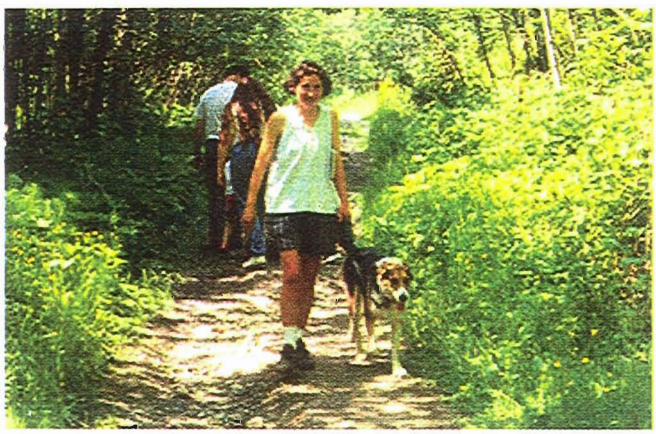
Lake Sammamish Water Quality Management Project






FINAL REPORT

July 1998

Funded by Washington State Department of Ecology
Grant Agreement #G9300126

WASHINGTON STATE DEPARTMENT OF ECOLOGY

KING COUNTY
Department of Natural Resources

CITY OF BELLEVUE WASHINGTON

CITY OF ISSAQUAH

THE CITY OF REDMOND WASHINGTON

Lake Sammamish
Water Quality Management Project

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Executive Summary

The Lake Sammamish Water Quality Management Project report documents the findings of nine research projects that were undertaken as part of a Phase 2 Lake Restoration project to evaluate different management alternatives for controlling phosphorus inputs to the lake. Major funding for these projects was provided by Referendum 39 funds through the Washington Department of Ecology. Additional support was provided by King County and the Cities of Bellevue, Issaquah, and Redmond. The management alternatives evaluated are both structural, including various chemical or physical phosphorus removal strategies that could be used to treat storm water runoff in storm water facilities in the basin; and non-structural including improved erosion control at construction sites, education concerning non-point phosphorus controls for homeowners, real estate agents and builders, and the identification of possible "point" sources of phosphorus throughout the drainage basin. The report includes a brief summary of the management history, water quality, and physical conditions in Lake Sammamish.

Lake Sammamish is located in western King County, Washington, five miles east of the City of Seattle. Lake Sammamish drainage basin includes urban, rural, and forest resource lands. It has a long history of water quality problems associated with both point and non-point sources of phosphorus in runoff entering the lake. The project findings were instrumental in guiding the current management strategy for Lake Sammamish. Specifically, the current management strategy directly or indirectly incorporates the results of five of the nine projects: in the use of wet ponds or sand filtration facilities either in combination, with a bioswale, or, if of sufficient volume, alone, for new urban density development; increased levels of erosion control at construction sites; phosphorus source control education for homeowners, businesses, forestry, and agricultural practices throughout the watershed; and removal or control of phosphorus sources at sites identified by the intensive survey. The facilities requirements do not include the use of chemical amendments since their utility to increase phosphorus removal without increasing construction and maintenance costs was not demonstrated conclusively. The use of soil amendment for residential developments is being further evaluated for application in this area by the City of Redmond.

Additional details regarding the extent to which the studied alternatives have or have not been incorporated into the current management strategy of Lake Sammamish, and the extent to which the alternatives should be considered for further study, are discussed in Appendix 1.

The most significant findings of the research projects are the following:

- The use of various chemicals, including alum, iron chloride, iron oxide coated sand, and processed steel fiber in a sand mixture are effective in the removal of both total and soluble forms of phosphorus from storm water in laboratory and pilot plant settings;

- The use of these chemical additives, in conjunction with the operation of on-site storm water facilities including the retrofitting of an underground detention vault (alum injection), and as additives to sand filtration facilities (iron-oxide-coated sand and processed steel fiber),

Lake Sammamish
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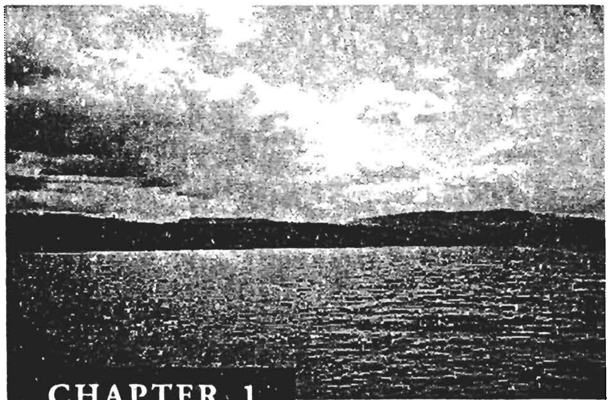

CHAPTER 1

Introduction to Lake Sammamish

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Chapter 1. Introduction to Lake Sammamish

Report Overview

This report summarizes the findings of the implementation phase (Phase 2) of the Lake Sammamish Water Quality Management Project. Major funding for this project was provided by Referendum 39 funds under Grant Agreement No. G9300126 with the Washington Department of Ecology. Additional support was provided by King County and the Cities of Bellevue, Issaquah, and Redmond. The focus of the report is on the findings of nine phosphorus control projects that were evaluated for protecting the water quality and beneficial uses of Lake Sammamish. The report starts with a summary of the physical and chemical conditions of Lake Sammamish, including a review of the water quality monitoring data available for the lake. The report includes a brief summary of the past and current inter-jurisdictional management of water quality in Lake Sammamish.

This report consists of an Executive Summary, 10 Chapters, and one Appendix. Technical reports for Chapters 2, 3, 4, and 5 are contained in a separate companion document:

Chapter 1: Introduction to Lake Sammamish
- Report Overview
- History of Lake Sammamish Management
- Physical and Water Quality Conditions

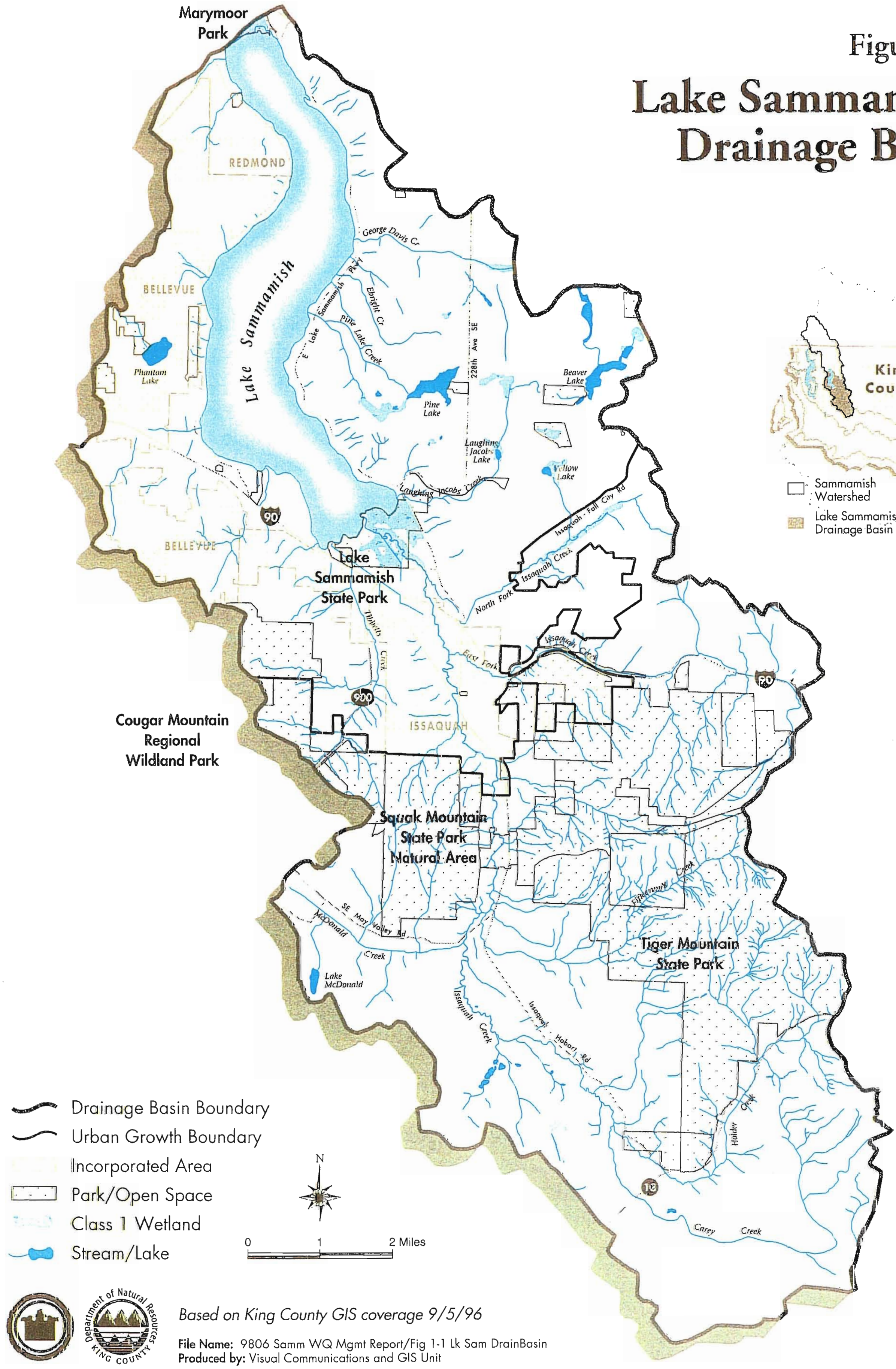
Chapter 2 through 10: Phase 2 Project Findings

Appendix 1: Adaptive Management Strategy

Lake Sammamish is the sixth largest lake in the State of Washington. It is located in central King County, approximately five miles east of Seattle (Figure 1.1). Lake Sammamish provides a wide range of recreational and natural resource opportunities that benefit the more than two million people who inhabit King County and the adjacent counties. The lake is used extensively by boaters, fishermen, water skiers, sail boarders, jet skiers, swimmers, and picnickers. Valuable view properties overlook many parts of the lake. Major public parks are located on the lake shore, including King County's Marymoor Park and the City of Redmond's Idylwood Park at the north end and Lake Sammamish State Park at the south end. The lake is designated as a resource of statewide significance under the Shoreline Management Act. It provides migratory and rearing habitat for many salmon species as well as being home for many warm water fish and wildlife. The water quality of the lake plays a key role in protecting the lake's recreational uses, its ecological health, and scenic beauty.

Figure 1.1

Lake Sammamish Drainage Basin



Based on King County GIS coverage 9/5/96

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Produced by: Visual Communications and GIS Unit

appeared to be consistent with the lake's recreational uses and ecological health. The report also proposed a variety of structural and non-structural controls to reduce or minimize future degradation of the lake. The structural controls involve detaining or treating water runoff for phosphorus removal. The non-structural controls include source controls such as education, regulatory controls, land use controls, and administrative strategies. It was recognized in the Report (Entranco, 1989) that some of the proposed controls had not been tested in situations similar to the Lake Sammamish watershed. These controls were designated as demonstration projects in order to test their potential effectiveness and feasibility in removing phosphorus.

Phase 2 Implementation and Management Structure

Phase 2, or the implementation phase of the Lake Sammamish Water Quality Management Project, began in 1990 and was partially (75 percent) funded by $500,000.00 from the Washington State Department of Ecology (latterly administered as part of the Centennial Clean Water Fund). The remaining 25 percent of project costs were provided by King County and the Cities of Bellevue, Issaquah, and Redmond. Chapters 2 through 10 of this document report on the results of these demonstration projects and other implementation project results.

Commitment of these funds required that the parties enter into an Interlocal Agreement. The Interlocal Agreement established two interjurisdictional committees, the Lake Sammamish Management (formerly Project Management) Committee, composed of department directors or designees of the jurisdictions sharing the drainage basin, and the Lake Sammamish Technical Committee composed of key staff from the jurisdictions. The two committees were responsible for local decisions and technical oversight of water quality projects for Lake Sammamish. The Management Committee includes directors or designees from jurisdictions responsible for the management of surface and storm water runoff and/or preservation of natural resources such as streams, wetlands, and lakes. Staff of the governmental agencies cooperating in the management of the lake are appointed or assigned by department directors to the Technical Committee.

The jurisdictions participating in these committees originally included the City of Bellevue, the City of Issaquah, the City of Redmond, Metro and King County. Since the 1996 merger of Metro and King County, membership to the committees consists of the three cities and King County. The Technical Committee has included various outside experts during parts of the last seven years, including representatives from local consultant firms and the University of Washington. The committees have continued to meet on a regular basis since 1991 and currently operate under the inter-jurisdictional direction of the Sammamish Watershed Forum. This Forum, generally comprised of elected officials from the jurisdictions, was established in 1996 as the result of the Regional Needs Assessment (King County, 1995). The Forum is an advisory board to the Councils of various jurisdictions that share the Sammamish Watershed and the Metropolitan King County Regional Water Quality Committee. The role of the Forum is to advise the local and regional governments on the appropriate interjurisdictional management of the water quality, floods, and fisheries habitat of the surface waters within the Sammamish watershed.

Lake Sammamish Initiative

In 1995 a water quality model for Lake Sammamish (King County, 1995; Perkins et al., 1997) evaluated the in-lake effects of non-point source phosphorus entering the lake. This model took into account non-point sources of phosphorus resulting from urban development of the drainage basin that occurred between 1990 and 1995 and new development that was predicted to occur under adopted comprehensive plans from each jurisdiction. The model estimated that phosphorus inputs to the lake would increase by approximately 35 percent in the future as the basin continued to develop in response to the adopted comprehensive plans. The increase was estimated to occur in spite of the water quality controls and watershed management strategies that the four jurisdictions were supporting. Subsequent land use analysis showed that the future increase in phosphorus inputs to the lake was closer to 45 percent and not the 35 percent originally estimated (Entranco, 1996).

In response to these threats, in August 1995 then King County Executive Gary Locke announced the Lake Sammamish Initiative and appointed an eight-member citizen task force, the Partners for a Clean Lake Sammamish. The Partners' mandate was to define water quality goals for the lake and to propose a long-term management and financial strategy to protect Lake Sammamish. The Initiative also included a set of short-term actions to be funded and completed by the four jurisdictions during 1996 and 1997 that would control specific sources of phosphorus and sediment throughout the drainage basin.

The results of the Partners' efforts were reported to the Sammamish Watershed Forum in July 1996. Their recommendations are contained in two companion documents (Partners for a Clean Lake Sammamish, 1996 and Entranco, 1996). Their work and recommendations were heavily dependent upon the findings of the Phase 2 demonstration projects. In addition, the short-term actions were largely identified by the intensive source sampling completed in Phase 2 (see Chapter 10).

Current Management Strategy

The Sammamish Watershed Forum and the four jurisdictions have based the current management strategy for Lake Sammamish on the Partners' recommendations and on the development of an adaptive management strategy for the lake. The collaboration among the cities and King County centers on preserving the water quality of Lake Sammamish by agreeing to implement specific controls as needed and, where technically feasible, to meet the goal of minimizing phosphorus input into Lake Sammamish. The four jurisdictions work together to identify, test, and establish implementation strategies for controls which have the potential for phosphorus removal in the Lake Sammamish basin. They also establish means for evaluating the effectiveness of both the overall program and specific controls. They incorporate this information into the ongoing management of the lake using the adaptive management strategy as described in Appendix 1 of this document. The role of the Sammamish Watershed Forum is to balance the management needs for maintaining water quality in Lake Sammamish with other surface water management needs (e.g. protection and restoration of salmon habitat, reduction of flood hazards) within the Sammamish Watershed and, when considered with Forums for the other major watersheds, with similar surface water management needs in the whole county.

Lake Sammamish Physical and Water Quality Conditions

Physical Characteristics

Lake Sammamish is the sixth largest lake in Washington and the second largest in King County. The basin of the lake is a long, uniform trough with steeply sloping sides. It runs essentially south to north and has a maximum depth of 32 meters (105 feet). The lake is generally shallow with a mean depth of 17.7 meters (58 feet). Physical characteristics of the lake and its drainage basin are shown in Table 1.1.

Average annual precipitation in the basin is about 39 inches (90 cm) with about 75 percent occurring during extended periods of nonintensive rainfall events from October through March. Snowfall and localized freezing are relatively rare, occurring on the average of once every three to five years.

The southern basin is characterized by steep-sided stream channels that rise in the south on Tiger, Squak, Taylor, and Cougar Mountains and flow north through relatively narrow valleys. The southern basin is highly erosive and represents about 64 percent of the total basin drainage area, including all of the City of Issaquah and parts of unincorporated King County. The major stream system, Issaquah Creek, provides approximately 70 percent of the annual inflow into Lake Sammamish (Moon, 1972). Land cover in the southern part of this basin consists largely of second growth forests, several large state and regional parks, a few small farms, and some dispersed rural residential development. The lower valley broadens into a wide plain that is occupied by the City of Issaquah. Major southern tributaries include Issaquah Creek and its tributaries, Holder and Carey Creeks, MacDonald Creek, and the North and East Forks, as well as Tibbetts Creek. The southern shoreline includes the largest stretches of undeveloped, vegetated shoreline, predominantly within Lake Sammamish State Park. The state park provides valuable habitat to a wide variety of water fowl and other wildlife, as well as the most important point of public access including swimming beaches and boat launching facilities.

The western basin is narrow and largely urbanized. It represents about 19 percent of the total drainage basin. Twenty percent of the City of Bellevue and two percent of the City of Redmond are in this basin. The western basin drops sharply to the lake through a series of steep small creeks and piped drainage channels that enter the lake through culverts at regular intervals along the narrow shoreline. It includes one small lake, Phantom Lake. With the exception of a small amount of vegetated park land at Idylwood Park, the entire western shoreline is developed. The largest creeks on the western side include, from south to north, Lewis Creek, Vasa Creek, Weowna Creek (sometimes known as Phantom Lake Creek), Wilkens Creek, and Idylwood Creek. All of these creeks, with the exception of Lewis Creek, have experienced severe downcutting and erosion during the past 15 to 30 years.

Table 1.1 Physical Characteristics of Lake Sammamish and its Drainage Basin
(following Welch et al. 1980)

Characteristic	English Units	Metric Units
Location	142° 05′ W 46° 36′ N	-
Ordinary High Water Mark	27 feet	9 meters
100 year Flood Elevation	33.5 feet	11 meters
Altitude (above sea level)	40 feet	12 meters
Watershed Area	56,000 acres	25,500 hectares
Lake Surface Area	4,897 acres	19.8 km^2
Lake Volume	283.86 acre-ft	3.5×10^8 m^3
Mean Depth	58 feet	17.7 meters
Maximum Depth	105 feet	32 meters
Flushing Rate	0.56/year	-
Average Depth of Epilimnion	30-35 feet	10-12 meters
Maximum Length	8 miles	12.9 km
Length of Shoreline	21.1 miles	34 km
Main Inflow Tributary	Issaquah Creek[1]	-
Main Outlet	Sammamish River	-
Typical Period of Stratification	mid-May to mid-November	-
Anaerobic Period	mid-July to mid-November	-
Typical Anaerobic Depth	66 feet	-20 meters
Trophic State	Mesotrophic	-
Average Annual Stream Inflow	1.64×10^5 acre-ft	0.198 km^3
Average Annual Stream Outflow	1.645×10^5 acre-ft	0.203 km^3
Average Annual Precipitation	39.14 inches	90 cm

[1] A mass balance study by Moon (1972) estimated that 70% of the annual TP load to the lake entered via Issaquah Creek.

The eastern basin is approximately 17 percent of the drainage area. It consists of a relatively flat plateau that includes some of the most rapidly developing urban lands in unincorporated King County and a series of steep, highly erosive channels that drain into the lake along the western shore. The majority of this basin is undergoing an incorporation study and is expected to become a new city, Sammamish, in early 1999. The most northern part of this basin is extremely narrow and consists of a series of steep, highly erosive ravines that, in an undeveloped forested state, rarely contain surface water flows. Development in this area is restricted through designation as a no disturbance zone (King County, 1993). The plateau is characterized by many high quality wetlands, including nine Class One wetlands and several small lakes, including Beaver Lake, Pine Lake, Yellow Lake, and Laughing Jacobs Lake. Many of the wetlands and Beaver Lake have specific management plans that have been adopted by King County (King County, 1993, 1995). Both Beaver and Pine lakes have public access and are used extensively for recreation. The shoreline along the eastern side of the lake includes the only area of remaining undisturbed shoreline, with approximately 2000 feet of natural vegetation. The remainder of the eastern shoreline is developed into small residential lots, many of which are undergoing redevelopment.

Public access to Lake Sammamish is limited, with only four public access points around the lake: Lake Sammamish State Park, Timberlake Park, Idylwood Park, and Marymoor Park at the entrance to the lake outlet. There are currently no public access points on the eastern shore although the City of Redmond has proposed a park at the northern end of the lake. Lake Sammamish State Park is the most heavily used park in the state system and typically has over 1.5 million visitors each year.

Land Use Cover

Land use changes in the drainage basin have been rapid in the last twenty years due to the basin's proximity to transportation corridors and employment centers. In 1994 approximately 46 percent of the drainage basin was designated within the urban growth boundary (UGB) as shown in Figure 1.1. Figure 1.2 shows land use estimates for 1985 (Entranco, 1989), and for 1996 and full build out at zoned capacity (Entranco, 1996). The time to full build out is estimated to occur some time before 2026. If current (1995-97) rates of development continue in the drainage basin, then full build-out could occur in less than the expected 30-year time period. Significant public forest lands are located within the drainage basin including Tiger Mountain State Forest, Taylor Mountain County Park, and Cougar Mountain Regional Wildlife Park.

Land use changes in the drainage basin have altered the quantity, quality, and timing of runoff entering the lake. In particular, the input of sediments and associated phosphorus from erosion and urban development have increased in the last few years. The 1996 Water Quality Management Plan estimated that total phosphorus loading to the lake would increase by approximately 45 percent during the period between 1996 and full build-out, in the absence of significant new management controls (Entranco, 1996). In addition, the increases in impervious surfaces and the subsequent decrease in ground water recharge associated with higher surface water runoff, have decreased summer low flows in several of the lake's tributaries (King County, 1993, 1995).

Water Quality Characteristics

Water quality conditions in Lake Sammamish have been monitored on an annual basis since 1979. Monitoring was intermittent between 1965 and 1979. Volume weighted, depth integrated samples are taken on a monthly or bimonthly basis at four mid-lake sites and three tributary sites (Figure 1.3) for total phosphorus, chlorophyll *a*, and Secchi disk transparency (a measure of water clarity). Whole lake volumetric average concentrations are calculated from these samples for total phosphorus on an annual basis as shown in Figure 1.4. Total phosphorus concentrations in recent years approach the water quality goal indicator of 22 μg/l total phosphorus, identified in the 1996 Water Quality Management Plan (Entranco, 1996).

The 1968 diversion of treated sewage and industrial discharge from the City of Issaquah and the Darigold Dairy respectively, resulted in a slow, ten to twelve year decrease in average total phosphorus concentrations. Since 1979, the water quality improvements that resulted from the diversion appear to be reduced by non-point sources of phosphorus associated with increasing basin development during the recent past. As shown in Figure 1.5, there is a trend of increasing total phosphorus concentrations in the lake that is statistically significant at the 95 percent confidence interval. In other words, 95 percent of the variation in phosphorus is explained by the passage of time. Some of the annual difference may be associated with annual differences in precipitation. For example, during two of the last three years, above average rainfall during winter months may have been associated with increased phosphorus inputs to the lake and the observed corresponding increase in average annual total phosphorus concentrations. However, high rainfalls during 1986 and 1990 did not produce similarly high annual total phosphorus concentrations. Further evaluation of the effect of seasonal variations in rainfall using the management model described in Appendix 1, and the in-lake model developed by Perkins, et al, 1997 would be needed to determine any causal relationship.

The water quality indicators for Secchi disk transparency and chlorophyll *a*, identified as measures of achieving the goals of the 1996 Management Plan (see Appendix 1), were not reached during parts of the last six summers. Figures 1.6 and 1.7 show the seasonal variability in measures of Secchi transparency and chlorophyll *a* for the summer months during 1996 and 1997. The years are relatively typical in that there is an early summer increase in chlorophyll *a* concentrations, and decrease in Secchi transparency, followed by a gradual decline in chlorophyll *a* and increase in transparency during July and early August; then a second peak and minimum during late August and September. The observed variability over the annual cycle is presumed to be a function of the relative seasonal availability and depletion of phosphorus following periods of algal growth during the summer months.

Spatial variability in the lake surface sampling sites typically shows that the highest chlorophyll *a* and total phosphorus concentrations are found at the south end of the lake (Station 614), while the mid-lake stations (Stations 611 and 612) are typically lower (Table 1.2). This spatial variability reflects the fact that the single largest phosphorus input to the lake enters through Issaquah Creek.

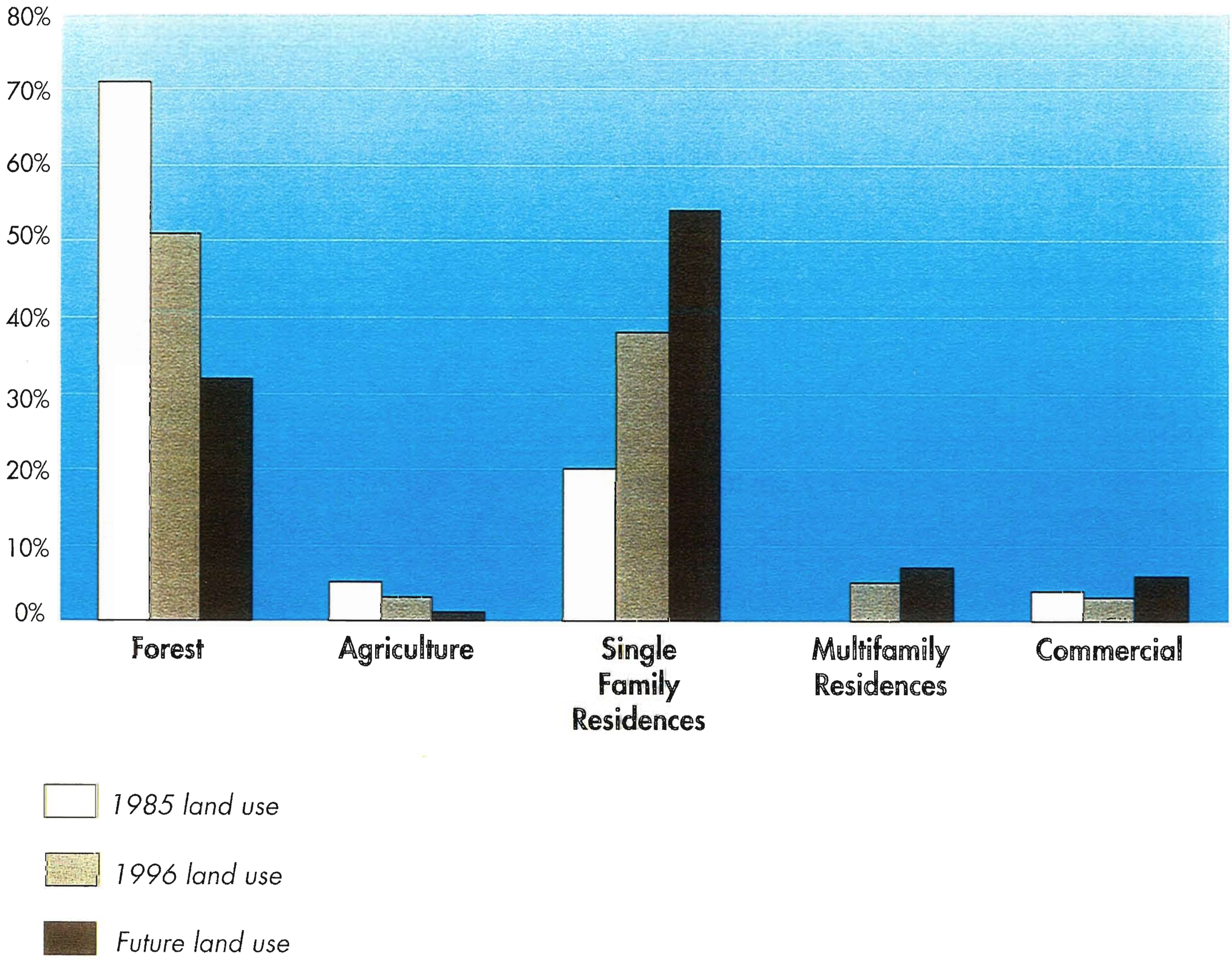
Temperature, pH, dissolved oxygen, and alkalinity are also measured but are not reported here. Additional information about the water quality of Lake Sammamish can be found on the King County website: http://splash.metrokc.gov/wlr/waterres/lakes/samm.htm.

An additional concern for the quality of water in Lake Sammamish occurred during the fall of 1997. On September 18, 1997 an algae bloom of *cyanobacteria*, a primitive life form known as "blue green algae," was found in the lake. Such blooms—rapid, exponential growth of a single species—can produce toxins that are a health risk to humans and potentially lethal to animals. In Lake Sammamish, the bloom producing the toxic substance lasted for three weeks, from September 18 through October 9, 1997. The toxicity began at the south end of the lake but covered the whole lake surface within the first week. The cyanobacteria identified in the lake was primarily *Microcystis aeruginosa* which produces a hepatotoxin, microcystin. Lake samples tested for the presence of toxins, using a mouse bioassay similar to the one used for detecting "red tide" toxins in marine environments, were considered to be relatively high in toxin concentration. As a precaution, warning signs were posted at Lake Sammamish State Park, Idylwood Park, and Marymoor Park for the duration of the toxic bloom. The news media cooperated by alerting citizens to the presence of the bloom. In the future we hope to set up a "hot line" so that lake users can find out if a bloom is toxic.

A bloom of algae is always a risk in any lake that receives high nutrient loads. Blooms of *cyanobacteria* are often characteristic of fresh water lakes that receive excess inputs of phosphorus since many of these simple organisms have the capacity to fix atmospheric nitrogen and are hence not limited by its availability. In Lake Sammamish the right conditions—bright sunshine, warm water (between 72 and 80 degrees), no wind and significant nutrient inputs—combined to produce the 1997 toxic bloom. Not all *cyanobacteria* blooms are toxic, and even blooms caused by known toxin producers may not always produce toxins at detectable levels.

Figure 1.2

1985, 1996 and Future Land Use in Lake Sammamish Drainage Basin



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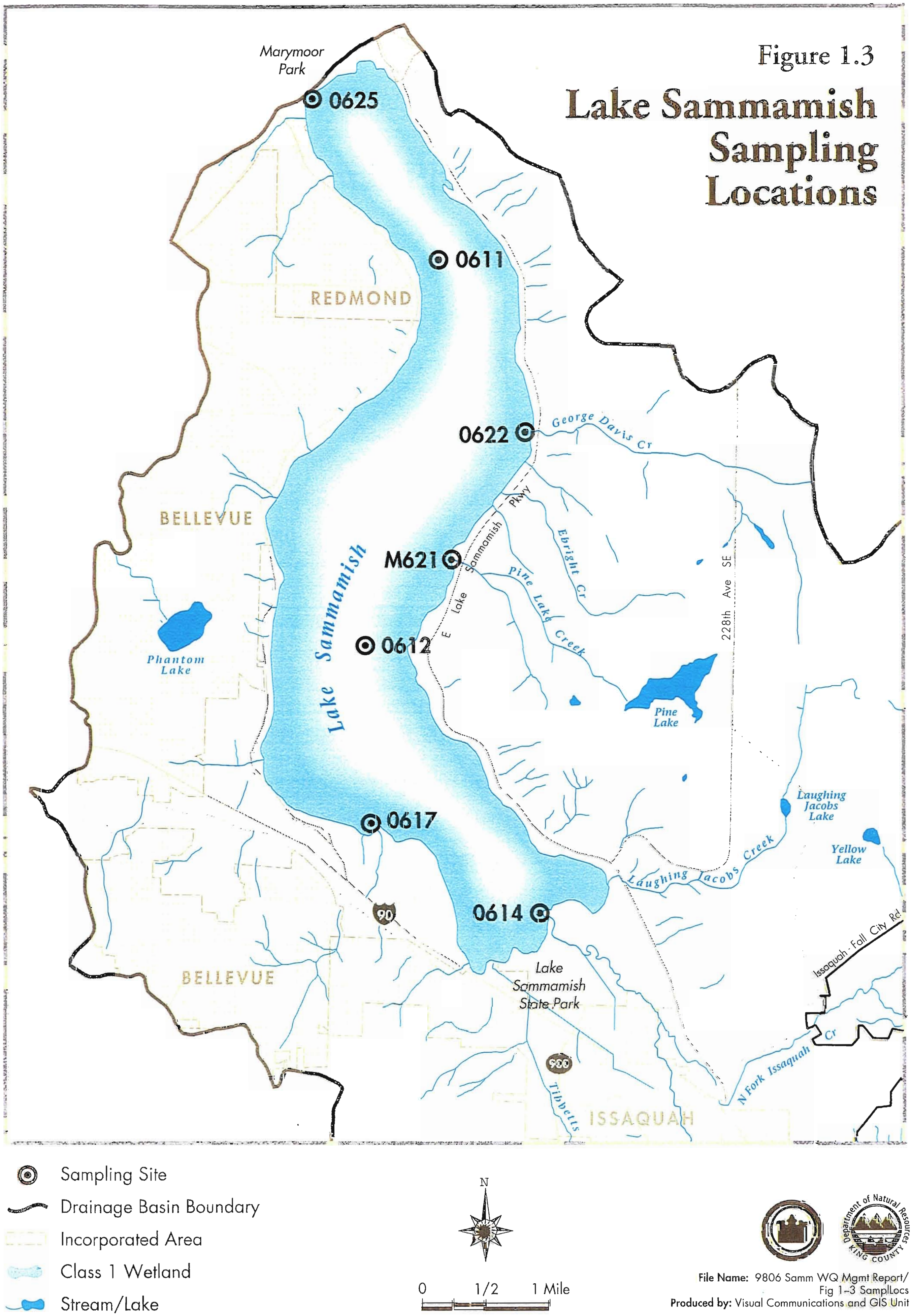

Figure 1.3
Lake Sammamish Sampling Locations

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Figure 1.4
Total Phosphorus Concentration 1964-1997

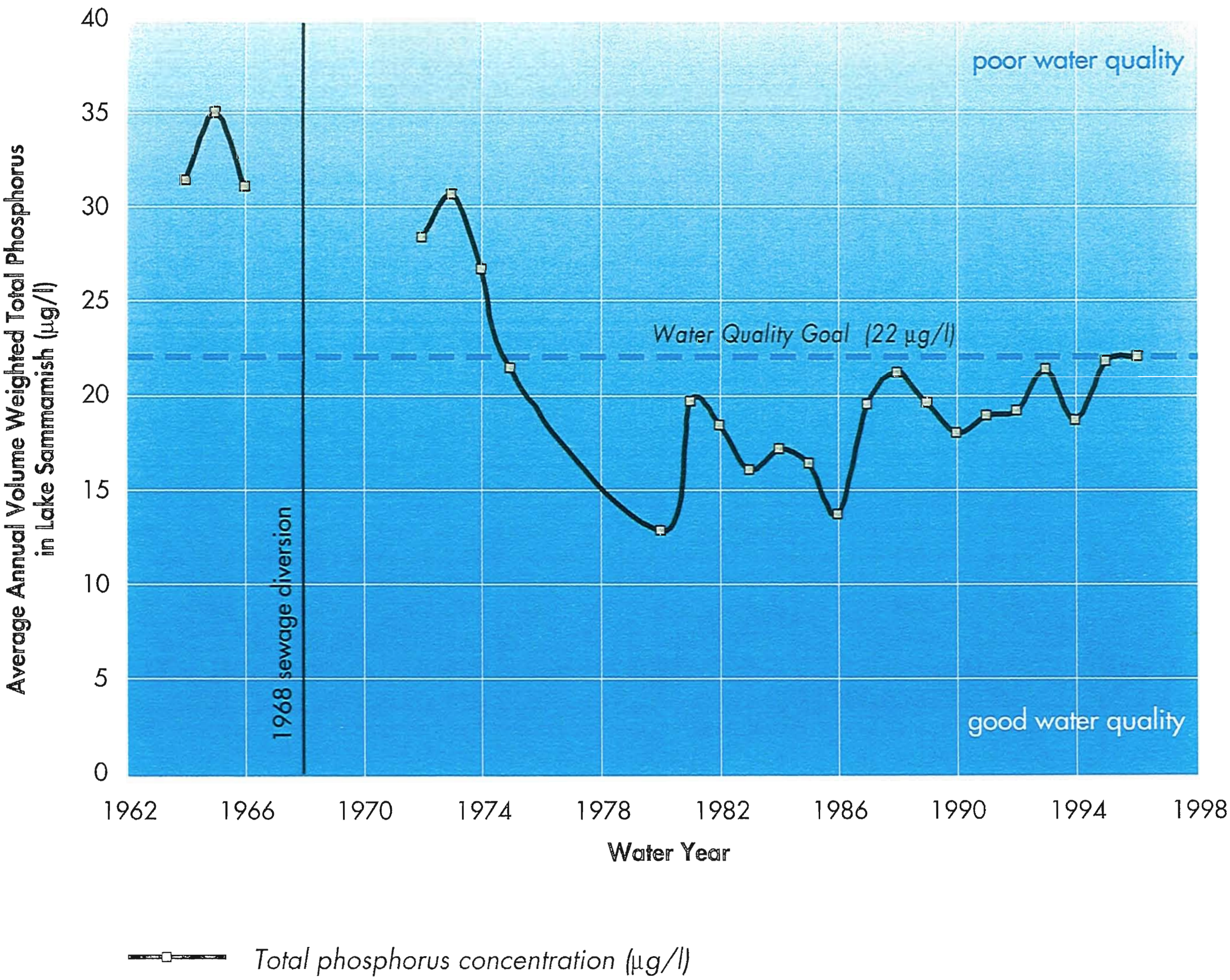

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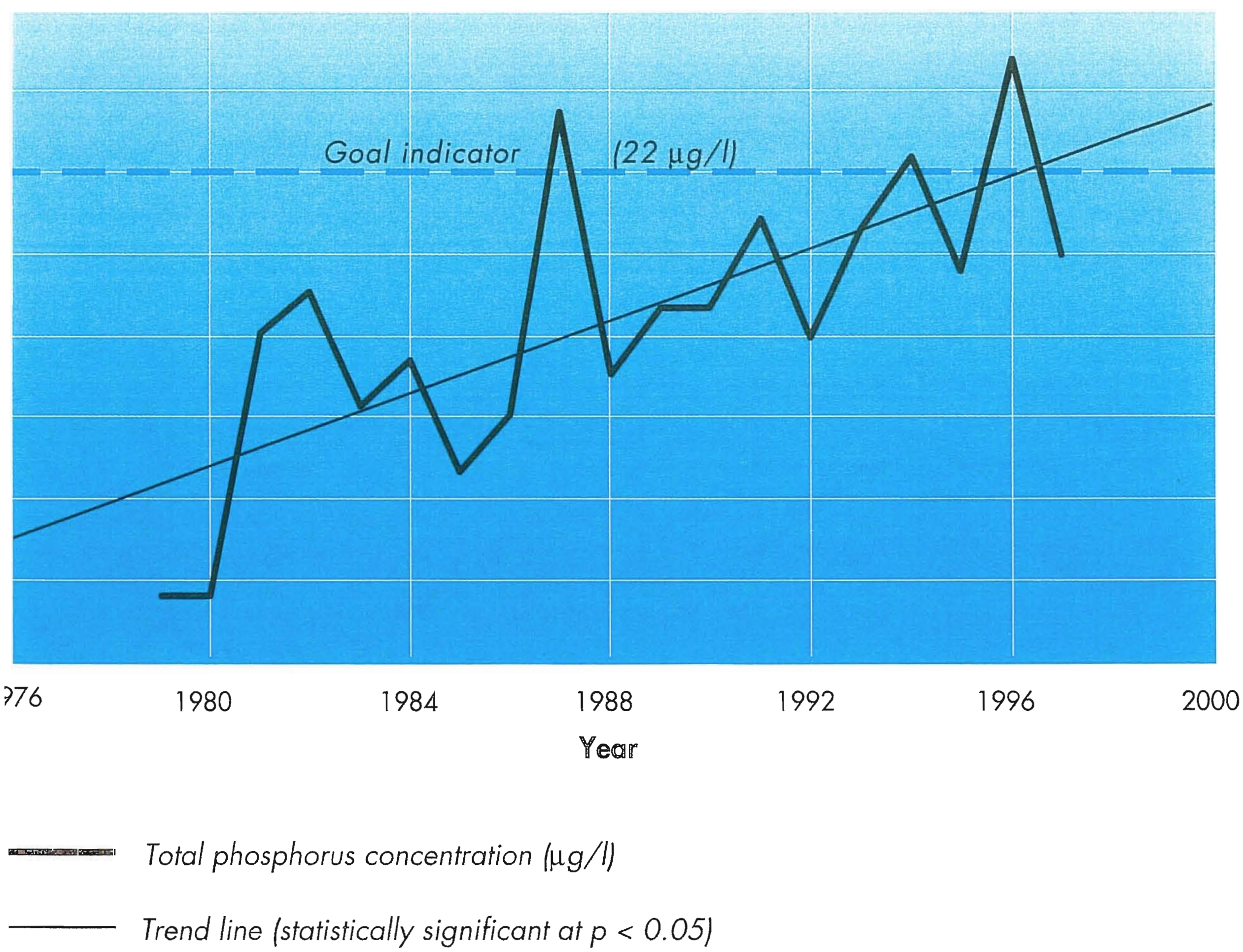
Figure 1.5

