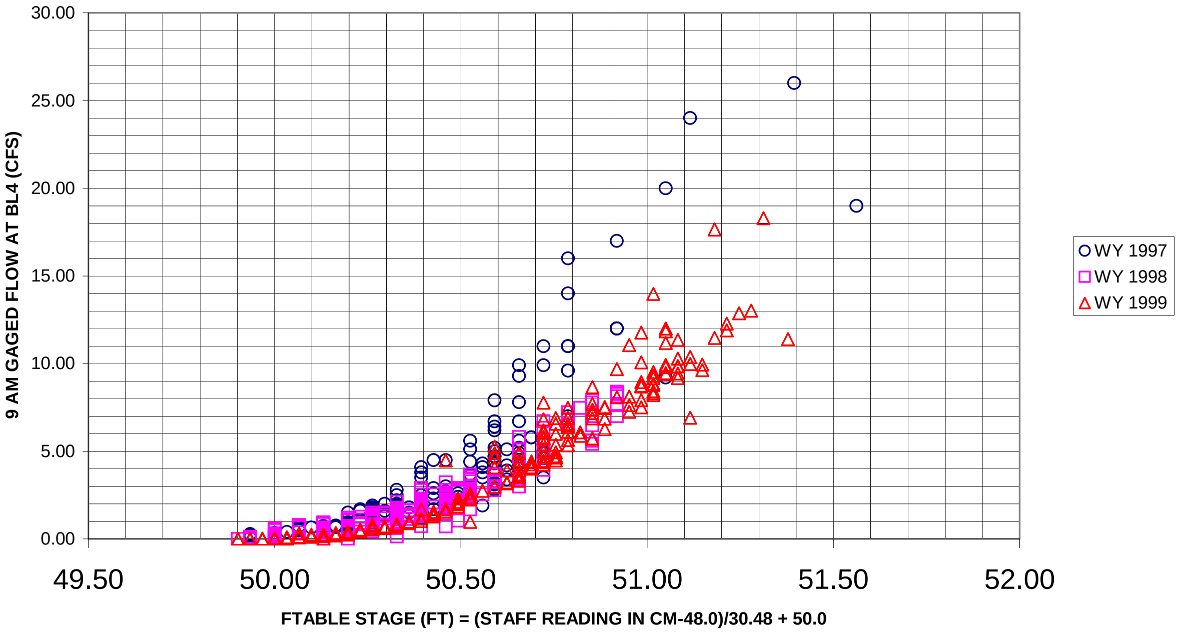
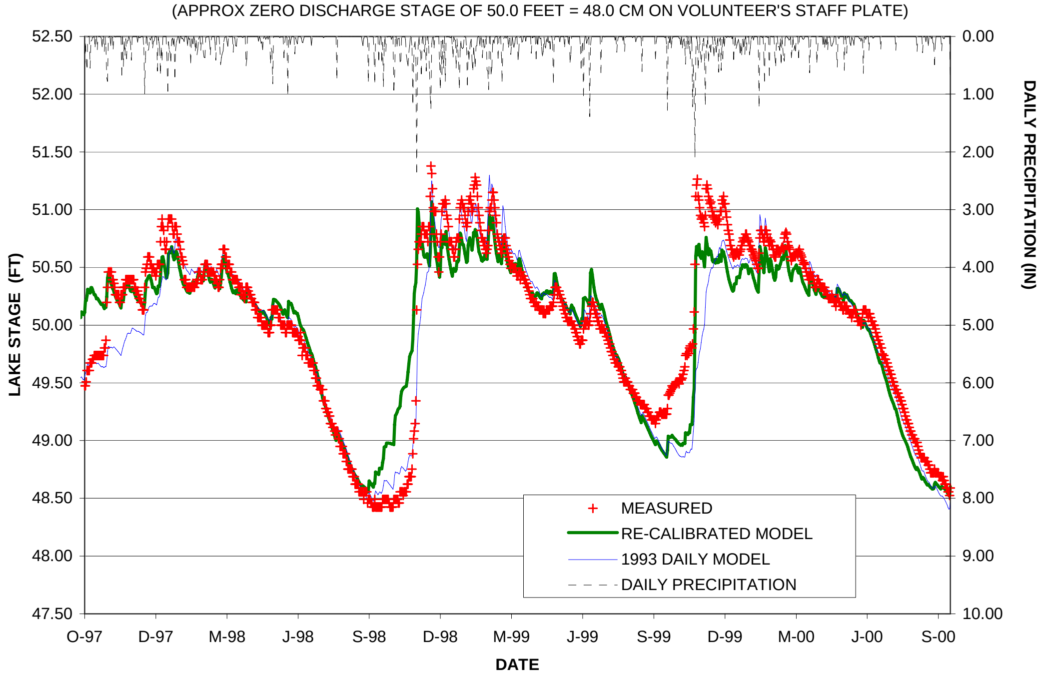


FIG 3- 9 A.M. GAGED AND MODELED LAKE STAGES
(APPROX ZERO DISCHARGE STAGE OF 50.0 FEET = 48.0 CM ON VOLUNTEER'S STAFF PLATE)



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Bicknell, B.R., J.C. Imhoff, J.L. Kittle, A.S. Donigian Jr. and R.C. Johanson. 1993. Hydrological Simulation Program - FORTRAN. User's Manual for Release 10. EPA/600/R-93-174. US EPA Environmental Research Laboratory, Athens, GA.

ENTRANCO, 1993. Beaver Lake Management Plan. Prepared for King County Department of Public Works, Surface Water Management Division. 130 p.

Appendix E

Beaver Lake Nutrient Budget

This section describes the methods, assumptions and results of the mass balance TP budget for Beaver Lake Basin 1 (BL1) and Beaver Lake Basin 2 (BL2). The 1993 study treated the loading to both lake basins as a whole and did not analyze BL1 and BL2 separately. Since BL1 flows into BL2, the approach of separating the basins was taken in order to better define the differences between the two basins in terms of their trophic responses to potential changes in nutrient loading. TP was the nutrient budgeted because P is the limiting nutrient (controlling production) for algae growth in Beaver Lake.

Methods and Assumptions

Hypolimnion – Epilimnion Volumetric Weighted TP Averages

The volumetric TP averages were determining calculated depth of the thermocline, which is defined as the largest change in temperature throughout the water column. The stratified period extended from March through November in both lakes for both the 1997 and 2000 water years. The remaining months, December through February, were considered to be the unstratified period, during which the lake basins were considered to mix from the surface to the bottom of the lakes.

TP Sources

Eight inputs were included in the TP budget based on the hydrologic budget: 1) tributary baseflow; 2) tributary runoff; 2) interflow; 4)-onsite treatment or septic sources; 5) atmospheric deposition (precipitation/air); 6) groundwater; 7) overland runoff; and 8) internal recycling. Inputs from waterfowl and decomposition of macrophytes were not included because there was limited data available and neither factor is likely to be a major contributor to TP input. Net internal loading from bottom sediment was calculated as residual (R) remaining in the model when inputs (I) were balanced against outputs (O) with positive values representing net internal loading and negative values representing net sedimentation and ΔTP is the change in TP in the lake:

$$-I + O + \Delta TP = -R$$

Although TP input from waterfowl was estimated to be 16% of the annual load to the lake in the 1993 study (Entranco, 1993), this source not included directly in the current TP budget. While the resident bird population was probably similar in 1993, 1997 and 2000, there were no data on its distribution in time and space for each lake. Moreover, the mode of addition to the lake by waterfowl excretion and the small fraction that is soluble renders it relatively unavailable to algae in the euphotic zone. By ignoring the waterfowl component, the net effect of waterfowl in the TP budget is to include it as a part of internal loading. Given the pausity of data, there is assumed to be less error in the TP budget by representing that source as part of internal loading rather than listing it separately. In the dynamic model, any contribution by waterfowl would be realized as a smaller loss to sedimentation, because internal loading is included as a gross release rate.

Similarly, the positive effect of macrophyte senescence, as a TP source to Beaver Lake, is at least partly offset by the bioavailability of plant-P at the time of plant senescence or die back and the uptake of phosphorus by attached algae and fungi growing on the plant. In lakes with substantial littoral area (where the ratio of littoral to pelagic water volume is one-half to one or more), the positive effect of aquatic plants (especially Milfoil) on the TP budget can be pronounced, as was the case in shallow Lake Wingra in Wisconsin (Smith and Adams, 1986). However, this is not the case in Beaver Lake where the littoral water volume is a small fraction of the total lake volume. Even in shallow lakes, macrophytes may represent more of a net sink than source such that TP concentrations in dense weed beds are less than in open water, such as in Long Lake (Kitsap) WA (Welch et al., 1994). Significant recycling of P during summer has been attributed primarily to milfoil (e.g. Lake Wingra) whereas waterlilies are the dominant macrophytes in Beaver Lake (Entranco, 1993). In addition, at the time of P release by the plants (mid to late summer and early fall) there should have been a definable increase in lake TP concentration and chl *a*, if indeed the P release amounted to as much as 11% as estimated in the 1993 study. Such increases in lake TP were not observed in 1997 or 2000.

TP loading from tributary was determined by splitting tributary (TP) concentrations into baseflow and stormflow. Baseflow of the tributary is the relatively constant flow found in the stream during the wet season and is due to the draining of water from soil storage. Stormflow is the streamflow that occurs due to storm water runoff into the stream system over and above the base flow volume. The baseflow was estimated at 5 cfs for Beaver Lake Tributary 1 (BLTR-1), and 10 cfs for Beaver Lake Tributary 2 (BLTR-2). Baseflow TP concentrations were approximated using the standard monthly data, and storm event concentrations were used for the stormflow period.

Interflow TP loading was determined by multiplying the interflow volume by the tributary soluble reactive phosphorus (SRP) concentrations from monthly stream data.

Estimations of TP loading from on-site waste treatment systems, specifically septic tank drain fields was based on a similar approach as that used in the 1993 study. The 9 of 215 drain fields in the Beaver Lake watershed that were considered to be failing in 1992 were used in this analysis and assumed to contribute all the TP from this source. The remaining 206 were assumed to be operating efficiently with no loss of P to the lake. The daily TP loading of 0.01 kg/day per system was used and is based on assuming 2.5 persons/household and 4 grams/day-person (USEPA, 1980). Leaching from the estimated failing drain fields to the lake was assumed to occur during November through May, the wet period for soils, and enter the lake in proportion to interflow volume. Therefore, the total mass entering the lake during that 7-month period was 18.9 kg. Assuming 25% retention in the settling tank, the total lost was 14.2 kg. Divided between the two basins based on number of residences observed in the 1960s, resulted in 2.8 and

11.4 kg for BL1 and BL2, respectively. The loadings were distributed volumetrically as a function of tributary interflow from BLTR1 and BLTR2.

Atmospheric deposition from both dryfall and precipitation adds TP to the surface of the lake. Bulk atmospheric deposition to Beaver Lake assumed a concentration of 27 micrograms per liter of precipitation, which was distributed volumetrically with precipitation events according to lake basin surface area.

TP loading from the groundwater was estimated by using the monthly SRP concentrations measured in the BLTR1 and BLTR2 tributaries multiplied by the monthly groundwater flow into the each lake basin.

Loading from overland flow TP was determined by multiplying tributary TP concentrations during stormflow events by overland runoff volumes determined by hydrologic model.

TP losses from the lake included: 1) surface outflow, 2)-groundwater discharge, and 3) sedimentation. The TP loss from BL1 through its outlet to BL2 was the same as the TP loading from BL1 to Bl2. TP leaving BL1 and entering BL2 was determined by multiplying the TP concentrations from the surface of the epilimnion in BL1 by the flow through the channel that connects BL1 to BL2.

Groundwater percolation losses of P used the hypolimnic SRP concentrations during the stratified period, and volume weighted average SRP during the unstratified period, by the volume of groundwater lost from the lake.

Sedimentation loss of TP in each lake basin was assigned to the negative residual in the TP mass balance. That quantity was therefore equated to the net loss (settling) of TP to the sediments.

RESULTS

Beaver Lake 1

In the 1997 water year, the TP loading to BL1 was 49.7 kg and the total outflow and sedimentation loss was 47.4 kg. External loading was 36.4 kg and net internal loading was 13.3 kg. In the 2000 water year, the total TP loading to BL1 was 29.3 kg and the total outflow and sedimentation loss was 29.5 kg. External loading was 24.1 kg and internal loading was 5.2 kg in 2000. Table 1 summaries the annual TP budgets for 1997 and 2000. The significant differences in the TP budgets from the two years was the loading increase due to the increase in the amount of precipitation in 1997 versus 2000. Loading from the inlet, groundwater, and overland runoff as well as atmospheric loading were the direct result of increased precipitation. Internal loading was calculated as a residual in the mass balance of phosphorus so the higher internal loading observed in 1997 over 2000 were in response to the lake maintaining nutrient equilibrium.

Table 1. Phosphorus Mass Balance for Beaver Lake 1 (years 1997 and 2000)

Loading/Loss Parameter	1997 Mass (kilogram)	2000 Mass (kilogram)
Tributary 1 Baseflow	10.7	7.8
Tributary Runoff	10.6	6.5
Interflow	0.5	0.1
Septic Interflow	2.8	2.8
Atmospheric	2.1	1.4
Groundwater	7.6	5.0
Overland Runoff	2.0	0.5
Internal Loading	13.3	5.2
Total Loading	**49.7**	**29.3**
Surface Outflow	30.3	17.0
Groundwater Discharge	1.2	2.0
Sedimentation	16.0	10.5
Total Losses	**47.4**	**29.5**
Increase or decrease in storage	**2.3**	**-0.2**

The tributary input (from both baseflow and runoff) was clearly the most significant source of TP to BL1 in both years. The percent concentration to the total load for each source to BL1 is illustrated in Figures 1 and 2 for 1997 and 2000, respectively.

Figure 1. Beaver Lake 1 1997 Annual Total TP Inputs

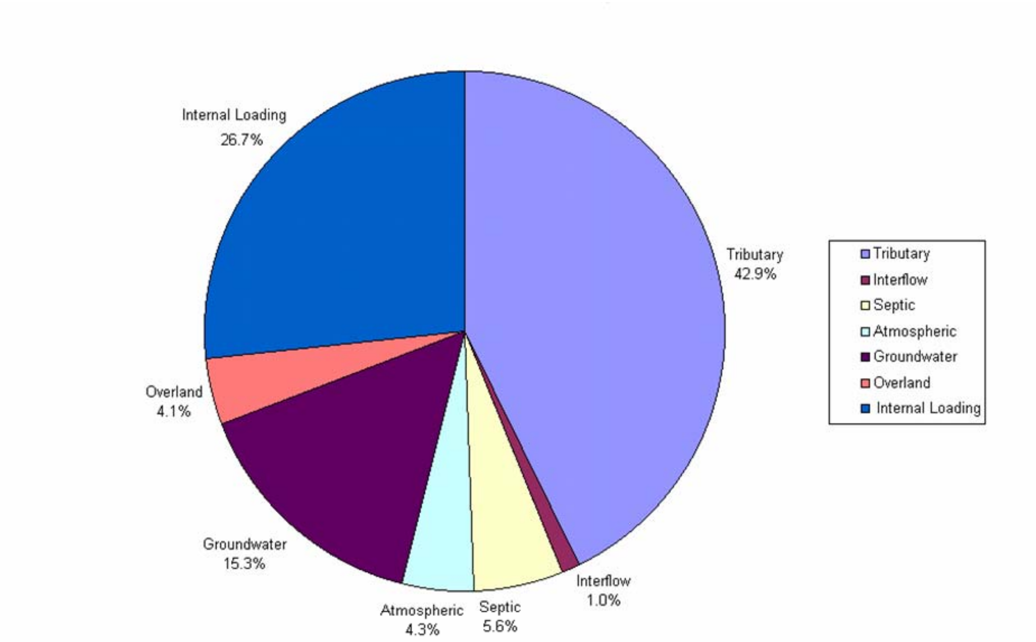


Figure 2. Beaver Lake 1 2000 Annual Total TP Inputs

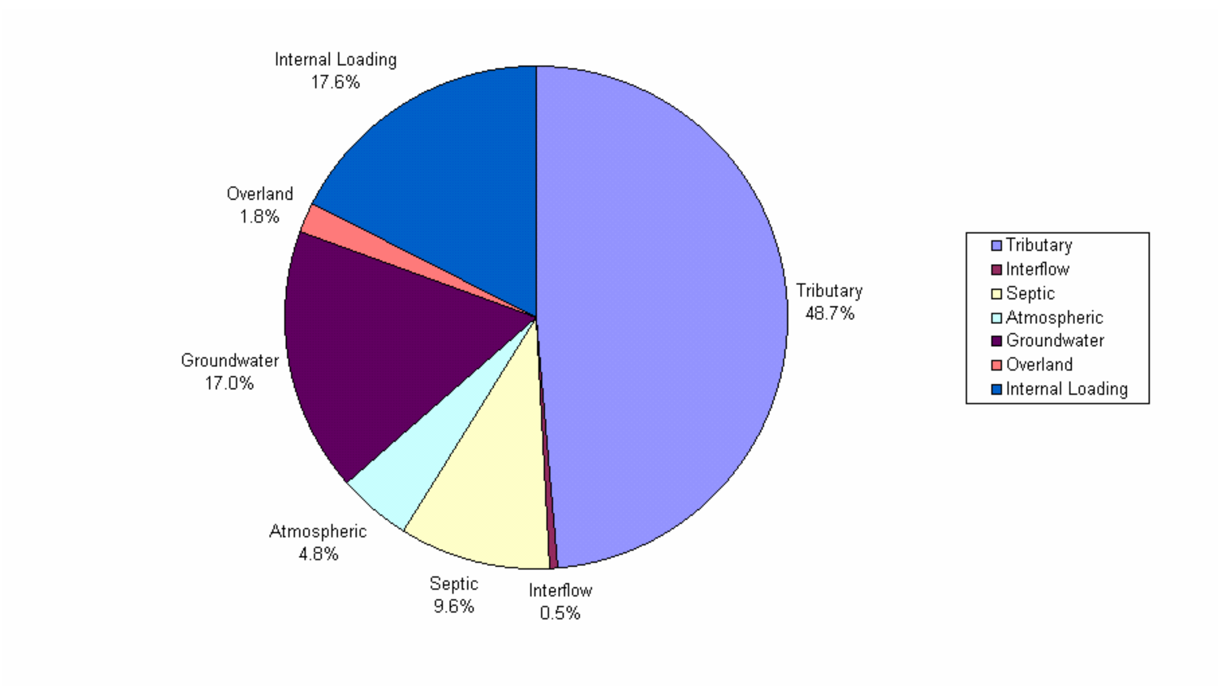


Figure 3 represents the weekly phosphorus loading to Beaver Lake 1 in kg. Figure 4 represents the weekly phosphorus loading to Beaver Lake 1 in 2000. TP loading during 1997 occurred largely in widely separated precipitation and flow events, whereas loading tended to be more continuously high during 2000.

