Beaver Lake Management Plan Update:
A report on the water quality of Beaver Lake

For 2001-2006

December 2007

Final Report for Beaver Lake Management District No.2
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Executive Summary

Background

Beaver Lake is located in Sammamish, Washington, on the Sammamish plateau east of Lake Sammamish and north of Interstate-90. This area has seen rapid development over the past decade, including the incorporation of the new city, Sammamish, in August 1999.

The original *Beaver Lake Management Plan* was completed in 1993. 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. An update in to the Plan in 2000 represented the culmination of this four-year monitoring program.

A second LMD was approved in 2001 and initiated in 2002, with an in-lake evaluation conducted during 2006. This report provides the second update to the original 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 as forested (King County, 1993a). In 2000, approximately 462 acres remained as forest, and in 2006 the forested acreage appeared to have held steady. Maximum build-out is uncertain, but with the City of Sammamish acquiring several tracts for preservation and with critical area regulations undergoing an update, the predicted 235 acres remaining at build-out (King County, 2000) is likely to be an underestimate, and it is more likely that permanently un-built acreage will be considerably more than that figure.

Loss of forest affects the hydrological processes of an area, delivering surface water more quickly downstream and bypassing 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 both the degradation of the upland wetlands and eventually to the lake.

Current Lake Condition

Thus far, water quality remains good and relatively unchanged from levels documented with the *Beaver Lake Management Plan* and its update (King County, 1993a and 2000). 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. Upon incorporation, this standard was carried forward by the City of Sammamish and currently remains in effect. This standard, in combination with preservation of wetland function, has been critically important to maintaining good water quality in Beaver Lake.

As additional residential development continues, Beaver Lake will remain vulnerable to a possible decline in water quality, thus making ongoing preservation measures essential. In particular, development near the high quality wetland ELS21 at the head of Beaver-1 (north basin) could impact water quality considerably, if not handled carefully, because of the vulnerability of the wetland to disturbance and changes in inputs.

Water quality modeling results in 1993 and 2000 for both lake basins showed that phosphorus levels would increase in the lake under the build-out land use scenario. The water quality modeling effort in 2006 could not balance the phosphorus budget for the lake, but efforts will continue to pinpoint the problems causing the modeling difficulties.

Discussion

Given the water quality vulnerability of Beaver-1, the preservation of wetland ELS 21 functions has been identified as critical to the ongoing protection of the lake. Safeguarding this wetland and its existing water quality functions should continue to 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 less regulatory protection in comparison to nearby wetland ELS 10, encompassed by the Hazel Wolf Wetland Preserve and discharging to Beaver-2. ELS 21 has already been impacted to a minor extent by the Trossachs subdivision where two stormwater quality facilities have been placed along the southeastern and eastern edges of the wetland. Further development of the Trossachs subdivision is expected within the next few years, and protection of ELS 21 from the effects of surface runoff originating from this development will be critical to the water quality of both the wetland and Beaver-1 (and hence, Beaver-2 as well). To prevent further impacts to wetland ELS 21, efforts should continue to 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 short term catastrophic events associated with new land development within the watershed. Efforts should be made to avoid erosion of recently cleared lands and the mass movement of sediment to surrounding wetlands, streams, or the lake.

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 is good and has remained stable over time, but additional development in the watershed could still cause degradation of water quality. A series of recommendations made originally in 1993 have been updated for 2006 (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	• Continue to acquire open space in critical areas of the watershed
R2	• Ensure wetland and stream buffers are maintained and functioning
R3	• Encourage long-term land conservation via incentive programs for property owners
	Future Land Development Guidelines
R4	• Enforce seasonal clearing and grading requirements
R5	• Enforce temporary erosion and sediment control standards
R6	• Encourage the use of Low Impact Development (LID) techniques
	Ongoing Stormwater Management
R7	• Maintain AKART standard for new development
R8	• Maintain stormwater facilities
	Local Shoreline and Watershed Actions
R9	• Encourage restoration of shoreline vegetation
R10	• Encourage reduction of lawn size and fertilizer use
R11	• Maintain on-site septic systems
R12	• Reduce phosphorus from pet waste, car washing, and exposed soil
	Ongoing Monitoring
R13	• Continue lake and stream monitoring; add wetland monitoring
R14	• Monitor several storms using an automated sampler

Wetland and Resource Land Preservation

To ensure the protection of Beaver-1 water quality, continuing measures should be directed toward the preservation of the functions of wetland ELS 21. These measures include direct land acquisition by the City of Sammamish with the intent of preservation, increased protection through implementation of Critical Areas regulations, and incentives for land conservation around the wetland. Preservation of wetland ELS 21 directly contributes to the preservation of Beaver-1 which, in turn, directly benefits Beaver-2 because it receives a considerable amount of inflow from Beaver-1 during most years.

Beaver-2 also benefits from the preservation of wetland ELS 10 because of the protection afforded by the Hazel Wolf Wetland Preserve. Downstream, it also benefits further from the Critical Area requirements, which protect the southern end of the wetland outside the Preserve as well as the stream itself (tributary 0166d) that flows into Beaver-2.

Future Land Development Guidelines

Beaver Lake remains vulnerable to catastrophic events that can occur during land development. These events are generally related to the seasonal timing of land clearing and the effectiveness 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 enforced, and all construction sites stabilized with TESC measures during the wettest parts of the year, generally October through April.

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 sand filters receiving extra attention given that these facilities may be vulnerable to plugging over time, reducing effectiveness.

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 impacts on the lake. Shoreline residents can restore shoreline areas with native vegetation, reduce adjacent lawn sizes, and create riparian 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 on a regular schedule, properly disposing of 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 2007, a ten-year lake and stream monitoring program will continue the evaluation of the quality of the water entering Beaver Lake. This monitoring program will be funded through a third Lake Management District, which was ratified by vote of the affected property owners, and which will be administered by the City of Sammamish.

Chapter 1: Introduction

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

This chapter provides a brief project history of local residents' efforts to preserve Beaver Lake, including the formation of the first Beaver Lake Management District (BLMD) while the area was under King County jurisdiction, and the second BLMD after the City of Sammamish incorporated. This chapter also briefly describes the scope of work in each of the first two BLMDs. A third BLMD was ratified in 2006, projected to continue monitoring and educational activities for 10 years.

History of Preservation Efforts

The Beaver Lake community has a long history of local activism and has been a strong advocate for the preservation and protection 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 residential development on the Sammamish Plateau.

By the late 1980s, Beaver Lake and the surrounding areas had experienced rapid growth, raising concerns over a 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 to ensure long-term protection of Beaver Lake water quality as development increased in the area.

In 1990, the Beaver Lake community worked with the King County Department of Public Works Surface Water Management Division on an application for a grant to fund the development of 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 to provide water quality data that would serve 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 therefore the plan was considered to be a pollution prevention plan rather than a clean-up plan. The plan provided a comprehensive approach for mitigating impacts to the lake that could result from increased surface water inflows 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 fund water quality monitoring and evaluation of the effectiveness of plan implementation.

During 1995, King County 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 non-point grant from the Washington Department of Ecology (WDOE), combined with revenues from the BLMD, funded a four-year lake and stream monitoring program. This monitoring program was designed to detect water quality problems related to land development and to identify specific corrective actions that could be implemented to minimize the potential for long-term impacts to Beaver Lake.

The water quality monitoring program was renewed in 2000 to extend from 2001 through 2006. Results have been previously reported in annual progress reports to the BLMD Board, to citizens living within the BLMD boundaries via the *Beaver Lake Monitor* newsletter, and previously in reports to the WDOE to satisfy grant requirements. (King County, 1998a; King County 1999a, King County 2000a, KC WQ report 2006).

From 2000 to 2006, no major water quality problems were detected, although there appears to be a small upward trend in total alkalinity in the tributary to the Beaver-2 basin. This plan update reports results of the monitoring program in the last year of the second LMD and updates the recommendations from the 1993 and 2000 updates to the *Beaver Lake Management Plan.*

Lake Management District

A Lake Management District (LMD) is a special purpose district created by local property owners in cooperation with a local government agency. LMDs can fund a variety of lake protection or restoration measures, including ongoing maintenance-related activities.

A district may be created for any specified period with assessment rates imposed either annually or as detailed 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 first 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 were appointed by the King County Executive to oversee the management of the district's funds and advise on the associated work program. The first district's authorization expired December 31, 2000.

Shortly following expiration of the first LMD, a second LMD was authorized by residents living within the district's boundaries. The City of Sammamish appointed three members to the advisory board to manage funds and direct the work program of the second LMD.

In each of the first two LMDs, 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 leveraged during the first period to obtain a grant from DOE that partially funded the lake and watershed monitoring program during the first BLMD. The second BLMD was funded entirely through collection of annual assessments from residents.

Project Description

This update to the *Beaver Lake Management Plan* reports results of the monitoring program in both lake basins and tributaries since the last plan update in 2000. Also included in this update for comparisons are the summarized data from the monitoring that occurred during the first BLMD. Monitoring programs in both BLMDs were designed to evaluate water quality of the lakes and tributaries as forested areas in the watershed were 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 1109-acre watershed (the watershed was estimated as 1184 acres in 1993).

This plan update provides an assessment of the current water quality of Beaver Lake. Water quality monitoring results can also serve 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.

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Chapter 2: Watershed Characteristics

This chapter describes specific characteristics of the watershed, wetlands, lakes, and tributary streams of the Beaver Lake area. Current demographic and land use information is also included.

Watershed

Beaver Lake is located in Sammamish, Washington, on 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 high point of the watershed 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 according to the 2000 phosphorus model. The 2006 phosphorus model was unable to determine interflow proportionality; this will be discussed in Chapter 5.

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 daytime temperatures 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.

Wetlands

The watershed includes two Class 1 wetlands: Hazel Wolf Wetland Preserve (Wetland ELS 10) and East Lake Sammamish 21 (Wetland ELS 21). A third, small Class 1 wetland, Patterson Creek 17 (Wetland PC17), straddles the watershed boundary on the east side of Beaver-2 and may drain in two different directions, depending on water levels and seasonality (Figure 2; King County, 1990a). Under the City of Sammamish jurisdiction, Beaver-1, Beaver-2, and Beaver-3 are defined as rural lakes rather than as wetlands.

Each of the wetlands helps to control the quality and quantity of water flowing to or through Beaver Lake and eventually to Lake Sammamish. The following is a brief description of each wetland.

Figure 1. Beaver Lake location.

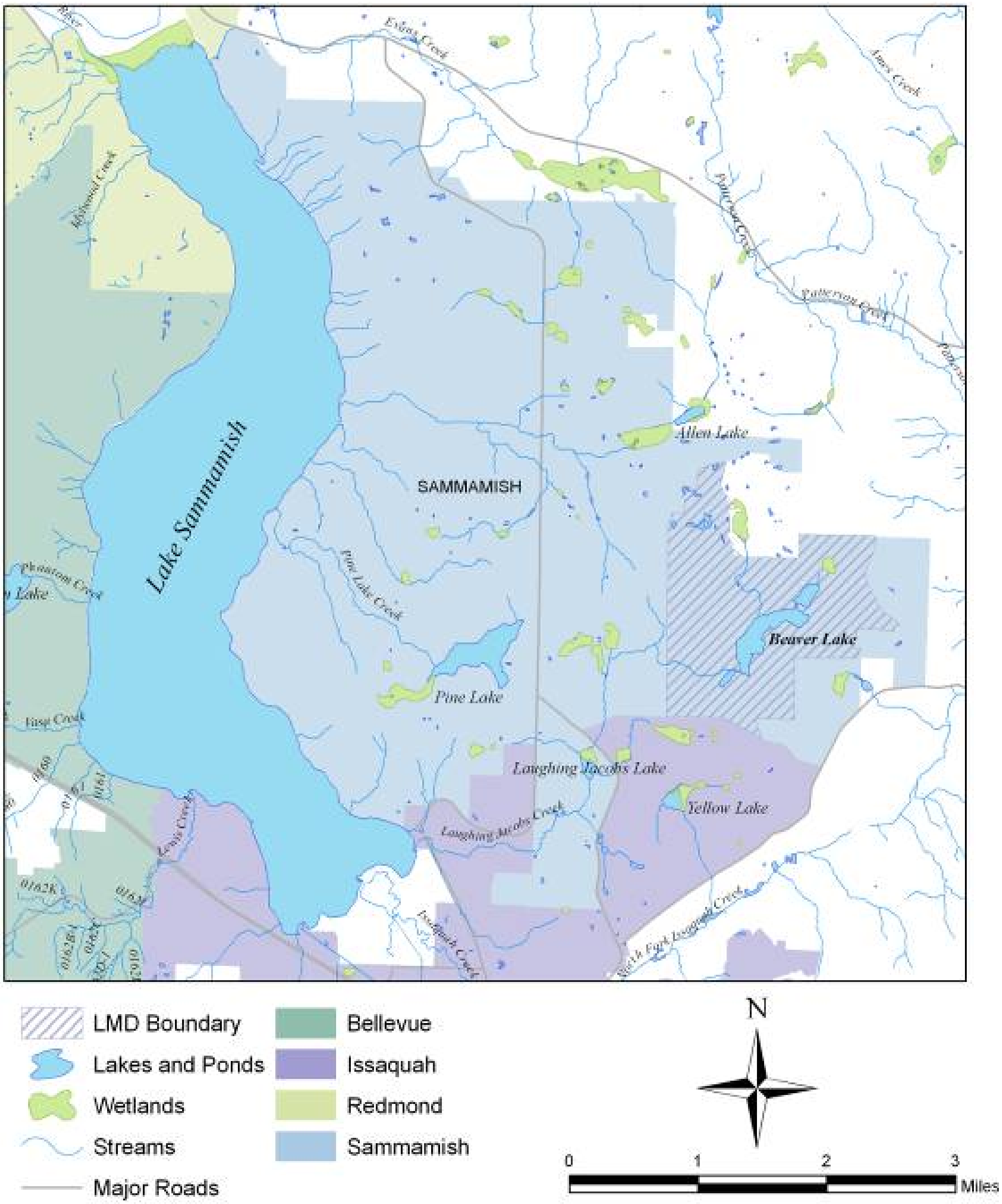


Figure 2. Major watershed features.

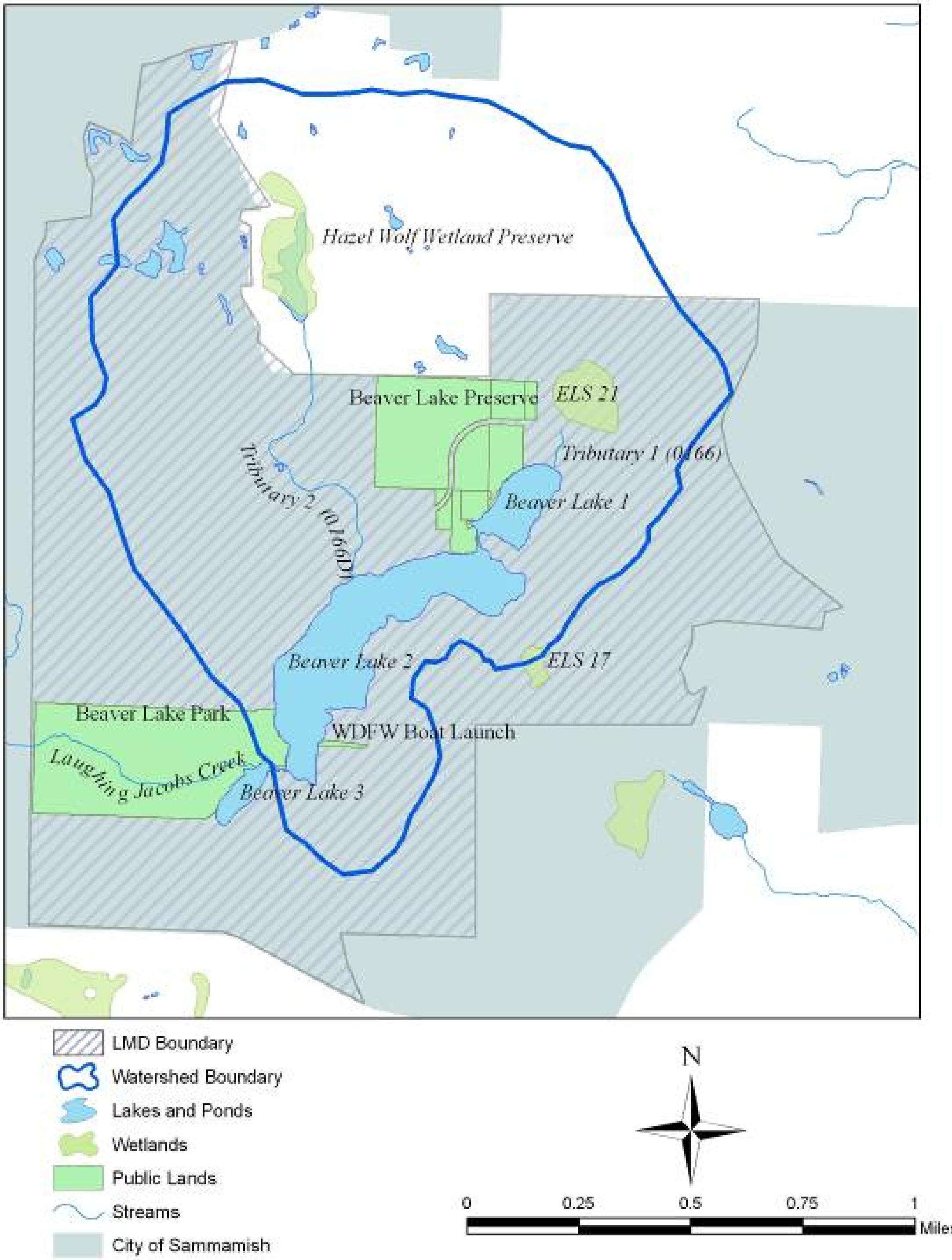
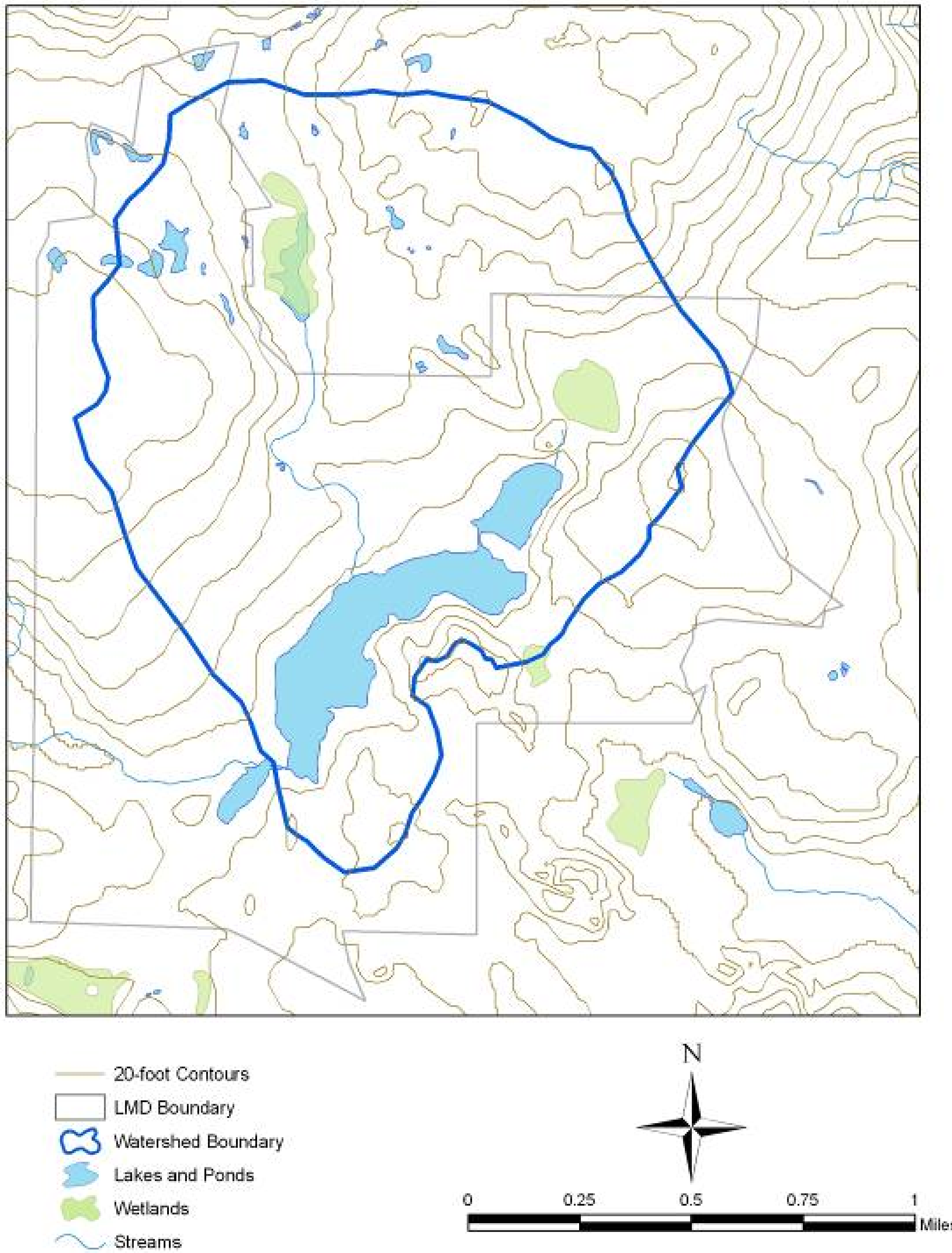


Figure 3. Topographic features.



Hazel Wolf Wetland Preserve

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

In 1995, this wetland area was preserved for the future 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 grass-roots advocate, who invigorated the regional environmental community with her spirit and foresight.

The preserve hosts several different wetland and forest habitats. This varied landscape supports many beautiful and sensitive plants and wildlife emblematic of the region. The preserve also links a network of protected habitats stretching from the Issaquah Alps to Lake Sammamish.

The wetland preserve is home to a wealth of animals. Bird life is diverse and includes ospreys, bald eagles, great blue and green herons, hooded mergansers, pied-billed grebes, and wood ducks (Land Conservancy, 1999). The wetland supports a variety of frogs, salamanders, and newts, as well as diverse mammals such as beavers, muskrats, raccoons, squirrels, bears, deer, and mice (Weinmann and Richter, 1999).

The preserve was established for a number of reasons, of which one of the most important was to protect water quality and habitat functions. The site has been also 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 to the mission of preserving the quality of the wetland and the 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 multiple characteristics common to bogs, including peat soil, low phosphorus levels, and acidic pH (King County, 1999b). The wetland is characterized by a central area of sphagnum moss and shrubs typical of bogs. Two intermittent streams flow into the wetland. A single outlet located on the south end flows directly to Beaver-1.

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

Patterson Creek 17

This three-acre wetland has no surface inflow channel. The wetland receives water from direct rainfall and surface runoff from the adjacent land. Outflow from the wetland occurs along both the western and eastern edges depending on water levels, so may contribute water to two different watersheds. The wetland vegetation is very similar to East Lake Sammamish 21, with a central mat of sphagnum moss (King County, 1999b). Currently the area surrounding this wetland is at the built out stage.

