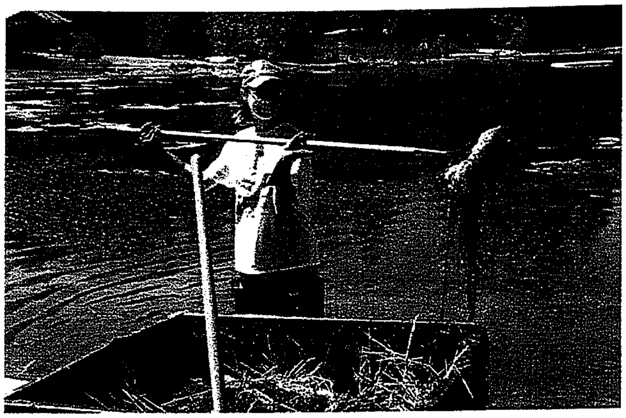
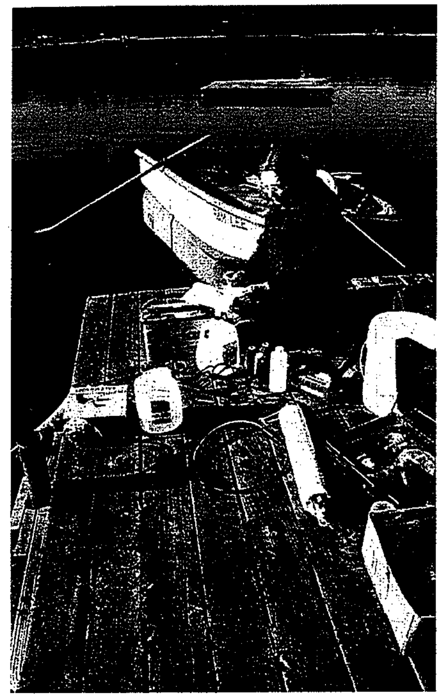




Lake Ketchum
Lake Restoration Plan

February 1997

ENTRANCO

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Snohomish County Public Works
Surface Water Management

Working together for people, streams & fish.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

THE LAKE AND ITS WATERSHED

Lake Ketchum is a 24-acre lake located in northwest Snohomish County. The lake is surrounded by residential development and recreational cabins and is used for fishing, swimming, boating, aesthetic enjoyment, and wildlife habitat. Public access to the lake is provided by a boat launch maintained by the Washington State Department of Fish and Wildlife. Single-family homes, forests, and agriculture are the major land uses in the watershed. Up to 50 more homes may be developed in the watershed in the foreseeable future.

LAKE WATER QUALITY

Past Water Quality Issues

Residents have been concerned about the water quality of Lake Ketchum since the late 1960s. At that time, excessive levels of aquatic plants were the major concern. The Ketchum Shores Improvement Club, a citizen's group, was formed in 1969 and began treating the lake with herbicides to control excessive aquatic plants. The lake has been treated almost every year between 1981 and 1992 for plants and algal growth.

Dense growths of duckweed were becoming more common; in the fall of 1992, the entire lake was covered with duckweed. The Everett Herald reported on November 20, 1992, that: "Lake Ketchum, near Stanwood, had the highest levels of algae-feeding phosphorus (in the State of Washington), causing it to look like 'a giant lawn' this summer... It was all green...we were literally rowing a path through it." Clearly, nutrient enrichment of the lake had reached a crisis situation and the aquatic plants and algae were responding accordingly.

As it became apparent that Lake Ketchum was declining in water quality and that chemical treatments were becoming more expensive and less successful, lake residents began to look for the sources of pollution in the lake. A potential contributor to the water quality problems of Lake Ketchum was a dairy farm located in the watershed. It was known that, in addition to the cow manure and fertilizer that might be discharging from the dairy operation, large amounts of chicken manure had been spread on the pasture lands in recent years.

Current Water Quality Issues

A major concern of the local residents is the severe pollution from a dairy farm (now a beef cattle farm) located in the watershed. Runoff from this farm flows through the southeast wetland and into the lake and therefore threatens the lake's water quality.

Near the end of 1992, in the midst of concerns about uncontrolled algae and duckweed growth and ongoing dairy farm pollution, lake residents approached Snohomish County and the Washington State Department of Ecology (Ecology) for assistance. Surface Water Management staff from the County recommended a comprehensive study to determine the causes of poor lake water quality and the actions needed to restore the lake. The County agreed to sponsor a Centennial Clean Water Fund grant application for a Phase I study.

The Ketchum Shores Improvement Club members supported the Phase I Lake Restoration Study both financially and through volunteer assistance. In 1993, Snohomish County applied for a Centennial grant to fund the restoration study at Lake Ketchum. The grant was awarded by Ecology and the project began in late 1994.

PHASE I LAKE RESTORATION STUDY

The focus of the Lake Ketchum Phase I Lake Restoration Study is to assess the current water quality status of the lake, to identify and quantify sources of algal nutrients, to provide a restoration plan to improve lake water quality, and to provide opportunities for the public to become involved in the management of the lake.

The water quality in the lake and its watershed were monitored for one year, from March 1995 through February 1996. Other elements of the monitoring program included mapping the lake's aquatic plants, groundwater sampling, surveys of nearshore pollution from septic systems, and stormwater sampling.

RESULTS OF THE MONITORING PROGRAM

Nutrients/Algal Levels/Water Clarity

Lake Ketchum has very high levels of algae when compared with most similarly-sized lakes in western Washington. The high levels of algae occur because nutrient (phosphorus and nitrogen) concentrations in the lake are excessive. Blue-green algae, a type of algae that is most often associated with nuisance conditions, formed a large part of the algal community throughout the year. The high concentrations of algae result in very low levels of water clarity.

Bacteria

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

Aquatic Plants

During the study year, large aquatic plants (macrophytes) covered about 30 percent of the lake surface during the summer months, which is a moderate density. The aquatic plants did not appear to be restricting recreational uses of the lake, with the possible exception of localized areas around certain docks. Duckweed, which has recently covered large areas of the lake, was mainly restricted to the narrow bays in the eastern portion of the lake. Both large aquatic plants and duckweed increased in density during the summer of 1996.

Overall Lake Condition (Trophic State)

Based on the traditionally-used scientific barometers called "trophic parameters," which included total phosphorus (food for algae), water clarity as measured by Secchi depth, and algae as measured by chlorophyll *a*, the condition of Lake Ketchum can be classified as poor. Lake Ketchum has very high algal levels and low water clarity. In addition, the lake's condition is considerably worse than other similarly sized-lakes in western Washington.

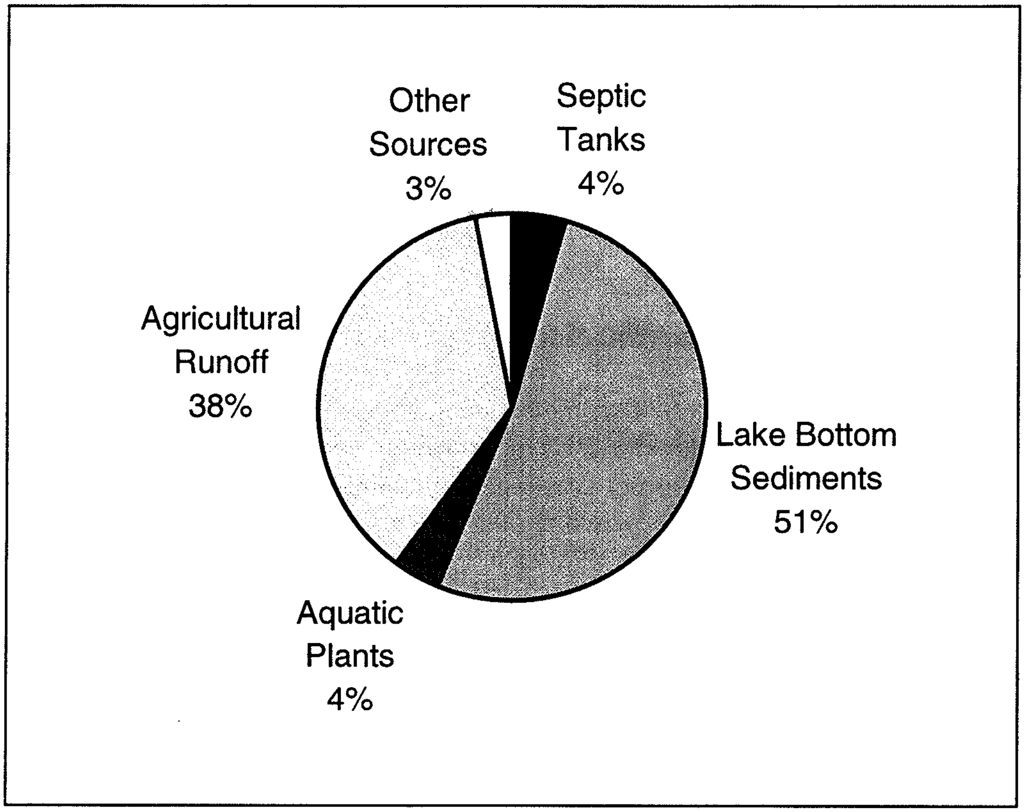
Sources of Phosphorus Loads to Lake Ketchum

The sources and amounts of algal nutrients draining to the lake were estimated from the monitoring program (see **Figure ES-1**). (See Chapter 5 for further discussion of these estimates.) The two largest sources of phosphorus to the lake are agricultural runoff, which drains to the lake via the main inlet, and phosphorus entering the lake from the bottom sediments. Together, these two sources contribute 90 percent of the annual amounts of phosphorus entering the lake. The concentrations of phosphorus measured in the farmland runoff (ranging between 7,000 to 13,600 µg/l) were 60 times higher than typical agricultural runoff and also were higher than what is usually measured in wastewater treatment plant effluent.

Most of the phosphorus contributed by the lake's bottom sediments enters the lake in fall (October), while the agricultural runoff enters the lake during the high rain period from November to April.

LAKE RESTORATION ALTERNATIVES

Another important focus of this study is to identify a combination of phosphorus control techniques that will improve the quality of the lake. In the process of evaluating restoration techniques for Lake Ketchum and its watershed, a total of 15 techniques were reviewed for effectiveness, cost, environmental considerations, and other factors. The restoration techniques involved both in-lake and watershed controls to reduce phosphorus concentrations in the lake and control aquatic plant growth.



* Other sources include rain, other surface runoff, and groundwater.

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Figure ES-1
Estimated Proportions of Annual Phosphorus Loads to Lake Ketchum

Based on this screening, six restoration techniques were selected for further study. Selected techniques were combined to define three alternatives. The lake's water quality response to these alternatives was predicted using a computer model. The results indicate that the lake's phosphorus levels could be reduced significantly. Following this analysis, selected restoration techniques were combined into a recommended restoration alternative and summarized below.

Water Quality Goal and Objectives for Lake Ketchum

Goal

The citizens' lake water quality goal is to improve the water quality of Lake Ketchum to protect public health and to support using the lake for swimming, boating, fishing, and visual enjoyment.

Objectives

- Control excessive algal blooms and duckweed growth to levels acceptable to the citizens' needs and financial resources.

- Control excessive aquatic plant growth that interferes with swimming, fishing, and boating. Maintain aquatic plants at moderate levels to allow a balance of human, fish, and wildlife uses in Lake Ketchum.

These broadly stated objectives have been restated in a more quantitative and scientific format below. Water quality objectives are quantified in this way so that the success of lake and watershed restoration activities can be monitored and verified following implementation.

Water quality objectives for Lake Ketchum are based on the scientific barometers of Carlson (**1977**) and on the predicted water quality results of the recommended restoration alternative. The objectives for average summer total phosphorus, algal levels (as measured by chlorophyll *a)* and water clarity (Secchi depths) are 30 µg/l, 6.4 µg/l, and 2 meters, respectively. The lake restoration strategy is based on phosphorus control. These levels would mean significantly improved water quality with less algal blooms and duckweed growth. The existing summer lake total phosphorus concentration is 434 µg/l; therefore, over a 90 percent reduction in phosphorus loading is needed to meet the phosphorus objective of 30 µg/l. This is an ambitious objective that can only be achieved if each recommended technique is as successful as predicted in reducing phosphorus loading.

Recommended Lake Restoration Alternative

Lake restoration alternatives should focus on restoration techniques that have the greatest potential for reducing phosphorus from the two major sources (agricultural runoff and lake bottom sediments). The evaluation conducted for this study indicates that to achieve lake water quality objectives, the recommended restoration alternative will need to include a combination of watershed and in-lake restoration measures. In view of the relatively long history of poor water quality conditions at Lake Ketchum, members of the Ketchum Shores Improvement Club Association are eager to take action and are in favor of implementing a restoration alternative that implements both watershed and in-lake restoration measures concurrently.

The recommended restoration alternative includes these watershed and in-lake techniques:

1. Farmland Soil Amendment

This innovative agricultural best management practice would involve application of alum and lime or calcium carbonate on the farmland south of 308th Street NW, in Subbasins 6 and 8 (**Figure ES-2**). (High phosphorus concentrations [between 7,000 to 13,600 µg/l] in agricultural runoff are attributed to chicken and dairy cow manure that has been applied intensively in Subbasins 6 and 8 in recent years). Recent research indicates that a combination of these chemicals can be effective in retaining nutrients (phosphorus and nitrogen) in the soil and reducing the amounts lost in watershed runoff. At rates of application used to date in this research, nutrient runoff concentrations were reduced by 63 to 87 percent. Cost-effectiveness may be enhanced if uncontaminated alum sludge can be obtained from a nearby water treatment plant at an even lower cost than commercially supplied alum. While this approach seems to hold considerable promise, longevity of treatment will need to be determined. This will be addressed as part of the performance evaluation monitoring.