Figure 3. Beaver Lake 1 Components of Total Phosphorus Loading 1997 Water Year

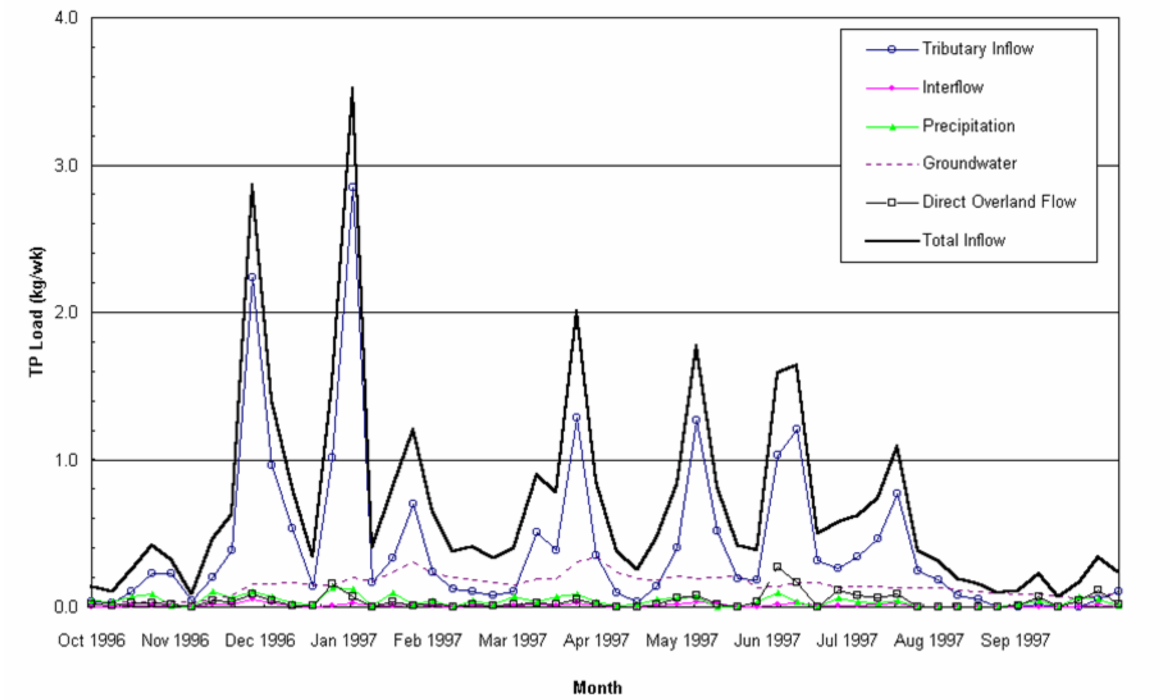
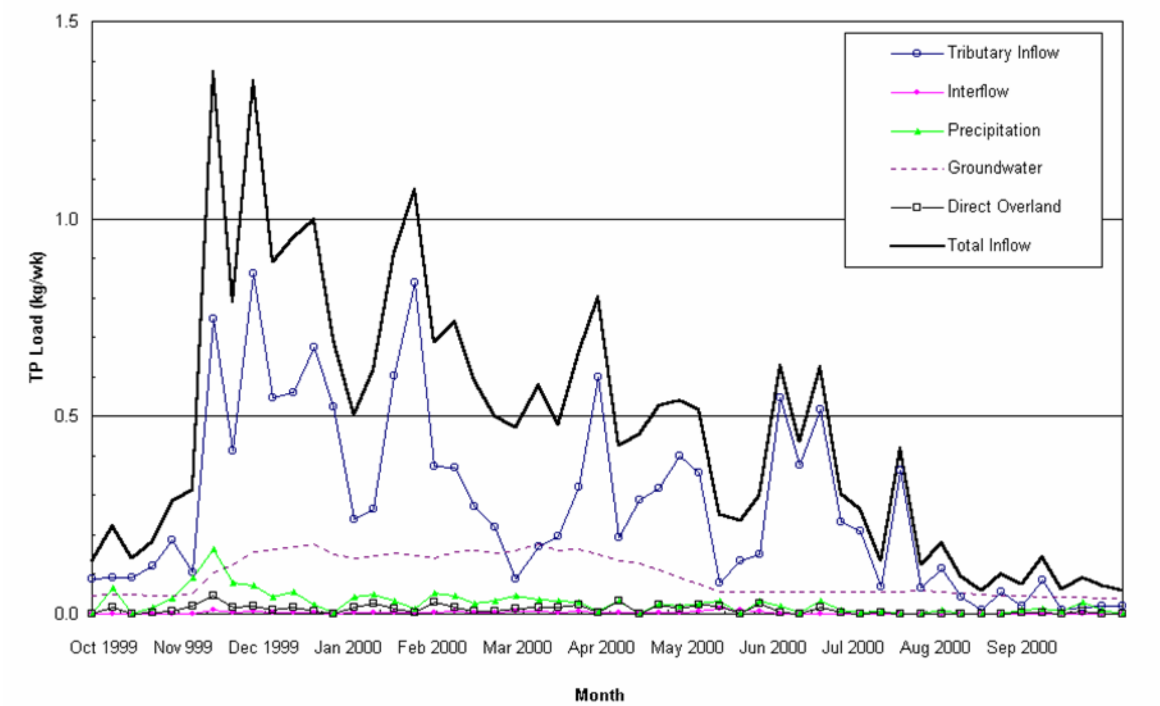


Figure 4. Beaver Lake 1 Components of Total Phosphorus Loading 2000 Water Year



Figures 5 and 6 give the relative portions of TP losses from BL1 for 1997 and 2000, respectively. The percentages are generally similar except that the outflow loss larger and groundwater loss less 1997 than in 2000.

Figure 5. Beaver Lake 1 1997 TP Total Outputs

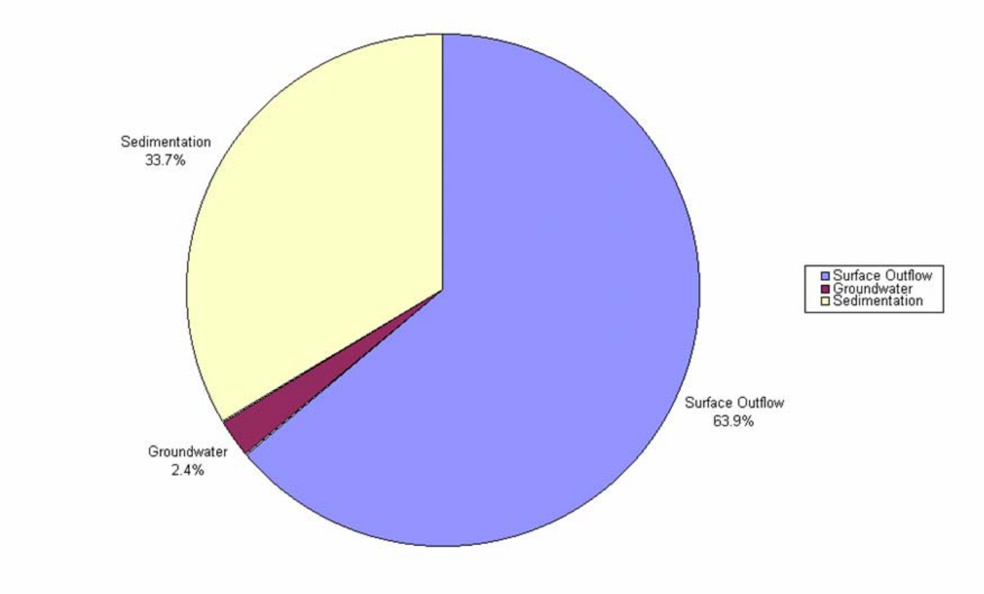
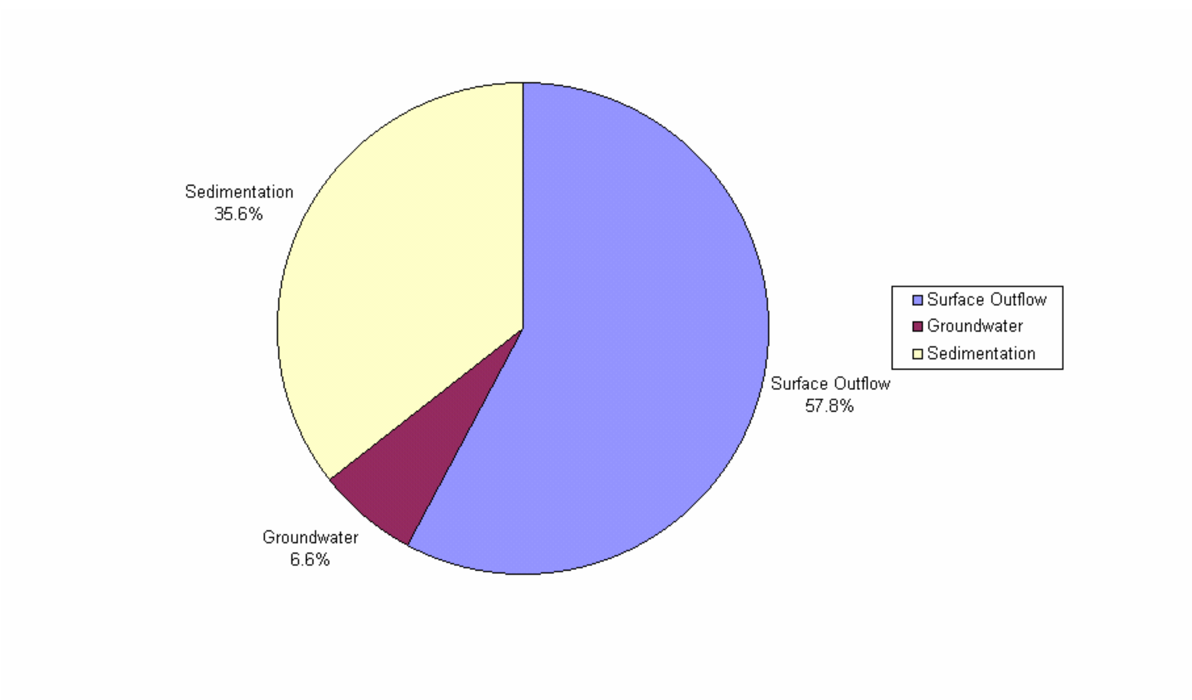


Figure 6. Beaver Lake 1 2000 TP Total Outputs



Beaver Lake 2

In the 1997 water year, the total TP loading to BL2 was 216.4 kg and total outflow and sedimentation loss was 220.5 kg. For 1997, the total external loading was 140.1 kg and internal loading was 76.3 kg. In the 2000 water year, TP loading to BL2 was 101.7 kg and total outflow and sedimentation was 89.3 kg. External loading was 84.9 kg and internal loading was 16.8 kg in 2000. As with BL1, external loading to BL2 was related to the amount of precipitation and flow. Table 2, below shows the phosphorus loading by source to BL2 for both 1997 and 2000.

Table 2. Phosphorus Mass Balance for Beaver Lake 2 (Water Years 1997 and 2000)

Loading/Losses Parameter	**1997 Mass (kilogram)**	**2000 Mass (kilogram)**
Beaver Lake 1 Outflow	30.3	17.0
Tributary 2 Baseflow	14.7	7.4
Tributary 2 Runoff	34.3	13.4
Interflow from BL1	0.4	0.2
Interflow	2.3	0.7
Septic Interflow	11.4	11.4
Atmospheric	10.2	6.8
Groundwater	23.6	23.6
Overland Runoff	12.9	4.4
Internal Loading	76.3	16.8
Total Loading	**216.4**	**101.7**
Surface Outflow	75.7	35.0
Groundwater Discharge	26.4	2.9
Sedimentation	118.4	51.4
Total Losses	**220.5**	**89.3**
Increase or decrease in storage)	**-4.1**	**12.4**

The tributary input (from both baseflow and runoff) and outflow from BL1 were clearly the most significant sources of TP to BL2 in both years. The percent of the total input load for each source to BL2 is illustrated in Figures 7 and 8 for 1997 and 2000, respectively.

Figure 7. Beaver Lake 2 1997 Annual TP Input

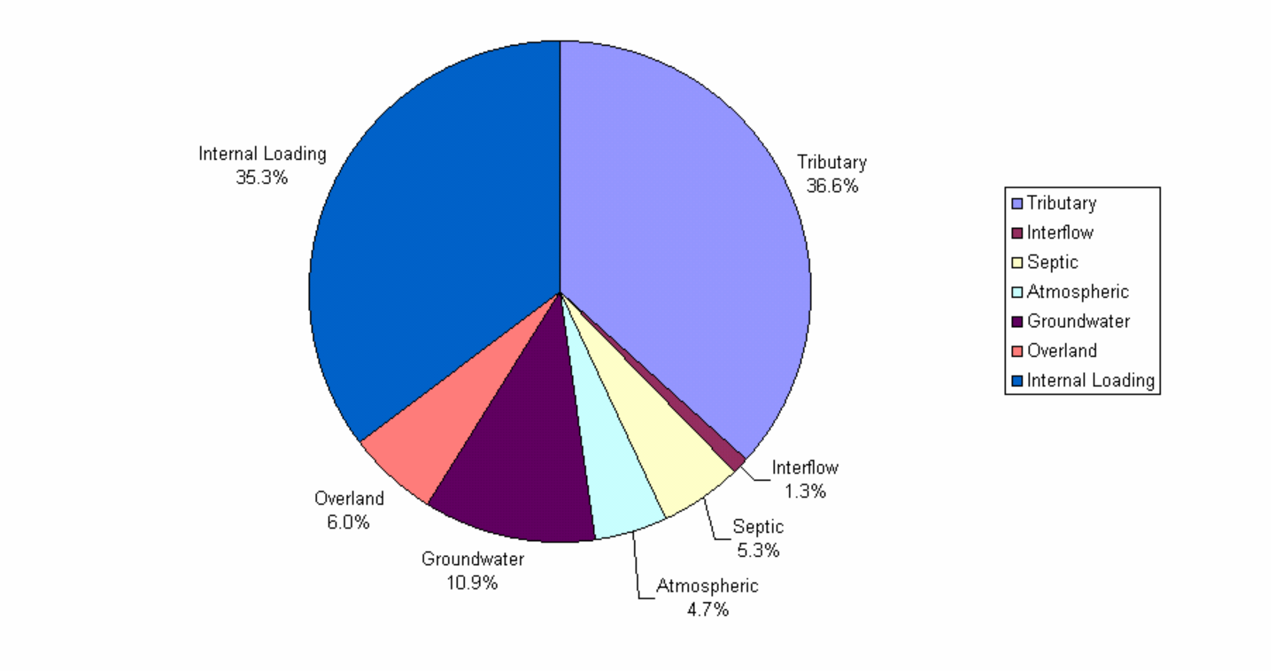


Figure 8. Beaver Lake 2 2000 Annual TP Input

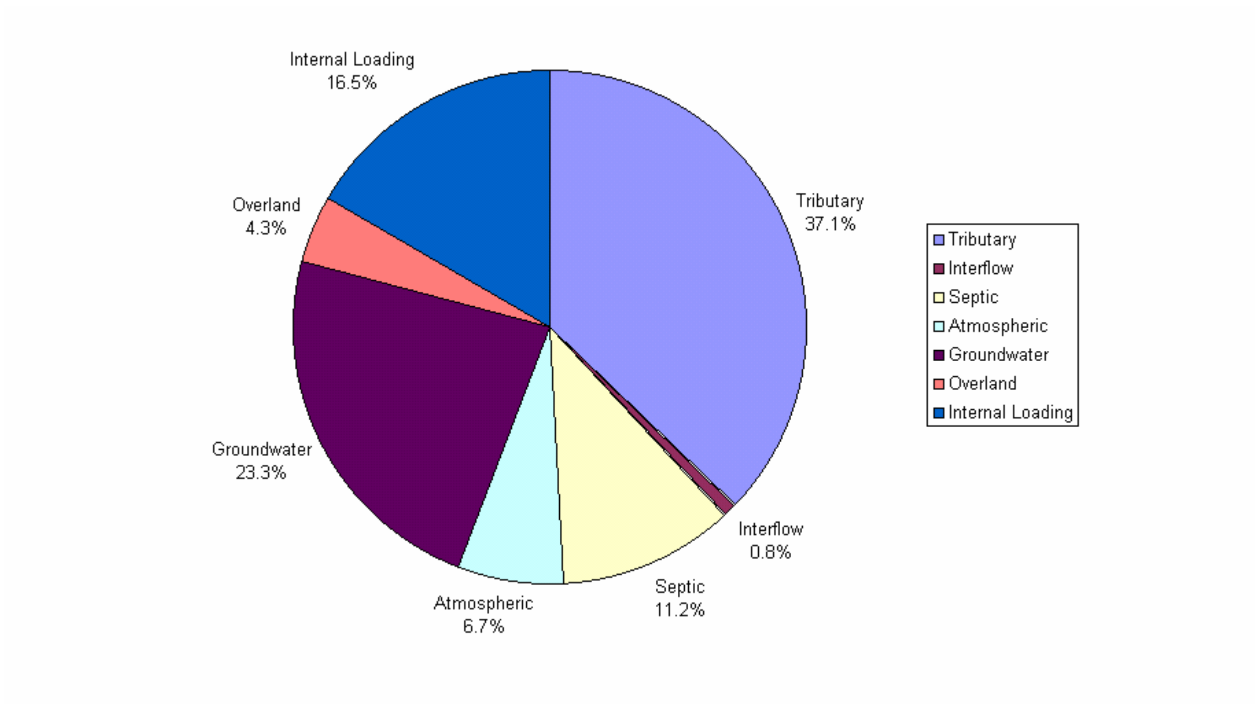


Figure 9 represents the weekly TP loading to BL2 in kg during 1997. Figure 10 represents the weekly TP loading to BL2 in kg during 2000. TP loading during 1997 occurred as a result of a few large precipitation and flow events in 1997 whereas inputs were more continuously high during the winter months during 2000.