Lakes

Beaver Lake consists of two interconnected water bodies: Beaver-1 and Beaver-2, which flow to a small open wetland, Beaver-3. The main outflow from the lake exits from Beaver-3. Beaver-1 is the northernmost basin and, at 13 acres surface area, is about one-quarter the size of Beaver-2 (Table 1). Beaver-1 has an average depth of 22 feet and a maximum depth of 55 feet (Bortleson et al. 1976).

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

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
** Wolcott 1965: Lakes of Washington Vol.1

Beaver-2, at 61.5 acres of surface area, is the largest basin and contains 82 percent of the total lake volume as well (Table 1). Beaver-2 is connected to Beaver-1 via a shallow channel and also receives wetland drainage from the Hazel Wolf Wetland Preserve through an inflow on the west shoreline. The water color of Beaver-2 is noticeably lighter than Beaver-1, with transparency generally ranging from 2 to 4 meters through the year.

Beaver-3 is four acres in size, with the lake outlet located on the western shoreline not far from the channel connecting to Beaver-2. The lake is generally very shallow during the summer. Aquatic vegetation dominates most of the surface area during the summer but the water depth allows small water craft to move between Beaver-2 and Beaver-3 through most of the year.

Streams

Inflow to Beaver Lake is seasonal, occurring primarily from November through June via two unnamed tributaries (Figure 2). The northernmost tributary (BLTRI1, stream 0166 on map) drains ELS-21 and portions of the Trossachs subdivision into Beaver-1. The westernmost tributary (BLTRI2, stream 0166D on map) drains into Beaver-2 from an area that includes the Plateau golf course and the Hazel Wolf Wetland Preserve.

Outflow from the lake is also seasonal, generally occurring from late fall through early summer. The lake water exits directly from Beaver-3 to Laughing Jacobs Creek, which ultimately discharges to Lake Sammamish. The limited flows from the watershed results in an estimated residence time (the average time required to completely renew the water volume of the lake basins) of nearly two years.

Demographics

The Beaver Lake watershed is located largely within the relatively new 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.

Since 1990, the population of the Sammamish area has nearly doubled, increasing from a base of 21,550 in 1990 to more than 39,000 in 2006 (King County, 2006b). Based on 2000 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 86 percent Caucasian, one percent African-American, eight percent Asian, three percent Latino, and two percent other ethnicities.

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 2006, approximately 782 households are located in the watershed, based on lake management district records (City of Sammamish, 2006). Further growth is expected to occur, with a potential for approximately 870 households by 2016.

Land Use

The Beaver Lake area was 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). In general, the City of Sammamish continued to use similar zoning regulations as those established by the County, with the most recent requirements established in the Sammamish Comprehensive Plan (2003, updated 2006). During the early 1990s, the potential for conversion of the mostly forested watershed to urban residential densities (primarily from three to eight units per acre) was a 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.

Ongoing development of the watershed continues to be viewed by the local community as having the potential to impact the long-term preservation of lake water quality, and Beaver Lake Management District No. 2 was passed in September 2001.

Land use can be compared between 2000 and 2006 to look for significant changes in land cover types that might impact quality of water delivered to the lake basins, as well as in the lake itself (Table 2).

Table 2. Watershed land use summary.

Land use Category	**Year 2000 acreage**	**Year 2006 acreage**	**Year 2006 Revised acreage**
Golf Course	121	90	89
Forested	462	565	462
Wetland	62	31	62
Rural Residential, 1 du/2.5-10 acres	63	70	70
Urban Residential, 1-3 du/2.5 acres	91	198	198
Urban Residential, 1-3 du/acre	148	97	97
Urban Residential, 4-12 du/acre	85	58	58
Roads/Right of Way	72	0	73
Total Acres	**1104**	**1109**	**1109**

Due to the availability and use of more accurate land cover classification and delineation techniques, the total acreage of each sub-basin was adjusted in the 2006 update to the Beaver Lake Management Plan (Table 2 and Figure 4). The change in land cover classification and delineation resulted in a reclassification of approximately 80 acres from the upper basin to the lower lake basin, and a 4 acre increase in the total combined watershed area (Table 2 and Figures 4, 5). The revised 2006 acreage was used in the hydrologic model and phosphorus model attempted by Tetra Tech, discussed later in this document.

In 1993, approximately 660 acres of the watershed was categorized in forested uses (King County, 1993a). In 2000, approximately 462 acres remained as forest, which was essentially unchanged in 2006 (Table 2 and Figure 5). Adjustments in forested acreage, wetlands, and roads including Right-of-Way were made in the 2006 coverage. The decreases in numbers of acres in higher density development can be explained by the change in methodology.

Figure 4. Beaver Lake drainage sub-basins.

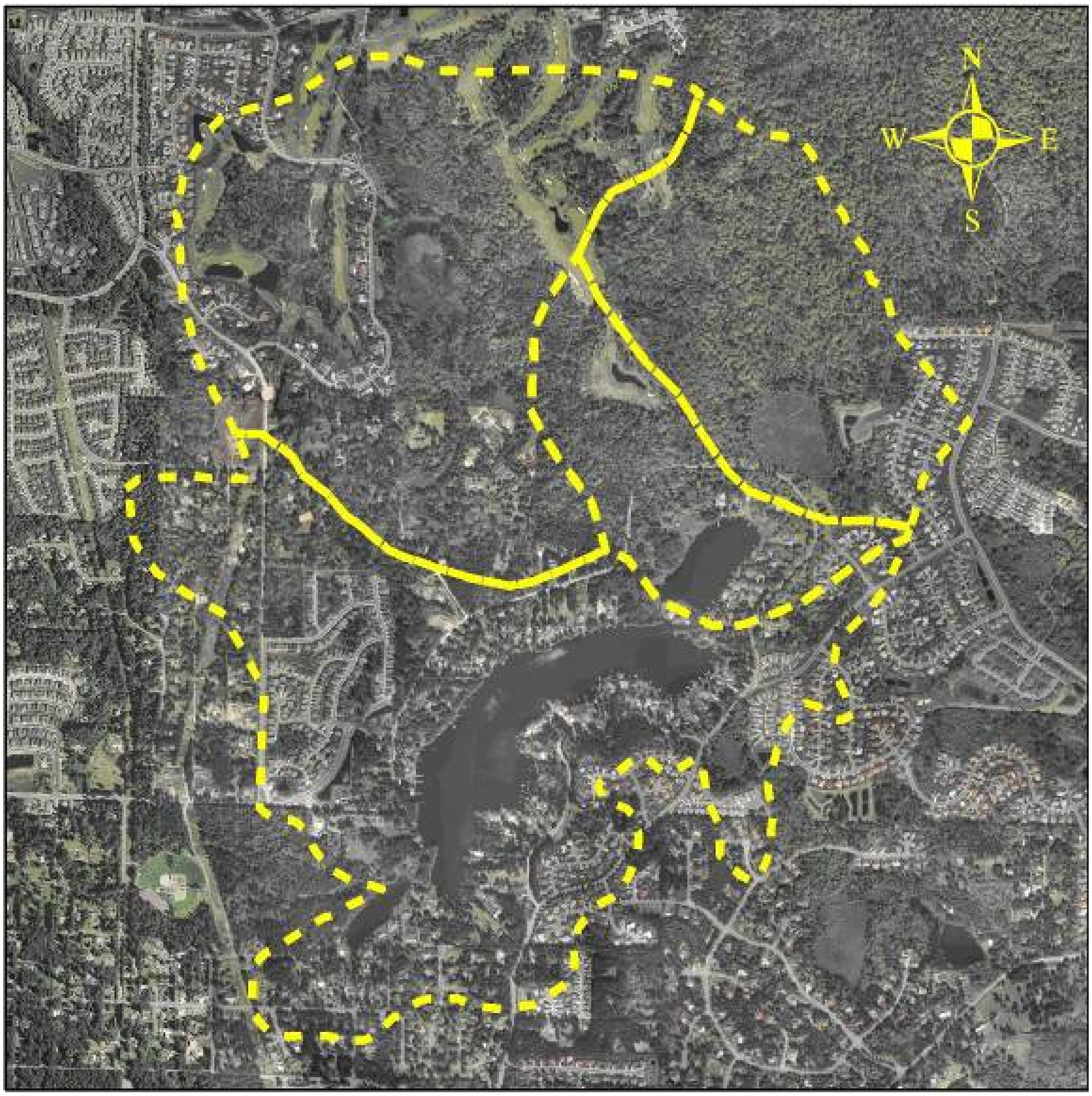
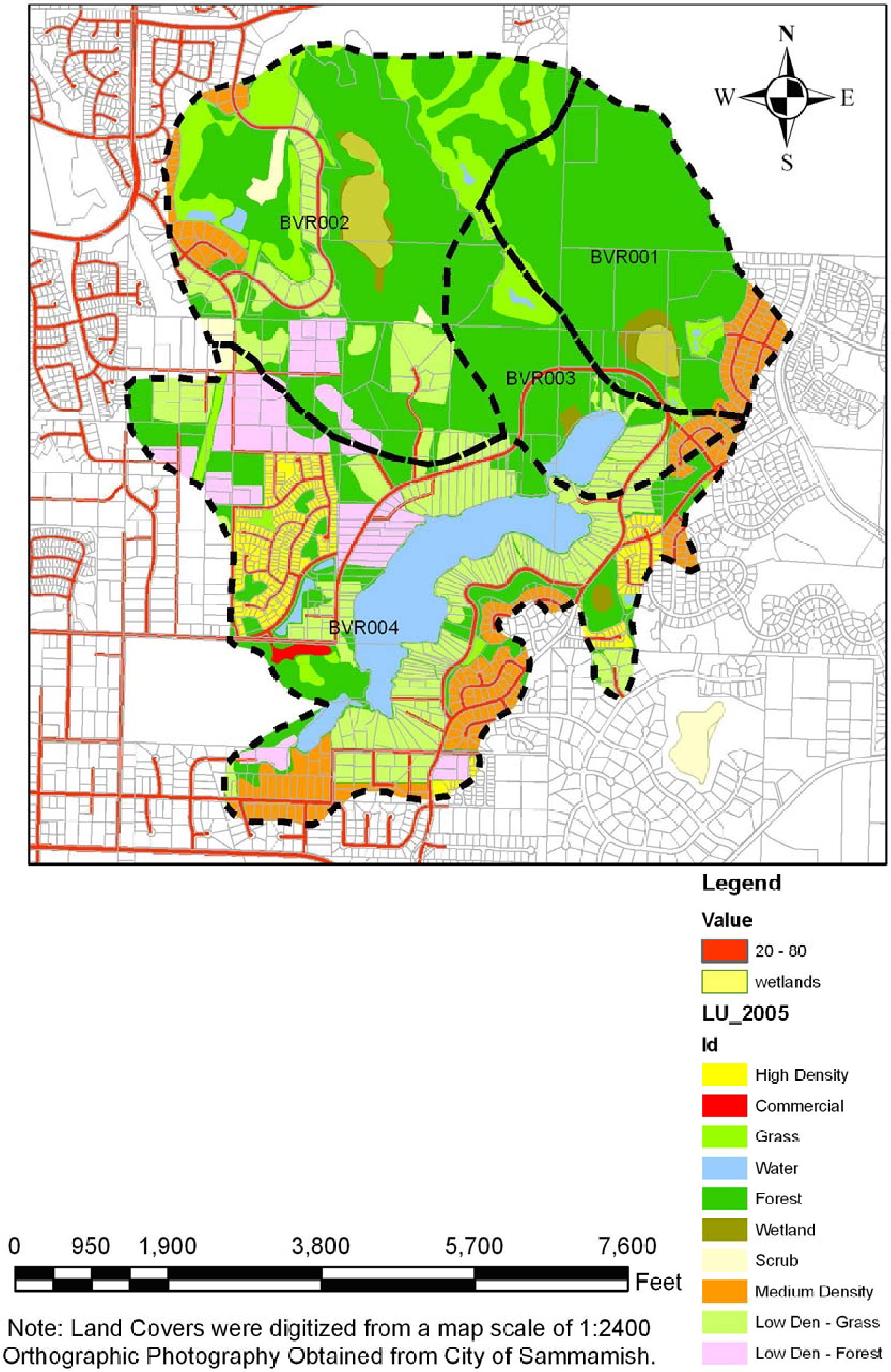


Figure 5. Current land use map used in hydrological and phosphorus analyses.



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.

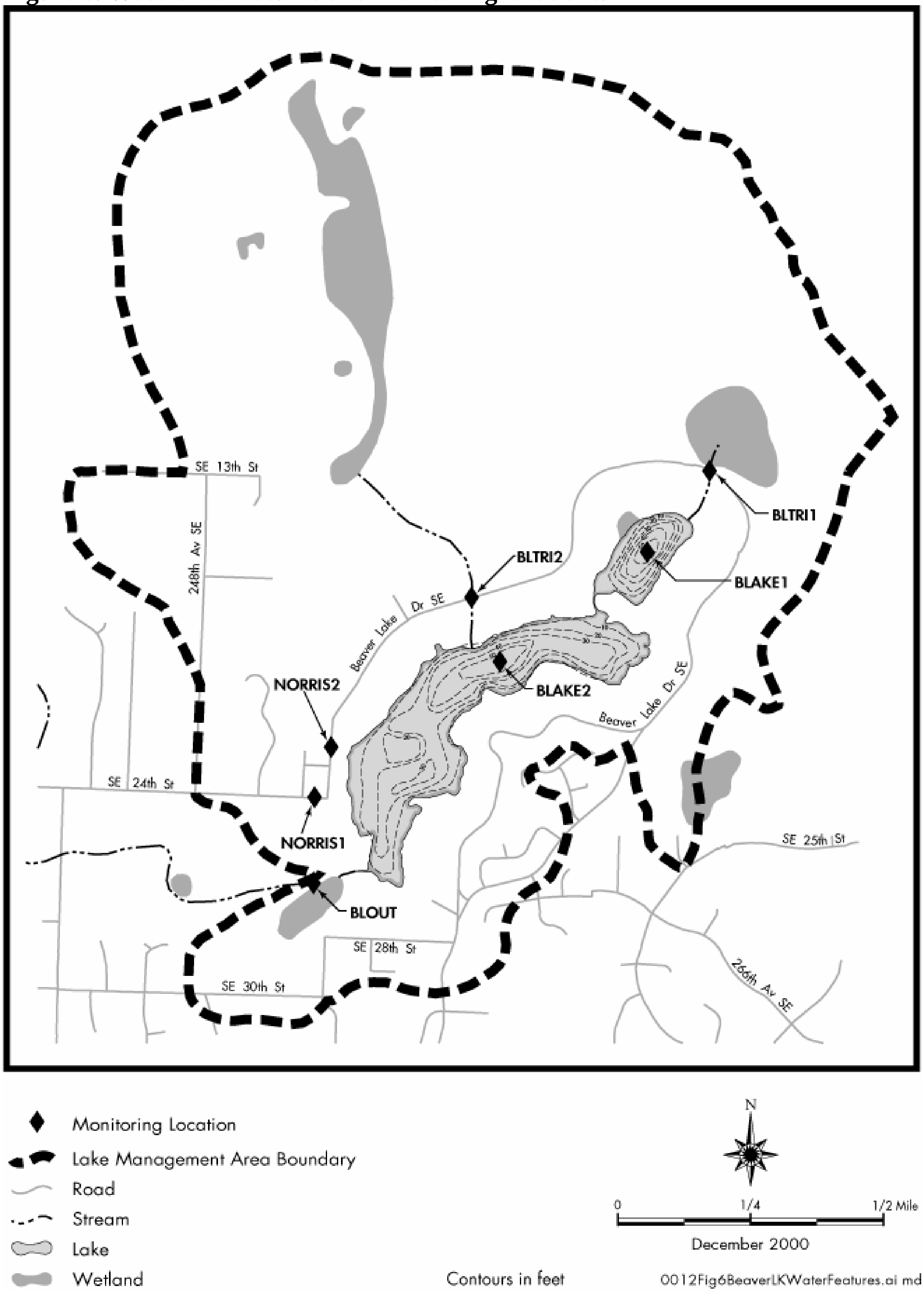
Sampling Sites

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

The lake has two primary inflows, tributary 0166 (station BLTRI1) and tributary 0166D(station BLTRI2). The outflow discharges to Laughing Jacobs Creek via an outlet channel (tributary 0166, station BL4 or BLOUT) located on the western-side of Beaver-3 (see Chapter 2, Figure 2).

Beginning in 1998, two additional sampling sites (NORRIS1 and NORRIS2) were added to the stream monitoring program to characterize stormwater runoff from the forested property located west of Beaver Lake 2 (Figure 6) that was subsequently developed as the single family residential area Wesley Park. These sites are characterized by intermittent flow which occurs only during large storm events. A large detention pond constructed at Wesley Park onsite rerouted some storm flow to Laughing Jacobs Creek, but flow is still observed entering Beaver-2 during very large precipitation events.

Figure 6. Watershed features and monitoring locations.



Lake Monitoring

The Beaver Lake Management District funded a comprehensive lake monitoring program that matched earlier efforts in 1993, 1997 and 2000, conducted from October 2005 through September 2006. The emphasis was on lake parameters measured monthly throughout the year and inlet stream variables during the wet season (biweekly, October – May). 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 collected by the Lake Management District was used for comparisons to previous efforts, developing lake nutrient budgets, and assessing the success of management strategies for the long-term protection of Beaver Lake. The data collected by Lake Stewardship 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 Chapters 4 and 5.

Management District Monitoring Program

Both lake sites (Figure 6) were monitored monthly for water quality during October 2005 through September 2006. These sites (BLAKE1 and BLAKE2) sample the water column over the deepest areas of the two lake basins. Water samples were collected for nutrient analysis from these sites at approximately 3 meter 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), which were followed for the period of 2001-2006 as well.

Table 3: Management District monitoring program water year 2006.

Component	Sampling	Stations	Parameters
Lake	monthly	2 mid-lake stations, at 0,3,6,9,12, and 14m	Total Nitrogen, Total Phosphorus, Soluble Reactive Phosphorus
	July and August	2 mid-lake stations, at 0,3,6,9,12, and 14m	Nitrite+Nitrate-Nitrogen, Ammonia
	monthly	2 mid-lake stations, water column composite (combined samples from 0.5, 1 2 and 3m)	Chlorophyll *a* , Phaeophytin *a* , Phytoplankton species, biovolume, and identification
	monthly	2 mid-lake stations, vertical tow 14m to the surface	Zooplankton species, enumeration, and identification
	monthly	2 stations, 0.5m or from the surface	Turbidity, Alkalinity, Color, Secchi depth
	monthly	2 stations, profile every meter	Temperature, Dissolved Oxygen, pH, Conductivity

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 monitored on approximately 45 small lakes in King County. Volunteer data are reported by King County in annual lake monitoring reports (King County, 1999c) and on line at

http://www.metrokc.gov/dnrp/wlr/water-resources/small-lakes/data/default.aspx.

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, 2006).

Table 4. 2001-2006 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)	Temperature, and Secchi depth
Lake (Level II)	Biweekly May-October	2 stations, surface (1m)	Total Phosphorus, Total Nitrogen, Chlorophyll *a* , Pheophytin *a* , Temperature, and Secchi depth. Phytoplankton species sometimes identified.
	Summer profile May and August	2 stations, surface, mid, and bottom depths	Same as biweekly parameters, with the addition of color, ammonia, nitrate-nitrogen, orthophosphate, and alkalinity at some depths.

Stream Monitoring

Water quality was also evaluated through the Lake Management District stream monitoring program. This program included the collection of baseflow and stormwater samples from the two tributaries to Beaver Lake, and when flow allowed, samples from two intermittent sites that exit the Wesley Park development (Figure 6).

Stream flow to the lake is seasonal, flowing typically from October through June only. Manual grab sampling methods were used to collect both baseflow and storm flow, and inlet and outflow samples (King County, 1996b). Storm events were measured as a composite of two grab samples taken approximately 8 hours apart.

Both of the major tributaries to the lake, BLTRI1 and BLTRI2, originate in wetland headwaters. BLTRI1 is the direct outflow from a 13-acre Class 1 bog that discharges directly into Beaver-1. BLTRI2 originates from a 31-acre open water wetland and flows about one quarter mile before entering Beaver-2 (Figure 6). The Wesley Park (Norris) discharge drains the eastern portion of the development and flows infrequently, only during the largest storms.

Discharge

Gaging data was collected from the inflow tributaries (BLTRI1 and BLTRI2) and the lake outlet (BLOUT) using 15-min stage recorders from November 2001 through September 2005. 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 bimonthly basis beginning November 2001 though June 2006. The water samples were analyzed for the parameters shown in Table 5. A complete description of stream sampling methods can be found in the *Water Quality Monitoring Plan* (King County, 1996b).

Table 5. 2001-2006 Stream monitoring program.

Component	Sampling	Stations	Parameters
Inlets/Outlets	Biweekly	2 sites at primary inflows for baseline (BLTRI1 and BLTRI2) plus 1 site ("Sauerbrey Crk" during storm flows); 2 dock stations on both Beaver Lake basins measured for pH, temperature, conductivity, color, and alkalinity.	Temperature, pH, Dissolved Oxygen, Conductivity, Total Phosphorus, Ortho-Phosphorus, Color, Turbidity, Total Suspended Solids
Flow/Hydrology	Daily	Lake level Inflow and Outflow Rain Gage	Volume Fluctuations Total Discharge Total Precipitation

Stormwater

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

During these sampling events, high flow samples were combined from two individual grab samples taken over the course of an individual storm event. A storm event was generally defined as 1 inch 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.

A goal of measuring four storm events was set for each year. However, because of the slow response of the tributaries to precipitation, the fact that storms come in series in the Pacific Northwest, and time guidelines for submitting samples to the King County Environmental labs, typically only two to three events could be sampled each year.

Chapter 4: Lake and Stream Quality

For both basins of Beaver Lake, water quality data are available from a variety of sources including the original *Beaver Lake Management Plan* (King County, 1993a), the *Beaver Lake Management Plan Update* (2000) and from the King County Lake Stewardship volunteer monitoring program (both the annual reports from 1995 – 2004 and web reports found at http://dnr.metrokc.gov/wlr/waterres/smlakes/.

As part of the Beaver Lake Management District monitoring program, selected parameters of stream quality were also monitored, and this will be addressed in a separate section in this chapter.

These data will be compared with data collected for the two previous management plans.

Lake Water Quality

For selected water quality parameters that were measured, average concentrations in the surface water (0.5 meters depth) are shown in Table 6. In general, values for these parameters have remained fairly similar for the four water years that have been measured (1992, 1997, 2000, and 2006), although some up and down variation can be seen between years. Differences between years are not unusual, given the large number of variables that affect conditions in lakes each year, such as the amount and timing of water inputs, the degree of windiness, the number and timing of sunny days, changes in seasonality, changes in predator populations, etc.