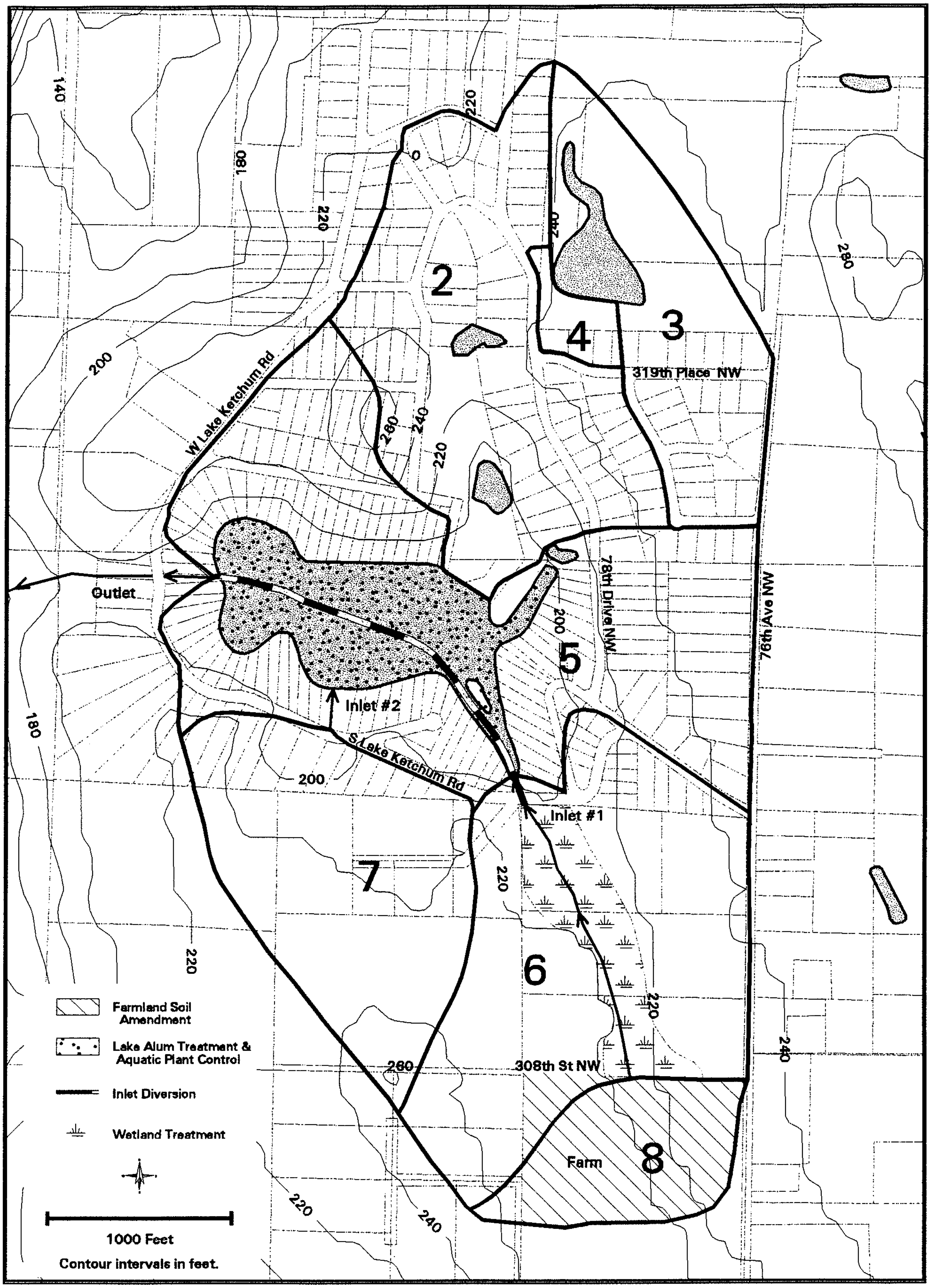

Figure ES-2. Recommended Restoration Actions With Watershed and Sub-Basin Boundaries

2. Wetland Treatment

A 12-acre wetland in Subbasin 6 (**Figure ES-2**) immediately downstream of the farm is suspected as a possible source of high phosphorus concentrations in the future. Even if agricultural phosphorus sources are effectively controlled, high phosphorus concentrations in the wetland could be flushed into the lake during periods of high runoff. Therefore, a separate phosphorus control program using aluminum sulfate and sodium aluminate is recommended for the wetland. Since alum has not been used in such an application elsewhere, this proposed use is experimental. Because of thick wetland forest and shrub communities, which should not be disturbed, the alum slurry would be manually sprayed onto the floor of the wetland. This treatment may be relatively short-lived due to the rapid flushing rate of the wetland, the shallow water depths in the wetland, and the high rate of leaf litter deposition in the wetland. However, combined with the farmland soil amendment, the wetland treatment is intended to enhance the effectiveness of the overall restoration plan.

3. Watershed Best Management Practices (BMPs)

A variety of watershed BMPs should be implemented to improve future watershed stewardship including:

- Public education and involvement
- Homeowner BMPs
- Preservation of existing wetlands
- Stormwater treatment for new development
- Roadside ditch protection for phosphorus control
- Other related BMPs

4. Alum Treatment In-Lake

Whole-lake alum treatment is considered the most cost-effective means to reduce internal phosphorus loads in Lake Ketchum. Alum is a chemical commonly used to treat drinking water throughout the United States, and also has been used to control internal phosphorus in a number of U.S. lakes over the past 20 years. A single treatment can produce internal load reductions of up to 95 percent and can last for ten years or more. However, to be effective, watershed controls and inflow diversion must implemented concurrently. Otherwise, continued watershed loading could totally override potential internal control benefits or dramatically reduce the longevity of alum treatment. Environmental consequences are considered insignificant as long as the chemical is properly applied.

5. *Inflow Diversion*

The concept for this restoration element would be to construct a pipeline from the main inlet to the lake (Inlet 1), which drains the high-phosphorus agricultural lands, to the outlet of the lake. Essentially, all the runoff from Subbasins 6 and 8 would then completely bypass Lake Ketchum. It is recommended that this technique be implemented in combination with farmland soil amendment, wetland treatment, and watershed BMPs since the benefit of farmland soil amendment, wetland treatment, and watershed BMPs may not provide the watershed load reductions necessary to achieve lake water quality goals in combination with whole-lake alum treatment.

6. *Aquatic Plant Control*

Aquatic plant control has been a serious problem in the past. Therefore, a contingency aquatic plant control program is proposed in the event that post-restoration water quality improvements result in enhanced water clarity and increased density or area of growth of aquatic plants. Possible control techniques include:

1. Volunteer pulling/raking/composting
2. Installation of bottom screening materials
3. Addition of plant-eating grass carp
4. Mechanical harvesting and
5. Herbicides

7. *Performance Monitoring*

To determine whether the recommended restoration techniques are successful, performance evaluation monitoring should be conducted. Performance monitoring would primarily involve water quality sampling of the lake, groundwater wells, and the main inlet to Lake Ketchum. Performance monitoring is normally required for all grant funded restoration programs.

Predicted Water Quality Benefits of Implementing Controls

The predicted response of Lake Ketchum to implementing the recommended elements of the restoration alternative is listed in **Table ES-1**. The lowest in-lake phosphorus concentrations are predicted with the implementation of farmland soil amendment and wetland treatment in combination with diversion of the main inlet and a whole-lake alum treatment. Slightly higher in-lake phosphorus concentrations are predicted without the diversion of the main inlet.

Table ES-1
Predicted Phosphorus Loading to Lake Ketchum and Phosphorus Concentrations of the Selected Restoration Alternative

Alternative	Total Phosphorus (kg/yr)	Phosphorus Load From Agricultural Runoff[1] (kg/yr)	Annual Average In-lake Phosphorus (μg/l)	Summer Average In-lake Phosphorus[2] (μg/l)
Recommended Alternative				
Farmland Soil Amendment, Alum Treatment and Diversion[3]	65–123	0–19	22–29	29–32
Other Alternatives Considered				
No Action	513	194	668	389
Farmland Soil Amendment and Alum Treatment[3]	85–181	19–78	27–45	30–35

1. Subbasins 6 and 8.
2. June through September.
3. Includes wetland treatment, watershed BMPs, and aquatic plant control. Assumes the following percent effectiveness: farmland soil amendment (60 to 90%); alum treatment (80 to 94%);and inflow diversion (75 to 100%).

Note: The amount of phosphorus load reduced by aquatic plant control, wetland treatment, and watershed BMPs was not included because these restoration techniques focus on the elements which contribute a relatively small portion of the phosphorus load to the lake and there is less certainty that these techniques would be as effective in controlling phosphorus loads from these sources. Wetland treatment is experimental and would enhance the effectiveness of the alternatives, but not beyond the ranges shown.

RECOMMENDED RESTORATION PLAN

Table ES-2 provides a summary of the recommended lake restoration plan, including lake and watershed restoration techniques, estimated costs, and responsibilities.

Funding Strategy

The recommended restoration plan is an aggressive program that will stretch the funding capabilities of Snohomish County and the citizens at Lake Ketchum. To implement this lake restoration plan, a combination of watershed resident funding, County funds, State grant funds, and farm owner investments will be needed. Watershed resident and County funds will be targeted toward watershed BMPs, the lake alum treatment, aquatic plant control, performance monitoring, park development/maintenance, and administration. State grant and loan funds will be targeted for each element of the restoration plan except for aquatic plant control and park development/maintenance. The farmland soil amendment, wetland treatment, and inflow diversion should be funded by Ecology in conjunction with the farm owner or other outside funding sources as part of an on-going water quality enforcement action.

Table ES-2
Summary of Recommended Lake and Watershed Restoration Elements

Restoration Element	Estimated 5-Year Cost	Estimated Annual Cost	Implementing Organization
1. Farmland Soil Amendment	$55,000	$11,000	Snohomish County/DOE[2]
2. Wetland Treatment	$45,000	$9,000	Snohomish County/DOE[2]
3. Watershed BMPs[1]	$45,000	$9,000	Snohomish County/KSIC[3]
4. Whole-lake Alum Treatment	$130,000	$26,000	Snohomish County
5. Inflow Diversion	$320,000	$64,000	Snohomish County/DOE[2]
6. Aquatic Plant Control	$50,000	$10,000	Snohomish County/KSIC[3]
7. Performance Monitoring	$120,000	$24,000	Snohomish County
8. Administration	$80,000	$16,000	Snohomish County
9. Park Development/ Maintenance[4]	$50,000	$10,000	Snohomish County/KSIC[3]
Total	**$895,000**	**$179,000**	

1. Includes public involvement and education for 5 years plus conservation easements for wetlands.
2. Washington State Department of Ecology.
3. Ketchum Shores Improvement Club.
4. Development of a park on the lake (about $35,000) and on-going park maintenance ($3,000/year) will be required if state grant funds are received for implementation of the restoration plan.

Watershed Resident Funding

Lakeshore residents have historically funded lake-related work through collection of dues from the members of the Ketchum Shores Improvement Club or through shorefront property assessments under RCW 90.24. They have been able to generate up to $10,000 per year with these programs. However, at the present time, there are a substantial number of retired residents who can no longer assume these costs. In addition, there may be some restrictions on the use of funds collected under RCW 90.24. For example, park development and maintenance are probably ineligible uses for these funds. Also, there may be a need to go back to Superior Court for authorization, if the proposed uses are substantially different than the uses specified under the original authorization.

Another option available for generating local matching funds would be to form a Lake Management District (LMD). The LMDs are special districts authorized under RCW 36.61 and 35.21.403. The law requires that the nature of improvements be specified along with their cost and that some reasonable procedure be developed to assess costs to individual property owners within LMD boundaries. Boundaries would be determined cooperatively between Snohomish

County and citizens of the area. The LMD could collect fees for specified uses for a period of up to 10 years. Prior to approval, a public hearing must be held to provide opportunity to discuss the purpose, boundaries, cost, method of assessment, and benefits of the LMD, and a majority of affected property owners must subsequently vote in favor of the LMD formation. Drawbacks of this option are that the LMD process is long (12 to 18 months) and somewhat costly.

Snohomish County Surface Water Utility

Another source for funding a portion of the recommended restoration plan is Snohomish County Surface Water utility fees. Existing fees have been contributing about $15,000 to $20,000 per year as matching funds for the Phase I grant. A similar level of funding may be available for implementing the restoration plan. One method for raising additional Surface Water utility funds would be to establish a surcharge on top of the current fees to be paid by all developed properties in the watershed. The surcharge would be for a specified length of time and would be collected in the normal manner with regular property taxes. While not requiring a formal vote, this option would only be chosen if supported by residents of the Lake Ketchum watershed.

Ecology/EPA 319 Nonpoint Source Grant

Phase II Lake Restoration projects, which would include many elements of the recommended alternative (farmland soil amendment, wetland treatment, other watershed BMPs, inflow diversion, and whole-lake alum treatment), have recently been authorized under Ecology guidelines for 319 funds. Preliminary discussions with Ecology staff indicate that 75 percent grant funding may be available for all lake restoration elements. The next cycle to apply for funding will extend from January 2, 1997, through the end of February 1997.

Ecology Centennial Clean Water Grants or Loans

Another source of grant or loan funds is the Centennial Clean Water Program. This program may provide up to 75 percent funding (in the case of grants) or more for Phase II implementation projects. The application process is combined with the EPA 319 grant process. The current application period closes February 28, 1997.

Farm Owner

The financial capabilities of the farm owner are unknown. However, agricultural runoff, affected by the former dairy farm, is contributing a large percentage of the nutrient pollution to Lake Ketchum. Therefore, Ecology should work with the farm owner and together address the costs of the farmland soil amendment, wetland treatment, and inflow diversion. Some of these costs could include donated labor and equipment. These restoration measures are specifically designed to control nutrient and bacteria loading from the farm, which currently violate state water quality standards. Without these agricultural controls, the proposed lake restoration plan will not be effective.

Ecology Aquatic Plant Control Grant Program

This grant program gives preference to projects involved in eradication of plants on the state list of noxious weeds. However, control of other aquatic plants may also be eligible.

Roles and Responsibilities

Snohomish County should take the lead in preparing grant applications, coordinating with Ecology, and managing the implementation of farmland soil amendment, wetland treatment, alum treatment in-lake, inflow diversion, and performance monitoring. Ecology should coordinate with the County and farm owner in implementing the farmland soil amendment, wetland treatment, and inflow diversion. The County also should continue to maintain close coordination with the Ketchum Shores Improvement Club for all restoration elements. The watershed citizens, through the Ketchum Shores Improvement Club, should have primary responsibility for implementing watershed BMPs and aquatic plant control.

Implementation Schedule

Implementation Action Items	Starting Date	Completion Date
Grant Applications/Negotiations	February 1997	November 1997
Supplemental Monitoring, Design	November 1997	May 1998
Environmental Review and Permits	November 1997	May 1998
Restoration Plan Implementation:		
Farmland Soil Amendment	July 1998	October 1998
Wetland Treatment	July 1998	October 1998
Watershed BMPs	July 1998	Ongoing
Alum Treatment In-lake	July 1998	October 1998
Inflow Diversion	July 1998	October 1998
Aquatic Plant Control	July 1997	Ongoing as needed
Performance Evaluation Monitoring	July 1998	November 2003

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

This chapter discusses the basis for the study and the goals and objectives of the project. It also includes public involvement activities, the lake's proposed public access plan, and steps taken to comply with the grant.

BASIS FOR THE STUDY

Introduction

Lake Ketchum is a 24-acre lake located in northwest Snohomish County. Approximately 40 year-around homes and 20 seasonal structures surround the lake. Several hundred other residences are located within one-half mile of the lake. Lake Ketchum supports swimming, fishing, boating, water supply, aesthetic enjoyment, and wildlife habitat. In addition, a public boat launch, maintained by the Washington State Department of Fish and Wildlife (WDFW), provides fishing and boating access to the lake for the public.

During the first half of this century, Lake Ketchum apparently had good water quality. In fact, the lake was used as a drinking water source for the City of Stanwood. However, residents have been concerned about the water quality of Lake Ketchum since the late 1960s. At that time, phosphorus levels were excessive and aquatic plants were the major concern.

The Ketchum Shores Improvement Club, a citizen's group, was formed in 1969 and began treating the lake with herbicides to control excessive aquatic weeds. The lake has been treated almost every year since 1981 for weeds and algal growth. From 1989 through 1996, lake front property owners spent over $40,000 of their own money for chemical treatments and legal fees to protect lake water quality.

One suspected source of pollution was the dairy farm located in the watershed south of 308th Street NW. It was known that, in addition to the cow manure and fertilizer that might be discharging from the dairy operation, large amounts of chicken manure had been spread on the pasture lands in recent years. This could present a direct threat to the lake water quality because runoff from the farm flows through the southeast wetland and into the lake.

Near the end of 1992, in the midst of concerns about uncontrolled algae and duckweed growth and on-going dairy farm pollution, lake residents approached Snohomish County and the Washington State Department of Ecology (Ecology) for assistance. Surface Water Management staff from the County evaluated the situation and recommended a detailed diagnostic study to determine the causes of poor lake water quality and the actions needed to restore the lake. The County agreed to sponsor a Centennial Clean Water Fund grant application for a Phase I study.

The Ketchum Shores Improvement Club members voted to support a Phase I Lake Restoration Study and to contribute $10,000 in cash and 700 hours of volunteer assistance as matching funds for the proposed grant. In 1993, Snohomish County applied for a Centennial grant to fund a $195,000 restoration study at Lake Ketchum. The grant was awarded by Ecology and the project began in late 1994.

Goals and Objectives of the Project

Two major goals were established for this project. Each one had a specific set of objectives that would be met with the achievement of the goal. Each goal and its objectives are described in the following paragraphs.

Goal 1: Lake Management Study

Develop a management plan that will be implemented, balancing the level of problem control with funding realities and citizen commitment.

Goal 1: Objectives

- Quantify the relative contributions of phosphorus from various watershed and in-lake sources, which currently cause excessive algae, duckweed, and aquatic plant growth in the lake.
- Determine the severity of bacterial contamination and toxic blue-green algae in the lake.
- Evaluate the effectiveness and costs of viable solutions to the algae, duckweed, aquatic plant, and bacteria problems in Lake Ketchum. Identify the highest priority actions.