Figure 9. Beaver Lake 2 Components of Total Phosphorus Loading 1997 Water Year

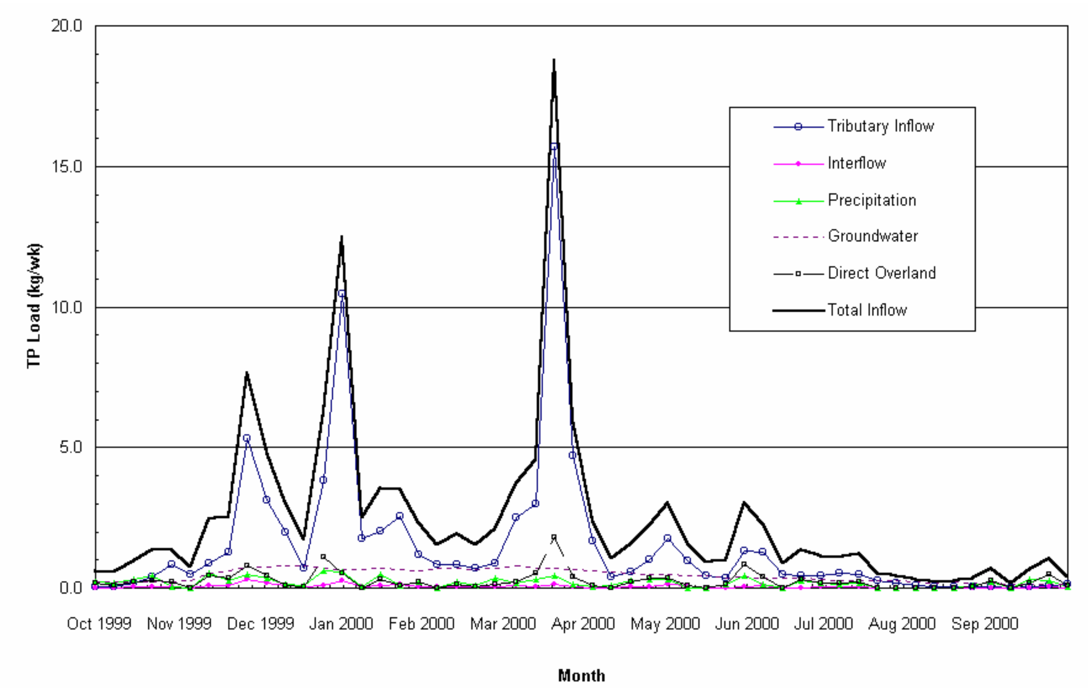
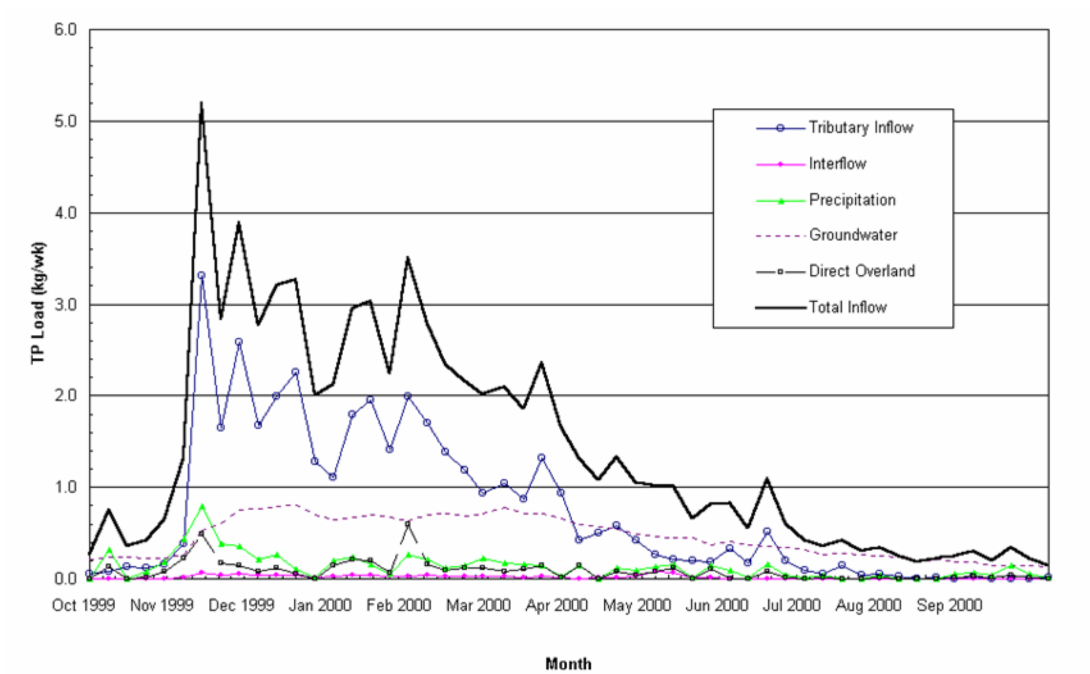


Figure 10. Beaver Lake 2 Components of Total Phosphorus Loading 2000 Water Year



Figures 11 and 12 give the relative portions of TP losses to BL2 for 1997 and 2000, respectively. The percentages are similar except that the groundwater loss was greater and sedimentation less in the wetter year 1997.

Figure 11. Beaver Lake 2- 1997 TP Annual Output

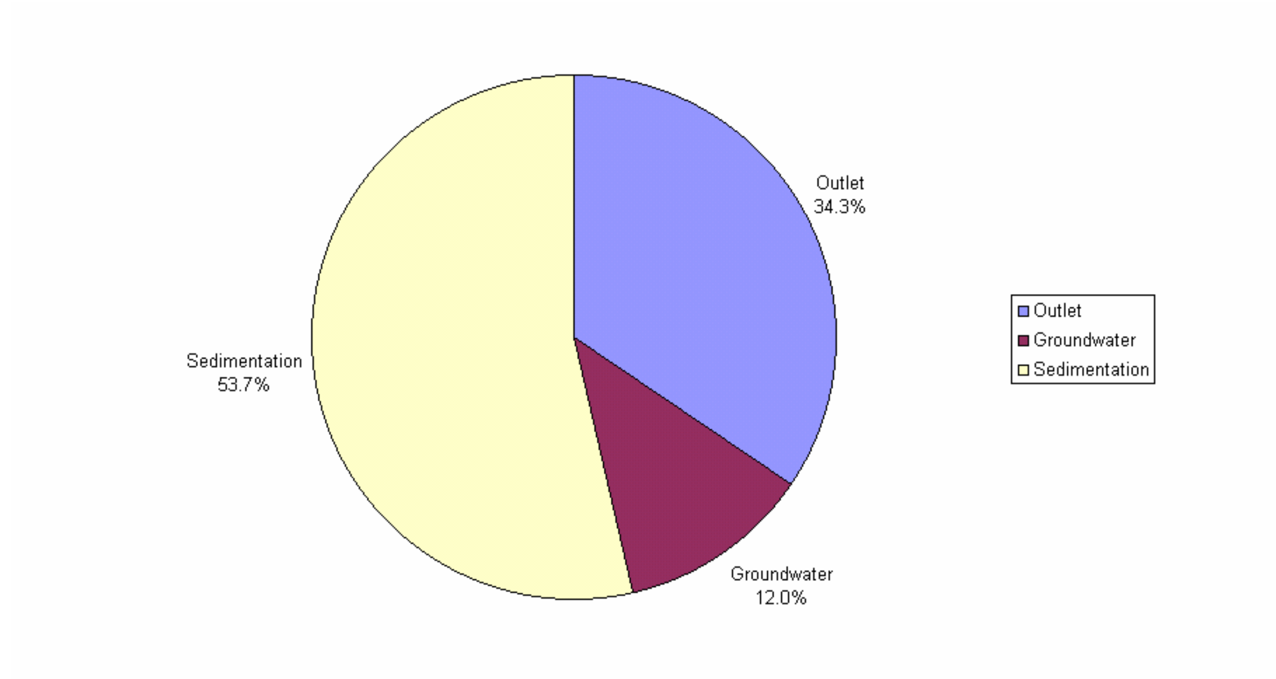
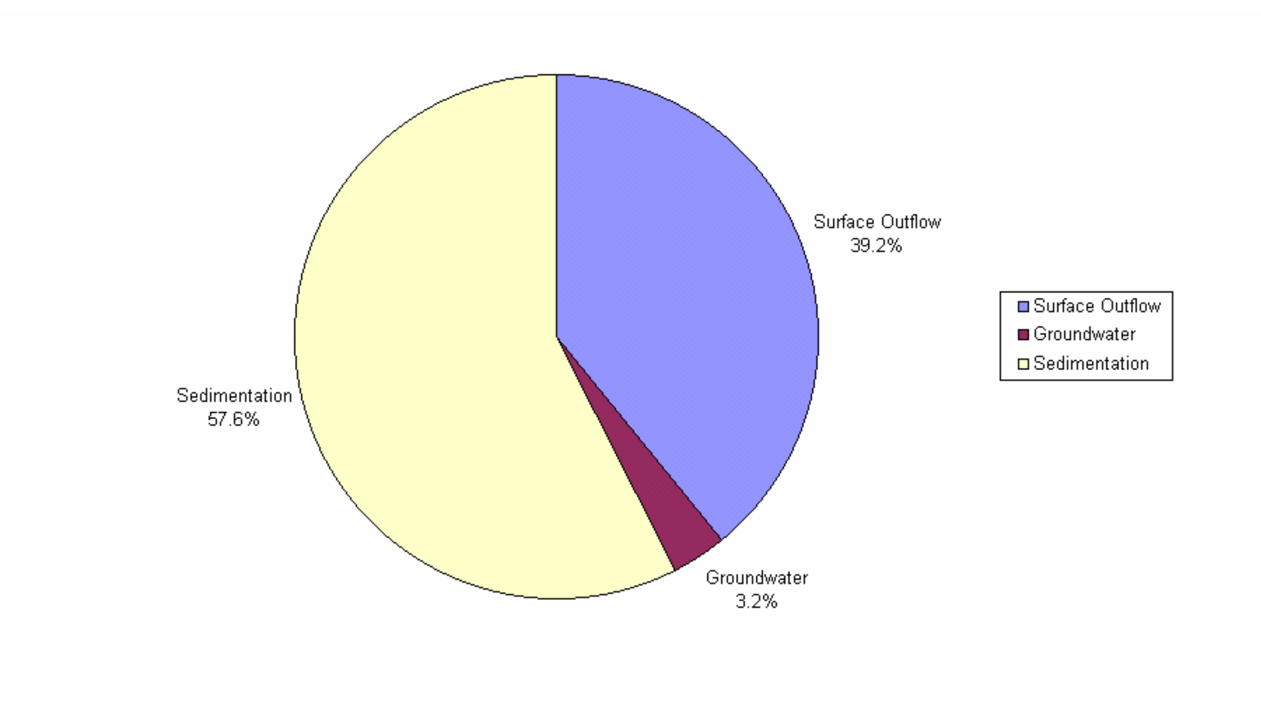


Figure 12. Beaver Lake 2- 2000 TP Annual Output



TP Comparison

In 1992 the total TP loading to Beaver Lake was 135.4 kg (excluding any TP contributed by waterfowl or macrophytes) and the total outflow and sedimentation loss was 168.3 kg. The 1997 total TP loads and total losses are considerably larger than the 1993 loads. The TP loading in 1997 to Beaver Lake 1 was 48.7 kg and the TP loading to Beaver Lake 2 was 216.4 kg. The TP loading in 2000 to Beaver Lake 1 was 29.3 kg and the TP loading to Beaver Lake 2 was 101.7 kg. The TP loading to the lake and the resulting TP concentrations in the lake appear to be influenced, in part, by precipitation patterns for the years of study

Appendix F

Phosphorus Modeling

Introduction

A two-layered, non-stead state (dynamic) mass balance total phosphorus TP model was used, similar to those for Lakes Sammamish (Perkins, 1995; Perkins et al. 1997) and Lake Onondaga (Auer et al. 1997), in order to simulate the effects of increased development on summer epilimnetic water quality. Empirical parameters wee generated from observed lake data during the 1997 and 2000 water years. This type of model avoids the uncertainties present in more complex models, that simulate dynamic changes in producers and consumers and nutrient recycling. However, it is able to capture the effect of seasonal changes in external total phosphorus loading and the relative effect of internal loading on the summer average concentration of algae and its effect on transparency. The effect of high external loading during the high-precipitation winter on summer total phosphorus would tend to be over estimated in an annual, stead-state model. Also, the effect high internal loading would be underestimated if spread throughout the year as would occur with an annual steady-state model, but possibly overestimated with non-steady state model that did not included two layers. Internal loading is often largely unavailable to the epilimnion until fall overturn in many highly stable, stratified lakes, such as in Lakes Sammamish and Onondaga. However, availability to the epilimnion via diffusion during the stratified period can be substantial if the concentration gradient between hypolimnion and epilimnion is high (Mataraza and Cooke, 1997).

Model Description

Internal Loading

Changes in total phosphorus mass and concentration were calculated using **Equation 1**. The change in phosphorus mass and concentration is a function of external loading, plus internal loading, less sedimentation and the outflow of total phosphorus through the outlet channel. For the two-layer model, total phosphorus flux across the thermocline from diffusion, entrainment and settling, were calculated as functions of total phosphorus concentrations in the epilimnion and hypolimnion during the stratified period.

$$\frac{dTP}{dt} = W_{ext} + W_{\text{int}} - W_s - W_{out}$$

External loading (W_{ext}) is defined as the contribution of total phosphorus from the Beaver Lake 1 and 2 watersheds through tributary, interflow, atmospheric precipitation/dryfall, septic, groundwater, and overland runoff. Internal loading (W_{int}) is defined as the contribution of total phosphorus through release of total phosphorus form lake bottom sediments. Sedimentation (W_s) is the removal of total phosphorus from the water column through the sedimentation total of phosphorus into lake bottom sediments. Outflow (W_{out}) is the removal of total phosphorus discharges through the lake outlet.

Model Development

Two water years of data, 1997 and 2000, were used to develop the Beaver Lake 1 & 2 empirical total phosphorus models. The model used existing total phosphorus budget data, which provided external loading, outflow loads and lake concentrations, in conjunction with a set of equations describing total phosphorus flux and sediment release rates to estimate lake total phosphorus concentrations. First, preliminary estimates of diffusion, entrainment and internal loading were generated for application to the model. These estimates were further refined as a part of model calibration. **Equation 2** is used to determine the amount of total phosphorus released from anoxic sediments termed internal loading.

$$W_{\text{int}} = SRR \cdot A_{anox} \cdot 10^{-6} (kg / wk)$$

The internal loading is equal to the sediment release rate (SRR), multiplied by the area of anoxic sediments and converted into kilograms per week (kg/wk). Determination of internal loading required the use of regressed relationships for anoxic depths of Beaver Lakes 1 and 2.

Anoxic depths were determined by identifying the depth where dissolved oxygen (DO) levels dropped below 1 mg/l. Selected measurements were used to develop mathematical relationships of anoxic depth from the water surface as a function of days removed from the start of the water year. The depth of anoxia decreases from October through December when the lake overturns. Then from beginning in spring and ranging through the summer and early fall, anoxic depths move up from the bottom of the lake to a depth approximately 6 to 9 meters below the water surface. **Figure 1** and **Figure 2** show the anoxic depth regression relationships using the pooled data for the two water years.