Two variables that have shown a steady upwards change over time in both basins are alkalinity and pH, which are related. Alkalinity is a measure of the acid neutralizing capacity of the water (sometimes called "buffering capacity"), while pH is a reverse measure of the number of hydrogen ions in the water, otherwise known as acidity (the lower the pH, the more hydrogen ions are present and the more acid is the water). The increase in alkalinity is likely related to the increase in development throughout the watershed, as both lakes naturally contain water low in buffering ions due to the nature of native soils and rock. Development generally involves producing cement structures, such as roadbeds, sidewalks, bridges, basements and slabs. All of these structures leach ions over time into rainwater, similar to what would be produced by limestone. Therefore, development is akin to adding limestone formations to the watershed, and an increase in alkalinity of surface waters is to be expected. Consequences are unclear at this point, but are unlikely to be dramatic unless a threshold is reached that gives an advantage to some plant and animal species over others, in which case ecological community structures may change.

Most freshwater lakes in temperate climates are phosphorus limited, which means that of all the nutrients necessary for algae (phytoplankton) to grow and reproduce, phosphorus is the least available in the water. Thus, increases in phosphorus concentrations in the lake can lead to larger algae populations that contribute to a perceived degradation of water quality in lakes.

For Beaver Lake, phosphorus was identified as the limiting nutrient in the original Beaver Lake Management Plan and therefore, in order to maintain Beaver Lake water quality, phosphorus control has been the focus of preservation efforts (King County 1993a). The data indicate that in both basins, Beaver-1 and Beaver-2, phosphorus levels have not changed significantly over the four water years. Higher values found in water years 1997 and 2006 may be linked to greater precipitation and subsequent storm water runoff, which can increase sediment inputs into the lake, but not result in an immediate response by the algae.

Other measured parameters, such as Secchi transparency, dissolved oxygen, turbidity, and color showed slight variation between the years, but did not suggest any directional changes over time.

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 other water years discussed can be found in the technical appendices of both the original Beaver Lake Management Plan (1993) and the Beaver Lake Management Plan Update (2000). Data for water year 2006 can be found in the technical appendices of this update.

Table 6. Average surface (0.5 meter) concentrations for select water quality parameters.

Parameter	Water Year*	Beaver Lake 1			Beaver Lake 2		
		Average	Min	Max	Average	Min	Max
Total Phosphorus (µg/L)	1992	28.4	10.0	40.0	19.3	11	32
	1997	30.6	14.5	47.5	21.2	9	42.8
	2000	23.3	12.2	37.4	15.9	10.1	33
	2006	27.5	15.2	57.7	18.8	8.8	38.6
Ortho-Phosphate (µg/L)	1992	8.6	5.0	29	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
	2006	12.3	<2	16.5	4.7	<2	19.9
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
	2006	6.9	<0.5	20.0	4.1	0.9	7.5
Secchi Depth (m)	1992	1.3	0.9	2.0	2.5	2.0	3.6
	1997	1.8	1.8	1.8	2.3	2.3	2.3
	2000	1.8	1.3	2.5	2.8	2.3	3.5
	2006	1.3	0.9	1.8	2.5	1.8	3.0
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	4.0	23.3	13.1	4.6	24.1
	2006	12.8	4.4	22.6	13.2	5.4	23.1
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
	2006	8.4	6.8	10.0	9.2	7.1	11.0
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
	2006	6.4	5.9	6.9	6.8	6.4	7.3
Conductivity (µmhos/cm)	1992	31	18	38	37	20	41
	1997	23	20	26	31	27	34
	2000	37	30	44	42	37	51
	2006	33	31	36	46	43	48
Alkalinity ($mgCaCO^3/L$)	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
	2006	11.2	7.1	18.0	15.6	11.3	25.0
Turbidity (NTU)	1992	0.6	0.3	1.1	0.5	0.3	0.9
	1997	1.3	0.6	2.8	1	0.6	1.6
	2000	1.1	0.5	2.4	0.9	0.5	1.4
	2006	1.2	0.7	2.1	1	0.6	1.9
Color (UV 254)	1992	0.365	0.231	0.463	0.144	0.051	0.257
	1997	0.442	0.206	0.617	0.273	0.206	0.463
	2000	0.406	0.360	0.463	0.185	0.129	0.257
	2006	0.475	0.437	0.543	0.224	0.198	0.262

* Water years last from October of the previous year to September of the named year. For example: WY2006 runs from October 2005 to September 2006.

**na = data not available.

Management District Monitoring Program

The monitoring program funded by the Beaver Lake Management District resulted in the collection of lake water quality data for October 2005 through September 2006. The data collected are compared with data collected previously for the original Beaver Lake Management Plan and the update in 2000. 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

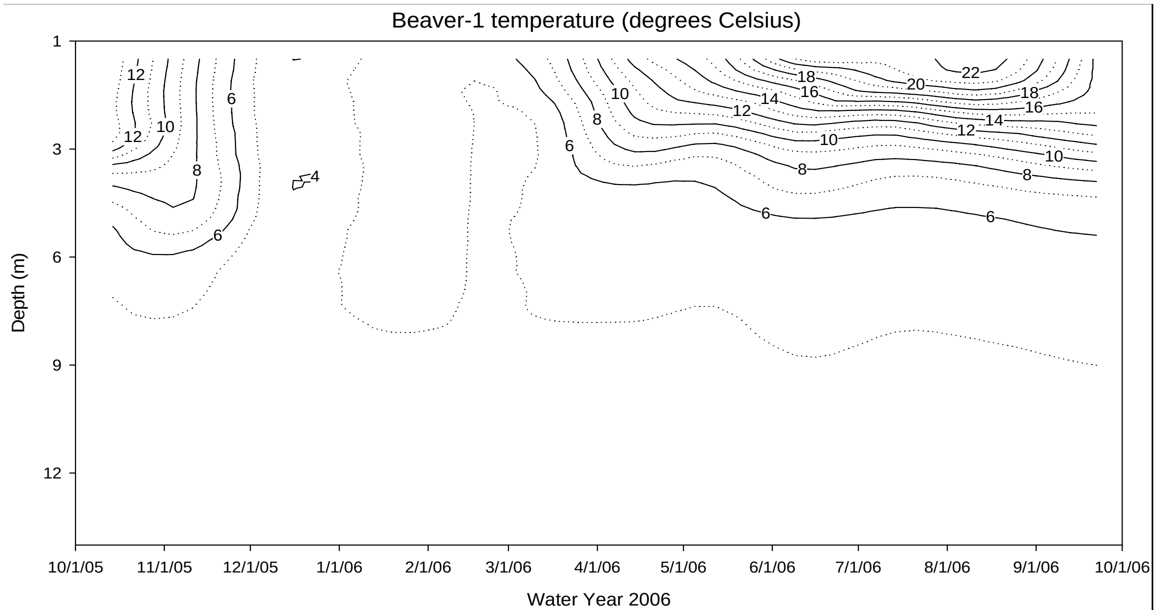
The density of water at different temperatures is important in the development of thermal stratification of lakes. Stratification is the layering of the lake water into sections with distinct temperature because water warmed by sunshine is lighter and will tend to sit on top of the water body rather than mixing into the deeper, cool water. This lack of mixing during warm seasons results in the separation of the lake water column into distinct temperature and chemical layers based on density.

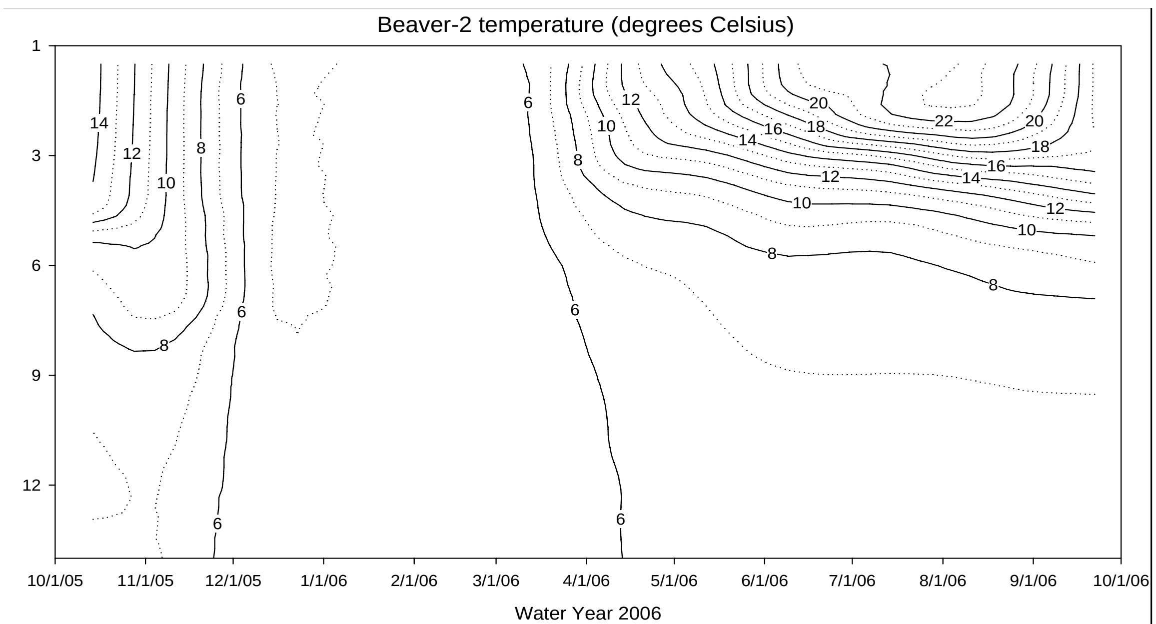
A typical seasonal pattern results, with water temperature being nearly uniform during winter followed by stratification in spring when sunlight starts significantly warming surface waters. This continues through summer, generally characterized by three distinct temperature layers: the epilimnion (upper), metalimnion (middle), and hypolimnion (lower). The metalimnion is characterized by large temperature changes from top to bottom of the layer, which effectively isolates the epilimnion from the hypolimnion and leads to distinct differences in chemical concentrations of the layers.

This pattern and its consequences can be depicted by plotting conditions in the water column over an entire water year on charts called **isopleths** or **contour charts**. These can be read like topographic maps, with the temperature lines taking the place of equal elevation lines. For each basin, time through the water year is along the X-axis (equivalent of east-west on a map) while water depth is from top to bottom along the Y-axis (equivalent of north-south). The temperature lines are drawn for every degree, with every other degree depicted as a solid line with the temperature identified, while the degree lines in between are dotted.

The temperature contour chart for Beaver-1 (see Figure 7) shows that when the water year began, the basin was thermally stratified from the surface down to 6 meters. Over the next two months, the top 6 meters of the water column cooled until by December, the lake was essentially the same temperature from top to bottom (i.e., thoroughly mixed). This remained the case through the winter until early to mid March, when warming at the surface began to separate layers in the water column, which remained in effect through the rest of the water year. The period of greatest difference was in August, when the surface water was 22 degrees Celsius, while the bottom remained the same temperature as it had been throughout the water year.

Figure 7. Temperature profiles of Beaver-1 and Beaver-2 basins, water year 2006.





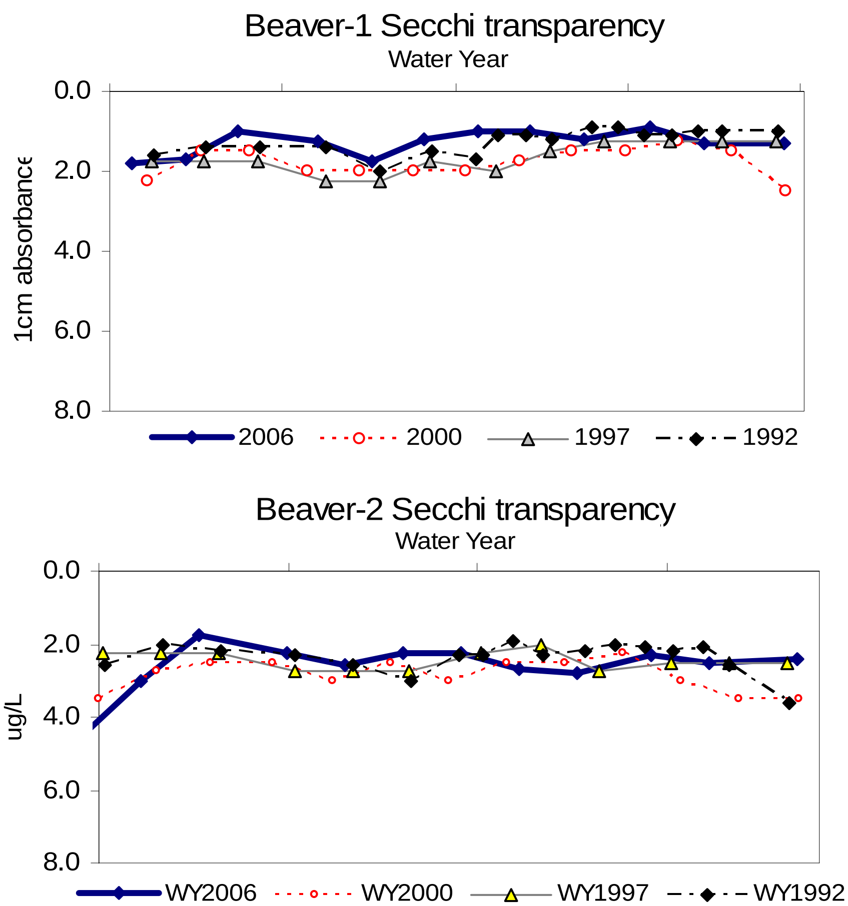
Beaver-2 shows a similar pattern, but there are a few differences largely attributable to basin size and degree of exposure. While both basins have similar maximum depths, Beaver-2 has more than twice the surface area and is long in the direction of the prevailing winds, which gives it much less protection from wave generation. This means that wind energy can push water more effectively, which results in different timing of stratification and overturn, as well as the epilimnion of Beaver-2 being a thicker layer of water. Comparing the contour maps of the two basins illustrates this. Beaver-2 mixes earlier than Beaver-1 in the fall, and it stratifies later in the spring, which results in the bottom temperature being a little warmer (it is above 6 degrees Celsius through the summer months), and the epilimnion is deeper as well.

Water Clarity and Color

Water turbidity and color affect water clarity, which controls the depth that light penetrates the water column. The availability of light affects plant growth, including both algae and rooted aquatic plants, since photosynthesis cannot occur in the darkness. Turbidity is generally related to suspended fine sediments, the abundance of small bodied algae, or occasionally decaying organic matter. Water color is often related to incomplete decomposition of organic in soils of the watershed or in wetlands that connect to the lake, leaving large organic molecules (called humic acids) that are then carried into the lake by surface water inputs. The yellow or tea color they give the water occurs naturally and has consequences for both water clarity and plants/algae living in the lake. Abundant algae can also color the water in lakes for a short time during blooms, giving them colors that range from pea soup to bright green, and occasionally even turquoise, brown, red or maroon.

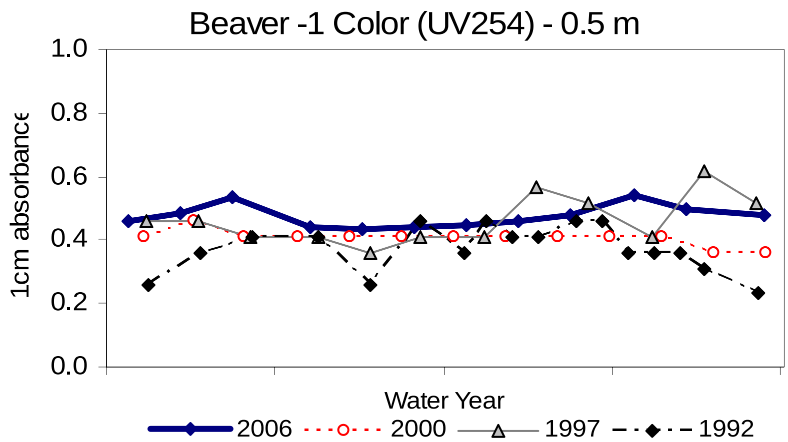
In Beaver-1, Secchi depth (a relative measure of water transparency) has averaged less then 2.0 meters over the four water years that have been measured. In Beaver-2, average water clarity is higher, ranging between 2.3 to 2.8 meters (see Figure 8a.)

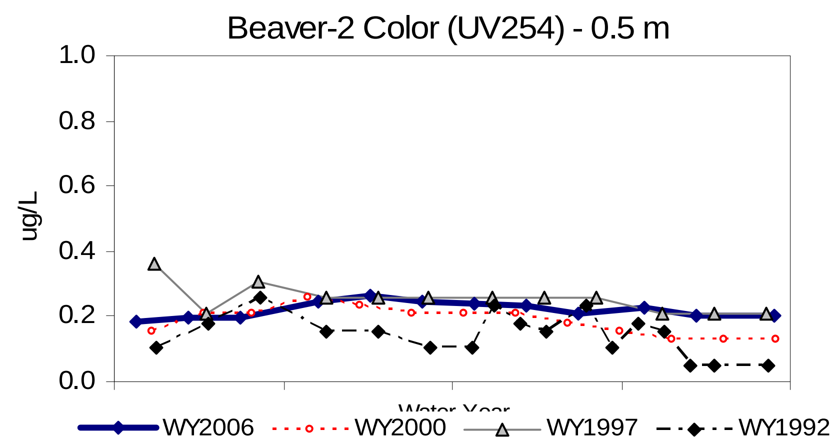
Figure 8a. Comparison of Secchi transparency values through the water year for the 4 different periods of measurement.



The water clarity in both lakes is certainly related to color, probably more so than to turbidity. In both basins the humic acid color of the water plays an important role in water clarity, although its impact is greater in Beaver-1 than in Beaver-2 (see Figure 8b). Water color was measured by light absorbance in the ultraviolet light range (UV254) in water year 2006 and earlier Platinum-cobalt color measurements (1992-2000) were corrected to UV units for comparison purposes (King County Environmental Labs, personal communication). The higher color values in Beaver-1 result in lower water clarity than in Beaver-2, which can be seen in the Secchi depth measurements. The source of color to both basins originates in upstream wetlands which discharge organic matter and highly colored water to Beaver Lake. The main tributary to Beaver-1 comes directly from a sphagnum bog wetland (ELS 21) that flows a very short distance, while the main tributary to Beaver-2 comes from a larger wetland complex (Hazel Wolf wetland) that flows through both wooded and developed areas for about 0.25 miles before it enters the lake, receiving other drainage flows before entering the lake.

Figure 8b. Comparison of water color values through the water year for the 4 different periods of measurement.





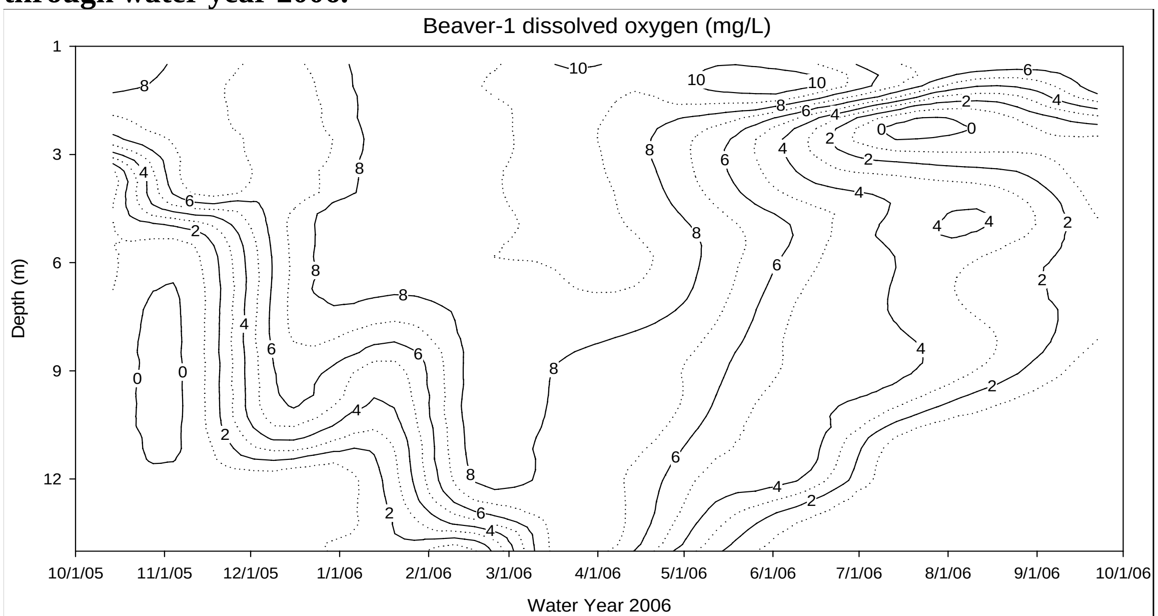
Note than in general, UV absorbance is nearly twice as high in Beaver-1 as it is for water in the Beaver-2 basin.

Dissolved Oxygen

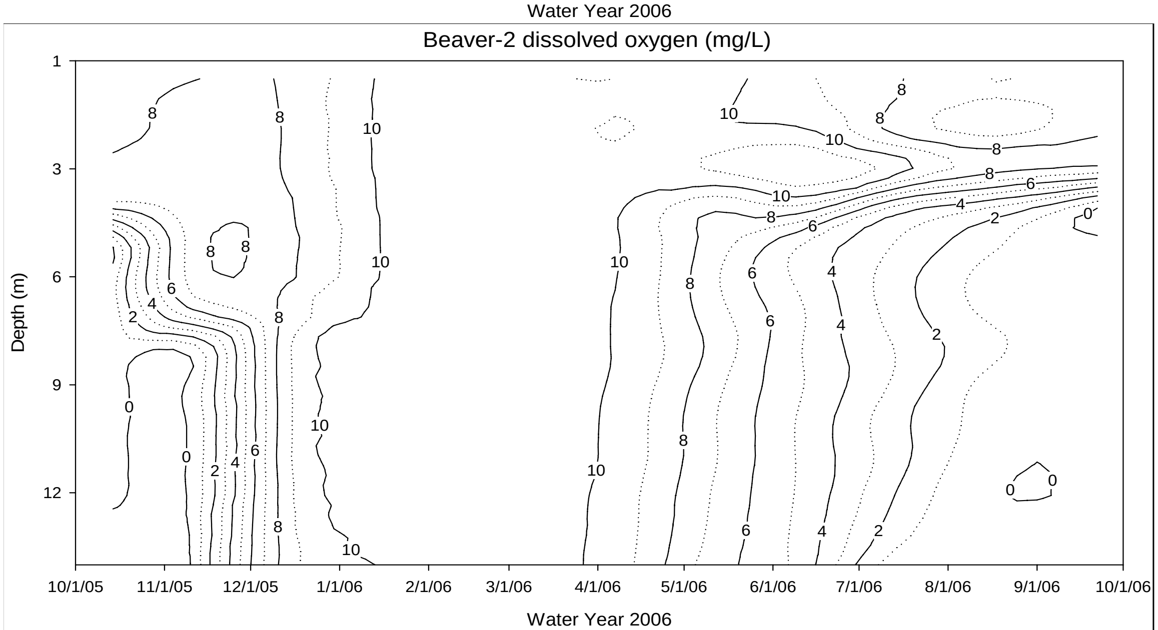
Oxygen is important for supporting most life forms found in lakes, as well as regulating some important chemical processes. Once a lake becomes stratified, oxygen levels begin dropping in the hypolimnion because there is no contact with the earth's atmosphere that would allow replenishment. Since decomposer organisms in the bottom sediments use oxygen, over time the amount available can decline to near zero. This can change the chemical reactions occurring at the lake/sediment interface, causing phosphorus that would remain in the sediments to be released to the deep water. This phosphorus then becomes available for plant growth in the upper water when the lake water mixes in the fall as the temperatures become uniform through the water column.