Total Phosphorus Concentrations in Lake Sammamish 1979-1997



Department of Natural Resources
KING COUNTY

Name: 9806 Samm WQ Mgmt Report/
1-5 Total Phos 79-97
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Figure 1.6

Lake Sammamish Secchi Disk Transparency Summer 1996 and 1997

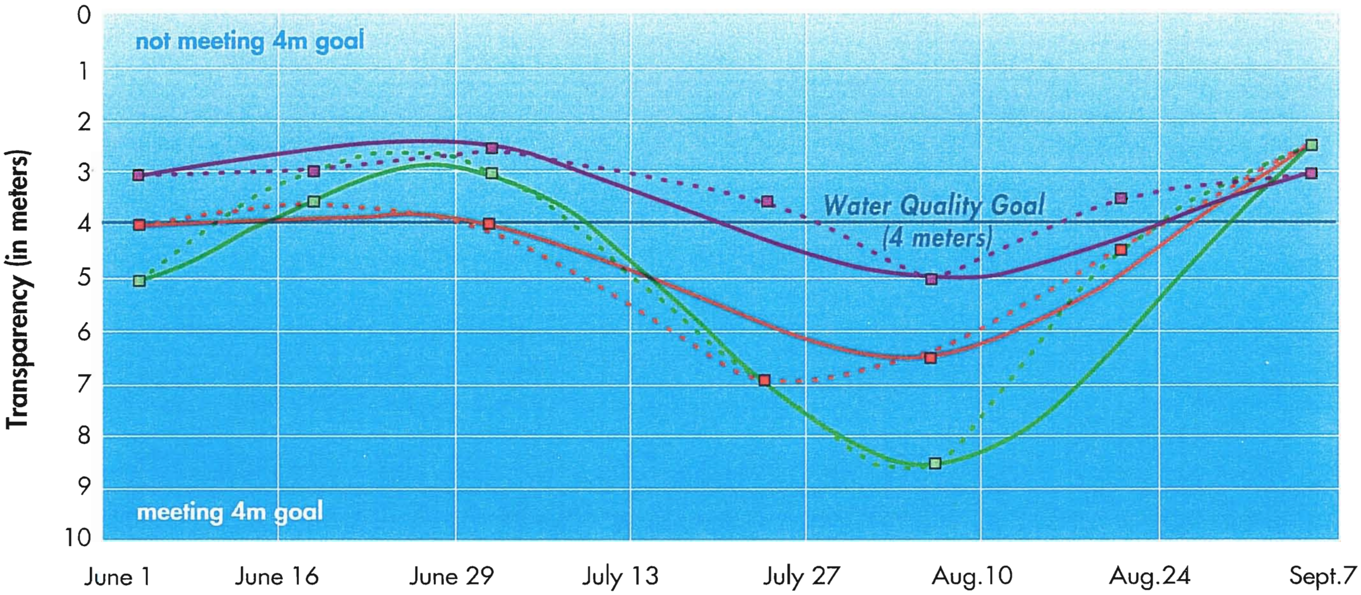
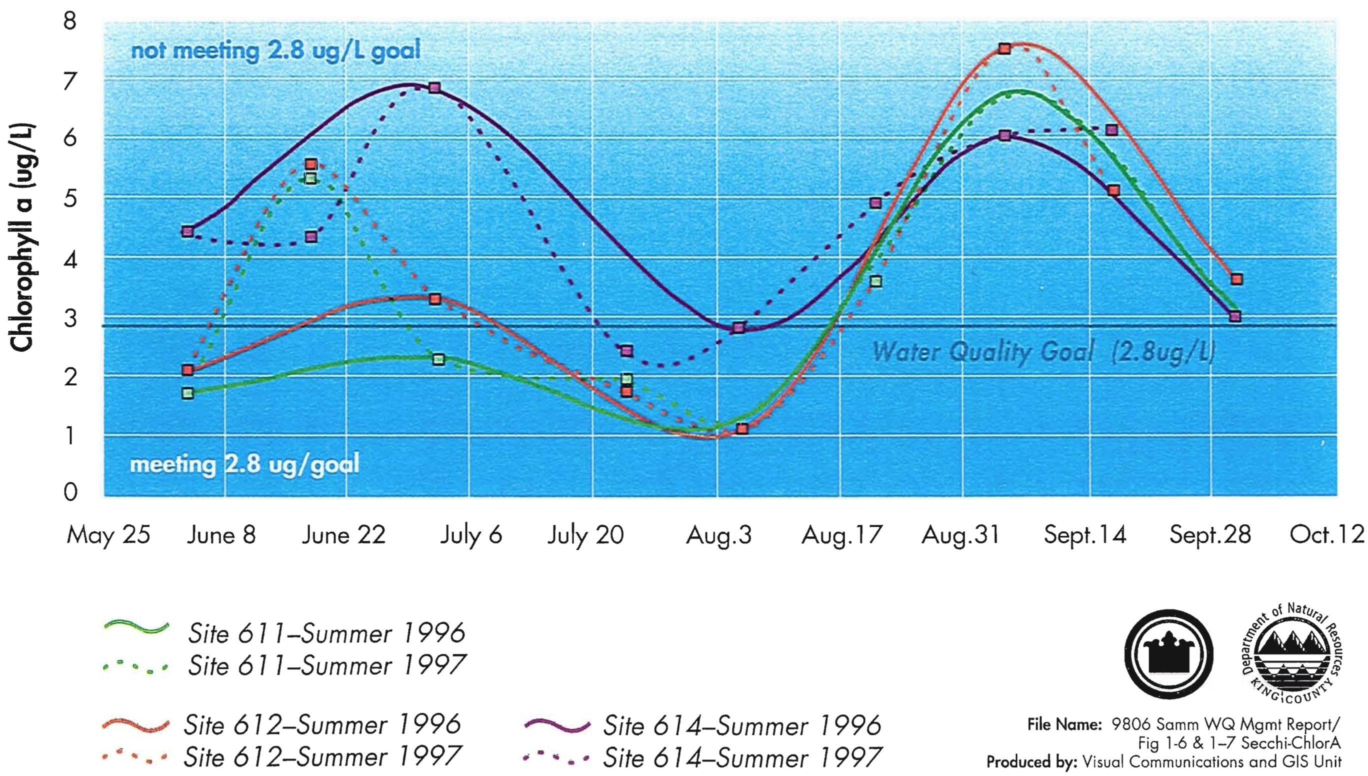


Figure 1.7

Lake Sammamish Chlorophyll *a* Summer 1996 and 1997



File Name: 9806 Samm WQ Mgmt Report/ Fig 1-6 & 1–7 Secchi-ChlorA
Produced by: Visual Communications and GIS Unit

Table 1.2 Nearshore and Midlake Concentrations of Chlorophyll a in Summers of 1996 and 1997

STATION 611-Midlake			
1996	Chlorophyll a	1997	Chlorophyll a
June 4	1.7	June 2	1.8
June 18	5.3	June 18	2
July 2	2.3	July 2	3.9
July 24	1.9	July 23	2.8
Aug. 6	1.3	Aug. 6	2
Aug. 21	3.8	Aug. 20	1.4
Sept. 5	6.7	Sept. 2	1.8
Sept. 17	5.8	Sept. 23	3.4
Jun-Sept. Mean	**3.6**		**2.4**

STATION 612- Midlake			
1996	Chlorophyll a	1997	Chlorophyll a
June 4	2.1	June 2	2
June 18	5.5	June 18	2
July 2	3.3	July 2	3.7
July 24	1.7	July 23	2.7
Aug. 6	1.1	Aug. 6	2.1
Aug. 21	3.6	Aug. 20	2.2
Sept. 5	7.5	Sept. 2	2.2
Sept. 17	5.1	Sept. 23	5.9
Jun-Sept. Mean	**3.7**		**2.9**

STATION 614 - Nearshore			
1996	Chlorophyll a	1997	Chlorophyll a
June 4	4.4	June 2	1.9
June 18	4.3	June 18	2
July 2	6.8	July 2	3.8
July 24	2.4	July 23	3.7
Aug. 6	2.8	Aug. 6	2.5
Aug. 21	4.9	Aug. 20	3.3
Sept. 5	6	Sept. 2	3.5
Sept. 17	6.1	Sept. 23	5.4
Jun-Sept. Mean	**4.7**		**3.3**

The goal for Lake Sammamish is a summer (June-September) mean of 2.8 mg/m^3

Occurrence of blooms, including toxic blooms, is greater than originally thought. A recent study by the Washington State Health Department Office of Toxic Substances, conducted by Dr. F.J. Hardy, documented bloom occurrence and identified several lakes in Washington with toxic blooms of *Anabaena* or *Microcystis* (personal communication, Dr. M. Crayton, 3/16/98). Thus, although the probability of another toxic bloom in the future is not expected to be greater than in the past, the same combination of conditions could easily occur and a toxic bloom could result. Since it is not possible to control the weather, the best protection against a bloom is to follow the phosphorus control actions in the 1996 Plan and keep as much phosphorus as possible out of the lake. Additional information about the bloom can be found on the King County website: http://splash.metrokc.gov/wlr/lakes/bloom.htm.

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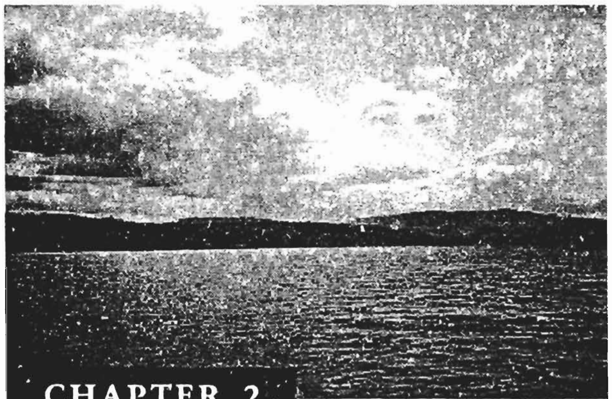

CHAPTER 2

Amended Sand Filtration with Under Drains

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Chapter 2. Amended Sand Filtration With Under Drains

Background

The primary purpose of this project was to test the effectiveness at which various sand filter amendments remove phosphorus from storm water being treated in a sand filtration facility and to install two sand filter amendments into an existing filtration treatment facility. This project was conducted by the City of Bellevue with assistance from Herrera Environmental Consultants during 1994-1997. Monitoring of the facility is being conducted separately by the City of Bellevue under separate funding from the Centennial Clean Water Fund, Grant No. TAX 91131. Monitoring began in 1995. Monitoring results are reported separately in Shapiro and Associates, 1997, 1998.

The filter amendments were installed at the City of Bellevue storm water treatment facility at Lakemont Park. The principal components of the study included:

- Installation of granular calcitic limestone into one of two sand filtration cells at the storm water treatment facility;
- Bench-scale and pilot testing of various filter amendments to determine their phosphorus removal potential; and
- Installation of the amendment recommended as the result of the tests into one of two sand filtration cells at the storm water treatment facility.

Sand Filtration Facility Design

The storm water treatment facility at Lakemont treats storm water runoff from 253 acres of single- and multifamily residential housing in the Cougar Mountain area. The treatment facility drains to Lewis Creek which discharges into Lake Sammamish.

The treatment facility is composed of several components (Figure 2.1): a flow splitter box, a wet vault for pretreatment, two sand filtration basins, and a dry pond. The splitter box "splits" the flow between treatment facilities and the dry pond. The vault and filters (treatment components) are designed to treat the runoff generated by the water quality design storm, 1.1 inches of rainfall in 6 hours (264,000 cubic feet). The wet vault contains approximately 131,000 cubic feet of live storage volume and approximately 75,000 cubic feet of dead storage volume. The filtration basins contain approximately 120,000 cubic feet of storage capacity. The dry pond has a live storage volume capacity of 1,134,800 cubic feet.

Treated flows pass through the vault and the filter basins; excess flow is bypassed to the dry pond. Flows that enter the filtration basins are collected by under drains beneath the filtration media before discharging to Lewis Creek. System controls alternate the flow between the two basins every 72 hours. Bypassed flows are released through a control structure before entering the creek.

Calcitic Lime Filter Amendment

Prior to the start of this study, analyses had been conducted on several filter media and sand samples to determine the optimal specifications for installation at the storm water treatment facility. Pilot studies conducted by Herrera Environmental Consultants (1991a) recommended sand and calcitic lime specifications for the filtration media. The specifications for the sand and calcitic lime installed at the treatment facility appear in Table 2.1.

Table 2.1 Sand Filtration Media

Sand Media[a]

Screen Analysis

Sieve Size	Percent Passage
No. 4	95-100
No. 8	50-95
No. 16	25-75
No. 30	10-45
No. 50	0-15
No. 100	0

Calcitic Lime[b]

Chemical Analysis

Compound	Concentration
Calcium Carbonate ($CaCO_3$)	98.5%
Magnesium Carbonate ($MgCO_3$)	1.2%
Silicates (SiO_2)	0.05%

Screen Analysis

Sieve Size	Percent Passing
No. 8	95.0
No. 10	80.0
No. 20	1.5

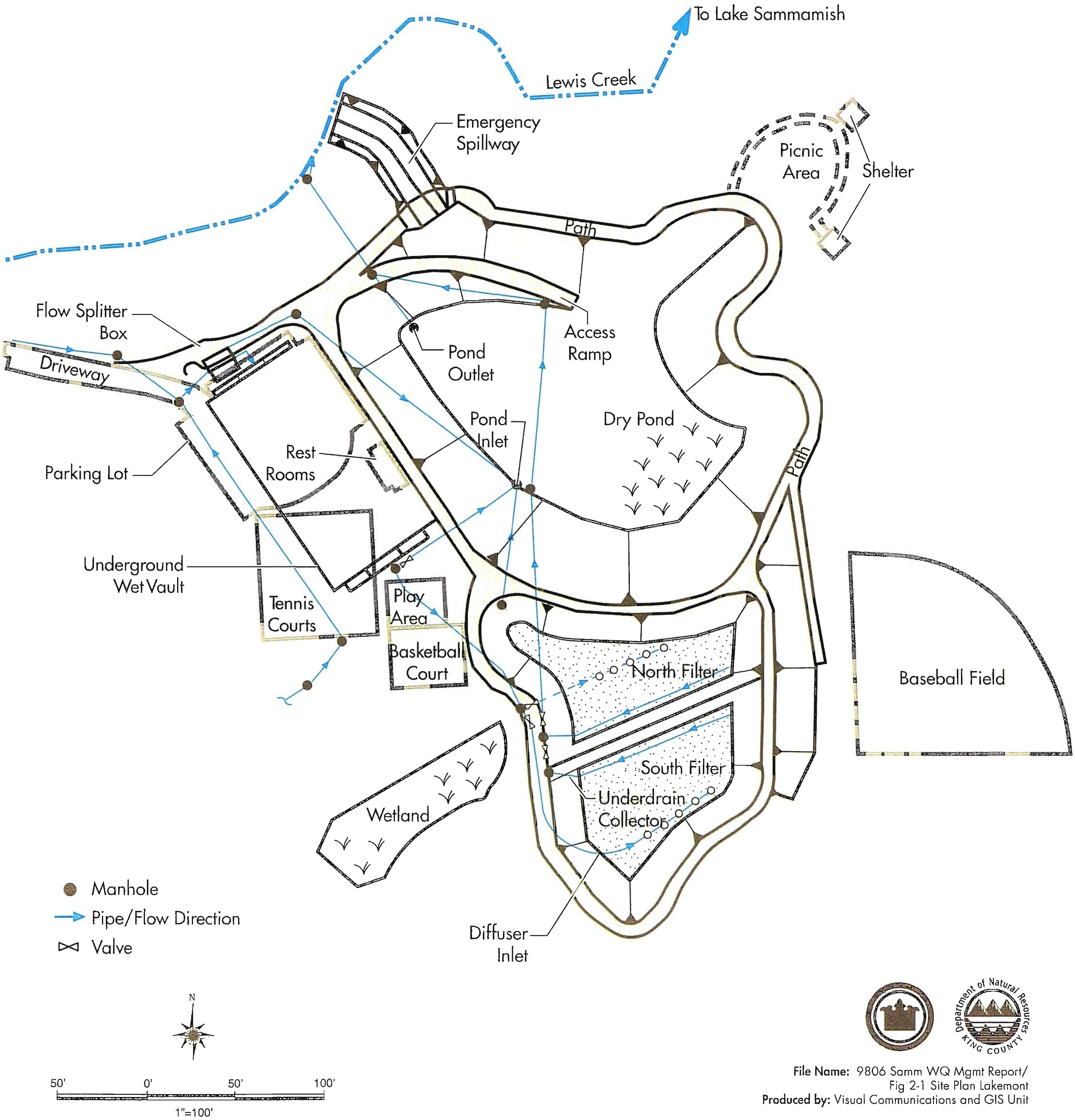
Physical Properties

pH	8.6
Moisture	0.03%
Specific gravity	2.7

a. Lone Star 8720 Sand
b. Source: J.A. Jack & Sons, Inc.

Figure 2.1

Site Plan of Lakemont Stormwater Treatment Facility



File Name: 9806 Samm WQ Mgmt Report/ Fig 2-1 Site Plan Lakemont
Produced by: Visual Communications and GIS Unit

The media in the north filter basin was installed at a ratio of 10:90 (volume to volume) calcitic lime to sand. The sand was placed in the two filter basins when the facility was originally built. City of Bellevue crews rototilled 55 tons of the limestone into the sand in the north filter basin to achieve a 10:90 calcitic lime to sand ratio. Subsequent to tilling the lime into the sand, a drought- and inundation-tolerant hydroseed was sprayed onto the surface (Herrera Environmental Consultants, 1991b). The cost of the installation appears in Table 2.2.

Table 2.2 Calcitic Lime Installation Costs

Calcitic Lime - 55 tons delivered	$2,761
Hydroseed	1,000
Sand	363
Crew Labor	2,267
Total Installed Cost	**$6,391**

Filter Amendment Bench and Pilot Scale Testing

The study evaluated the hydraulic conductivity and phosphorus removal capabilities of seven different filter media for the south filtration basin. The study was conducted in two phases. Initially, a bench scale test evaluated eight separate amendment and sand mixtures to determine which media should be evaluated more thoroughly. The amendments tested were: dolomite, calcitic limestone (as installed in the north filtration basin at Lakemont), processed steel fiber (PSF), ilmenite, alumina, iron-oxide coated sand, and hematite. A description of the various media tested is found in Chapter 1 of the Technical Appendix.

The bench-scale tests were conducted by running simulated storm water through columns containing the various media mixtures. The depth of the media in the column was determined so that the media to water volume ratio was approximately equal to the design storm condition for the full scale facility. The bench scale test found that the total phosphorus removal by the PSF was at least two times greater than other media tested, and soluble reactive phosphorus (SRP) removal was at least three times greater than other media tested. A more detailed discussion of the bench-scale test results is included in Chapter 1 of the Technical Appendix.

Pilot Testing

Based on the bench scale tests, a pilot test was conducted to evaluate the performance of three different mixture ratios of PSF. The following sand/PSF mixtures were tested:

95% sand: 5% processed steel fiber
90% sand: 10% processed steel fiber
90% sand: 10% oxidized processed steel fiber.

The oxidized PSF test column was introduced to simulate the performance of aged media. The column's physical dimensions and sand amendment depth were constructed to simulate the configuration at the storm water treatment facility. Simulated storm water was manufactured to represent expected SRP (41 - 73 µg/l), total suspended solids (TSS, 13 - 31 mg/l), and alkalinity (16.8 – 20.4 mg $CaCO_3$/l) characteristics typical of storm water runoff in the facility watershed. Flow rates through the filter media were regulated to simulate actual operating conditions.

Pilot Test Results

Test results indicate that sand mixed with PSF is an effective media for the removal of total phosphorus and SRP. Although little difference in phosphorus removal efficiency was evident for the mixtures analyzed, the ratio of 95:5 of sand to PSF consistently exhibited the highest removal efficiency (range of 65% to 87% TP removed, range of 73% to 89% SRP removed). The higher PSF volume did not appear to increase phosphorus removal. Hydraulic conductivity through the media was sufficient (range of 144 to 314 inches/hour) for application at the storm water treatment facility. Reduced dissolved oxygen and increased pH levels were observed when the media was submerged for periods longer than 48 hours. Anoxic conditions inhibit phosphorus removal and increase the potential to release the captured phosphorus from the filtration media. To minimize this possibility, it appears that the filter should be operated for a maximum of 48 hours before draining completely. The 72-hour cycle was deemed viable given the two-celled nature of the Lakemont facility. The filter should then be allowed to reaerate for a minimum of 24 hours before allowing storm water to flow back into the media. The filter basin influent and effluent should be monitored for dissolved oxygen, pH, and alkalinity to determine if raised levels have an affect upon phosphorus removal. Chapter 1 of the Technical Appendix document includes a more detailed discussion of the pilot test results.

Processed Steel Fiber Installation

A single source for the PSF was identified, the Rhodes American Company, located in the Chicago, Illinois area. The steel fiber is a byproduct of a steel component manufacturing process. In its raw form the fiber is granular, resembling a coarse powder. The fiber is coated with a spark-retardant lubricant used in the manufacturing process. Before the steel fiber could be used for the tests and installed in the treatment facility, the lubricant needed to be removed. After several methods were explored to remove the lubricant, a method of heating the steel fiber to 400° F in a batch furnace was determined to be most effective. The PSF was then packed into 1-cubic-foot waterproof sacks, placed on pallets, and shipped via truck to Bellevue.

Prior to installation of the new media, the hydraulic conductivity of the media in the north and south filter basins had greatly diminished. As a result, it was necessary to remove a layer of media from the filter basins. Approximately 9 inches of sand was removed from the top of the south basin and approximately 3 inches of sand/lime mixture was removed from the top of the north filter basin. Analysis of both media prior to removal determined that the media was acceptable for use by the City of Bellevue Parks Department as a topping mixture for the grass in City parks. Recycling the media in this way minimized disposal costs.

Sand matching the exact specifications originally placed in the filter basins was not available. Instead, a sand closely matching the specifications (Table 2.3) was mixed with the PSF. An equal amount of PSF was added to each truck load of sand prior to placement to ensure that the PSF would be evenly distributed throughout the filter. The resultant average concentration of PSF in the filter media was 4.2 percent. (An exact 5 percent mixture was not achievable due to the unpredictability of the PSF yield from the manufacturing process.) The PSF and sand were mixed by working the PSF into the sand with a bulldozer as the sand was spread across the filter basin. A 12-inch layer of the mixture was installed into the basin.

Table 2.3 Sand Specifications

October 1996 Lakemont South Cell Installation
8724 Paving Sand, Lone Star Northwest, Inc.

Sieve Size	Percent Passing
No. 4	99.5
No. 8	82.8
No. 16	51.7
No. 30	32.8
No. 50	12.1
No. 100	2.3
No. 200	0.6

The sand/PSF mixture was covered with a 6-inch layer of sand. This top layer served two purposes. Pilot scale tests indicated that the PSF had a tendency to float to the top of the mixture and clog. Thus, the layer served as a barrier to any PSF migration to the top of the mixture. Second, the sand layer could be scraped and replaced in the future without disturbing the more costly mixture layer should the top few inches become contaminated or clogged. The cost of the sand/PSF installation is shown in Table 2.4.

Media Performance

By April 1997, six months after installation of the new media, operation of the filter basins was severely hampered due to a reduction in hydraulic conductivity caused by clogging of the filter surface by fine, granular material. The hydraulic conductivity dropped to approximately one inch per hour. During the 72-hour filter cycle time, the basin containing the PSF/sand mixture often did not empty. To alleviate the condition, in June the basins were allowed to drain completely and then rototilled to break up the surface layer. The action appeared to eliminate the hydraulic conductivity problem. In order to ensure no future problems, the maintenance procedures for the facility will include regular rototilling or scraping of the top 1 to 3 inches of the media. With additional monitoring of the filter media condition, it will be possible to determine the long-term hydraulic conductivity of the two media.

A Centennial Clean Water Grant was awarded by the Department of Ecology to the City of Bellevue to monitor the storm water treatment facility for a four-year period. The study primarily monitors the phosphorus removal performance of the facility components. Annual reports for this study were completed in April 1997 and 1998 (Shapiro and Associates, 1997, 1998). The first report includes a period prior to the installation of the PSF into the south filter basin and does not evaluate the individual performance of the sand filter basins. The latter report includes a preliminary performance evaluation of the calcitic lime and processed steel fiber media.

Table 2.4 Lakemont Storm Water Treatment Facility Filtration Media Installation Costs

Item	Cost
Processed Steel Fiber	$30,595
Freight	2,700
Sand	14,646
Trucking	2,085
Construction (media mixing, heavy equipment)	28,500
Fence Removal and Reinstallation	2,217
Fork Lift Rental	232
Total Installation Costs	**$80,975**

Conclusion for Application to Lake Sammamish

At the time of this writing, preliminary performance of the calcitic-lime-amended filter and the PSF-amended filter has been analyzed (Shapiro, 1998). Based upon average concentration levels, the total phosphorus and orthophosphorus removal for the calcitic-lime-amended filter is 67 percent and 18 percent, respectively. The average concentration removal for the PSF-amended filter for total phosphorus and orthophosphorus are 68 percent and 50 percent, respectively. **Note that the removal efficiencies are based upon average concentration and conclusions regarding the relative performance of the amendments from this preliminary effort would be premature.**

Monitoring continues to evaluate the long-term effectiveness of the sand-calcitic limestone mixture and sand-PSF mixture independently. Loss of hydraulic conductivity or media clogging is a maintenance problem at the Lakemont facility. To date, this problem is being relieved by regular—every 3 to 6 months—reconditioning of the top of the media.

The results of these experimental amendments as effective means of increasing phosphorus removal from storm water in sand filtration facilities are still inconclusive. Although the preliminary monitoring results are encouraging and could significantly increase the possibility of achieving a greater than 50 percent total phosphorus removal performance standard for similar treatment facilities, the increased cost of the amendments, their negative effects on hydraulic conductivity, their long-term effectiveness, and any increased maintenance needs must be to be further evaluated before widespread application in the Lake Sammamish basin. Since on-site water quality facilities, including sand filtration facilities, are a part of the adaptive management strategy, this evaluation will be ongoing.

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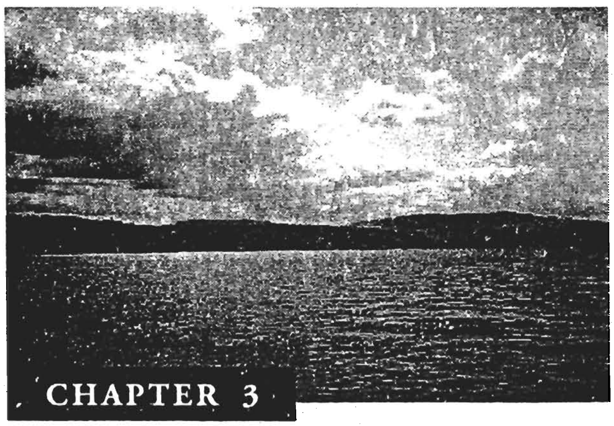

Block Alum Applications
(Alum in Checkdams)

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Chapter 3. Block Alum Applications (Alum in Checkdams)

Introduction

The Block Alum Applications project evaluated a potential "low technology" way of using a chemical called "alum" to mix with storm water runoff and extract phosphorus being transported by the storm water runoff. This work was conducted by the City of Redmond during 1994 and 1995.

Alum is a chemical compound* which uses aluminum ions to remove phosphorus $(PO_4)^{-3}$ by forming an insoluble precipitate, aluminum hydroxide. The aluminum hydroxide forms a floc and phosphorus ions adsorb onto its surface. The floc settles by gravity, thus removing phosphorus from the water column. The process occurs after the complete mixing of the solid or liquid alum with water. When alum is added to water, the aluminum ion (Al^{+3}), goes through a series of reactions with water molecules, H_2O, breaking them apart to form the compound aluminum hydroxide. $Al(OH)_3$ is the final form, and $Al(OH)^{+2}$ and $Al(OH)^{+}_2$ are intermediate forms of this compound. Additional H_2O molecules are complexed into aluminum hydroxide formation such that a white gelatinous substance known as floc or flocculent is formed. Phosphorus, suspended in the water column, is attracted to the floc and is adsorbed into it. The floc has negative buoyancy and thus settles to the bottom of a lake or pond. While it is settling, it traps suspended matter, including inorganic (silt) and organic (algae) forms that contain phosphorus, carrying these to the bottom, along with the adsorbed phosphorus.

The pH of the water is influential in the process. A pH between 6 and 8 typically produces the best results.

An additional method of removal of phosphorus is the coating of the bottom sediments in a lake or pond with the flocculent. This layer of floc seals off the potential release of phosphorus originating in the lake sediments. However, this method of removal is not considered in the following discussion due to its applicability only to "quiet" waters versus the proposed more dynamic instream and detention pond use.

The emphasis on "low technology" meant that flow measuring systems and mechanically-controlled, variable injection levels of alum would not be used. Instead the target was to find a simple way for storm water runoff to contact alum, dissolve some of it, and then allow it to bind onto phosphorus contained in the storm water. Finally, the combined phosphorus-alum material would be allowed to settle out from the runoff.

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* The composition of block alum, as sold locally, is $Al_2(SO_4)_3*14H_20$ or $Al_2(SO_4)_3*18H_20$

Initial Goals

As the project was initially formulated, its goals were as follows:

1. Remove the nutrient phosphorus from storm water using alum.

   Alum is the water treatment chemical of choice as it has a long history of use for water treatment with regard to nutrient phosphorus removal, and its use was evaluated for storm water treatment in other parts of the Lake Sammamish watershed basin. Alum is also commonly used as a water clarifier in drinking water treatment plants. The floc removes suspended sediments.

2. Implement a removal process using low technology.

   The goal of low technology is to provide an applicator which ideally harnesses local available energy for its power needs and has few moving parts. All parts should be available locally at a minimal cost. In this case, the alum applicator ideally would not use electrical service or would use gravity driven water flow as a power supply for dosing, mixing, dispersal, and self-cleaning. Another project completed in the overall program is a "high tech approach" using alum for storm water treatment for the removal of nutrient phosphorus (Chapter 6). This other project treated storm water in measured doses that were regulated by a flow meter, monitors, and pumps. It required a power supply, an all-weather access road, and an above ground, concrete block structure. Ideally the low technology approach would provide an applicator which could be used in many places with a minimum of installation and maintenance effort.

3. Implement a removal process that will be suitable as a retrofit in existing bioswales and detention systems.

   The goal of the retrofit is to design an alum applicator that can fit into an existing storm water detention system. Much of the phosphorus that comes into Lake Sammamish comes from existing developments that have detention systems and bioswales already in place. Usually these facilities are in public easements where the local storm water management agency has access. Therefore, a retrofit of these detention systems and bioswales need not require additional right-of-way negotiations.

4. Implement a removal process that will be acceptable to local, regional, and state regulatory agencies for use in aquatic environments.

   The use of alum is regulated by the Washington State Department of Ecology. This project would put alum or alum by-products into streams and swales. If the project is to be successful, it must satisfy Ecology (and other agencies) that its use will not incur acute or chronic toxicity in the aquatic environment.

5. Remove phosphorus from storm water using an inline process as opposed to a batch process.

The project proposes to add alum to storm water as an inline process. Previous uses of alum in the area have been batch processes. An example of a batch process is the one- or two-time treatment of a lake or pond. Here the necessary water quality parameters are determined prior to treatment and alum dosing is based on the goals of the treatment and water quality data gathered. The inline process treats storm water as it goes by the applicator, regardless of its water quality. This means the alum applicator, in order to effectively remove phosphorus, has to provide a dosage which varies with the rate of storm water flow.

Although the original goals of the project were not achieved, the remainder of this chapter describes the findings of the research, and the relation of these findings to the project goals.

Key Questions

Several key questions emerged from the goals. These questions, and a summary of information found in this project to answer them, follow:

A. What are the relevant physical and chemical properties of alum, including the dissolution rate of solid alum?

- The dissolution rate of solid alum could not be determined from the literature available. Specifically sought were tables, graphs, charts, or field data that related instream water velocity and temperature to a rate of flux of the solid alum to a liquid form. Frequently the literature reviewed described the process as " . . . the solid alum was mixed until it was dissolved . . . and the lake was treated . . . "

- Solid alum is a more compact form of aluminum than liquid alum. Unbroken solid alum occupies 40 to 50 percent less space than liquid alum for the same treatment efficacy. However, if it is broken into chunks, and if one assumes a porosity or void space of 30 percent then space reduction changes to 10 to 20 percent.

- Researchers that have studied the effects of alum treatment can cite many cases of alum treatment of lakes where no harmful effects were observed. However, they state that the long-term effects of alum dosing are unknown, as there are few studies of long-term effects.

B. What are the dosing rates of alum based on levels of storm water flow?

- The dosing of alum is based on the amount that will keep the pH from dropping below 6.0. An effluent pH below 6.0 is considered toxic to the aquatic environment. The aluminum ion (Al^{+3}) by itself is considered toxic.

- A common dosing rate found was 10 mg of aluminum per liter of storm water to be treated. Lesser rates did not perform optimally and greater rates dropped the pH of the solution to a level near 6.0. However all rates are subject to the alkalinity and pH of the influent storm water. Researchers have found that all the different forms of phosphorus available to plants may not be removed unless an optimum dose is used. Part of the dosing determination includes an effort to keep the pH between 6.0 and 8.0.

- The Al^{+3} ion, considered to be the most toxic of the alum treatment process, is short-lived if the pH of the treated storm water is above 6.0. Concentrations of the ion were found to drop to an approximate level of 50-100 μg/l within 60 seconds after flash mixing.

C. What concerns should there be about the flocculent produced and its downstream impacts?

- Flocculent is a whitish gel residual that coats whatever it settles on.

- Flocculent information was usually in the context of a settling pond environment, either at the location of treatment or a short way downstream. Discussions were made about flocculent and water quality in the context of 30 minutes, 3 hours, or 24 hours after dosing.

- Flocculent tends to concentrate other contaminants also. Researchers found anomalously high *E. coli* bacteria counts in flocculent after a lake was treated. Hence human contact with the flocculent should be restricted after dosing.

- In the case of bioswales, resident time of the storm water is one to three minutes. Detention systems may have detention times of several hours for larger storms. Both of these systems can have turbulent flow.

- If deposited on the ground as a result of overland flow, flocculent will dry out and form a bioavailable form of phosphorus that is a stable mineral called gibbsite. Drying time is unknown. If the flocculent is deposited underwater, the conversion to gibbsite may take as long as a year.

- Flocculent may not be acutely toxic, however chronic toxicity has been documented in aquatic invertebrates (Harper, 1990). Flocculent may also have a smothering effect on biota beneath the floc.

D. What are prior uses of alum as an inline process?

- Documentation for the use of solid alum as an inline process was not found. Two proposals for the use of solid alum were found. The first one provided the source for the goals and specific objectives used in this project.

- The idea for the use of alum in checkdams came from a proposal put forth in 1991 by Tom Smayda of Harper Owes Engineers, Inc., Seattle. Mr. Smayda had obtained the idea from reading about the use of block limestone (calcium carbonate) in streams affected by acid rain. These streams were in Sweden. Mr. Smayda suggested the permanent use of block alum in checkdams as a way of mitigating the release of phosphorus from the construction of a proposed subdivision on the southwest shoreline of Lake Sammamish. Mr. Smayda proposed the use of block alum in bioswales. These bioswales were part of the water quality management plan proposed for the subdivision.

- Another proposal for the use of alum in checkdams came from Dr. Richard Horner of Seattle, Washington to the City of Portland. The proposal advocated research on the use of chemicals to remove phosphorus from storm water. Dr. Horner proposed an investigation using alum in checkdams for phosphorus control in the Tualatin River Basin.

- The use of liquid alum for inline treatment of storm water was found. Liquid alum was injected into the storm water pipes prior to their flowing into an urban lake, Lake Ella, in Tallahassee, Florida. The treatment was performed from 1987 to 1990 for the restitution of the lake. Fortunately the information obtained was well documented regarding the procedures and investigations performed. These investigations were centered on the alum treatment's effectiveness and toxicity for the period of study. Further discussions of this study are in Chapter 2 of the Technical Appendix and in Lamb and Bailey, 1981.

E. What are the policies of the regional and state agencies on the use of alum?

- The only written policy found was that of the Washington State Department of Ecology. The text of the policy, in memo form, is given in Chapter 2 of the Technical Appendix document, along with the full technical report for this project.

- On July 25, 1990, Ecology issued a memo that provided its position on the use of alum in lakes. Since this project worked towards the use of alum in the Lake Sammamish watershed, the policies put forth in the memo were significant. The Ecology memo recommended many procedures. These procedures were very influential as they are extensive, expensive, and time-consuming to follow. Specific direction on which of these guidelines to follow was not provided by Ecology, therefore it was assumed that these guidelines would be in effect throughout any research which allowed release of alum dissolution species and alum floc into the environment.

- Ecology expressed the following concerns in the memo:

  ⇒ Few scientific studies have been performed on the long-term effects associated with the use of alum in lakes; long-term effects of alum use are unknown.

  ⇒ The creation of a waterbody acidity with a pH lower than 6.0 is not acceptable. This pH level is considered to be at the toxic threshold for fish and invertebrates.

  ⇒ The long-term toxicity of bioavailable aluminum in the treated water body is a serious concern.

Potential for Future Applications

Low Technology Approach

The desire to use solid alum in checkdams as a low technology retrofit option implies that the following elements exist in a storm water treatment scenario:

- Solid alum is used.
- Treatment occurs in the detention system or bioswale (usually near the lowest point of the retrofitted subbasin).
- The majority of the flocculent produced would be captured by the grass stems in the bioswale and the biologically available phosphorus captured could thus be removed by routine maintenance of the bioswale/detention facility.
- All the influent storm water is treated.

To address concerns about the use and effects of a low-tech alum system, a three-phase approach was envisioned:

Phase I would be to develop a research program that would determine the dissolution rate of solid alum in a stream of water. Its elements would include:

- Determination of the dissolution rates at varying temperatures and velocities. These two parameters usually play a major role in a dissolution rate study.
- Determination of the dissolution rate changes by varying other water quality parameters, e.g., hardness, pH, TSS, etc.

Phase II would use the findings of Phase I to develop one, or possibly two, prototype applicators that dispense solid alum for storm water treatment. A period of prototype development would be necessary, consisting of testing and modification with controlled discharge (perhaps to a sanitary sewer).

Phase III would be placing full-size systems in two locations for field-testing with actual storm water runoff. Performance would be monitored, evaluated, and summarized in a technical report. The technical report would be the basis for judging the safety and acceptability of general use of this potential technology.