W_{int} = Internal Loading
SRR = Sediment Release Rate ($mg/m^2 \cdot wk$)
A_{anox} = Area of anoxia (m^2)

Figure 1. Beaver Lake 1 – Anoxic Depth Regression Relationship

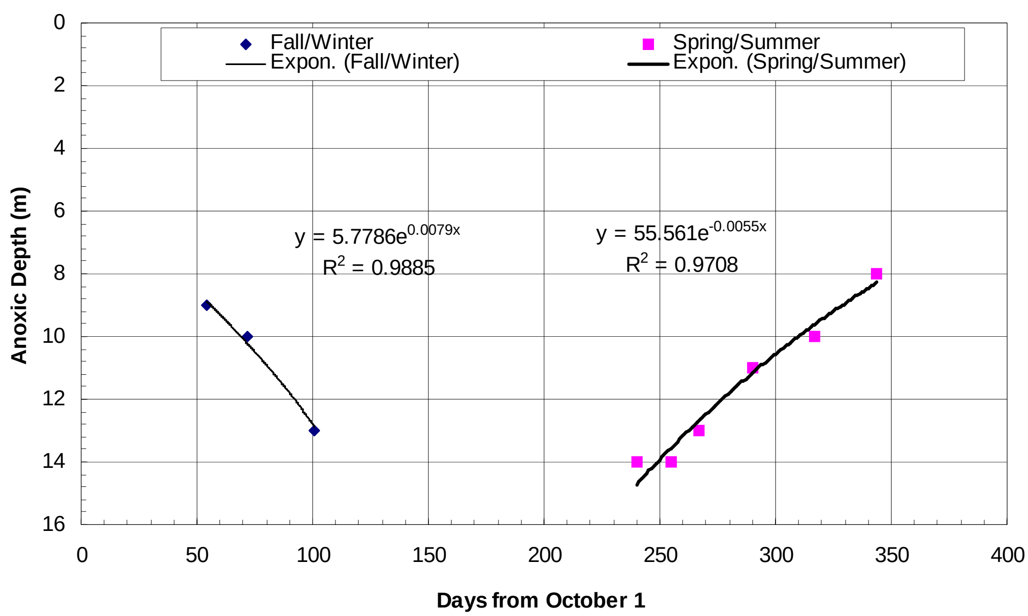
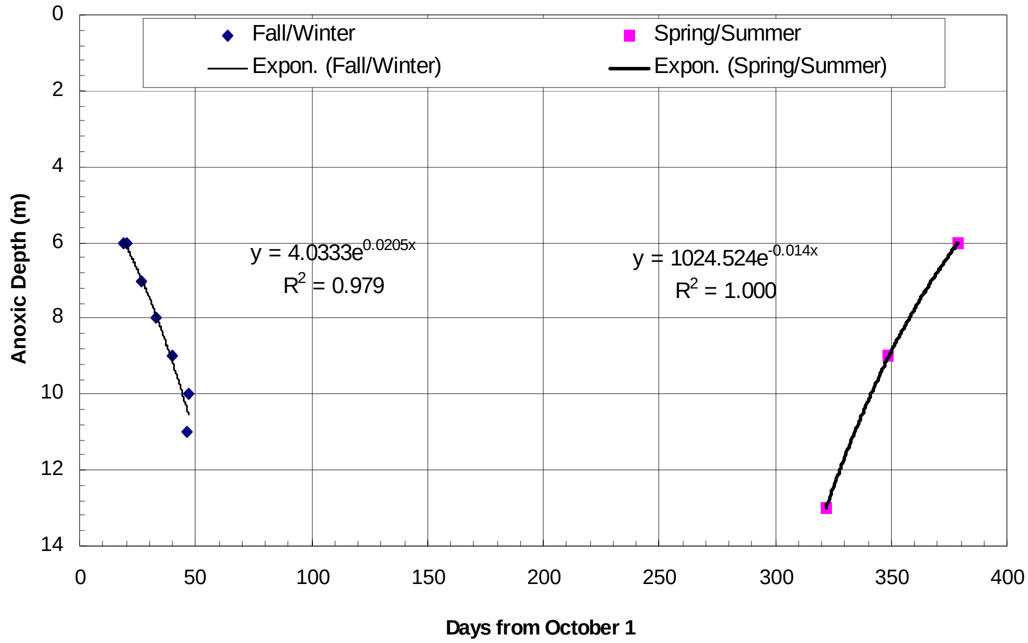


Figure 2. Beaver Lake 2 – Anoxic Depth Regression Relationship



Sediment Release Rate

Sediment release rates for both Beaver Lake 1 and 2 were determined by calculating the net increase in hypolimnetic concentration, under anoxic conditions, between May and September. SRRs were determined using the hypolimnetic surface area, but internal loading is applied in the modeling process using the SRR multiplied by the anoxic area, rather than the hypolimnetic area. The equation for determining the net increase in total phosphorus is shown below. Sediment release rates were used as estimates for initial model calibrations and the final step in the calibration process was to further adjust the sediment release rate so that modeled concentrations approximated measured total phosphorus concentrations. SRRs will be further discussed in the model calibration section.

$$SRR = \sum_{May}^{Sept.} \frac{V_t}{A_t} \cdot \frac{(C_1 - C_o)}{(t_1 - t_0)} \qquad \textbf{(3)}$$

Variable definitions:

V_t: Hypolimnetic lake volume (m^3)
A_t: Hypolimnetic lake area area of thermocline (m^2)
C_o: Initial total phosphorus concentration (μg/l)
C_1: Next total phosphorus concentration (μg/l)
t_o: Initial sampling date
t_1: Next sampling date

The average net SRR for Beaver Lake 1 was calculated to be 5.6 mg/m^2-wk while the rate for Beaver Lake 2 was 40.2 mg/m^2-wk. The data used to develop the SRRs are in **Tables 1 & 2.**

Morphometric Characteristics

Two variables, volume of the thermocline (V_t) and area of the thermocline (A_t), are required for the SRR calculations, as well as other calculations within the model that are primarily associated with the total phosphorus flux. These variables are a function of the thermocline depth. Regressed relationships were developed for thermocline depths versus time, as well as depth-area and depth-volume relationships. **Figures 3 – 6** depict the relationships with time for thermocline depth with time, and lake area and volume with depth, respectively.

Figure 3. Beaver Lake 1, Thermocline Depths

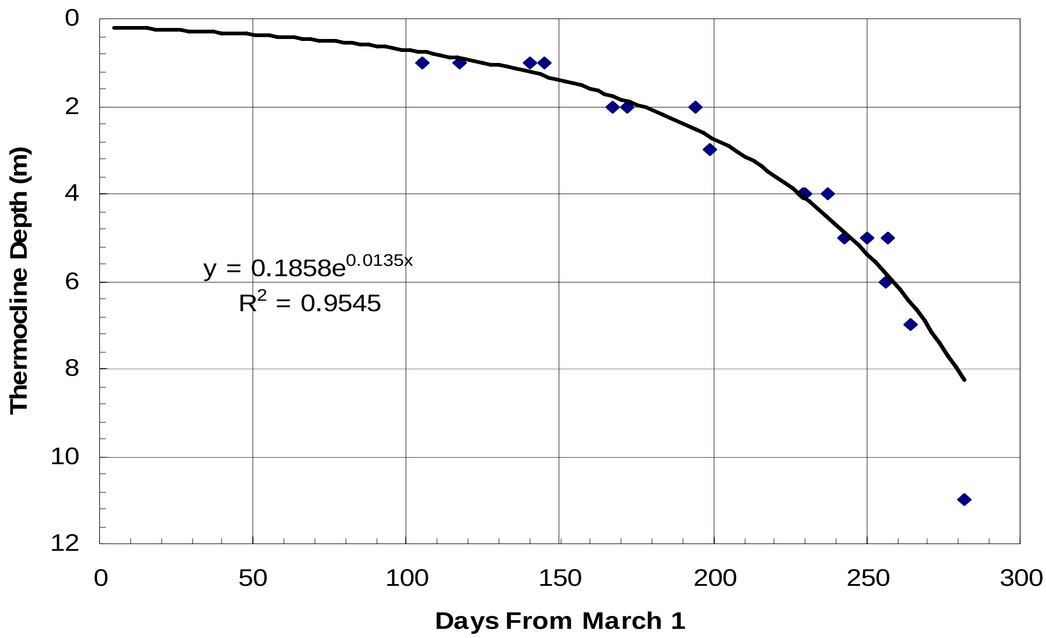


Figure 4. Beaver Lake 2, Thermocline Depths

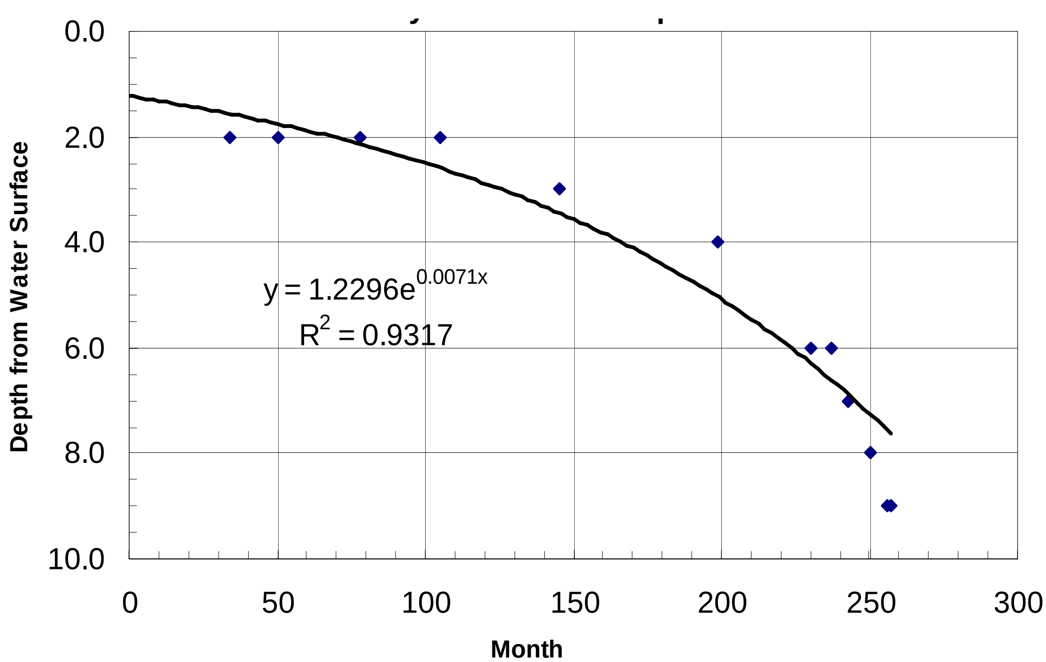


Figure 5. Beaver Lakes, Depth vs. Area

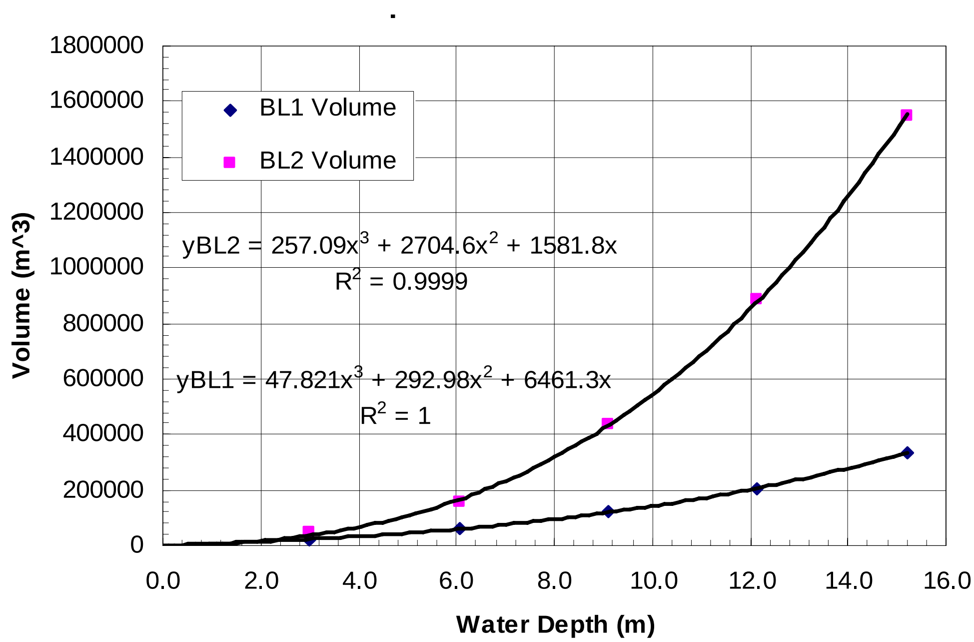


Figure 6. Beaver Lakes, Depth vs. Volume

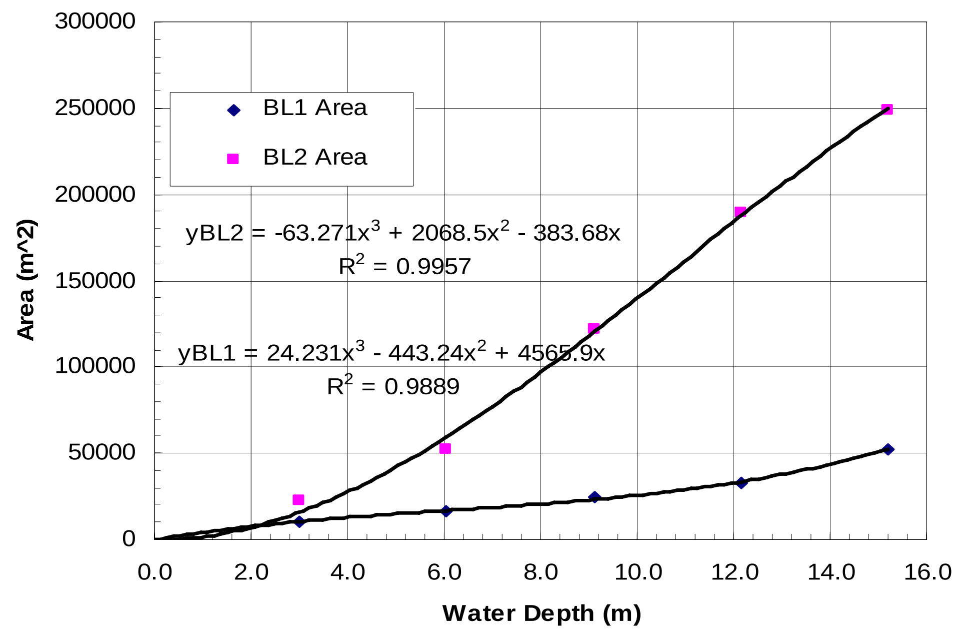


Table 1. Beaver Lake 1 Sediment Release Rate

Date	Hypolimnetic TP BL1	Time Interval (d)	Thermocline Meas. Depth (m)	Thermocline Water Depth (m)	Vol. Hyp (m^3)	Area Hyp. (m^2)	Sr = V/A*((C1-Co)/(t1-to))	Units
17-Mar-97	37.09	na	0.5	14.70	310205	240360		
21-Apr-97	27.64	35.00	2.0	13.20	246445	209830	-0.32	Disregard
19-May-97	30.10	28.00	0.5	14.70	310205	240360	0.11	
16-Jun-97	44.20	28.00	0.5	14.70	310205	240360	0.65	
21-Jul-97	39.20	35.00	2.0	13.20	246445	209830	-0.17	
18-Aug-97	57.75	28.00	2.0	13.20	246445	209830	0.78	
15-Sep-97	56.44	28.00	2.0	13.20	246445	209830	-0.05	
			Net sediment release rate per day (may - september)				**1.32**	mg/m^2-d
			Net sediment release rate per week (may - september)				**9.23**	mg/m^2-wk
08-Mar-00	31.09	na	4.0	11.2	176491	166284		
05-Apr-00	25.91	28.00	0.5	14.7	310205	240360	-0.24	Disregard
03-May-00	23.15	28.00	2.0	13.20	246445	209830	-0.12	Disregard
31-May-00	24.83	28.00	2.0	13.20	246445	209830	0.07	
28-Jun-00	26.39	28.00	0.5	14.70	310205	240360	0.07	
26-Jul-00	28.39	28.00	2.0	13.20	246445	209830	0.08	
23-Aug-00	29.83	28.00	2.0	13.20	246445	209830	0.06	
20-Sep-00	24.65	28.00	2.0	13.20	246445	209830	-0.22	Disregard
			Net sediment release rate per day (may - september)				**0.29**	mg/m^2-d
			Net sediment release rate per week (may - september)				**2.01**	mg/m^2-wk
Two year net sediment release rate per week average (May – September)							**5.62**	mg/m^2-wk

Table 2. Beaver Lake 2 Sediment Release Rate

Date	Hypolimnetic TP BL2	Time Interval (d)	Thermocline Meas. Depth (m)	Thermocline Water Depth (m)	Vol. Hyp (m^3)	Area Hyp. (m^2)	Sr = V/A*((C1-Co)/(t1-to))	Comments & Units
17-Mar-97	35.28	na	0.5	14.7	1425612	48309		
21-Apr-97	18.06	35.00	2.0	13.2	1084339	38770	-13.76	Disregard
19-May-97	22.79	28.00	2.0	13.2	1084339	38770	4.72	
16-Jun-97	37.69	28.00	2.0	13.2	1084339	38770	14.89	
21-Jul-97	19.85	35.00	2.0	13.2	1084339	38770	-14.26	
18-Aug-97	21.71	28.00	2.0	13.2	1084339	38770	1.86	
15-Sep-97	23.45	28.00	4.0	11.2	718771	29581	1.51	
			Net sediment release rate per day (may - september)				**8.72**	mg/m^2-d
			Net sediment release rate per week (may - september)				**61.06**	mg/m^2-wk
08-Mar-00	14.59	na						
05-Apr-00	12.36	28.00	2.0	13.2	1084339	38770	-2.23	
03-May-00	13.83	28.00	2.0	13.2	1084339	38770	1.47	
31-May-00	10.82	28.00	2.0	13.2	1084339	38770	-3.00	
28-Jun-00	11.82	28.00	2.0	13.2	1084339	38770	1.00	
26-Jul-00	13.01	28.00	2.0	13.2	1084339	38770	1.18	
23-Aug-00	23.78	28.00	4.0	11.2	718771	29581	9.35	
20-Sep-00	15.43	28.00	4.0	11.2	718771	29581	-7.25	
			Net sediment release rate per day (may - september)				**2.75**	mg/m^2-d
			Net sediment release rate per week (may - september)				**19.24**	mg/m^2-wk
Two year net sediment release rate per week average (may – september)							**40.15**	mg/m^2-wk

Settling and Sedimentation

Settling is the transfer of total phosphorus through sedimentation from the epilimnion to the hypolimnion during the stratified period. Sedimentation (st) is the process whereby total phosphorus is removed from the water column in the hypolimnion to the lake bottom sediments. Settling and sedimentation were calculated by **equation 4**. The apparent settling velocity V_a is substituted into **equation 5** for the hypolimnetic sedimentation calculations ($V_{a,hypo}$) to adjust for the increase in hypolimnetic total phosphorus concentration from SRR, which effectively decreases the "apparent" settling velocity.

$$St = U_a \cdot A_t \cdot TP_{conc} \text{ (kg/wk)} \qquad \textbf{(4)}$$

$$U_{a,hypo} = U_a \cdot \left(\frac{TP_{epi}}{TP_{epi} + SRR \cdot U_t}\right) \text{ (m/wk)} \qquad \textbf{(5)}$$

$$U_a = \frac{St}{A_t \cdot TP_{conc}} \text{ (m/wk)} \qquad \textbf{(6)}$$

Rearranging **equation 4** allows for the solution of the apparent settling velocity shown in **equation 6**. The calculation produced a settling velocity (V_a) of 0.28 m/wk for Beaver Lake 1, 2000 that is reasonable. Other results from different years and Beaver Lake 2 were not within a reasonable range and therefore the value of 0.28 m/wk was used as the preliminary estimate, which was adjusted further during the calibration process for Beaver 1 in 1997 and Beaver 2 in both years.