Surface concentrations of oxygen are generally higher in Beaver-2 in comparison to Beaver-1 (Table 6). Contour maps show the pattern of oxygen concentrations in the two lakes over water year 2006 (Figure 9). One interesting thing to note is that oxygen concentrations are uniform from top to bottom in Beaver-1 for only a very short period in the winter, while they are mixed much longer in Beaver-2. This is likely because the relatively small surface area of the lake relative to its depth means that water (and therefore the oxygen content) is mixed fairly slowly by the wind. Another interesting pattern is the development in Beaver-1 during summer of an isolated oxygen minimum around 3 meters deep. This is probably caused by animals such as fish and zooplankton, staying at this depth, using more oxygen in their metabolism than is replenished by either photosynthesis or surface diffusion from the atmosphere. This does not happen in Beaver-2, again likely because its shape and surface to depth ratio allows for wind to push the water more efficiently.

Figure 9. Contour maps of oxygen concentrations in Beaver-1 and Beaver-2 basins through water year 2006.



Water Year 2006



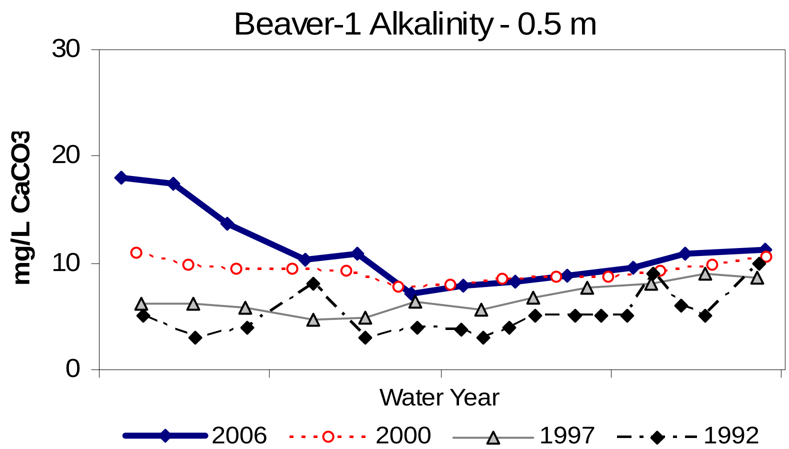
is relatively small, leading to short contact time between rainwater and the soils of the watershed. Conductivity in Beaver-2 was slightly higher in both 2000 and 2006 than in previous years, suggesting that development may be contributing to a minor increase.

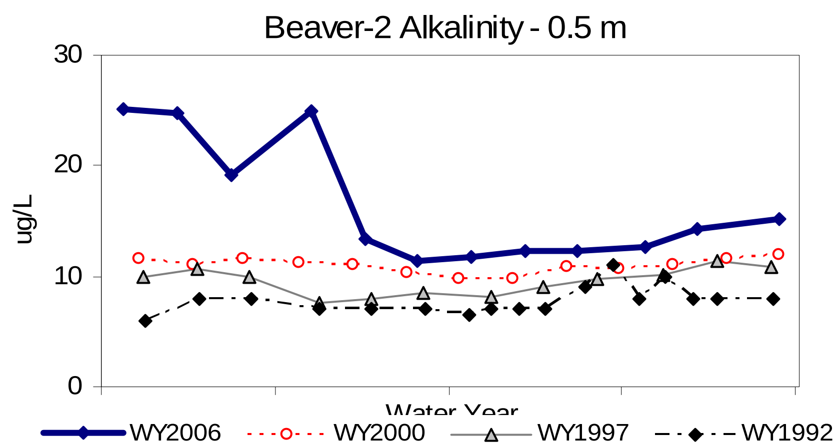
Alkalinity (or acid neutralizing capacity) is a measure of a water body's ability to neutralize the acidity caused by hydrogen ions, while pH is a direct measure of the hydrogen ion concentration. Because pH plays an important role in many biological and chemical processes, alkalinity can also have an important affect on the character of a lake and its ability to buffer chemical processes and support a range of animal and plant species.

In Beaver-1, both pH and alkalinity levels are lower than those in Beaver-2 (Table 6). Comparisons can be made between years for alkalinity (Figure 10). In both basins, it is clear that slightly higher values are found every year than for the previous period of measurement. The exceptionally high values in the beginning of water year 2006 did eventually drop to levels more similar to previous years, but are suggestive of what may happen in the future. The trend is steadily upward for the lake as a whole.

Upstream wetlands and the processing occurring in them heavily influence lake chemistry. In Beaver-1 the surface pH ranged from 5.9 to 6.9 and averaged 6.4 in 2006, while in Beaver-2 the surface pH ranged from 6.4 to 7.3 and averaged 6.8. Highly productive lakes and lakes in limestone areas with high alkalinities can have pH values of 9 to 10, while Beaver Lake remains in the slightly acid range typical of the soft water Pacific Northwest lakes.

Figure 10. Comparison of alkalinity values through the water year for the 4 different periods of measurement.





Nutrient Limitation

Most lake water quality problems from the community point of view are related to increased nutrients for plants that result in nuisance plant growth, generally as algae, but sometimes as rooted aquatic plants in the shallow areas. Prior to evaluating management options if nuisances or health risks are occurring, the nutrient that limits plant growth must be determined, since reducing the availability of the limiting nutrient should bring about the most effective results. Both nitrogen and phosphorus are major nutrients that are important to plant growth. Most often in lakes in the temperate areas of the world, phosphorus is limiting, although in some cases nitrogen has been found to be in smaller supply. However, in general the management focus has been on reducing phosphorus inputs to lake waters.

When determining nutrient limitation, studies have examined the nitrogen to phosphorus ratios of surface water and related that to the kinds and abundances of algae found. Ratios greater than 17:1 generally suggest that phosphorus limits algal growth (Carroll and

Pelletier, 1991) while ratios of less than 10:1 suggest nitrogen or concurrent limitation. Previous data for Beaver Lake suggested that phosphorus was the limiting nutrient for the lake (King County, 1993a).

To confirm whether phosphorus levels continued to drive algal growth, limited nitrogen data were collected for July and August in 1997, 2000, and 2006. Based on this data, nitrogen to phosphorus ratios for Beaver-1 ranged from 14:1 to 37:1 while in Beaver-2 ratios ranged from 28:1 to 38:1. These ratios indicate that phosphorus continues to be the limiting nutrient for algal growth and thus controlling phosphorus inputs is the most important goal for management of water quality.

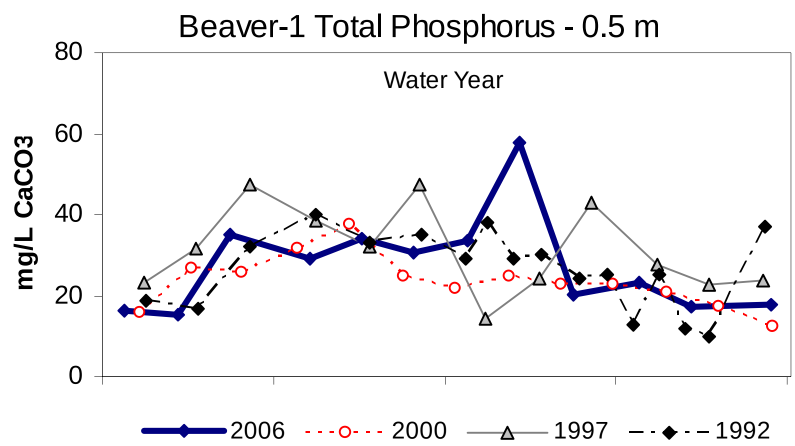
Phosphorus

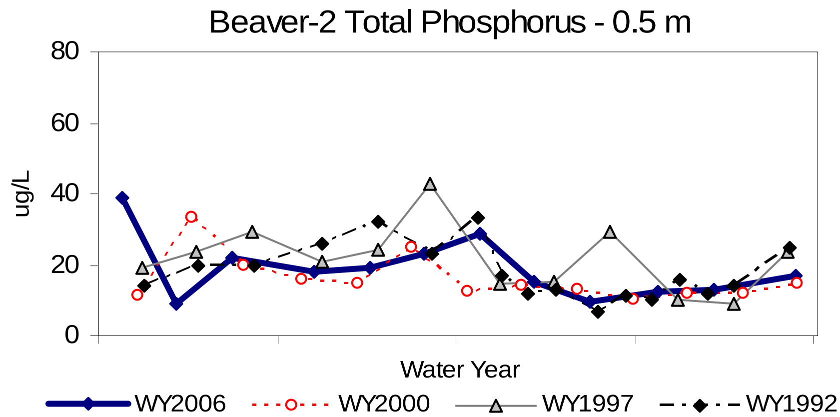
Phosphorus is a common element found in soil, rock, plant and animal tissue, as well as in the atmosphere. All organisms rely on phosphorus to survive and grow. In freshwater environments, phosphorus availability provides for algal growth that through food web dynamics supports higher organisms such as zooplankton and fish.

Phosphorus can be measured in a variety of different forms, but the most common methods estimate total phosphorus and ortho-phosphate. Total phosphorus represents both organic and inorganic forms of phosphorus while ortho-phosphate represents the dissolved fraction of inorganic phosphorus that is immediately available for algal growth.

Both forms of phosphorus have been measured in Beaver Lake for the four water years (see Figure 11). Comparisons are made between years for total phosphorus in the surface waters of the two basins. Surface concentrations vary, but show no general pattern that suggests a trend or change over time.

Figure 11. Comparison of total phosphorus values through the water year for the four different periods of measurement.





Concentrations are typically higher in Beaver-1 than in the larger Beaver-2, possibly reflecting the difference in inputs between the two basins. In 1992, 2000, and 2006 total phosphorus surface concentrations were lower than those observed in 1997 (Table 7). Year-to-year variability in phosphorus concentration can be partially attributed to the amount and timing of precipitation. During 1997 which was a wet year, higher phosphorus concentrations were measured in both basins.

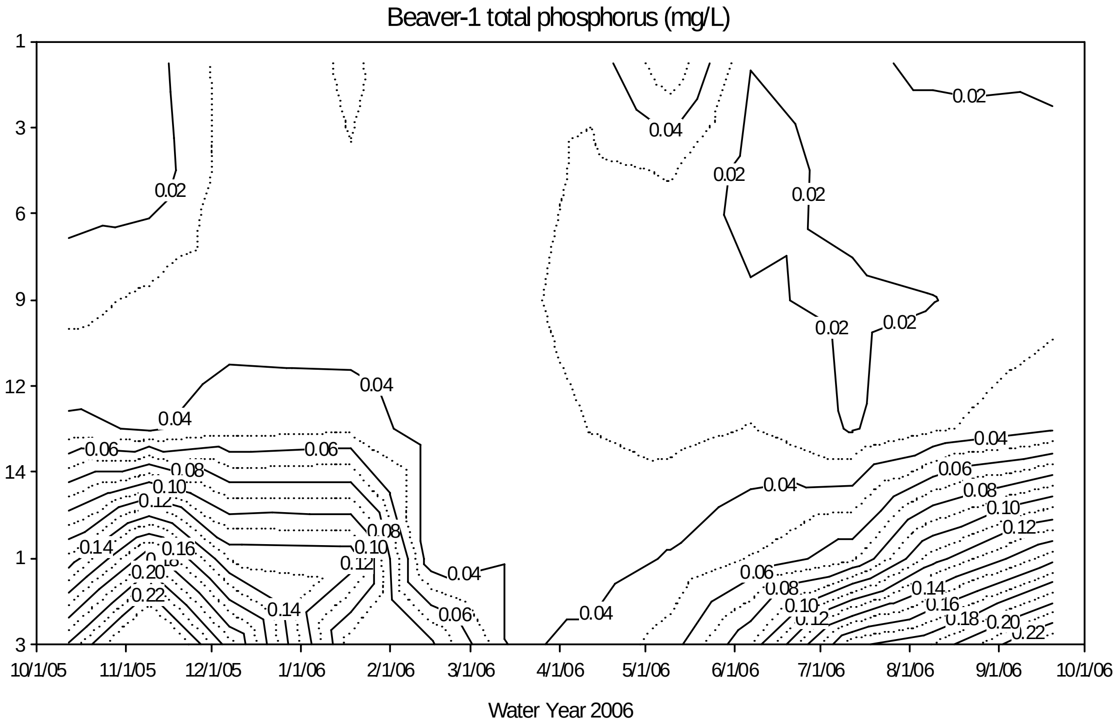
Table 7. Average surface total phosphorus concentrations for four water years.

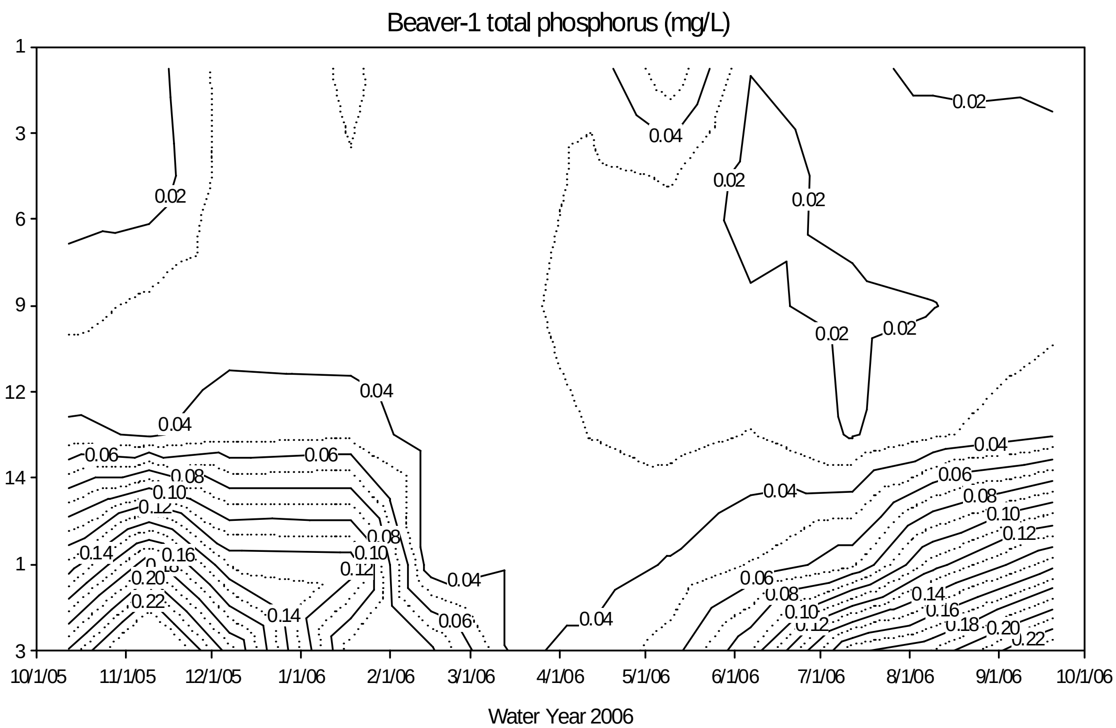
Water Year	Beaver-1 Total P (µg/L)	Beaver-2 Total P (µg/L)	Rainfall @46U* (inches)	Rainfall @MLU* (inches)	Rainfall @18Y* (inches)	Rainfall Level I* (inches)
1992	28.4	19.3	45	not available		not available
1997	30.6	21.2	70	63		55
2000	23.3	15.9	not available	41		40
2006	27.5	16.4			43	50

* 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.

When averaged over the period, phosphorus levels are relatively stable from year to year when precipitation levels are similar, although if the rainfall comes in the form of large storms it can affect the outcome. Patterns of phosphorus concentrations seen in contour plots for water year 2006 (Figure 12) show that increases in phosphorus in the deep water occur over the summer in both basins, suggesting that internal recycling in the hypolimnion may be another important process that provides phosphorus to algae for growth and reproduction. This clearly results in higher levels of phosphorus in the deep water of Beaver-1, which probably relates to the longer period of anoxia observed in the oxygen contour plots (Figure 9).

Figure 12. Contour maps of total phosphorus concentrations in Beaver-1 and Beaver-2 basins through water year 2006.





Nitrogen

Nitrogen exists in a variety of forms in the aquatic environment. These forms include nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), organic nitrogen (many molecular forms), and elemental nitrogen (N_2). NO_3 and NH_3 are the forms most commonly used by algae and plants, although some bluegreen algae can use N_2 through a special process carried out by bacteria that they harbor, similar to alders and other N-fixing plant species.

Limited nitrogen data was collected for Beaver Lake during the years of measurement, mainly because nitrogen availability does not appear to limit algal growth in Beaver Lake. Total nitrogen, NO_2-NO_3, and NH_3 were measured in July and August during the four water years (Table 8). For all water years, total nitrogen levels in the surface water are consistently higher in Beaver-1 than in Beaver-2. Summer levels of available nitrogen appear to be lower in both 2000 and 2006 for both basins than in previous years, but the earlier years were still fairly close to the lower analytical levels of detection.

Table 8. Average summer (July and August) surface nitrogen concentrations for four water years.

Water Year	Total N (mg/L)	NO2-NO3 (Ξg/L)	NH3 (Ξg/L)
Little Beaver			
1992	597	50	13
1997	533	25	24
2000	547	<MDL*	<MDL*
2006	715	<MDL*	<MDL*
Big Beaver			
1992	385	42	25
1997	331	25	26
2000	345	<MDL*	<MDL*
2006	363	<MDL*	<MDL*

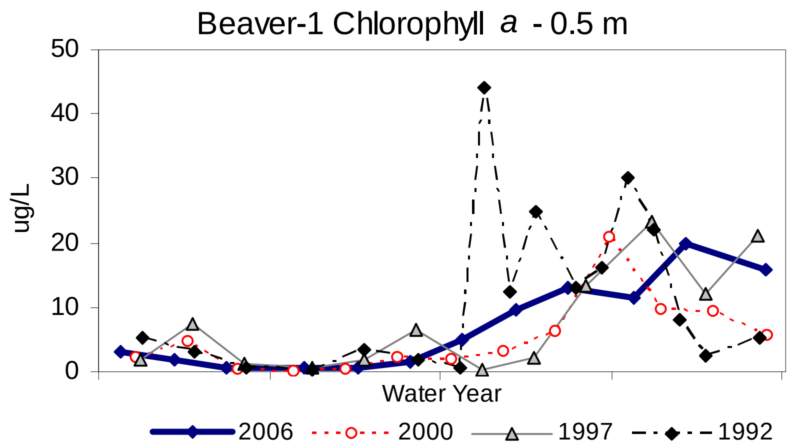
* <MDL = below analytical level of detection. For Nitrate-Nitrite, this equals 20 ug/L. For ammonia, this euqals 10 ug/L

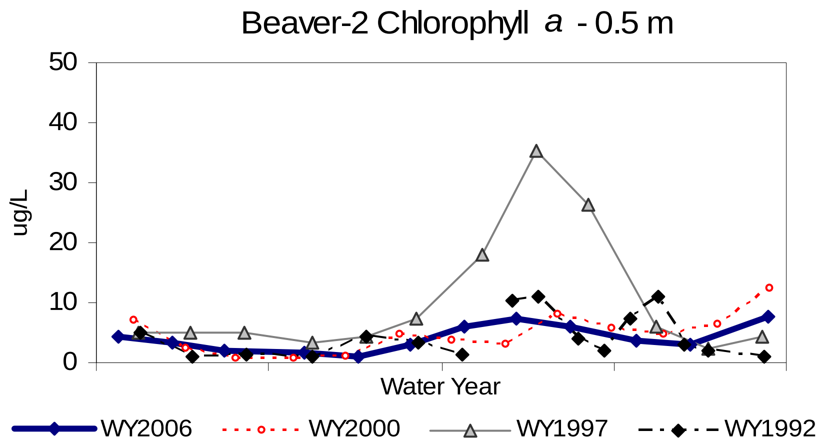
Chlorophyll a

Chlorophyll *a* is one of most common photosynthetic pigments found in algae. Measurement of this pigment is frequently used to characterize the volume of algae in freshwater, which is often linked directly to beneficial uses of a lake since abundant algae can decrease water clarity and create nuisance conditions.

For both lakes, very small amounts of chlorophyll are recorded in the surface waters during the winter, while varying amounts are found during the summer (Figure13). With the exception of 1997, Beaver-1 generally has more chlorophyll a in the summer, suggesting higher algae biovolume, which is consistent with its higher phosphorus content. On 1997, Beaver-2 experienced a persistent algae bloom through much of the summer, which contributed to a higher average chlorophyll content during that year.

Figure 13. Chlorophyll *a* annual record for four water years.