Costs and time requirements were not detailed but appeared to be beyond the cost/time parameters set for the initial work on this potential technology. The approach may hold potential due to its target simplicity (and, therefore, low cost). It is not a method for near-term, widespread application in the Lake Sammamish basin and, at this point, could not be counted upon as a potential technology unless it proved safe and acceptable following additional research. The limitations regarding flocculent discharge or disposal appear to be a significant barrier to the design of a cost-effective application.

Moderate Technology Approach

A potential alternative to the low technology approach, but not as "high tech" as the methodology described in Chapter 6 could emphasize "moderate" technology as an approach. This option is presented in recognition of accurate dosing (and buffering) used by all the researchers in the publications reviewed. The course of "moderate" technology would allow for the following:

- use of liquid alum and peristaltic pumps for alum dispersal;
- use of a solar panel or storage batteries for a power supply at remote sites;
- more compact size and more applicator deployment options; and
- use of flow meters, data collector and data analyzer, pH sensors, and pump controllers.

An example of moderate technology would be the use of the automatic samplers for storm water quality and the use of storm drainage structures known as 48-inch diameter Type II catch basins. Some of the automatic storm water quality samplers can be equipped with 5-gallon containers and still fit inside the Type II catch basins. If these units are used to pump doses of the liquid alum from the 5-gallon container, based on a signal from a flow sensor/data logger, then the storm water could be dosed and flashed mixed at numerous points upstream of the detention system. In a conservative estimate, if the dose were 10 mg/l, then 5 gallons of liquid alum could treat approximately 5,400 cu. ft. of storm water; at 2.5 mg/l the 5 gallons of liquid alum could treat 22,000 cu. ft. Relative to a 10-acre subdivision, the following flow quantities were estimated for the respective 24-hour precipitation: 5420 cu. ft for 0.5 in., 2100 cu. ft. for 0.3 in., 990 cu. ft. for 0.2 in.

A further variation might be to continue development of a solid alum applicator which fits in a Type I (18" x 22") or a Type II catch basin and would use incoming surface runoff mixed with solid alum to drip a measured dose of alum into the stormdrain pipe below. Although simpler in concept, this option would require development of the dosing apparatus for the alum, the investigation of solid alum's dissolution rate, and possibly development of a dosing apparatus for the alum buffer.

Either option would allow for the application of alum at many locations in the urbanized drainage basin. The prerequisite of having the applicator at the detention pond and/or bioswale for storm water may not be required. An "upstream" applicator would probably be easier to service (in the street versus in a detention easement) and have no visual impact or elements of being an attractive nuisance. Impacts of flocculent production and acceptance by regulatory agencies are seen as common challenges to these or any other instream alum applicator. It may be found that for the best removal of alum floc, a minimum of 30 minutes of ponding time is required in a detention pond. This requirement poses a further application challenge. In addition, since the optimal removal of bioavailable phosphorus requires the use of a buffer, appropriate buffer dosing would need to be evaluated in any test of potential applications. Also it may be found that for the best removal of alum floc, a minimum of 30 minutes of ponding time is required in a detention pond.

If further "low tech" or "moderate tech" efforts involving the use of block alum for treatment of storm water are to be pursued, the technical report for this project (Chapter 2 of the Technical Appendix to this report) should be consulted for useful information, including an annotated bibliography.

Conclusion for Application to Lake Sammamish

The use of solid alum as a low technology, in-stream process or moderate technology retrofit for catch basins, may have potential application, but concerns about safety and acceptability of its use as well as its viability in a minimal maintenance environment, would need to be more thoroughly investigated and documented prior to any general use.

At this time, the low and moderate technology approaches using block alum for phosphorus removal cannot be considered a viable, ready to apply option for runoff treatment. The method is not being considered as a potential technology for phosphorus management in the Lake Sammamish Basin. However, the evaluations of this project represent a conservative approach to the introduction of alum-based flocculants to surface waters. The approach may have utility in situations where the release of these flocculants could be carefully controlled, such as at large construction sites. Such applications were not evaluated in this study.

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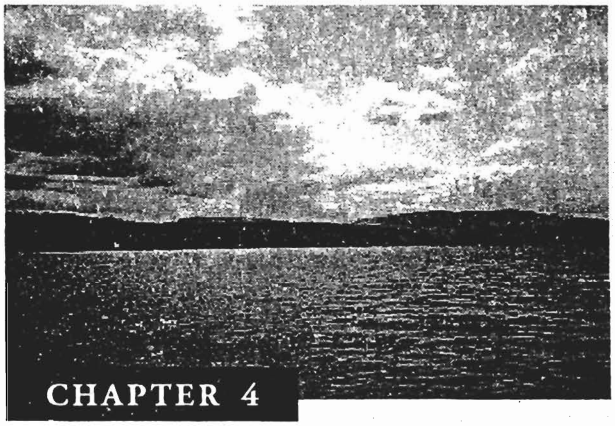

CHAPTER 4

Soil Amendment Research

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Chapter 4. Soil Amendment Research

A. Literature Review and Laboratory Evaluation of Soil-Phosphorus Interactions Using Compost Amendments

A.1 Literature Review

Introduction The purpose of this part of the Lake Sammamish Water Quality Project was to evaluate the use of compost as a soil amendment on the nature and solubility of phosphorus through a literature review and a laboratory evaluation. This project was conducted by the College of Forest Resources at the University of Washington and the City of Redmond during 1994 and 1995. Test plots were located at the Center for Urban Horticulture.

Compost amendments have been suggested as potentially useful to tackle specific environmental problems such as improving water quality through environmental restoration of disturbed sites, and treatment of runoff from polluted sites. Compost has been shown to be relatively effective at increasing infiltration and retention of water, and is highly adsorptive of oil and trace metals. It may also have potential for the adsorption of phosphorus which can be a source of pollution in some lake systems.

The first step in understanding whether or not compost amendment to soil could serve as a tool in water quality protection was to evaluate what is known and what has already been done in this regard. A literature review of the potential effects of compost amendment to soils on phosphorus properties in the soil and runoff was performed.

Project Overview The following is a short summary of the literature review, reprinted in its entirety in Chapter 3 of the Technical Appendix. It covers literature in some detail that is pertinent to how compost might affect soil-phosphorus interactions. The first section considers the nature of phosphorus in soils, including types of phosphorus in soils, inorganic and organic phosphorus retention mechanisms in soils, and the nature of the physics, chemistry, and biology of phosphorus solubility.

A second section considers how compost can potentially affect the pathways of water over or through soil and how compost amendments can affect water retention and soil interactions. It concentrates on how compost amendment might enhance water holding capacity, and increase infiltration and interaction of water with soil.

A third section considers the potential and known effects of compost amendment to soil and soil factors that affect phosphorus solubility. It concentrates on compost as a source of phosphorus, the effect of compost on soil organic matter, how compost can affect soil inorganic properties, the effect of compost on water retention and flow pathways, how compost may affect soil erodibility, and the use of composts as an alternative to inorganic phosphorus fertilizers. The technical report in Chapter 3 of the Technical Appendix should be consulted for detailed information.

Project Conclusions Composts are variable materials, just like soils. The potential for changes in phosphorus runoff from compost amendment of soil depends on a variety of factors. Where composts are used to amend phosphorus-deficient soils, such as Alderwood subsoils, phosphorus will generally be more soluble, with a higher potential for leaching additional phosphorus. However, enhanced plant growth and soil aggregation in compost-amended soil compared to infertile soils will likely result in increased water percolation, longer soil-water contact times and less erosion of surface soil. This would act to reduce phosphorus levels in runoff.

Thus, the final result in terms of the amount of phosphorus in runoff from a particular land area is not well defined. Most of the phosphorus in compost is generally organic and insoluble, as compared to inorganic fertilizers, where the majority of phosphorus is soluble. Where compost is used in place of inorganic fertilizer, the final effect on phosphorus in runoff is likely to be a reduction for similar application levels. Phosphorus in inorganic fertilizer is generally soluble and the soil does not receive any of the increased percolation and water-holding advantages associated with the compost.

Phosphorus in runoff from soils receiving inorganic phosphorus in fertilizers could be extremely high, particularly if fertilizer is added during periods of high runoff and low plant uptake.

A.2. Laboratory Evaluation of Phosphorus Retention Properties of Compost Soil Amendments

Introduction and Project Overview A laboratory study was completed to determine: 1) whether soil amendment with compost will potentially increase or decrease phosphorus retention by soil adsorptive mechanisms; and 2) what the loading rate of phosphorus fertilizer would be that could meet the water quality objectives of the City of Redmond for compost-amended soil. This report includes results from a bench-scale study to determine the potential for a local-phosphorus compost (Cedar Grove compost) used as a soil amendment to increase plant-growth qualities of soil to adsorb phosphorus, and to determine the mechanisms of phosphorus retention and ultimate phosphorus adsorption potential for an Alderwood subsoil and compost/soil mixture. The following report is a short summary of the entire study, which is in Chapter 3 of the Technical Appendix.

Summary of Results A major objective of this study was to demonstrate whether compost amendment to soil would result in changes in retention or release of phosphorus to equilibrating water. The results of these studies show that chemically, compost is a nutrient-rich material compared to Alderwood subsoil, with about 200 mg/kg of total phosphorus in the Alderwood subsoil and about 800 mg/kg of total phosphorus in the soil and compost mixture. It is thus no surprise that more total phosphorus and soluble phosphate is released from the phosphorus-rich soil/compost mixture than from the Alderwood subsoil, which is very low in total phosphorus and extremely low in soluble phosphate. At high phosphate-phosphorus addition levels, both Alderwood subsoil and soil/compost mixtures are capable of adsorbing high amounts of phosphate, but the control concentrations (about 3 mg/l for the soil-only and 5 mg/l for the soil/compost mixture), are much higher than desirable for surface water runoff.

The results of these studies show that an Alderwood subsoil or soil/compost mixture is capable of adsorbing considerable amounts of phosphate when water high in phosphate concentration is equilibrated with it. When water with no or very low phosphate concentrations is equilibrated with Alderwood subsoil, very little phosphate is released from the soil into solution. When water is equilibrated with the soil and compost mixture, an equilibrium solution concentration of 0.95 mg/l total phosphorus was measured. As solution phosphate concentrations are increased, the equilibrium phosphate concentration also increases, resulting in a higher phosphorus concentration in water with compost addition.

Based on observations of a solution phosphate maximum concentration and thermodynamic analysis of solutions, soil or soil/compost pH seems to be a primary controlling factor for phosphate retention at high phosphate addition levels. However, this was not directly tested in this study. With high concentrations of phosphate in water added to these systems (as occurs during lawn fertilization), the primary determinator of phosphate concentration of runoff will be the degree of interaction of the solution running off the land with the soil or soil/compost mixture. This was also not considered in our laboratory experimental design, where all solutions were forcibly leached through a soil column.

Conclusions The potential for retention and release of phosphorus from glacial till subsoil and compost-amended subsoil was evaluated with a laboratory study. The study results indicate that phosphorus-enriched organic materials, such as compost, can increase phosphorus availability in amended soils, and that waters mixed to equilibrium with such materials have the potential for higher phosphorus concentrations. Results also showed that there is high retention capacity in both native soils and compost-amended soils, but that the addition of compost does not increase the ability of an Alderwood subsoil to remove phosphorus from water that passes through it. This study did not evaluate any changes in soil contact time that might be caused by increased percolation from compost treatment. Since the degree of interaction of moving water with soil or soil/compost mixtures was equivalent in this study, but would likely not be in the field, it would also be extremely important to evaluate the effect of physical properties on the ultimate nature of water running off of a disturbed area. Such studies have not been completed as far as is known.

B. Field Evaluation of Phosphorus Retention Properties of Compost Soil Amendments

Introduction and Project Overview The University of Washington College of Forest Resources and City of Redmond examined the effectiveness of using compost as a soil amendment to increase surface water infiltration and thereby reduce the quantity and/or intensity of surface and subsurface runoff from land development projects. In addition as part of the Lake Sammamish Water Quality Project, the compost amendment was evaluated for its ability to reduce the transport of dissolved or suspended phosphorus (P) and nitrogen (NO_3) from drainage waters. Currently, due to the wide distribution and inherent stability of till soils in the region, most residential housing developments are sited on the Alderwood soil series, which is characterized by a compacted subsurface layer that restricts vertical water flow. When disturbed (and particularly when disturbed with cut and fill techniques such as are used during residential or commercial development), water flow patterns are changed due to restricted permeability. A horizontal flow of water on the surface and subsurface develops and contributes to excessive overland flow, especially during storm events. This flow leads to increased transport of dissolved and suspended particulates into surface waters.

Compost is effective in improving the soil's physical properties of porosity, continuity of macropores, and water-holding capacity. The changes in the soil directly influence soil-water relationships. It is clear that the chemical properties of compost can also be valuable in some cases, such as in complexing potentially harmful trace metals including copper, lead, and zinc. Under this premise, this study examined the effectiveness of using compost to increase storm water infiltration and water holding capacity of glacial till soils. Additionally, the study examined whether or not increasing the infiltrative and retentive capacity of glacial till soils (Alderwood series) can increase the contact with, and retention of, phosphorus and nitrogen by soil absorptive mechanisms, and the production of phosphorus and nitrogen in surface and subsurface runoff by unamended and amended soils during rainfall events.

The study utilized the existing Urban Water Resources Center (UWRC) project site at the University of Washington's Center for Urban Horticulture (CUH) for conducting the study. The study used the UWRC design of large plywood beds for containing soil and soil-compost mixes. These beds were located at the College of Forest Resources CUH at the University of Washington. Plots were amended with two different commercially available composts, Cedar Grove and GroCo. Water was supplied from a nearby existing water supply system and used to simulate actual rainfall conditions. Simulated rainfall events of varying intensity were scheduled to characterize infiltration rate, quantity of water flowing overland and subsurface, quantity of water leaving study plots, and water quality leaving study plots. Samples were taken from March 7 to June 9, 1995. Detailed study methods are described in Chapter 3 of the Technical Appendix.

Summary of Results The results of these studies clearly show that compost amendment alters soil properties known to affect the water relations of soils, including the water holding capacity, porosity, bulk density, and structure, as well as increases soil carbon and nitrogen, and probably other nutrients as well. Results also show that compost amendments affect water runoff patterns during and following storm events, and runoff of nutrients from unamended vs. amended sites. In all cases, compost amendment increased the lag time of response of a soil runoff hydrograph to a storm event, increased the time to peak flow, decreased the rapidity of drop in the hydrograph following cessation of the storm event, and increased the "base flow" in the period following the storm event. The amendment increased the peak storage and field capacity of plots nearly 100 percent and reduced the total runoff, depending on the intensity and duration of the storm event (i.e., small storms = little or no runoff; large storms = almost complete runoff). Following one storm with another showed that antecedent conditions were very important in determining total runoff from a particular storm event.

These observations were true of both the Cedar Grove and GroCo amendments. However, one GroCo:soil mixture appeared to have a much higher water holding capacity than the Cedar Grove:soil mixture. This is probably due to the fact that the GroCo is made with biosolids, and contains much more finely divided and decomposed organic matter as well as flocculents designed to precipitate suspended material from water during the water treatment process. GroCo amendment also had a more pronounced effect on increasing lag times and base flows.

Nutrient production from sites was highly variable. Following intense leaching during the winter of 1994 and spring of 1995, concentrations and total runoff of phosphorus were slightly higher from compost-amended sites. Nitrate concentrations and runoff were about the same. However, there was insufficient grass growth in unamended sites, even following an establishment fertilization, so an additional fertilizer addition was made. The compost-fertilized site was very attractive and needed no fertilization. In fact, an initial establishment fertilization probably was not necessary either based on studies of turfgrass growth in compost-amended soils without inorganic fertilization at test plots at the University of Washington on similar soils. Following the fertilizer addition in the control plots, 72 percent of the phosphorus fertilizer added immediately ran off the site during the first storm following fertilization. This resulted in a 200-fold increase in phosphorus runoff during a single storm. The fertilizer did seem to increase the rate of grass growth. Nutrient concentrations rapidly decreased over time in the control sites.

The limited results available from these studies point out the necessity of conducting a field study that incorporates sufficient repetitions, time, and fertilization regimes to establish similar turfgrass. Unfortunately, a lot of effort was spent on development of methods to conduct this study, since no similar studies had been conducted previously.

Total loss of nutrients in runoff was affected by compost amendment, but primarily due to the lowering of total runoff volumes and not due to lowering of nutrient concentrations in runoff. Compost-amended turfgrass was uniformly beautiful, and required little or no fertilization, which is a definite positive aspect of compost amendment. The poor quality of the unamended plots would likely have resulted in additional nutrient application in a development setting. However, when fertilizer was added, almost all of the phosphorus fertilizer was lost during the next storm event. This resulted in greater nutrient loss from unamended sites than from compost-amended sites. The biggest benefit of compost amendment may be reduced need for further lawn fertilization.

Conclusions The results of this study clearly show that compost amendment is likely an effective means of decreasing peak flows from all but the most severe storm events following very wet antecedent conditions. An added benefit of amendments is that base flow increases in antecedent conditions following storm events. The relative increase in water holding capacity with compost amendment showed that storms up to 0.8 inches total rainfall would be well buffered (i.e., not result in significant peak flows) in amended soils, whereas without the amendment, significant peak flows would occur with storms of about 0.4 inches total rainfall.

Differences in the sites were attributed more to the changes in water flux rates than to water chemistry, but both accounted for the lowered phosphorus with compost amendment. The results of this study suggest that the promise of the use of organic amendments can improve water-holding capacity, runoff properties, and runoff water quality in Alderwood soils converted to turfgrass from urban development. The variability of results indicates a need for larger-scale field confirmation (with replicated plots) of the results from these constructed research plots. Ideally, any future study would include a turf established with other common commercially used methods, such as the practice of placing sod directly onto glacial till soil and the use of phosphorus-free fertilizer.

Future Directions

Application of compost material similar to that in this study would be possible by applying 4 inches of compost onto the surface of an Alderwood soil and tilling to a total depth of 12 inches, including the compost amendment (8 inches into the soil). Such mixing would need to be thorough and deep to achieve the conditions of this study, and would be difficult to achieve with most existing equipment. If the compost was well incorporated into the soil, however, most of the benefits of amendment seen in this study could be expected from a field application.

The resources available to this study were largely consumed in the development of an effective sampling system. Although there will always be similar problems in such studies, a lot more could be gained from additional work on the CUH sites. For instance, a range of medium-intensity simulated storms needs to be run, and longer-term evaluations could be made since all plots are likely to change in chemistry and structure over time. Two critical questions need to be answered:

1) Is the compost amendment permanent?
2) Will the properties of the unamended site improve with time?

If these question could be answered using these sites, the long-term effectiveness of the amendment as a mechanism for both storm water quantity and quality control could be evaluated. In addition, a series of field trials would ideally be created, with the area of compost-amended vs. unamended evaluated for runoff into a small catchment. Whether or not such a site exists is not easily answered here, but such a test of the use of compost would be the ideal means to evaluate its effect on runoff quantity and quality. Ideally, any future study would include a turf established with other common commercially used methods, such as the practice of placing sod directly onto glacial till soil.

Conclusions for Application to Lake Sammamish

The results of this study are too preliminary to be applied to current management practices. However, the results discussed here and the results of the companion hydrologic studies (Kolsti, et al, 1995) that demonstrated the compost amended soils have the ability to reduce total runoff volumes by up to 70 percent suggest that further evaluation of soil compost amendments on the quantity and quality of storm water runoff from residential and commercial sites is warranted. In particular the study shows that the application of fertilizers prior to storm events results in significant loss of nutrients in runoff and that the use of soil amendments such as Cedar Grove compost may reduce the need for additional application of fertilizers to turf grass. Additional evaluations are being done by the City of Redmond and the University of Washington prior to application.

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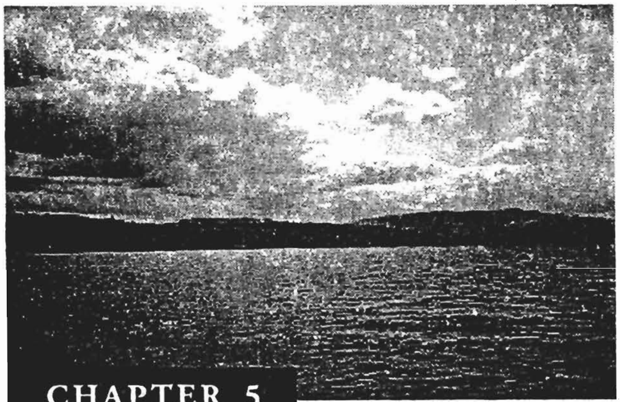
CHAPTER 5

Iron-Oxide-Coated Sand Project

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Chapter 5. Iron-Oxide-Coated Sand Project

Background

The primary purpose of this project was to test the effectiveness of iron chloride in solution and iron-oxide-coated sand as a filter medium to remove phosphorus (both total phosphorus - TP, and soluble reactive phosphorus - SRP) from synthetic and real storm water in a laboratory environment. The studies were completed by the Department of Civil Engineering at the University of Washington during 1995. At or near neutral pH, trivalent iron forms iron hydroxide flocs that can bind certain forms of phosphorus. If these flocs can be subsequently settled or filtered out of the water, the phosphorus is removed along with them. However, separation of the iron flocs from the solution can be problematic.

The project was based on experimental results that demonstrated that iron oxide coated sand, (IOCS), a thin coating of iron oxide that is strongly attached to silica sand grains, has the ability to remove soluble and particulate phosphorus from aqueous solutions (Benjamin, et al., 1995). Passing water through a column packed with IOCS removes the phosphorus from solution in much the same manner as occurs when water contacts iron oxide flocs, but the problem associated with solid/liquid separation is eliminated (Bailey, 1992; Benjamin et al., 1995). The objectives were to assess the effectiveness with which phosphorus could be removed from storm water by two iron-based solids, IOCS and an iron hydroxide precipitate. The full project report, Treatability of Phosphorus in Storm water Using Ferric Chloride and/or Iron Oxide Coated Media by M.M. Benjamin (1996) is reprinted as Chapter 4 in the Technical Appendix.

Experimental Design

The project included experiments in which synthetic and real storm water were treated by exposure to an iron hydroxide precipitate (prepared from iron chloride, $FeCl_3$) and by passage through filters packed with IOCS. The treated solutions were analyzed for total reactive phosphorus (TRP), soluble reactive phosphorus (SRP), and total phosphorus (TP), as well as other constituents of interest.

Removal of Phosphorus by Iron Oxide Flocs

The first treatment used solutions of iron chloride ($FeCl_3$) in various concentrations of 0, 0.4, 0.8, 2.0, 5.0, and 10.0 mg Fe/L to react with synthetic solutions of both SRP and TP in a batch reaction chamber. The pH was adjusted to 6.5 and was monitored and maintained throughout the tests. Continuous mixing maintained the suspension. Samples were taken at 25 minutes, 1.5 hours, and 3 hours and measured for SRP and TP content. Preliminary tests showed that longer contact times did not improve the removal significantly.

Removal of Phosphorus by IOCS

Adsorption isotherms for the binding of phosphate to IOCS were developed at pH values of 5.0, 6.5, and 8.0 using stock phosphate solutions and IOCS. Adsorption density (g P/g sand) was calculated based on the SRP concentration at the end of the equilibration step in conjunction with a mass balance analysis.

Batch tests were then conducted to evaluate the kinetics of phosphorus adsorption onto IOCS. This treatment option used plexiglas columns packed with IOCS prepared using the methodology described in Benjamin, et al. (1995) and various influent solutions. Columns were treated with deionized water amended with either 50 or 200 µg P/L, filtered Lake Washington water with 200 µg P/L, and filtered and unfiltered storm water. Samples were taken at regular intervals. Reaction times and TP and SRP removal were measured. After Run 9 and 10, the IOCS was regenerated, and a final run was completed to compare the results of regenerated IOCS to fresh, unused IOCS. Details for regeneration using NaOH are included in the complete project report. All chemical analyses were performed using standard methods as described in the complete project report.

Experimental Results

Removal of Phosphorus by Addition of Iron Chloride

The results indicate that flocs resulting from iron chloride concentrations of up to 5 mg Fe/L adsorb soluble reactive phosphorus (SRP) effectively and rapidly from synthetic solutions of storm water, but have little impact on particulate phosphorus. Concentrations above 5 mg Fe/L and contact times greater than 25 minutes did not increase removal of SRP. Removal occurred via adsorption to the settled floc. Apparently most of the particulate P did not associate with the settled flocs.

The effective use of iron chloride to treat storm water in a detention facility would be dependent upon the ability to separate the flocculated solids from the solution. Nevertheless the initial laboratory test results suggest that the use of iron chloride might be a feasible P-removal process for areas with high SRP in storm- or runoff water if the floc could be removed from the detention system efficiently. The opportunity to use such a treatment as a secondary treatment following initial settling of particulate material may also be feasible.

Removal of Phosphorus by IOCS

The results of the adsorption kinetics tests showed that the majority of adsorption occurred in the first several minutes, although phosphate removal continued for at least 100 minutes. The capacity of the IOCS to adsorb phosphorus was also greater at lower pH.

Removal of phosphorus from real and synthetic storm water through the use of columns packed with IOCS showed that the majority of phosphate loss occurred in the first several minutes (two to 20) of contact time. Effective removals were observed consistently with five minute empty (column) bed contact times. The columns effectively removed almost all phosphorus from synthetic storm water, i.e., deionized or lake water with phosphorus added. Fifty to 60 percent SRP was removed from real storm water that was prefiltered, but removal efficiencies varied between 20 and 60 percent for SRP when unfiltered storm water was treated. Removal efficiencies for unfiltered storm water for TRP varied between 30 and 60 percent and between 20 and 50 percent for TP. Smaller sand grain sizes were more effective in phosphorus removal than were coarse sand grain sizes. As a result, prefiltering of storm water would almost certainly be required for adequate P-removal in a field setting to ensure achievement of a 50 percent TP removal performance standard on a regular basis.

Long-Term Performance Capability of IOCS

The long-term performance of IOCS was evaluated by treating up to 4000 empty (column) bed volumes with sequential volumes of storm water. Removal efficiency appeared to decrease after approximately 2000 to 2500 empty bed volumes. Regeneration of the IOCS with sodium hydroxide (NaOH) restored the original P-removal capacity. To put this finding into perspective, in a field application, if storm water from an area of 20 hectares (the size of a typical subdivision in the Lake Sammamish drainage basin) were to be treated, approximately 10.5 m^3 of IOCS would be required. Under average storm frequency and volume conditions in the Lake Sammamish drainage basin, the filter medium would need to be regenerated approximately six times a year.

The potential deterioration of the IOCS with many sequential regeneration cycles was not investigated, nor was the effect of cyclic drying and wetting of the filter medium between storms such as would occur in a field condition. Finally field scale evaluations of cost for the medium, regeneration and operation of such a treatment facility were not investigated. These costs and operational needs would need to be further evaluated if a full-scale design were to be considered.

Conclusion for Application to Lake Sammamish

The experimental results demonstrate that both batch flocculation using iron chloride at a dose of 5 mg/L Fe and contact with IOCS have the ability to rapidly remove up to 50 percent of the SRP from filtered and unfiltered storm water samples. Typical complete reaction times were 20 to 25 minutes. However, in the case of iron chloride, the removal mechanism, flocculation, would require a second treatment process for the removal of the flocculent to avoid its introduction to surface waters.

The ability of IOCS to remove phosphorus is improved with prefiltering of storm water. Without filtering, phosphorus removal by IOCS does not appear to be as great as by other media tested in column settings as described in Chapter 2. Total removal rates for unfiltered storm water were consistently less than those observed with processed steel fiber and sand mixtures. The bulk availability and use of IOCS does not appear to be warranted since other materials are available which achieve similar or better phosphorus removal rates. The use of iron chloride in certain situations—for example intermittent high SRP concentrations such as might occur in an animal waste treatment or construction site situation—may warrant further evaluation of costs and floc removal options.

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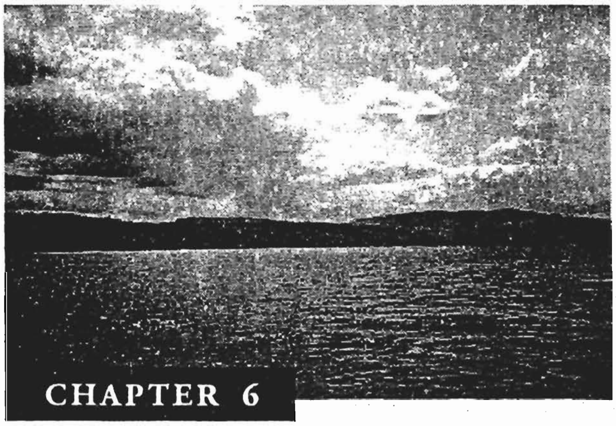

CHAPTER 6

Alum Injection in Storm Water Facilities

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Chapter 6. Alum Injection in Storm Water Facilities

Introduction

The project analyzed the effectiveness of alum treatment of storm water for phosphorus removal[1]. The project was conducted by the City of Bellevue and King County during 1994 through 1996, using an existing underground wet vault located in the City of Bellevue. The alum injection system was designed and constructed by Environmental Research and Design, Incorporated in Orlando, Florida. The system was trucked to Bellevue for installation as a retrofit to the built storm water facility. The mechanical delivery system was used to "inject" the alum into the wet vault.

This report focuses on two goals:

1. To determine the ability of the system to remove phosphorus from storm water; and
2. To assess the operational performance of the alum delivery system.

Due to numerous equipment failures, the original sampling program was severely curtailed. Although the data presented below are a good indicator of the phosphorus removal capability of the system for the limited samples collected, the small number of samples reduce the certainty that these results could be duplicated.

Background

Chemical treatment has been used for treating drinking- and wastewater for decades, but has only recently been used to treat urban runoff. Several chemicals can be used to precipitate nutrients and heavy metals from water. The most common coagulants used in precipitation are commercial polymers, ferric chloride, and alum (aluminum sulfate).

Phosphorus in storm water is found in particulate and dissolved forms. Storage facilities such as wetvaults and wetponds are effective in removing particulate phosphorus, which is removed by sedimentation (settling). The quantity of the particulate constituent which settles out is dependent upon the length of time the storm water remains in the vault. Very little dissolved phosphorus is captured by the settling. Alum injection removes dissolved phosphorus by chemical processes such as precipitation and adsorption.

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[1] Alum, or aluminum sulfate, is often used in the treatment of drinking water, wastewater, and for lake restoration.

The pH of storm water is usually between 6.5 and 7.0. Adding alum (pH 3.5) acidifies storm water. To mitigate the acidic effect of the alum additive, an alkaline buffering agent was added to the storm water and alum solution. Initially, sodium hydroxide was used as the buffering agent. However, the temperature at which saturated aqueous solutions of sodium hydroxide crystallize is 58° F, prohibiting its use in the local climate. Magnesium hydroxide was substituted due to its lower crystallization temperature.

Injection System Design

The vault selected for this study is located in the Lakemont Subdivision - Division II (formerly called High Park) in the City of Bellevue. Runoff from approximately three acres of the single-family subdivision is directed to the detention vault that drains to a tributary of Lewis Creek in the Lake Sammamish watershed (see Figure 6.1).

The vault was designed to control peak runoff rates after development to the existing pre-development rates for the 2-, 10-, 24-, and 100-hour storm events using a multi-orifice control and to provide water quality treatment. A series of three orifices is used at the outlet structure for controlled release of the storm water from the vault. The vault has a live storage volume of 29,570 cubic feet and contains three feet of dead storage (7,245 cubic feet) for water quality treatment.

The alum system is a flow-paced chemical injection system comprised of the following three components:

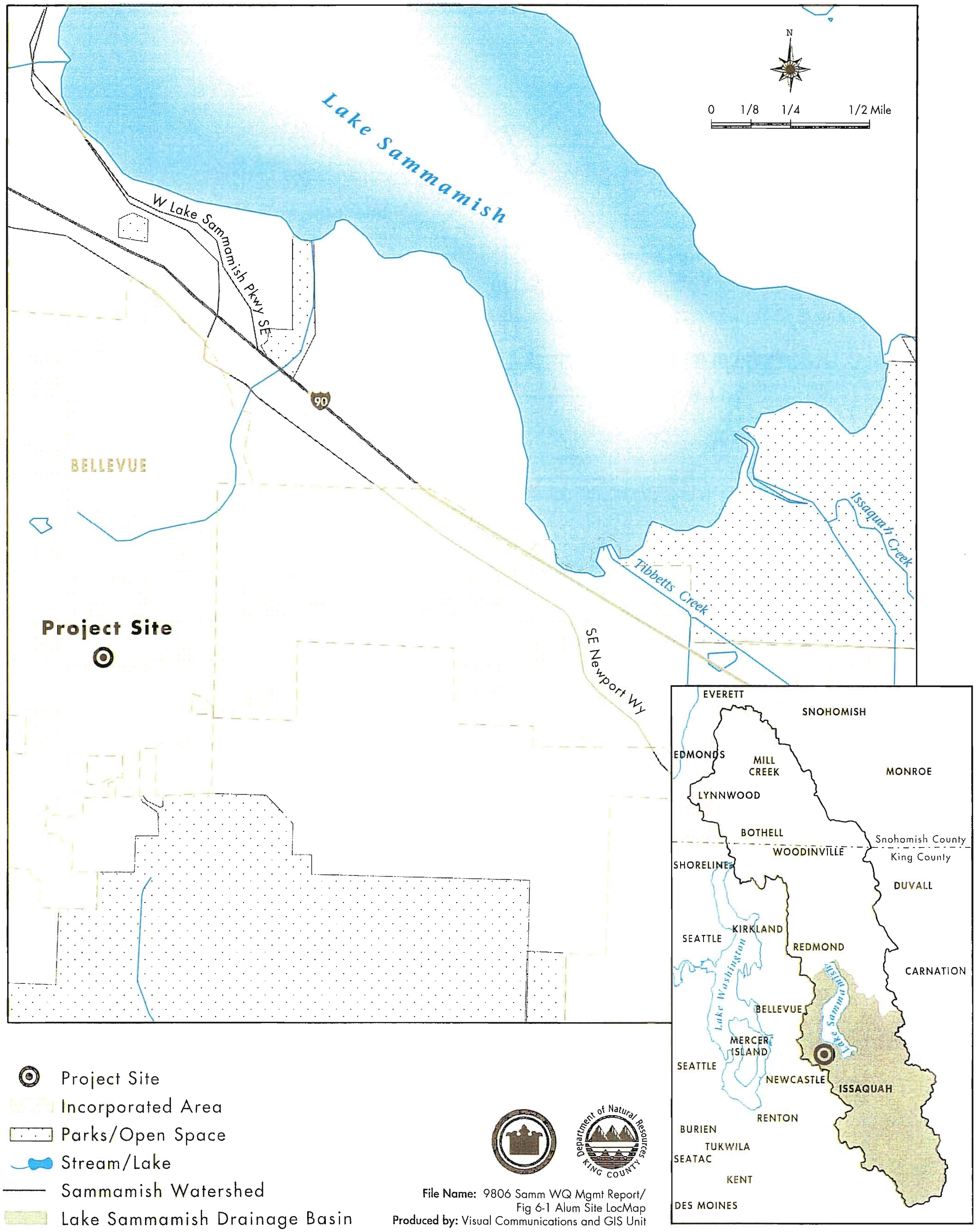
- Flow metering and controls
- Alum injection
- Buffering agent injection (magnesium hydroxide) for pH control

Flow pacing was achieved using a Badger (Model 6100) velocity flow meter. The flow meter was installed in a manhole located upstream of the detention vault to measure incoming flows (Figure 6.2). Alum dosage was regulated by the flow meter at a rate of 15 mg/l. For sampling purposes, a weir was installed in the manhole to separate the incoming runoff from the chemical injection chamber. The alum was injected downstream of the weir. Chemical dosage was delivered by a Wallace & Tiernan (45 Series Chempulse) metering pump. An air blower connected to a plastic pipe delivered air to the injection side of the manhole to rapidly mix the alum with the incoming runoff.

A pH probe was installed downstream of the injection point at the inlet of the vault (see Figure 6.2) to monitor pH levels following alum injection. If the pH was less than 6.5, buffering agent was added at this point using a second metering pump. The buffer injection rate was regulated based upon pH, at an 18.5 mg/l average rate. As a safety precaution, the alum system was shut down if the pH dropped below 5.5. A pH probe was also installed in a manhole downstream of the vault to monitor pH in the discharge from the vault.

Figure 6.1

Location Map for Alum Injection Stormwater Treatment Site



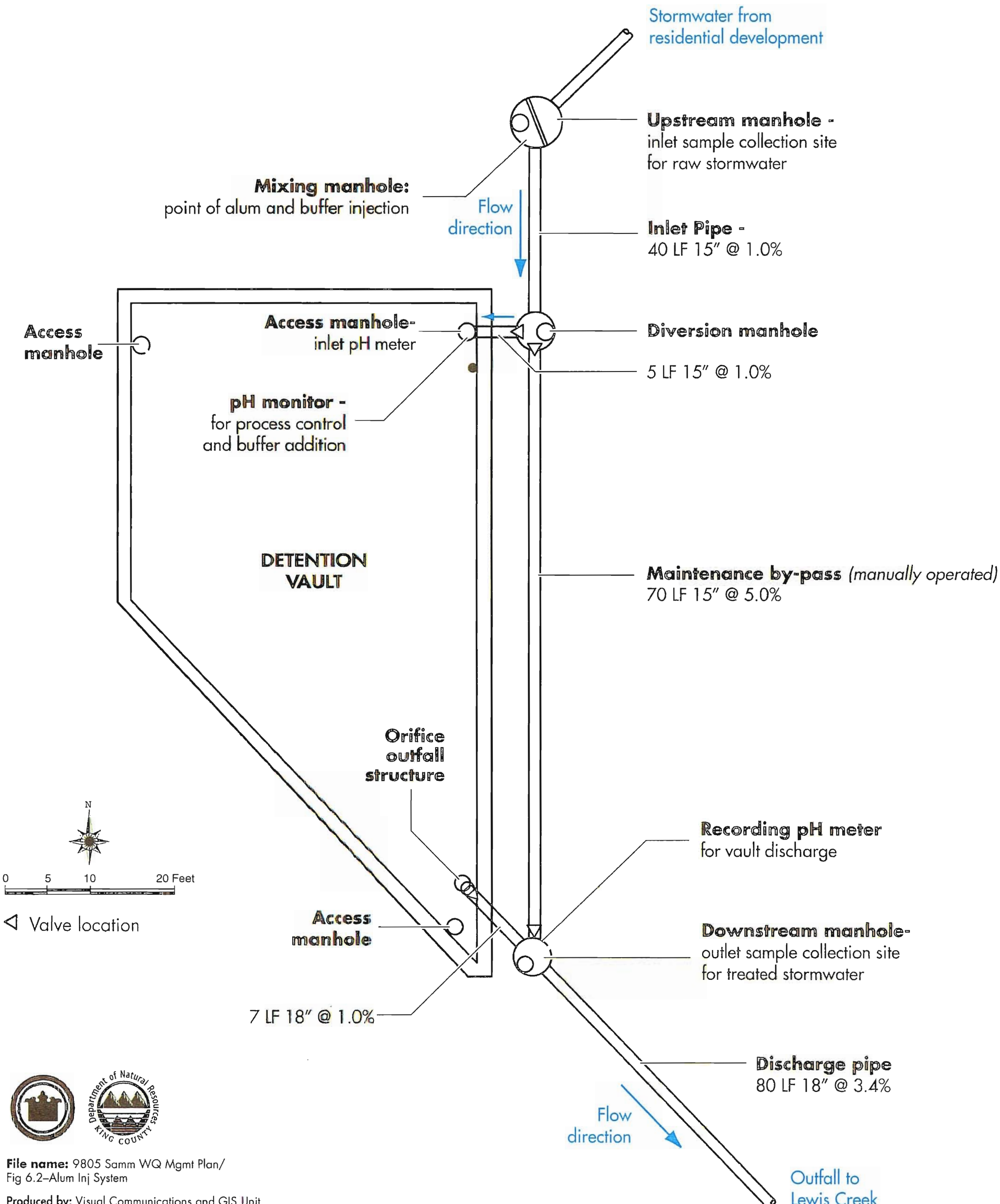
Project Site
Incorporated Area
Parks/Open Space
Stream/Lake
Sammamish Watershed
Lake Sammamish Drainage Basin

Department of Natural Resources King County

File Name: 9806 Samm WQ Mgmt Report/ Fig 6-1 Alum Site LocMap
Produced by: Visual Communications and GIS Unit

Figure 6.2

Alum Injection System Components



File name: 9805 Samm WQ Mgmt Plan/
Fig 6.2–Alum Inj System

Produced by: Visual Communications and GIS Unit,
King County Department of Natural Resources

The main components of the system were housed in an 8-foot by 8-foot concrete prefabricated shed. The alum was stored in a 300-gallon tank. A filling spigot was mounted on the outside of the shed for mass delivery from a tanker truck. However, no local source that delivers alum in a tanker could be identified and the spigot was never used. Instead, the alum was purchased in 55-gallon drums and transferred to the 300-gallon tank with a portable pump. The magnesium hydroxide was delivered and stored onsite in a 55-gallon. The magnesium hydroxide suspension required periodic mixing to maintain an even suspension in the solution. A mixer was assembled by fastening a propeller to the shaft of a motor extending into the drum. A special lid was constructed to support the motor on the drum. Periodic mixing was maintain by an electronic timer to minimize wear on the motor.