St = Settling and sedimentation rate (kg/wk)
U_a = Apparent settling velocity (m/wk)
U_t = Vertical heat exchange coefficient (m/wk)
TP_{conc} = Total phosphorus concentration (μg/l)
TP_{epi} = Total phosphorus concentration – epilimnion (μg/l)
TP_{hyp} = Total phosphorus concentration – hypolimnion (μg/l)
A_t = Area of thermocline (m^2)
SRR = Sediment release rate (mg/m^2-wk)

Internal Total Phosphorus Diffusion and Entrainment

Diffusion is defined as the process whereby total phosphorus diffuses from high concentration zones into zones of lower concentration, in this case across the thermocline. **Equation 7** defines the amount of total phosphorus that diffuses across the thermocline during the stratified period.

$$Diff = U_t \cdot A_t \cdot (TP_{epi} - TP_{hyp}) \cdot 10^{-6} \quad \text{(kg/wk)} \qquad \textbf{(7)}$$

Diffusion is equal to the vertical heat exchange coefficient multiplied by the area of the thermocline, and by the volume weighted average difference in total phosphorus concentrations between the epilimnion and the hypolimnion in kg/wk. Estimation of the vertical heat exchange coefficient is described by **Equation 8**.

Equation 8

$$U_t = \frac{\overline{V}_{hyp}}{(\overline{A}_t \cdot t_s)} \ln \frac{(\overline{T}_{hyp-\min} - \overline{T}_{epi-avg})}{(\overline{T}_{hyp-\max} - \overline{T}_{epi-avg})} \quad \text{(m/wk)}$$

The vertical heat exchange coefficient for the Beaver Lake 1 was determined to be 0.095 and for Beaver Lake 2, 0.244 (m/wk).

Diff = Diffusion rate (kg/wk)
U_t = Vertical heat exchange coefficient (m/wk)
$\overline{T}$ = Average temperature (°c)
t_s = Time from avg. temperature maximum to avg. temperature minimum in the hypolimnion (wk)

Entrainment is the process whereby total phosphorus is captured by the epilimnion as the thermocline levels plunge deeper as the summer progresses. **Equation 9** is the mathematical approximation of the exchange of total phosphorus from the hypolimnion to the epilimnion during the stratified period. No coefficient estimations were necessary for entrainment calculations.

$$E = (TP_{hyp} - TP_{epi}) \cdot (D_{t+dt} + D_t) \cdot A_t \cdot 10^6 \text{ (kg/wk)} \qquad \textbf{(9)}$$

TP_{epi} = Total phosphorus concentration – epilimnion (μg/l)
TP_{hyp} = Total phosphorus concentration – hypolimnion (μg/l)
D_t = Initial depth of thermocline (m)
D_{t+dt} = Depth of thermocline at time t+dt (m)
A_t = Area of thermocline (m^2)

Model Calibration

The Beaver Lake Total Phosphorus Model was calibrated by applying known total phosphorus inflows and outflows, from the total phosphorus budget, and adjusting the preliminary estimates of internal loading, sedimentation and total phosphorus flux to match lake concentrations. Coefficients and rates that were varied for calibration purposes include the SRR, heat exchange coefficient, and settling velocities until modeled lake concentrations represented measured volume weighted lake concentrations in the epilimnion, hypolimnion and whole lake. The SRR is the primary calibration component and was varied in magnitude throughout the water year to generate a good fit with measured lake total phosphorus concentrations. The heat exchange coefficient and settling velocity were also varied, to a lesser degree, to fit measured lake volume weighted total phosphorus concentrations. Models for both Beaver Lakes 1 and 2 were calibrated with variable coefficients for separate years, 1997 and 2000, to produce a good fit with measured total phosphorus concentrations. **Tables 3-6** list the calibrated heat exchange coefficients, settling velocities and SRRs for each of the Beaver Lake total phosphorus models and years. **Figures 7-18** depict the model calibration results for the epilimnetic, hypolimnetic and whole lake total phosphorus concentrations of each Beaver Lake model and year.

Table 3. Total Phosphorus Model Calibration Coefficient Results for Beaver Lake 1, 2000

Date	Septic Input kg/year	Atmospheric Concentration Input Rain/Air Conc µg/l	Diffusion Excg. Coeff. m/wk	Settling Velocities Mixed m/wk	Settling Velocities Epilimnion m/wk	Settling Velocities Hypolimnion m/wk	SRR Mg/m²-wk
Oct1-Dec10	2.80	8.00	0.50	0.00	0.28	0.28	40.00
Dec10-Sep30	2.80	8.00	0.10	0.10	0.40	0.40	0.25

Figure 7. Beaver Lake 1, 2000, Epilimnetic Total Phosphorus Model Calibration Results

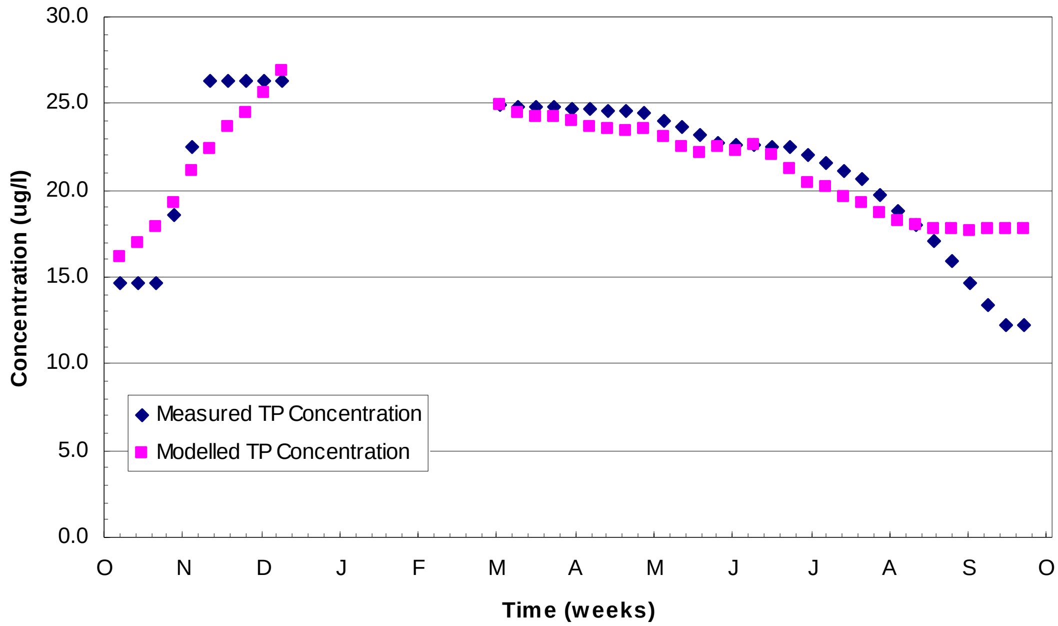


Figure 8. Beaver Lake 1, 2000, Hypolimnetic Total Phosphorus Model Calibration Results

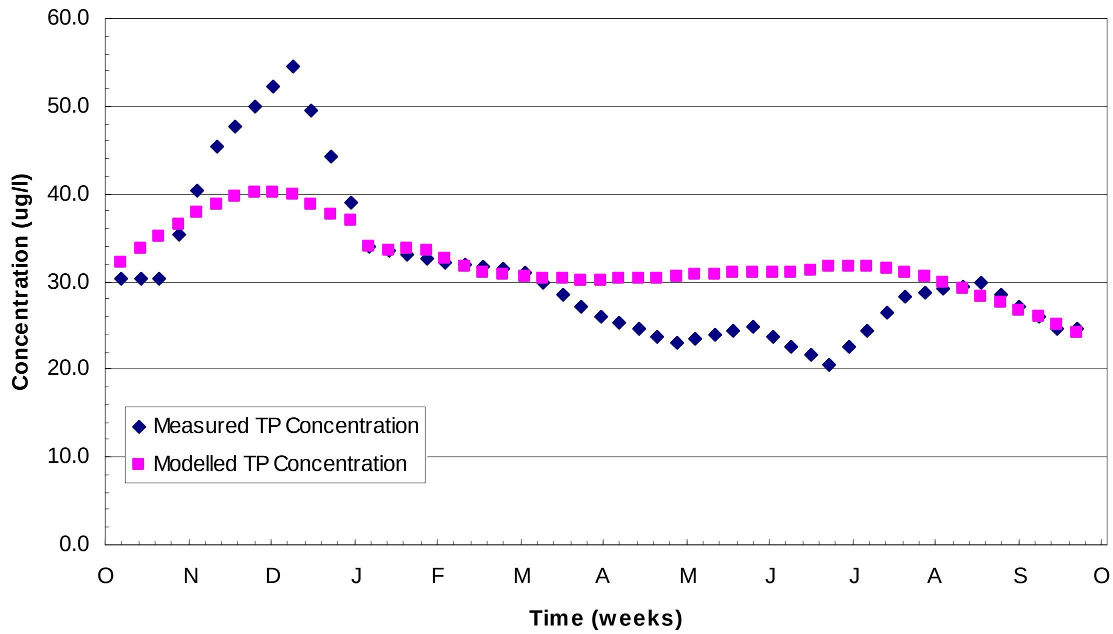


Figure 9. Beaver Lake 1, 2000, Whole Lake Total Phosphorus Model Calibration Results

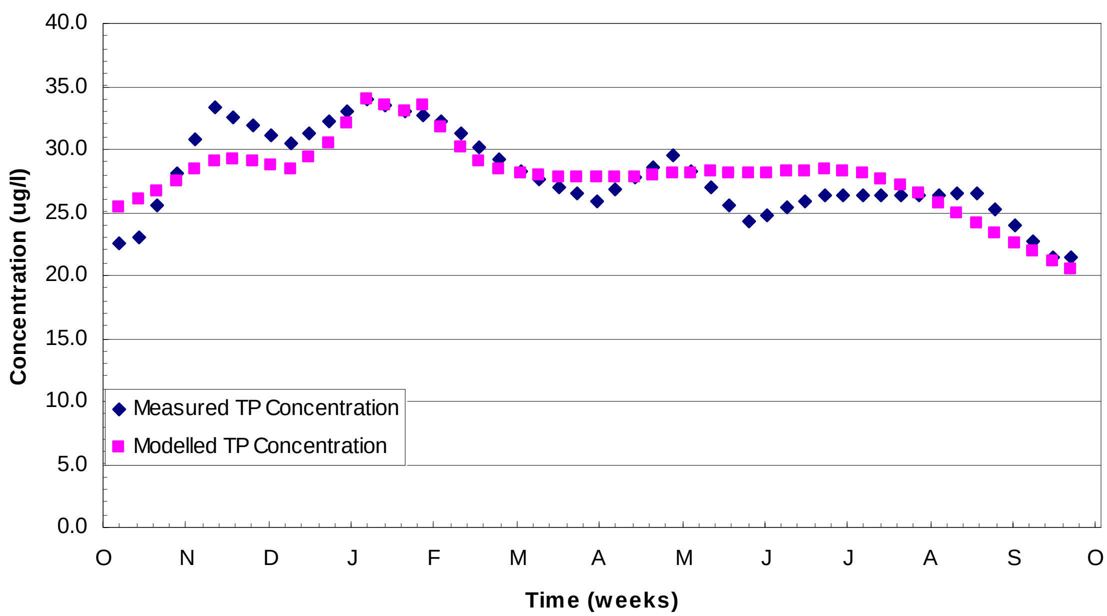


Table 4. Total Phosphorus Model Calibration Coefficient Results for Beaver Lake 1, 1997

Date	Septic Input kg/year	Atmospheric Concentration Input Rain/Air Conc ug/l	Diffusion Exchange Coef. m/wk	Settling Velocities Mixed m/wk	Settling Velocities Epilimnion m/wk	Settling Velocities Hypolimnion m/wk	SRR mg/m^2-wk
Oc1t-Dec13	2.80	8.00	0.10	0.00	0.28	0.28	2.00
Dec13-Feb18	2.80	8.00	0.00	0.28	0.00	0.00	0.00
Feb18-Sep30	2.80	8.00	0.10	0.00	0.25	0.28	30.00

Figure 10. Beaver Lake 1, 1997, Epilimnetic Total Phosphorus Model Calibration Results

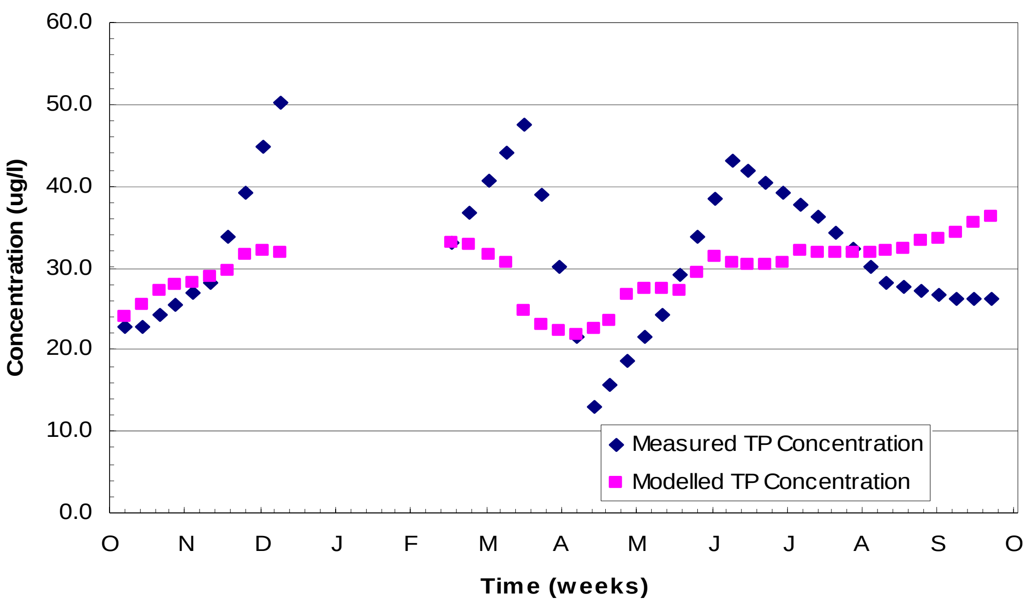


Figure 11. Beaver Lake 1, 1997, Hypolimnetic Total Phosphorus Model Calibration Results

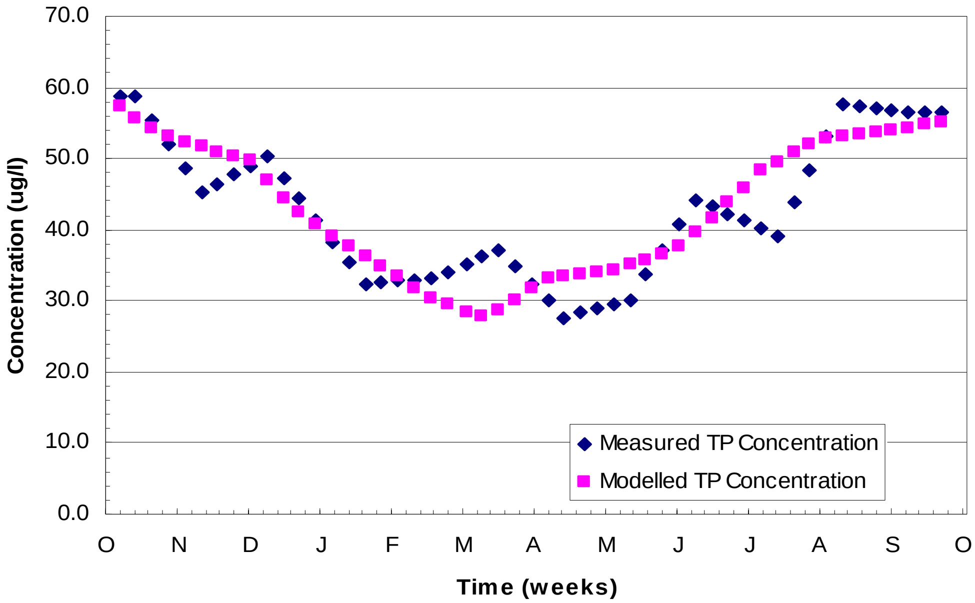


Figure 12. Beaver Lake 1, 1997, Whole Lake Total Phosphorus Model Calibration Results