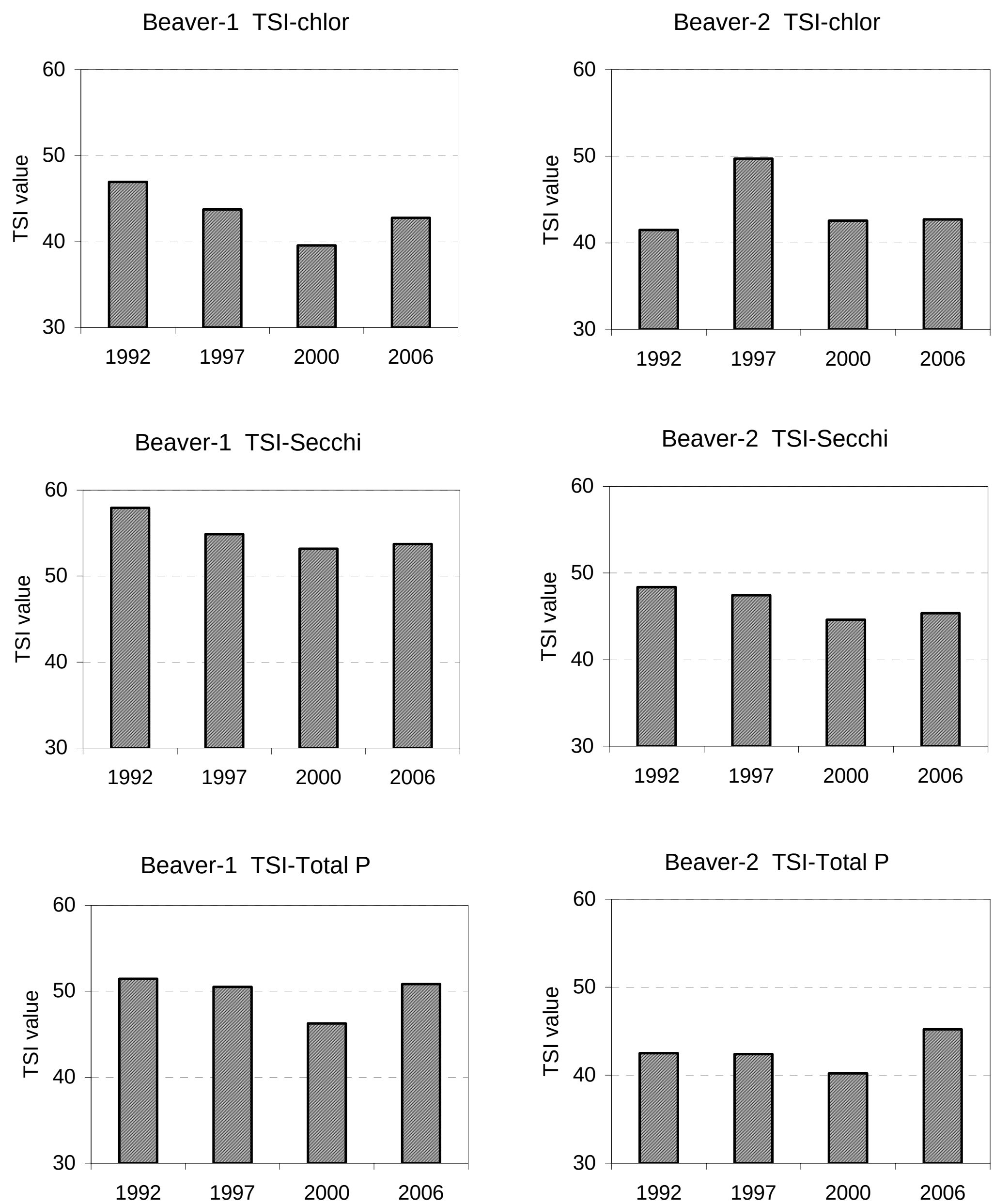


Trophic State Indices

The Carlson Trophic State Index (1977) calculates index values from data on Secchi depth, chlorophyll *a* concentrations, and total phosphorus concentrations to estimate a lake's level of phytoplankton production. These values are then classified into 3 defined levels of lake productivity: oligotrophic (or low productivity), mesotrophic (medium) and eutrophic (high). TSI values ranging between 40 and 50 are defined as mesotrophic or moderately good conditions, while values greater than 50 are indicative of eutrophic or fair conditions. TSI values are usually calculated for the period of May – October, which coincides with the growing season in the northern hemisphere. Since October is the beginning of the water year, for Beaver Lake, the average TSI values were calculated for the period May – September (Figure 14).

TSI values for chlorophyll show that for three out of the four water years, Beaver-1 is above the threshold for eutrophy, though one of those years is very close. In contrast, Beaver-2 rates somewhat lower. The 1997 summer season is above the eutrophic threshold, but the other 3 years are mesotrophic, although 2000 is just under that limit.

Figure 14. Average Trophic State Indices for both lake basins for the period of May – September for all four water years. TSI-chlor = chlorophyll. TSI-Secchi = Secchi transparency. TSI-TP = total phosphorus.



TSI values for Secchi transparency show a similar pattern of higher values derived for Beaver-1 than for Beaver-2. In the case of TSI calculations for Secchi, it must be remembered that water color can have a negative effect on water clarity, so the values for Beaver-1 undoubtedly reflect more water color as well as more algal production in comparison to Beaver-2. This is probably the reason why TSI-Secchi values for Beaver-1 rank higher than the TSI-chlorophyll values for the basin, while for Beaver-2, the TSI-Secchi values are actually lower than for TSI-chlorophyll.

TSI values based on total phosphorus are lower for both lakes than the values calculated based on the other two parameters. Water years 2000 and 2006 are lower than 1992 and 1997 in Beaver-1, with the later years being in the mid-range for mesotrophy. For Beaver-2, values have been within the mesotrophic range for the entire period, although there is an increase in 2006 from previous years. This is likely within normal variability, but needs to be tracked over time.

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 were measured mid-lake during water years 1992, 1997 and 2000 (Beaver Lake Management Plan Update 2000). All data were below the state threshold standard for primary contact (50 colony-forming units per 100 mls of water). The strategy for measurement was changed in 2006 to measure *E.coli*, which is a fecal coliform bacteria species that is directly harmful, and to add stations along the perimeter of the lake that might better reflect sources such as goose feces or failing septic systems, as well as report on conditions in the water where most people swim or do other recreational activities. Testing once a month from May through October for several years has shown that no sites in the lake have recurrent violations of the state standard (King County annual reports to Sammamish, 2005-2006). Several higher values from water samples taken near Beaver Lake Park may reflect pet waste from dogs playing along the shoreline or from congregations of Canada geese.

Phytoplankton

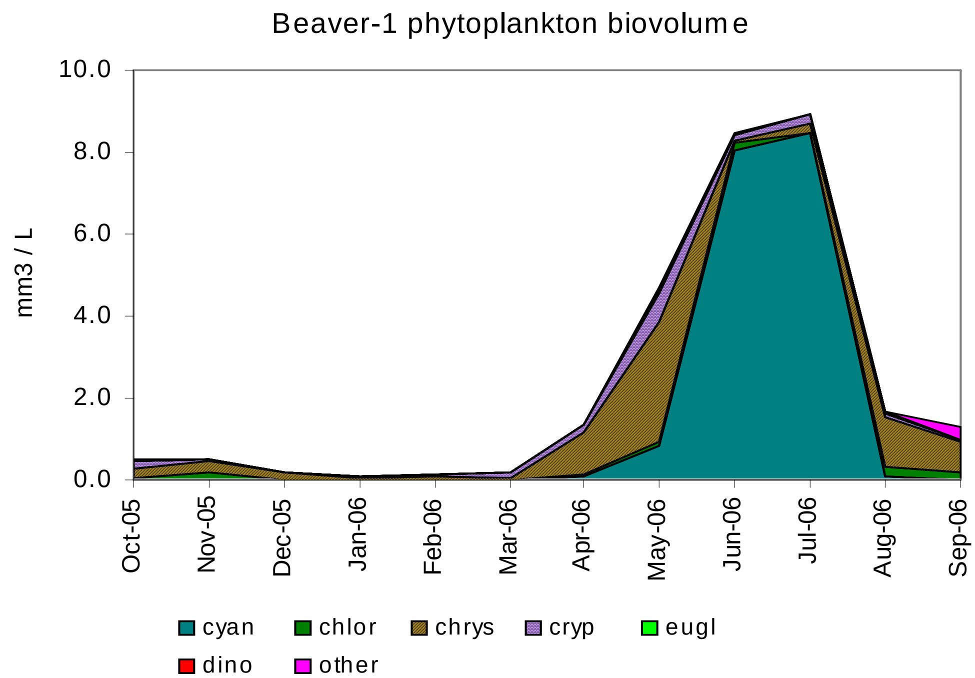
Freshwater phytoplankton include a variety of algae, bacteria and certain stages of some species of fungi and actinomycetes (Reynolds, 1984), but the algae are the most conspicuous and prominent group in the phytoplankton. These microscopic, photosynthetic plants form the basic foundation of food production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

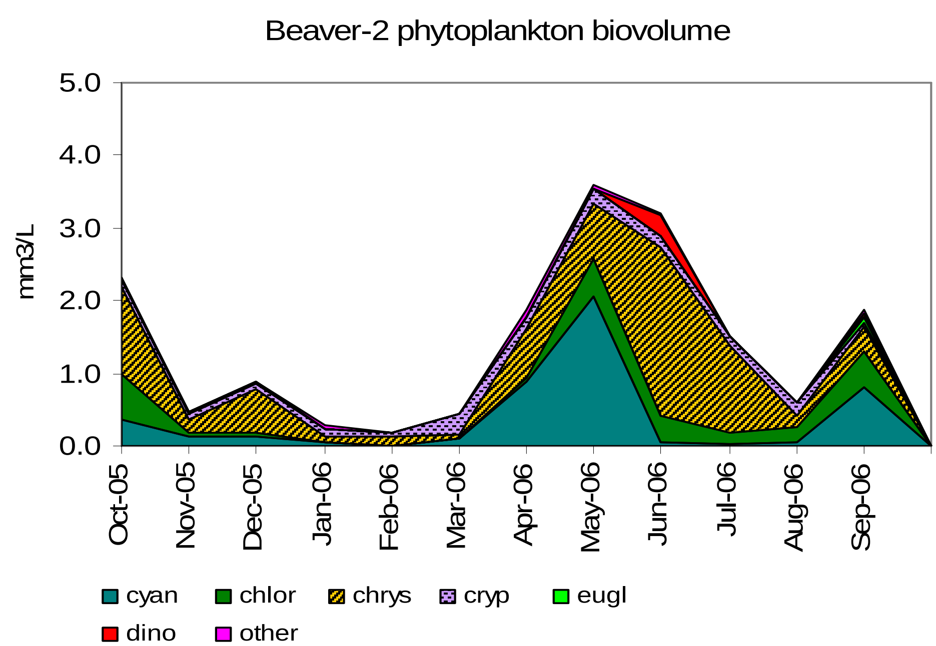
Major groups of algae commonly occurring in a lake are the blue-green bacteria (Cyanobacteria, sometimes also called bluegreen algae), the green algae (Chlorophyta), the golden brown algae (Chrysophyta, both diatoms and other species), the dinoflagellates (Pyrrhophyta), euglenoids (Euglenophyta), and 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 and other chemical factors, light, temperature, competition between species, sinking rates, and preferential invertebrate grazing. The algae in a lake can often be used as indicators of the overall nutrient status of the waterbody, as well as sometimes predicting the likelihood of nuisance algae blooms.

For Beaver-1 and Beaver-2 basins, phytoplankton trends were analyzed for the 2006 water year and compared with data collected for the *Beaver Lake Management Plan Update* (King County, 2000). This section describes recent trends found in phytoplankton biovolume 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.

Figure 15. Algal biovolume for 2006 water year, both basins

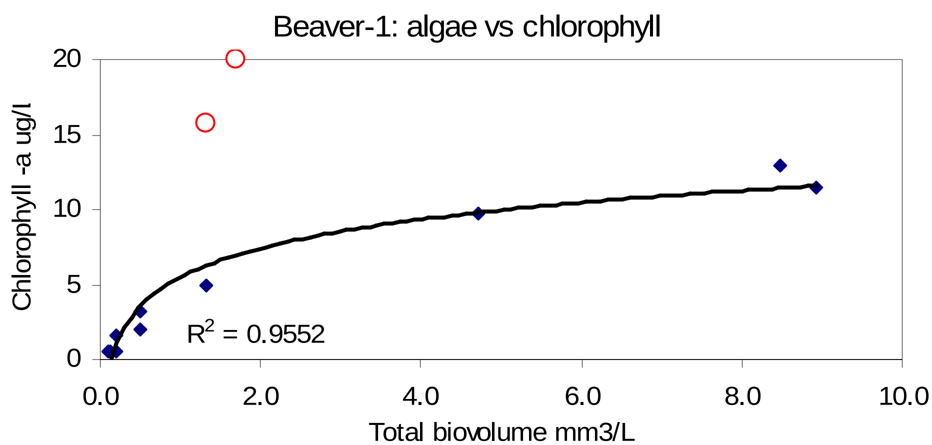


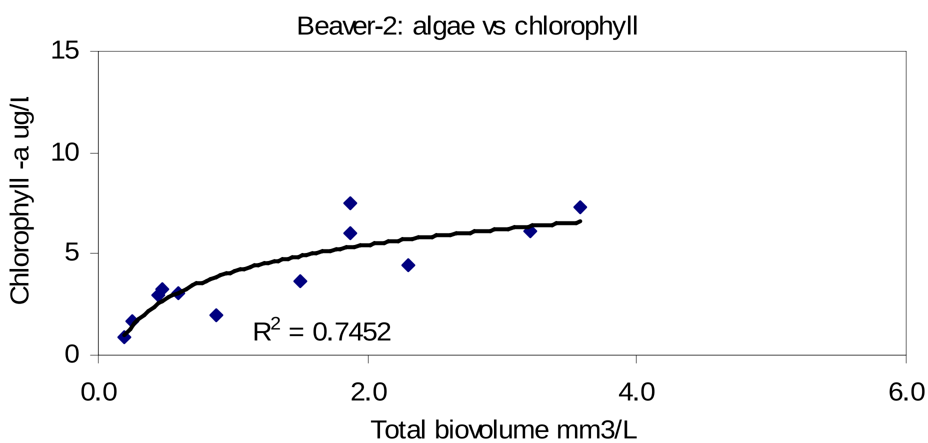


Biovolume Trends

Overall phytoplankton biovolume patterns, including timing and intensity of peaks, were distinctly different for each Beaver Lake basin during the 2006 water year (Figure 15). Note that the scale of the chart for Beaver-1 algal biovolume is twice that for Beaver-2. Beaver-1 algae peaked at a time when the algae in Beaver-2 were beginning to decline, although both dropped by the time the water year had ended. The phytoplankton in Beaver-2 rose again on the last date, suggesting a fall bloom may have begun. While both lakes had significant amounts of cyanobacteria, Beaver-2 supported large volumes of chrysophytes that replaced the cyanobacteria in midsummer, while the cyanobacteria replaced the reverse occurred in Beaver-1. Beaver-2 also had a distinct population of dinoflagellates in June, which was not found in Beaver-1.

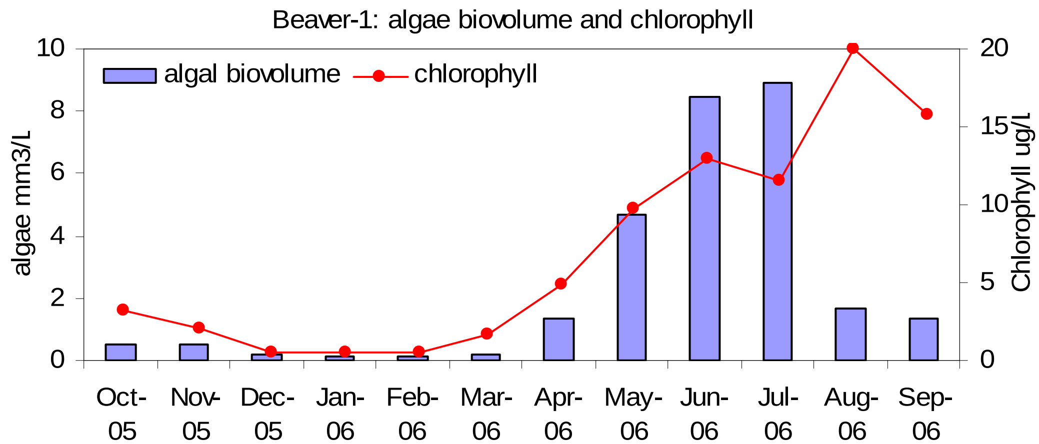
Figure 16a. Beaver Lake chlorophyll a versus algal cell volume for the 2006 water year.

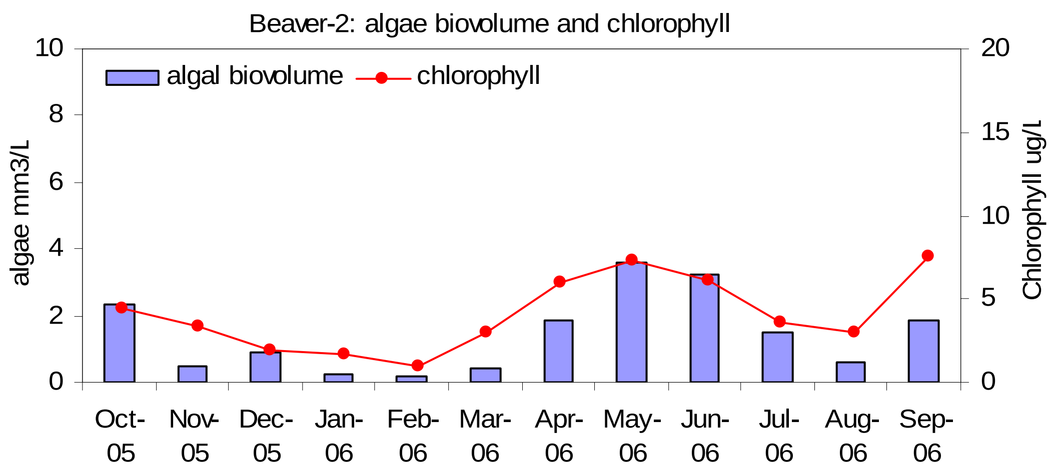




Both basins showed a high degree of correlation between algal biovolume and chlorophyll-*a* content during 2006 water year (Figure 16a). The calculated trend lines (solid lines derived from the points on each chart) have correlation coefficients (R^2) of 0.9552 and 0.7542, both of which show a high degree of connection between the variables. The coefficient for Beaver-1 was calculated without the last two data points of the water year, which are plotted as large red open circles. The disparity between the two parameters occurred when large, rare colonies of the chrysophyte *Dinobryon* were present that may have biased the values. A comparison through time of the chlorophyll and phytoplankton values are presented in Figure 16b.

Figure 16b. Beaver Lake chlorophyll versus algal biovolume for the 2006 water year.





Community Patterns

In Table 9, average algal cell volume (also known as biovolume) in each basin is estimated for the growing season (April through September) and the water year (October through September) for the four water years. Average algal cell volumes during the growing season for Beaver-1 are fairly close between all years, varying slightly from 1.5 to 2.1 mm^3/L. The growing season biovolume averages for the Beaver-2 algal community show a greater fluctuation between the four years, ranging from 0.6 to over 4.4 mm^3/L, with 1997 and 2006 having the highest values.

Algal biovolumes averaged over the entire water year show slightly different patterns, but are nearly always lower, with one exception, reflecting the lower biological activity in the lakes outside the growing season. In Beaver-1, the values are again approximately equivalent, except for 1997, when the large-bodied chlorophyte colony *Volvox* was found in enough numbers on several occasions to boost the annual average. In Beaver-2, 2006 again has the highest volume, followed by 1997. However, 1997 is closer to 2000 than the growing season average. Again, it appears as if the presence of *Volvox* may be skewing the values. Estimates of *Volvox* biovolume may be overly high, since the colonies are shaped like basketballs, with all the cells are arranged the outside of an empty sphere and the void may not have been subtracted from the volume calculation. *Volvox* has also been found in Beaver-1 in other years, during monitoring by citizen volunteers with the Lake Stewardship program.

Average chlorophyll *a* values also were computed for the growing season and annual water year for the four Beaver Lake water years (Table 9). These values generally correlate with cell volume means, with the exception of the Beaver-1 annual biovolume average for 1997, which may be reflecting *Volvox* presence. However, the high growing season biovolume in Beaver-2 is also found in the chlorophyll data, so the situation is not clear cut.

As with biovolume computations, chlorophyll *a* values for the growing season exceeded annual values for both basins, corresponding with higher biological activity during the growing season. Average chlorophyll *a* levels computed in Beaver-1 during the 2000 were lower than comparative values in 1992 and 1997, but it rebounded in 2006 to the 1997 level. Highest mean chlorophyll *a* levels (19.1 μg/L) occurred in Beaver-1 during the 1992 growing season and coincided with the occurrence of large numbers of the small euglenoid, *Eutreptia viridis*.

In Beaver-2, the highest chlorophyll average was 15.5 μg/L during the *Volvox* bloom in 1997, which appeared to carry over into the water year average, so that 1997 had also the highest annual average chlorophyll, although average biovolume was less than 2006.

Table 9: Comparison of growth season (April - September) and average water year phytoplankton biovolume and chlorophyll-a content.

Basin	April-September	Cell Volume (mm^3/L)	Chlorophyll *a* (µg/L)
Beaver-1	1992	2.10	19.1
	1997	2.02	12.0
	2000	1.49	8.1
	2006	2.10	12.5
	Water year		
	1992	1.67	10.8
	1997	3.00*	7.5
	2000	1.28	5.1
	2006	1.43	6.9

	April-September	Cell Volume	Chlorophyll *a*
Beaver-2	1992	0.63	5.4
	1997	3.30*	15.5
	2000	1.67	6.2
	2006	4.41	5.6
	Water year		
	1992	0.54	3.9
	1997	1.93	10.4
	2000	1.21	5.6
	2006	2.34	4.1

* 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, no single algal group continuously dominated average cell volumes in either basin from one monitoring period to the next (Table 10), although the chrysophytes (diatoms) and bluegreens were prominent in both basins each year. Relative dominance by the major algal groups varied not only within each basin between years, but also between the two basins over the four water years.

In Beaver-1 during the 1992 water year, euglenoids dominated total annual volumes followed by the chrysophytes, while in Beaver-2 bluegreens were dominant, followed by with the chrysophytes and cryptomonads.

The chlorophytes (green algae, mostly *Volvox* during part of the year) accounted for most of the annual cell volume in both Beaver-1 and Beaver-2 during 1997. In Beaver-1, the chrysophytes were secondary importance, followed by much smaller amounts of bluegreens and dinoflagellates. In contrast, the groups of secondary importance in Beaver-2 were the dinoflagellates and cyanophytes, with very few chrysophytes.

During the 2000 water year, blue-greens comprised the largest portion of total annual biovolume in Beaver-1 with chlorophytes next in importance, followed by the chrysophytes. In Beaver-2, the chrysophytes made up the greatest percentage of total volumes, followed by approximately equivalent amounts of chlorophyte and bluegreen groups.

In 2006, the chrysophytes dominated in Beaver-1, similar to 1992, with similar amounts of bluegreens and cryptomonads of secondary importance. In Beaver-2, the pattern was fairly similar to Beaver-1 with the same groups in primary and secondary positions of importance.

Table 10: Percentage of annual biomass by major algal groups by water year.

Basin	Algal Group	1992	1997	2000	2006
Beaver-1	Blue-greens	13	9	43	18
	Chlorophytes	3	62*	29	9
	Chrysophytes	36	19	17	48
	Cryptomonads	5	1	3	19
	Dinoflagellates	2	8	8	<1
	Euglenoids	41	0	<1	<1
	Unidentified				4
Beaver-2	Blue-greens	32	25	16	22
	Chlorophytes	8	38*	20	13
	Chrysophytes	23	8	58	42
	Cryptomonads	23	3	5	19
	Dinoflagellates	9	26	1	1
	Euglenoids	5	0	<1	1
	Unidentified				3

* 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 were summarized for both basins, as well as by each basin (Table 11). Based on cell density data, blue-greens dominated the phytoplankton community in both lake basins during the growing season (see report in Appendix C). The filamentous form, *Aphanizomenon flos-aquae*, has been the principal blue-green bacteria species represented in epilimnetic samples collected in both Beaver Lake basins during the growing season.

Data from the four 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.

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-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 the other water years (Table 11, both lakes) is interesting given the naturally high amount of organic matter associated with wetland inflows to the lake which might have supported the dominance of this species in 1992. There are clearly more factors coming into play in the phytoplankton community.

Table 11. Major recurring phytoplankton patterns over three water years.