Goal 2: Lake Water Quality

Improve the water quality of Lake Ketchum to protect public health and to support use of the lake for swimming, boating, fishing, and visual enjoyment.

Goal 2: Objectives

- Control excessive algal blooms and duckweed growth to levels acceptable to the citizens' needs and financial resources.
- Control excessive aquatic plant growth that interferes with swimming, fishing, and boating. Maintain aquatic plants at moderate levels to allow a balance of human, fish, and wildlife uses in Lake Ketchum.

PUBLIC EDUCATION AND INVOLVEMENT

Public involvement and education have been valuable elements of the Phase I Lake Restoration Study. During the project, citizens living in the watershed learned about water quality issues and were kept well informed about the study's progress. More importantly, citizen input, especially from the Advisory Committee, shaped the direction of the study and the recommendations of this report. The various components of the Phase I public involvement and education program are summarized below.

Public Meetings/Workshops

The first public workshop was held on March 4, 1995. Notices were mailed to all residents in the lake watershed. About 40 people attended. This workshop presented background information on the history of problems at Lake Ketchum, on "How Lakes Work," and on "What is a Lake Management Plan." Citizens also helped develop a problem statement and preliminary water quality goals.

The Ketchum Shores Improvement Club, representing all the properties on the lake shore, also held public meetings on October 29, 1994, May 20, 1995, July 19, 1995, October 28, 1995, May 18, 1996, and October 26, 1996. Snohomish County staff and/or the consultant attended each of these meetings to inform citizens about the project.

A second public workshop was held January 18, 1997 to present the draft report and to solicit comments on the proposed restoration plan.

Advisory Committee

The Lake Ketchum Citizen Advisory Committee met seven times between October 1994 and February 1997 to help guide the Phase I study. The committee discussed the water quality problem statement, water quality goals, the monitoring plan, public education activities, volunteer tasks, park planning, the septic system dye tests, monitoring results, restoration alternatives, costs, and implementation strategies.

Lakeside Potluck

An educational Lakeside Community Potluck, attended by almost 40 residents, was held on Saturday, July 29, 1995. There were presentations about lake monitoring techniques, study progress, and the new island wildlife sanctuary.

County Council Briefings

During the course of the Phase I study, Snohomish County staff briefed the County Council twice on the status of the project. In addition, on September 21, 1995, Council Member John Garner met with Lake Ketchum citizens to discuss the lake's water quality problems, citizen concerns, volunteer activities, and the study's progress. He also took a watershed tour and a boat trip on the lake.

Newsletters

The first newsletter (called a "newsflash") was published and distributed in July 1995. Copies of the newsflash were mailed to all households in the watershed. This edition reported on progress of the Phase I study, water quality goals, volunteer activities, and an upcoming Lakeside Community Potluck. The second newsflash, published in December 1995, covered the results of the potluck, the aquatic plant survey, toxic algae testing, and lake monitoring. The newsflash also explained the effects of nutrient pollution on the lake and provided an update on the dairy farm clean-up. A third newsflash, distributed in early January 1997, summarized the findings and recommendations in the draft report.

Newspaper Articles

The Stanwood-Camano News reported on the condition of Lake Ketchum and citizen involvement in the Phase I study in articles published on March 7, 1995, August 8, 1995, February 1996, January 14, 1997, and January 28, 1997.

Informational Signs

Two informational signs were designed and installed next to the public boat launch to publicize the lake restoration project. The first sign (3-foot x 6-foot) is permanent and explains the Lake Ketchum's water quality project and the lake restoration goals. The second sign (2-foot x 6-foot) is temporary and explains the purposes, costs, and sponsors of the Phase I study.

Volunteer Monitoring

Volunteers were extremely helpful in conducting the lake and stream monitoring for the Phase I study. Citizens conducted bi-weekly monitoring of lake water clarity and temperature; monthly groundwater level monitoring; verification monitoring of lake levels, flows through the inlet weir, and rainfall; regular bird counts; a limited fishing survey; toxic algae monitoring; and a watershed watch for pollution sources.

Public Involvement

Other examples of public involvement in the Phase I study included: septic system dye testing (over ninety percent of lakeshore residents participated), development of a logo for the newsletters by a school class, and volunteer research into the history of development and the uses of Lake Ketchum.

LAKE KETCHUM PUBLIC ACCESS PLAN

Background

One requirement of Centennial Clean Water Fund grants is that full-scale public access must be provided at the lake. Although there is a public boat launch at Lake Ketchum, it does not provide facilities for swimming and other activities. Therefore, one element of the Phase I Restoration Study is to develop a plan for creating a new park on the lake. If additional grant funds are received from the State to implement the lake restoration plan, then the park must be constructed.

The Lake Ketchum park planning process began in November 1995. The process was conducted in cooperation with the Lake Ketchum Citizen Advisory Committee, the Snohomish County Parks Department, and the WDFW. The following summarizes the park planning process and the park proposal. For more information, please refer to **Appendix G** for the complete Public Access Plan.

Site Selection

Prior to selecting potential alternative sites for a park, Snohomish County staff and the Advisory Committee identified site selection criteria and general design requirements. The criteria included location on the lake, adequate size, adequate soils, willing ownership, and citizen support. The general design requirements were that the site be adequate for a picnic area, swimming beach, restroom, open space, and parking. The number of potential park users, based on population of the surrounding area, also was estimated.

Based on a preliminary survey of existing properties around the lake, five possible park sites, which met most of the criteria, were selected for further analysis. These lakeshore sites were chosen primarily because either they are vacant or are used for a similar purpose (such as public or community access). Then, background information was gathered on each site regarding the property size, soils, topography, vegetation views, wildlife habitat, property ownership, land value, land uses, roads, utilities, and other improvements.

This analysis resulted in eliminating three sites. The Community Beach Club on the northwest end of the lake and the Community Lot next to the public boat launch were both rejected early in the process because of the difficulty of obtaining agreement from all 52 or 54 property owners who own shares in these community lots.

The 12-acre wetland on the north end of the lake (formerly known as the Wilderness Ridge Community Park) also was rejected because of two main disadvantages:

- wetland soils make it difficult to find enough dry land to provide parking and toilets, and
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However, Ecology has determined that the boat launch site alone is too small to provide the public access required of Phase II lake restoration projects. Therefore, the proposed public access plan includes acquisition of the vacant lot to the west to augment the existing WDFW boat launch.

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The proposed plan includes gravel parking for approximately four vehicles and three boat trailers, an 800-square-foot swimming beach, and an existing 45-foot fishing pier. These facilities satisfy many of the recommendations in the 1994 Snohomish County Comprehensive Park and Recreation Plan for waterfront parks in this area of the county.

Acquisition, Construction, and Maintenance

The proposed park plan, as required by Ecology, involves acquisition of the lot just west of the WDFW boat launch. This lot may or may not be available for purchase. Possible funding sources for acquisition include the Ketchum Shores Improvement Club, WDFW (which has expressed interest in acquiring the site), and grant funds from the Interagency Committee for Outdoor Recreation.

If this site is acquired, only minimal changes would be necessary to convert the two lots to a public park. The fence between the lots would have to be removed and a new fence installed west of the vacant lot. In addition, several picnic tables and sand for the swimming beach would need to be installed.

The estimated costs for acquisition and park development are about $35,000. On-going park maintenance is estimated at about $3,000 per year.

The Snohomish County Parks Department has no funds for and does not operate small community parks like this one. Therefore, operation and maintenance of the park must be the responsibility of the local community, probably through the Ketchum Shores Improvement Club, however, liability coverage would be an issue.

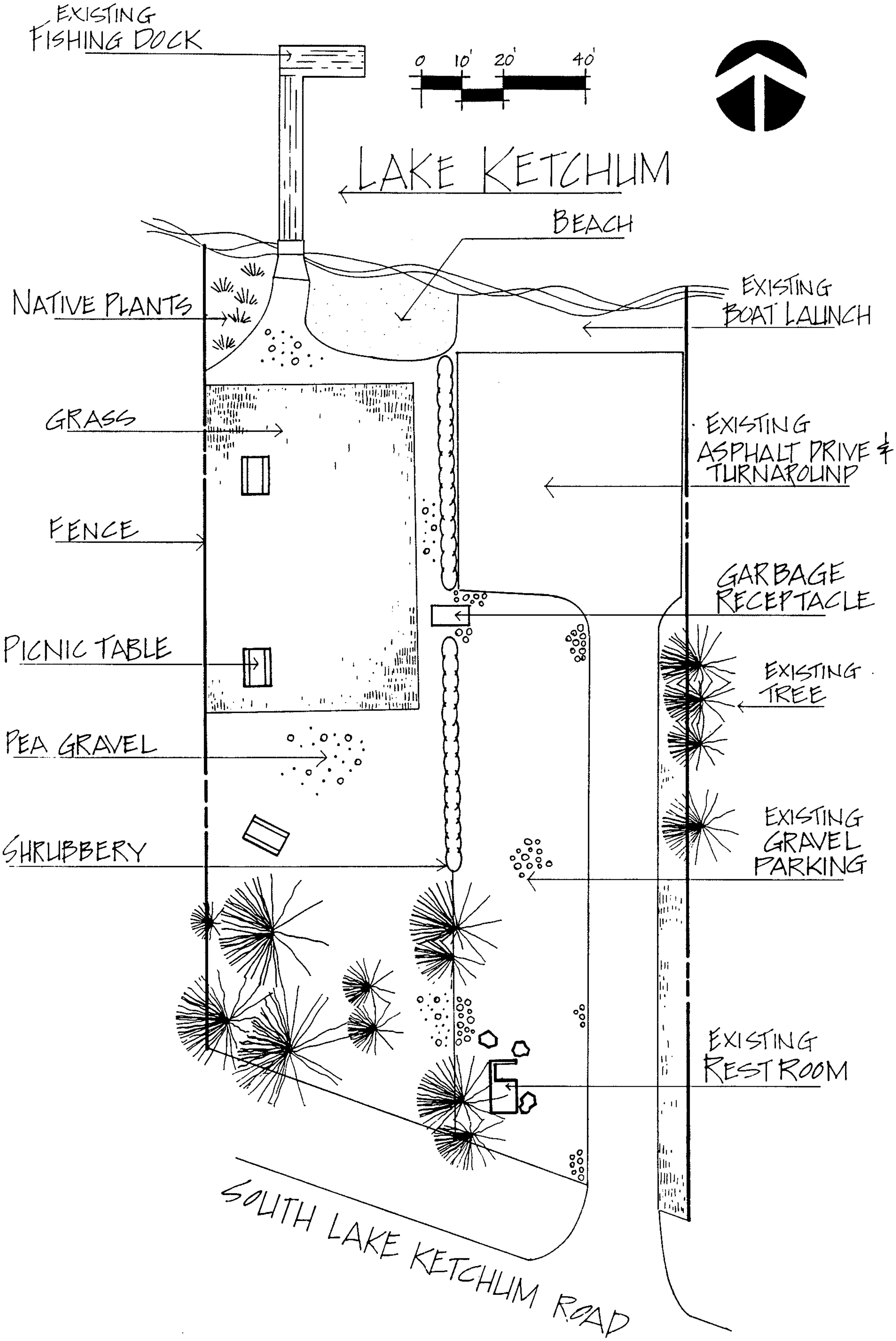

Figure 1-1. Proposed Park Site Plan

GRANT COMPLIANCE

This Phase I restoration study was conducted in accordance with Centennial Clean Water Fund grant contract number G9400103 between Ecology and Snohomish County. All elements of the study—project management, public education, water quality monitoring, data analysis, and development of the restoration plan—were accomplished to meet the required performance measures and special terms and conditions of the grant contract.

ACKNOWLEDGMENTS

This project was funded through a Centennial Clean Water Fund grant from the Washington State Department of Ecology. Local matching funds and volunteer services were provided by Snohomish County Surface Water Management and the Ketchum Shores Improvement Club.

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Snohomish County Council

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ADVISORY COMMITTEE: Thanks to the Lake Ketchum Advisory Committee for their unfailing dedication from the beginning of this project and for helping to make this the best plan possible. The Advisory Committee includes the following members:

Cheryl Allen	Eldon Allen
Dana Base	Rick Bowzer
Tom Buckingham	Clint Copeland
Eunice Flatray	Mona Flatray
Jane Hilleary	Marilyn Kennell
Eg Kromann	Ruth Kromann
Ray Lee	

VOLUNTEERS: Thanks also to the following volunteers for their help. Without them, this study would not have been possible:

Cheryl Allen	Lake Ketchum Logo
Rick Bowzer	Algae Sampling, Inlet/Outlet Monitoring
Tom Buckingham	Creel Survey
Martha Burress	Groundwater Monitoring
Elsa Dodman	Potluck Organizer
Anton Ehinger	Lake Monitoring
Art Flatray	Bird Counts
Eunice Flatray	Lake Ketchum History
Mona Flatray	Volunteer Coordinator
Tom Herman	Watershed Watch
Jane Hilleary	Groundwater Monitoring
Ruth Kromann	Island Bird Sanctuary
Ray Lee	Boat, Miscellaneous Monitoring
Tami Robb	Potluck Organizer
Otis Simpson	Inlet Monitoring

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Bert Albert	Cheryl and Eldon Allen
Mona Flatray	Marilyn Kennell
Ray and Mary Lee	

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

This chapter discusses the basis for the study and the goals and objectives of the project. It also includes public involvement activities, the lake's proposed public access plan, and steps taken to comply with the grant.

BASIS FOR THE STUDY

Introduction

Lake Ketchum is a 24-acre lake located in northwest Snohomish County. Approximately 40 year-around homes and 20 seasonal structures surround the lake. Several hundred other residences are located within one-half mile of the lake. Lake Ketchum supports swimming, fishing, boating, water supply, aesthetic enjoyment, and wildlife habitat. In addition, a public boat launch, maintained by the Washington State Department of Fish and Wildlife (WDFW), provides fishing and boating access to the lake for the public.

During the first half of this century, Lake Ketchum apparently had good water quality. In fact, the lake was used as a drinking water source for the City of Stanwood. However, residents have been concerned about the water quality of Lake Ketchum since the late 1960s. At that time, phosphorus levels were excessive and aquatic plants were the major concern.

The Ketchum Shores Improvement Club, a citizen's group, was formed in 1969 and began treating the lake with herbicides to control excessive aquatic weeds. The lake has been treated almost every year since 1981 for weeds and algal growth. From 1989 through 1996, lake front property owners spent over $40,000 of their own money for chemical treatments and legal fees to protect lake water quality.

One suspected source of pollution was the dairy farm located in the watershed south of 308th Street NW. It was known that, in addition to the cow manure and fertilizer that might be discharging from the dairy operation, large amounts of chicken manure had been spread on the pasture lands in recent years. This could present a direct threat to the lake water quality because runoff from the farm flows through the southeast wetland and into the lake.

Near the end of 1992, in the midst of concerns about uncontrolled algae and duckweed growth and on-going dairy farm pollution, lake residents approached Snohomish County and the Washington State Department of Ecology (Ecology) for assistance. Surface Water Management staff from the County evaluated the situation and recommended a detailed diagnostic study to determine the causes of poor lake water quality and the actions needed to restore the lake. The County agreed to sponsor a Centennial Clean Water Fund grant application for a Phase I study.

The Ketchum Shores Improvement Club members voted to support a Phase I Lake Restoration Study and to contribute $10,000 in cash and 700 hours of volunteer assistance as matching funds for the proposed grant. In 1993, Snohomish County applied for a Centennial grant to fund a $195,000 restoration study at Lake Ketchum. The grant was awarded by Ecology and the project began in late 1994.

Goals and Objectives of the Project

Two major goals were established for this project. Each one had a specific set of objectives that would be met with the achievement of the goal. Each goal and its objectives are described in the following paragraphs.

Goal 1: Lake Management Study

Develop a management plan that will be implemented, balancing the level of problem control with funding realities and citizen commitment.