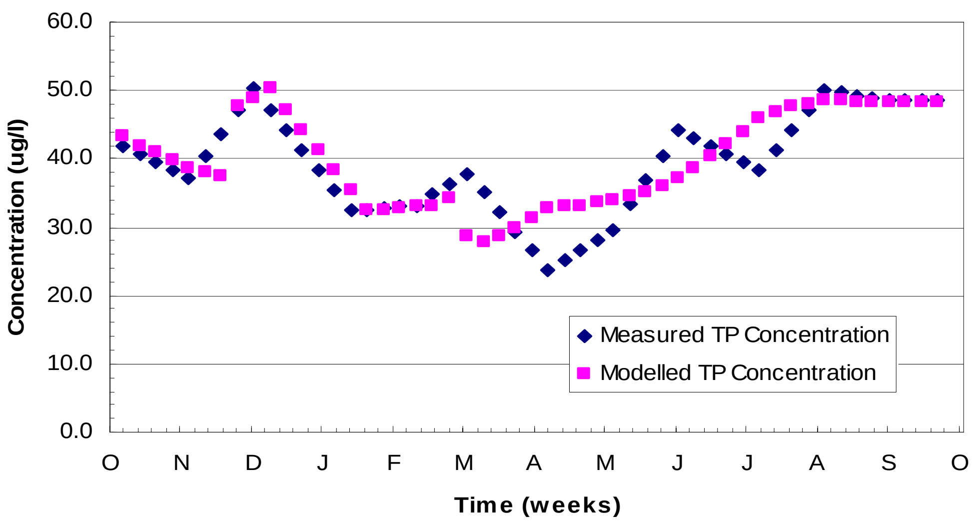


Table 5. Total Phosphorus Model Calibration Coefficient Results for Beaver Lake 2, 2000

Date	Septic Input kg/year	Atmospheric Concentration Input Rain/Air Conc ug/l	Diffusion Exchange Coef. m/wk	Settling Velocities Mixed m/wk	Settling Velocities Epilimnion m/wk	Settling Velocities Hypolimnion m/wk	SRR mg/m^2-wk
Oct1-Dec10	11.40	8.00	0.24	0.00	0.30	0.30	25.00
Dec10-May1	11.40	8.00	0.24	0.60	0.40	0.40	0.00
May1-July1	11.40	8.00	0.24	0.00	0.60	0.40	0.00
July1-Sep30	11.40	8.00	0.24	0.00	0.00	0.40	6.00

Figure 13. Beaver Lake 2, 2000, Epilimnetic Total Phosphorus Model Calibration Results

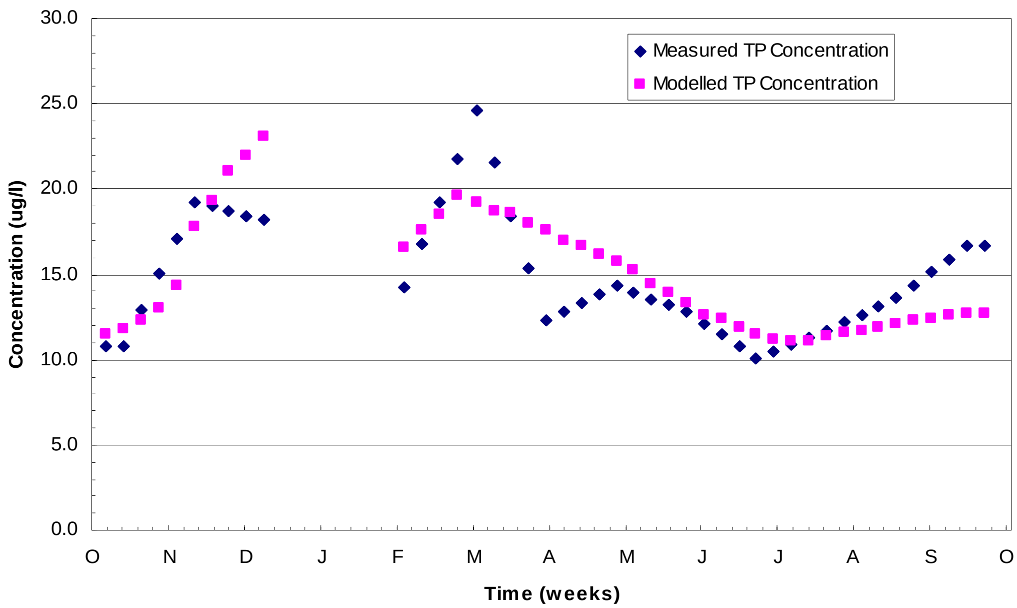


Figure 14. Beaver Lake 2, 2000, Hypolimnetic Total Phosphorus Model Calibration Results

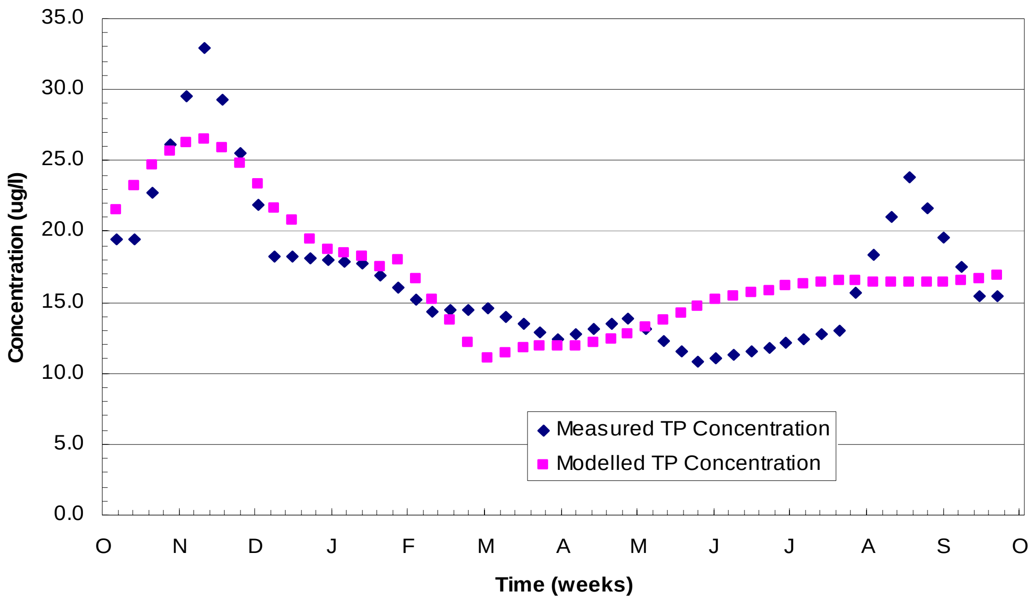


Figure 15. Beaver Lake 2, 2000, Whole Lake Total Phosphorus Model Calibration Results

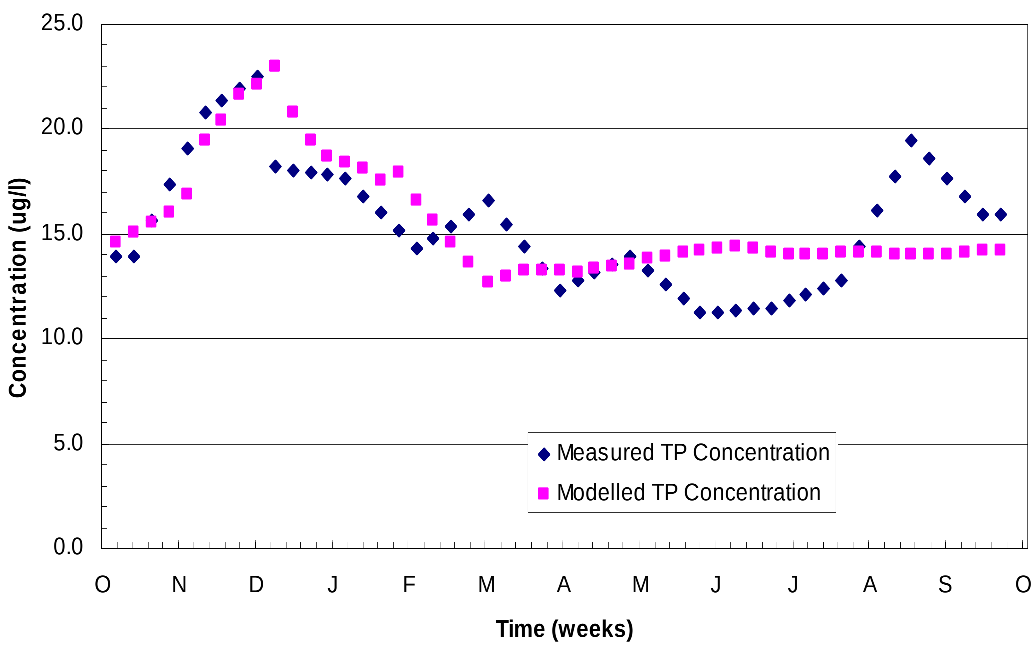


Table 6. Beaver Lake 2, 1997, Total Phosphorus Model Calibration Coefficient Results

Date	Septic Input kg/year	Atmospheric Concentration Input Rain/Air Conc ug/l	Diffusion Exchange Coef. m/wk	Settling Velocities Mixed m/wk	Settling Velocities Epilimnion m/wk	Settling Velocities Hypolimnion m/wk	SRR mg/m^2-wk
Oct1-Nov12	11.40	8.00	2.50	0.00	0.20	0.20	30.00
Nov12-Feb18	11.40	8.00	0.24	0.40	0.00	0.00	0.00
Feb18-June1	11.40	8.00	0.24	0.00	0.60	0.30	0.00
June1-Sep30	11.40	8.00	0.24	0.00	0.30	0.30	4.00

Figure 16. Beaver Lake 2, 1997, Epilimnetic Total Phosphorus Model Calibration Results

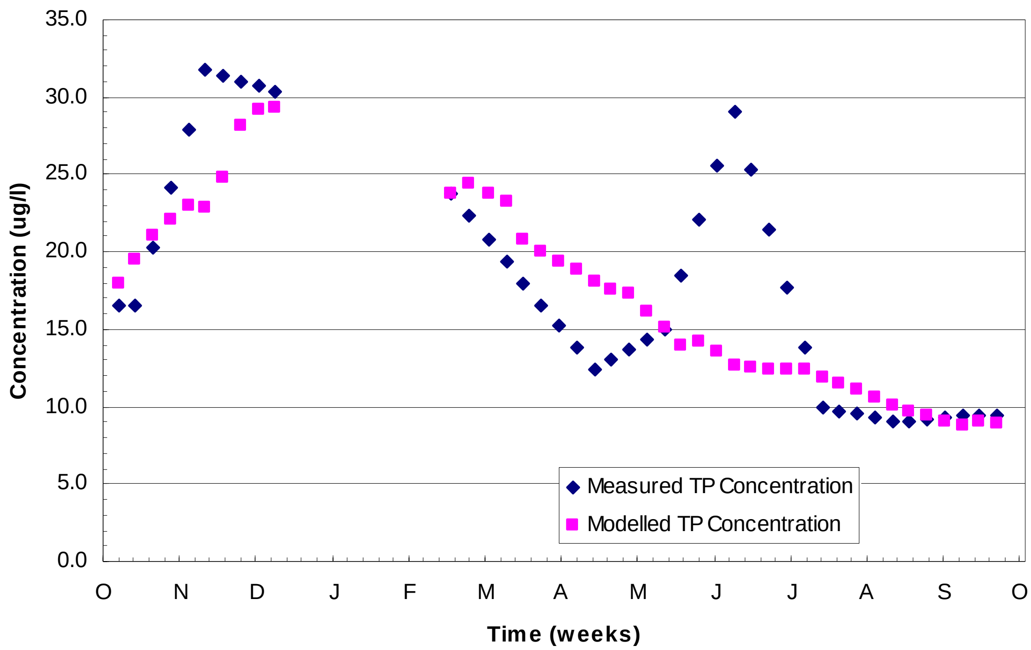


Figure 17. Beaver Lake 2, 1997, Hypolimnetic Total Phosphorus Model Calibration Results

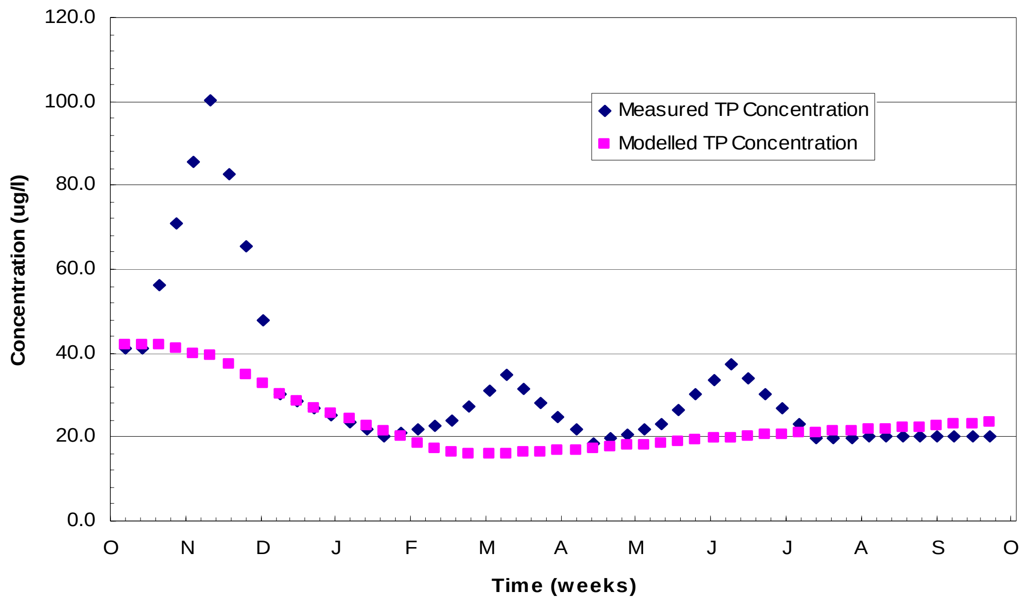
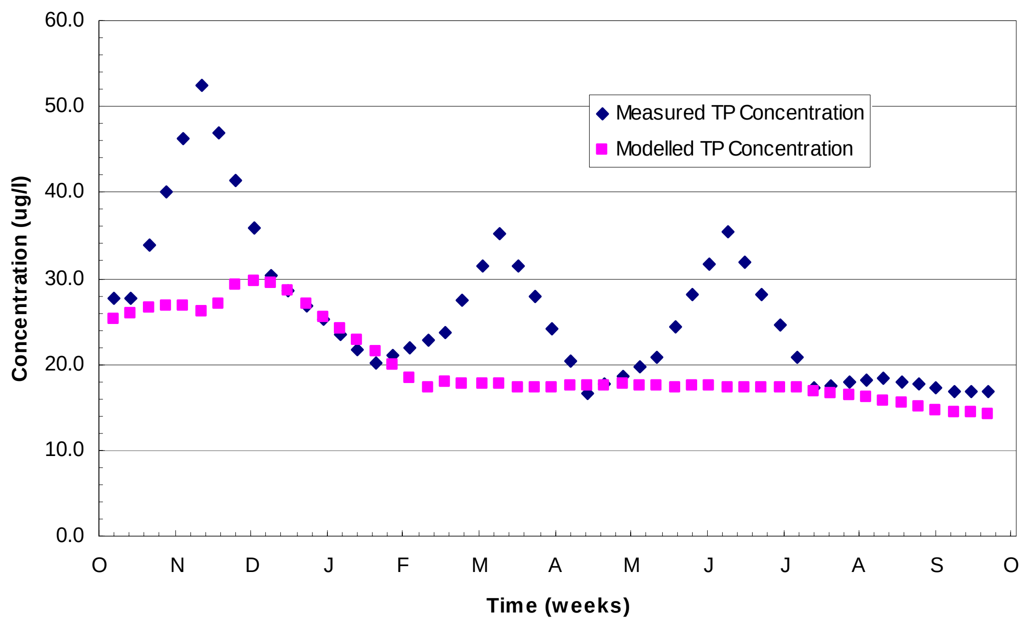


Figure 18. Beaver Lake 2, 1997, Whole Lake Total Phosphorus Model Calibration Results



Predicting Chlorophyll a from TP

The chl/TP ratio in Bearver Lakes 1 and 2 is usually much higher than in other lakes in the area. The cause may be due to the high color content in the lake that reduces the light available for photosynthesis and causes the algae to raise their cellular chl/chl ratio. Pine Lake has a similar high chl/TP ratio and it has high color content, especially before diversion of the wetland input (Jacoby et al. 1997). Deep, clear water lakes in the area (Chester Morse) show higher cellular chl content and higher photosynthetic effeciencies at the bottom of the photic zone for the same reason (Welch, 1992). Nurnberg and Shaw (1998) have show that productivity is higher in colored lakes than clear lakes worldwide, probably due in part to the higher chl/TP ratios resulting from higher cellular chl concentrations.

Because of the higher chl/TP ratios, the values of chl from both Beaver Lakes lie well above the line of typical relationships of TP regressed on chl, such as the Dillon and Rigler (1974) relationship (Figure 19). The predictions for summer mean epilimnetic chl from TP are calculated using the relationship that generally lies above the Dillon and Rigler line shown in Figure 19.

As a result of the relatively higher chl values for given TP concentrations that occur in Beaver Lakes, the values for chl fall rather near the line for typical plots of transparency versus chl, such as that by Carlson (1977), as shown in Figure 20. The higher than normal chl per unit TP is apparently partially compensating for color in Beaver Lakes to result in about the same relationship between chl and transparency, even though transparency is lower than would be expected from a given TP concentration. Secchi transparency will therefore be calculated from chl based on the relationship for Beaver Lake in Figure 20.