Lake/Patterns	1992	1997	2000	2006
Both Lakes				
Blue-greens cell density dominate Apr.-Sep.	X	X	X	X
Aphanizomenon primary blue-green	X	X	X	X
Euglenoids biovolume dominant Sep.-Apr.	X	-	-	-
beaver-1				
Aphanizomenon present only during growing season	X	X	X	X
Blue-green cell volume dominant May-July	X	X	X	June-July
Cell volume/density peaks in June or July	X	X	X	X
Blue-greens absent from winter samples	X	X	X	X
Yellow-brown cell volume dominant fall	X	X	X	X
Beaver-2				
Blue-greens present throughout year	X	X	X	X
Blue-green cell density peaks in April	X	X	X	May
Golden cell volume/density dominant briefly in fall	X	X	X	June

Aphanizomenon was present in Beaver-1 only during the growing season, with bluegreens generally rare or absent during the nongrowth period (October – March). Cell biovolume peaked in June or July of each year and declined after that. Another regular feature of the phytoplankton community was domination of biovolumes by non-diatom chrysophytes, mainly *Dinobryon* and *Mallomonas* spp., during the late summer/early fall period.

In Beaver-2, the bluegreen group (dominated by *Aphanizomenon flos-aquae*) made substantial contributions to phytoplankton community throughout most of the year, unlike the group's more time-limited presence Beaver-1. Results from 1997 and 2000 water years reveal occurrence of an early growing season density peak in April varying in magnitude, but this was delayed until May in 2006. In 1992, 1997, and 2000, the non-diatom chrysophyte group (represented primarily by *Dinobryon* spp.) typically dominated Beaver-2 biovolume measures for a short time during the fall season. In 2006, this occurred in June.

Zooplankton

The zooplankton are microscopic aquatic animals adapted to living a planktonic existence in the water, similar to the algae. 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 both filter-feeding calanoids and raptorial cyclopoids. The insect family Chaoboridae (Phylum Arthropoda, Subphylum Uniramia) is also 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 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 for planktivorous fish. Copepods also can be significant primary and secondary consumers, as well as a food source for higher invertebrate and fish predators.

The rotifers also play an important role in the aquatic food web as a food source for aquatic invertebrates, which in turn are consumed by invertebrate predators and planktivorous fish. Rotifers may be also consumed directly by many adult planktivorous fish and can be a highly nutritious dietary component of certain larval fish. It is clear that the zooplankton provide an important link between the primary producers (algae) and higher order consumers (larger invertebrates and fish) in aquatic systems.

The occurrence of certain groups or species of zooplankton, called indicator organisms, can be a signal of either the existence of detrimental water quality conditions or the presence of high quality conditions relative to human beneficial uses.

For both basins, zooplankton trends were analyzed for the 1997, 2000, and 2006 water years and compared with data collected for the *Beaver Lake Management Plan* (King County, 1993a). This section describes recent results in zooplankton biomass and summarizes community information for both lake basins. A complete analysis of zooplankton data for 2006 is reported in Appendix C.

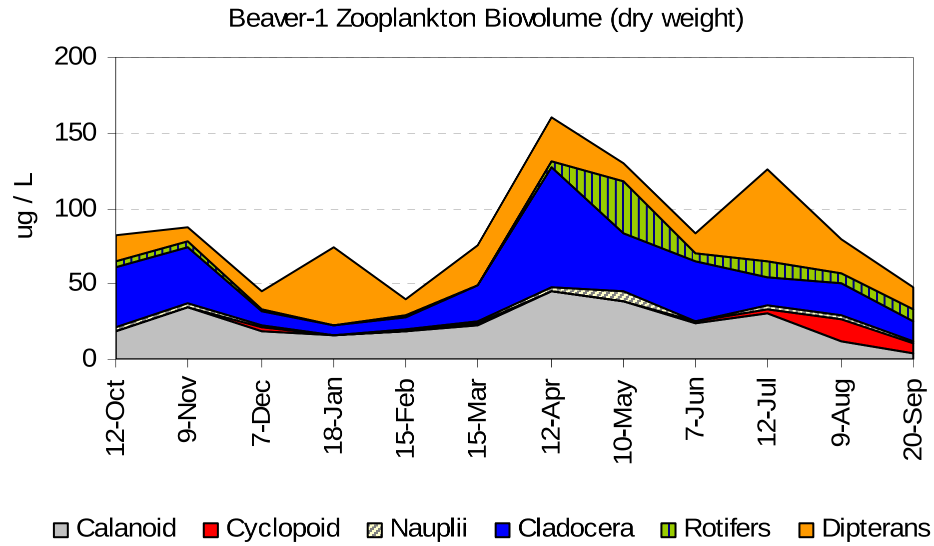
Biomass Trends

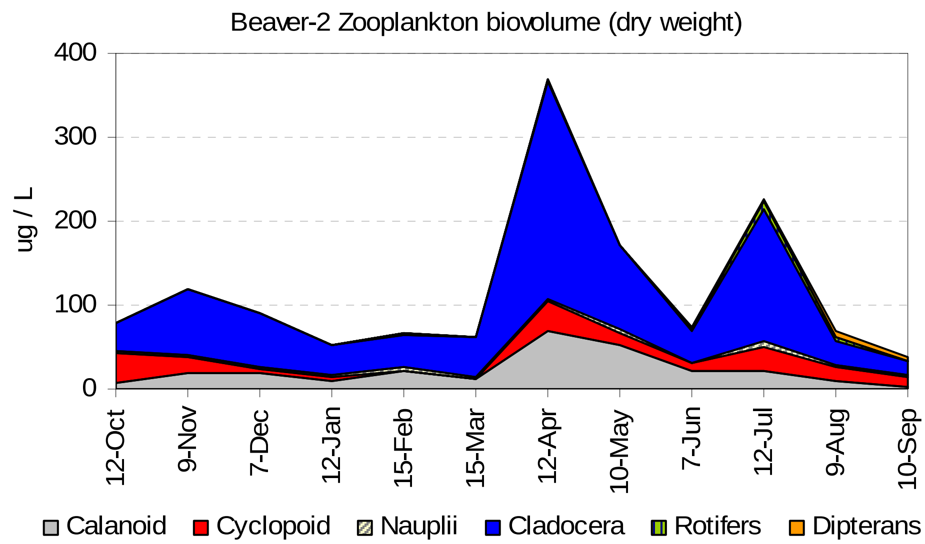
Zooplankton sample biomass patterns differed somewhat between the two Beaver Lake basins during the 2006 water year (Figure 17). These differences were largely the result of variations in the relative biomass contributions by predacious cyclopoid copepods and dipteran larvae, as well as the filter-feeding rotifers, cladocerans, and calanoid copepods throughout the water year. The early stages (nauplii) of all the copepods were numerous on occasion, but never contributed substantially to biomass.

Substantial contributions to dry weight mass by the rotifer, calanoid, and dipteran groups occurred in Beaver-1 over the course of the water year, while the cyclopoids contributed very little biomass to the zooplankton community. Biomass peaked in April and May, fueled by the Cladocera. Two smaller peaks in January and July were due to dipteran larvae. Rotifers were significant through summer, starting in May. They are such small animals that it takes many individuals to make a moderate biomass contribution.

The cladocerans were the most significant contributors to zooplankton biomass in Beaver-2, and the peaks in April and July were due to their presence. Although the cyclopoid copepods were present in larger amounts than in Beaver-1, neither they nor the rotifers contributed much to community totals.

Figure 17. Zooplankton dry weight biomass for the 2006 water year.





In general, zooplankton biomass in Beaver-1 is about half of what it is in Beaver-2, which has a significant impact on the phytoplankton communities and may account for some of the differences seen between the two lakes.

Community Patterns

Average zooplankton density and biomass values are compared between both Beaver Lake basins (Table 12). For all four water years, the zooplankton community in Beaver-2 exhibited higher yearly average densities than did the Beaver-1 community.

In 2006, average arthropod densities within both basins were lower than in 1997 or 2000, but were higher than in 1992. In contrast, the numbers of rotifers were substantially higher than in 2000, particularly in Beaver-1. Data were not available for 1992 or 1996

Table 12. Comparison of zooplankton mean density and biomass for four water years.

Beaver-1	**1992**	**1997**	**2000**	**2006**
Mean Density Arthropods/L	11	49	40	18
Mean Density Rotifers/L			34	82
Biomass (µg/L, dry weight)		39	35	86

Beaver-2				
Mean Density Arthropods/L	13	58	40	27
Mean Density Rotifers/L			33	51
Biomass (µg/L, dry weight)		44	39	119

Note: Zooplankton biomass estimates were not conducted in 1991-1992.

Mean annual biomass measures were substantially higher in 2006 than in either1997 and 2000. Average dry weight biomass for Beaver-2 was also significantly higher than for Beaver-1 in 2006. Biomass was not estimated for the 1992 samples. The amount of increase in zooplankton biomass in 2006 is very interesting and appears to be driven by the weight of large-bodied cladocerans, even though the total arthropods declined between 2000 and 2006. Rotifers are very small and do not generally contribute a great deal of dry weight biomass to the community biomass totals. The relative contributions of the major zooplankton were calculated to study biomass relationships (Table 13).

For all years, the filter-feeding cladoceran and calanoid copepods combined to form the largest percentages of total dry weight biomass estimates in the both basins, while the predacious dipteran larvae were also important, especially in Beaver-1.

Differences between the two basins for both years were seen mostly in the relative importance of the cladocerans and the dipterans. Dipterans had a major presence in terms of biomass in Beaver-1 in all three years, constituting about a third of the community biomass. Cladocerans were approximately equal with calanoids in biomass contributions, with cyclopoids, rotifers and copepod nauplii all making minor contributions.

Cladocera were increasingly dominant in Beaver-2 through time, while the dipterans were at all not important in 2006. Calanoid copepods were distinctly less in biomass. Cyclopoid copepods were present in small amounts in all three years, but the percentage jumped 6-fold in 2006. Rotifers and copepod nauplii contributed approximately the same as in Beaver-1.

Table 13: Percentage of total annual biomass by major zooplankton group for three water years.

Basin	Zooplankton Group	1997	2000	2006
Beaver-1	Cladocerans	31	23	33
	Calanoid copepods	23	36	27
	Cyclopoid copepods	<1	1	3
	Copepod nauplii	2	2	2
	Rotifers	5	8	8
	Dipteran larvae	38	30	27
Beaver-2	Cladocerans	43	53	63
	Calanoid copepods	26	22	18
	Cyclopoid copepods	3	2	13
	Copepod nauplii	5	2	2
	Rotifers	6	4	2
	Dipteran larvae	17	17	1

Note: 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, probably due to smaller numbers of larger-bodied crustacean zooplankton (daphnids, calanoid copepods) and higher densities of small-bodied plankters (rotifers, and to a lesser extent, copepod immatures and small non-daphnid cladocerans) in the Beaver Lake zooplankton community (Table 14).

Smaller zooplankters do well under environmental conditions that may be less optimal for survival of larger crustaceans, such as: low dissolved oxygen, high water temperatures, low pH, cyanobacteria dominance of phytoplankton, and increased presence of potential predators (e.g., dipteran larvae). In fact, summer depressions in *Daphnia* populations during conditions of reduced water quality and increased potential predation (spring time trout introduction and increasing invertebrate predator populations) has been documented in both Beaver-1 and Beaver-2 basins in all four water years. These factors, as well as presence of additional minute food sources, including bacteria, organic and detrital matter associated with cyanobacterial blooms and/or with wetland and surface drainage, may be giving a competitive advantage to the rotifer group for much of the year in the Beaver Lake system, particularly in Beaver-1.

Table 14. Major recurring zooplankton patterns in four water years.

Basins	Patterns	1992	1997	2000	2006
Both	Rotifer dominance by numbers of organisms throughout year	X	X	X	X
	Crustacean and dipteran groups dominate annual biomass		X	X	X
	Summer decline in *Daphnia* spp. populations	X	X	X	X
	Biomass patterns are different from density patterns		X	X	X
	Presence of eutrophic indicator organisms (*Trichocerca cylindrica*, *T. pusilla*, and *Pompholyx sulcata*)	X	X	X	X
Beaver-1	Dipterans significant contributor to annual biomass		X	X	X
	Higher annual average rotifer numbers than Big Beaver		X	X	X
Beaver-2	Higher annual average numbers of arthropods than Little Beaver	X	X	X	X
	Cladocerans highest contributor to annual biomass		X	X	X

Indicator Species

In all four water years, several rotifer species occurred in the Beaver Lake zooplankton community that is 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 King County Lake Stewardship Program Level II monitoring data is gathered annually from may though October and can be used to compare information for those years that were not assessed by LMD activities. Some of these data can be used to characterize the lake's trophic status, similar to what was discussed earlier in this chapter (Table 12).

Table 15. Beaver Lake 1 and 2 summer (May-October) trophic state index (TSI) summary.

Year	Depth	No. of Samples	Secchi (m)	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	23	60	58	49	56
1997	1	12	1.4	16	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
2001	1	13	1.3	10.6	20	56	47	48	47
2002	1	14	1.8	6.1	18	52	48	46	47
2003	1	12	0.9	10.2	22	57	52	48	50
2004	1	14	1.1	7.8	20	58	50	47	48
2005	1	12	0.9	8.5	31	62	49	51	50
2006	1	11	0.9	13.6	24	58	54	49	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
2001	1	13	2.9	5.4	16	45	46	43	45
2002	1	14	2.4	6.2	13	47	47	40	45
2003	1	12	2.4	4.1	11	46	44	39	43
2004	1	14	2.7	4.2	14	46	44	41	43
2005	1	12	2.4	5.3	13	48	46	40	45
2006	1	11	2.9	4.7	12	46	45	40	43

* Chl *a*-chlorophyll *a* and TP-total phosphorus
** Data from 1991-92 management plan.
*** Samples were composites of water taken at 1 meter and at the Secchi depth.

To recap, trophic state indices (TSI) can be calculated using Robert Carlson's (1977) regressions relating several commonly measured lake parameters to phytoplankton biovolume. Parameters used include Secchi depth, total phosphorus, and chlorophyll *a*. By calculating TSI values, lake data is transformed to a common scale and comparisons can be made between parameter predictions and relationships over time. Carlson suggested that index values between 40 and 50 indicated mesotrophic (moderately productive) or good water quality conditions while values greater than 50 indicated eutrophic (highly productive) or fair water quality conditions. For the Beaver-1 and Beaver-2 basins, results including the Lake Stewardship data for TSI are discussed in this section.

Beaver-1

The Beaver-1 basin was not included in the original 1985 small lakes volunteer monitoring program (METRO, 1986), so there are fewer consecutive years for trend analysis (Table 15). Average TSI values for 1997 through 2006 are compared with past data collected for the 1993 *Beaver Lake Management Plan* (1992 water year). The 2006 TSI values have varied a little since 1998, but are lower than 1992 and 1997. The dark color of the water contributes to higher TSI numbers for Secchi transparency. The volunteer lake data is consistent with the LMD collected data and indicates that Beaver-1 water quality has been stable over the past decade.

Beaver-2

For the Beaver-2 basin, a long term data record from 1985 through 2006 (minus 1990) is available (Table 15). Between 1985 and 1989, the TSI ratings for Beaver Lake 2 scored in the mid-range for mesotrophic lakes. Notably, the TSI-Secchi is not greatly different from either the TSI-chlorophyll or TSI-phosphorus, and this is likely the effect of lower amounts of color-producing molecules in the water in the Beaver-2. Between 1991 and 1998, the trophic status value ranged in the high end of mesotrophic, nearly reaching the eutrophic threshold in 1997 and 1998. Since then it has dropped and remained steady in the lower range for mesotrophy.

As noted in previous reports (King County Annual Lake Stewardship Volunteer Monitoring Reports, 1995 – 2004 and website data reporting), Beaver-2 has shifted from the lower end of the mesotrophic range to the middle of the range and then back down again. While there was variability in the shifts in all the parameters, TSI-Secchi has never returned to the lowest values found in the late 1980s, while TSI-phosphorus is at its lowest values since 1997.

Stream Monitoring

Both base flow and storm flow were characterized for the two main tributaries that drain to Beaver Lake. Baseflow is the relatively constant flow found in streams during the wet season and is due to the steady draining of water through the shallow soils of a watershed, entering an organized stream system at a relatively constant rate through the year. Stormflow is the streamflow that occurs due to storm water runoff into the stream system over and above the base flow volume and is generally characterized by quick transit times and less contact with shallow soils. In this section, flow, baseflow quality, and stormwater quality monitoring results are summarized for the two tributaries to Beaver Lake that were measured.

Annual Discharge

Beaver Lake has two main inflows (BLTRI1 and BLTRI2) and a single outlet (BLOUT). Generally, the direct surface flow (BLTRI1) entering Beaver-1 is about half of the flow

(BLTRI2) that enters the larger Beaver-2 basin, although there are some notable exceptions, such as in 2001 and 2002 (Table 16).

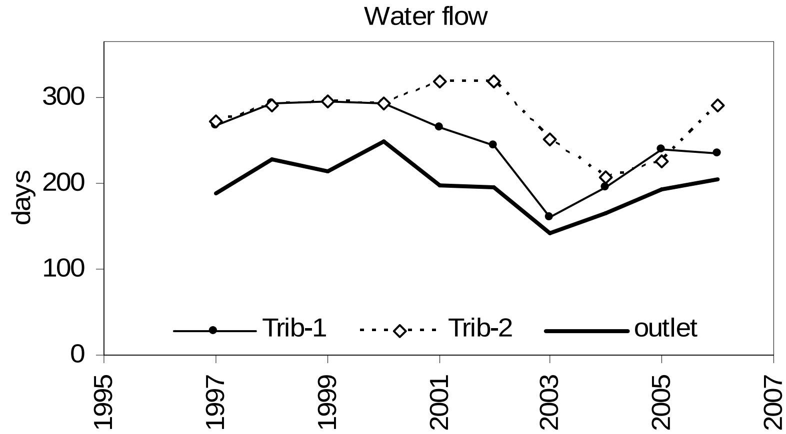
Table 16. Mean annual daily discharge and number of days of flow for inlets and outlet in cubic feet per second (cfs).

Water Year	BLTRI1 flow days	BLTRI1 cfs	BLTRI2 flow days	BLTRI2 cfs	BLOUT flow days	BLOUT cfs
1997	268	0.7	271	1.3	188	2.5
1998	294	0.4	291	0.6	228	1.3
1999	296	0.5	295	1.1	215	2.5
2000	293	0.5	293	1.0	248	1.9
2001	264	0.2	318	0.4	197	0.7
2002	244	0.6	318	0.4	196	2.3
2003	161	0.2	252	1.4	141	1.3
2004	196	0.4	208	0.9	165	1.4
2005	240	0.2	225	0.8	194	0.6
2006	235	0.5	291	0.9	204	1.6

During this 10-year monitoring period, outflow from the lake ranged from 60% to more than 200% of the combined stream inputs reflecting major differences in the impacts that the timing and amount of precipitation had on the lake, as well as groundwater inputs and changes in storage capacity that may have occurred with beaver activity or damming of the outlet by debris accumulation. This made calculating the hydrologic budget challenging, as well as balancing the nutrient budget, which will be discussed later.

The number of days of flow recorded at the two inlets and the outlet were compared (Figure 18), and it is clear that the fairly steady relationship between measurable flows for 1997 – 2000 changed in subsequent years. The outlet always flowed for a shorter period than the inflows, which is reasonable since the lake can be below the threshold for long periods in the late summer. However, for four of the six years after water year 2000, BLTRI1 flowed for substantially fewer days than BLTRI2, possibly changing the hydrological relationships between the two basins. It is difficult to say whether the differences in flow rates between BLTRI1 and BLTRI2 are due to structural problems with the weir above the measuring station of BLTRI1 that might lead to erroneous flow measurements, or if these data represent a change over time in the character of the inflows to the different basins.

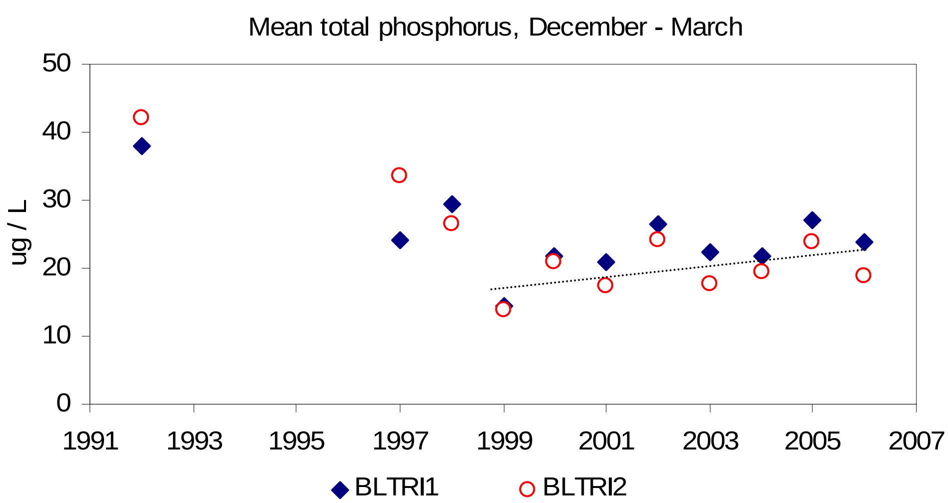
Figure 18. Number of days of measurable flow for the inlets and outlet of Beaver Lake.



Baseflow

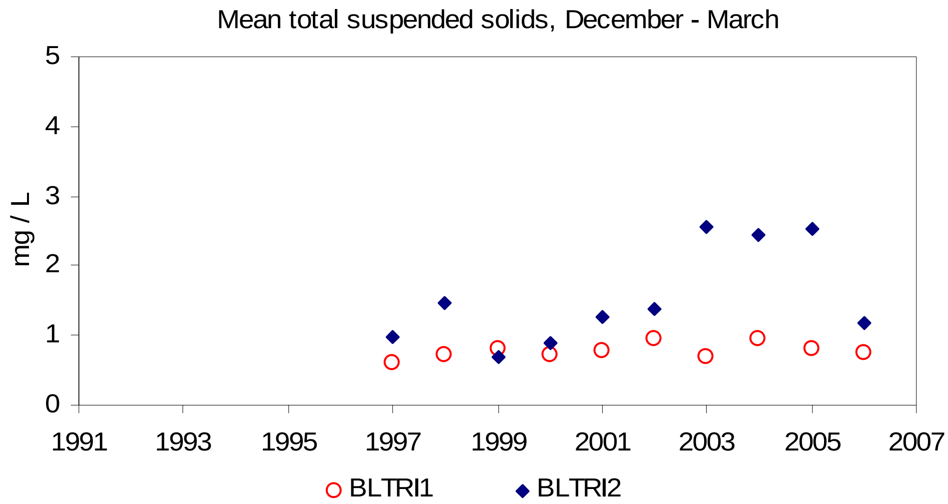
Baseflow water quality was measured for a variety of parameters, including total phosphorus, total suspended solids, and turbidity (Fig 19a-c). Overall, values for these three parameters continue to remain low or are similar (or lower) to values recorded in 1992. Values were averaged for the period of December through March of each water year, since the chemical constituents of the intermittent and low flows at the beginning and end of the wet season can skew water quality averages, not reliably reflecting the character of most the of water entering the lake basins.

Figure 19a. Baseflow total phosphorus comparison.