Goal 1: Objectives

- Quantify the relative contributions of phosphorus from various watershed and in-lake sources, which currently cause excessive algae, duckweed, and aquatic plant growth in the lake.
- Determine the severity of bacterial contamination and toxic blue-green algae in the lake.
- Evaluate the effectiveness and costs of viable solutions to the algae, duckweed, aquatic plant, and bacteria problems in Lake Ketchum. Identify the highest priority actions.

Goal 2: Lake Water Quality

Improve the water quality of Lake Ketchum to protect public health and to support use of the lake for swimming, boating, fishing, and visual enjoyment.

Goal 2: Objectives

- Control excessive algal blooms and duckweed growth to levels acceptable to the citizens' needs and financial resources.
- Control excessive aquatic plant growth that interferes with swimming, fishing, and boating. Maintain aquatic plants at moderate levels to allow a balance of human, fish, and wildlife uses in Lake Ketchum.

PUBLIC EDUCATION AND INVOLVEMENT

Public involvement and education have been valuable elements of the Phase I Lake Restoration Study. During the project, citizens living in the watershed learned about water quality issues and were kept well informed about the study's progress. More importantly, citizen input, especially from the Advisory Committee, shaped the direction of the study and the recommendations of this report. The various components of the Phase I public involvement and education program are summarized below.

Public Meetings/Workshops

The first public workshop was held on March 4, 1995. Notices were mailed to all residents in the lake watershed. About 40 people attended. This workshop presented background information on the history of problems at Lake Ketchum, on "How Lakes Work," and on "What is a Lake Management Plan." Citizens also helped develop a problem statement and preliminary water quality goals.

The Ketchum Shores Improvement Club, representing all the properties on the lake shore, also held public meetings on October 29, 1994, May 20, 1995, July 19, 1995, October 28, 1995, May 18, 1996, and October 26, 1996. Snohomish County staff and/or the consultant attended each of these meetings to inform citizens about the project.

A second public workshop was held January 18, 1997 to present the draft report and to solicit comments on the proposed restoration plan.

Advisory Committee

The Lake Ketchum Citizen Advisory Committee met seven times between October 1994 and February 1997 to help guide the Phase I study. The committee discussed the water quality problem statement, water quality goals, the monitoring plan, public education activities, volunteer tasks, park planning, the septic system dye tests, monitoring results, restoration alternatives, costs, and implementation strategies.

Lakeside Potluck

An educational Lakeside Community Potluck, attended by almost 40 residents, was held on Saturday, July 29, 1995. There were presentations about lake monitoring techniques, study progress, and the new island wildlife sanctuary.

County Council Briefings

During the course of the Phase I study, Snohomish County staff briefed the County Council twice on the status of the project. In addition, on September 21, 1995, Council Member John Garner met with Lake Ketchum citizens to discuss the lake's water quality problems, citizen concerns, volunteer activities, and the study's progress. He also took a watershed tour and a boat trip on the lake.

Newsletters

The first newsletter (called a "newsflash") was published and distributed in July 1995. Copies of the newsflash were mailed to all households in the watershed. This edition reported on progress of the Phase I study, water quality goals, volunteer activities, and an upcoming Lakeside Community Potluck. The second newsflash, published in December 1995, covered the results of the potluck, the aquatic plant survey, toxic algae testing, and lake monitoring. The newsflash also explained the effects of nutrient pollution on the lake and provided an update on the dairy farm clean-up. A third newsflash, distributed in early January 1997, summarized the findings and recommendations in the draft report.

Newspaper Articles

The Stanwood-Camano News reported on the condition of Lake Ketchum and citizen involvement in the Phase I study in articles published on March 7, 1995, August 8, 1995, February 1996, January 14, 1997, and January 28, 1997.

Informational Signs

Two informational signs were designed and installed next to the public boat launch to publicize the lake restoration project. The first sign (3-foot x 6-foot) is permanent and explains the Lake Ketchum's water quality project and the lake restoration goals. The second sign (2-foot x 6-foot) is temporary and explains the purposes, costs, and sponsors of the Phase I study.

Volunteer Monitoring

Volunteers were extremely helpful in conducting the lake and stream monitoring for the Phase I study. Citizens conducted bi-weekly monitoring of lake water clarity and temperature; monthly groundwater level monitoring; verification monitoring of lake levels, flows through the inlet weir, and rainfall; regular bird counts; a limited fishing survey; toxic algae monitoring; and a watershed watch for pollution sources.

Public Involvement

Other examples of public involvement in the Phase I study included: septic system dye testing (over ninety percent of lakeshore residents participated), development of a logo for the newsletters by a school class, and volunteer research into the history of development and the uses of Lake Ketchum.

LAKE KETCHUM PUBLIC ACCESS PLAN

Background

One requirement of Centennial Clean Water Fund grants is that full-scale public access must be provided at the lake. Although there is a public boat launch at Lake Ketchum, it does not provide facilities for swimming and other activities. Therefore, one element of the Phase I Restoration Study is to develop a plan for creating a new park on the lake. If additional grant funds are received from the State to implement the lake restoration plan, then the park must be constructed.

The Lake Ketchum park planning process began in November 1995. The process was conducted in cooperation with the Lake Ketchum Citizen Advisory Committee, the Snohomish County Parks Department, and the WDFW. The following summarizes the park planning process and the park proposal. For more information, please refer to **Appendix G** for the complete Public Access Plan.

Site Selection

Prior to selecting potential alternative sites for a park, Snohomish County staff and the Advisory Committee identified site selection criteria and general design requirements. The criteria included location on the lake, adequate size, adequate soils, willing ownership, and citizen support. The general design requirements were that the site be adequate for a picnic area, swimming beach, restroom, open space, and parking. The number of potential park users, based on population of the surrounding area, also was estimated.

Based on a preliminary survey of existing properties around the lake, five possible park sites, which met most of the criteria, were selected for further analysis. These lakeshore sites were chosen primarily because either they are vacant or are used for a similar purpose (such as public or community access). Then, background information was gathered on each site regarding the property size, soils, topography, vegetation views, wildlife habitat, property ownership, land value, land uses, roads, utilities, and other improvements.

This analysis resulted in eliminating three sites. The Community Beach Club on the northwest end of the lake and the Community Lot next to the public boat launch were both rejected early in the process because of the difficulty of obtaining agreement from all 52 or 54 property owners who own shares in these community lots.

The 12-acre wetland on the north end of the lake (formerly known as the Wilderness Ridge Community Park) also was rejected because of two main disadvantages:

- wetland soils make it difficult to find enough dry land to provide parking and toilets, and
- the high cost of the property.

The remaining two sites are the WDFW public boat launch property on the south shore of Lake Ketchum and a vacant, landscaped lot west of the boat launch. The boat launch property was favored by residents because of cost savings and limited park size. The boat launch currently has parking facilities and a new pit toilet. Also, the WDFW has agreed to lease the land at no cost to allow development of a park.

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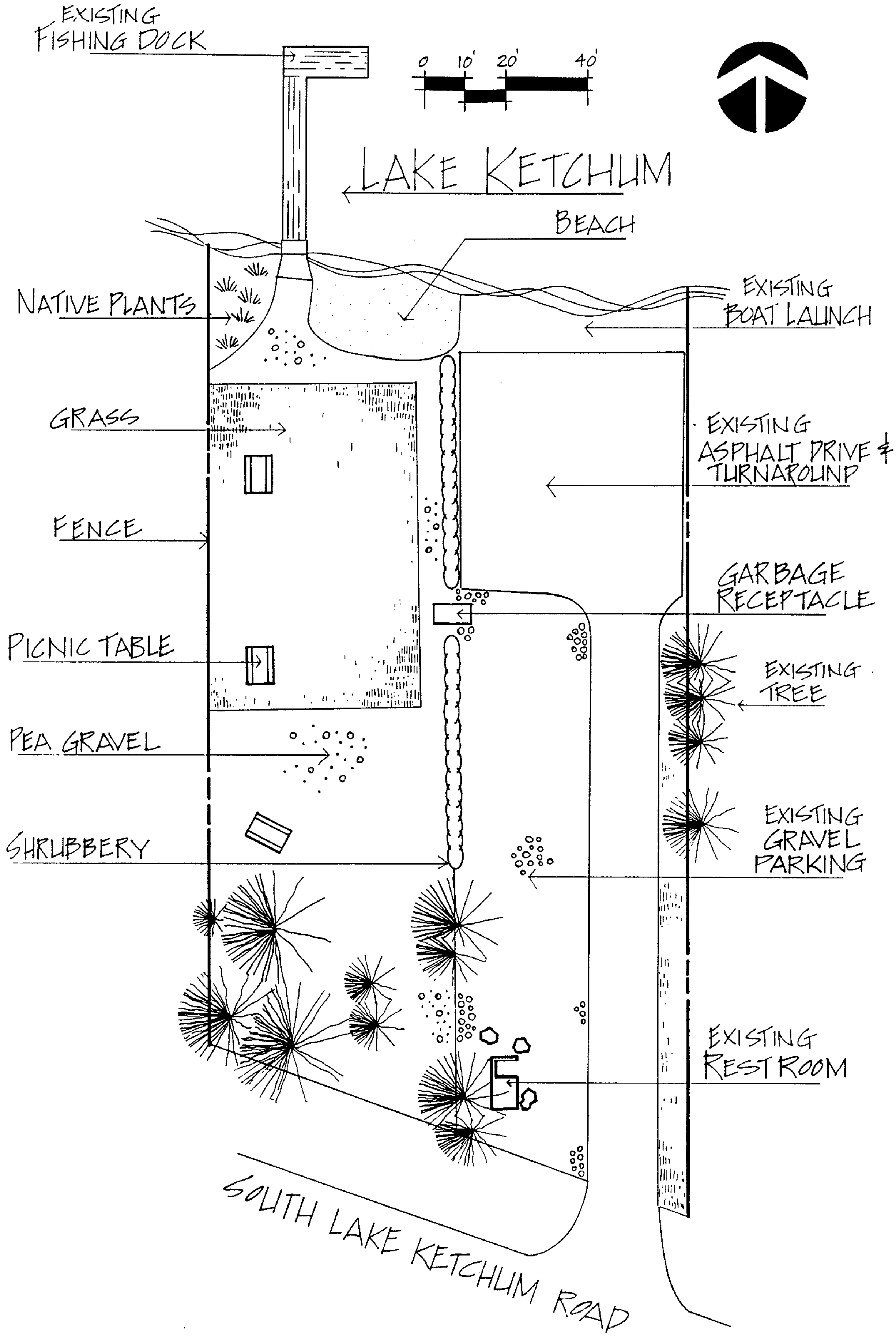

Figure 1-1. Proposed Park Site Plan

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CHAPTER 2

STUDY AREA DESCRIPTION AND BACKGROUND

2. STUDY AREA DESCRIPTION AND BACKGROUND

This chapter discusses the physical features of Lake Ketchum and its watershed, such as topography, geology, soils, and drainage features, as well as the current and future land uses around the lake. Past water quality conditions and management efforts also are described in this chapter.

LAKE DESCRIPTION

Lake Ketchum is a 24-acre lake located 2.5 miles north of Stanwood in northwest Snohomish County (**Figure 2-1**). The lake is surrounded by residential development and recreational cabins. Public access is provided by a boat launch maintained by the Washington State Department of Fish and Wildlife (WDFW).

The lake is fairly shallow, with an average depth of 12 feet and a maximum depth of 21 feet (**Figure 2-2**) (**Sumioka and Dion 1985**). The narrow northeast and southeast arms of the lake are not natural features. During the 1950s, these arms were excavated to increase lake frontage; the small island was formed from the dredge spoils. The physical characteristics of the lake are summarized in **Table 2-1** below:

Table 2-1
Physical Characteristics of Lake Ketchum and Its Watershed[1]

	English units	Metric units
Lake Surface Area	24 acres	9.7 hectares
Maximum Depth	21 feet	6.5 meters
Mean Depth	12 feet	3.7 meters
Lake Volume	296 acre-feet	460,000 cubic meters
Watershed Area	330 acres	134 hectares
Shoreline Length	1.3 miles	2.09 kilometers
Elevation	190 feet	57.9 meters
Watershed: Lake Area Ratio	14:1	14:1