Figure 19. Observed Chla related to TP Concentrations from Surface Samples in Beaver 1&2 and from Dillon and Rigler (1074)

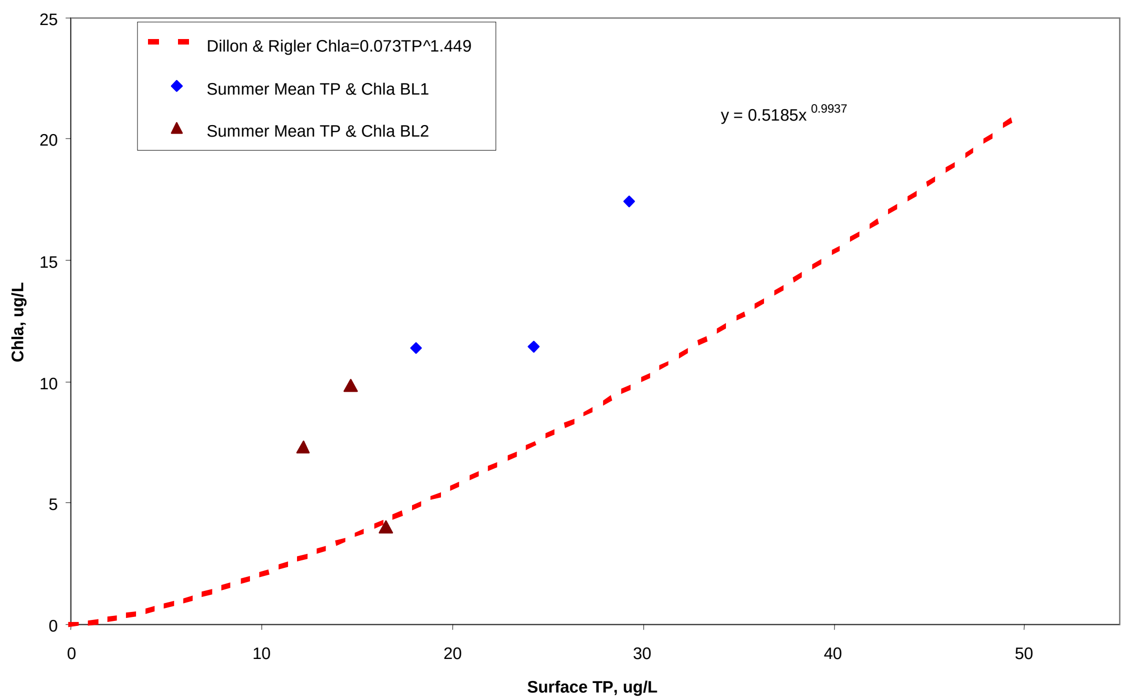
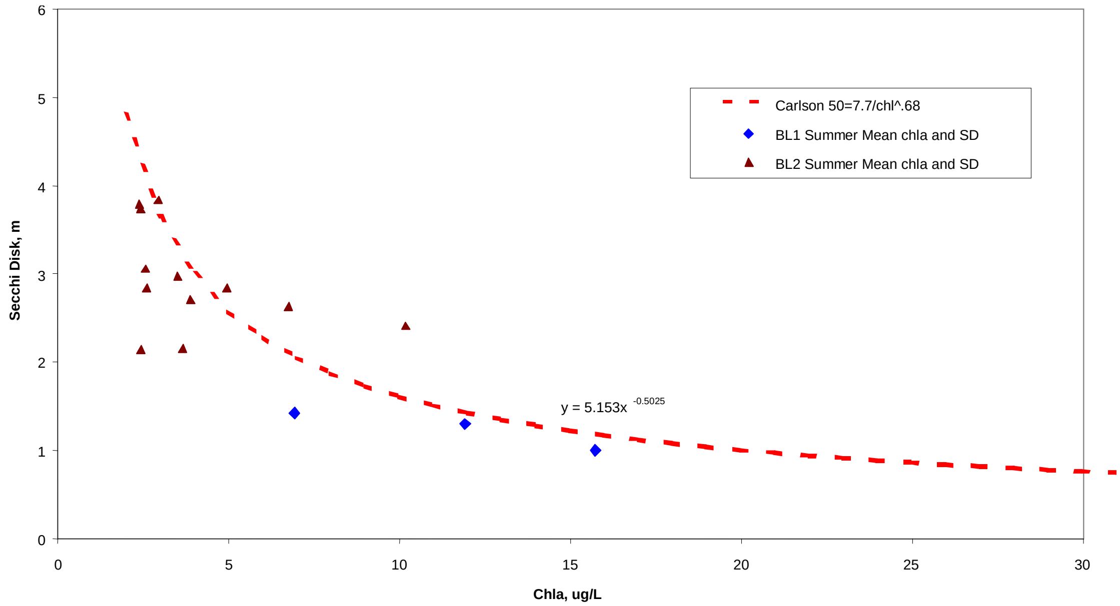


Figure 20. Observed Secchi Disk Depth Related to chl Concentration in Beaver Monitoring Program and from Carlson (1977)



Land use P yield coefficients

TP loading was determined from land use coefficients in order to extrapolate from loading during the current to future land use scenarios. Results from Lake Sammamish research was used to develop land use TP runoff coefficients for the Beaver Lake 1 and 2 watersheds (Perkins 1995; Perkins et al. 1998). Coefficients for forest, agriculture, single family residence (SFR), multiple family residence (MFR) and commercial for Lake Sammamish were developed from those from Beaulac and Reckhow (1982) and scaled to match measured loading. They varied among watersheds due to slope. Values from the west side of Lake Sammamish were used as a starting point for Beaver Lake. There is no commercial or agriculture land use in the Beaver Lake watershed, so values for forest (0.14 kg/ha-y) and SFR (0.78 kg/ha-y) were used as a starting point in Beaver Lake.

The Beaver Lake watershed to yields less P per unit area than most areas in the Puget Sound Lowlands. That was observed by Entranco (1993) and was also the case for the loading results reported here. In order to match the observed loading from each watershed with that calculated from land use coefficients and land use area, similar coefficients for the following were used in both basins for 2000, the moderate rainfall year; forest was assumed to be less than Sammamish at 0.1 kg/ha-y, golf course at 0.18 kg/ha-y, roads at 0.2 kg/ha-y and wetland at 0.05 kg/ha-y (assumed to be half of forest). These values were held constant for the two basins for the 2000 water year.

Values for the other land uses were scaled from forest so that the total yield approximately matched the observed TP load for current conditions of land use for the two water years (Table 7 and 8). Coefficients were raised for 1997 by a factor of 1.5 based on the difference in precipitation (Table 7 and 8). The increase was slightly greater for Beaver Lake 2 in order to match the observed 1997 load.

Table 7. TP Loading by Land Use Coefficients - Current Conditions (ignores septic tank leachate)

Beaver Lake 1 (Upper)			0.405		1997		2000	
Land Use		Area		Ratio	Coefficient	Load	Coefficient	Load
	(s.f.)	(acres)	(ha)		(kg/ha/yr)	(kg)	(kg/ha/yr)	(kg)
Forested	9972982	228.9	92.7		**0.15**	14.1	**0.10**	9.3
Golf Course	3199872	73.5	29.7		**0.27**	8.1	**0.18**	5.4
Roads/ROW	601805	13.8	5.6		**0.30**	1.7	**0.20**	1.1
Wetland	728155	16.7	6.8		0.08	0.5	0.05	0.3
Rural Residential, 1 du/2.5-10 acres	253514	5.8	2.4	**1.0**	0.15	0.4	**0.10**	0.2
Urban Residential, 1-3 du/2.5 acres	423562	9.7	3.9	**1.5**	0.23	0.9	0.15	0.6
Urban Residential, 1-3 du/acre	537921	12.3	5.0	**2.0**	0.30	1.5	0.20	1.0
Urban Residential, 4-12 du/acre	1111210	25.5	10.3	**2.0**	0.30	3.1	0.20	2.1
Total		386.3	156.3		**0.19**	**30.3**	**0.13**	**20.0**
Measured						**31.5**		**19.9**

Beaver Lake 2 (Lower)			0.405		1997		2000	
Land Use		Area		Ratio	Coefficient	Load	Coefficient	Load
	(s.f.)	(acres)	(ha)		(kg/ha/yr)	(kg)	(kg/ha/yr)	(kg)
Forested	10158771	233.2	94.4		0.17	16.5	0.10	9.4
Golf Course	2063826.7	47.4	19.2		0.31	6.0	**0.18**	3.5
Roads/ROW	2558229.9	58.7	23.8		0.35	8.3	**0.20**	4.8
Wetland	1964455.2	45.1	18.3		0.09	1.6	0.05	0.9
Rural Residential, 1 du/2.5-10 acres	2511655.5	57.7	23.3	**1.0**	0.36	8.5	**0.21**	4.9
Urban Residential, 1-3 du/2.5 acres	3544592.9	81.4	32.9	**1.5**	0.54	17.9	0.31	10.3
Urban Residential, 1-3 du/acre	5899776.3	135.4	54.8	**2.0**	0.73	39.8	0.42	22.8
Urban Residential, 4-12 du/acre	2601592.4	59.7	24.2	**2.0**	0.73	17.5	0.42	10.1
Total		718.6	290.8		**0.40**	**116.1**	**0.23**	**66.5**
Measured						**106.7**		**66.6**

	Lake Area	1997		2000		Ratio	Runoff Coeff	BL2 Coeff
Rainfall Ratios	(acres)	vol (a-f)	depth (ft)	vol (a-f)	depth (ft)		(1997/2000)	(BL2/BL1)
BL1	12.90	64.5	5.0	42.5	3.3	1.517647	1.5	
BL2	61.80	304.9	4.9	204.5	3.3	1.490954	1.5	1.15

Table 8. TP Loading by Land Use Coefficients - Future Conditions (ignores P from septic tank leachate and precipitation)

Beaver Lake 1 (Upper)			0.405		1997		2000	
Land Use		Area		Ratio	Coefficient	Load	Coefficient	Load
	(s.f.)	(acres)	(ha)		(kg/ha/yr)	(kg)	(kg/ha/yr)	(kg)
Forested	6042533	138.7	56.1		0.15	8.5	**0.10**	5.6
Golf Course	3199862	73.5	29.7		0.27	8.1	**0.18**	5.4
Roads/ROW	601801	13.8	5.6		0.30	1.7	**0.20**	1.1
Wetland	728156	16.7	6.8		0.08	0.5	0.05	0.3
Rural Residential, 1 du/2.5-10 acres	253514	5.8	2.4	1.0	0.15	0.4	**0.10**	0.2
Urban Residential, 1-3 du/2.5 acres	423565	9.7	3.9	1.5	0.23	0.9	0.15	0.6
Urban Residential, 1-3 du/acre	1888953	43.4	17.5	2.0	0.30	5.3	0.20	3.5
Urban Residential, 4-12 du/acre	3690601	84.7	34.3	2.0	0.30	10.4	0.20	6.9
Total		386.3	156.3		**0.23**	**35.8**	**0.15**	**23.6**

Beaver Lake 2 (Lower)			0.405		1997		2000	
Land Use		Area		Ratio	Coefficient	Load	Coefficient	Load
	(s.f.)	(acres)	(ha)		(kg/ha/yr)	(kg)	(kg/ha/yr)	(kg)
Forested	4191800.8	96.2	38.9		0.17	6.8	0.10	3.9
Golf Course	2063832.8	47.4	19.2		0.31	6.0	0.18	3.5
Roads/ROW	2535479.1	58.2	23.6		0.35	8.2	0.20	4.7
Wetland	1964458.2	45.1	18.3		0.09	1.6	0.05	0.9
Rural Residential, 1 du/2.5-10 acres	0	0.0	0.0	1.0	0.36	0.0	0.21	0.0
Urban Residential, 1-3 du/2.5 acres	1507528.6	34.6	14.0	1.5	0.54	7.6	0.31	4.4
Urban Residential, 1-3 du/acre	8177207.6	187.7	76.0	2.0	0.73	55.2	0.42	31.6
Urban Residential, 4-12 du/acre	10862557	249.4	100.9	2.0	0.73	73.3	0.42	42.0
Total		718.6	290.8		**0.55**	**158.7**	**0.31**	**90.9**

	Lake Area	1997		2000		Ratio	Runoff Coeff	BL2 Coeff
Rainfall Ratios	(acres)	vol (a-f)	depth (ft)	vol (a-f)	depth (ft)		(1997/2000)	(BL2/BL1)
BL1	12.90	64.5	5.0	42.5	3.3	1.518	1.5	
BL2	61.80	304.9	4.9	204.5	3.3	1.491	1.5	1.15

Incorporation of land use P yield coefficients

The total loads for the two basins, calculated from land use coefficients, were distributed throughout the year 2000 based on inflow volume **(Figure 21 and 22**). The same procedure was used for current conditions for the higher flow year 1997 with the higher TP yield coefficients, although seasonal results are not shown.

Loading calculated for the two basins during the high (1997) and moderate (2000) rainfall years for future land use projections are shown in Tables 7 and 8. These loadings were then used with the TP models calibrated for the two years to predict a range in epilimnetic TP, chl and Secchi depth transparency (SDT) for the future scenarios.

Figure 21. Measured External TP Load for the 2000 Water Year Compared to Loads from Land Use Coefficients Distributed with Flow in Beaver Lake 1

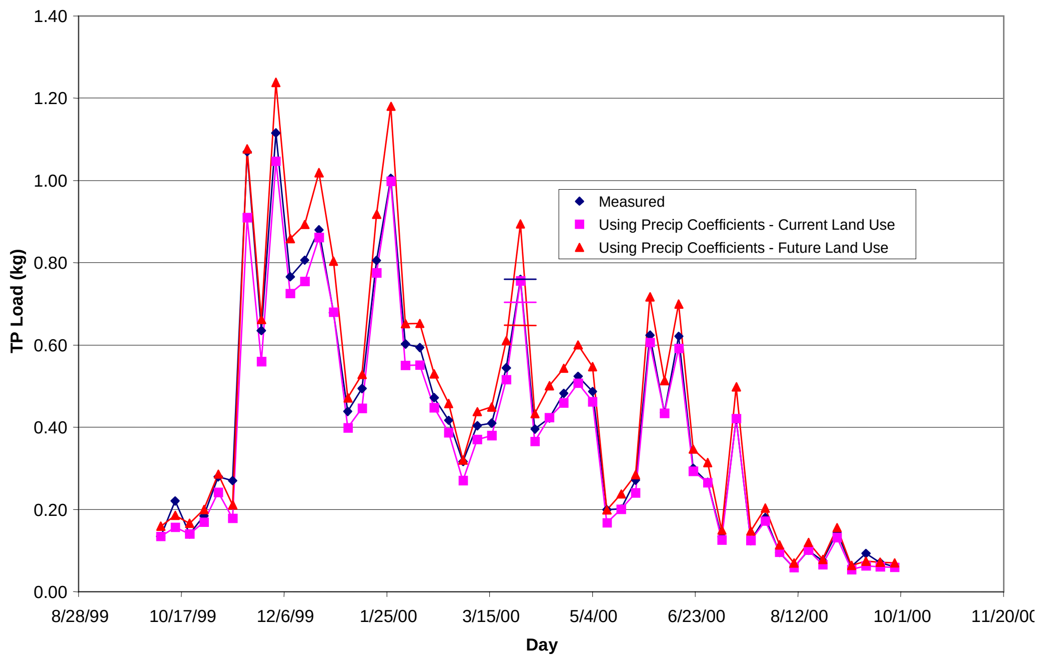
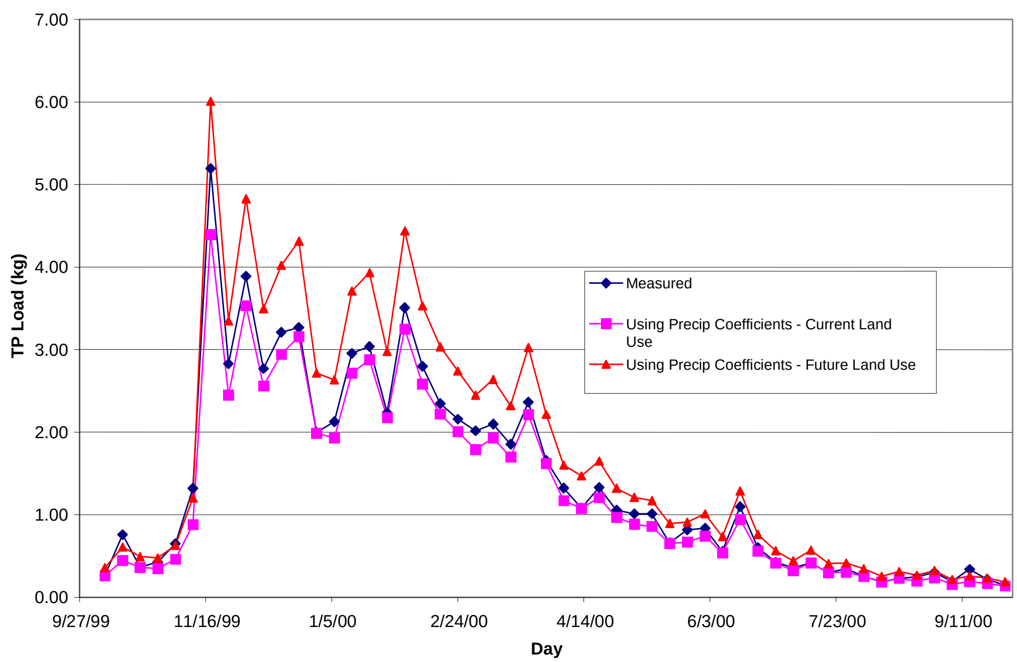


Figure 22. Measured External TP Load for the 2000 Water Year Compared to Loads from Land-Use Coefficients Distributed with Flow in Beaver Lake 2



Results of Total Phosphorus Predictive Model

The predictive model generates epilimnetic, hypolimnetic and whole lake total phosphorus concentrations based upon weekly timestep calculations of external loading, internal loading and flux between layers, sedimentation and outflow. External loading distributions were generated using the techniques described in the Export Coefficient Development section of the report and were determined for each individual water year and lake. total phosphorus flux variables, including diffusion, entrainment and settling, across the thermocline, were calculated on a weekly timestep. Solutions were determined directly from weekly-predicted epilimnetic and hypolimnetic concentrations using **Equations 2, 4,** and **7** with the probabilistic thermocline and anoxic areas presented in the model development section of the report. Weekly total phosphorus outflow concentrations were determined from the KC-DNR hydrologic budget and model predicted weekly average epilimnetic total phosphorus concentrations.