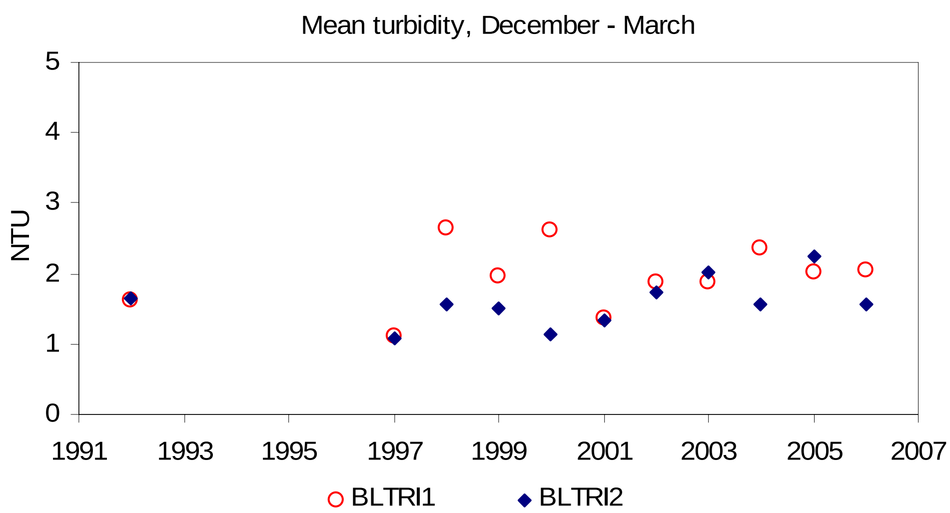
The data suggest that phosphorus inputs from baseflow have decreased considerably since 1992 and 1996-7, but have either remained steady or perhaps have risen slightly since 1999.

Figure 19b. Baseflow total suspended solids comparison.



In contrast, totals suspended solids in BLTRI2 were elevated in 2003 – 2005 when comparing to other years, which were approximately equivalent. With the exception of data from 2000, total suspended solids in BLTRI1 were essentially stable over the period of record. No tests were made for suspended solids in 1992.

Figure 19c. Baseflow turbidity comparison.



Turbidity measurements in the two inlet streams appear to be variable within a relatively small range over time, and there are no trends or notable exceptions to point out. From 1998 – 2000 BLTRI1 was cloudier than BLTRI2, but since then they have either been approximately the same or have traded positions.

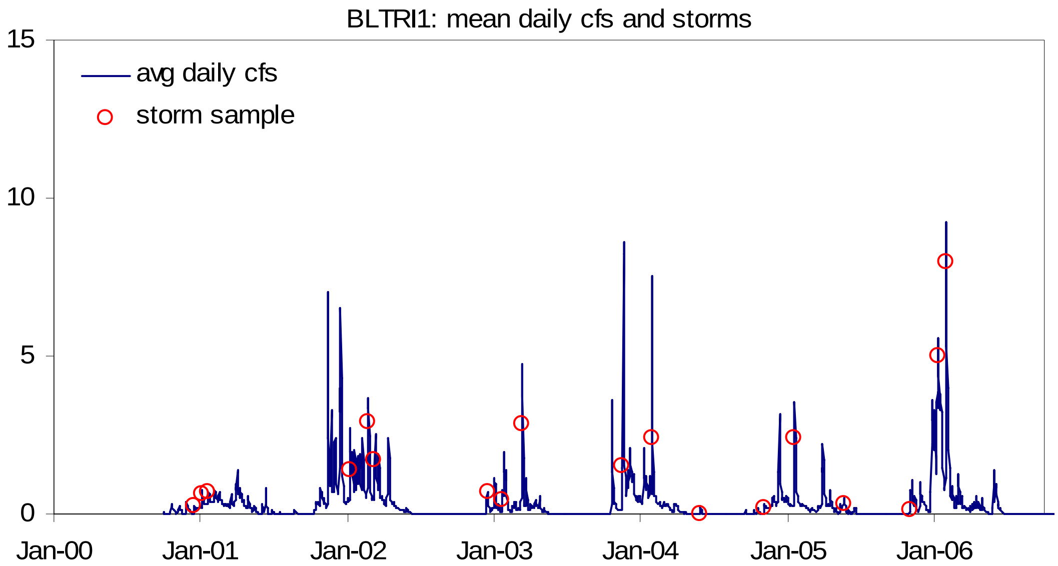
Stormwater

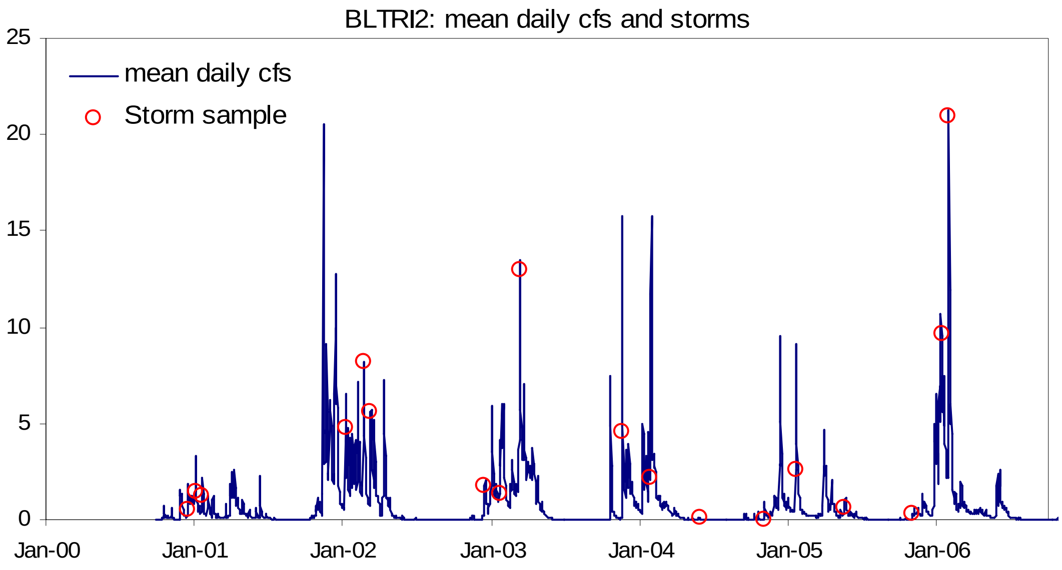
For stormwater samples, average values for total phosphorus, total suspended solids, and turbidity are provided in Table 18. Although the sample sizes are small, the samples appear fairly representative of high flow events for Beaver Lake (Figure 20).

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.

The goal of the storm water monitoring program was to capture data for four storms a year, although getting to that number was dependent on many different criteria being met. Figure 16 depicts the dates of storm sampling between 2001 and 2006, with the sample dates superimposed on the average daily flow. It is important to recall that the rising arm of a storm event generally brings the most material into the lake, so that sampling at the highest flow may not actually be sampling the time when the most total phosphorus was entering the basin.

Figure 20. Average daily flows and storm sample dates.

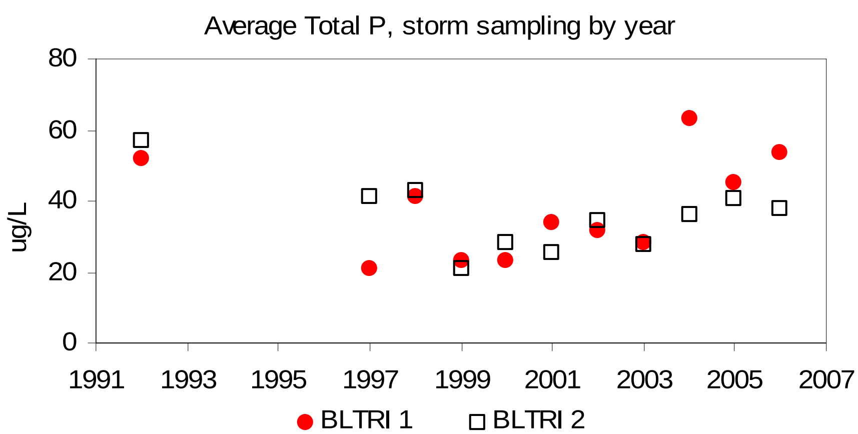




Note that 2001 was a very low flow year for both tributaries, while 2003 and 2005 were relatively lower for BLTRI1 than for BLTRI2. Early storms in 2005 and 2006 were measured in an attempt to characterize the "first flush" storm of the season, when relatively more sediment and nutrients may be washed into the lake after the long period of dry summer and fall weather.

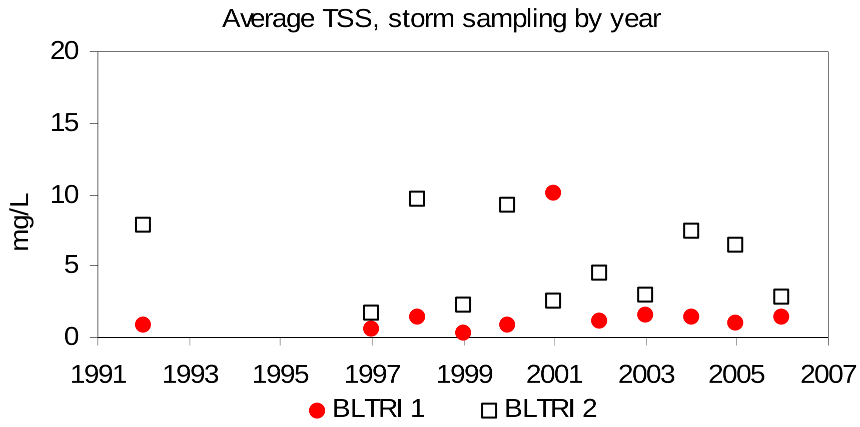
In general, the same parameters were measured for storm samples as for base flow samples (Figures 21a-c).

Figure 21a. Storm sample phosphorus concentration comparison.



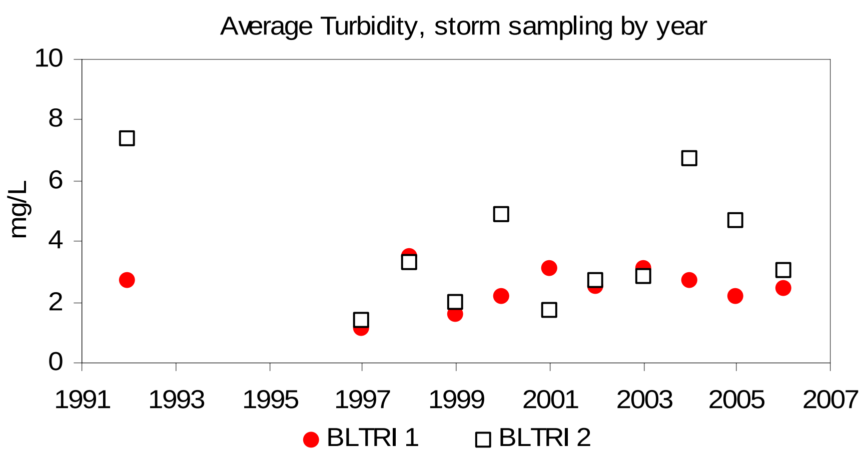
The averages suggest that phosphorus concentrations from storm flows decreased between 1992 and 1997-99, but have been increasing slowly since then. However, these data are merely snapshots, since only 2-4 storms were sampled each year and each storm measurement was a composite of 2 grab samples taken during the storm.

Figure 21b. Storm flow total suspended solids comparison.



By contrast, totals suspended solids have shown no consistent trend, although they appear to vary from year to year within boundaries. BLTRI1 were essentially stable over the period of record, with the exception of 2001, which was affected by one very high value in January of that year. BLTRI2 was highly variable between years.

Figure 21c. Storm flow turbidity comparison between years.



Turbidity measurements during storms in the two inlet streams also appear to be variable over time, and there are no trends observed over time in storm water turbidity. BLTRI2 appears to be cloudier than BLTRI1 during some years, which is reasonable given that it drains more area with development than BLTRI1, but during many years, they are quite similar.

Precipitation and Phosphorus Loading

Annual precipitation totals have varied significantly over the time in which stream data was collected, as have the gages used to record totals (Table 17). While the values vary between stations each year, there is a general consistency between the stations for every year that makes it possible to determine whether it was a relatively wet or dry year. Individual station measurements have ranged from a minimum of 28 inches recorded at both Mystic Lake stations in 2001 to a maximum of 70 inches recorded in 1997 at the Black Nugget station (46U). The longest continuous record of measured rainfall for the local area has been collected by the Lake Stewardship Program Level 1 monitor.

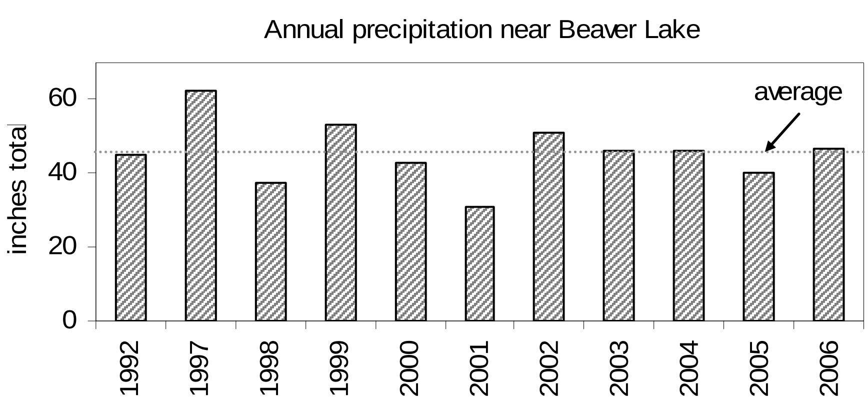
Table 17. Rainfall and inflow phosphorus loading estimates.

Water Year	Rainfall 46U* (inches)	Rainfall MLU* (inches)	Rainfall 18Y* (inches)	Rainfall Level I (inches)	Stream BLTRI1 (Kg P/year)	Stream BLTRI2 (Kg P/year)
1992	45	na**		na**	**8.2**	**13**
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**
2001		28	28	36	**4.6**	**5.3**
2002		47	47	59	**20.8**	**34.1**
2003			34	58	**4.5**	**16.4**
2004			42	51	**12.4**	**18.6**
2005			38	43	**8.3**	**14.3**
2006			43	50	**13.8**	**22.4**

* Note: 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), Mystic Lake East (18Y), and the Beaver Lake2-Level I gage sites are also shown to allow comparison of annual rainfall levels.
** na-not available

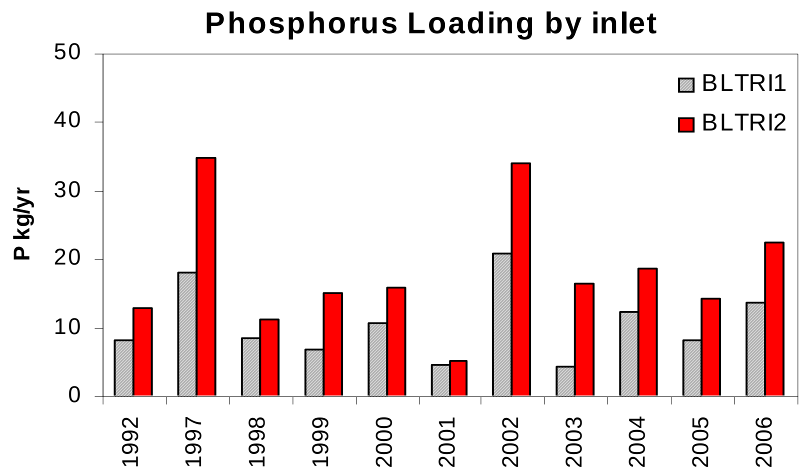
Although the precipitation totals are different between the three gauges (Table 17), the general pattern between water years can be determined (Figure 22). Both water years 1998 and 2001 were relatively dry years, while 1997 received the most recorded precipitation. The average over the whole period is 45.6 inches per year.

Figure 22. Total annual precipitation near Beaver Lake based on mean values from reporting stations.



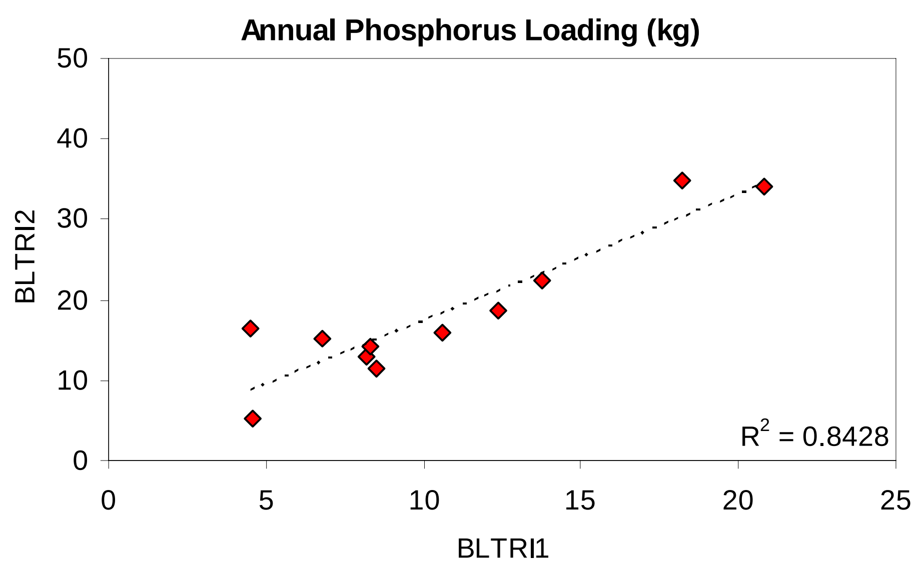
One way to estimate phosphorus loading to the lake basins from inlet flow is to calculate an estimated phosphorus concentration for each day using the measured baseflow and storm values and interpolating between the dates, then applying this value to flow measurements and summing up over the water year to get the total amount of phosphorus delivered to the basins from each inlet (Table 17 and Figure 23).

Figure 23. Estimated phosphorus delivery to Beaver Lake basins via inlet streams.



Using this method, it is clear that more phosphorus comes from BLTRI2 than BLTRI1, which is not surprising since BLTRI1 drains a much smaller area that is largely covered by a highly rated wetland bog. Although there are variations from year to year, the low years of 1998 and 2001 were characterized by smaller phosphorus inputs. It must be kept in mind that the timing of the rain events are also extremely important, and this snapshot method of phosphorus measurements for the streams can miss some big events. However, the relationship between phosphorus inputs from BLTRI1 and BLTRI2 is remarkable, given all the variables that can affect the two different streams and the nutrients they deliver to the lake basins (Figure 24).

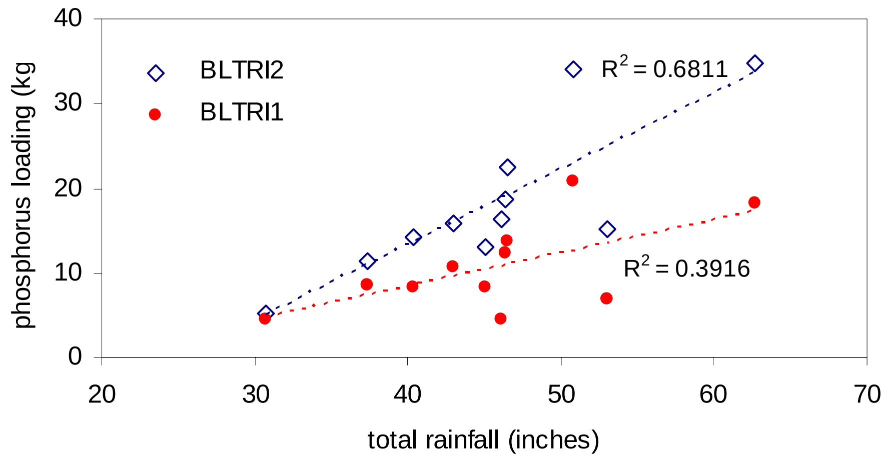
Figure 24. Phosphorus loading via BLTRI1 compared to BLTRI2.



A regression line drawn through the plot of the points relating the two estimates for each year has a correlation coefficient of 0.8428, which is highly significant and shows that the phosphorus delivery by the two streams each year has a very regular relationship. This suggests that to date, any impacts due to development in the watershed have not differentially affected one sub-basin of the watershed more than the other. The point that falls furthest from the line is 2003, which can also be seen in Table 17 and Figure 23. The phosphorus delivery from BLTRI2 is higher than expected based on delivery from BLTRI1.

It is also possible to compare phosphorus delivery with rainfall to see if the two inlets show different patterns (Figure 25). It is clear that the two streams respond at different rates to increases in rainfall, as would be expected from the sizes of their respective catchments and the type of land use in each one. However, the correlation coefficient for the regression between BLTRI2 and rainfall is more supportive of the relationship (a higher r^2 number) than the correlation for BLTRI1, suggesting that additional factors other than rainfall may be important in determining the phosphorus loading from BLTRI1. Since a large bog occupies much of the watershed for BLTRI1, there may be lags present in water delivery or nutrient movement because of the large amount of sphagnum present in the system or potentially other biological relationships within the bog may also affect the delivery of phosphorus relative to total precipitation amounts.

Figure 25. Phosphorus Loading from BLTRI1 and BLTRI2 compared to rainfall.



In summary, neither large changes nor increasing trends in phosphorus loading from the inlet streams have been found over the time period of monitoring, as the watershed for Beaver Lake has been developed. There is a highly correlated relationship between the two streams in terms of the amount of phosphorus delivered to the lake basins each year, and there is also a good relationship between total rainfall and the amount of phosphorus delivered by BLTRI2. However, the data presents a less compelling relationship between total rainfall and BLTRI1.

Chapter 5: Modeling and Analysis

This chapter briefly describes the methods that were used to analyze land use, develop the water and nutrient budgets, and complete water quality modeling for both the 2000 and 2006 updates. Results for the hydrological and water quality modeling analyses are also briefly described here, although this work will be ongoing as the 2006 exercise was inconclusive and further data collection will be needed to resolve the problems encountered by the model.

Information contained in this chapter is summarized from separate reports on hydrology (land use and water budget), nutrient budgets, and lake modeling. The 2006 reports can be found in Appendices D and E. The 2000 reports are attached as Appendices to the 2000 Beaver Lake Management Plan update.

Land Use

Land use in 2006 was determined by assigning land use categories to geographical areas based on 2006 high resolution photographs obtained from the City of Sammamish. Land use / land cover was assessed independently from parcel boundaries, unlike the system used in 2000, when land use was determined on a parcel basis using King County Assessor's data combined with some interpretation of 1998 aerial photos. The discussion of differences and comparisons of results between the systems can be found in Appendix D and in Chapter 2, Table 2.

Although the basis for classification changed between the three different efforts, it is still clear that since the 1993 *Beaver Lake Management Plan* analysis was carried out, continued development has reduced forest area, while increasing both grass and impervious areas within the watershed. Out of all possible land uses, areas of urban residential development have increased the most.

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), again in 2000 and with as little change as possible in 2006 (see Appendix D)..

For the 1992 HSPF model, the lake was modeled as a single basin. In developing the water budgets for the 2000 water year, the HSPF model treated the lake as two separate lake basins, and the same scheme was followed in 2006.