1. Source: Sumioka and Dion (1985)

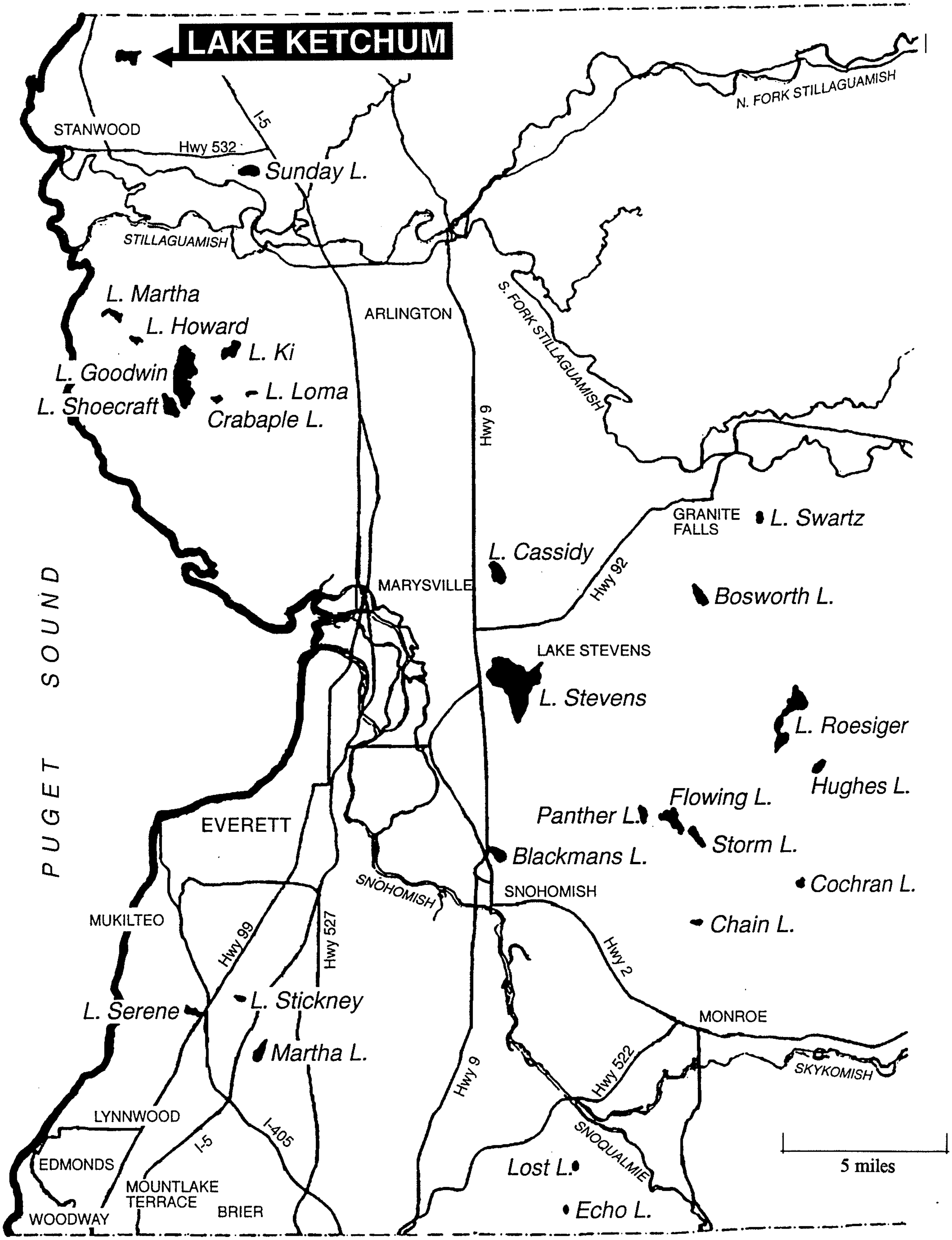


Figure 2-1. Project Vicinity

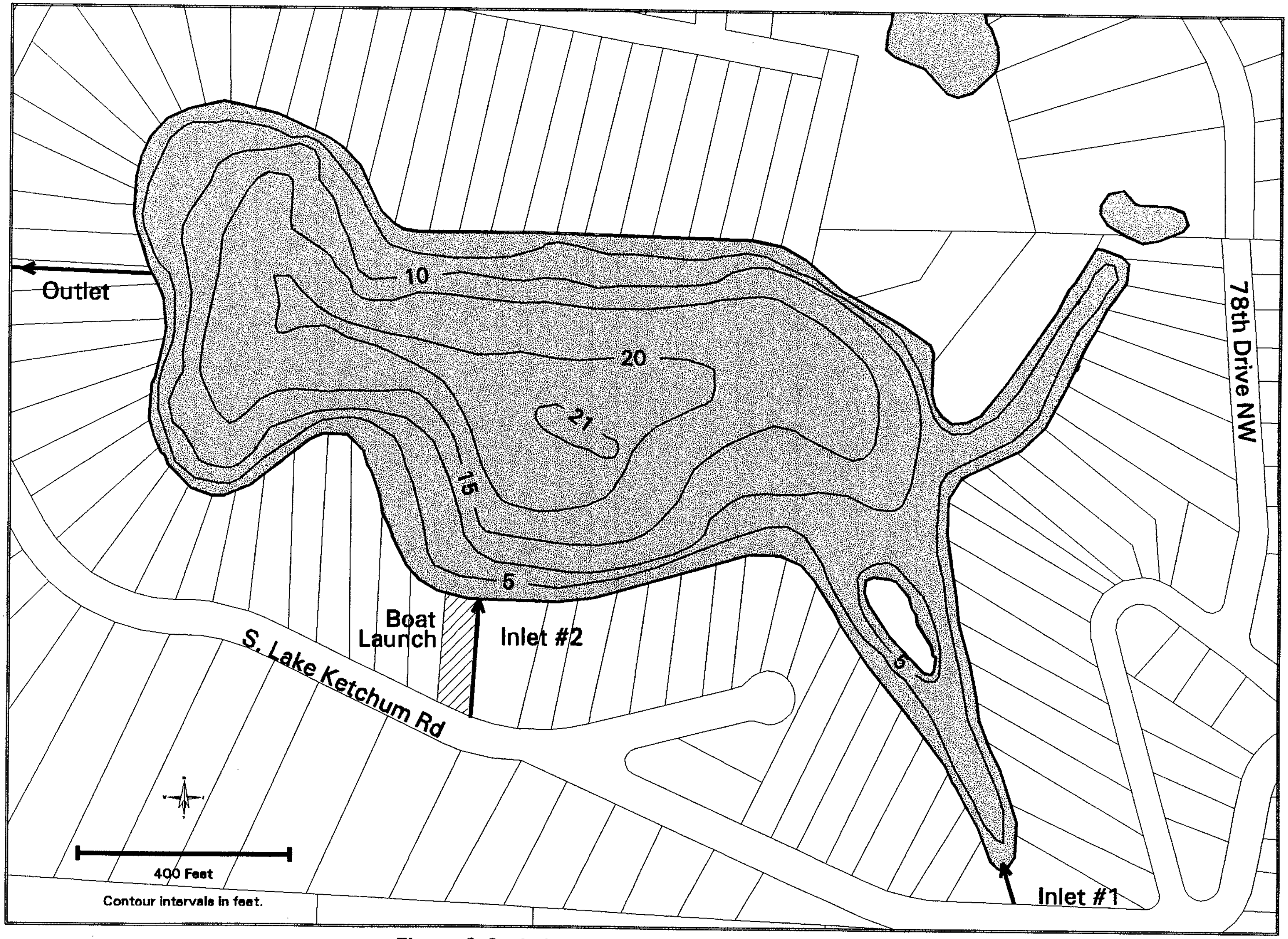


Figure 2-2. Lake Ketchum with Depth Contours

Beneficial Uses of Lake Ketchum

The historical and existing beneficial uses of Lake Ketchum are described below. (Refer to **Appendix D** for a detailed description of the beneficial uses of Lake Ketchum.)

Water Supply

For most of the first half of this century, Lake Ketchum served as the drinking water source for the City of Stanwood and for early residents at the lake. Many homeowners around the lake now have shallow wells—30 to 60 feet deep—which draw water from an aquifer that interacts directly with the lake.

Recreation

Boating, fishing, and swimming are the primary recreational uses of Lake Ketchum. These uses are severely impaired by the current water quality problems. There is a public boat launch and two community lots to provide access to the lake. Internal combustion boat motors are banned on the lake.

Fish and Wildlife Habitat

The WDFW manages the lake for mixed fish species. Each year between 1,000 and 2,000 catchable rainbow trout are stocked in the lake. Yellow perch, largemouth bass, black crappie, bluegill sunfish, and brown bullhead catfish are also present in the lake. Fishing success during the study year was low.

Lake Ketchum also is host to breeding populations of mallards and wood ducks. About 22 other species of migrant waterfowl and aquatic birds use the lake for portions of the year. Up to six otters reside in the lake for parts of the year.

Aesthetics

Lake Ketchum provides aesthetic benefits to lakeshore residents and lake users. However, the aesthetic values have been severely diminished by the current water quality problems.

WATERSHED DESCRIPTION

The land area around Lake Ketchum that drains to the lake (called the "watershed") covers 330 acres, excluding the lake (see the watershed map **Figure 2-3**). The watershed is 14 times the size of the lake itself. This watershed to lake area ratio is slightly smaller than the average for Snohomish County lakes, but the watershed is big enough that activities in the watershed have a significant effect on the condition of the lake.

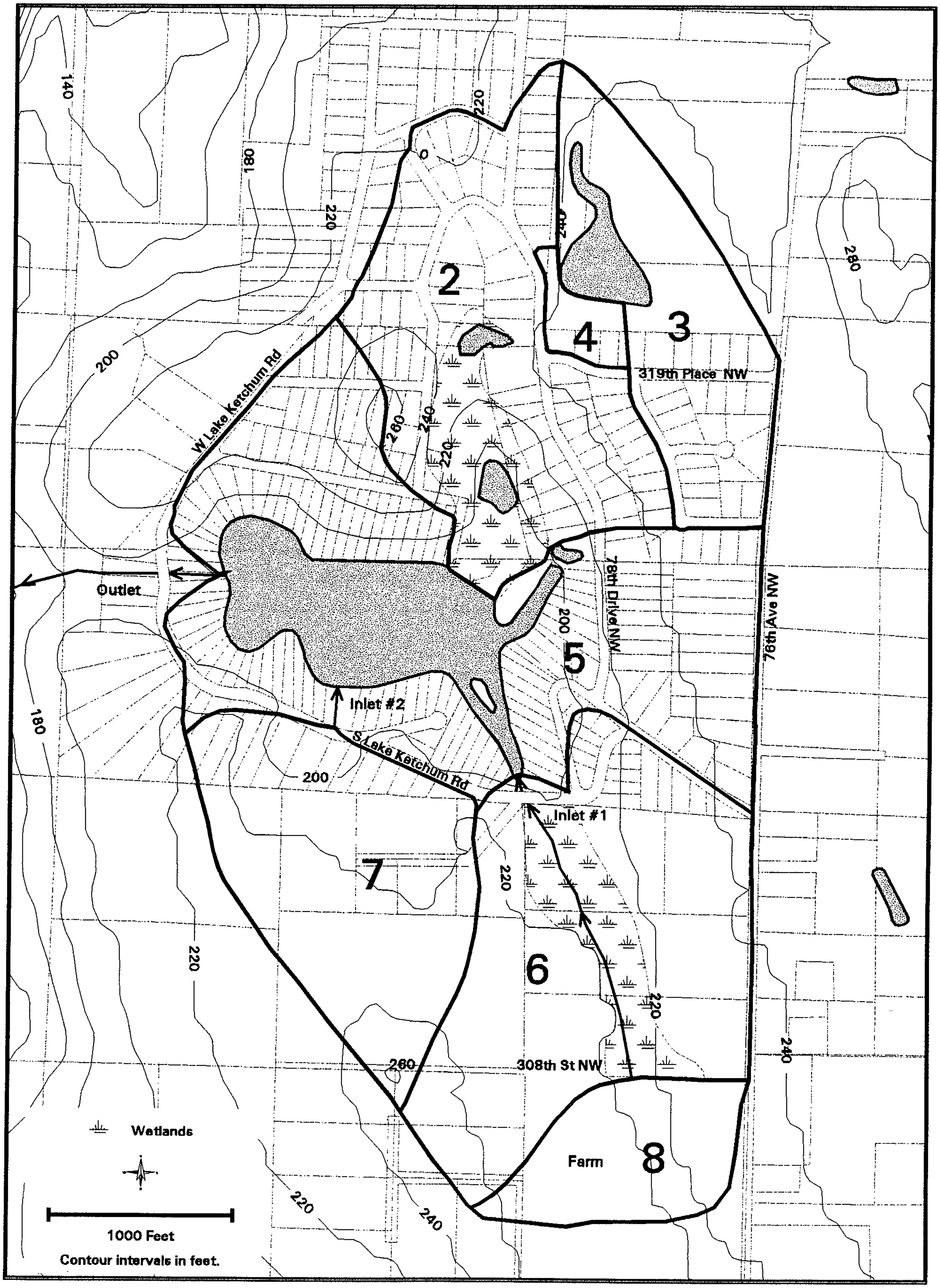


Figure 2-3. Lake Ketchum Watershed and Sub-Basins

For the purposes of this study, the Lake Ketchum watershed was subdivided into seven Subbasins or drainage areas, as illustrated in **Figure 2-3**. The acreage for the Subbasins are listed in **Table 2-2**. Several of the Subbasins drain into each other before they reach the lake. For example, Subbasin 3 empties into Subbasin 4, which drains to Subbasin 2 and then into Lake Ketchum. Similarly, Subbasin 8 empties into Subbasin 6 before it reaches the lake.

Table 2-2
Areas of the Seven Subbasins
Within the Lake Ketchum Watershed

		Area	
Subbasin	**Location**	**Acres**	**Percent**
2	North of Lake	63.7	19.4
3	Northeast	37.3	11.3
4	80th Ave	4.2	1.3
5	Lake Shore	83.9	25.5
6	Southeast	72.6	22.0
7	Southwest	48.2	14.6
8	Farm	19.5	5.9
Total		**330**	**100**

Topography

Elevations in the watershed range from 190 to 260 feet above mean sea level. The majority of the watershed consists of gently sloping hills. Near the lakeshore, the land is moderately sloped (6 to 15 percent) from the north and west, with gentler slopes (0 to 6 percent) from the south and east. Slopes also are steeper (6 to 15 percent) along 78th Drive NW (see elevation contours on **Figure 2-3**).

The central portion of the south shore is a former wetland that has been filled to develop the boat launch and adjacent houses. This area is low lying, with a groundwater level just a few feet below the surface.

Geology

Like most lakes in the Puget Sound lowlands, Lake Ketchum occupies a depression in the surface of materials deposited by the last of the ice age glaciers (the Vashon glaciation). These depressions are either elongated troughs cut by the passing ice sheet or are more circular kettles formed by the melting of ice blocks. Lake Ketchum appears to be the result of adjoining kettles that formed a shallow bowl in an area of sands and gravels that washed out of the receding glacier.

Since the ice ages, Lake Ketchum has partially filled in with sediments from the surrounding hillsides. Shallow lakes, like Lake Ketchum, are likely to be naturally eutrophic lakes. That is, they are naturally enriched with nutrients and have vigorous growths of aquatic plants and algae. However, human actions can greatly accelerate the process of eutrophication.

Soils

The soils around the lake are very permeable, so much of the rainfall soaks directly into the ground very quickly, leaving drainage channels and ditches dry throughout much of the year. Therefore, a large proportion of the water reaching the lake comes from groundwater seepage through the permeable sand/gravel soils and from runoff from lakeshore properties.

The soils around Lake Ketchum were primarily formed in glacial outwash and volcanic ash. There are five types of soils around the lake: two excessively well-drained soils (Everett gravelly sandy loam and Winston gravelly loam), two very poorly drained organic soils (Mukilteo muck and Terric Medisaprists), and one moderately well drained soil with a hardpan 20 to 40 inches below the surface (Tokul). **Appendix D** describes the location, characteristics, and extent of the various soils in the Lake Ketchum watershed.

DRAINAGE FEATURES

Surface Inflows and Outlet

There are three main sources of surface flow into Lake Ketchum: Inlet 1 entering the southeast arm of the lake, Inlet 2 next to the boat launch, and the north shore wetland area (**Figure 2-3**). Additional water entering the lake comes from groundwater flows and direct surface water runoff from the remaining watershed area. Lake Ketchum's outlet drains to the west into a small unnamed creek which empties into Skagit Bay (**Figure 2-4**).

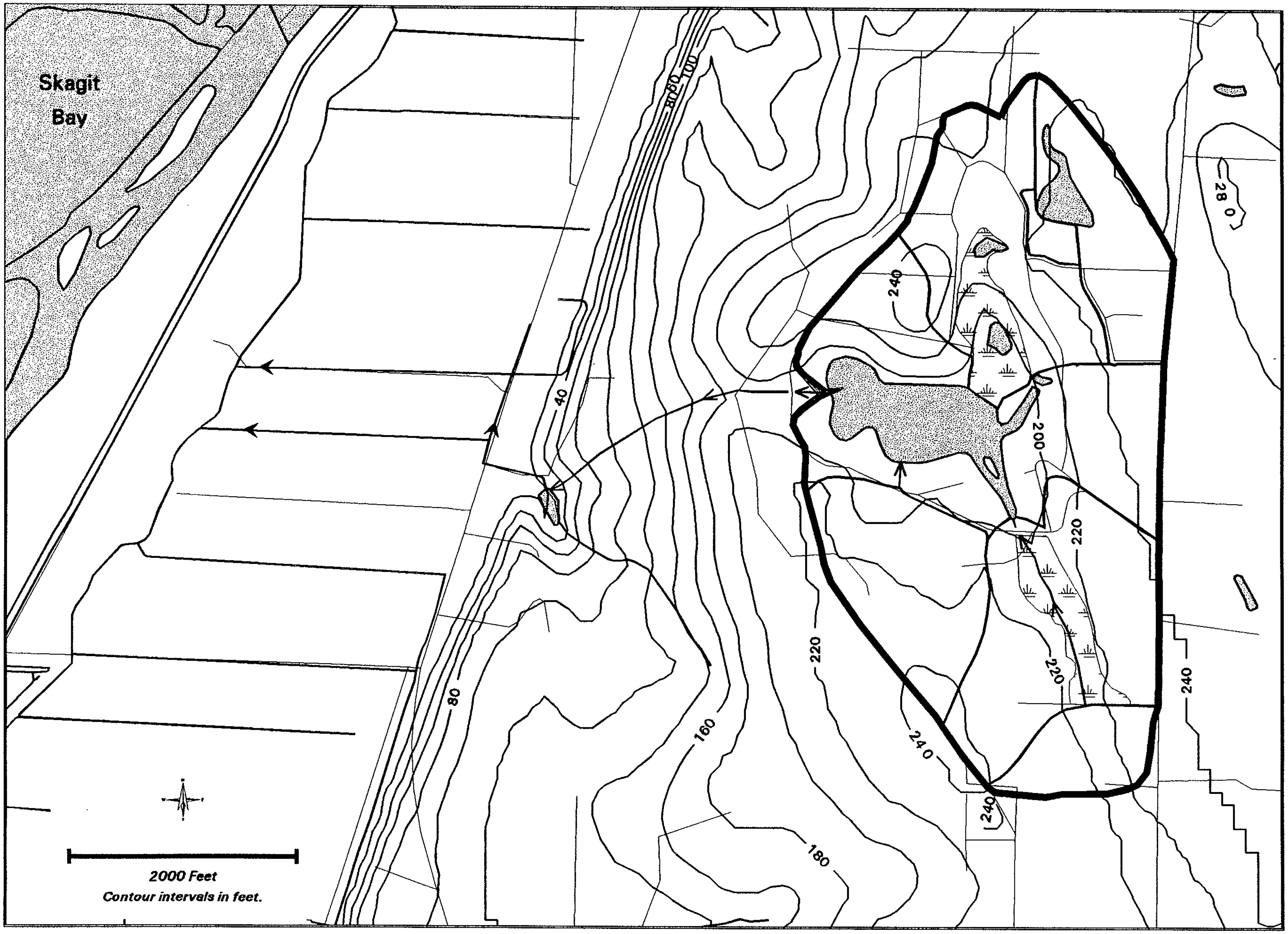


Figure 2-4. Lake Ketchum Regional Drainage

Inlet 1 (southeast inlet from the farm): This inlet is the major surface flow to Lake Ketchum and drains Subbasins 6 and 8. The stream flows about eight or nine months of the year and is fed by a forested wetland below the cattle farm to the south. The stream channel through the wetland is fairly natural. There is a thick canopy of trees and shrubs to provide shade to keep the water cool and to stabilize the banks against erosion. Recently, there has been some clearing along a section of this stream just north of 308th Street NW. A ditch north of South Lake Ketchum Road joins this stream before it reaches the lake. This ditch, dry most of the year, drains several residences to the south.