At the start of the project, electricity was not available at the site. A transformer, approximately 600 feet of electrical conduit, cable, and electric meter were installed prior to operating the system. Costs for the installation were approximately $4,500 for the materials and electrical connections. (Costs for City of Bellevue utility crew to dig the trench for the conduit are not included.)

The system was assembled inside the 8-foot by 8-foot concrete shed and tested in Orlando, Florida prior to shipment to the site. A crane lifted the shed into place. Conduit pipes for the injection tubes and measurement apparatus were laid in the ground after the system was delivered. The inlet manhole flow measurement weir and the injection system pH and flow monitors were installed in the inlet manhole and vault. The outlet weir and sampling equipment were installed after the injection system installation was complete.

Costs for the components of the system appear in Table 6.1.

Table 6.1 Alum Injection System Component Costs

Item	Cost
Housing (pre-fabricated concrete, including shipping)	$11,000.00
Storm water Meter	2,700.00
Alum Pump/Controls	2,811.00
Alum Tank	350.00
Valves/Piping	900.00
Electrical, including wall heater	2,500.00
pH Sensor	1,600.00
Buffer Pump/Controls/Drum Scale	3,200.00
Total	**$25,061.00**

Chemical usage was estimated to be approximately 155 gal alum/yr and 27.3 gal $Mg(OH)_2$/yr for an annual runoff of 3.5 ac-ft.

Sampling System Design and Methods

Sample collection was performed in accordance with a Quality Assurance Plan developed for the project (Environmental Research and Design, Inc., 1994). Samples were collected at the inlet and outlet of the system (Figure 6.2). The alum injection point was downstream of the weir. Inlet samples were collected in the manhole upstream of the weir so that the inlet samples did not contain treated storm water. The inlet sampler was activated using the injection system flow meter and collected flow proportional composite samples.

Outlet flow composite samples were collected at the outlet manhole. A stainless steel 22.5 degree v-notch weir, capacitive depth transducer, and Unidata (Model 6003b) logger were installed in the manhole to monitor flow, and to trigger the sampler. The logger calculated flow using the stage discharge relationship for the weir. A pH meter with logger was installed at the outlet manhole to continuously monitor pH.

The samples were collected in 5-gallon cubitainers for each storm event. The inlet sampler was automatically started as sufficient volume (100 cubic feet) of runoff passed through the inlet pipe. The outlet sampler was started at a time after the runoff from the storm event appeared at the vault inlet.

A rain gage is located in Lakemont Park within 1,500 feet of the vault site. Table 6.2 shows the distribution of rainfall events during the sampling episodes.

Table 6.2 Summary of Sampled Rainfall Events

Storm	Date	Antecedent (dry hours)	Precipitation (inches)	Duration (hours	Intensity (inch/hour)
A	3/31/95	>5 days	0.15	12	.013
B	4/7/95	6	0.40	10	.040
C	4/10/95	35	0.35	11	.032
D	4/12/95	27	0.35	22	.016
E	4/13/95	14	0.26	14	.019
F	4/14/95	11	0.20	7	.046
G	4/17/95	61	0.55	24	.023
H	4/20/95	37	0.20	7	.046
I	11/24/95	6	0.72	20	.037
J	11/27/95	36	0.84	19	.046
K	11/28/95	*	1.36	24	.057
L	11/29/95	*	1.37	32	0.43
M	12/9/95	>4 days	1.54	60[a]	.026

Notes: * continuous event beginning 11/27 through 11/29
[a] partial event sampled

All samples were analyzed for total phosphorus, bioavailable phosphorus, orthophosphorus, turbidity, and dissolved aluminum.

The system suffered from several failures which severely hampered the sampling effort (discussed below). The problems resulted in cutting the sampling effort short and limiting the sample period. As a result, sampling for a full distribution of storm events was not achieved, the requirement for antecedent dry period was relaxed to compensate for the lost time due to the system failures, and the sample period was limited primarily to the months of April and November.

Laboratory Analysis

The King County Environmental Laboratory conducted the analysis on the collected samples. Analytical procedures for total phosphorus, orthophosphorus, turbidity, and dissolved aluminum were conducted following the procedures outlined in the Quality Assurance Plan (Environmental Research and Design, Inc., 1994). Bioavailable phosphorus analysis procedures were developed by the University of Washington for prior lake studies pertaining to Lake Sammamish and are regularly performed by the King County Environmental Laboratory.

Data Analysis

Approach

The data were evaluated based on the event mean concentration (EMC) as determined from flow-proportioned samples. Past analyses have indicated that storm water pollutant constituents in the region follow a log-normal distribution. The following formula was used to determine the mean of the data set of the EMCs (Marsalek, 1990):

(1) $$C_{mean} = e^{(\mu+s2/2)}$$

where: μ = mean of natural logarithms of EMCs;
s^2 = variance of natural logarithms of EMCs.

The efficiency of the system for removing the pollutant constituent was determined by the equation:

(2) $$\text{Efficiency} = (C_{inlet} - C_{outlet})/C_{inlet} \times 100\%$$

where: C_{inlet} is the natural logarithmic mean for each pollutant at the inlet to the vault as calculated in equation (1);
C_{outlet} is the natural logarithmic mean for each pollutant at the outlet of the vault as calculated in equation (1).

As mentioned above, a reduced number of sampling events were collected due to system failures. In addition, all samples did not meet the 24-hour antecedent dry period (see Table 6.2) and sampling period conditions (rainfall events greater than 0.1 inches and less than 1.0 inches) as described in the QA/QC plan. As a result, the data set is not statistically valid. Calculating the loadings for the pollutant constituents would be misleading.

Results

Tables 6.3, 6.4, and 6.5 show the pollutant sampling data and estimated removal efficiencies. The results indicate that the alum injection system performed well for phosphorus removal. Average total phosphorus, orthophosphorus and bioavailable phosphorus removal efficiencies are 70, 85, and 46 percent respectively (Figures 6.3 - 6.5). It is not surprising to find that the removal efficiency of the orthophosphorus, the dissolved fraction, is better than the removal efficiency for total phosphorus because the alum treatment results in forming particulate phosphorus from the dissolved fraction. However, bioavailable phosphorus removal efficiency is not as good as the removal for the other forms of phosphorus. Bioavailable phosphorus is the measure of the dissolved fraction plus the fraction of particulate phosphorus that is likely to become dissolved.

The turbidity removal efficiency (36 percent) was relatively low (Figure 6.6), probably due to inaccurate measurement of turbidity in the incoming runoff. The mean turbidity in the incoming runoff was less than 6.0 NTU. The accuracy of measurements in this range, less than five times the method detection limit, is questionable.

An increase in dissolved aluminum was due to the treatment of the storm water with alum. Dissolved aluminum increased by 59 percent from the inlet to the outlet of the vault (Table 6.5). However, the aluminum concentration in most of the sample data fell in a range less than five times the method detection limit.

There is no Washington State Standard for dissolved aluminum. The EPA has published water quality criteria[2] for total recoverable aluminum. The criterion for the four-day average concentration (chronic) of aluminum is not to exceed 87 μg/l; the criterion for the one-hour average concentration (acute) of aluminum is not to exceed 750 μg/l. Data presented in Table 6.4 indicate that the outlet measurements for dissolved aluminum never exceeded either of these parameters, and in only one incident approached the lower chronic limit.

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[2] Water Quality Criteria for Aluminum, Federal Register Vol. 53, No. 168, page 33177, August 30, 1988.

Figure 6.3 Total Phosphorus Removal Efficiency

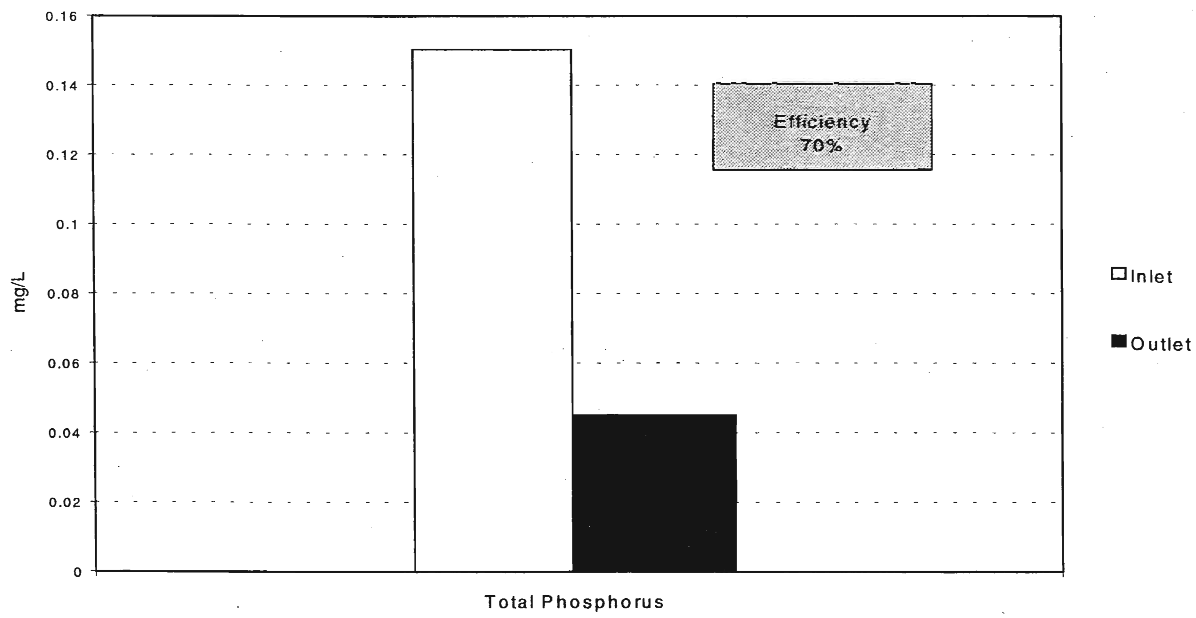

Figure 6.4 Ortho-Phosphorus Removal Efficiency

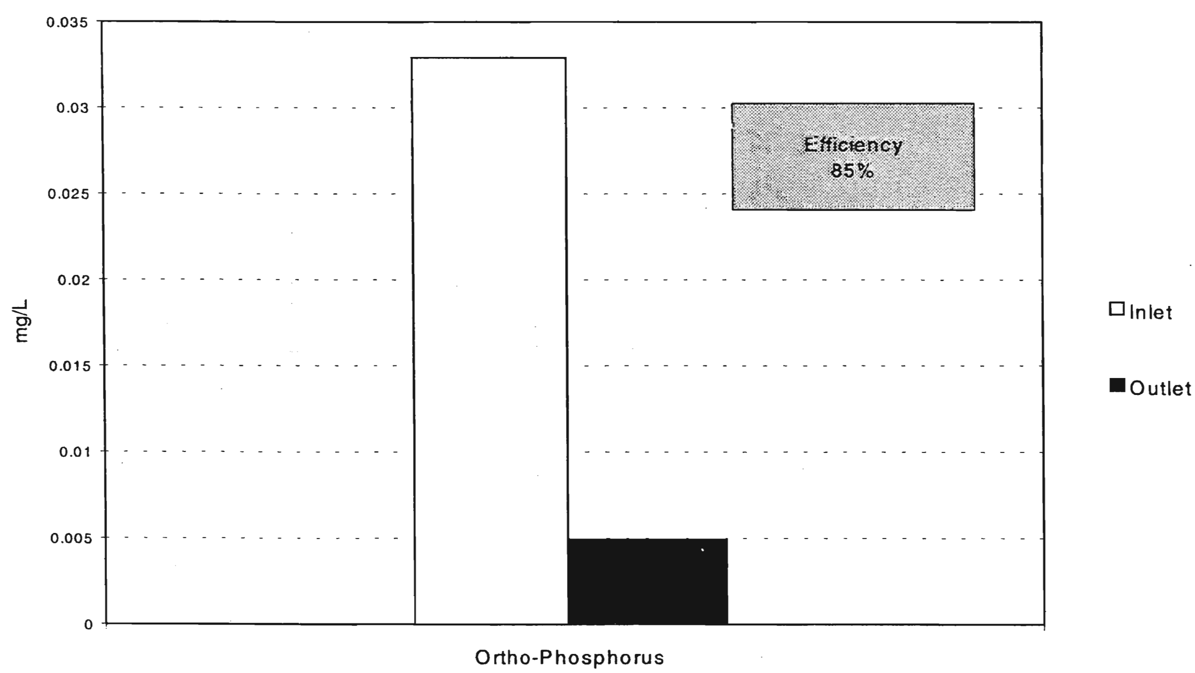

Figure 6.5 Bioavailable Phosphorus Removal Efficiency

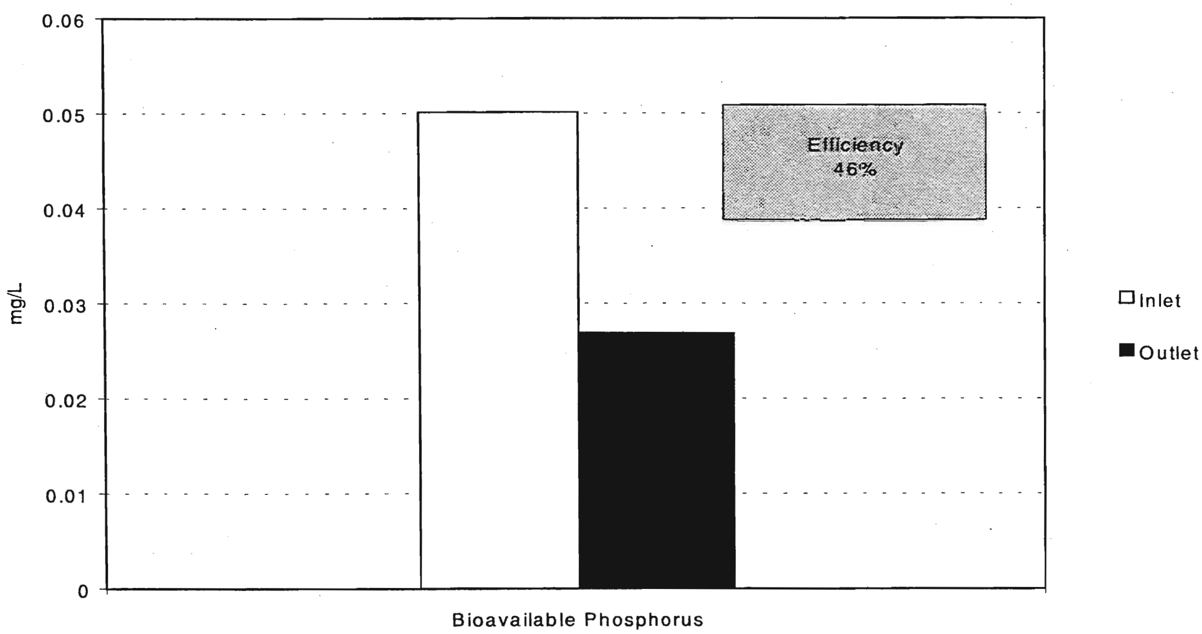

Figure 6.6 Turbidity Removal Efficiency

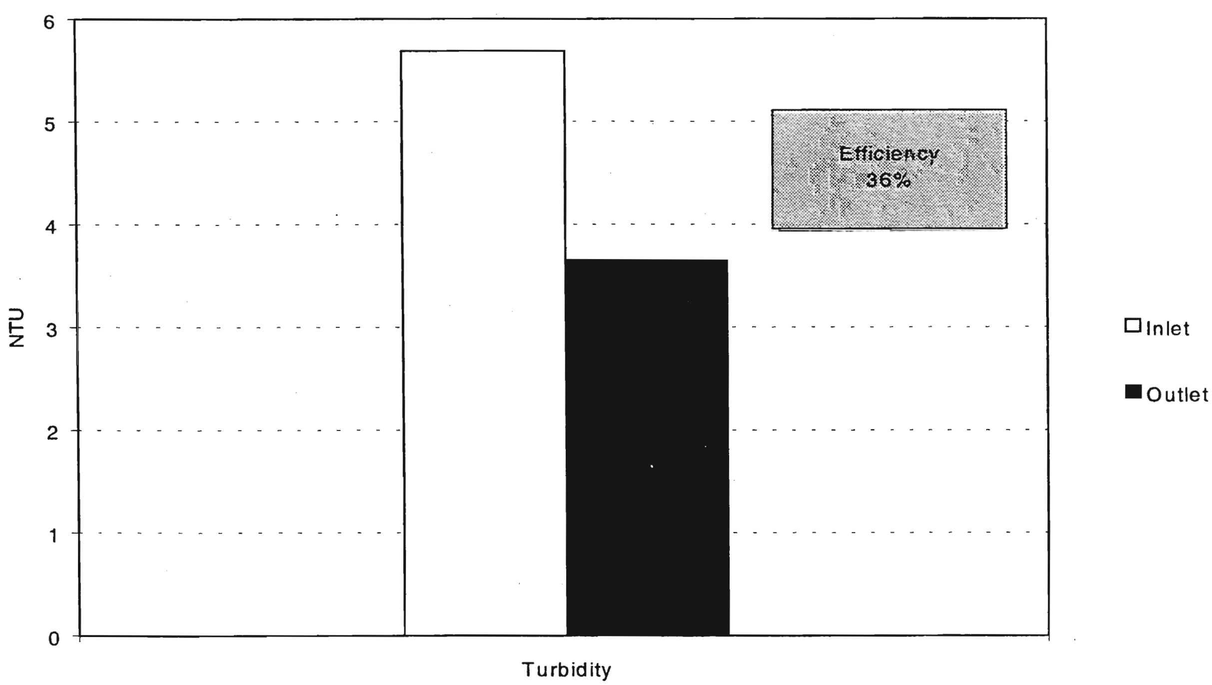

Table 6.3 Alum Injection System Inlet Parameters

	TP		OrthoP		BAP		Turbidity		Diss. Al	
Sample Date	mg/l	ln*	mg/l	ln	mg/l	ln	NTU	ln	mg/l	ln
04/01/95	0.1750	-1.74	0.00200	-6.21	0.0078	-4.85	46.0	3.83	0.0163	-4.12
04/08/95	0.1080	-2.23	0.01410	-4.26	0.0149	-4.21	1.7	0.53	0.0188	-3.97
04/11/95	0.0650	-2.73	0.01330	-4.32	0.0210	-3.86	2.6	0.96	0.0204	-3.89
04/13/95	0.1250	-2.08	0.00901	-4.71	0.0140	-4.27	2.4	0.88	0.0231	-3.77
04/14/95	0.2920	-1.23	0.00250	-5.99	0.0262	-3.64	3.9	1.36	0.0299	-3.51
04/15/95	0.0980	-2.32	0.00300	-5.81	0.0145	-4.23	2.2	0.79	0.0261	-3.65
04/18/95	0.2110	-1.56	0.01610	-4.13	0.0257	-3.66	4.1	1.41	0.0248	-3.70
04/20/95	0.0632	-2.76	0.00528	-5.24	0.0112	-4.49	1.6	0.47	0.0139	-4.28
11/24/95	0.2220	-1.51	0.07200	-2.63	0.1350	-2.00	7.0	1.95	0.0250	-3.69
11/27/95	0.0950	-2.35	0.06800	-2.69	0.0800	-2.53	1.3	0.26	0.0260	-3.65
11/29/95	0.2050	-1.58	0.02340	-3.76	0.1280	-2.06	13.0	2.56	0.1720	-1.76
11/30/95	0.1680	-1.78	0.10700	-2.23	0.1140	-2.17	2.2	0.79	0.0460	-3.08
12/10/95	0.1190	-2.13	0.04700	-3.06	0.0538	-2.92	2.6	0.96	0.0194	-3.94
ln/mean	-2.001		-4.234		-3.454		1.288		-3.615	
Variance	0.211		1.640		0.921		0.902		0.367	
Mean - Concentration	0.150		0.033		0.050		5.688		0.032	

* ln = natural logarithm

Notes: 1. Undetected quantities were evaluated at the Method Detection Limit (MDL) value.
2. "No data" reported values were omitted from the analysis
3. Detection limits

Detection limits	MDL	RDL (Reported)
TP(total phosphorus)	0.005	0.01
Ortho-P(orthophosphorus)	0.002	0.005
BAP(bioavailable phosphorus)	0.005	0.01
Turbidity	0.5	1
Diss Al(dissolved aluminum)	0.002	0.01

Table 6.4 Alum Injection System Outlet Parameters

Sample Date	TP mg/l	TP *ln**	Ortho-P mg/l	Ortho-P *ln*	BAP mg/l	BAP *ln*	Turbidity NTU	Turbidity *ln*	Diss. Al mg/l	Diss. Al *ln*
04/01/95	0.0210	-3.86	0.00200	-6.21	0.0050	-5.30	1.8	0.59	0.0149	-4.21
04/08/95	0.0350	-3.35	0.00330	-5.71	0.0061	-5.10	2.0	0.69	0.0394	-3.23
04/11/95	0.0230	-3.77	0.00200	-6.21	0.0050	-5.30	2.2	0.79	0.0233	-3.76
04/13/95	0.0310	-3.47	0.00738	-4.91	0.0110	-4.51	2.3	0.83	0.0315	-3.46
04/14/95	0.0390	-3.24	0.00200	-6.21	0.0091	-4.70	3.4	1.22	0.0351	-3.35
04/15/95	0.0360	-3.32	0.00200	-6.21	0.0065	-5.04	2.4	0.88	0.0574	-2.86
04/18/95	0.0290	-3.54	0.00200	-6.21	0.0050	-5.30	3.4	1.22	0.0323	-3.43
04/20/95	0.0238	-3.74	0.00280	-5.88	0.0080	-4.83	1.3	0.26	0.0211	-3.86
11/24/95	0.2830	-1.26	0.00400	-5.52	0.2230	-1.50	14.0	2.64	no data	no data
11/27/95	0.0290	-3.54	0.00500	-5.30	0.0260	-3.65	3.7	1.31	0.014	-4.27
11/29/95	0.0260	-3.65	0.00200	-6.21	0.0204	-3.89	4.1	1.41	0.011	-4.51
11/30/95	0.0400	-3.22	0.00200	-6.21	0.0693	-2.67	5.5	1.70	0.0717	-2.64
12/10/95	0.0520	-2.96	0.04700	-3.06	0.0318	-3.45	3.2	1.16	0.0431	-3.14

	TP	Ortho-P	BAP	Turbidity	Diss. Al
ln mean	-3.303	-5.683	-4.248	1.132	-3.560
variance	0.406	0.745	1.264	0.326	1.180
mean concentration	0.045	0.005	0.027	3.651	0.051

**ln* = natural logarithm

Notes: 1. Undetected quantities were evaluated at the Method Detection Limit (MDL) value.
2. "No data" reported values were omitted from the analysis
3. Detection limits

Detection limits	MDL	RDL (Reported)
TP(total phosphorus)	0.005	0.01
Ortho-P(orthophosphorus)	0.002	0.005
BAP(bioavailable phosphorus)	0.005	0.01
Turbidity	0.5	1
Diss Al(dissolved aluminum)	0.002	0.01

Table 6.5 Estimated Percent Removal Efficiencies

Efficiencies	Percent
Total Phosphorus	70.01
Orthophosphorus	84.99
Bioavailable Phosphorus	46.37
Turbidity	35.81
Dissolved Aluminum	-58.77

System Performance

The flow measurement and control system adequately monitored and controlled the dosing rate and provided adequate safety shut-off parameters. However, the system experienced a series of critical shutdowns due to design faults and component failures: some of the failures were due to the quality of the components selected as a result of budget restrictions; others were due to the state of the measurement technology; and other system failures were a result of the difficulties associated with retrofitting an existing system with a technological solution that had never been tested in a similar environment.

The most significant difficulties associated with system performance are presented below:

1) It was not possible to find a local chemical supplier that could provide the alum and buffer in a form that could be easily transferred to the 300-gallon tank. Instead, the alum was delivered in 55 gallon drums and was transferred by staff to the tank with a portable pump. Although this supply substitution did not contribute to lack of system performance, it increased staffing needs. Local supply is critical to the successful use of injection systems.

2) When the specified sodium hydroxide buffer was introduced to the system, it crystallized as it passed through underground tubing due to its high crystallization temperature. Therefore, magnesium hydroxide was substituted for the sodium hydroxide.

3) The system did not inject the alum and the magnesium hydroxide buffer into the incoming storm water on a consistent basis without regular operator intervention. The delivery system tubes clogged frequently which required dismantling the hoses and flushing the system with water. The delivery system was originally designed for the sodium hydroxide solution. Its design was poorly structured for the substitute buffer, magnesium hydroxide, which requires constant mixing. A mixing system was designed and fabricated in the field to maintain the magnesium hydroxide in suspension, but did not eliminate the tubing plugging problems.

4) The flow metering equipment originally installed in the upstream manhole, which consisted of a weir with level transducer, failed due to excessive leaking through the weir. As a result, the original flow meter was replaced with an area-velocity meter that measured flow directly.

5) Several electrical and mechanical system components failed resulting in frequent system shutdowns: pH meter preamplifier; pump control relays.

6) The flow measurement system design did not consider all possible flow regimes into the vault. As a result, the inlet manhole weir became submerged during larger storm events and contaminated the inlet flow sample with treated water.

7) The vault outlet control orifice plugged on several occasions. The plugging stopped the outflow from the vault and increased the detention time of the treated storm water. The vault was drained gradually to gain access so that the obstruction could be removed from the control orifice.

The failures resulted in multiple lost sampling opportunities and increased maintenance needs. Consequently, the criteria used to define storm conditions for the purpose of sampling had to be modified to enable samples to be collected within the allotted project schedule and budget. Instead of 0.25 inches of precipitation in 24 hours to define a storm as originally proposed, storms with 0.15 inches of rainfall were sampled.

Conclusion

As the results of the data analysis indicate, the system shows promising phosphorus removal capabilities. System failures, however, were a deterrent to successful completion of the study and the data presented have some serious omissions. Nevertheless, the data are supportive of the general phosphorus removal performance of the technology. The technology should not be overlooked as a possible phosphorus control mechanism that showed orthophosphorus removal efficiency greater than 80 percent. Other treatment technologies to date have not exhibited the capability to remove dissolved phosphorus as efficiently. An improved design could eliminate or minimize the failures experienced by this initial effort and reduce system maintenance costs. The most beneficial adjustment would include a better delivery system, perhaps mixing the alum and buffer in an external location so that temperature and flow quantities are more easily monitored. However, prior to any major investments in the technology, further analysis and testing of a more robust system design should be completed by the participating jurisdictions. In addition, treatment of a larger subarea with this technology would help to justify operator expenses for system maintenance.

Although analysis of the costs to operate the system are outside the scope of this study, it appears that the operation and maintenance costs of this alum injection system exceed those of more passive systems (wet ponds, vaults). The need for an operator to monitor the system performance, conduct preventive maintenance, and repair failed components cannot be justified for a sole installation in a small basin. If a system were to be built, it should serve a large drainage basin or should be a member of a group of treatment systems where economies of scale can be realized. Moreover, the cost-benefit of the technology should be carefully measured against other treatment methods for each application. These issues should be explored thoroughly before any decision to use or reject the technology can be made.

Conclusion for Application to Lake Sammamish

The operational and design difficulties associated with this project would necessitate the development of a completely different design and/or operations management for future applications. The use of alum injection for storm water treatment with operator oversight, such as could be provided at a subregional or emergency treatment facility, or at a site where high levels of dissolved phosphorus are present, may have merit. Alum treatment is currently proposed if necessary for auxiliary phosphorus treatment for runoff from the Lakemont Boulevard construction site. In this case the flocculent would be discharged to the sanitary sewer while the storm water is discharged to the lake. Additional feasibility studies for site-specific or subregional treatment are not being pursued at this time.

References

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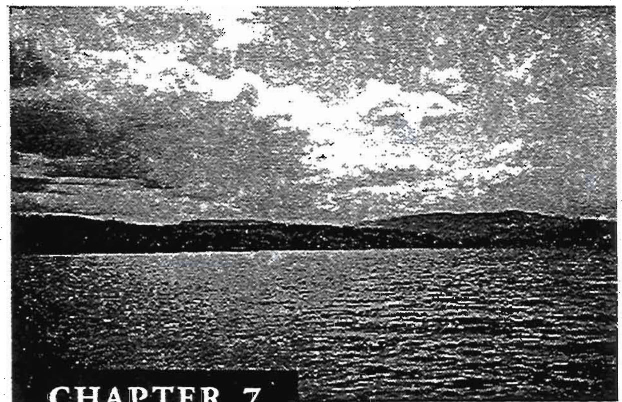

CHAPTER 7

Wet Pond Evaluation

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Chapter 7. Wet Pond Evaluation

Objectives

The purpose of this study was to determine the effectiveness with which wet retention/detention ponds remove pollutants from storm water. The project was conducted by the Center for Urban Water Resources at the University of Washington, in cooperation with the City of Bellevue. The King County Environmental Laboratory provided analytical support and King County provided project oversight. The project site was modified during 1994 and 1995 for the study. Sampling was completed during late 1996 through 1997.

The pollutants of interest in this study were total suspended solids (TSS), total phosphorus (TP), soluble reactive phosphorus (SRP), and biologically available phosphorus (BAP). A variety of metals were also investigated, including copper, lead, cadmium, and zinc. Phosphorus was the particular focus of the study, however, because of the detrimental effects that it is known to have on urban lakes and streams.

Background

This project was a joint effort by the City of Bellevue, King County, and the University of Washington's Center for Urban Water Resources Management. The County was responsible for project oversight and sample analysis; the City was responsible for equipment installation, maintenance, and project management; and the University performed field monitoring, data collection, and interpretation.

The study measured the effectiveness of the removal of phosphorus and other pollutants from storm water by two wet ponds located in the City of Bellevue (see Figure 7.1). Initially, a single wet pond, Pond A, was selected based upon its similarity to the specifications for King County water quantity/quality wet ponds (King County 1990). Pond A is a three-celled wet pond containing 282,000 cubic feet of live storage for flow control and 36,000 cubic feet of dead storage for water quality treatment. Another water quality wet pond, Pond C, is located in the drainage tributary upstream from Pond A and contains no live storage. Pond C's design was for the specific purpose of removing pollutants from storm water. Thus, by adding Pond C to the study, a comparison could be made between the performance of a water quality pond (Pond C) and a combined water quality/quantity pond (Pond A).

A water quality wet pond such as Pond C is a stormwater facility for water quality treatment that contains a permanent pool of water. Such a facility is designed to optimize water quality by providing long retention times (on the order of a week or more) to settle out particles of fine sediments to which pollutants such as heavy metals or phosphate absorb, and to allow biologic activity to occur that metabolizes nutrients and organic pollutants (King County 1996). In contrast, Pond A is a combined detention/water quality pond. A combined wet pond is a stormwater facility that maintains a permanent pool of water, above which is room for storage of rainfall runoff during storms (live storage). The live storage is released at a controlled rate after the storm until the water level of the permanent pool is again reached. The permanent pool (dead storage) is sized for water quality treatment, and the live storage is sized to provide flow control for storms of prescribed size.

Pond A was chosen for this study because of its similarity to the 1990 King County Standards. However, Pond A was originally designed in 1980, prior to the development of these standards. For the pond to more closely meet the 1990 County standards desired by the study, it was modified before the study began. To increase its permanent pool capacity, approximately 1,300 cubic yards of material were removed from the bottom of the center cell of the three-celled pond. Subsequent to the pond modification, the County proposed revising its standards for wet ponds and the Department of Ecology released its own wet pond standards. All of these specifications differ somewhat from the modifications that were made to the design of Pond A. A comparison of the King County and Department of Ecology standards to the Pond A and Pond C designs appears in Table 7.1. An additional water quality feature of Pond A is an oil/water separator located at the pond's inlet.

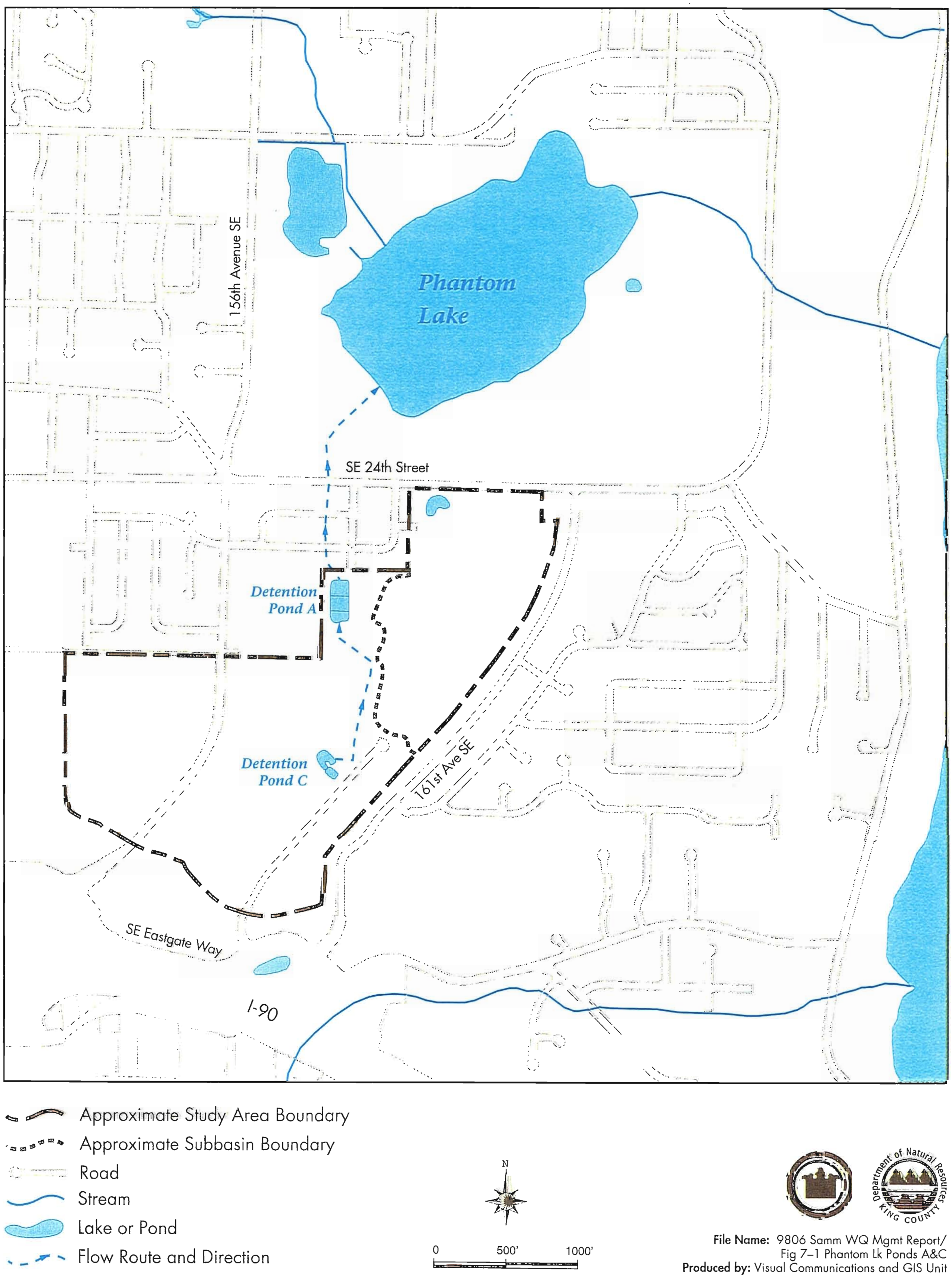
Table 7.1 Comparison of Pond A and Pond C Design to Standards

	King County 1990 Standards[1]	King County 1996 Draft Standards[2]	Department of Ecology Standards[3]	Pond A Design	Pond C Design
Length to width ratio	3:1 minimum	3:1 minimum	3:1 minimum 5:1 preferred	2.6:1	2.3:1
Pond surface area (ft^2)	1 % of impervious area	N/A	N/A	10,736 (0.4% impervious area)	18,400 (6% impervious area)
Cell surface area/ volume: *Inlet cell*	10% permanent pool surface area	25 - 35% of permanent pool volume	33% of permanent pool volume	3% of permanent pool volume; 10% of surface area	42%
Cell surface area/ volume: *Middle cell*	45% permanent pool surface area	65 - 75% of permanent pool volume	33% of permanent pool volume	62% of permanent pool volume; 38% of surface area	N/A
Cell surface area/ volume: *Outlet Cell*	45% permanent pool surface area	N/A	33% of permanent pool volume	35% of permanent pool volume; 52% of surface area	58%
Total permanent pool depth	3 to 6 feet	3 to 6 feet	6 feet max average	3.2 feet average	6 feet
Permanent pool volume (cubic feet)	139,800	438,800	332,400	36,100	77,043
Live storage (cubic feet)	N/A	N/A	N/A	282,000	18,000

1. King County, Washington, Surface Water Design Manual, 1990
2. King County, Washington, Draft Surface Water Design Manual, 1996
3. Washington State Department of Ecology Stormwater Management Manual for the Puget Sound Basin, 1992

Figure 7.1

Phantom Lake and Ponds A and C Drainage Basin



File Name: 9806 Samm WQ Mgmt Report/ Fig 7-1 Phantom Lk Ponds A&C
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While Pond A was designed to provide both water quality and quantity control, Pond C was designed as a water quality pond only, with little contribution to flow attenuation. The U-shaped two-cell design of Pond C will treat up to one-third of a 2-year, 24-hour storm which is approximately a 6-month, 24-hour storm assuming comparable design parameters for specific sites are being compared. Runoff in excess of this capacity bypasses the pond and is routed to Pond A. It is important to note that neither pond was designed to the 1996 King County draft standards.

The study period was not of sufficient duration to address maintenance issues. No maintenance that would have affected pond performance was conducted during the study period. Standard maintenance includes removal of debris from the Pond A outfall structure as needed on a weekly basis during the winter.

Site Description

The two wet-pond facilities (Pond A and Pond C) included in this study are located in the south end of the Phantom Lake watershed in southeastern Bellevue. More than half of the property in this section of the basin belongs to Boeing (CH2M Hill 1993). The remaining portions are a combination of small businesses and residential regions. Basin areas contributing to each pond are summarized in Table 7.2.

Table 7.2 Drainage Basins Areas for Ponds A and C

Drainage Area (ac)	Pond A	Pond C
Pervious	42.1	05.1
Impervious	55.4	06.9
Total	**97.5**	**12.0**

In the southernmost portion of the basin, runoff from 12 acres of the Boeing facility is initially received by Pond C (CH2M Hill, 1993). Pond C was originally designed to treat runoff from a 38.4 acre area, but to date only about 12 acres are developed and routed to the pond. Following treatment by Pond C, discharge is routed via underground pipes to the inlet of Pond A. In addition to the water from Pond C, Pond A also receives runoff directly from the remaining 86 acres of the sub-basin. After receiving the additional quality treatment and flow control that Pond A provides, outflow from Pond A is discharged into Phantom Creek, which flows into Phantom Lake. Lake Sammamish ultimately receives the water flowing from Phantom Lake.