In general, the predicted (from land-use coefficients) average epilimnetic total phosphorus concentrations closely matched both the model calibration values and the measured epilimnetic total phosphorus concentrations. The only exception to this was the predicted epilimnetic total phosphorus concentrations using a settling velocity of 0.6 m/wk for Beaver Lake 2 in 1997 during February through September. Epilimnetic concentrations were overestimated so the settling velocity was adjusted accordingly to 0.8 m/wk to provide a better fit with measured concentrations. **Figures 23-26** show comparisons between measured, model calibration, and model predicted (land-use coefficiants) epilimnetic concentrations.

Figure 23. Beaver Lake 1, 2000, Epilimnetic Total Phosphorus Concentration Comparisons

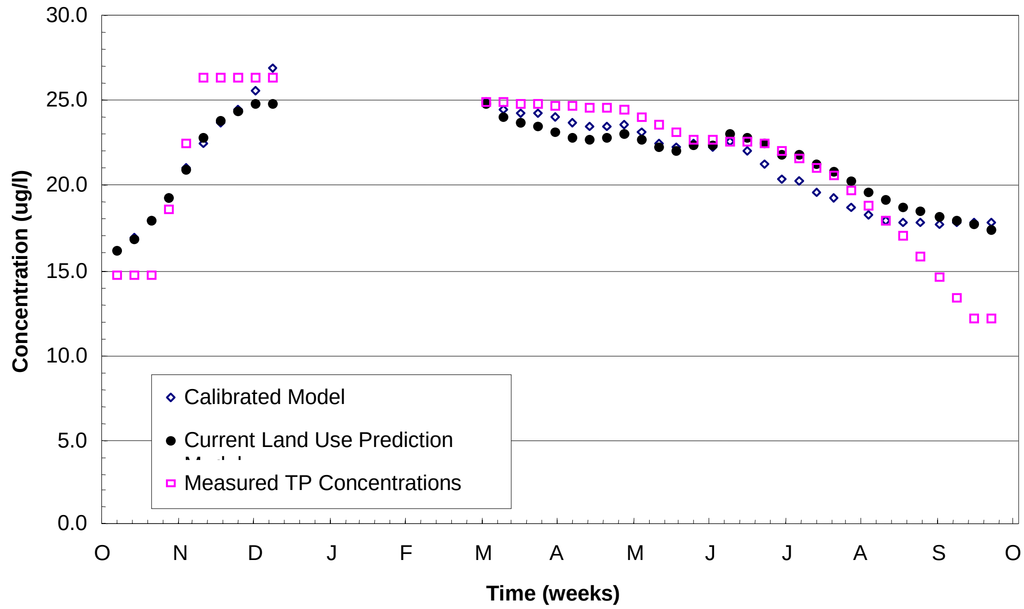


Figure 24. Beaver Lake 2, 2000, Epilimnetic Total Phosphorus Concentration Comparisons

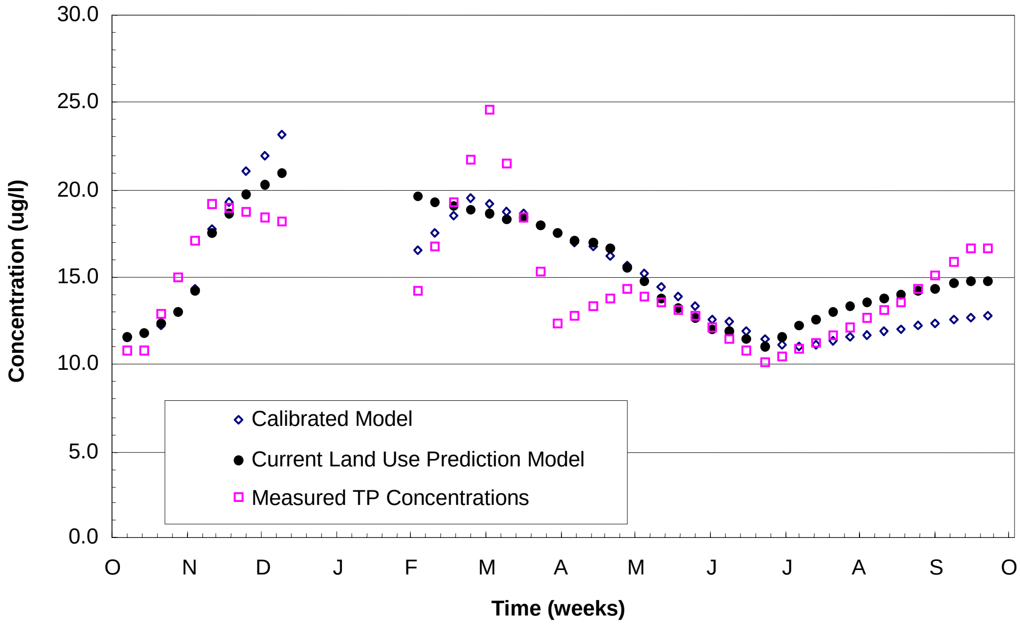


Figure 25. Beaver Lake 1, 1997, Epilimnetic Total Phosphorus Concentration Comparisons

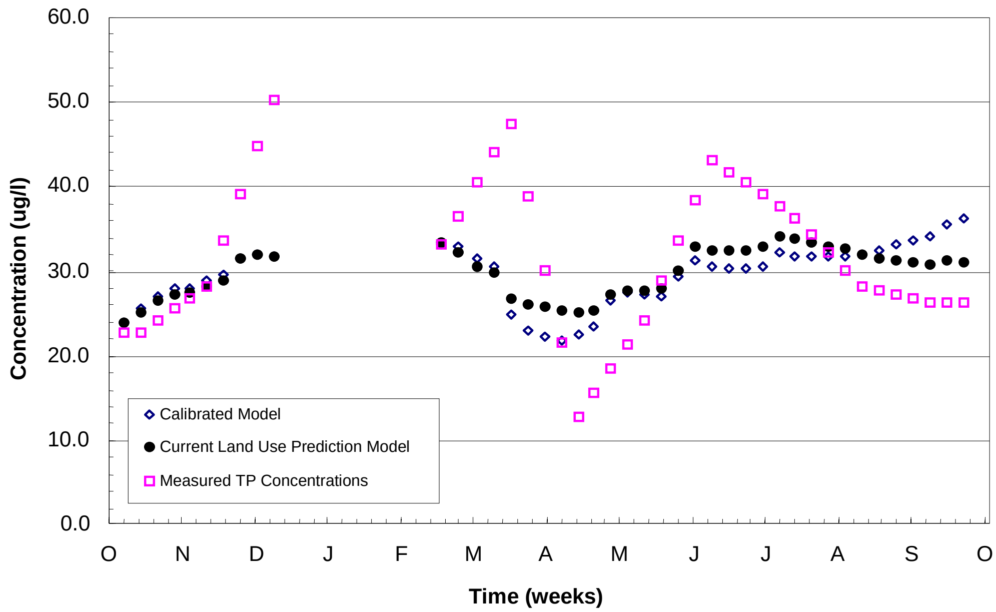
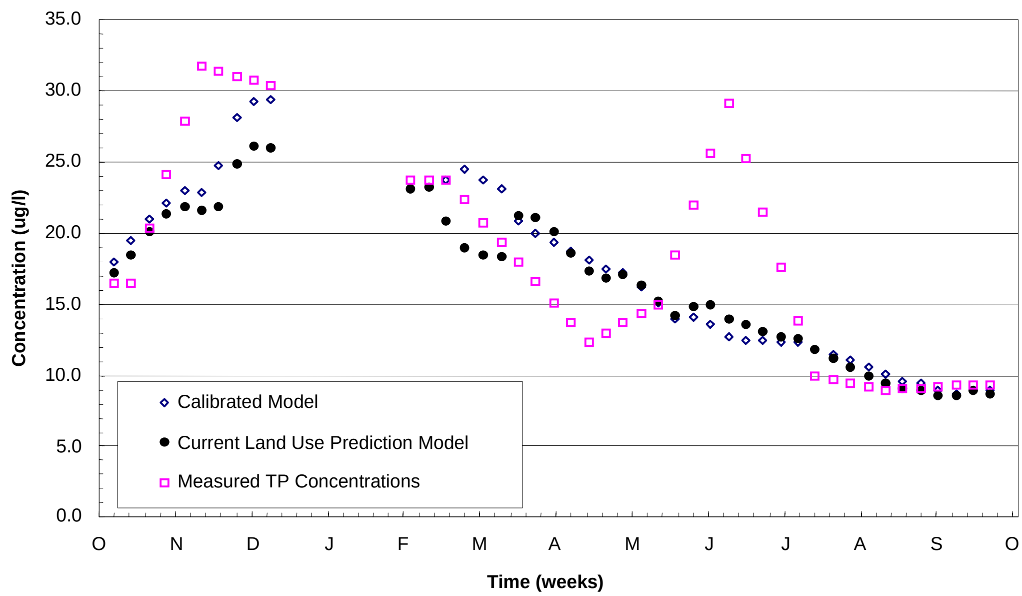


Figure 26. Beaver Lake 2, 1997, Epilimnetic Total Phosphorus Concentration Comparisons



The next step in predictive modeling included applying external loading expected to accompany changes in land-use areas from watershed development (future conditions). Increases in internal loading in the future were examined to determine effects on epilimnetic total phosphorus concentrations. **Tables 9-12** quantify summer averages, of epilimnetic total phosphorus concentrations, during the summertime for each of the predictive scenarios. **Figures 27-30** depict the changes of epilimnetic total phosphorus concentrations for the future development scenarios and internal loading scenarios created for the study.

Table 9. Monthly Summer Epilimnetic Total Phosphorus Concentrations for Beaver Lake 1, 2000

Month	Measured (ug/l)	Current Land-Use Conditions (ug/l)	Future Land-Use Conditions (ug/l)	Future Land-Use Internal Loading x 2 (ug/l)
June	22.6	22.6	26.7	30.6
July	21.3	21.2	25.4	29.0
August	17.5	19.0	23.1	26.4
September	13.1	17.8	21.6	24.8

Figure 27. Beaver Lake 1, 2000, Land-use Development Predicted Concentrations

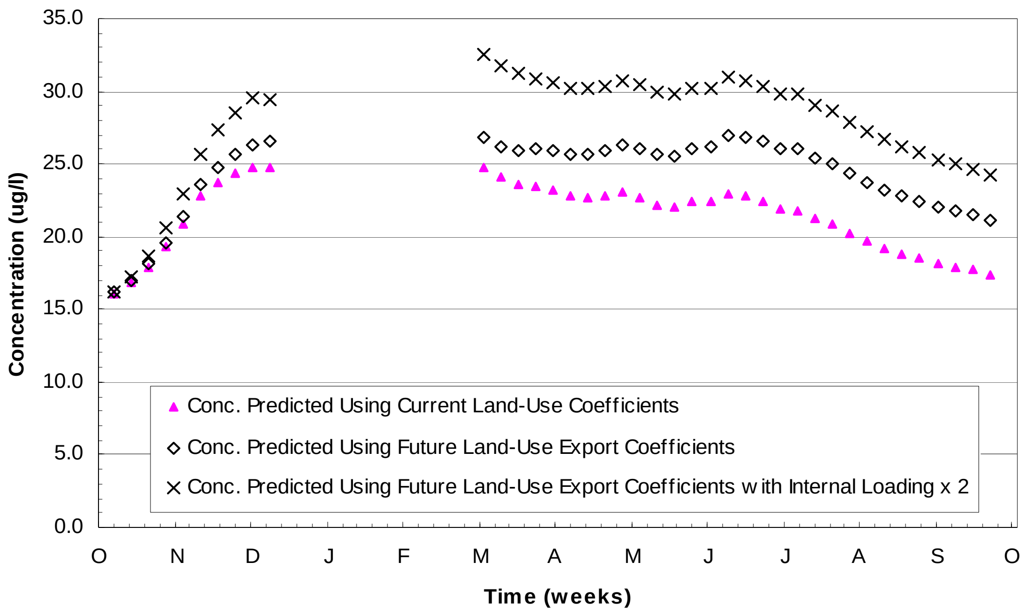


Table 10. Monthly Summer Epilimnetic Total Phosphorus Concentrations for Beaver Lake 2, 2000

Month	Measured (ug/l)	Current Land-Use Conditions (ug/l)	Future Land-Use Conditions (ug/l)	Future Land-Use Internal Loading x 2 (ug/l)
June	12.4	12.5	15.3	16.1
July	10.6	11.6	14.5	15.3
August	12.4	13.4	16.6	17.6
September	14.7	14.3	17.6	18.9

Figure 28. Beaver Lake 2, 2000 Land-use Development Predicted Concentrations

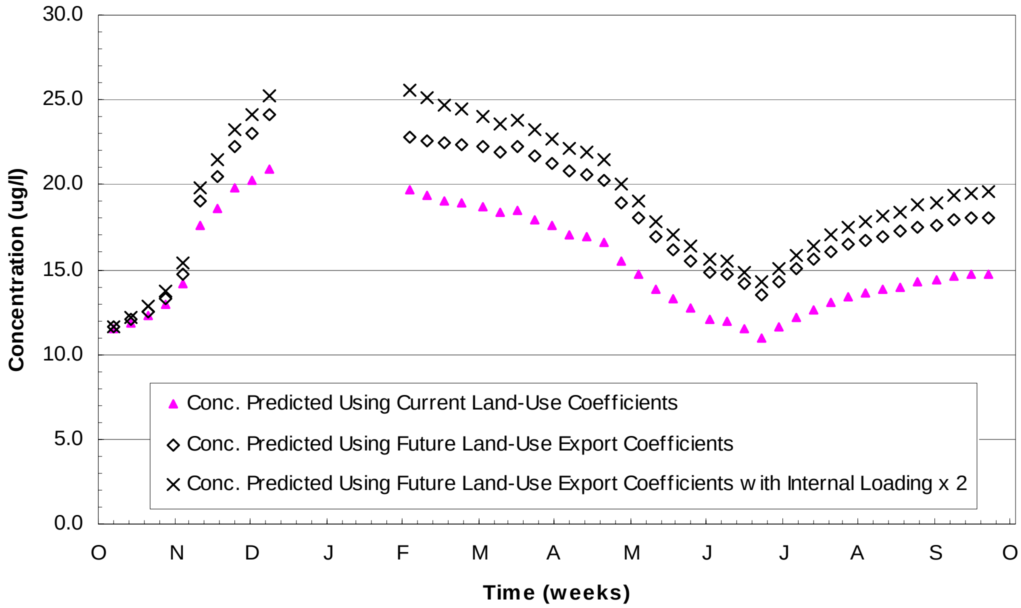


Table 11. Monthly Summer Epilimnetic Total Phosphorus Concentrations for Beaver Lake 1, 1997

Month	Measured (ug/l)	Current Land-Use Conditions (ug/l)	Future Land-Use Conditions (ug/l)	Future Land-Use Internal Loading x 2 (ug/l)
June	25.4	28.2	32.2	32.3
July	41.0	32.6	37.5	37.6
August	35.9	33.4	38.5	38.8
September	28.3	31.9	36.4	37.5

Figure 29. Beaver Lake 1, 1997, Land-use Development Predicted Concentrations

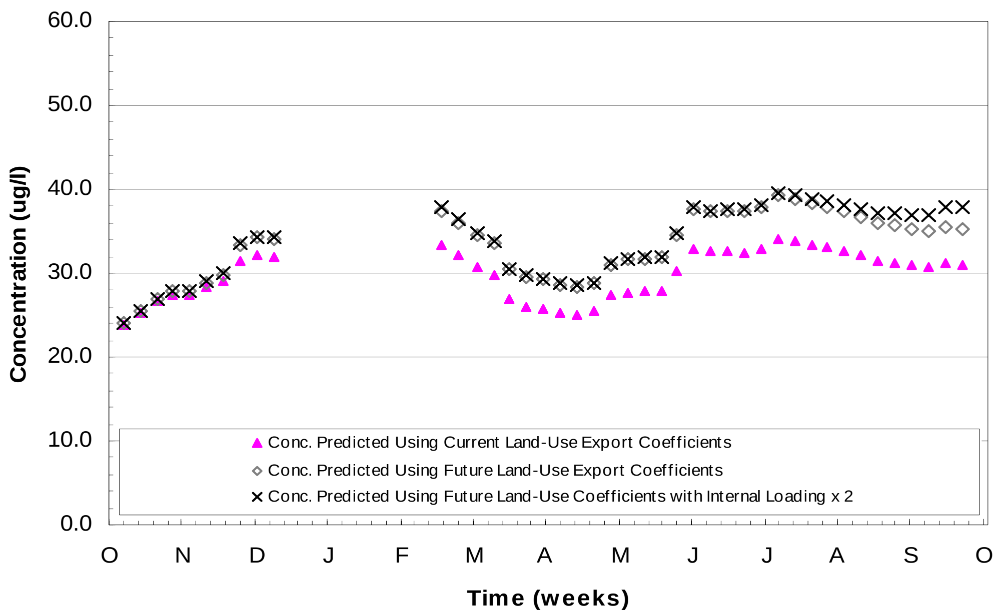


Table 12. Monthly Summer Epilimnetic Total Phosphorus Concentrations for Beaver Lake 2, 1997

Month	Measured (ug/l)	Current Land-Use Conditions (ug/l)	Future Land-Use Conditions (ug/l)	Future Land-Use Internal Loading x 2 (ug/l)
June	16.7	15.6	19.3	19.9
July	25.4	14.0	17.5	17.9
August	12.1	11.8	14.8	15.2
September	9.1	9.4	11.7	12.2

Figure 30. Beaver Lake 2, 1997, Land-use Development Predicted Concentrations