Inlet 2 (next to the boat launch): The second inlet drains 48 acres of homes and grasslands south of the boat launch (Subbasin 7). The runoff from this area formerly flowed across a wetland, but now flows directly into the lake through an excavated ditch along the east side of the boat launch. Since this wetland has been filled for development, its original filtration value has been lost and the wildlife habitat greatly reduced. While Inlet 2 usually holds standing water at the level of the groundwater table, it only conveys flows during the winter and early spring.

North Shore: Water entering Lake Ketchum from the depressional area on the north shore is not channelized. Instead, water seeps into the lake from the adjacent wetland area as shallow groundwater or as overland sheet flow. This northeast wetland is fed by runoff from surrounding uplands and by an intermittent creek that flows through a culvert under 80th Avenue NW. The entire north shore drainage through this wetland (Subbasins 2, 3, and 4) collects runoff from approximately 105 acres of the lake watershed.

Lake Outlet Stream: The outlet channel is located on the west end of the lake. The lake level is controlled at this outlet by a weir operated by the Ketchum Shores Improvement Club. The weir was refurbished by Snohomish County in 1996. Under natural conditions, the outlet channel would contain outflow from the lake about eight or nine months of the year. However, during the study year, the weir was operated so that no water flowed out of the lake from April until the end of November (except for minor seepage).

The first 380 feet of the outlet channel is contained in a 24-inch pipe located in an easement across private property. The outlet continues through a culvert under West Lake Ketchum Road. On the west side of the road, the unnamed stream has been channelized, but has a fairly natural character with good streambank vegetation and a forested overstory that provides shade to keep the water cool. The unnamed outlet stream continues west, crossing farmland, until it empties into Skagit Bay.

Groundwater

Groundwater is a dominant component of the Lake Ketchum water regime. There are two identifiable groundwater aquifers in the area (refer to **Appendix B** for more information on groundwater). The topmost aquifer, formed by Vashon recessional outwash sands and gravels, is from a few feet to about 100 feet deep. Many older private wells around the lake are 30 to 60 feet deep and draw water from this aquifer. This aquifer appears to have direct interaction with Lake Ketchum.

In most areas, there is a layer of glacial till below this aquifer. The till is composed of unsorted sands and gravels, compacted by the overlying glacier. The layer is so dense that water cannot easily pass through it. Below this barrier, there is another aquifer formed from materials washed out of the glacier before the ice passed over. This Vashon advance outwash layer may be several hundred feet deep. Most of the newer private wells around the lake are 120 to 200 feet deep and take water from this aquifer.

SENSITIVE AREAS

Wetlands

There are two major wetlands in the Lake Ketchum watershed as described below.

Northeast Wetland (Wilderness Ridge Community Tract A): This 12-acre wetland system is relatively undisturbed. Much of the original native vegetation remains. The wetland contains a mixture of open water (two ponds), forest, and shrub/meadow. Because of the diversity, this area has considerable value for wildlife habitat. Much of this wetland was originally platted as a Community Park as part of the Wilderness Ridge plat. The park tract has since been sold to private owners who plan to preserve the area as a wetland.

The portion of the wetland adjacent to Lake Ketchum is about 350 feet in width. The dominant plants here are cattails, spiraea, willows, alder, cedar, juncus, and nightshade. A small section adjacent to the lake has been disturbed and planted with grass.

Southeast Wetland: This wetland, located between South Lake Ketchum Road and the cattle farm (previously a dairy farm), is an important source of base flow for the lake during the drier summer months. This 12-acre wetland also is relatively undisturbed and forested. The wetland serves a highly important role in filtering the pollution coming from the farm to the south. However, the wetland soils may be saturated with dairy waste and nutrients, so that the wetland's pollution absorption function may be reduced.

Island

The small island located at the east end of the lake was formed by dredge spoils when the southeast arm of the lake was enlarged in the 1950s. The island is owned by the Ketchum Shores Improvement Club and has been designated as a bird sanctuary and wildlife preserve. The island is posted with "Keep Out" signs to prevent disturbances to birds and wildlife. The island is forested and densely vegetated. Unfortunately, much of the understory vegetation is non-native nightshade plants. A citizen committee plans to remove the nightshade over time and plant native vegetation in its place.

LAND USE AND DEVELOPMENT AT LAKE KETCHUM

Current Land Use

As of 1996, over 50 percent of the Lake Ketchum watershed is developed with roads and residences. (Refer to **Appendix D** for a history of development in Lake Ketchum's watershed.) Within the developed area, there are about 200 existing single-family residences.

Currently, the most common land use in the watershed (31 percent of the acreage) is single-family residences on small, mostly cleared lots (**Table 2-3**). An additional 12 percent of the watershed is classified as having single-family homes with "limited clearing," where much of the natural vegetation of the lots remains intact. About 28 percent of the watershed is still forested or undisturbed wetlands and ponds. **Figure 2-5** shows the locations of the current land uses.

Table 2-3
Acreage and Percentage of Land Covered by Existing Land Uses

	Area	
Land Use	**Acres**	**Percent**
Single-family	102	31
Single-family (limited clearing)	40	12
Roads	25	8
Forest	62	19
Wetland	24	7
Pond	6	2
Agriculture	49	15
Grassland/Shrub	13	4
Cleared Land	6	2
Total	**327**	**100**

Lots immediately around Lake Ketchum are generally narrow and long, averaging about 15,000 square feet. The north and east portions of the watershed have somewhat larger lot sizes (between 20,000 square feet and one acre). In the southern third of the watershed, the land is still semi-rural or agricultural, with lots of 2 to 20 acres in size or larger.

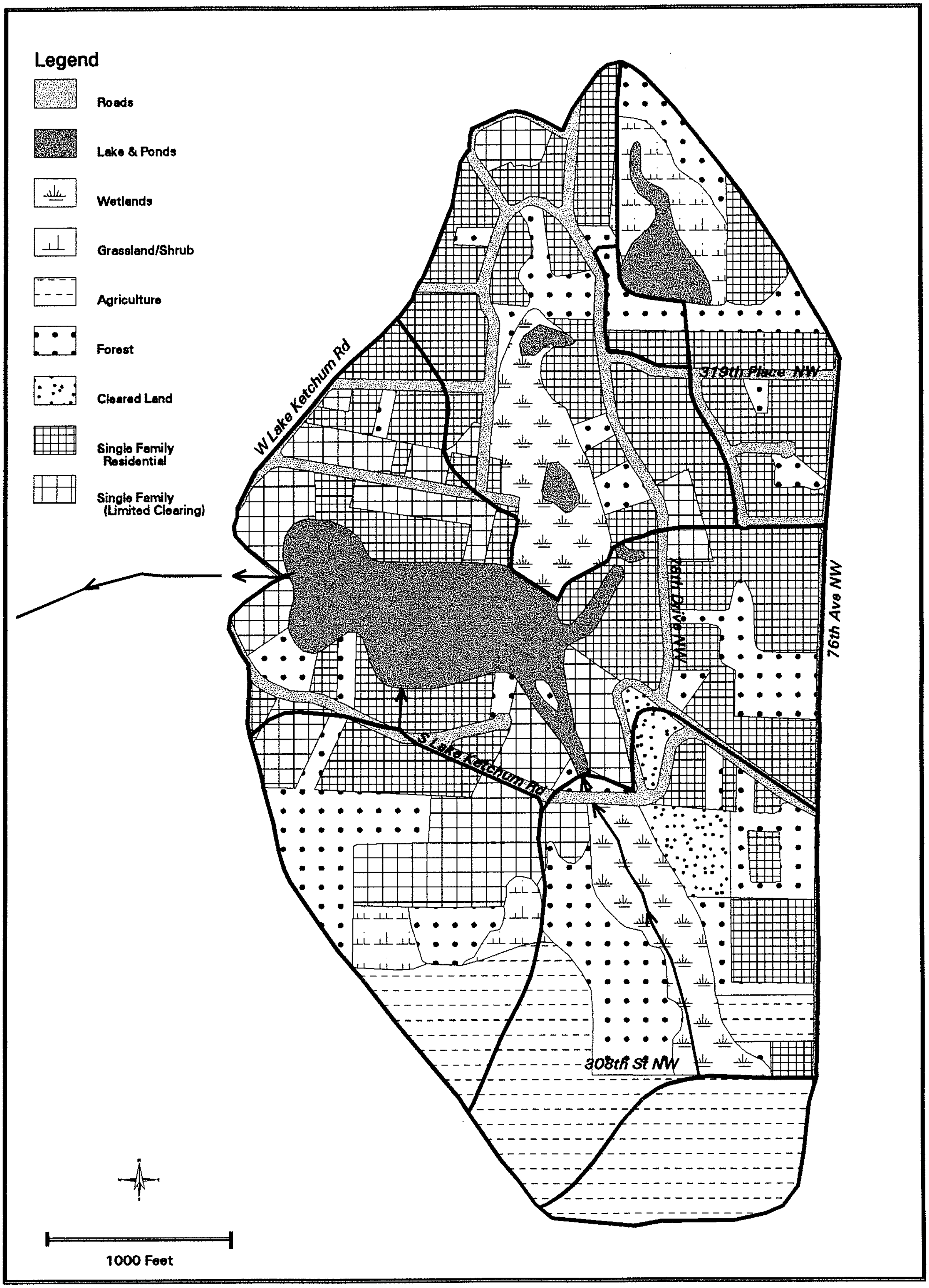


Figure 2-5. Lake Ketchum Watershed Current Land Use

Recent development activity is occurring west of the lake across West Lake Ketchum Road and in a small block near the southeast corner of the lake. Elsewhere, new homes are gradually filling in the undeveloped lots scattered around the watershed.

Future Land Use

Significant changes in land use are not expected in the future for the Lake Ketchum watershed. The Comprehensive Plan land use designations (see **Figure 2-6**) allow Medium Residential development (two dwelling units per acre) around the lake and in most of the northern portion of the watershed, Agricultural uses south of 308th Street NW, and Medium Rural Residential (one dwelling unit per 5 acres) in the rest of the watershed. The current zoning map matches the Comprehensive Plan designations. The Medium Residential areas are zoned R-20,000 and the Medium Rural Residential areas are zoned R-5.

Most of the land in the residential portions of the Lake Ketchum watershed has already been platted and developed at these, or greater, densities. There are a few one-acre lots within the R-20,000 zone that could be legally subdivided and developed into two lots of 0.5 acre each. Also, in the R-5 zoned areas, many of the lots are 10 to 20 acres in size, so some potential exists for additional development there. However, only about 30 more lots and about 50 more homes are likely to be added to the Lake Ketchum watershed in the foreseeable future.

Table 2-4 summarizes future land uses in the Lake Ketchum watershed. It should be noted that wetlands and ponds are included within the acreage but are not actually available for development.

Table 2-4
Acreage and Percentage of Land Covered by Future Land Uses

Future Land Use	Area: Acres	Area: Percent
R-20,000 (2 houses per acre)	159	49
R-5 (1 house per 5 acres)	99	30
Agriculture	45	14
Roads	24	7
Total	**327**	**100**

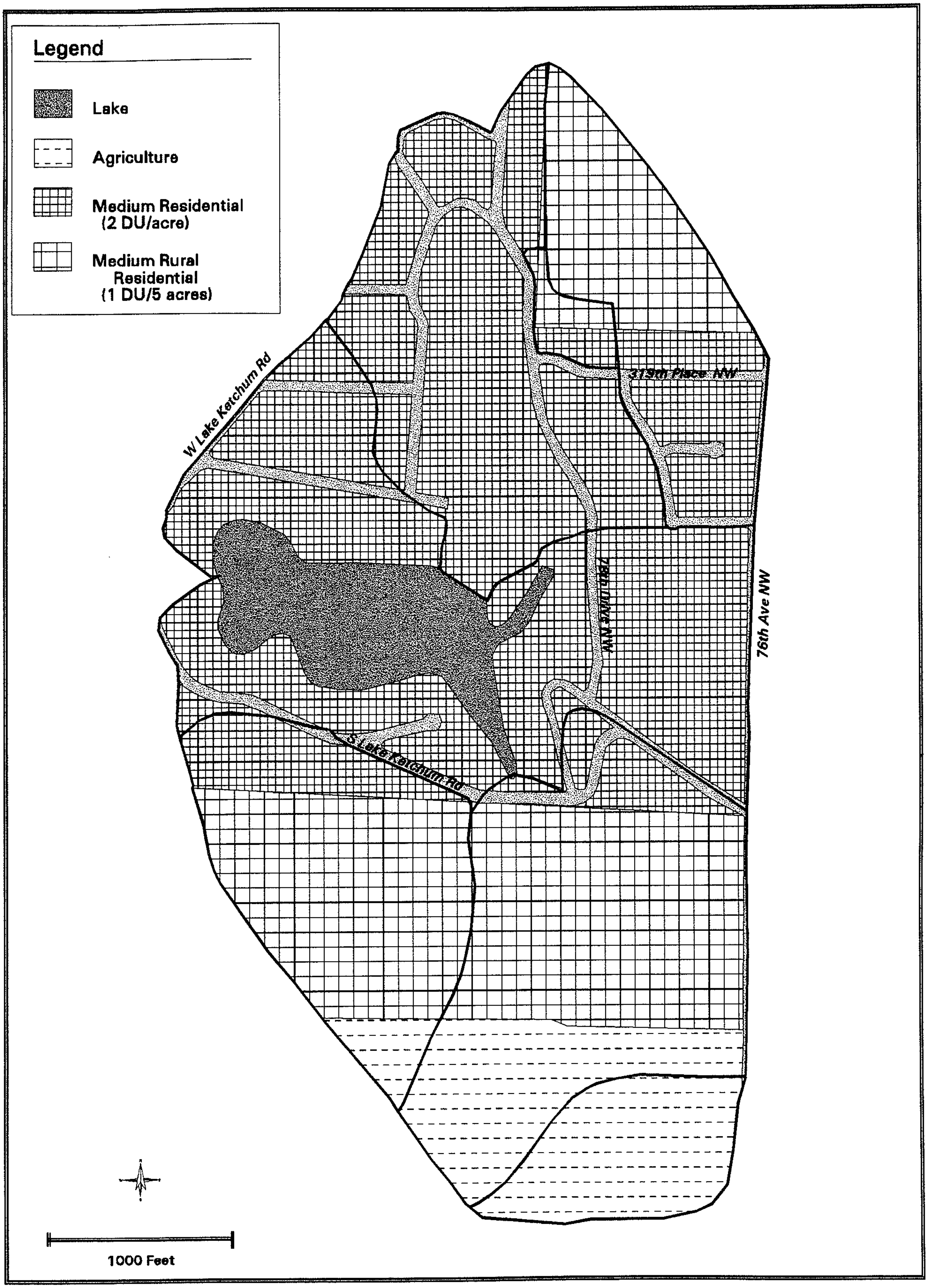


Figure 2-6. Lake Ketchum Watershed Future Land Use

PAST WATER QUALITY CONDITIONS AND MANAGEMENT

Prior to 1981

Reliable water quality data from the 1950s and 1960s for Lake Ketchum are not readily available. However, anecdotal accounts from long-time lake residents suggest that the water quality of Lake Ketchum was acceptable during this period. Lake uses were not impaired because of algae and aquatic plants. This assessment seems to be supported by the fact that, up to about the 1940s, the City of Stanwood imported water from Lake Ketchum for its drinking water supply.