Methods

Sampling procedures

Sampling/monitoring stations were set up at the inlet and outlet of each pond. Each station used a sampler to draw water samples from the inlet and outlet pipes of each pond. At all four sampling locations, the flow measuring equipment allowed flow-weighted composite samples to be collected by American Sigma, Streamline automatic samplers. Specific sampling arrangements differed, however, at the two ponds. At Pond A, ISCO 4150 velocity-flow meters were used at both the inlet and outlet to record flow values at ten-minute increments. At the outlet of Pond C, flow was measured through a 60-degree v-notch weir and transducer and recorded every fifteen minutes with a Unidata logger. The flow through the weir was calculated by using a stage-discharge algorithm for the weir.

The inlet pipe to Pond C flows underneath the main roadway leading to the Boeing facility before entering the pond at a point that is submerged. By necessity, the sampling station at the inlet to Pond C was located on a swath of grass that lies between the roadway and the pond. Because the inlet pipe is submerged at this point, flow measurements could not be directly recorded at this station. Instead, water volumes for this station were determined by mass balance using precipitation data collected on site and evaporation data collected at a Boeing facility nearby. The inability to accurately measure flow at this station was also a hindrance to the collection of samples that needed to be flow-proportional. In place of using a flow meter to determine when to draw samples, the on-site rain gauge was used instead. Since the runoff response time for this catchment is on the order of one hour, rainfall provides a reasonable estimate of flow proportions for collecting the samples at this station.

Storm samples were collected over a six-month period from October 1996 through March 1997. During the study period, 35.71 inches of rain fell. These six months typically represent 71 percent of the annual rainfall for Bellevue. The monthly averages used to determine this percentage were recorded by the Bellevue Service Center (Table 7.3). The events that were sampled (Table 7.4) represent a broad range of storm events characteristic of western Washington and generally fulfill the criteria set forth by CH2M Hill in the Wet Pond Monitoring Project Quality Assurance Plan (CH2M Hill, 1993). These criteria defined storm events as having a minimum rainfall of 0.1 inches over a six-hour period preceded by 48 hours of dry conditions. Storm event precipitation ranged from 0.22 to 1.94 inches while intensities ranged from 0.015 to 0.088 inches per hour. The majority of the sampled storms followed a dry period of at least 48 hours with antecedent dry periods that extended up to greater than one week.

Table 7.3 Average Monthly Rainfall from Bellevue Service Center Data – 1981 - 1996

Month	Precipitation (in.)	Study Period Precipitation (Oct., 1996 to Mar, 1997)
January	4.08	7.04 (1997)
February	3.15	2.02 (1997)
March	2.78	7.74 (1997)
April	2.75	
May	1.86	
June	1.37	
July	0.99	
August	0.84	
September	1.52	
October	3.15	5.67 (1996)
November	5.30	6.26 (1996)
December	4.67	6.98 (1996)

Laboratory Analysis

Following collection, the King County Environmental Laboratory analyzed the composite samples. This state-certified laboratory used the analytical methods established in the Quality Assurance Plan for the project (CH2M Hill, 1993).

Table 7.4 Summary of Sampled Events

Storm Characteristics						Samples Taken			
Storm	Date	An. Dry (hours)	Precip (inches)	Duration (hours)	Intensity (in/hour)	A in	A out	C in	C out
A	10/4/96	> 4 days	0.83	11	0.075			X	X
B	10/12/96	> 7 days	0.56	17	0.033	B	B		X
C	10/17/96	68	0.77	14	0.055	B	B	B	B
D	10/21/06	80	0.67	21	0.032	X	X	X	X
E	10/28/96	81	1.13	15	0.075	X	X	B	B
F	11/3/96	136	0.22	5	0.044	X	X	X	X
G	12/4/96	43	0.79	9	0.088	XR			X
H	12/19/96	> 7 days	0.29	19	0.015	X		X	X
I (flood)	1/2/97	4	1.94	34	0.057	X	X	X	X
Baseflow	1/10/97					X	X	X	X
J	1/17/97	> 7 days	1.26	25	0.050	XR	X	XR	X
K	1/28/97	> 7 days	0.41	6	0.068	B	BR	B	B
L	1/30/97	44	0.56	11	0.051	B	B	B	B
M	2/12/97	> 7 days	0.42	10	0.042	X	XR	X	X
N	3/1/97	> 7 days	1.12	24	0.047	X	X	X	X
O	3/6/97	39	0.32	16	0.020	B	B	B	B
Baseflow	4/7/97					X	X	X	X
Baseflow	6/11/97					X	X	X	X
data points collected per station						14	12	13	15

'X' indicates that a sample was collected, 'B' indicates samples that were analyzed for BAP, and 'R' indicates field replicates.

Data Analysis

Throughout the literature there are a variety of methods that are used for calculating loading from storm water runoff. All of these methods use the basic principle of multiplying the pollutant concentration by a flow volume to obtain a total mass of pollutant. Because the goal of this study was to determine how the ponds perform in any given year and not the winter of 1997 alone, the Modified Direct Average Method was chosen for the analysis. By this method, an average pollutant concentration is determined using the entire set of event mean concentrations (EMC) collected. The EMC is simply the concentration of the composite sample collected during each complete storm event.

The number of data points collected in this study was insufficient to statistically verify the distribution of the data set. However, a previous study of urban storm water in the City of Bellevue (Bellevue, 1995) was able to verify conclusively, using the Kolmogorov-Smirnov test on log-normally transformed data, that storm water constituents in this region have a log-normal distribution. Based on the assumption that storm water constituents typically have a log-normal distribution, the data were transformed as ln (x+1), and the following formula was used to determine the mean of the data set EMCs (Marsalek, 1990).

$$C_{mean} = \exp(\mu + s^2/2) - 1$$

where: exp signifies exponentiation on the base of natural logarithms, e;
μ = Mean of natural logarithms of EMCs;
s^2 = Variance of natural logarithms of EMCs.

This mean was then multiplied by the total flow volume over the period of interest to obtain the loading for that period. The efficiency of each pond was determined from the resulting loading by dividing the amount of each constituent that was removed by the loading that entered the pond as is expressed below.

% efficiency = (inlet load - outlet load)/inlet load

Results

The ponds were reasonably effective at removing pollutants from storm water runoff. Total removal generally ranged from 25 to 75 percent of the measured components. Of the four constituents measured, TSS exhibited the greatest removal efficiency (81 percent in Pond C and 67 percent in Pond A). This was anticipated because the primary TSS removal mechanism is gravity settling as the runoff velocity is greatly slowed by the ponds. Similarly, much of the total phosphorus is removed by settling due to the fact that significant portions of phosphorus that are carried by storm water are in the form of particulate P (Stanley 1996). Figures 7.2 – 7.5 show the loading through each pond for the period studied as well as the percent removal for each constituent measured.

The removal efficiencies for SRP (62 percent in Pond C and 17 percent in Pond A) are quite a bit higher than has been seen in similar studies. One study that compared the removal efficiencies of several dry ponds indicated a range of SRP removal from –12 to 26 percent (Stanley 1996).

Another study investigating the performance of older wet ponds found SRP removal efficiencies as poor as –50 percent (Maristany, 1993). The removal of SRP is primarily due to two mechanisms: adsorption by soil or sediment at the bottom of the pond and uptake by photosynthesizing organisms living in the pond. Because the study took place during fall and winter months, it is unlikely that large amounts of SRP removal can be attributed to biological uptake. Thus, the removal rates are more likely due to interaction with the pond sediments.

Removal efficiencies for BAP (54 percent for Pond C and 31 percent for Pond A) followed the removal efficiency trend for SRP.

Figure 7.2

Removal of Total Suspended Solids

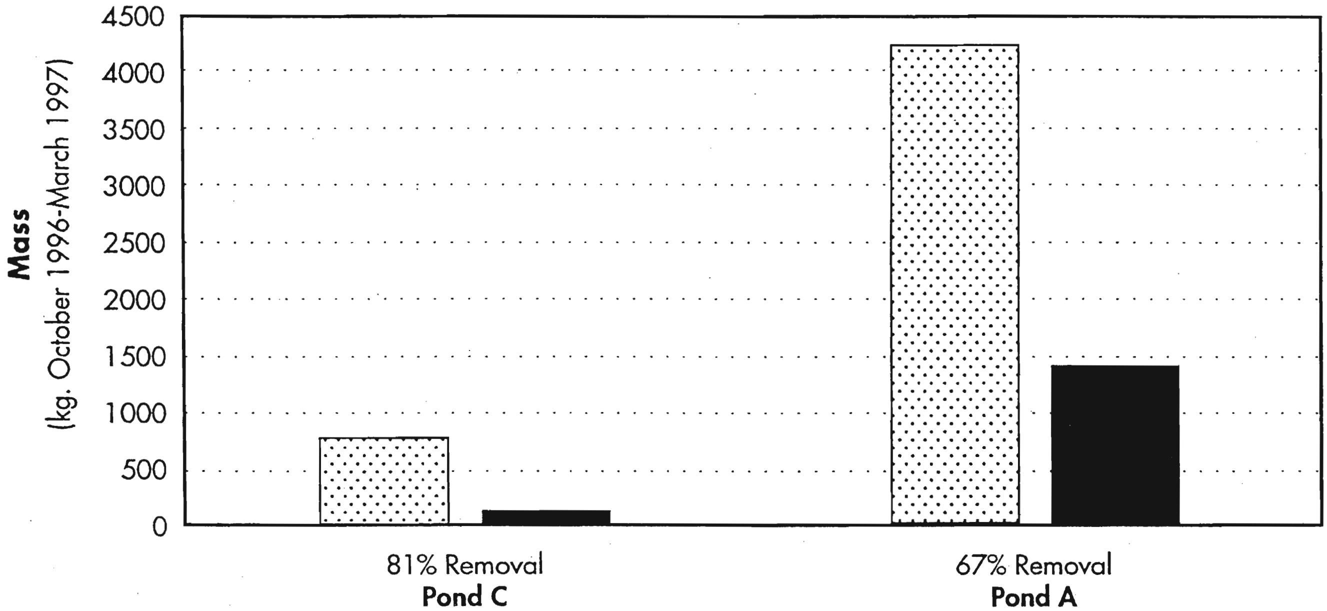
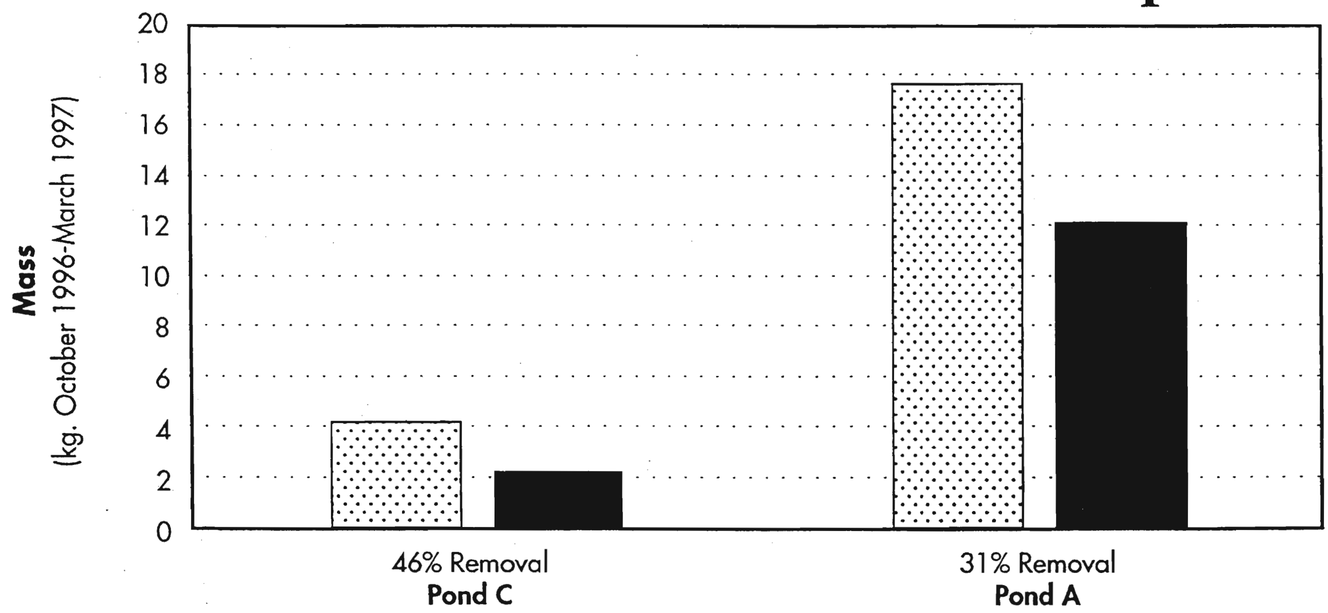


Figure 7.3

Removal of Total Phosphorus



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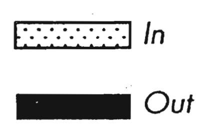


Figure 7.4

Removal of Soluble Reactive Phosphorus

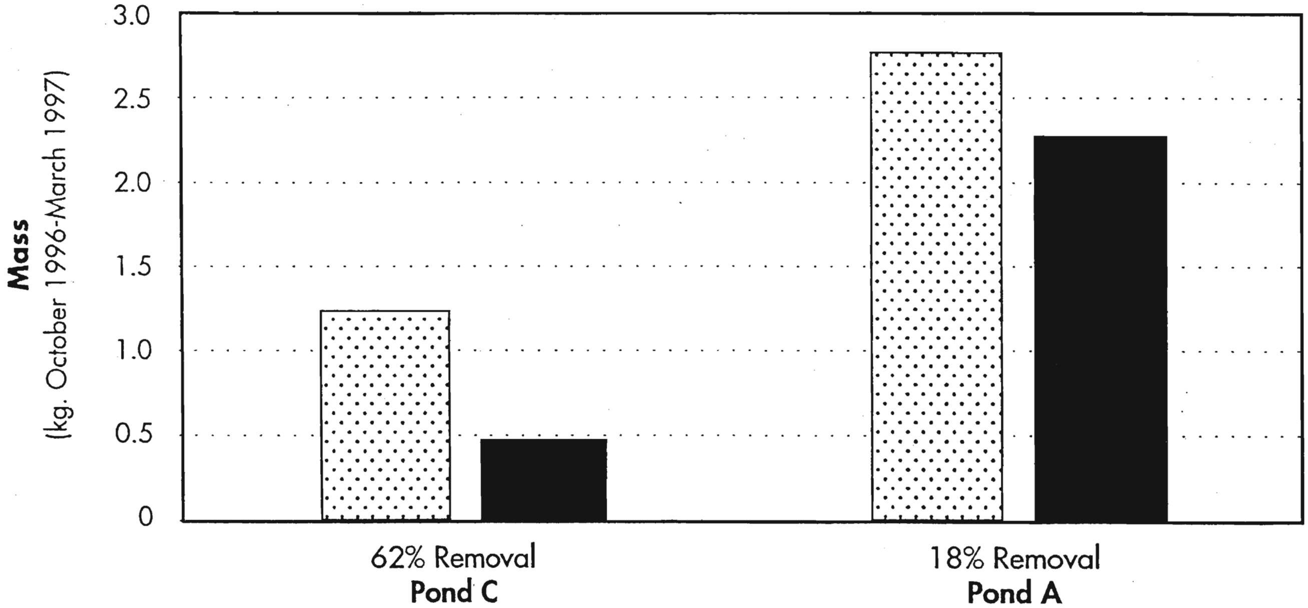
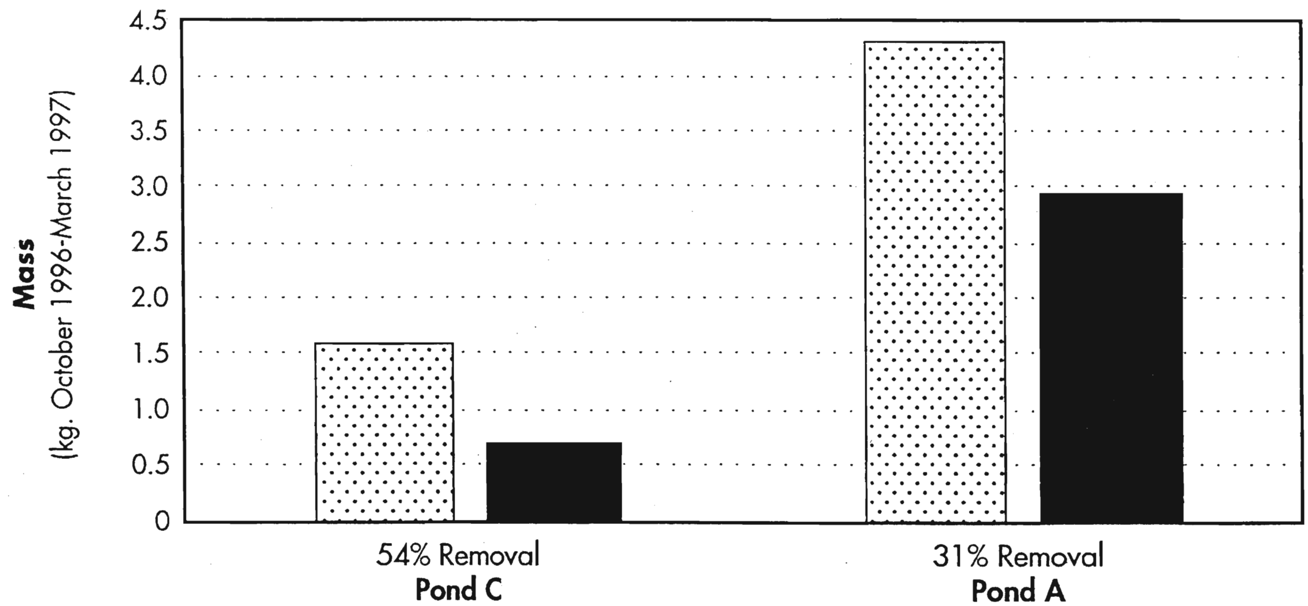


Figure 7.5

Removal of Biologically Available Phosphorus



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Annual Loading Estimates

Annual loading for the investigated constituents was calculated by assuming that the six month study period represents 71 percent of the annual loading, because 71 percent of the mean annual rainfall falls within this period. Table 7.5 summarizes the annual loading at each site for each of the constituents studied.

Table 7.5 Annual Loading at Each Station, (kg)

	C inlet	C outlet	A inlet	A outlet
TSS	1100	200	6000	2000
TP	6.0	3.2	25	17
SRP	1.8	0.67	3.9	3.2
BAP	2.2	1.0	6.0	4.1
Cadmium	0.017	0.008	0.082	0.022
Copper	0.24	0.13	1.0	0.54
Lead	0.15	0.04	1.24	0.28
Zinc	5.6	1.6	14	6.6

A comparison of the constituent loading with and without the ponds demonstrates the contribution that the ponds make to the quality of runoff from this site. The pie charts in Figure 7.6 show the portions of each constituent that are removed by each pond from the total loading that comes from the basin. Even though Pond C has greater efficiencies in all cases, its overall contribution is not as much as Pond A, because Pond C only treats approximately 12 percent of the basin runoff while Pond A receives 100 percent.

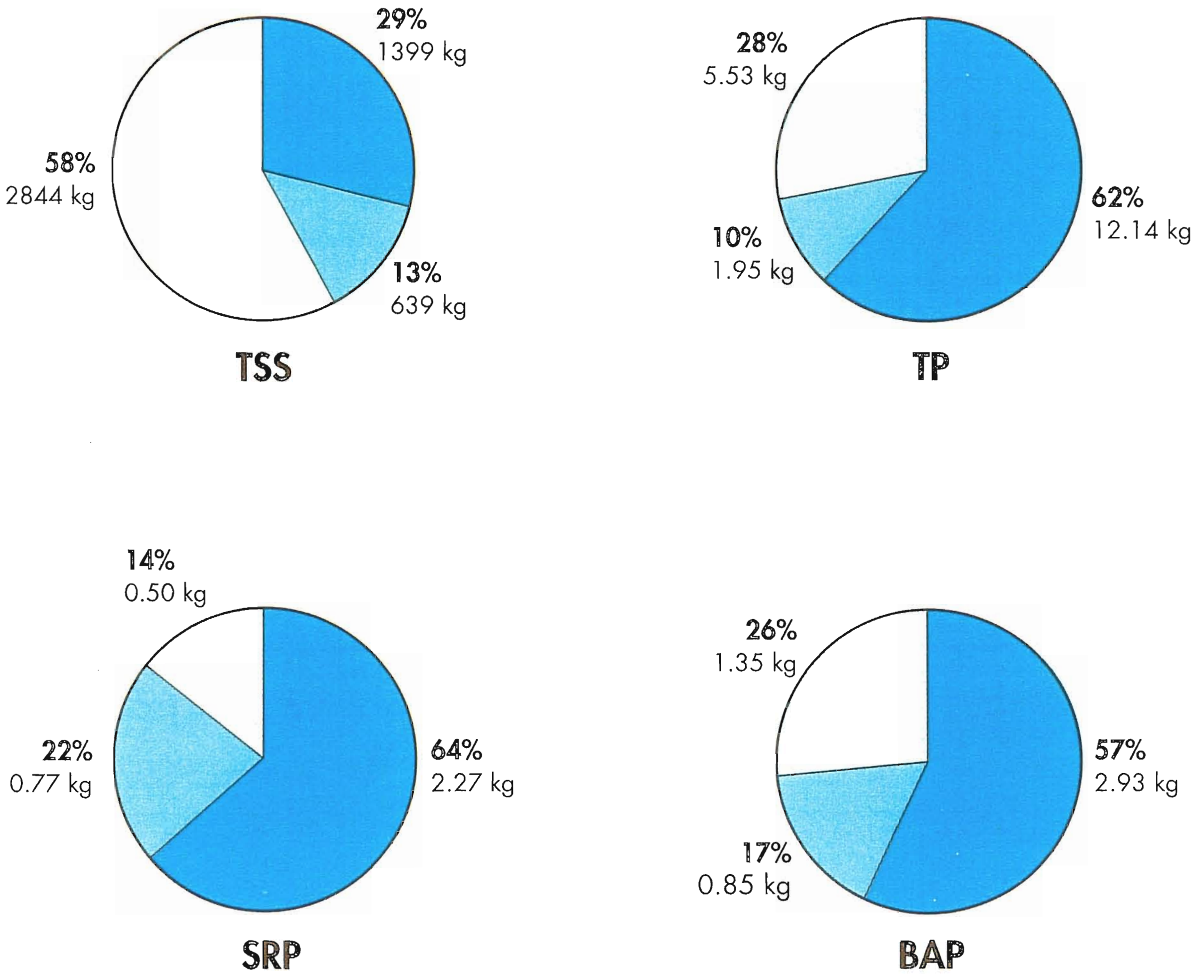
Discussion

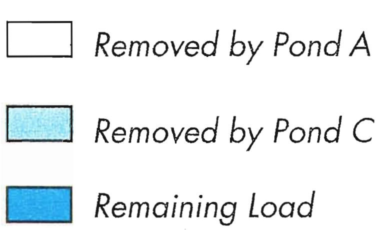
Both of the ponds studied in this investigation work well given their design criteria. For all constituents, Pond C was more effective in removing pollutants than Pond A. This was anticipated considering Pond C was designed specifically for the purpose of water quality improvement and because flows exceeding the design capacity of the pond were bypassed. It is likely that much of the phosphorus removal observed in these ponds is related to the current condition of the pond sediments. As the ponds become older there is the possibility that phosphorus may build up in the sediments, diminishing their capacity for removal (Maristany, 1993).

The findings of this study are an indication of the potential for water quality treatment by wet ponds. However, caution should be used in applying these results because there is always variation among ponds at different locations. Because this study occurred only during fall and winter months, the performance of the ponds during seasons of biological growth is still unknown and could be quite different from pond performance when photosynthetic organisms are dormant. Spring and summer months in the Pacific Northwest produce relatively little rainfall and therefore are less likely to have as much of an impact as fall and winter months.

Figure 7.6

Distribution of Total Loading from Site October 1996-March 1997





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Conclusion

The results of this study indicate that wet ponds provide a significant benefit toward improving the water quality of urban runoff. Pond C considerably outperformed Pond A, demonstrating the importance of pond design. Even so, Pond A considerably reduced the loading from the basin. The upgrades made to Pond A undoubtedly played a role in improving the pond's ability to enhance water quality. There are, potentially, other wet ponds in the Lake Sammamish Basin that could be similarly improved. However, an evaluation of potential retrofit options for improved phosphorus removal completed for the 1996 Water Quality Management Plan (Entranco, 1996) showed that the relative costs and potential phosphorus removal opportunities, were respectively very high (cost) and relatively lower (phosphorus) than other management options. This study supports the need for new developments to install retention/detention ponds that follow the King County criteria. The King County design of a three-celled wet pond functions as anticipated for both water quality as well as flood attenuation. In cases where water quality is the primary stormwater facility goal, a design such as that of Pond C should be employed to maximize phosphorus.

Conclusion for Application to Lake Sammamish

The study results demonstrate that wetponds can be an effective part of controlling total phosphorus loading from commercial land use. However, even Pond C removals did not quite achieve the 50 percent removal standard for total phosphorus that is recommended in the 1996 Management Plan. It would appear that wetponds of this design need to be used in conjunction with an additional treatment facility—for example, a bioswale—in order to ensure achievement of the recommended performance standard. It is anticipated from the results of this study and additional studies completed for the 1996 Manual updates (King County 1996) that wetponds designed to the proposed King County 1996 Surface Water Design Manual would easily achieve the 50 percent removal standard given their relatively large storage volume.

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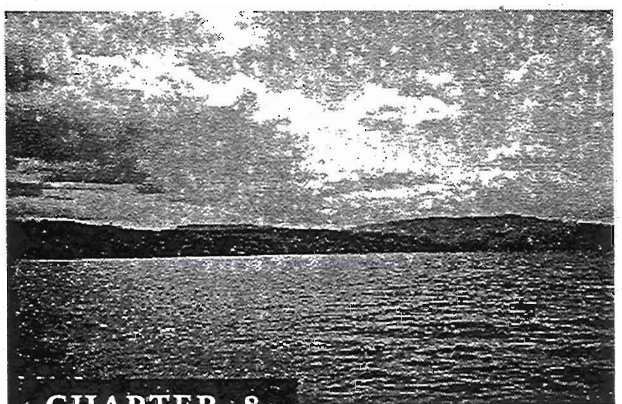

CHAPTER 8

Temporary Erosion and Sediment Control Program

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Chapter 8. Temporary Erosion and Sediment Control Program

Introduction

The purpose of this project was to test the effectiveness of a dedicated inspector for temporary erosion and sediment control (TESC) at construction sites in the King County and City of Issaquah parts of the Lake Sammamish Basin, and to compare the consistency of TESC regulations among the four jurisdictions. The project was conducted by King County and the City of Issaquah during 1995 and 1996. The Cities of Bellevue and Redmond participated in the regulatory comparison portion of the project. The project was continued during 1997 and 1998 with additional support from the two jurisdictions.

The dedicated inspector was part of a TESC Program developed by King County in response to a mandate from the Metropolitan King County Council. The TESC Program included an evaluation of facilities, practices, and regulations in King County, as well as two research projects that evaluated the effectiveness of different facilities and practices in controlling sediment and phosphorus from construction sites and the effect of sediments on salmonid fish populations. The results of the whole program are reported in King County (1997). This document is available upon request from the King County Department of Natural Resources.

The TESC Program was originally recommended in the 1989 Lake Sammamish Water Quality Management Project (Entranco, 1989) because of concerns over excessive erosion at construction sites located on steep and erosion-sensitive soils within the Lake Sammamish basin. The program was introduced at the request of the Metropolitan King County Council (King County 1992) as an alternative to a prohibition on construction-related clearing and grading during the winter season (October through March). Seasonal restrictions had been considered as an original recommendation in the East Lake Sammamish Basin and Nonpoint Action Plan (1994). However, a strict seasonal prohibition on clearing and grading was anticipated to have significant impacts on the local development community by restricting some construction activities during six months of the year. As a result, the King County Council mandated the development and pilot implementation of an alternative to seasonal restrictions.

The only TESC program element funded by this project is a dedicated full-time erosion control inspector in the King County parts of the drainage basin. This inspector provided technical assistance and compliance support to contractors and inspectors regarding the installation and maintenance of erosion control facilities and performed enforcement action in areas with non-compliance. A part-time inspector was also funded within the City of Issaquah. The discussion of the dedicated inspector in this chapter reports only the findings in King County. An additional element of the TESC program reported in this chapter is a comparison of regulatory consistency among the four jurisdictions.

Inspector Project Overview

The King County project consisted of a dedicated erosion control inspector who worked in partnership with the clearing, grading, and building inspectors and the development community to ensure effective installation and maintenance of erosion control facilities and Best Management Practices (BMPs). The inspector provided enhanced inspections of construction sites and technical assistance throughout the King County parts of the drainage basin. Coverage included residential, commercial, plat, short-plat, grading, and utility activities; and King County capital improvement projects activities. Additionally, code enforcement and assistance with erosion problems associated with non-permitted activities were part of the inspector's work.

Inspection and Compliance

In the King County parts of the drainage basin, the TESC inspector's duties were to minimize offsite impacts due to erosion and sedimentation by performing inspections of permitted activities and ensure that BMPs were implemented. The inspector was also responsible for observing non-permitted activities within the drainage basin, and taking corrective actions on all potential TESC problems. King County's TESC program also includes the following elements:

- The TESC inspector attends preconstruction meetings with the land use inspectors on sites adjacent to resource sensitive areas, and/or on sites that are potential TESC problem sites. During these meetings, the TESC program is fully explained to the contractor, and methods of compliance and enforcement actions are reviewed.

- Residential permits include a card (Figure 8.1) explaining TESC measures that need to be implemented for small sites, and a second sheet (Figure 8.2) outlining the potential enforcement action that will take place if these measures are not implemented. All residential homes must have TESC measures in place before the foundation inspection can be signed.

- Copies of the King County Drainage Manual's TESC chapter (King County, 1990) are handed out to contractors so they can review and implement the proper techniques for Temporary Erosion and Sediment controls.

- All inspectors and contractors are given the TESC inspector's pager number so that the inspector is available for emergency situations.

TESC Oversight Committee

During the project, the inspector was also involved in a partnership between the public and private sectors. The partnership was established to gain consistent understanding of TESC practices across both sectors, and to ensure common understanding of the goals and constraints of the TESC program. The partnership took the form of a working group called the TESC Oversight Committee. This Committee included representatives from King County, the construction industry, and environmental groups. Meetings were held regularly to discuss the program elements and to evaluate solutions or alternatives for problem areas.

Small Site TESC Measures

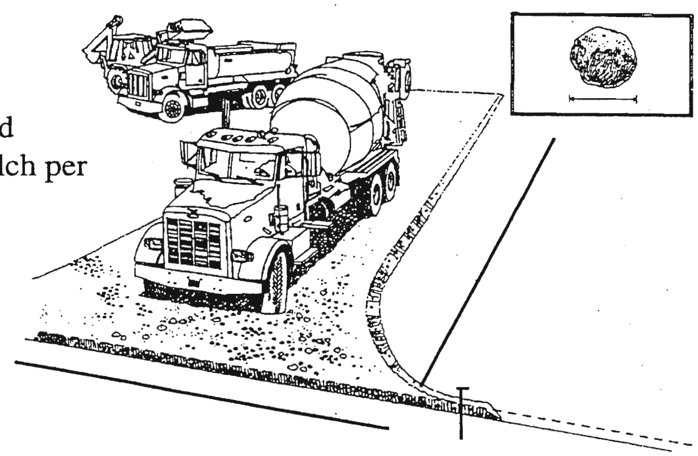
PERMIT APPLICANT MUST POST THIS ON SITE

Federal, state, and local regulations prohibit sediment-laden water from leaving a construction site or from entering a natural drainage system.

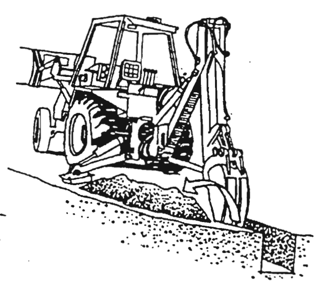
King County Erosion Control Requirements

- **To prevent erosion, during the rainy season, all disturbed areas left unworked must be covered with mulch, sodding, or plastic covering.**
- **Provide a rock construction entrance.**

How To Keep Soil On Site

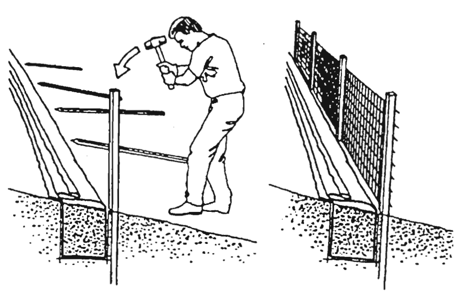


1. Restrict vehicular site access to only the rock constuction entrance.
2. Keep enough material on site for covering disturbed areas during the rainy season. (3 bales of straw mulch per 1000 square feet, sodding, or plastic cover).
3. Install silt fence(s) or leave established vegetation to remove sediment from water (or use both if necessary) for the following cases:
   a. Where storm water has the potential for leaving the site; or
   b. Where storm water can enter certain environmentally sensitive areas and their required buffer. These include wetlands, streams, steep slopes, landslide and erosion hazard areas.

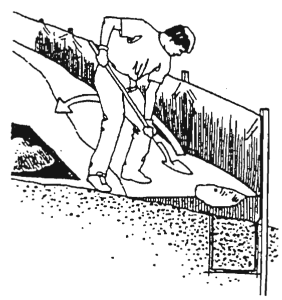


Dig Trench

Toe-in Fabric



Stake and Reinforce



Maintain and Clean

4. Protect highly erodible soils (silt or clay) and slopes that drain away from the site or toward sensitive areas with mulch or other cover or by installing interceptor ditches to direct water to a sediment pond.
5. Keep streets clear of dirt, mud, rock or other construction materials.

Figure 8.2

Small Sites Enforcement Actions

For questions regarding temporary erosion control, contact the assigned King County DDES building inspector.

KING COUNTY CODES RELATED TO TEMPORARY EROSION CONTROL

Building/Construction Standards and Grading Standards
K.C.C. 16.82.100 Operating conditions and standards of performance

Surface Water Management
K.C.C. 9.04.050 Drainage Review - requirements
K.C.C. 9.04.090 Procedures and conditions related to constuction, timing and final approval
K.C.C. 9.04.130 Hazards

Special Control Areas
KC.C. 21.54.170 Erosion hazard areas- protection mechanisms and permitted alterations

If problems persist with sediment leaving the site or contaminating sensitive areas, a Stop Work Order will be issued effective until the end of the rainy season.

Methods of Inspection

Inspections were performed throughout the basin on a regular basis. Sites with a history of problems, larger sites, and sites adjacent to or inclusive of sensitive areas (e.g., steep slopes, wetlands) were visited more frequently. Inspections consisted of reviewing approved TESC plans, visiting the site and making sure that the approved BMPs were adequate, and walking the site to make sure that the approved BMPs were installed correctly. If there were deficiencies, the inspector identified them for the contractor and/or site supervisor, and gave a 24-hour time limit to correct the problems. If the problem was not corrected within that time frame, a written correction notice was given to the project, with an additional 24 hours to correct. If the problem still was not corrected, enforcement action was then taken. This would be a Notice and Violation and/or a Stop Work Order. Once the Stop Work Order was issued, no other work except TESC implementation could proceed until the project achieved compliance. An additional part of the enforcement action is the levying of a fine of $95.00 per hour incorporating all the inspections to that point. The fine was instituted for two reasons: 1) to pay for the additional inspector workload; and 2) to improve compliance. The fine was successful on both counts. If there was extensive erosion with sedimentation leaving the site, the warnings and correction notices were forgone. Instead, a Notice of Violation with a Stop Work Order was issued immediately for the site.

Technical Assistance

The inspector provided additional technical assistance within the basin with the following activities:

- Workshops with the King County Department of Development & Environmental Services staff to increase consistency of inspections and effectiveness of enforcement actions.
- Provision of technical assistance to contractors for use of BMPs on projects.
- Education for contractors on the proper installation of BMPs being used.
- Education for citizens regarding TESC techniques for use during remodeling and/or landscaping projects.

Examples of Issues and Problems Observed in the Field

Two major storm events occurred during the project period. The first event was on February 9, 1996, and the second was a major snowfall in late December 1996 (24 inches), followed by a rain storm during the first week of January 1997. The second event resulted in a rise in the lake elevation to 31.70 feet, only 0.80 feet below the 100-year flood mark. The following case studies demonstrate successes and failures that occurred during those events; while the events were extreme, the issues that arose highlight some of the challenges associated with an effective erosion control inspector program.

Trossacks – On-site inspection and weekly reports

- Trossacks is a large multi-phased development on the eastern edge of the East Lake Sammamish Plateau. After the first storm event, inspections were made. While most of the BMPs were functioning, there were a few that had failed due to undercutting of the silt fence and breaching of checkdams and sediment traps. The inspectors met with both the developer and contractor to review the TESC plan and develop ideas for more effective controls. The results of those meetings were implemented and the plat was required to provide the inspector with weekly maintenance reports. As a result erosion was kept to a minimum and all sediment remained within the boundaries of the plat.

Beaver Dam and golf course infiltration pond - phasing of project

- Beaver Dam is a large two-phased project with residential development and an 18-hole golf course. This project drains into three separate drainage areas: Lake Sammamish, Evans Creek, and Patterson Creek. The eastern portion of the residential sites is located adjacent to a large wetland (Saddle Swamp) which discharges to Beaver Lake and eventually to Lake Sammamish. Three large infiltration ponds make up the majority of the stormwater drainage facilities. The golf course contains 26 retention/detention (R/D) ponds and lakes to manage runoff and perform water-quality treatment. Part of the grading permit conditions for the golf course was to phase-in fairway construction by being limited to opening only three fairways at a time.

  As the deadline for grading limitations approached, the golf course cleared the remaining fairways to make them accessible for shaping and finishing. The inspector met with the golf course personnel in September 1996 to discuss what TESC measures would be required to close up the site for the winter months. Delays in implementing the TESC measure meant that several measures were not in place by late October. As a result a large amount of sediment was deposited in the R/D and infiltration facilities.

  The enforcement action taken was to post the site with a Stop Work order, allowing only TESC to be performed on the site. The enforcement action remained in place from October 1996 until April 1997. This was due to the sensitivity of the site combined with large amounts of open cleared space. Problems that resulted were severe reduction of infiltration rate in the ponds and mass reduction of storage capacity of the R/D facilities. This led to the waters being collected into the infiltration pond and eventually reaching an emergency overflow state.

  The ponds are now in the process of being resized and converted into R/D ponds as continued use for infiltration is no longer possible. The R/D ponds became non-functional during the enforcement period and required reconstruction, adding considerable expense to the construction. It should be noted that the golf course did have 9 of the 18 holes seeded and grassed. These areas of the golf course only experienced minor erosion and sediment problems.

Providence Point – seasonal closing of a site

- Providence Point is another multi-phased development of multi-family homes (condominiums and townhouses) being built on the hillside of the Plateau adjacent to Laughing Jacobs Creek (a salmonid stream flowing directly into Lake Sammamish). During the spring and summer of 1996, a large hillside was cleared and graded for construction of additional townhouses. The contractor planned to close the site for the winter and had scheduled construction to achieve this goal.

  The contractor constructed a series of sediment ponds, intercept trenches, and checkdams for sedimentation control. Erosion control consisted of rock walls built on steep slopes augmented with hydroseed/tackifier mix, and all exposed areas were either hydroseeded with tackifier, or hydroseeded and mulched (on level areas). Slope drains were also used to transport water down the hillside into drainage ditches that are rocked and had a series of checkdams before entering a stormwater vault. All roadways were either rocked or ATB (asphalt-treated base) was laid to prevent tracking of mud. The site was monitored on a weekly basis and after every storm event of 0.5 inches of rainfall in a 24-hour period. With the preparation prior to the wet season, along with the monitoring, no major failures were observed at this site even during the severe storms that were experienced.