Comparison among Flow Modeling

Simulated flows at gages BLTRI1, BLTRI2, and BL4 (outlet)) were compared to gage records of mean daily flows for the three different modeling periods. The results of the simulations were summarized using total volume error and mean daily error for 1993, 2000, and 2006 (Tables 18a-c).

Table 18a. Check of 1993 calibration with updated land use/cover.

Catchment	Total Volume Error*	Mean Daily Error**
BLTRI1	-31 percent	84 percent
BLTRI2	-42 percent	82 percent
BL4 (BLOUT)	-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.

In 2000, a recalibration of the 1992 HSPF model was performed, and both the total volume error and the mean daily error were reduced from those calculated for the earlier version. 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 18b).

Table 18b. Re-calibrated 2000 HSPF model error improvement.

Catchment	Total Volume Error*	Mean Daily Error**
BLTRI1	1 %	74 %
BLTRI2	-7 %	69 %
BL4 (BLOUT)	1 %	36 %

* 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 %age of the gaged root mean square flow.

`The 2006 recalibration of the hydrological model correlated well with the 2000 model in terms of error calculations, although the basis went from daily to hourly error estimation.

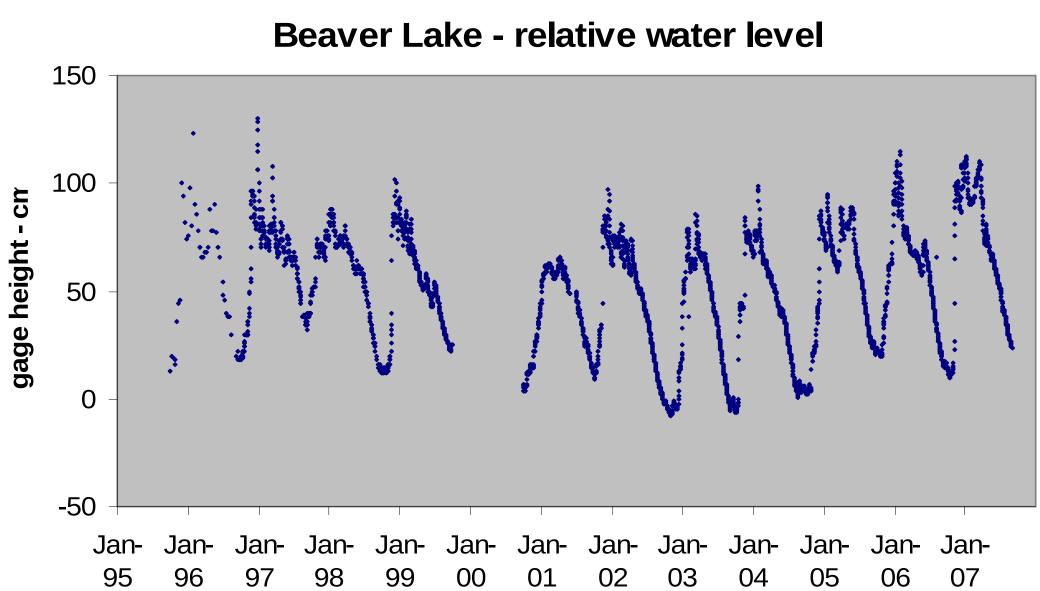
Table 18c. Summary of error analysis for 2006 update

Station	Total Volume Error	RMSE	Mean Hourly Error
BLTRI1 (cfs)	4%	0.39	26%
BLTRI2 (cfs)	-7%	1.11	46%
BL4- outlet (cfs)	-6%	1.33	-13%
Lake Stage (feet)		0.17	-1%*

Lake Level Simulation

Volunteers have measured daily water levels at the lake since October 1993 (Figure 26), with minimal gaps in the record. Using this water level data, the HSPF model's performance was evaluated for its ability to simulate fluctuations in lake level. The 2006 recalibration shows a good match between predicted and measured lake water volumes for time period calibrated (see Appendix D, calibration plot p.15).

Figure 26. Lake level record for Beaver-2 over the entire period of monitoring.



Annual Water budget

Based on the recalibration of the hydrological model, water budgets for water years 2005 and 2006 were constructed (Tables 19 and 20).

Table 19. Comparative water budgets for years 1997, 2000, 2005 and 2006 for Beaver Lake 1.

Beaver Lake 1	1997	2000	2005	2006
Inflows				
Precipitation	64.5	42.5	38.3	44.2
Tributary Inflow	448.4	429.5	237.0	347.1
Lake Inflow				
Surface Runoff	30.1	15.4	21.2	40.0
Interflow	17.2	11.0	21.6	33.0
Groundwater	205.9	134.2	116.1	147.3
Total	**766.1**	**632.5**	**434.3**	**611.6**
Outflows				
Outflow	670.6	507.8	89.8	285.7
Evaporation	25.5	24.5	25.0	20.7
Percolation	62.2	104.4	319.0	306.3
Total	**758.5**	**636.7**	**433.8**	**612.7**
Difference	7.6	-4.2	0.5	-1.1

*Note: Water Year 2006 = 10/1/2005 - 7/31/2006

Table 20. Comparative water budgets for years 1997, 2000, 2005 and 2006 for Beaver Lake 2.

Beaver Lake 2	1997	2000	2005	2006
Inflows				
Precip	304.9	204.5	197.0	230.2
Tributary Inflow	1036.3	786.6	373.0	614.0
Lake Inflow	670.6	507.8	89.7	285.7
Surface Runoff	258.8	146.7	210.0	321.9
Interflow	151.2	104.3	79.8	120.9
Groundwater	622.7	638.8	351.2	420.3
Total	**3044.7**	**2388.6**	**1300.7**	**1993.0**
Outflows				
Outflow	2066.7	1583.7	429.0	1189.7
Evaporation	120.7	126.5	130.0	110.0
Percolation	820.0	719.7	729.0	668.0
Total	**3007.4**	**2429.9**	**1288.0**	**1968.0**
Difference	37.3	-41.3	12.7	25.0

*Note: Water Year 2006 = 10/1/2005 - 7/31/2006

It is noteworthy that the totals for both inputs and outputs for Beaver-1 are lower but still approximately the same for all 4 years, while the totals for Beaver-2 are distinctly lower in 2005-6 than for 1997 and 2000. Because water year 1997 had the highest precipitation recorded of any of the four years modeled, it makes sense that it would be the highest of all the years. However, neither 2005 nor 2006 had much different rainfall than 2000, so that differing precipitation does not explain the changes between those years. One difference that is particularly marked is the estimate of water flowing into Beaver-2 from Beaver-1, although by itself this would not make up the difference between the years.

Build-out Conditions

Build-out conditions could not be simulated for this update because the City of Sammamish does not separate out future building projections by sub-area of the city at this time. However, build-out is likely to be lower than estimated for the 2000 Beaver Lake Management Plan update for several reasons. One major reason is that the City has acquired a large tract of land to the northwest of Beaver-1 to keep as a reserve in perpetuity, thus taking that land out of the development pool. The second reason is that through the process of updating critical areas regulations for the City, more stringent policies and regulations have been adopted that will lead to lower density development and larger buffers created around sensitive water features, such as Wetland ELS21 in the headwaters for Beaver-1.

Nutrient Budget

Prior to developing a nutrient budget for any lake, the limiting nutrient must be determined. For freshwater systems in temperate latitudes, phosphorus is often the nutrient of interest because it is in general more limited relative to nitrogen and other elements needed for algal growth.

Previously, phosphorus was determined to be the limiting nutrient for algal growth in Beaver Lake (King County, 1993a and 2000) and was again confirmed to be the limiting nutrient based on lake data for the 2006 water year.

For the 1993 *Beaver Lake Management Plan*, the nutrient budget was developed for the lake as if it were a single basin, so the budget represented the combination of nutrient sources to both Beaver-1 and Beaver-2. For the 2000 Management Plan update, Beaver Lake's nutrient budget was separated for the two lake basins, allowing for better definition of the water chemistry differences between the two basins and refining the analysis of possible differential trophic responses to changes in nutrient loading.

The same scheme was followed for 2006, but a balanced budget could not be reached based on the collected data (see Appendix E), resulting in an inability to assign proportionality to the various inputs or to make new projections based on future build-out scenarios.

Since neither the lake data nor the calculated phosphorus loading from inlets show any upward trends in phosphorus since the 2000 in-lake evaluation, the general assumption can be made that controls and regulations affecting development in the area have so far been successful in preventing deterioration of water quality in the lake basins.

It is likely that the proportions assigned to the various sources of inputs have not changed dramatically, but it cannot be determined without balancing the nutrient budgets based on measured and estimated nutrient and water inputs and outputs.

Contractor Recommendations

Eight sources for inputs can be defined for the phosphorus budget based on the hydrologic data: tributary baseflow; tributary runoff; interflow, onsite waste treatment or septic sources, atmospheric deposition (precipitation/dustfall), groundwater, overland runoff; and internal recycling.

Recommendations for resolving the nutrient modeling problems include:

- Comparing predicted and observed data over the 6-year period from 2000 to 2006 to set expected ranges for internal loading parameters
- Better defining dates for mixing and stratification
- Refining contributions from septic systems
- Better defining the threshold between baseflow and stormflow in Beaver Lake Tributaries (BLTRI1 and BLTRI2)
- Better defining stormflow TP concentrations
- Refining soluble reactive phosphorus concentrations in the tributaries
- Implementing a consistent land cover classification for the 2000 and 2006 water years
- Using the same catchment delineations and total acreages for the 2000 and 2006 water years
- Incorporating a scaling factor to account for differences in the analytical techniques used to quantify the concentrations of phosphorus in the observed data

Several next steps to resolve the nutrient budget problems will be undertaken over the coming year to check for accuracy of both water and phosphorus measurements, particularly for storm events sand the impact to the tributaries, which appear to be responsible for much of the phosphorus input to the lake basins through each annual cycle. For example, automated compositing storm sampling devices will be used in water year 2007 to capture samples based on flow measurements through each storm event.

Resolving these issues and revising the nutrient budget for the lake will be among the top priorities of the LMD work in order to be sure that sources or quantities of phosphorus inputs have not shifted dramatically over time as the watershed continues to develop.

The next few seasons of work will also include a rigorous look at the components of both the hydrological and phosphorus models to see if any embedded assumptions could be responsible for the failure of the phosphorus modeling effort. After new data are collected and analyzed, the team members will confer with the contractor to see if the new data will result in a successful run of the model.

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Chapter 6: Recommendations

Beaver Lake water quality has benefited from nearly two decades 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) and the *Beaver Lake Management Plan Update* (King County, 2000), the *East Lake Sammamish Basin and Nonpoint Action Plan* (King County, 1994b) and the *Lake Sammamish Water Quality Management Project* (King County, 1998b).

Resulting actions based on these plans and associated recommendations have included more stringent water quality treatment standards for new development (both *Beaver Lake Management Plans)*, 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.

The City of Sammamish has continued the efforts to protect Beaver Lake water quality through zoning and planning for development, as well as producing and implementing a Critical Areas Ordinance that takes seriously the responsibility to protect the city's water bodies for future generations to enjoy.

In this chapter, key findings associated with the 2001-2006 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, measured parameters indicate that water quality remains good and relatively unchanged from levels documented with the original *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. The same standards were adopted by the City of Sammamish upon incorporation of the city, and they continue to be required as the area develops. This standard, in combination with the preservation of wetland functions, 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 continue to predict 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-1 because of its lower assimilative capacity than the larger Beaver-2 basin.

However, with the continued implementation of many of the recommendations made in previous Lake Management Plans, water quality in Beaver Lake has remained stable through the development of the Wesley Park and Beaver Lake Estates. Some further development is anticipated within the Coyote Country neighborhood and around the upper reaches of the watershed, such as in Trossachs, which makes critical the continued enforcement of the water quality protection standards in this chapter.

Under the build-out land use scenario in 2000, a two-fold increase in phosphorus levels was predicted for Beaver-1 in comparison to Beaver-2. This predicted phosphorus increase strongly suggested that the northern basin would be more vulnerable to added phosphorus than the larger main basin. Although the modeling results from the 2006 data were difficult to interpret, there is no reason to suppose that the situation has changed significantly.

Currently, Beaver-1 has a total average annual surface phosphorus concentration of about 27 µg/L, which would be expected to increase under build-out conditions. In Beaver-2 , the current phosphorus average of 19 µg/L would also be expected to increase, but at a lower rate.

The increases in surface phosphorus concentrations in Beaver Lake could noticeably alter lake water quality in the upper lake basin by increasing algal bloom frequency or by changes in the species present, thus diminishing water clarity. This is more likely to be seen in Beaver-1 than in Beaver-2, since it is the more vulnerable of the two basins and would probably experience more changes.

Given the water quality vulnerability of Beaver-1, the preservation of wetland ELS 21 function has been identified as absolutely critical to the ongoing preservation of the lake. Protection of this wetland and the 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 the most stringent wetland regulatory protection, although it has not been acquired and placed in a preserve similar to wetland ELS 10 which is encompassed by the Hazel Wolf Wetland Preserve (which discharges to the Beaver-2 basin). Historically, wetland ELS 21 was impacted by the Trossachs Division 7 subdivision when two stormwater quality facilities were placed along the southeastern and eastern edges of the wetland. The proposed Trossachs Division 14 subdivision is located to the north of ELS 21 and will be required to maintain a 215 foot buffer from the edge of the wetland and to dedicate 50% of the site to the north of the wetland as permanent open space. To prevent further impacts to wetland ELS 21, continuing efforts are recommended to maximize preservation of open space around the wetland, ensuring that wetland functions are not further degraded.

Beaver Lake also remains vulnerable to possible catastrophic events associated with new land development. Efforts should be made through seasonal construction windows and required temporary erosion control structures 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 may cause degradation of water quality. To ensure the ongoing preservation of the current condition 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 21.

Table 21: Management recommendations.

No.	Recommended Actions
	Wetland and Resource Land Preservation
R1	• Continue to acquire additional publicly owned open space along critical areas of the watershed and along the lake shorelines
R2	• Continue to ensure that wetland and stream buffers are maintained and functioning
R3	• Encourage long-term land conservation via incentive programs for property owners
	Future Land Development Guidelines
R4	• Enforce seasonal clearing and grading requirements
R5	• Enforce temporary erosion and sediment control standards
R6	• Encourage the use of Low Impact Development (LID) techniques
	Ongoing Stormwater Management
R7	• Maintain AKART (all known, available, and reasonable methods of prevention, control, and treatment) standard for new development
R8	• Maintain stormwater facilities
	Local Shoreline and Watershed Actions; Educational opportunities
R9	• Restore shoreline vegetation
R10	• Reduce lawn size and fertilizer use
R11	• Maintain on-site septic systems or connect to sewer where available
R12	• Reduce phosphorus inputs from pet waste, car washing, and exposed soil
	Ongoing Monitoring
R13	• Continue lake and stream monitoring; add wetland monitoring to look for changes
R14	• Monitor several storms using an automated sampler

Wetland and Resource Land Preservation

To ensure the protection of Beaver-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 2000). As a condition of development, the Trossachs subdivision was required to amend their sand filter 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 enough to ensure the preservation of wetland ELS 21. Specific measures must be carried out to protect and preserve the water quality functions that are naturally present within 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: Continue to Acquire Additional Open Space

Open space acquisition should be targeted for more parcels which include or are located immediately adjacent to wetland ELS 21.

To the south and west of wetland 21, the City of Sammamish has acquired 57 acres located on the northern end of Beaver Lake. Initiated by the community, this acquisition has been completed 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 abuts the Hazel Wolf Wetland Preserve. The City plans to leave the land largely undeveloped, creating a preserve with a loop nature trail and educational signage. This will contribute to the preservation of Beaver Lake, not only by maintaining a large space in native vegetation, but by public education as well.

R2: Continue to Ensure that Wetland and Stream Buffers are Maintained and Protected

Buffer requirements for wetlands and streams depend upon how the water feature is classified. For example, Category I bog wetlands require 215-foot buffers while other types of wetlands require between 50 and 200-foot buffers, respectively (SMC 21A.50, City of Sammamish, 2007). Similarly, Type F streams and Type S streams with salmonids require a 150-foot buffer otherwise Type Np streams and Type Ns streams require 75-foot and 50-foot buffers, respectively (SMC 21A.50.330, City of Sammamish, 2007).

The City of Sammamish recently adopted amendments to its environmentally critical areas regulations, which included increasing the required wetland buffer for ELS 21 from 150 feet to 210 feet; this increase in buffer protection exceeded the recommendation of this chapter, which had recommended increasing the buffer to 200 feet. ELS 21 is identified as a category I bog wetland, which is the basis for the 215 foot buffer; other wetlands within the Beaver Lake Basin, are subject to wetland buffer requirements that will range from 50 feet to 215 feet, depending on the wetland category and the habitat value of the wetland.

Beaver-2 water quality will benefit directly from the preservation of Beaver-1, which provides about 20 percent of the annual inflow to Beaver-2 during a typical year. Moreover, Beaver-2 already benefits from the preservation of wetland ELS 10 through the establishment of the Hazel Wolf Wetland Preserve and is expected to benefit further with the increase to a required 215-feet buffer for the wetland area outside of the preserve. This larger buffer should provide additional protection for the southern end of the wetland outside the preserve.

Tributaries 0166 (BLTRI1) and 0166D (BLTRI2) are the outlets for wetlands ELS 21 and ELS 10, respectively. Currently, these streams do not have specific buffer requirements. As a general rule, non-salmonid bearing streams require a buffer between 50 and 75 feet, depending on the seasonal or perennial nature of the stream. If salmonids are present within the stream, a 150-foot buffer is required.

With the adoption of these recent updates to the stream and wetland buffers, the City of Sammamish should work to ensure that application of the buffers is applied consistently and appropriately within the Beaver Lake sub-basin. In particular, avoiding or eliminating further disturbance of the new buffer areas will require ongoing coordination between property owners and the City.

R3: Encourage Long-term Land Conservation via Incentive Programs

Land conservation can be secured by other means besides outright acquisition. Interested property owners might participate in a variety of resource incentive protection programs if offered through the city or county. Examples of these programs include King County’s current use and open space taxation programs, which are based on property tax reduction in exchange for long-term land conservation.

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 Limits:

During the periods from October 1 to March 31, bare ground associated with clearing, grading, utility installation, building construction, and other development activity should be covered or re-vegetated in accordance with City of Sammamish regulations (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 approved plan, or alternative best management practices as approved or required by the inspector or the City of Sammamish, 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. With the incorporation of the City of Sammamish, inspection of TESC has been included as part of the City of Sammamish inspection services.

R6: Encourage the use of Low Impact Development (LID techniques

Landscaping and land use techniques have been developed that reduce the amount of surface water leaving developed sites, increase percolation to soils to replenish groundwater, and reduce movement of toxins and nutrients to downstream water bodies.

The most recent version of the King County Surface Water Design Manual (2005, http://dnr.metrokc.gov/wlr/dss/manual.htm) incorporates LID techniques into appropriate menus. A good general resource for the Puget Sound area was published by the Puget Sound Action team in conjunction with WSU Pierce County Extension (PSAT 2005).

Ongoing 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.

R7: 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. The following standards were adopted by the City of Sammamish as part of the critical areas code and remain in effect:

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. AKART is defined as: all known, available, and reasonable methods of prevention, control, and treatment.

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 in the past two management plans have shown that phosphorus levels will increase. Continued removal of excess phosphorus from new development will help minimize future impacts to Beaver Lake water quality.

R8: 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 has contracted with King County to establish a regular maintenance schedule for all facilities in the watershed. All facilities should be inspected prior to the fall and maintenance needs identified. Sand filters 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.

Local Shoreline and Watershed Actions; Educational Opportunities

Undoubtedly, residents living along the shores of Beaver Lake have more direct impacts on water quality of the lake than residents away from the lake but inside the watershed, depending on their daily activities, how their yards are maintained, and the degree of shoreline alteration that has occurred. However, 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.

R9: Restore Shoreline Vegetation

Over time, the Beaver Lake shoreline has been substantially altered and vegetation removed as residents have built bulkheads and docks, imported gravel for beaches, and developed lawns and gardens of non-native plants along the shoreline. Residents can minimize their impact to the lake by restoring the shoreline with native vegetation, removing bulkheads or setting them back away from the shore, reducing lawn sizes, and creating buffer areas 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 will not be impacted by shoreline property development.

R10: 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, which is the time when algae and lake plants are actively growing. Direct runoff from lawn watering, especially on shoreline properties, can reach the lake and be a significant source of nutrients to the actively growing aquatic plants. By reducing or eliminating fertilizer use (which stimulates growth of both lake and land plants), residents can decrease local water quality impacts.

Overall, lawns traditionally require more maintenance and chemical use than other garden components. Reducing lawn size and growing drought tolerant and native plants can significantly decrease 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.

R11: Maintain On-site Septic Systems or Connect to Sewer Where Available

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. Drain field areas should also be maintained in grass only and compaction of the area avoided.

The Sammamish Plateau Sewer and Water District has started to expand its sewer services to properties around Beaver Lake. As sewer becomes available, residents should consider connecting directly to sewer and decommissioning the existing septic systems.

R12: Reduce Phosphorus inputs from Pet Waste, Car Washing, and Exposed Soil

Pet ownership is quite popular in the Beaver Lake area. Survey results showed that about 74 percent of households in the area had dogs or cats (King County, 1998c). Proper disposal of pet waste, as well as waste from larger domestic animals such as horses, is important in preventing nutrients and pollutants (phosphorus, nitrogen, and bacteria) associated with the 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 disposal in the garbage.

Equally important is the reduction of phosphorus generated by car washing activities and erosion of exposed soil in residents' yards. Cars should be washed at car wash facilities instead of in the driveway or street to avoid runoff of soapy water to the lake. Bare soil should be covered with mulch or re-vegetated as quickly as possible to reduce erosion of exposed 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 ten 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 track the success of the stormwater treatment standards established through the *Beaver Lake Management Plan* and King County, followed by City of Sammamish regulations. Thus far, these standards in combination with other phosphorus reduction efforts have resulted in stable water quality in Beaver Lake.

As further development of the watershed occurs, monitoring remains important as an early detection tool for identifying water quality problems or trends. Monitoring the tributaries that enter Beaver Lake provides pulse points on the quality of upstream wetlands. 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.

R13: Continue Lake and Stream Monitoring; Add Wetland Monitoring

Beginning in 2007, a ten-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 that whole lake monitoring is proposed to occur only during the 2012 and 2017 water years. This monitoring program would be funded through a third lake management district, which has recently been formed by the City of Sammamish, based on the majority vote by watershed residents in favor of forming the district.

The program of monitoring bacteria concentrations in the lake during summer, and the pH and alkalinity of both basins during the winter should be continued as adjuncts to the basic stream monitoring programs. Monitoring conditions in ELS 21 should also be considered as an important tool for detecting signals of environmental degradation as a result of continuing development around the periphery of the wetland.

R14: Monitor several storm events using an automated sampler

To answer the questions raised concerning the accuracy of grab samples and to address the problems the modeling consultant had with balancing the phosphorus budget, several storm events per year should be sampled using an automated sampler that composites water taken at intervals determined by stream flow estimates.