Indications of declining water quality began to appear in the late 1960s and the 1970s. Algae and plant growth were becoming problems. Partly in response, the Ketchum Shores Improvement Club was formed in 1969. Purposes of the club were to:

- Work with State agencies regarding algae problems
- Install a water gate at the outlet to help regulate the lake level
- Restrict the use of boat motors on the lake
- Recondition drainage ditches around the lake and install additional drain pipes
- Work on road improvements and safety

In the same year, the Club began to observe the lake's water level, quality, drainage, and circulation. The Club also sponsored social activities, such as a fishing derby, a water festival, and an annual weed pulling and potluck dinner. Neighbors worked together to pull weeds out of the lake when the water level was low in the early fall. They rewarded their weed-pulling efforts with a potluck dinner.

1981 to 1991

Over time, it became clear that hand-pulling the aquatic plants was not enough to maintain the condition of the lake. By May 1981, the aquatic plant problem (primarily *Elodea* and *Potamogeton* sp.) had gotten so bad that the Club decided to hire Allied Aquatics to chemically treat the lake to reduce the numbers of aquatic plants.

Also, on one date in July 1981, the first reliable water quality data about Lake Ketchum were collected by the State (**Sumioka and Dion 1985**). These data (see **Table 2-5**) indicated that Lake Ketchum was highly enriched with nutrients (phosphorus and ammonia nitrogen).

Annually from 1981 through 1992, the aquatic plants in Lake Ketchum were treated with chemicals to control their abundance. For most of those years, copper sulfate was also applied to the lake to control algae blooms. Annual costs of herbicide and algaecide treatments rose from $750 in 1981 to over $4,000 in 1992. For most of those years, the lake residents were satisfied that chemical treatments were successfully maintaining the lake uses.

Table 2-5
Past Water Quality Summary for Lake Ketchum

Sampling Parameter	Sampling: Sumioka and Dion[1]	Sampling: Citizen Volunteer or Ecology[2] Range (Avg)	Sampling: Citizen Volunteer or Ecology[3] Range (Avg)
Secchi Depth (meters)	3.1	1.1–2.0 (1.5)	0.6–4.0 (2.2)
Dissolved Oxygen (mg/L)			
Surface:	7.2	8.9–16.6	
Bottom:	0.2	0.0	
Phosphorus (µg/L)			
Surface:	190	460–592	392–632 (519)
Bottom:	950	2,342–3,095	1,956–2,731 (2,343)
Ammonia (µg/L)			
Surface:	160	—	—
Bottom:	980	—	—
Total Nitrogen (µg/L)			
Surface:	—	1,110–1,120 (1,115)	550–1,140 (980)
Bottom:	—	2,440–3,430 (2,935)	1,210–2,550 (1,880)
Fecal Coliform			
Surface:	—	1–2	—
Color		60	—
Chlorophyll a (µg/L)	2.0	9.2–13.4 (11.3)	5.4–20.8 (13.1)

Notes:
1. Sampling date was 7/9/81
2. Sampling dates were Secchi: 5/92 - 10/92 Other: 5/18/92 & 8/31/92
3. Sampling dates were Secchi: 5/94 - 10/94 Other: 5/19/94 & 8/27/94

1992 to Present

However, dense growths of duckweed were becoming more common. In 1992, chemicals were applied in May, but by late summer the duckweed grew back. By that fall, the entire lake was covered in duckweed. The Everett Herald reported on November 20, 1992, that: "Lake Ketchum, near Stanwood, had the highest levels of algae-feeding phosphorus [in the State of Washington], causing it to look like 'a giant lawn' this summer...It was all green...we were literally rowing a path through it." Clearly, nutrient enrichment of the lake had reached a crisis situation and the aquatic plants and algae were responding accordingly.

At the same time that aquatic plant and algae problems were increasing, State agencies were tightening restrictions on the use of herbicides in lakes. The only herbicides approved by Ecology for the types of plants in Lake Ketchum were Sonar and Aquathol K. An application of Sonar was recommended by Allied Aquatics in the summer of 1992 but, at $10,000 to $12,000 for a one time application, Sonar was too expensive for the Ketchum Shores Improvement Club. Aquathol was not guaranteed to be effective against duckweed. So, no additional herbicide or algaecide treatments were applied in 1992.

All chemical treatments for aquatic plants and algae in the lake were suspended in 1994. Plans for any further treatments were put on hold to await the results of this Phase I water quality study.

Additional water quality data were collected for Lake Ketchum during the summers of 1992 and 1994 (see **Table 2-5**). Citizen volunteers recorded water clarity measurements taken with a Secchi disk. Ecology staff collected other physical and chemical data. The results of the data collection were as follows:

- ***Water Clarity*** – Water clarity averaged 1.5 meters in 1992 and 2.2 meters in 1994. Readings as low as 0.6 meter were observed in 1994. The 1992 and 1994 averages suggest that Lake Ketchum is quite eutrophic.
- ***Dissolved Oxygen*** – Just as in 1981, water quality measurements taken in 1992 showed that Lake Ketchum is strongly stratified during the summer. This means that the lake separates into warm upper waters and cool lower waters and that dissolved oxygen becomes depleted near the lake bottom. Also, dissolved oxygen near the surface was quite high in August 1994, indicating an intense growth of oxygen-producing algae.
- ***Nutrients*** – Phosphorus measurements made in 1992 and 1994 were much higher in Lake Ketchum than in other Snohomish County lakes. This indicates severe nutrient pollution coming from the watershed and/or more vigorous internal release from the lake sediments.
- ***Algae*** – Chlorophyll *a* concentrations are a measure of the amount of algae suspended in the water. The chlorophyll *a* concentrations in the summers of 1992 and 1994 indicate that Lake Ketchum is highly eutrophic.

The overall condition of Lake Ketchum from 1992 to 1994 could be described as hyper-eutrophic (extremely high productivity of plants and algae). During this period, swimming, fishing, and aesthetic uses of the lake were effectively lost for much of the year.

Dairy Farm Pollution

By the early 1990s, as it became apparent that Lake Ketchum was declining in water quality and that chemical treatments were becoming more expensive and less successful, lake residents began to look for the sources of pollution in the lake. One concern was the dairy farm located in the watershed south of 308th Street NW. It was known that, in addition to the cow manure and fertilizer that might be discharging from the dairy operation, large amounts of chicken manure had been spread on the pasture lands in recent years. This could present a direct threat to the lake water quality because runoff from the farm flows through the southeast wetland and into the lake.

Citizens took at least two water quality samples from the stream below the dairy farm and found very high levels of fecal coliform bacteria. This information was presented to Ecology, the Snohomish Health District, and the Snohomish County Conservation District in 1992.

At the direction of Ecology, the farm owner received assistance from the Conservation District to remedy water quality problems with the dairy farm. In June 1992, a Conservation Plan was recommended for the farm. The plan identified changes in farm design and operation which would help reduce runoff problems. The plan recommended implementing these changes over a 19-month period.

The Health District also took water quality samples below the farm in early 1993. The results confirmed that bacteria levels were violating State standards and that the farm was discharging very high nutrient concentrations. The Health District filed a formal water quality complaint with Ecology.

To force action to protect the lake from the farm runoff, the Ketchum Shores Improvement Club filed a lawsuit in May of 1993 against the farmer. An out-of-court settlement was reached in mid-1994 based on an Ecology enforcement order that required the farmer to complete a farm plan with the Conservation District by November 1994 and to correct the problems by June 1995. Unfortunately, the farm plan was not completed and not implemented by the deadlines. Instead, the farmer chose to discontinue the use of the barns and to switch from dairy cows to beef cattle to reduce the amount of pollution generated by the farm. This action satisfied the pending enforcement order (which was based solely on bacteria contamination) but did not guarantee that nutrient and bacterial contamination would no longer be discharged from the farm.

CHAPTER 3

STUDY METHODS

3. STUDY METHODS

This chapter discusses the field methods used in the Phase I study. The objectives of the monitoring program were to collect the necessary data to:

1. Evaluate existing biological, chemical, and physical conditions of Lake Ketchum and its watershed
2. Support development of hydrologic and nutrients budgets for the lake to determine the major sources of nutrients
3. Calibrate a mass-balance nutrient model to evaluate the effectiveness of restoration techniques

The water quality of Lake Ketchum was monitored from March 1995 through February 1996. The monitoring program included the following elements:

- Lake and inlet stream sampling
- Lake sediment sampling
- Groundwater sampling
- Septic dye survey
- Aquatic plant (macrophyte) survey

The Lake Ketchum monitoring program is summarized in **Table 3-1** and described below.

MONITORING PLAN

A monitoring plan for the field effort of this project was prepared in February 1995, and approved by the Washington State Department of Ecology (Ecology) in December 1995. The purpose of the plan was to provide guidance on sample collection, quality assurance, and data management, and to define responsibilities for team members. Each element of the monitoring program followed the guidelines specified in the monitoring plan.

LAKE AND INLET STREAM MONITORING

Lake Sampling

Lake Ketchum's present water quality condition was assessed by a baseline limnological study. This study collected biological (plants and animals), chemical (nutrients, oxygen, and conductivity), and physical (Secchi depth, temperature, flow, and precipitation) variables from March 1995 through February 1996 at monitoring stations shown in **Figure 3-1**.

Table 3-1
Summary of Lake Ketchum Monitoring Program

Component	Sampling Frequency	Stations/Depths	Parameters
In-Lake	18/year[1]	Deep Station/Epilimnion and hypolimnion composites (2 samples)	pH, cond, SRP, TP, NO_2+ NO_3-N, NH_3, TN, turb, alk[2]
	18/year[1]	Deep Station/ 1 meter intervals	DO, Temp
	18/year[1]	Deep Station	Secchi disk transparency
	18/year[1]	Deep Station/surface	Fecal coliform
	18/year[1]	Deep Station/ Euphotic zone composites	Chlorophyll *a*, Phaeophytin *a*, phytoplankton species biovolume, and identification
	18/year[1]	Deep Station/ vertical tow	Zooplankton species enumeration and identification
	Growing season (3 total)	4 lake stations	Duckweed, wet & dry weight, TP photo log, and areal coverage
	Swimming season (6 times)	4 nearshore stations	Fecal coliform
	Three times during bloom	Nearshore	Mouse toxicity bioassay for blue-green algae
	Quarterly	Deep Station/ epilimnion and hypolimnion	Ca, Mg, Na, K, Cl, Al, SO_4, Fe, Cu, TOC
Inlets/Outlet	12/year, plus three storm events[3]	3 inlet stations 1 outlet station	Temp, pH, DO, Cl, SRP, TP, TN, NO_2+NO_3, NH_3, fecal coliform, SO_4, Fe, cond, TOC (storm only)
Flow	Continuous/ instantaneous	1 inlet (continuous), 1 outlet (instantaneous)	Flow records
Lake Level	Continuous	1 station	Lake level record
Groundwater	Quarterly	8 groundwater wells (4 locations)	SRP, TP, NO_2+NO_3-N, NH_3, TN, Cl, fecal coliform, turbidity
	Quarterly	4 seepage meters	flow
Shoreline Septic Dye Study	Once (early spring)		
Lake Sediments	Once	3 stations surface Petite Ponar Grab	Phosphorus fractionation, percent water, LOI, TN, Al, SO_4, Cu, and Fe.

Table 3-1 (continued)

Component	Sampling Frequency	Stations/Depths	Parameters
Precipitation	Daily	1 or 2 sites	Volume
Macrophytes	Once August	5 transects: 2 samples/transect	Species identification, biomass density, TP, area mapping
Citizen Monitoring	Throughout study		Lake level, groundwater levels, precipitation, algal bloom sampling, photo documentation, bird usage, Watershed Watch.
Coordination with Ongoing Monitoring by Others	Throughout study		Farm Implementation Plan Snohomish County's Volunteer Monitoring Program Ecology's Volunteer Monitoring Program

1. April–Sept., twice/month; Oct.–Mar, once/month
2. Sampled every other time
3. Samples collected during storms were composites of three samples

Samples were collected over the course of one year during 18 monitoring trips according to the frequency listed in **Table 3-1**. Water samples were collected from Lake Ketchum at the deepest portion of the lake using a Van Dorn Sampler (**Figure 3-1**). The lake samples consisted of epilimnion and hypolimnion composites, each made up from two equally-proportioned discrete samples. The epilimnion composite samples were usually collected at 0.5 and 3 meters and the hypolimnion composite samples were usually collected at 4 and 5.5 meters. Dissolved oxygen concentrations and temperature were measured at one-meter intervals.

Lake level was measured at 15-minute intervals by a pressure transducer located in the lake and connected to a Unidata Macro electronic data logger. A citizen volunteer read a staff gage in the lake on a weekly basis to verify the electronic data.

Surface grab samples were collected for fecal coliform at the deep station for each monitoring trip and at four nearshore stations between June and August. Quarterly samples of additional water quality parameters (Fe, Al, Ca, Mg, Na, K, Cl, SO_4, Cu, and TOC) also were taken (**Table 3-1**).

Phytoplankton and chlorophyll *a* samples were collected from the epilimnion composite. Phytoplankton samples were collected in 250 ml glass bottles and preserved with 5 ml of Lugol's solution. Phytoplankton samples were analyzed for species identification, enumeration, and biovolume.