Citizen Awareness – increase in program effectiveness

- One of the contributing factors to the success of the TESC inspector project in the Lake Sammamish drainage area are the citizens that live in the area. They are the eyes and ears that can be useful to the inspector in the field. However, due to the lack of education concerning erosion and sediment control, they can also become part of the problem. An example of this was a call received from a citizen concerning silt-laden water running into a stream adjacent to a construction site. The inspector responded to the complaint and inspected the site. Finding no silt leaving the construction site, the inspector backtracked the silt and found it to be coming from the tilled garden of the complainant. The inspector advised the citizen of proper TESC techniques to use on his garden. The homeowner mulched his garden and placed a silt fence around the downstream portion, thereby correcting the problem.

Relationship Between TESC Program and Grading/Clearing Limits

Following a mandate from the King County Council as part of the adoption of the East Lake Sammamish Basin and Nonpoint Action Plan (King County, 1994), the TESC program was set up as an alternative to seasonal clearing and grading restrictions. Throughout the period of TESC program implementation, it has been shown that there are sites and conditions where clearing and grading limitations can be removed without increasing erosion and sedimentation from construction or exposed sites. However, if erosion and sedimentation are to be prevented using a TESC program, then the permitting process needs to look at all conditions of a site including soil conditions, slopes and sensitive area proximity; the TESC facilities and practices then need to take these site conditions into account. Furthermore, once appropriate TESC measures are identified for a site, field inspections and revisions need to be made regularly to ensure continued effectiveness of the TESC measures during all phases of site development. There are some areas where seasonal clearing and grading limitations are still needed, for example large development sites with steep slopes and erosion prone soils. However, this program has shown that at many sites it is possible to effectively control erosion and sedimentation through review of the TESC plan, phasing of site clearing and grading education, proper installation of facilities and best management practices, satisfactory maintenance, timely inspections, field revisions, and appropriate disincentives.

Conclusions

Effective erosion control at constructions sites is a function of contractor and inspector expertise, contracting procedures, regulations, permitting procedures, inspection frequency, level of enforcement, adequate financial disincentives, and attitudes of the personnel involved at the site. The project described above was successful in several areas: the provision of technical assistance; an enhanced level of inspection (i.e., more eyes in the field) at all sites including small residential sites; active and inactive permitted sites and non-permitted sites; and the provision of additional educational and training opportunities, both formal and informal, for building inspectors, contractors, and citizens. Although the project did not include a formal project monitoring element, it would be desirable to complete monitoring at several sites to further quantify the relative effectiveness of different practices. The provision of technical assistance could also be formalized by developing an inventory of different methods including a brief evaluation of each method's strengths and weaknesses.

The following are recommendations based on the project described above. The recommendations focus on how to improve TESC programs, gain a higher level of consistency in inspections, and make effective erosion/sediment control a more reachable goal.

- Ensure that erosion control is conducted on a year round basis, not just during the wet season to reduce the number of sites that are caught unprepared. Discretion should be exercised by the contractor and inspectors with respect to site conditions and the elements of weather. The season should be one of multiple factors considered in establishing TESC conditions at a site.

- Establish erosion control requirements according to site conditions rather than only in regard to the season during which construction activity occurs. In addition to standards set forth in ordinance and drainage manuals, requirements would be based upon soil type, slope, and proximity to sensitive areas. For some site conditions, enhanced levels of erosion control with an emphasis on maintenance of the BMPs will allow the contractor to continue clearing and grading operations during the wet season. In resource sensitive areas, some site conditions may warrant restrictions on some construction activities during the wet season, but with continued site monitoring to ensure that facilities remain fully operational. Both conditions need to be defined as part of the permit process.

- At larger sites, require development of several TESC plans that are phased according to the phases of site development, instead of one final TESC plan. Current standards in King County require a TESC plan that outlines TESC BMPs after the final grade is completed. Having phased TESC plans would allow for proper implementation of TESC standards at all stages of construction. Such plans should allow for effective TESC measures by taking into account the conditions during grading. These could include changes to soil type in fills and cuts, site contours, and drainage.

- Provide and require monitoring for any site that is closed down for the wet season. Currently, only grading permits are conditioned to require monitoring of an inactive site for TESC measures. This practice needs to be extended to other types of permits. Sites with large cleared areas being worked should also require site monitoring. Recommended conditions include having weekly monitoring/inspection of TESC BMPs, with additional monitoring after each storm event of 0.5 inches of rainfall within a 24-hour period. These conditions should be required of both active and closed sites. The reason for this is to assure that all BMPs are effectively controlling erosion and sedimentation, and to allow for a maintenance plan. Inspection forms should be given to the contractors with copies faxed to the building inspector.

- Define the level of staffing required for effective erosion and sediment control inspection and monitoring for different sites during both dry and wet seasons. If this level cannot be maintained for a site, restrict clearing and grading during the wet season.

- Identify and implement contracting and contract management practices for public agencies that will enable them to provide adequate response to TESC needs. The improvements should include:

  a) All public agencies should develop phased erosion control plans and a material cost list for each plan in the bid process.

  b) Public agencies should develop a contingency plan and cost estimate that could be implemented in unforeseen circumstances such as extreme weather or mechanical failure.

  c) Public agency management should use training and literature to communicate to employees and contractors that the mandate to build roads, schools, stormwater facilities, and utility poles does not negate the mandate to protect public resources such as water quality or fish habitat. This is especially important since public facilities are frequently built in sensitive areas and should be achieving the same standards as the private sector.

  d) Restrict the rapid use of restoration bonds.

  e) In order to maintain a proper "paper trail" for public agencies, it is best that the inspector by-pass the verbal correction and write correction notices. Written notices allow communication of concise instructions for required corrections, and give documentation for the contractor.

- Require that small residential sites have TESC BMPs in place prior to clearing and/or grading rather than at the time of the foundation inspection. This requirement is much the same as for any grading permit application. Additionally, since clearing and grading restrictions do not normally apply to small residential sites, it will allow for effective TESC throughout the building process. While some small residential sites may have access to stormwater retention and detention facilities, pipes, and catch basins, they should not be the primary BMP for TESC.

- Increase effective training for developers, contractors, laborers, inspectors, and citizens to explain new techniques and to achieve consistency in the expectations and improve professional commitment to the task. Grants funds could be used to provide education to citizens. This education would provide a resource in identifying problems both on construction sites and in neighborhoods, and give the citizen knowledge to either contact the inspector or the neighbor to gain correction before it becomes a problem.

- Improve disincentives for non-compliance of erosion and sediment control: increase fines, and/or allow for citation issuance. Without adequate disincentives, inspectors will not have the ability to provide effective enforcement. The fines and citations should be adequate so that they becomes an incentive for the contractor to install and maintain the TESC BMPs. Citations could be used to ensure that projects constructed in sensitive areas will have adequate protection.

- Develop guidelines for TESC site inspections, complaint investigations, and handling of enforcement actions. This will allow for better communications between inspectors and will aid in maintaining consistency in the inspection process.

- The Lake Sammamish jurisdictions should routinely coordinate with, and communicate to, the Washington State Department of Ecology (DOE), any construction sites with water quality problems that have NPDES construction permits. Such communication could take the form of routine carbon copying DOE that a site is violating permit conditions and/or that enforcement actions and stop work orders are being issued.

TESC Regulations in King County and the Cities of Bellevue, Issaquah, and Redmond

The Lake Sammamish Technical Committee reviewed and compared existing programs and standards for erosion control at construction sites in all jurisdictions across the watershed during 1995 and 1996. The project was a joint effort of the four jurisdictions. The goal of the comparison was to determine the nature of the programs and relative consistency across jurisdictions in regard to control of erosion and sediments at construction sites.

The comparison specifically evaluated regulatory standards, techniques, and practices that reduce erosion from construction sites, and education for both jurisdictional staff and developers about the techniques and practices that reduce the impact of grading, clearing and construction site management. Since most programs typically relied on implementation through site inspectors, who have expertise in erosion control technology and who work with contractors at the construction site, evaluation of site inspection was part of the comparison.

Methods

Under the direction of the Lake Sammamish Technical Committee, a single individual interviewed and summarized information from public works and building department staff and managers about the regulatory authority (code or program), permit review and inspection practices, maintenance and enforcement, incentives, and education or training practices associated with erosion and sediment control at construction sites in the four jurisdictions. The data were reviewed by the Technical Committee and participating individuals and finalized in tabular form.

Results

The following table summarizes the comparison information regarding erosion and sediment control at construction sites in the four jurisdictions. The comparison information is currently being used by the four jurisdictions to determine the most effective strategies for control of erosion and sedimentation at construction sites in the drainage basin as part of the implementation of the 1996 Management Plan.

Table 8.1 Comparison of Temporary Erosion and Sediment Control (TESC) in King County, Bellevue, Issaquah, and Redmond

MANAGEMENT OR PROGRAM AREA	CITY OF BELLEVUE	CITY OF REDMOND	CITY OF ISSAQUAH	KING COUNTY
Regulatory Authority (Code or Program)	Clearing and Grading Code (B.B.C.23.76); Ecology Design Manual; Standard Design Details Seasonal Restrictions apply in sensitive drainage basins and on sites with protected areas or those that discharge directly to a stream or lake where no permanent sediment trap or detention system exits. Seasonal restrictions may be lifted at discretion of Director if a determination is made that the proposal ensures protection of receiving waters. Large and complex sites receive special attention.	Ecology Design Manual plus Redmond Stormwater Notebook. Seasonal restrictions may be applied; Large and complex sites receive special attention	King County Design Manual Seasonal restrictions in some instances Large and complex sites receive special attention.	King County Design Manual East Lake Sammamish Basin drainage: seasonal restrictions in Wetland Management Clearing and Grading Code (K.C.C. Title 16). King County Water Quality Code (K.C.C. 9.12)
Permit Review and Inspection	Consistent with Ecology manual minimum requirements. Exception: Minimum requirements apply to all parcels—no minimum parcel	Two-step project review: 1. Site plan/ SEPA 2. Construction drawings Site specific conditions added in Step 1. Detailed plan	Permit review of TESC plans. Inspection by Public Works staff.	TESC pilot program with dedicated inspector. Increased inspections on sites adjacent to sensitive areas or natural resources.

MANAGEMENT OR PROGRAM AREA	CITY OF BELLEVUE	CITY OF REDMOND	CITY OF ISSAQUAH	KING COUNTY
Permit Review and Inspection (continued)	size; seasonal restrictions; daily coverage between 10/1 and 4/30. Twice weekly inspection of most construction sites—more in the winter. Daily inspection of major sites, especially in the winter. Special focus on single family residences.	review including TESC in Step 2. Step 2 can involve meetings including construction inspectors for large or complex sites.		Grading permits necessary in absence of building or agricultural permit. 65 percent forest retention regulation in rural zoned lands. Increased inspection on single family residential sites.
Maintenance	Property owner responsible. City conducts periodic monitoring to ensure proper functioning of BMPs.	Separate code enforcement inspectors for private sites. City maintenance of public sites.	Required by Design Manual; as directed by Inspector.	Weekly written on-site reviews may be required by the Department of Development and Environmental Services. Sites required to perform any needed maintenance on BMPs within 24 hours of a rainfall event of 0.5 inches or greater. Major sites may be required to have TESC Specialist on site.
Enforcement	Correction notice, stop work order, restoration, revocation of permit, civil infractions and penalties up to $500 per day. Three stop work orders results in permit suspension	Correction notice; stop work order; civil misdemeanor penalty; site restoration; other financial penalities.	Correction notice, stop work order.	Correction notice; stop work order; fines; site restoration. Re-inspection of single family residential on Stop Work charged $184 for each

MANAGEMENT OR PROGRAM AREA	CITY OF BELLEVUE	CITY OF REDMOND	CITY OF ISSAQUAH	KING COUNTY
Enforcement (continued)	until dry season, or for summer work, until weather conditions are favorable and effective erosion control is in place.			reinspection. Work done on project other than residential is charged at $95/hour with a minimum of 2 hours. Violation of Stop Work subject to civil penalties up to $2,000 per day per violation.
Incentives	Inspections charged by the hour, so fewer inspections result in lower charges. Partial transfer of buildable area density credit for sensitive areas.	Clustering encouraged on sites with sensitive areas; Permit fee credit if applicant participates in pre-application conference; clustering used to reduce imacts.	None	None
Education	Pre-application and pre-construction meetings with developers and construction team. Brochures Cooperative effort with King County on business education.	Pre-application process; Educational handouts and materials	In-house education program for inspectors.	Pre-construction meetings with developers/ contractors. In-house education for inspectors. Basinwide education and site-specific technical assistance program; Brochures Business and industry educational events.

Conclusion for Application to Lake Sammamish

The dedicated inspector project appeared to significantly reduce erosion at constructions sites within the Lake Sammamish basin. No quantitative measurements of reduction were made although field measurements of turbidity were made frequently to verify effectiveness of facilities and practices at specific sites. The dedicated inspector position has been funded by King County for the last two years following the expiration of grant funds. Continuation and expansion of the program to include all elements identified in the preceding section would help to control sediment and phosphorus loading to Lake Sammamish from new development. Additional dedicated funding sources are being evaluated.

The various jurisdictions in the watershed are continuing to analyze their TESC programs in order to develop a greater degree of consistent control of erosion and sedimentation from construction sites using the findings of this program and successful working models in other jurisdictions.

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King County, 1992, *Final Bear Creek Basin Plan.* King County Department of Public Works Surface Water Management Division.

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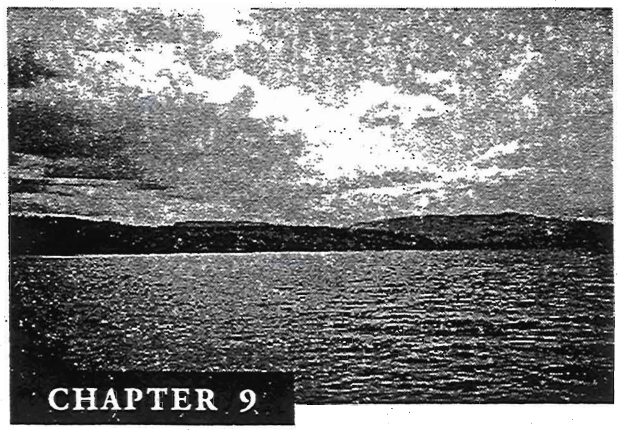

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Chapter 9. Workshops and Public Education

Background

The Public Education project was conducted by King County with planning assistance from the City of Bellevue during 1994 and 1995. It originally targeted two audiences: new home buyers and the builder/contractor community working in the field. However, during the development of a strategy to reach new home buyers, it was determined that the builder/contractor group had already been reached through a series of training programs given by another King County department. In addition to this, early results from the Temporary Erosion and Sediment Control (TESC) project indicated that on-site inspection and education were a very effective means of educating the building and contractor community. Therefore, the funding for the builder and contractor seminars was transferred to the TESC project.

Program Coordination

The original plan called for two agencies to split the education program: the Municipality of Metropolitan Seattle (Metro), now a part of King County's Department of Natural Resources, and the King County Department of Development and Environmental Services (DDES). It was felt that because of DDES's relationship with the development community it would be more appropriate for it to handle the new home buyer program and for Metro, as a more neutral entity, to sponsor the builders' and contractors' portion. When the decision was made to not host the builder and contractor seminars, Metro staff assisted DDES staff with the remaining program.

New Home Buyer Program Development

The first step in planning this outreach program was to convene a planning group of experienced public involvement experts. The following people met once to set the direction of the program: Susie Kalhorn, David Dudley, and Claire Dykeman from DDES; Nancy Hansen from the City of Bellevue; Sheryl Corrigan from King County Surface Water Management (SWM) Division, now the Water and Land Resources Division; and Jacqueline Reid and Kristi Silver from Metro, now King County Water and Land Resources Division. Their combined expertise in creating and conducting quality public education programs was very important in the development of this program.

This group determined the following directions for the program:

- The message needs to contain pertinent ways to improve water quality and impart a "sense of place"—a sense of what the Lake Sammamish area is, its attributes, its resources, and instill a sense of stewardship.

- The rate of new buyers in the Lake Sammamish area warrants focusing on this audience.

- Realtors consider themselves to be educators of new home buyers.

- A product or information could be distributed to realtors that they could then distribute to new home buyers.

- An educational slide show/seminar for realtors with supportive handouts would provide good results.

- The "hook" to encourage participation of realtors would be to offer educational credits through their professional organization.

With these elements identified, the staff from DDES and Metro worked together with a group of realtors to provide oversight in the creation of the program. An eight-minute slide show was created using slides from both agencies as well as the local citizen action group, Save Lake Sammamish. The slide show was then synchronized with narration by the head of the citizen action group, Joanna Buehler. The script of the slide show is included at the end of this chapter. To increase ease of operation, increase distribution, and reduce the cost of reproducing the show, the slide show was video taped and duplicated. Copies of the video tape were distributed to persons involved in environmental education in the drainage basin. These persons were: Tina Miller, East Lake Sammamish Basin Steward; Joanna Buehler, Save Lake Sammamish; Lexi Truman, Metro (now King County Water and Land Resources Division) Schools Program; and public libraries in Issaquah, Bellevue and Redmond. The video is available to others upon request.

Staff then evaluated what to include in a book of printed resources for new homeowners. Although the initial desire was to print a new brochure or booklet specific to Lake Sammamish, staff decided to collect and review available examples of pertinent resources as a first step. It was then determined that since the available brochures, newsletters and booklets were so plentiful, affordable, and contained very current information that a different approach should be used. All that would be needed would be to package this existing information. By assembling the existing information into a binder, the amount of information that could be distributed within the budget was increased. The information was either punched for insertion or placed in pocket holders. The resulting three-ring binder contained the following information:

Water Resources Section

- *Water in Issaquah Creek/ East Lake Sammamish Basins*, KCSWM
- *Streamside Savvy - SWM's Guide to the Good Life at the Water's Edge*, KCSWM
- *Ground Water and the Rural Homeowner*, U.S. Department of the Interior
- *Downstream News*, KCSWM
- *Get Your Feet Wet - SWM's Community Stewardship Program and Volunteer Opportunities,* KCSWM
- *Wetlands and Streams*, KCSWM
- *Protecting Your Wetland*, King County Wetland Preservation Program
- *Indoor Water Conservation*, Seattle Water Department

Air Quality Section

- *It's Time We Cleared the Air*, Puget Sound Air Pollution Control Agency
- *Air Pollution - What Can I Do?*, Puget Sound Air Pollution Control Agency

Hazardous Products and Waste Section

- *Hazard Free Home*, Washington Toxics Coalition, Metrocenter YMCA and King County Cooperative Extension
- *How to Dispose of Household Hazardous Waste*, Metro
- *Hazards on the Homefront*, Local Hazardous Waste Management Program
- *Turning the Tide on Toxics in the Home*, Washington State Department of Ecology
- *The Care and Feeding of Septic Tanks*, Washington State University Cooperative Extension
- *Properly Managing Your Septic Tank System*, Washington State University Cooperative Extension
- *Properly Managing Your Mound System*, Washington State University Cooperative Extension
- *Welcome to the Renton Treatment Plant*, Metro
- *Working to reduce society's reliance on toxic chemicals*, Washington Toxic Coalition
- *Are You Pouring Water Quality Down the Drain?*, Metro

Lawns and Gardens Section

- *The Eastpointe NATIVE Plant Demonstration Garden*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Native Plant - The Ethics of Collection*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Native Plants - Why use them & Where to find them*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Traditional Native American Uses of Native Plants*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Drought Tolerant Native Plants*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Planting Natives for Wildlife*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Native Trees for Attracting Wildlife*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Native Shrubs for Attracting Wildlife*, NATIVE (Nature Appreciation Through Indigenous Vegetation at Eastpointe)
- *Sound Gardening - Gardening with an eye on water quality*, King County Cooperative Extension
- *Backyard Wildlife Sanctuary*, Washington State Department of Wildlife
- *King County Wildlife Program Newsletter*
- *Water-Wise Plants for the Northwest Garden*, Water Conservation Coalition of Puget Sound
- *Water Conservation in a Northwest Garden*, Water Conservation Coalition of Puget Sound
- *Water Conservation and the Northwest Lawn*, Water Conservation Coalition of Puget Sound
- *Purple Loosestrife*, Washington Department of Wildlife
- *Home Composting*, King County Solid Waste Division
- *The Urban Wild - A King County Guide*, King County Environmental Division

Additional Information Section

- *Guide to Recycling Major Appliances,* King County Solid Waste Division
- *Wild about Farms - Farming Practices that Attract Wildlife*, King County Environmental Division
- *We do not inherit the earth from our ancestors, we borrow it from our children*, Washington Environmental Council

Quick Reference Section

Comprehensive listing of agencies and phones numbers relating to water resources, air pollution, gardening, hazardous waste, community organizations, and solid waste.

Program Implementation

The final implementation of the program took place during 1994 and 1995. Flyers advertising the program were posted and distributed to all the major realty companies in the watershed. DDES staff hosted approximately 15 classes and reached about 170 individuals in the real estate industry. In addition to realtors, there was a broad auxiliary group who benefited from this program through receipt of the binder and video tape: King County Assessor's office; City of Issaquah personnel; Leadership Redmond; members of the citizens' group Save Lake Sammamish; enrollees in a program called Pesticide Free Neighbors; various local homeowners associations (Klahanie); and a local stream preservation group.

Attendees to classes for the realtors were given up to ten copies of the special Lake Sammamish binder of assembled information as well as a copy of the video slide show. The realtors, in turn, were encouraged to lend these resources to both potential and actual new home buyers.

Conclusions for Application to Lake Sammamish

The creation of the slide show and information binder set the stage for the development of an increased educational program in 1996, 1997, and 1998. DDES has continued to utilize the resources developed in the program in other outreach programs. Specifically, materials are used as examples of why wetlands are important and the role they play in water quality protection, to illustrate why water quality protection is a worthwhile matter, and to help realtors in understanding the importance of protection through regulation. These outreach programs are intensive two-day workshops with 15 hours of clock time for continuing education credits through the Washington State Board of Realtors. An additional unanticipated audience that DDES reached and will continue to reach was their own staff. These courses focusing on Lake Sammamish issues will continue over many years and reach an ever-growing number of people.

A secondary benefit of the project was to demonstrate that diffuse adult audiences can be reached through targeted programs of environmental education. This finding has been extended into the development of a broad-based program of home and garden education about nonpoint source pollution control for residents of the Lake Sammamish drainage basin during 1997 and 1998.

Script of the Education Video:

Buying or Selling a Home Near Lake Sammamish

1. So you're thinking of buying or selling a home near Lake Sammamish,
2. a lake that is known for its beauty and stunning views,
3. its notable bald eagle populations and diverse wildlife,
4. the fish that anglers pull out of the lake each year,
5. and the salmon runs,
6. not to mention its recreational opportunities.
7. Lake Sammamish and its rivers and streams are home to numerous plants, animals, and lifestyles that typify the Northwest.
8. No wonder people want to live in this area.
9. Lake Sammamish is scenic from the trickling beginnings of a distant stream on the slopes of many regional mountains,
10. down the hillsides through varying habitats,
11. through salmon spawning, hatching, and rearing areas,
12. through the meandering shallows,
13. and on to the lakes or ponds in the basin.
14. Yet, the water bodies that make up the greater basin we call Lake Sammamish are both complex and related to one another,
15. as seen on this map.
16. The water systems, all of them, provide food, shelter, habitat, and enjoyment for many.
17. But the basin and its related systems are changing.
18. Increasing population pressures have pushed development further up river and stream corridors.

19. Once lush forest areas have given way to the need for more space, new homes, and additional roads.

20. You may be asking yourself, "What's the problem?" Why worry about a few homes?"; "What does this have to do with the Lake? It is a long way from here!"

21. Well, as the landscape changes, small streams and rivers are often forced to alter their paths.

22. Their natural meandering becomes channelized, confined, or blocked,

23. while, at the same time, the plants and animals native to the area may change significantly.

24. Our favorite places to climb, boat, hike, view the mountains, and enjoy the area are becoming increasingly distant and scarce.

25. Wetlands and groundwater are also affected as land use changes and as sites are altered, both on commercial and residential lands.

26. Development will continue and we need it to continue.

27. Yet we must develop our lands responsibly. Any amount of soil that leaves a site,

28. no matter how slight or trivial it may seem,

29. can create tremendous pressures on the lake.

30. Irresponsible development can create a potential for sediment to leave a site, and with that sediment goes the phosphorus that is naturally present in our northwestern soils.

31. As we push outward with growth,

32. it is important that we keep soils stationary,

33. preventing water from moving them, whether in small

34. or large amounts, both in rural

35. and urban development areas.

36. The water ends up in the lake, carrying with it the soil particles, pollutants, and phosphorous from upstream,

37. and these can wreak havoc in the lake.

38. Algal growth accelerates with the increase in phosphorus,

39. depleting the available oxygen in the lake, and creating a scum layer that not only smells bad,

40. but is troublesome to lake users.

41. The worst case ... a lake and water system that possess only aesthetic values

42. and are unable to support the species which once thrived.

43. But there are ways to prevent further decline and begin the recovery process.

44. Developers, contractors, and builders are working with local jurisdictions to create workable methods to control erosion,

45. thus reducing the sediment and phosphorus leaving a site.

46. But soils and runoff are only parts of the problem. Many other sources of phosphorus are present in the greater Lake Sammamish basin.

47. Our automobiles, streets, roads, and parking lots contribute numerous pollutants to our streams and water bodies.

48. Automobile products and wastes can have

49. tremendous and lasting effects in ecosystems.

50. Check out alternative methods of transportation, and at least be sure that if you use an automobile that it is tuned and running correctly.

51. We can all protect the lake through responsible landscaping. Native plants flourish in this area and provide habitat for wildlife.

52. Other landscapes, like lawns, can be energy and water intensive. Consider your landscape decisions, as well as your use of pesticides and fertilizers, and give some alternatives a try.

53. Other household products, those that we use everyday and those that we use seldom, can contribute phosphorus and other pollutants to the lake, especially when used incorrectly.

54. Whether we live in close proximity,

55. or in open spaces, water connects us all above and below ground.

56. Septic systems can contribute phosphorus and other pollutants to Lake Sammamish via groundwater and surface water.

57. only the areas shown have waste water collected and treated by a sewage treatment facility.

58. When we look at the entire picture, the problems seem overwhelming and the sources uncontrollable,

59. especially when you consider the storm events that are so common in the Northwest.

60. Whether there is a stream on your lot or not,

61. our daily actions influence the quality of the water system where we live and work. Each of us can help protect the lake.

62. We can all improve the health and quality of this ecosystem by considering our actions and making responsible choices.

63. Familiarize yourself with the numerous programs going on in your area to help reduce pollutants.

64. Participate in the ongoing dialogue.

65. Get involved in the programs that help to enhance your basin.

66. Provide ideas to local jurisdictions who are cooperating to solve the problems.

67. Whether you plan to buy in a newly developed area,

68. or you are purchasing an existing home or business,

69. you are part of the lake and its greater basin.

70. A fragile, beautiful lake and its native wildlife,

71. the rivers, streams and fishes,

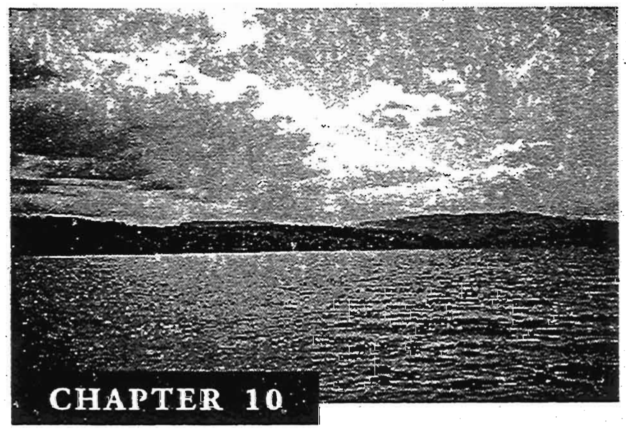
72. and the recreational and living opportunities

73. are all part of Lake Sammamish.

74. We are all a part of the lake, and it is our responsibility to be sure that it remains alive and healthy.

75. Credit

76. Credit



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Chapter 10. Non-point Source Intensive Survey

Introduction

The Lake Sammamish Non-point Intensive Survey was designed to locate and survey non-point sources of phosphorus in the Lake Sammamish watershed primarily within the Issaquah and Tibbetts Creeks sub-basins. This project was conducted by King County during 1994, 1995, and 1996. All samples were analyzed by the King County Environmental Laboratory. Project oversight was provided by the Lake Sammamish Technical Committee.

Sampling Design

In the first phase of this study, elevated concentrations of phosphorus were found over a wide area of the watershed. Phosphorus sampling sites were selected by windshield surveys of the basin. The windshield surveys identified areas and activities that had potential for adding phosphorus to surface waters. Grab samples were collected at low flow during the summer dry season and during three to four storm events during the fall and winter wet season. Flows were collected at some of the sites and total phosphorus loading estimates were calculated where data were available. Due to the low number of samples collected at individual locations, and the long temporal and wide geographic design of the study, there were insufficient samples to accurately calculate loads for more than relative comparisons.

The second phase of the study included a combination of new sites, primarily in the North Fork Issaquah Creek and the Tibbetts Creek areas, and further sampling of Phase 1 sites in the Sycamore neighborhood in south Issaquah and commercial areas in downtown Issaquah (Figures 10.1-10.3; Table 10.1). In the first phase of the survey, samples from several of the commercial areas of Issaquah had some of the higher concentrations of phosphorus. In Phase 2 an attempt was made to better identify, and geographically pinpoint sources of high phosphorus in the drainage basin. The Phase 2 portion of the study sampled as broad an array of land uses in the basin as possible, as well as those Phase 1 sites which had highest concentrations of total phosphorus (TP), ortho phosphorus (PO_4) and turbidity (NTU), and loading of TP.

Results and Conclusions

Phase 1: A number of sampling sites that had high concentrations of phosphorus in Phase 1 sampling were placed on a Short Term Action list for remediation (see Appendix 1). Specific sites placed on this list from the Phase 1 study were the Issaquah Fish Hatchery, Kelly Ranch, Sunset Quarry, and the Valley Growers Nursery site. There were no quantitative load estimates from these sites, but all of these sampling sites had consistently high concentrations of phosphorus in the grab samples collected. Concentrations from all four of these sites were closer to levels typically observed in point sources than in non-point sources. Instead of continuing to study the sites to generate a quantitative TP load, a decision was made by the interjurisdictional Lake Sammamish Management Committee to directly address these sources.

Table 10.1 Sampling Sites for Lake Sammamish Non-point Intensive Survey, Phase 2

LOCATOR	SWM LOCATOR	NAME	DESCRIPTION	FIELD INFORMATION
LSI101	67W-01690-002	Tibbetts below confluence.	At footbridge in Lake Sammamish Park. Follow path along right side of stream channel to bridge.	
LSI102	67W-01700-001	Tibbetts tributary 0170	Tibbetts tributary 0170 above drive into Lake Sammamish State Park.	
LSI104	67W-01700-005	Tibbetts tributary 0170 in cloverleaf.	I-90 westbound on-ramp from SR 900 northbound. First ditch crossed.	
LSI105	67W-0170A-001	Triple culvert tributary in cloverleaf.	I-90 westbound on-ramp from SR 900 northbound. Second ditch crossed. Outlet of three culverts.	Park on shoulder of on-ramp. Walk down to channel.
LSI106	67W-0170C-001	Ernst parking lot ditch south of Gilman.	Open channel south of Gilman, before street drainage enters.	Sample as close to Gilman as possible.
LSI107	67W-0170B-001	Gilman drainage from west.	24" cmp in catch basin below sidewalk off Gilman.	Pipe is ~10' down. Use rod to dip sample. Manhole lid may be sticky.
LSI108	67W-01700-008	Gilman drainage from east.	Catch basin by fire hydrant in sidewalk off Gilman.	Basin ~ 10' deep. Use rod to dip sample.
LSI109	67W-0170C-005	Inlet to Woods R/D pond.	Open ditch in southeast corner of fenced pond.	Need City of Issaquah key to enter gate
LSI110	67W-0170C-003	Outlet to Woods R/D pond.	12" pipe on west side of pond or in catch basin outside of the fence.	Need City of Issaquah key to enter gate.
LSI111	67W-0170C-004	Road runoff inlet to Woods R/D pond.	24" CMP by gate.	Need City of Issaquah key to enter gate.
LSI201	25W-0199A-003	Duck Pond outlet near Sycamore.	Issaquah Creek tributary crossing Front Street near Sycamore Drive Southeast.	Sample culvert outlet downstream side of Front Street Will need some brushing. Collect fecal coliform samples too.
LSI202	25W-01780-052	Issaquah Creek below Sycamore.	End of Southeast Sycamore Creek Lane. Follow path to stream.	Collect fecal coliform samples too.
LSI203	25W-01780-066	Issaquah Creek at Southeast 113th Street crossing.	Issaquah Creek below road bridge at Southeast 113th Street.	Collect fecal coliform samples too.

Table 10.1 Sampling Sites for Lake Sammamish Non-point Intensive Survey, Phase 2 (continued)

LOCATOR	SWM LOCATOR	NAME	DESCRIPTION	FIELD INFORMATION
LSI204	25W-01990-001	Tributary 0199 at 238th Way Southeast.	Tributary 0199 culvert crossing on 238th Way Southeast.	Collect fecal coliform samples too.
LSI301	46W-0181E-002	Gilman drainage to North Fork.	18" X 24" grate by landscaping at Texaco car wash Gilman by Front Street.	Collect fecal coliform samples too.
LSI302	46W-0181F-002	Front Street drainage to North Fork.	18" manhole in sidewalk by freeway sign on Front Street near I-90.	Collect fecal coliform samples too.
LSI303	46W-0181G-001	Issaquah Fall City Road drainage to North Fork.	Outfall to 18" RCP pipe across street from Ryder truck rental.	Pipe about 1/2 full of sediment and garbage.
LSI304	46W-01810-018	North Fork at Black Nugget Road.	Below road bridge on Black Nugget Road. Grand Ridge monitoring gauge 46T.	Tape down to water surface from top of crest-stage gauge.
LSI305	46W-01810-013	North Fork at Southeast 66th.	At road bridge on Southeast 66th. Site of KC SWM gauge 46A.	Read staff plate.
LSI306	46W-0181X-001	Catch basin near 1st Avenue Northeast.	Square grate basin in gravel draining Cadman.	May not be flowing.
LSI307	46W-0181H-001	Ditch draining Cadman wetland area.	Ditch by house west of First Avenue Northeast.	
LSI308	46W-01810-010	North Fork at I-90 on-ramp.	North Fork below Front Street drain.	
LSI309	46W-0181E-001	Gilman Drainage to North Fork	Rectangular grate catch basin on side of south-bound Front Street near I-90 off ramp. 12" RCP is about 4' below street	

Phase 2: The results of the Phase 2 sampling effort are reviewed in the following sections for each parameter measured.

Fecal Coliform Bacteria

Fecal coliform samples were collected at a number of sites along Front Street in Issaquah to determine if suspected sewage cross connections had been made in the area. Based on the low counts of fecal coliform bacteria measured at these sites, sewage pollution from direct cross connection is very unlikely, as the counts would be orders of magnitude higher (Table 10.2; Figure 10.4). Bacterial concentration at the Front Street drain site (LSI302) was high in October 1995 and was the highest of all of the sites sampled for bacteria during the April 1996 storm. This site drains an area where a few sheep are kept. The source of these bacteria may be wastes from these livestock.

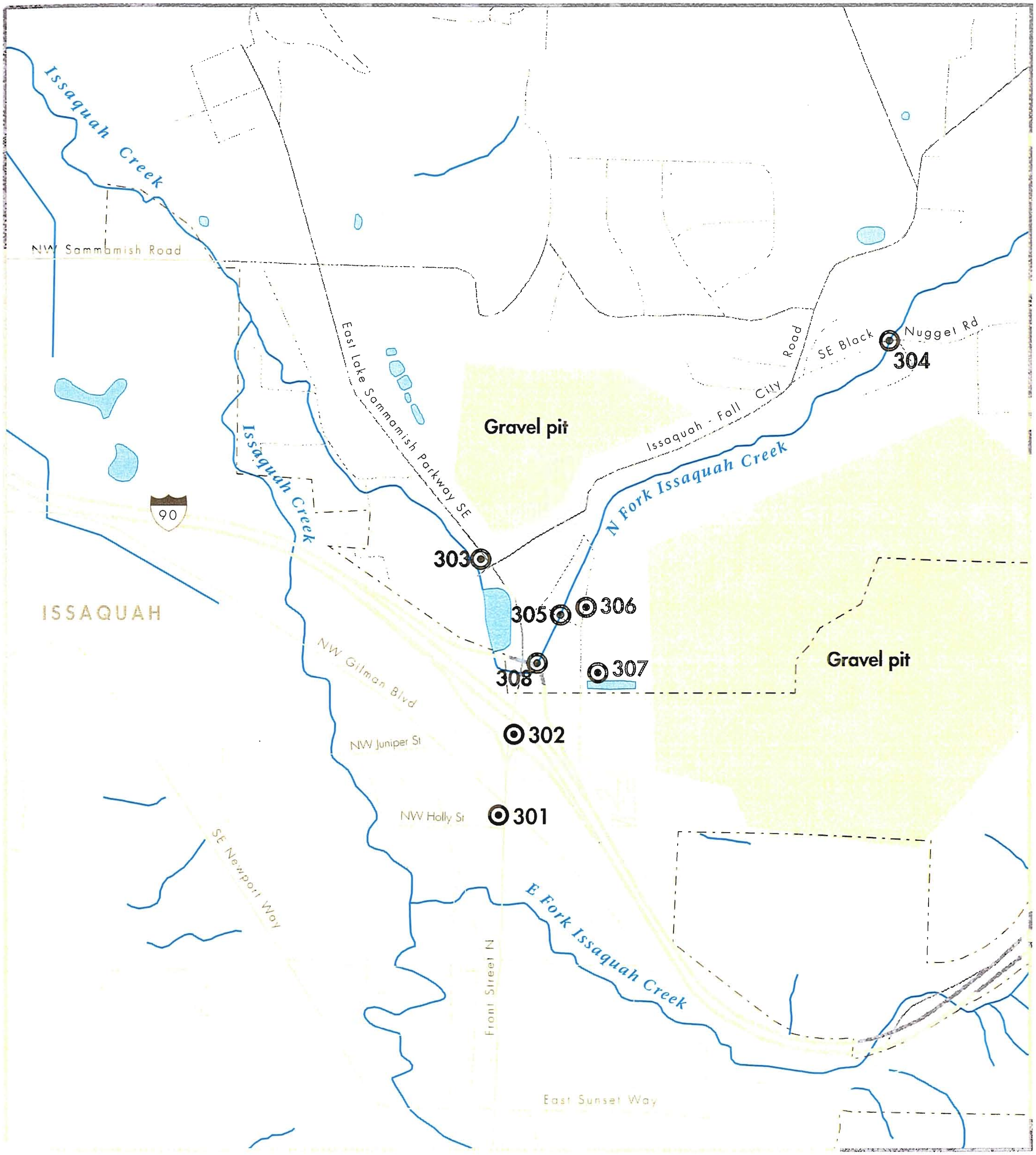
Fecal coliform was also looked at in the Sycamore neighborhood where problems with septic tanks were suspected. Samples were collected from a small duck pond on the east side of Front Street South near Lewis Street Southeast, Nudist Camp Creek, and Issaquah Creek both upstream and downstream of the Sycamore development (Figure 10.3). The duck pond had the highest fecal bacteria counts on every sampling date, with a non-storm count of over 1000 MPN/100ml, to nearly 6000 MPN/100ml during the October 10, 1995, storm (Table 10.2, Figure 10.5).

At all of the sites sampled, the highest bacterial counts were collected during the first storm event in October 1995, and likely represent a "first flush" response. Fecal coliform counts upstream of the Sycamore residential area were consistently lower than downstream of the development. The contribution of bacteria from Nudist Camp Creek, between these two sites, makes it unclear whether the Sycamore development is the source of the increased bacteria, or more likely, there are diffuse contributions from a number of sites in this area.

The bacterial counts are not cumulative; all of the upstream counts (LSI203, LSI204, and LSI201) drain into Issaquah Creek at LSI202, but the fecal bacteria counts at this site did not reflect the sum of the upstream sites. The site downstream of Sycamore did not have higher fecal bacteria counts during the October and November 1995 storms, but did during the February and April storms. The non-additivity of the bacterial samples probably reflects both dilution effects from water inputs between sample sites and the large variability often seen in fecal coliform bacteria data. The high fecal coliform bacteria counts in this general area, particularly during the first storm event when all of these sites were >2000 MPN/100ml, are of concern and should be examined in more detail.

Table 10.2 Fecal Coliform Bacteria Counts Collected in the Sycamore Area

Locator	28-Aug-95 MPN	10-Oct-95 MPN	7-Nov-95 MPN	6-Feb-96 MPN	16-Apr-96 MPN	Description
LSI201	1100	5900	3800	1000	800	duck pond outlet
LSI202	54	2500	800	180	410	downstream
LSI203	120	2600	490	170	200	upstream
LSI204	45	2400	1000	140	16	Nudist Camp Creek



North Fork Issaquah Creek Sampling Sites

Figure 10.1

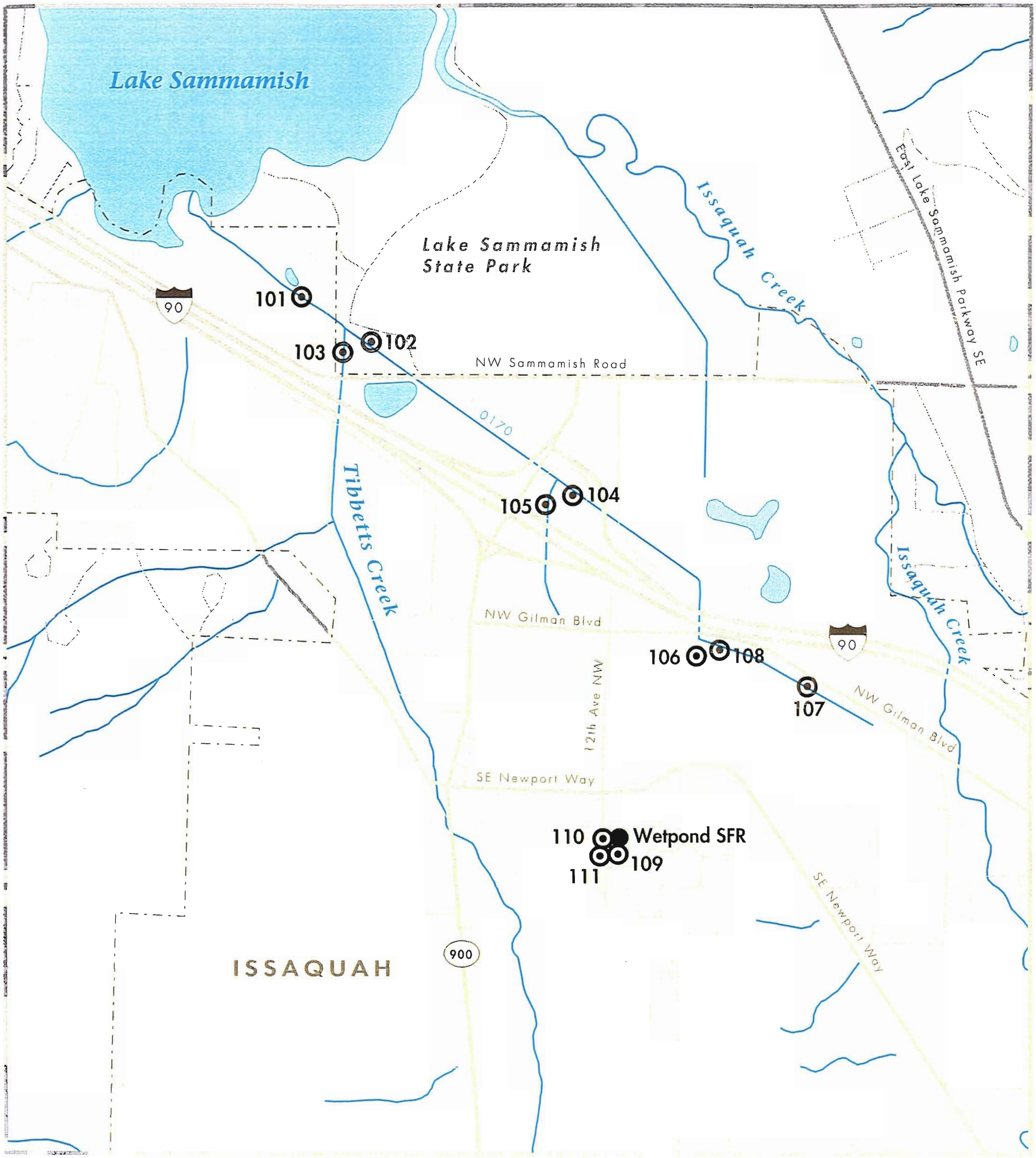
- Sampling Site Location
- Road
- Stream
- Lake
- Incorporated Area

N

0 400 800 1200 1600 2000 Feet

File Name: Fig 10-1 NForkIss Sites
Produced by: Visual Communications and GIS Unit

Department of Natural Resources KING COUNTY



Tibbetts Creek Sampling Sites

Figure 10.2

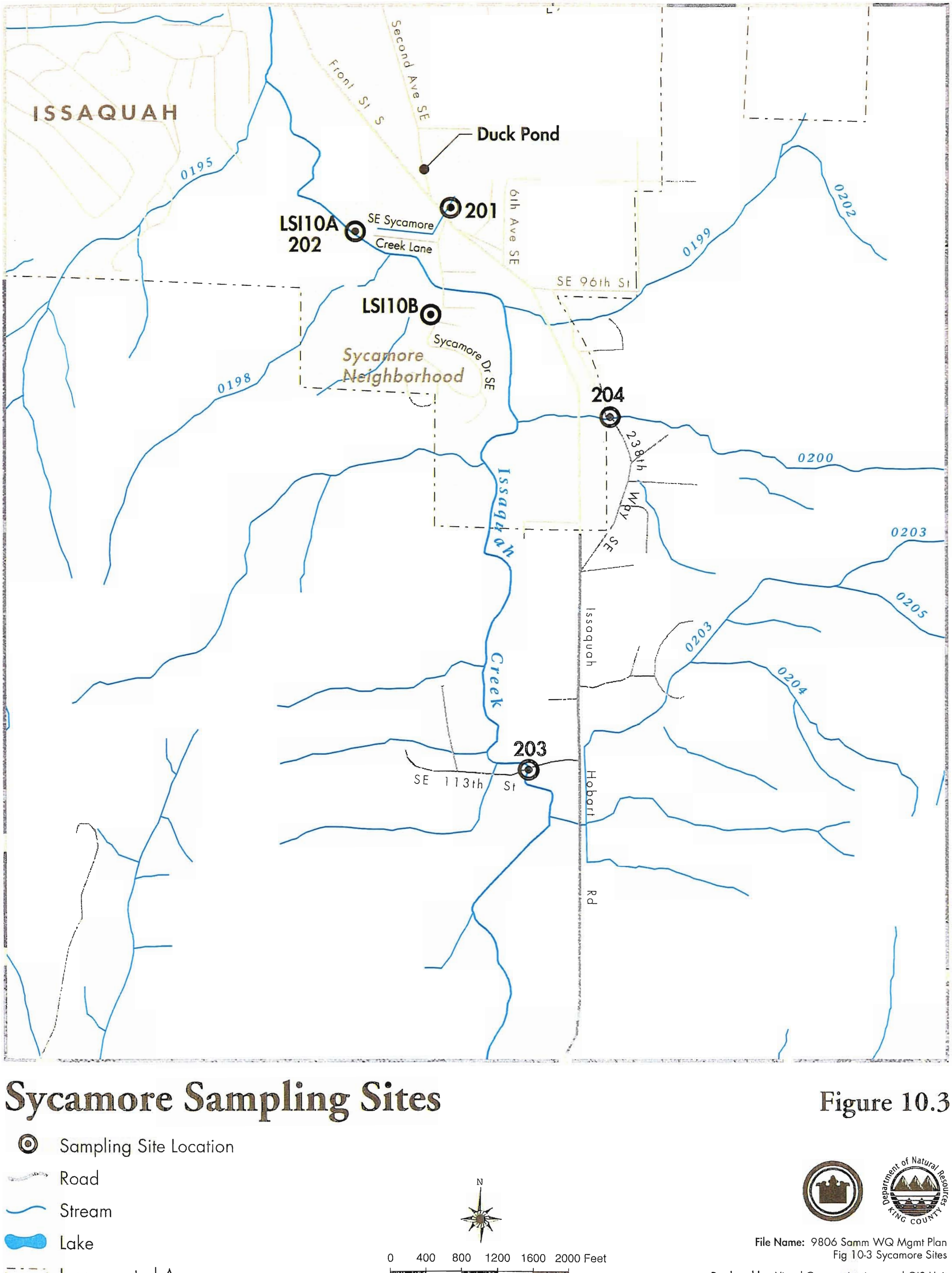
Sampling Site Location
Road
Stream
Lake
Incorporated Area

N

0 400 800 1200 1600 2000

Department of Natural Resources
KING COUNTY

File Name: 9806 Samm SW Mgmt Plan/
Fig 10-2 Tibbetts Sites
Produced by: Visual Communications and GIS Unit



Sycamore Sampling Sites

Figure 10.3

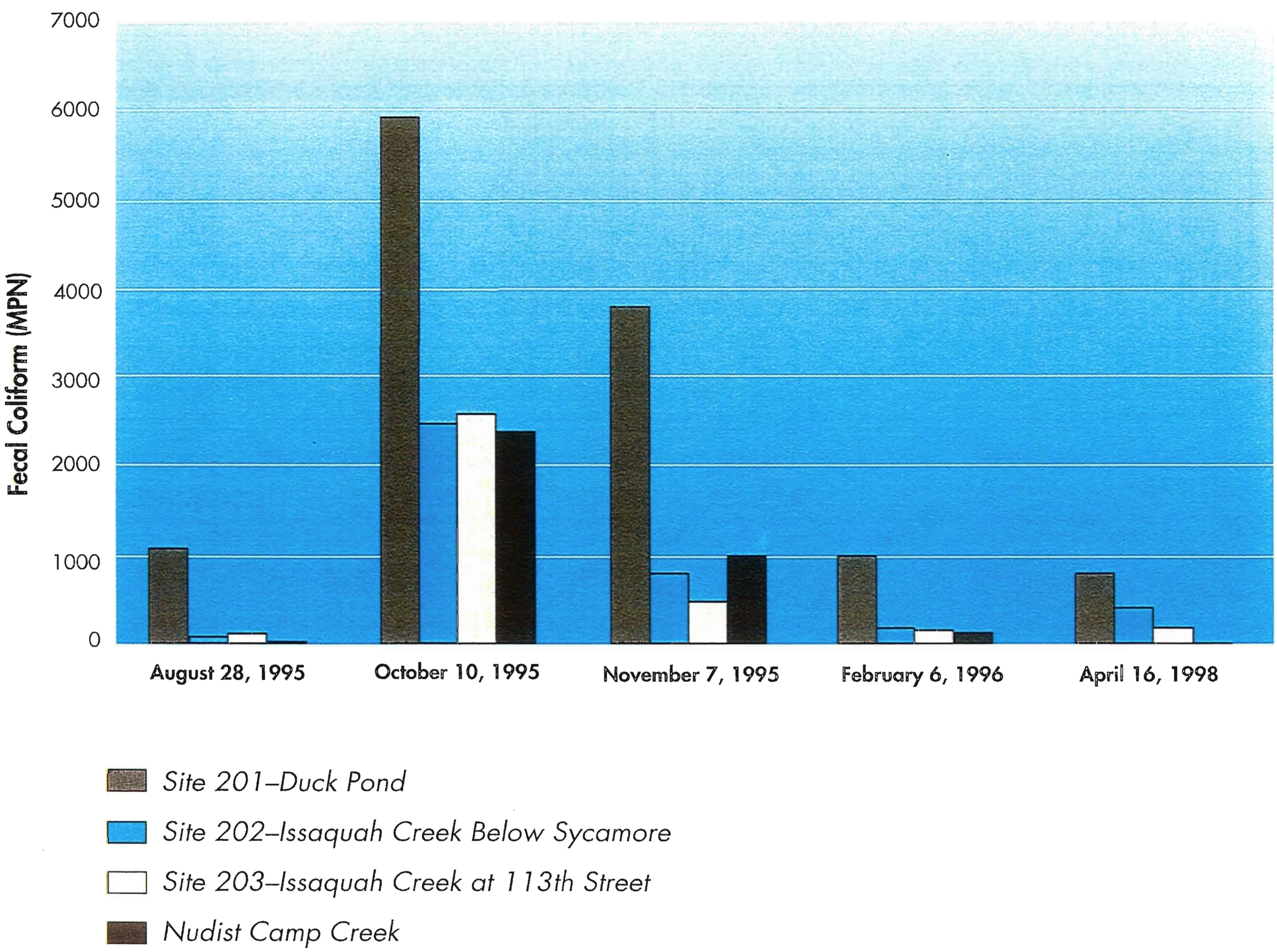
- Sampling Site Location
- Road
- Stream
- Lake
- Incorporated Area

File Name: 9806 Samm WQ Mgmt Plan
Fig 10-3 Sycamore Sites

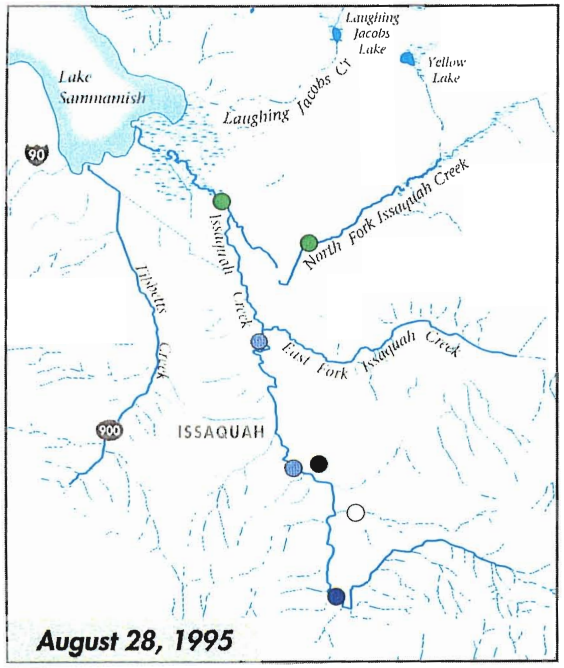
Produced by: Visual Communications and GIS Unit

Figure 10.4

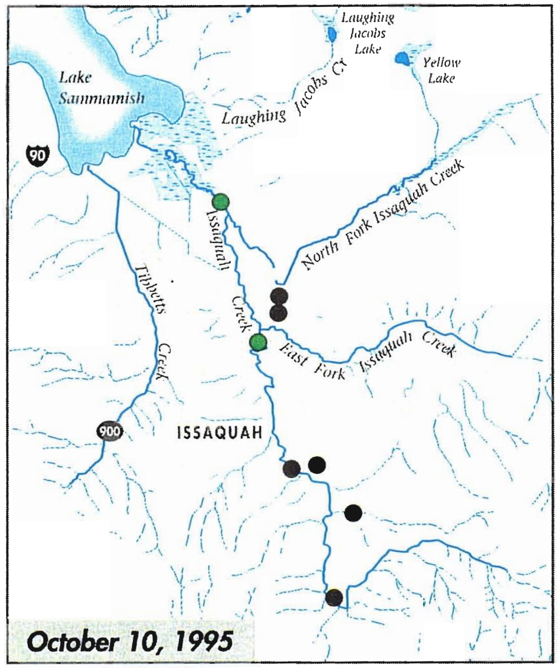
Sycamore Neighborhood Bacterial Concentrations



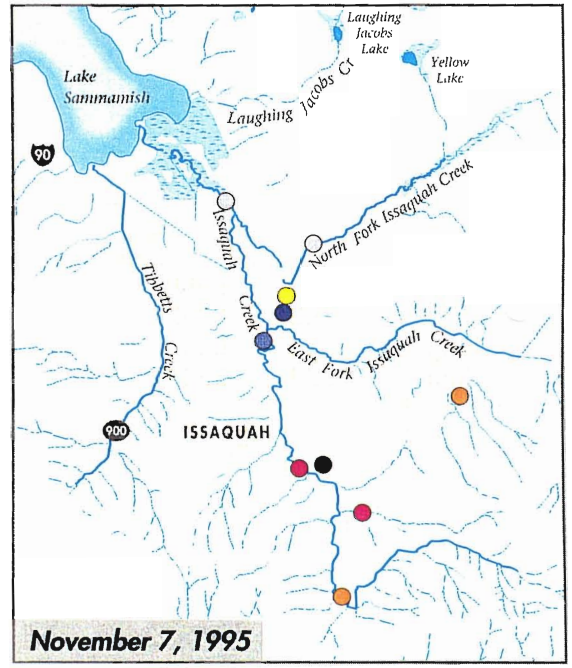
File Name: 9806 Samm WQ Mgmt Report/
Fig 10.4 Sycamore Bacteria
Produced by: Visual Communications and GIS Unit



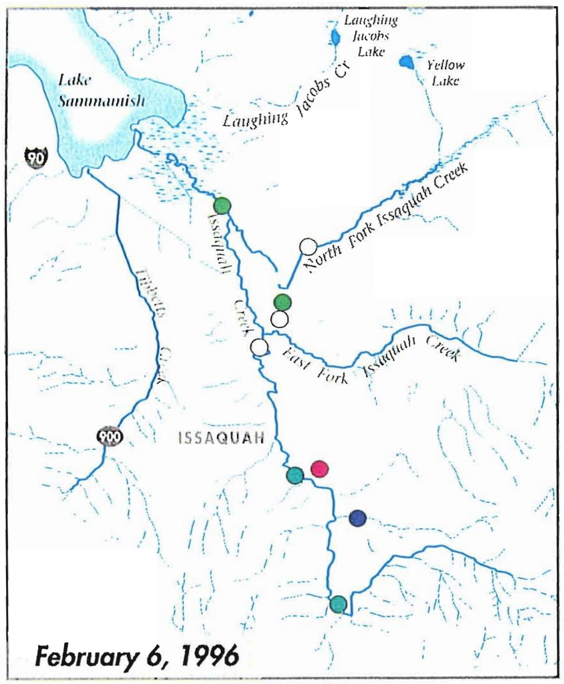
August 28, 1995



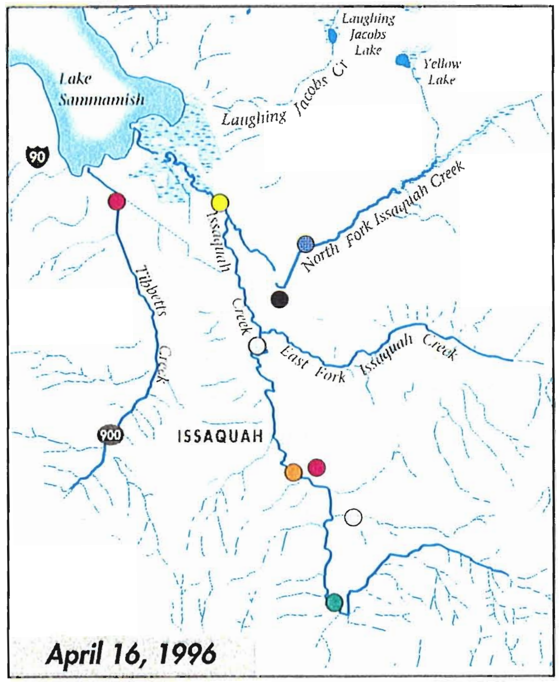
October 10, 1995



November 7, 1995



February 6, 1996



April 16, 1996

Figure 10.5

Phase II Fecal Coliform Bacteria

- 1-50
- 51-100
- 101-150
- 151-200
- 201-300
- 301-400
- 401-500
- 501-600
- 601-1,000
- 1,001-1,000,000

MPN/100 ml

N

0 1/2 1 Mile

File Name: 9806 Samm WQ Mgmt Report/ Fig 10-5 Fecalcol maps
Produced by: Visual Communications & GIS Unit

Turbidity

High turbidity at the Phase 2 sampling sites was often associated with construction activity and gravel mining operations (Figure 10.6). During the low flow sampling of August 1995 the highest turbidities (66 and 69 NTU) were in the swales draining the construction site of the new commercial development along Gilman Boulevard (LSI106 and LSI107) and in Tibbetts Creek (39 NTU, A630) downstream of the I-90 culvert. Low flow samples collected downstream of the Gilman Boulevard commercial construction site had lower turbidities, probably resulting from removal and deposition in the downstream swale and stream channel.

During the sampled storm events the highest turbidities (Table 10.3) were consistently associated with the sampling sites adjacent to, or downstream of, the gravel mining operations (LSI306, LSI307; Figure 10.6). Samples collected synoptically in North Fork Issaquah Creek upstream of the gravel pit discharges at Black Nugget Road (LSI304) and at the Southeast 66th Street bridge (LSI305) were consistently lower than turbidity measurements in runoff from the mining operations. Data collected as part of the non-point survey are being used to evaluate the impact of gravel mining in the basin. Correlation between total phosphorus and turbidity in the samples collected in North Fork Issaquah Creek and downstream of the gravel pits was high (r^2=0.7188), indicating that there is a strong relationship between turbidity and total phosphorus concentrations (Figure 10.7). The data are being were used by the Technical Committee as part of the Grading Permit Review.

Table 10.3 Turbidity in the North Fork Issaquah Creek Area (NTU)

locator	8/28/95	10/10/95	11/7/95	2/6/96	4/16/96	site description
LSI301		16	1.9	36		Gilman drainage to North Fork.
LSI302		27	49	35	14	Front Street drainage to North Fork.
LSI303		32	52	47		Issaquah-Fall City Road drainage to North Fork.
LSI304	3.9	7.3	5	3	3	North Fork at Black Nugget Road.
LSI305	1.3	13	3.4	3.8	3.5	North Fork at Southeast 66th.
LSI306		25	620	65	73	Catch basin near First Avenue Northeast.
LSI307	4.6			180	54	Ditch draining Cadman wetland area.
LSI308	1.2	7.5	6.3	7.5	6.6	North Fork at I-90 on-ramp.
LSI309	7.2			25	7.3	Gilman drainage to North Fork

Phosphorus

Elevated concentrations of phosphorus during storm events were found throughout the sampling area (Figures 10.8 and 10.9). The highest measured total phosphorus concentrations and highest turbidity samples were collected in stormwater draining the gravel mining operations along lower North Fork Issaquah Creek and around commercial and urban areas. During the low flow sampling conducted on August 28, 1995, most samples had relatively low total phosphorus concentrations, with the main stem of Issaquah Creek having the lowest concentration, typically less than 30 µg/L. At the same time, the main stem of Tibbetts Creek had a concentration of 292 µg/L, apparently associated with high sediments from the I-90 culvert and construction activity along Gilman Boulevard. Samples collected at these sites also had the highest turbidity of any of the sites sampled on August 28 (Table 10.3; Figure 10.6). Higher flows in the main channels of the streams, resulted in greater mass loadings of phosphorus in kilograms per day from the mainstem than from off channel sites, despite the lower concentrations in the mainstem streams (see below).

Phosphorus loading in kilograms per day was estimated on the days the grab samples were collected (Figure 10.10). While these estimates do not represent continuous loading at these sampling sites, the calculations are useful for comparative purposes (Table 10.4). The estimated total phosphorus loadings were much higher during storm events than during the summer low flow sampling. High total phosphorus concentrations occurred over almost all of the sampling area during the first storm of the year in October, and represent the "first flush" for the season. The first flush refers to accumulated material from the preceding dry period that is washed off during the first major rainfall of the season.

During the low flow sampling in August, the highest phosphorus loading was calculated in the mainstream sites. This is because of the much higher relative flows in the main channels of the streams than in the tributaries or drainage ditches where a majority of the sampling stations were located. During storm events, the upper Issaquah Creek mainstem sites contribute the greatest source of phosphorus loading, again a result of the high flows at these sites and phosphorus contribution from the large upper watershed. Sampling of the mainstem stream sites did not always occur on the same day as non-point sampling, so direct comparison of the calculated total phosphorus loading was not always possible.

Comparisons were made between samples taken near the mouth of Issaquah and Tibbetts creeks and the sum of the estimated loadings from upstream sites (Table 10.4, Figure 10.10). Downstream sites were assumed to reflect a sum of the sources from the upstream sources; it was also assumed that phosphorus load values were additive. However, phosphorus loads calculated from the upstream sites were cumulative not additive, and there were no data for inflow of water or phosphorus between sampling sites. This probably results in adding some of the load from upstream sites more than once, which would tend to increase the estimated load from the sum of the upstream sites. These estimates may have also been impacted by the simplifying assumption that the downstream sites instantaneously reflect the sum of the upstream sites. Even with the sampling constraints of this approach the comparisons were relatively good, and the individual loading estimates were valuable for locating areas for potential phosphorus control measures.

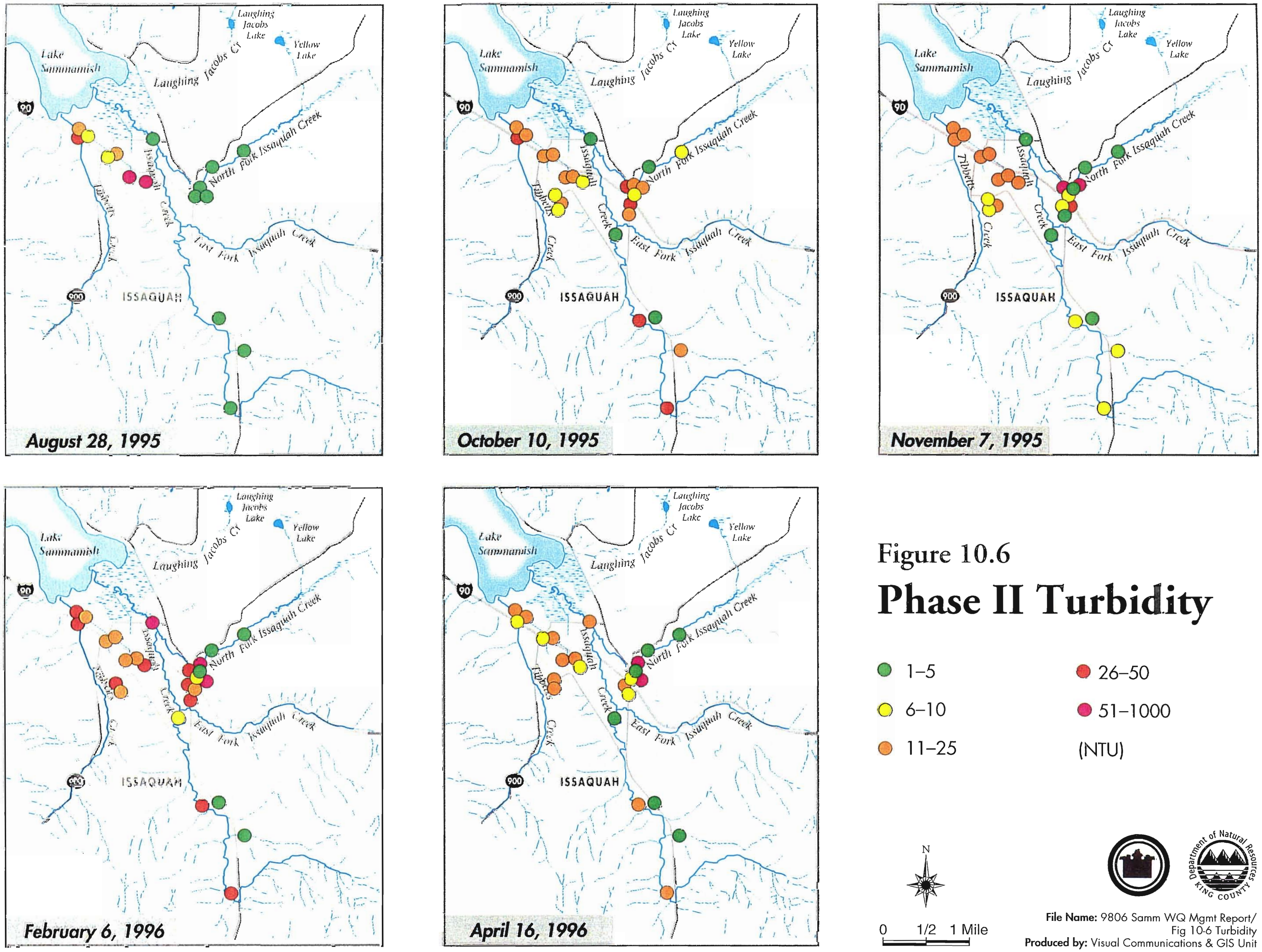


Figure 10.6

Phase II Turbidity

File Name: 9806 Samm WQ Mgmt Report/ Fig 10-6 Turbidity
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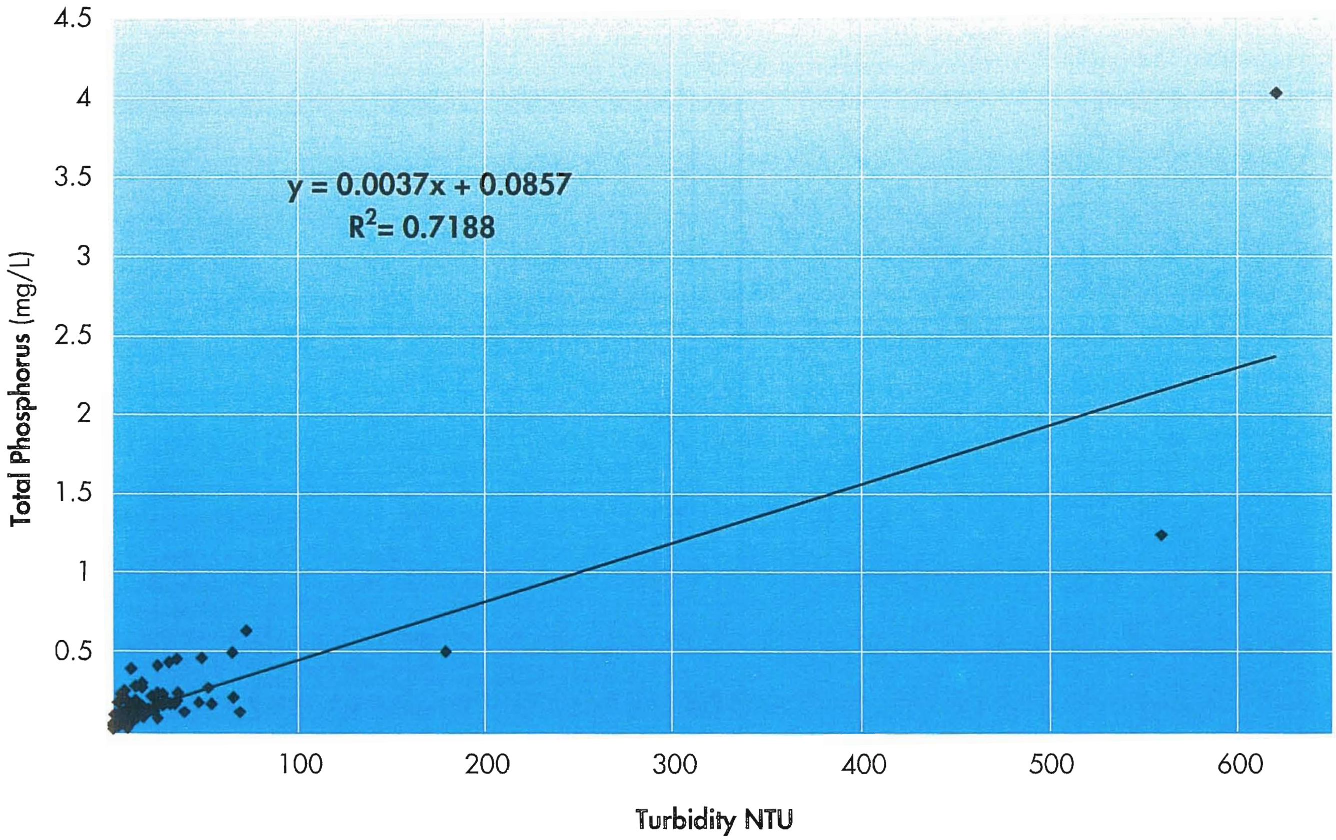
Figure 10.7

Regression of Total Phosphorus and Turbidity for Phase 2 Sampling



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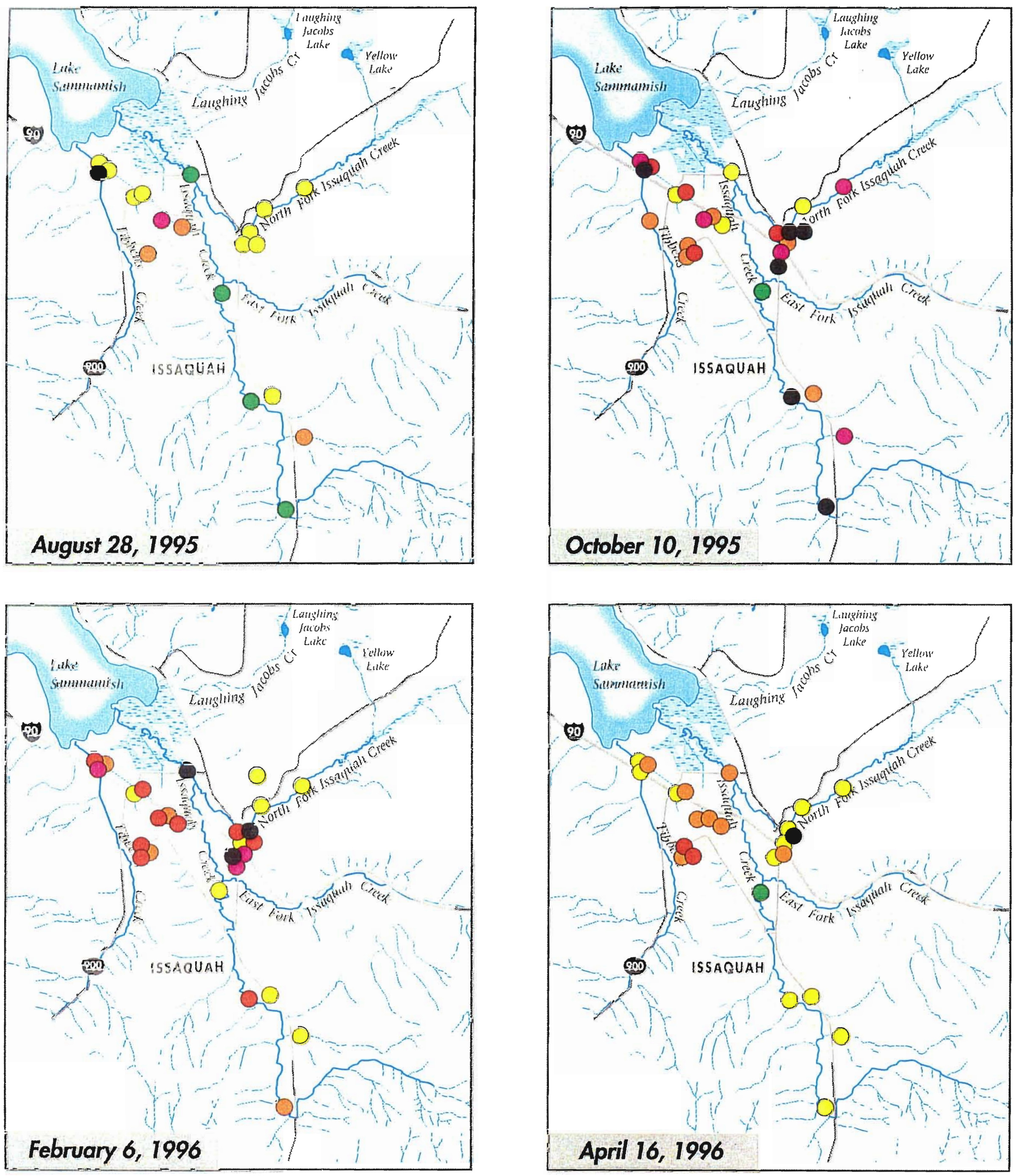


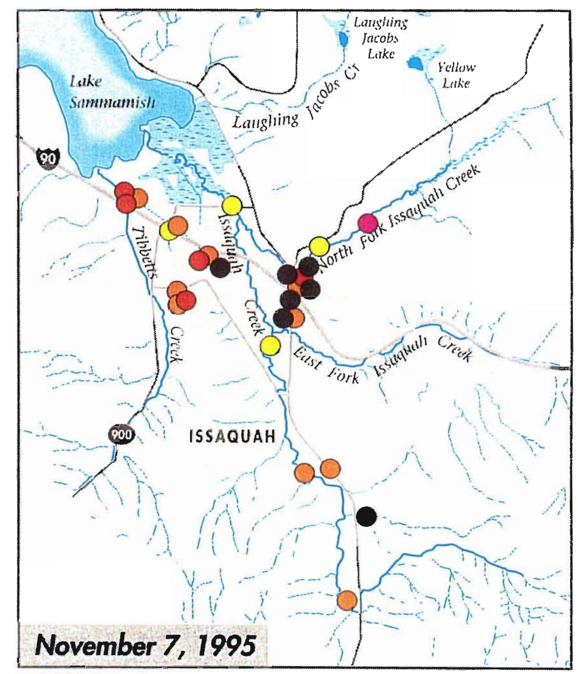


Figure 10.8

Phase II Total Phosphorus

- 0.001–0.03
- 0.031–0.100
- 0.101–0.150
- 0.151–0.200
- 0.201–0.250
- >0.251

(mg/L)

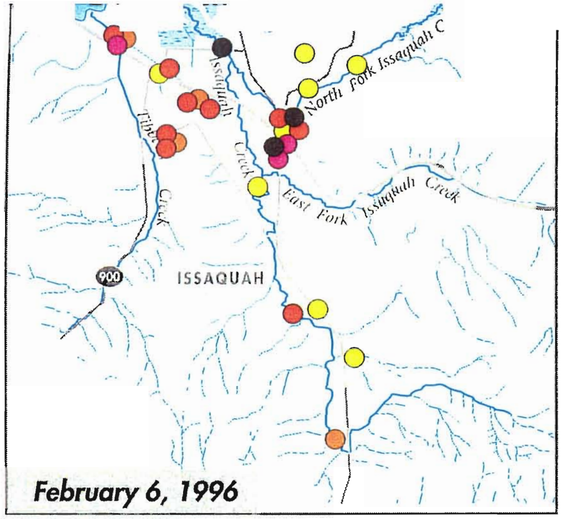
N

0 1/2 1 Mile

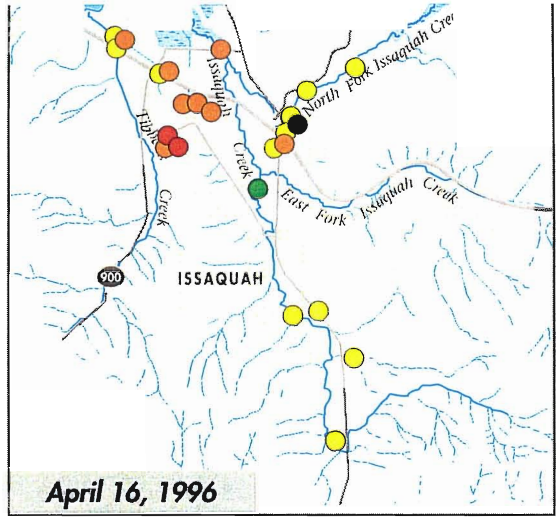
Department of Natural Resources KING COUNTY

File Name: 9806 Samm WQ Mgmt Report/ Fig 10-8 Total Phos maps
Produced by: Visual Communications & GIS Unit

Total Phosphorus



February 6, 1996



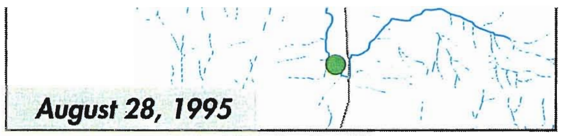
April 16, 1996

- 0.001–0.03
- 0.031–0.100
- 0.101–0.150
- 0.151–0.200
- 0.201–0.250
- >0.251

(mg/L)

0 1/2 1 Mile

File Name: 9806 Samm WQ Mgmt Report/ Fig 10-8 Total Phos maps
Produced by: Visual Communications & GIS Unit



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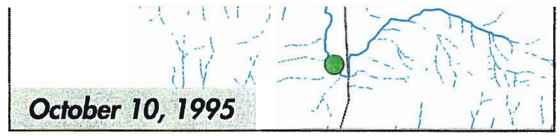

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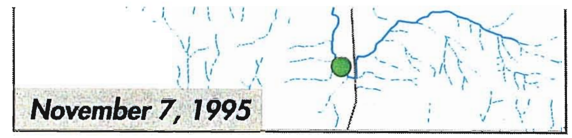
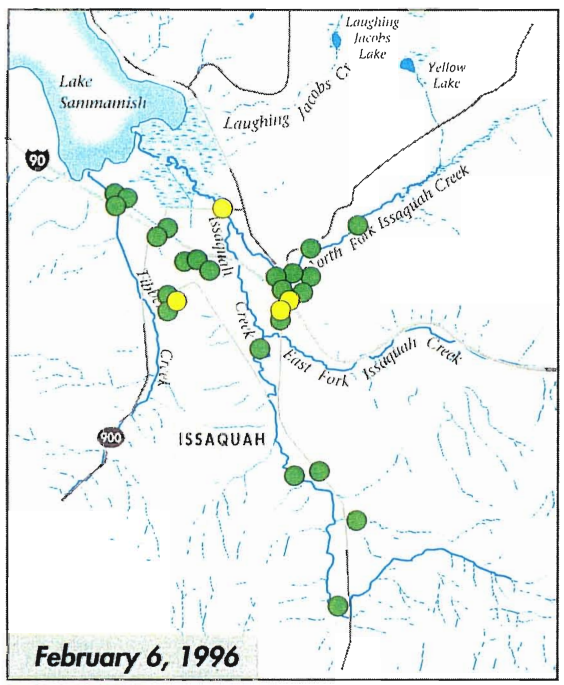
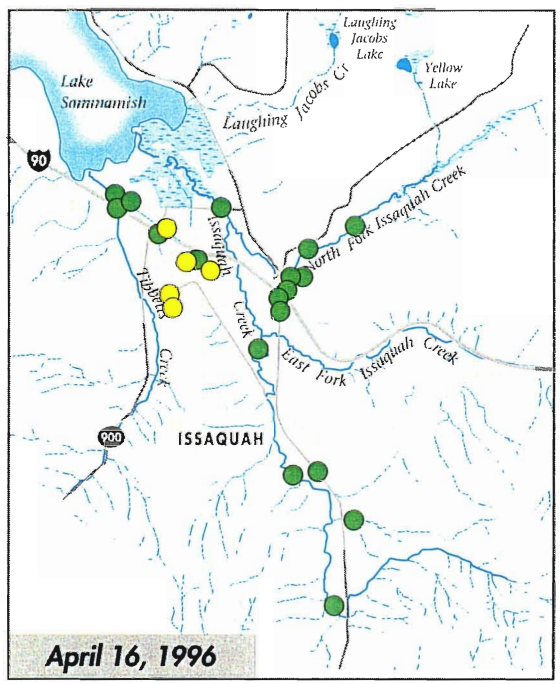


November 7, 1995



February 6, 1996



April 16, 1996

Figure 10.9

Phase II Ortho–phosphate

- 0.001–0.030 (mg/L)
- 0.031–0.100 (mg/L)

0 1/2 1 Mile

File Name: 9806 Samm WQ Mgmt Report/ Fig 10-9 OrthoPhos maps
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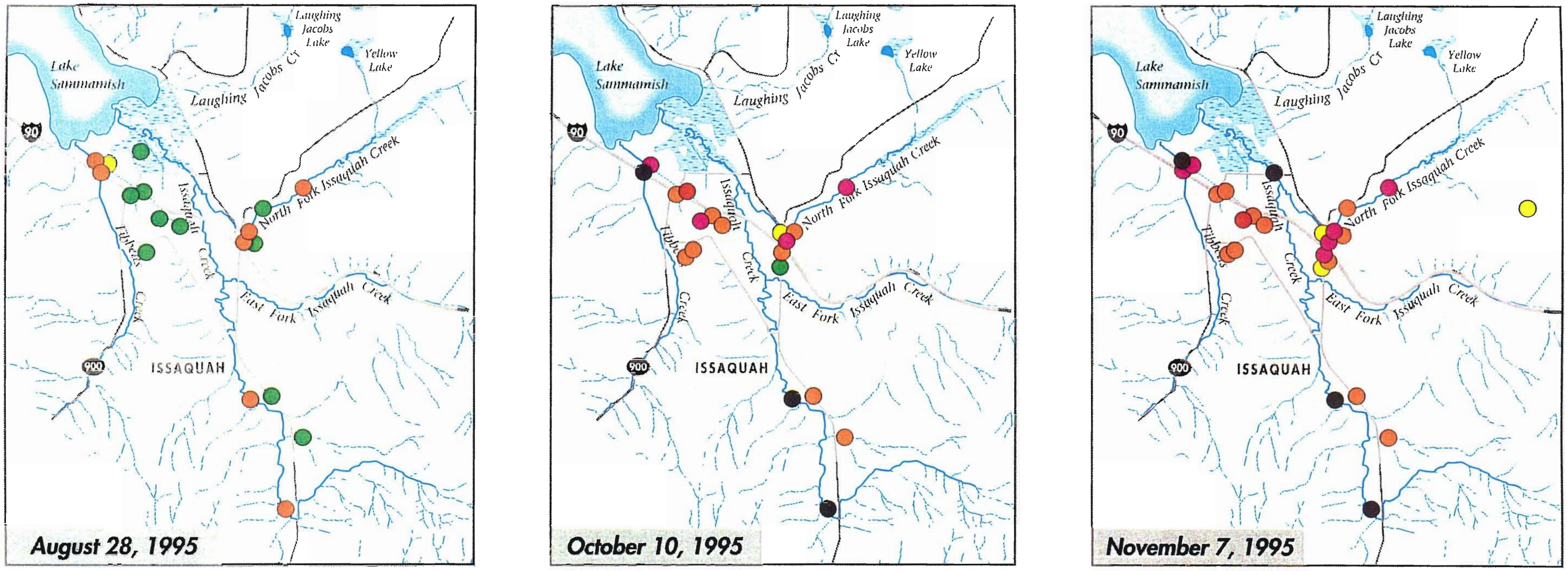

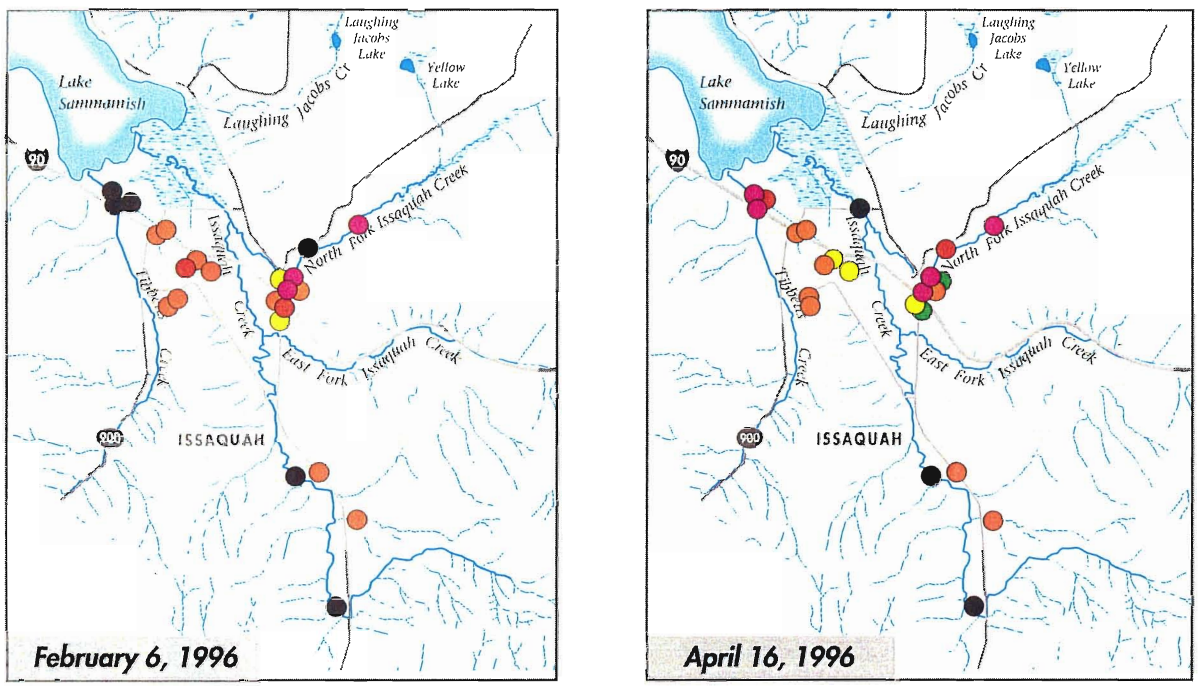

Figure 10.10

Phase II Phosphorus Loading

- 0.016 - 0.025
- 0.026 - 0.075
- 0.076 - 1.000
- 1.001 - 1.500
- 1.501 - 5.000
- >5 .000

(kg/day)

N

0 1/2 1 Mile

File Name: 9806 Samm WQ Mgmt Report/ Fig 10-10 PhosLoading
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Table 10.4 Calculated Total Phosphorus Loads at Phase 2 Sampling Sites[a].

locator	non-storm 8/28/95	storm 10/10/95	storm 11/7/95	storm 2/6/96	storm 4/16/96
	kg/day	kg/day	kg/day	kg/day	kg/day
0631 [b]	2.17				84.33
A632 [b]	0.02		0.83		1.30
LSI101[c]	0.14		6.06	17.43	2.56
LSI102	0.03	3.33	2.15	5.99	1.04
LSI104	0.00	1.21	0.80	0.95	0.64
LSI105	0.00	0.24	0.35	0.95	0.12
LSI106	0.02	2.42	1.15	1.40	0.34
LSI107	0.02	0.12	0.27	0.12	7
LSI108		0.15	0.26	0.17	0.06
LSI109	0.00	0.82	0.42	0.49	0.11
LSI110					0.18
LSI111		0.33	0.12	0.18	0.10
LSI201	0.01	0.58	0.28	0.20	0.09
LSI202	0.92	106.85	18.98	112.57	23.12
LSI203	0.78	111.72	19.14	61.33	21.66
LSI204	0.00	0.25	0.24	0.27	0.16
LSI301		0.01	0.07	0.06	
LSI302		0.59	3.48	0.25	0.03
LSI303		0.04	0.07	0.05	
LSI304	0.14	2.54	2.37	1.95	2.04
LSI305	0.12		1.88	3.36	2.66
LSI306		0.10	0.98		0.02
LSI307	0.00			0.31	0.45
LSI308	0.14	3.45	1.84	3.53	2.37
LSI309			0.10	1.23	0.02
Tibbetts Creek Summary					
LSI101	0.14	8.62	6.06	17.43	2.56
Sum of Tibbetts sites	0.21	8.62	11.59	27.69	5.21
Issaquah Creek Summary[d]					
0631	2.17				84.33

a. blanks do not equal 0, but were due to lack of flow data or lost total phosphorus data

b. loading data was only calculated when the stream site was sampled on the same day as the intensive survey (0631 – Issaquah main stem, A632 North Fork Issaquah Creek)

c. LSI101 - Tibbetts mains stem below confluence

d. estimates based on the sum of the loadings (point estimate of flow X grab sample concentration) calculated from total phosphorus samples for the Tibbetts and Issaquah watershed

At the Tibbetts Creek sites (Figure 10.2), there was very good comparison during the August low flow and during the first recorded storm in October 1995, but during subsequent storm samplings, upstream estimates were greater than at the downstream sites (Table 10.6). The phosphorus loading estimates were higher at sites lower in the watershed such as LSI102, which was located in the drainage ditch that flows into Tibbetts Creek at the State Park entrance. Phosphorus loads were also high in the commercial parking lot drain near the former Ernst Hardware store. While the East Fork of Tibbetts Creek (tributary 0170) drains a relatively small area of single family residences and commercial developments, the phosphorus export is high. Concentrations of ortho-phosphate in this drainage were slightly higher than at other sampling sites (Figure 10.9). There is space available (inside the I-90 on-ramp and upstream of the confluence with Tibbetts Creek) to install phosphorus BMPs.

In the Issaquah Creek drainage, the phosphorus load is high in the mainstem from upstream of the City of Issaquah, down through Lake Sammamish State Park. Total phosphorus concentrations were high in the mainstem and larger tributaries of Issaquah Creek during the October 10, 1995, sampling which was the first major storm of the season. Ortho-phosphate concentrations in North Fork Issaquah Creek (Figure 10.1) were also higher than most other sites, even at sampling sites above inflows from the gravel mining operations (Figure 10.9). Samples collected during subsequent storms did not have as consistently high concentrations over as wide an area. In North Fork Issaquah Creek, total phosphorus concentrations were consistently high at sites downstream of the gravel mining operations from the beginning of Phase 2 sampling through the sampling in April 1996. King County (1995) and Perkins, et al (1997) showed that groundwater in the Issaquah Creek sub-basin had relatively high total phosphorus concentrations. The gravel pit north of Issaquah-Fall City Road could provide sufficient space for the construction of phosphorus and turbidity control.

Except for the August low flow samples, phosphorus loading was relatively high in Issaquah Creek upstream and adjacent to the Sycamore area (Table 10.5). Only during the February 6, 1996 storm was there a significant increase in the total phosphorus concentration and load within the reach between LSI203 located at Southeast 113th Street (upstream of the Sycamore development) and LSI202 (downstream of the development). During this storm, the loading from Nudist Camp Creek (LSI204) and the duck pond on Front Street (LSI201) was not appreciably higher and did not account for the increased load in this stretch of the stream. Leaking septic tanks have been suggested as a potential source of pollution in this area, but had this been the source, the fecal coliform bacteria counts would have been much higher at the downstream site (LSI202) than was observed (180 MPN/100 ml). For the size of the area drained, the duck pond on Front Street is a significant source of both phosphorus and fecal bacteria. Routing runoff water around this pond instead of through it may provide an opportunity to reduce pollution to the creek. It is unknown what the source of additional phosphorus in this stretch of stream was during the February 6, 1996, storm.

Table 10.5 Phosphorus Loading at Sampling Sites in the Sycamore Neighborhood

	locator	dry weather	storm	storm	storm	storm
		8/28/95	10/10/95	11/7/95	2/6/96	4/16/96
		kg/day	kg/day	kg/day	kg/day	kg/day
LSI203	upstream	0.8	111.7	19.1	61.3	21.7
LSI204	Nudist Camp Ck.	0.0	0.2	0.2	0.3	0.2
LSI201	duck pond	0.0	0.6	0.3	0.2	0.1
LSI202	downstream	0.9	106.8	19.0	112.6	23.1

Summary

Fecal Coliform Bacteria

- Based on the low counts of fecal coliform bacteria at the sites along Front Street, sewage pollution from direct cross connection is very unlikely.

- It is not clear whether fecal coliform in the Sycamore Creek Lane residential area are associated with failing septic tanks. Fecal coliform counts upstream of the Sycamore area were consistently lower than downstream of the development. The contribution of bacteria from Nudist Camp Creek and the duck pond between the two Issaquah Creek sites makes it unclear whether the Sycamore development is the source of the increased bacteria, or more likely, the result of diffuse contributions from a number of sites in this area. The high fecal coliform bacteria counts in this general area, particularly during the first storm event sampled when all of these sites were >2000 MPN/100ml, are of concern and need to be examined to determine the source of contamination.

- The small duck pond along Front Street had the highest fecal bacteria counts of all sampling sites on every sampling date.

- At all of the sites sampled, the highest bacterial counts were collected during the first storm event of the autumn, and may show a "first flush" response.

Turbidity

- High turbidity measures at Phase 2 sampling sites were associated with construction activity and gravel mining operations.

- During the low flow sampling of August 1995 the highest turbidities were observed in swales draining construction sites and in Tibbetts Creek downstream from the I-90 culvert.

- During the sampled storm events, the highest turbidities were consistently associated with sample sites adjacent to, or downstream of, the gravel mining operations

Phosphorus

- Correlation between total phosphorus and turbidity in the samples collected in North Fork Issaquah Creek and downstream from the gravel pits was high (r^2=0.72).

- Elevated concentrations of phosphorus were found during storm events in samples from all sites.

- The highest measured total phosphorus concentrations and highest turbidity levels were collected in stormwater draining the gravel mining operations along lower North Fork Issaquah Creek and around commercial and urban areas.

- The highest total phosphorus concentrations observed at most sites occurred during the first autumn storm of the year (October 10, 1995).

- Except for the August low flow samples, estimated daily phosphorus loading for the storm events sampled was relatively high in Issaquah Creek upstream and adjacent to the Sycamore Creek Lane residential neighborhood.

- For the size of the area drained, the duck pond on Front Street appears to be a significant source of both phosphorus and fecal bacteria to Issaquah Creek.

Conclusions for Application to Lake Sammamish

Non-point loading of phosphorus from the parts of Issaquah Creek draining the Sycamore residential area, Front Street and gravel mine operations, and lower Tibbetts Creek in the Lake Sammamish drainage basin is widespread. The highest inputs occur during storm events, regardless of season. Specific land use activities such as gravel mining, quarrying, and construction activities produce high turbidity and high phosphorus concentrations. Reducing many, if not all of the identified non-point sources of phosphorus, needs to be addressed if the water quality goals for the lake are to be met. Specific activities to address these pollution sources are described in the 1996 Lake Sammamish Water Quality Management Plan (Entranco, 1996) and in Appendix 1 of this report. Some of the sources are being addressed under permit modifications, or as part of the adaptive management program (Appendix 1). For example, the sand and gravel mining NPDES permit has been modified to include a requirement for phosphorus monitoring (since it drains to a phosphorus-sensitive lake). Several of these short-term action projects are currently underway, or in design or feasibility analysis.

Additional specific projects that should be implemented include:

- Control sediment and phosphorus discharge from the gravel mining operations. The gravel pit north of Issaquah-Fall City Road could provide sufficient space for the construction of phosphorus and turbidity control facilities.

- Control of commercial runoff from the small watershed that drains the East Fork of Tibbetts Creek and collects the water from a densely developed commercial area. There is space available (inside the I-90 on ramp and upstream of the confluence with Tibbetts Creek) to install phosphorus BMPs.

- For the size of the area drained, the duck pond on Front Street is a significant source of both phosphorus and fecal bacteria. Routing runoff water around this pond instead of through it may reduce phosphorus inputs to the creek.

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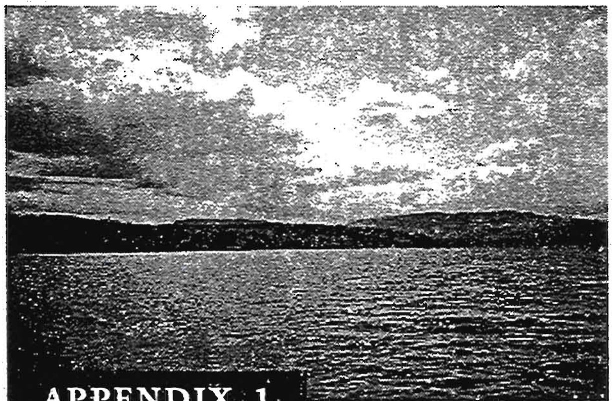


APPENDIX 1

Adaptive Management Strategy

Appendix 1. Adaptive Management Strategy

The coordinated effort to protect water quality in Lake Sammamish has been directed by the Cities of Bellevue, Issaquah, and Redmond; and King County and the Sammamish Watershed Forum, a regional advisory body made up of elected officials who represent the local jurisdictions in the watershed. The management goal for protecting the water quality in the lake as identified in the 1996 Lake Sammamish Water Quality Management Plan (Entranco, 1996) is:

> *Protect the ecological health and public benefits of Lake Sammamish as described in the 1989 Lake Sammamish Water Quality Plan. The proposed measurements to confirm achievement of this goal are:*
>
> *4.0 meters Secchi disk transparency (summer average)*
> *2.8 µg/liter chlorophyll a (summer average)*
> *22 µg/liter annual volume-weighted total phosphorus*
>
> *These are the average levels observed in summer 1995, and will be maintained through a management tracking program[1] for phosphorus inputs using the most cost effective measures available.*
>
> [1] The management tracking program will use an adaptive management strategy.

The goal was recommended by the majority of a citizen task force, Partners for a Clean Lake Sammamish, in its report to elected officials from the four jurisdictions (Partners for a Clean Lake Sammamish, 1996). The goal was reviewed by the Sammamish Watershed Forum and included in the Forum's 20-year vision for the watershed as follows:

> *Lake Sammamish is healthy and provides community value to its surrounding neighborhoods and businesses. The water quality goals of the 1996 Water Quality Management Plan have been achieved and maintained so that ecological health and public benefits have been protected.*

Achievement of the goal is based on a multi-faceted management strategy that seeks to maintain annual phosphorus loading to the lake at 1996 levels (16,713 kg total phosphorus/ year). The overall strategy was developed following extensive analysis of the costs, effectiveness, and feasibility of multiple structural and non-structural controls as described in the 1996 Plan (Entranco, 1996). The strategy depends upon six program areas, evaluation and implementation of capital facilities projects, and a management tracking program that guides the adaptive management strategy. The six program areas are based on the recommendations of the Partners for a Clean Lake Sammamish and the 1996 Plan (Entranco 1996). They include the following:

1. Forest Conservation Program
2. Non-point Source Control Program
3. Regulatory Compliance and Enforcement Programs
4. Enhanced Operations and Maintenance of Stormwater Facilities for Phosphorus Control
5. Adoption and Implementation of Lake Protection Standard (facilities to remove 50 percent total phosphorus) for New Urban Development and Roads
6. Increased Public Ownership and Shoreline Access including Stewardship of Public Lands

Table A1.1 details specific elements for each of these program areas as they were implemented in 1997. Parts of all programs are being implemented in all four jurisdictions to the extent that funding allows, except the Forest Conservation Program. The Forest Conservation Program, which applies only in King County, is being implemented by King County, in coordination with the Washington State Department of Natural Resources and the Washington State University Cooperative Extension Service.

Adjustments to each of the program areas are evaluated by technical staff and managers from each of the jurisdictions on a regular basis in order to develop work programs and funding strategies to protect the lake's water quality. The technical staff and managers function within a 2-tier inter-jurisdictional committee structure (the Lake Sammamish Management and Technical Committees) that was set up as part of an inter-local agreement for implementation of the 1989 Lake Sammamish Water Quality Management Project (Entranco, 1989). Local funding decisions are made by the four jurisdictional councils on an annual or biannual basis. Regional funding decisions are based on recommendations of the Sammamish Watershed Forum to the Regional Water Quality Committee of the Metropolitan King County Council.

The two committees also exchange information regarding program and regulatory effectiveness and performance among the different jurisdictions, and share technical resources and materials. Each jurisdiction then decides on its own standards for performance and compliance for the different program areas and regulations.

The capital facilities projects are updated annually by each jurisdiction within the context of their Capital Facilities Plans. Currently, the high priority capital projects include completion of the Short Term Actions identified in the Lake Sammamish Initiative on the basis of the findings of Phase 1 of the nonpoint source intensive survey monitoring described in Chapter 10. These projects and their current status are shown in Table A1.2.

The Adaptive Management Strategy described above was developed and is managed collaboratively by the Lake Sammamish Management and Technical Committees under the direction of the Sammamish Watershed Forum and the fiscal authority of the Metropolitan King County Council and the three city councils.

Adaptive management is defined by the Environmental Protection Agency as a process to improve resource management incrementally as managers and scientists learn from experience and new scientific findings. Adaptive management allows for continuous improvement and evaluation of the management program and response to the changing dynamics of the natural environment. The strategy in Lake Sammamish includes the following elements:

1. lake water quality monitoring;
2. monitoring of costs and effectiveness of specific management actions in the different program areas (both structural and non-structural);
3. monitoring of land use changes within the drainage basin;
4. use of predictive computer models to evaluate future phosphorus loading to the lake and the lake response;
5. adjustment of management actions or goal indicators in response to findings; and
6. recommendation of funding strategies to the Sammamish Watershed Forum and jurisdictional councils

This iterative process is shown schematically in Figure A1.1. It is expected that during the first few years of the adaptive management program, the monitoring data for program effectiveness will be relatively limited. Adjustments to the management program will likely be minimal as a result.

The strategy described above was recommended by the Partners' for a Clean Lake Sammamish in their report (Partners' for a Clean Lake Sammamish, 1996) and in the 1996 Lake Sammamish Water Quality Management Plan (Entranco, 1996). The recommendations in these two reports were based on the results of a predictive computer model, the Watershed Quality Cost Effectiveness Model (WAQCEM). This model is described in detail in the 1996 Plan (Entranco, 1996) and in Richey, et al., (1998). The WAQCEM model compares the feasibility, costs, and effectiveness of different structural and non-structural management alternatives for both current and future land use in the drainage basin. It predicts average annual total phosphorus loading to the lake on the basis of land use and management alternatives as well as the annual costs of the different management alternatives. The model's conceptual basis and the treatment efficiencies for the different management alternatives were partially based on information in the 1989 project findings (Entranco, 1989), and application of the results of the projects evaluated in Chapters 2 through 10 of this report (Table A1.3). The model output helps to track the large-scale trends in phosphorus loading due to land use change and in the relative effectiveness and costs of the different management program areas.

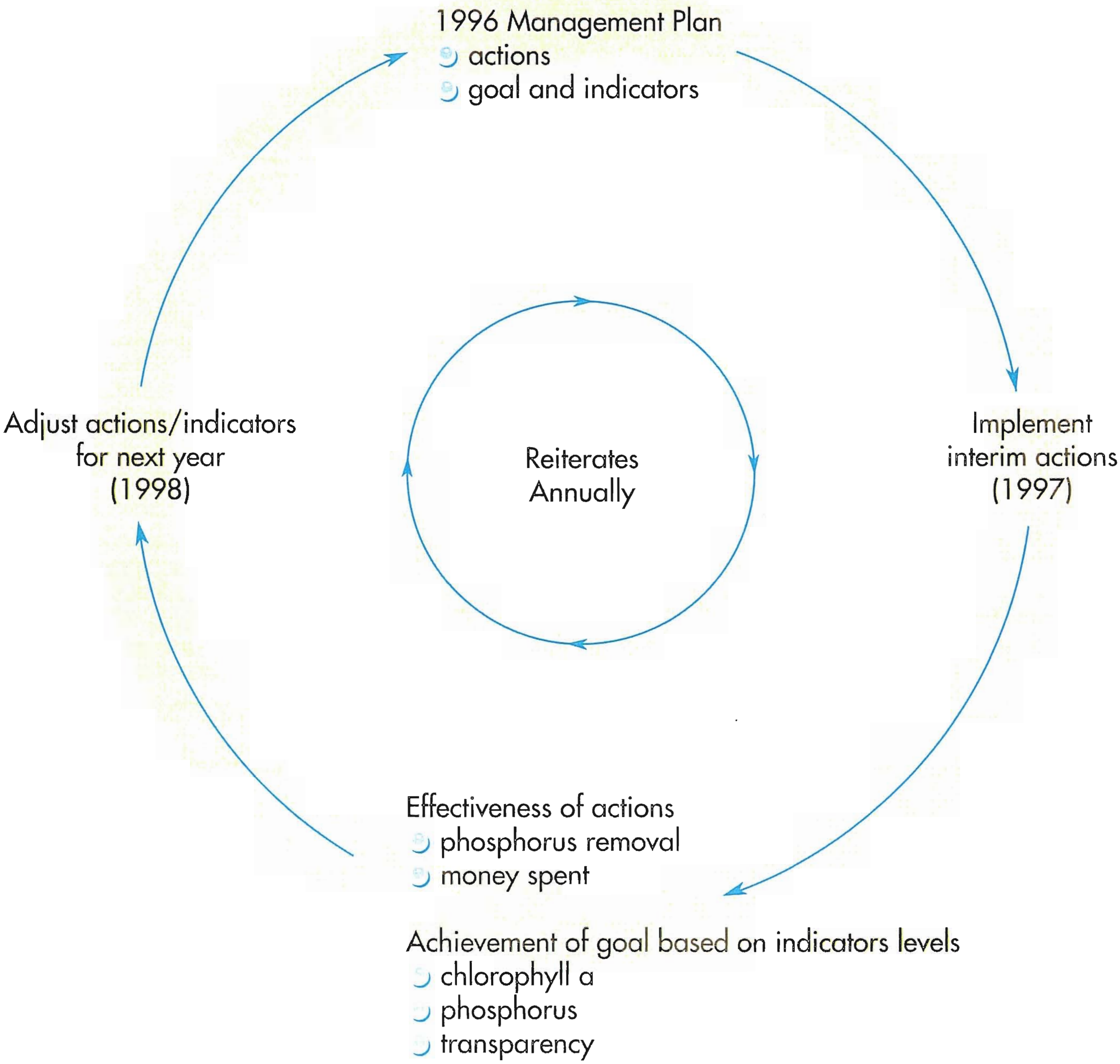
*Table A1.1. 1997 Work Program for Lake Sammamish Water Quality Management**

Program Area/Jurisdictions Involved	Program Elements
Forest Conservation Program/rural and forest production lands in King County in cooperation with Washington State Department of Natural Resources, Washington State University Cooperative Extension	♦ 65 percent retention of forest in rural areas ♦ acquisition of 1700 acre Taylor Mountain ♦ Best management practices for rural and forest production zoned forestry ♦ Education programs in backyard forestry ♦ Identification of existing forested parcels ♦ Timberland current use taxation and public benefit rating system
Nonpoint Source Control Programs/ Bellevue, Issaquah, Redmond, King County	♦ Non-point source control best management practices education program for homes/gardens ♦ Shoreline stewardship demonstration project ♦ Development of water steward's manual ♦ Development of Lakeside Living video ♦ Lake and watershed stewardship ♦ Business best management practices program ♦ Monitoring of best management practices and program effectiveness ♦ Analysis of sediment sources and sinks, Issaquah Creek
Regulatory Compliance and Enforcement/ Bellevue, Issaquah, Redmond, King County (includes identification of minimum standards for pertinent regulations)	♦ Erosion control program (King County, Bellevue, Issaquah, Redmond) ♦ Evaluation of regulatory consistency and working models for erosion and other pertinent regulations (King County, Bellevue, Issaquah, Redmond) ♦ Education for industry in erosion and sediment control practices and sensitive areas controls (King County and Issaquah) ♦ Shoreline Management Act compliance and enforcement support (King County)
Operations and maintenance to enhance phosphorus removal/ Bellevue, Issaquah, Redmond, King County	♦ Facilities maintenance for pollutant removal ♦ Re-evaluation of road ditch and stormwater facilities maintenance practices and costs through the UW Storm Water Technology Consortium
Adoption and implementation of Lake Protection Standard (facilities to remove 50 percent total phosphorus) for new urban development/ Issaquah, Redmond, King County (as noted)	♦ Implementation of the Lake Protection Standard for new urban development (King County and Issaquah) ♦ SEPA conditioning with Lake Protection Standard (Redmond) ♦ Evaluate alternative approaches to achieving goal, maintenance needs and other technology for water quality facilities (all jurisdictions)
Increased public ownership and access (watershed-wide)	♦ Mapping of potential land conservation, habitat and shoreline access sites in the basin ♦ Evaluation of funding strategies including regional options

*All elements shown on this table were implemented during 1997. The specific actions implemented during subsequent years may change using the adaptive management strategy described in the text.

Figure A1.1

Lake Sammamish Water Quality Management Tracking Program



Note: Cycle repeats for each incremental year.

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Fig A1-1 Mgmt Track Program
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Table A1.2 Short-Term Actions

Lake Sammamish Initiative: Status of Short-Term Actions

Project	Scope	April 1996	March 1997	September 1997
1. Valley Growers Nursery; future park-n-ride lot	Improve runoff from nursery; incorporate storm water controls into future Park 'n Ride Lot	Site clean up and stabilization carried out by the City of Issaquah in June and July 1995; DOT and Metro Transit scheduled to construct lot in 1998.	First phase has been completed. Runoff problems concerning livestock solved; area has been regraded and seeded. Second phase: Issaquah Parks and Metro Transit are conducting active negotiations; retrofitting has been funded by Metro Transit.	No change
2. Issaquah State Fish Hatchery	Connect hatchery discharge from pond cleanings to Metro sanitary sewer to remove wastewater from creek and lake or develop on-site treatment	Shoreline improvement funds located for hatchery waste water diversion expenses. Metro advertised for a change in the water rights diversion point which would allow the hatchery to consume water (thus sending it to Renton treatment plant). OK from Dept. of Ecology is pending. Cost for diversion estimated at $50,000; $15,000 per year for maintenance. Moving ahead either now or in 1997 is dependent on Hatchery upgrades.	Water right diversion permitted by Dept. of Ecology. Hook-up fee to divert pond washings to sewer system estimated at $325,000. Annual O& M expected to be $20,000 - 25,000. No funds identified at this point. On-site treatment options are being evaluated in conjunction with Hatchery upgrade.	Feasibility study of treatment and diversion alternatives being conducted; completion scheduled for Spring 1998.
3. Sunset Quarry	Correct runoff problems generated by quarry operations	Minimum grading fees are being paid in order that permits do not expire. Work to reroute Tibbetts Creek/construct additional holding ponds has not been initiated to date. Private / Public mitigation partnership is being evaluated.	Pacific Topsoils has leased 50 acres of the site. The company is interested in correcting runoff problems and has hired a consultant to develop plans. Dept. of Ecology and Dept. of Development and Environmental Services are working with company to develop management plan. King County Parks is negotiating to purchase the remaining 70 acres (no mitigation needed on this part of the property)	Evaluation of site mitigation for 50 acres is underway. King County Parks has final review of management plan.
4. Bianca Mine	Stabilize eroding mine spoils on Tibbetts Creek tributary	King County capital project: design and permits 1995-1996; construction in 1997. Cost estimated at $620,000.	Land has been annexed to City of Issaquah. King County has completed the alternative design report and is working with Issaquah to transfer responsibility. Final construction costs will depend upon solution chosen. Evaluation of solution has been added to the East Village EIS assessment and Issaquah capital projects list.	Issaquah evaluating cost share options.

Table A1.2 *Short-Term Actions*
(continued)

Lake Sammamish Initiative: Status of Short-Term Actions

Project	Scope	April 1996	March 1997	September 1997
5. Interpace Mine	Stabilize eroding mine spoils on Tibbetts Creek tributary	King County is currently preparing preliminary project scope and cost estimates; dependent on geotechnical analysis. King County will coordinate with land owner for solution.	Preliminary scope and cost estimates complete. The project is on the King County CIP list for funding through a 1998 bond.	No change
6. Kelly Ranch	Develop and implement farm management plan; fence and re-vegetate banks of Tibbetts Creek	King Conservation District developed plan July 1995; homeowner installed partial fence.	Property is for sale. Several interested parties have come forward including a condominium developer, East Village developer, and Issaquah Parks	No change
7. Weowna Park	Correct severe erosion created by Phantom Creek by re-constructing stream channel	City authorized action October 1995; ILA with County Parks; Task Force advising design options; cost dependent upon final design. MOU signed between Bellevue and King County for cost share.	Consultant had been hired to complete design work. City of Bellevue has completed site survey. Final designs being developed spring 1997	Public evaluation of final design alternatives completed in Summer 1997. Trail work being initiated in 1997. Final construction scheduled spring/summer 1998
8. Idylwood Creek	Correct drainage problems and bank erosion along creek	Evaluation and design 1997-1998; Coordination by Redmond	Divided into two parts: 1. Severe bank erosion has occurred in several locations; local city drainage system has been jeopardized. 2. A basin level project will be developed in spring/fall 1998 (Idylwood Park); construction expected at selected phases in mid-1999.	Most severe area will be addressed summer 1998

Table A1.3 Application of Phase 2 Control Technologies to Current Management of Lake Sammamish

Control Method	Acceptable and Useful for Current Application	Some Potential for Future Application (pending further evaluation)	No or Low Potential for Future Application
Filtration Media		X	
Block Alum: low technology approach			X
Soil Amendments		X	
Iron Oxide Coated Sand			X
Alum Injection		X	
Wet Ponds	X		
Temporary Erosion and Sediment Control Program	X		
Education	X		
Intensive Source Monitoring	X (as needed)		

See Text of Chapters 2 through 10 for additional information.

The WAQCEM model predicted that total phosphorus loading to the lake would increase by an average of 45 percent when the watershed becomes fully developed if no management actions beyond those being implemented prior to 1996 were implemented in the future. The model assumed that the current zoning in the drainage basin remains the same and that the basin will be built out to this capacity over 30 years. The output of the WAQCEM model can be linked to the Lake Sammamish Total Phosphorus Model (King County, 1995) to predict water quality conditions in the lake. Using this linkage, the predicted level of increased loading to Lake Sammamish (at full basin development) would result in a doubling of summer time chlorophyll *a* levels and a 20 percent reduction in water clarity. It is anticipated that the WAQCEM model and/or refinements of this model will continue to be the predictive tool for estimating annual phosphorus loading to the lake and relative costs and effectiveness of the different management areas. Annual variability in lake conditions and error propagation in computer model output will be taken into account in the adjustment of management for the lake. The predictive models will be updated or revised as new information becomes available.

The current program for reducing future increases in phosphorus loading to the lake depends upon controlling about 40 percent of the projected increase with the forest conservation and best management practices, about 25 percent with water quality facilities for new urban development, and about 20 percent with improved operations and maintenance of facilities, non-point source controls, improved regulatory compliance, and stewardship. The program is based on the analyses completed for the 1996 Water Quality Management Plan (Entranco, 1996) and the recommendations made by the Partners for a Clean Lake Sammamish (1996).Funding for the implementation in 1997 and 1998 has come from the four jurisdictions. Mechanisms to control the remaining 15 percent of the reduction goal will be identified as part of the adaptive management strategy on the basis of effectiveness monitoring, lake response, and new or improved technology or implementation practices. For example, the jurisdictions are continuing to seek funding to further evaluate the feasibility of regional water quality treatment facilities in view of the fact that future conditions in either the watershed or the lake may require re-consideration of such an approach to phosphorus control. The jurisdictions are also continuing to investigate the most effective maintenance practices for water quality treatment facilities. Additional research is also being conducted in cooperation with the Center for Urban Water Resources Management at the University of Washington regarding other sources of phosphorus and potential management options including sediment sources and transport in Issaquah Creek and maintenance practices for road side ditches. Other areas of inquiry will continued to be reviewed by the Technical and Management Committees as monitoring information becomes available and implementation of the Plan continues.

At present, the jurisdictions and the Sammamish Watershed Forum are negotiating an Interlocal Agreement to continue this coordinated program for protecting the water quality in Lake Sammamish in accordance with the 1996 Plan goals and the Adaptive Management Strategy. Under the auspices of this Interlocal Agreement, the specific management program can be altered, within the Adaptive Management Strategy, based on new information. The jurisdictions are also evaluating the involvement of other parties in overall management of the lake's water quality. Other stakeholders being discussed include the Muckleshoot Indian Tribe, the state Departments of Ecology, Transportation, Fish and Wildlife, Natural Resources, State Parks and the Puget Sound Action Team and any new jurisdictions that drain to Lake Sammamish. Citizens in the watershed play an important role through participation in Forum proceedings, technical review teams, restoration and stewardship projects, non-point source control actions, multiple outreach and education programs and opinion surveys.

Although the success of this multi-faceted program is not guaranteed, the four jurisdictions and the Sammamish Watershed Forum believe that the program and management process in place takes into account the changeable nature of knowledge and technology, and changing realities in public needs and available funds. The process embraces change and, by including an ongoing monitoring program, includes the continuous development of information to direct change appropriately. The program includes a mix of structural and nonstructural strategies as well as land conservation components which spread the responsibility and costs of management across all segments in the watershed. The program is based on extensive knowledge of the effectiveness and costs of these different types of controls. Much of this knowledge was gathered from the projects funded as part of the Lake Sammamish Water Quality Management Program as described in Chapters 2 through 10 of this report.

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