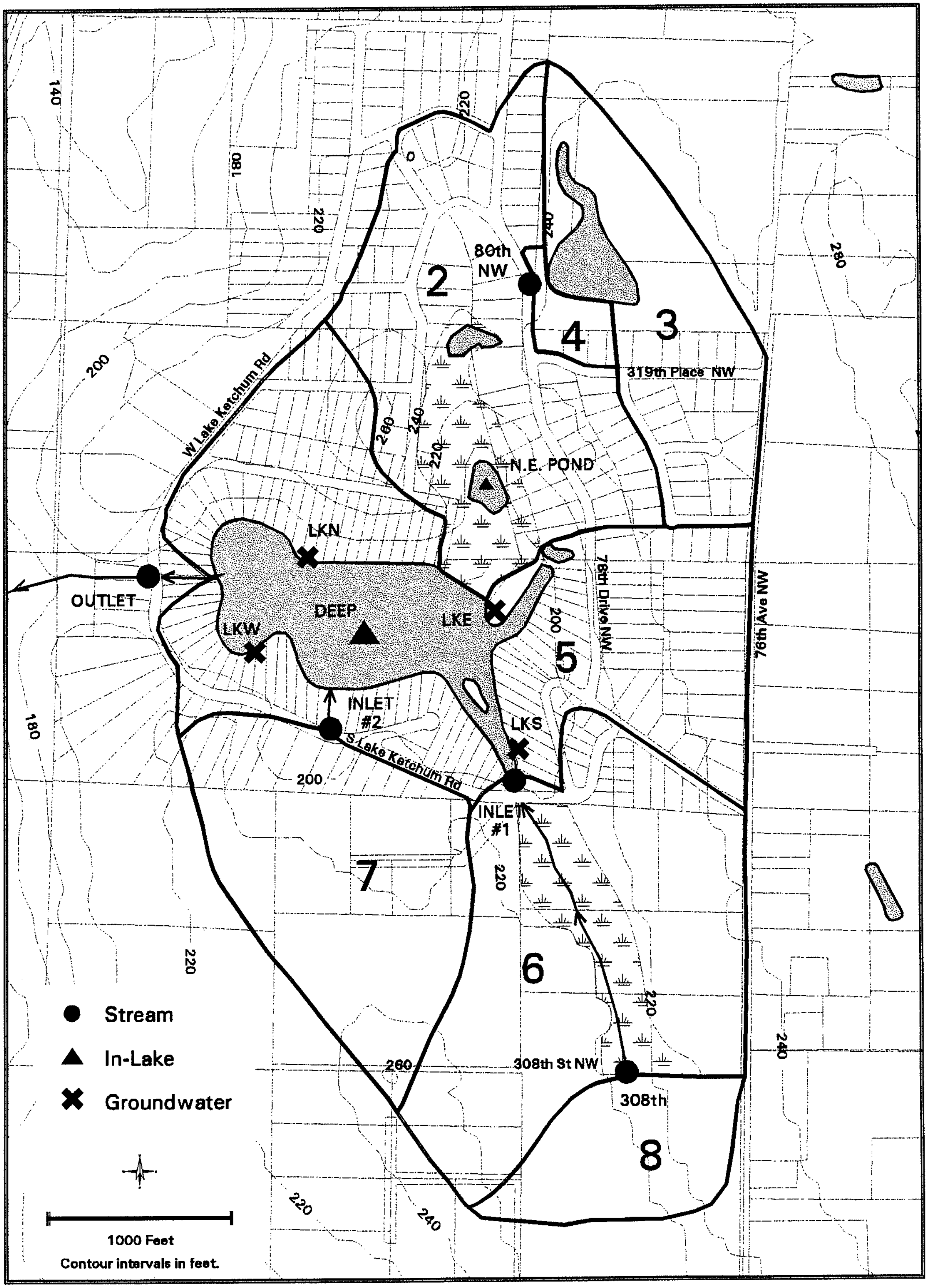


Figure 3-1. Lake Ketchum Monitoring Stations

Zooplankton samples were bottom-to-surface hauls taken from the lake using a 70-micron plankton net. Samples were preserved with 10 ml of formalin for every 250 ml of sample, and samples were identified for zooplankton species and density.

To assess potential algal toxicity, blue-green algal samples were collected (July 18 and September 19, 1995) when surface scums of algae are present. As much of the cellular mass of algae as possible, while excluding as much water as possible, was placed in a clean glass jar and kept cool until delivery to Dr. Michael Crayton at Pacific Lutheran University.

A limited creel census was conducted to evaluate the overall quality of the fisheries of the lake. (**Appendix D**).

Stream Sampling

The locations of each inlet station (308th, Inlet 1, and Inlet 2) and one outlet station are shown in **Figure 3-1**, and **Table 3-1** lists the water quality parameters used in sampling. The three inlet stations were sampled during three storms in February and March 1996. The samples collected during these storms were used to characterize the existing water quality in the streams during high flows. Samples were collected by the grab composite method. Under this method, three grab samples were composited.

To measure flow at Inlet 1, a small wooden dam with a holding pool and a 60 degree V-notch weir outlet was constructed approximately 40 feet from the lake. Flows through the structure were calculated from water depths in the pool measured by a pressure transducer connected to the same Unidata Macro data logger. Volunteers measured pool depths with a staff gage almost daily during the wet months of the year to verify the electronic data. Stream flows at Inlet 2 were measured during storm event sampling by a temporary 60 degree V-notch weir placed across the stream.

Outlet flows were estimated by comparing lake level with the known dimensions and elevations of the weir structure on the outlet. From March 1995 until December 1995, the outlet weir was a rectangular wooden sharp-crested weir 2.37 feet wide. After December 1995, the outlet weir was changed to a 2.0-foot-wide rectangular aluminum sharp-crested weir. The weir elevation was adjusted by the Ketchum Shores Improvement Club on several occasions during the study year. The dates and new elevations were recorded to compare with the lake level.

Precipitation was measured using a Texas Electronics 6-inch-diameter automatic tipping bucket located on a dock near the southeast corner of the lake. This rain bucket has a resolution of 0.01 inch and was connected to the same data logger. A Tru-check plastic rain gage read by a volunteer after each rain storm was used to verify precipitation data.

LAKE SEDIMENT SAMPLING

Bulk sediment characteristics were sampled in the summer of 1995 to evaluate the potential for the lake sediments to release phosphorus. Lake Ketchum surface sediments were sampled using a Petite Ponar Grab to a depth of approximately 5 cm at three deep-water locations. The samples were analyzed for the parameters listed in **Table 3-1**.

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

- NH_4Cl extractable P—loosely bound phosphorus that is easily released to the lake.
- NaOH extractable P (iron and aluminum bound P)—this fraction is sensitive to changes in pH or redox conditions and will be released or sorbed accordingly.
- HCl extractable P (calcium bound P)—this fraction is tightly bound and unavailable for release under most natural conditions.
- Organic phosphorus—estimated by determining the difference between the sum of the three inorganic fractions and total phosphorus in the sediments.

GROUNDWATER SAMPLING

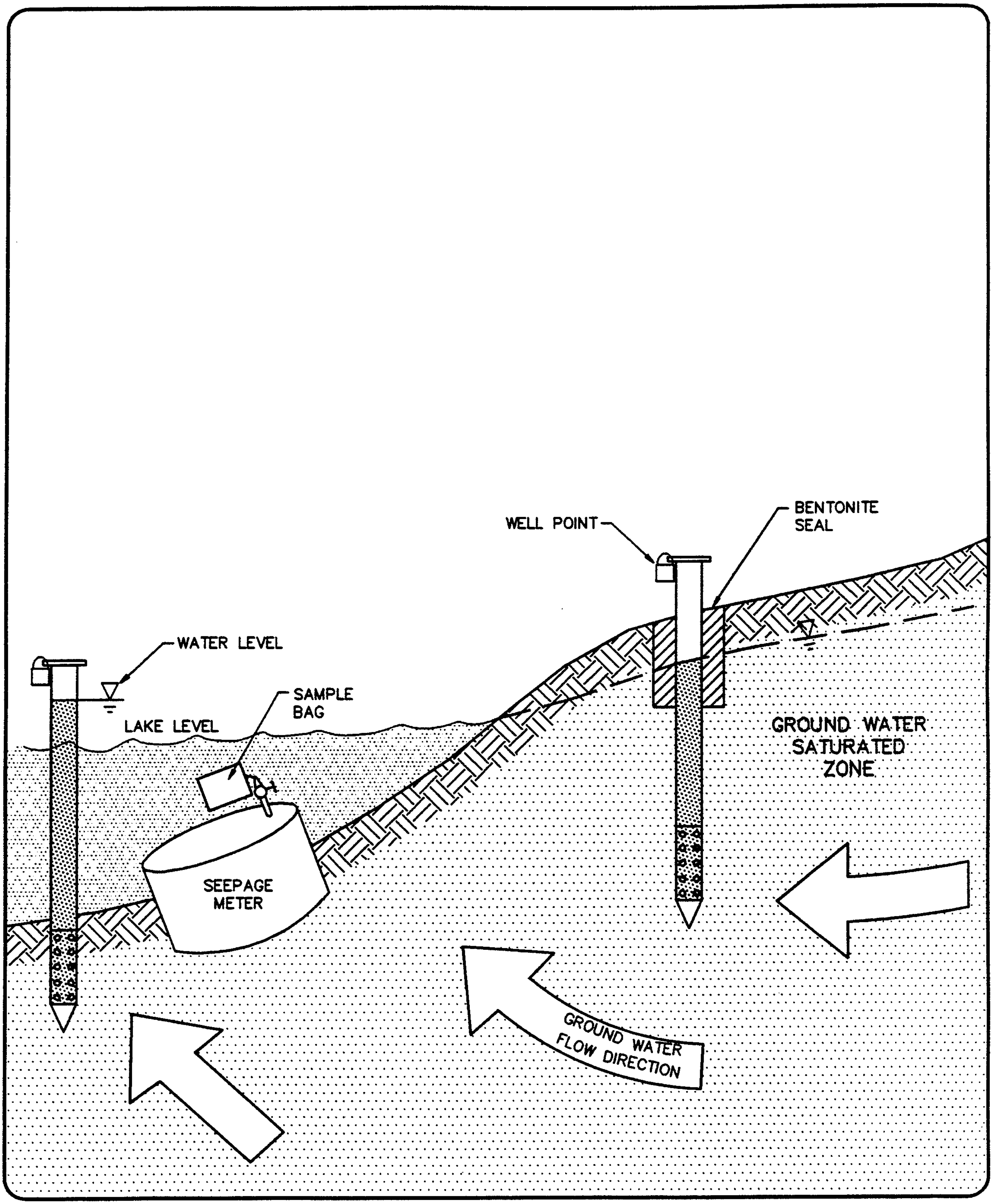
The objectives of the groundwater sampling were to:

- Characterize the relationship between groundwater and surface water within the watershed.
- Determine if shallow groundwater is a significant source of nutrients contributing to the deterioration of lake water quality.

Four shallow groundwater monitoring stations were located around Lake Ketchum's shore and sampled quarterly (**Figure 3-1**). Each station consisted of the following (**Figure 3-2**):

- One hand-driven well point approximately 10 to 20 feet from the lake shore.
- One hand-driven well point in the lake in five to ten feet of water.
- One seepage meter, using a half drum in three to five feet of water to estimate of groundwater inflow/outflow along the shoreline.

Each monitoring station was to provide hydraulic gradient information, nutrient loading data, and recharge/discharge information between the lake and groundwater system. Water quality parameters are listed in **Table 3-1**. The four quarterly sampling rounds were performed using a peristaltic pump.



HWA HONG WEST & ASSOCIATES, INC.

LAKE KETCHUM
HYDROGEOLOGIC STUDY

TYPICAL SITE INSTALLATION

PROJECT NO.: 95015 FIGURE: 3-2

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SEPTIC DYE SURVEY

The assessment of the contribution of on-site domestic wastewater systems to the pollution of Lake Ketchum was based, in part, on two procedures:

- a comprehensive lake shoreline dye survey for shallow concentrated effluent plumes, and
- groundwater sampling of four wells along the lake's shoreline (as described above).

The objective of the septic dye survey was to document the contributions of septic leachate entering Lake Ketchum as a whole and to determine areas where major failures are occurring. The intent of the survey was to evaluate the extent that septic systems are contributing to higher nutrients in Lake Ketchum, rather than to isolate problems with specific septic systems.

Types of failures include:

- subsurface hydraulic overloadings in porous soils, resulting in a plume of partially-treated wastewater emerging from the bottom sediments into the lake,
- effluent "short-circuits" through subsurface cracks or highly permeable gravel layers and entering the lake either above or below the water surface, and
- overflow of septic systems yielding surface runoff of wastewater into tributaries feeding a lake or directly into lake perimeters.

The septic dye survey of the shoreline of Lake Ketchum was conducted using a Turner Designs Model 10-60 digital field fluorometer. The instrument is a field fluorometer that measures the concentration of dyes in water. The fluorometer consists of a pump to flow the water continuously through the instrument, a cell to measure the concentration of dye, and a recorder.

The dye used in the survey was Rhodamine WT, which is the most suitable of the whole range of fluorescent dyes for surface and groundwater tracing under natural water conditions (**Smith 1981**). Fluorescent tracers are frequently used to study and measure the sources of contamination because they can be readily measured at very low concentrations (10 parts per trillion), are invisible to the human eye, and are harmless to the environment. The dye is approved by the U.S. Environmental Protection Agency (EPA) and most states in the use of drinking water.

Pilot Test

To aid in determining the appropriate dosing of the dye and the period to measure dye concentrations in the lake, a pilot test was performed four weeks prior to conducting the septic survey. Fluorescein dye (which is visible) and Rhodamine dye were added to sinks of three residents in different areas of the lake on February 10, 1996. The following assumptions were made for the pilot test:

- Size of the septic tank: 100 gallons. The intent was to achieve approximately 10 ppm in each septic tank, so that concentration by the time the dye reached the lake would not be less than 5 ppb (2,000 times less than the concentration in the septic tank).
- Distance from shoreline: 100 feet. Based on groundwater flow tests performed as part of this study, it was estimated that it would take approximately two weeks for the groundwater to reach the lake from a septic system that is approximately 100 feet from the shoreline.

A visual survey for fluorescein was made four days after the dye was added. No visible plume was observed. The fluorometer was used in the lake in front of the three homes on February 26 to measure the concentrations of Rhodamine WT dye.

Septic Dye Survey

Thirty-eight out of the 41 year-round residents agreed to participate in the dye survey. Approximately 16 ml of Rhodamine dye were added to the sinks or toilets of the participating residents on February 29 or March 1, 1996.

To bracket the estimated travel times, three septic dye surveys were performed (March 12, 15, and 19, 1996). The residents participating in the survey were requested to not use excessive bleach during the test (or eliminate it if possible) because chlorine degrades the dye. The survey was performed by scanning the shoreline from a boat. By moving at a near constant speed along shorelines, the instrument maps the position and approximate magnitude of underground plumes emerging into the lake waters from hydraulically overloaded or "short circuited" systems. If evidence of failing systems were detected, discrete water samples would then be collected for nutrient and bacterial analysis (see Chapter 4 for results of the septic dye survey).

MACROPHYTE (AQUATIC PLANT) SAMPLING

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

Aquatic plants in Lake Ketchum were surveyed in August 1995. The entire nearshore area of Lake Ketchum was visually inspected for the presence of emergent and submergent macrophytes. A rake sampler was used to determine the presence of submergent macrophytes below a depth of 3 feet. The rake sampler consisted of a weighted bow rake with a square foot area of 0.5-inch wire mesh for entangling macrophytes. Visual observations and rake samples were used to identify macrophyte species and estimate the relative dominance of each species.

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

CHAPTER 4

MONITORING RESULTS

4. MONITORING RESULTS

This chapter presents the results obtained from the one-year monitoring program conducted in Lake Ketchum and its watershed from March 1995 through February 1996.

A summary of selected water quality parameters sampled in Lake Ketchum during the study year is presented in **Table 4-1**. The complete water quality database is presented in **Appendix A**.

Table 4-1
Summary of Selected Water Quality Variables

	Units	Lake Ketchum Surface[a]	Lake Ketchum Bottom
Alkalinity	mg/l as $CaCO_3$	51	60
Conductivity	µmhos/cm	199	215
Total Nitrogen	µg/l	1,655	1,770
Nitrate+Nitrite-Nitrogen	µg/l	9	8
Total Phosphorus	µg/l	494	1,225
Soluble Reactive Phosphorus	µg/l	321	998
pH[b]	s.u.	6.7–10.4	6.7–9.1
Secchi	m	2.0	na
Chlorophyll *a*	µg/l	22	na
Fecal Coliform	(#/100 ml)[c]	4	na

Notes: Sampled in Lake Ketchum during the study year, March 1995 through February 1996.
a. Values are median values of surface samples (composite samples of two depths in the epilimnion, usually to a depth of 2.5 meters) and bottom samples (composite samples of two depths in the hypolimnion, usually between 3.5 and 5 meters)–unless otherwise noted. Eighteen samples were collected during the monitoring program.
b. pH values are annual ranges.
c. Fecal coliform value is a geometric mean.
s.u. = standard units

LAKE PHYSICAL CONDITIONS

Water Temperature

The temperature of water has a large effect on a lake's water quality and ecology. As water warms, it becomes less dense and floats on top of colder water. Unless there is enough wind to mix the water and therefore equalize the temperature of the lake, the water will tend to form two separate layers. This phenomenon is known as thermal stratification.

After stratification starts, the upper layer, which is called the epilimnion, is warmed by sunlight, while the lower layer, which is called the hypolimnion, remains cool (**Figure 4-1**). Between these two layers is the metalimnion (or thermocline), which is marked by a rapid change in temperature from top to bottom. Because of the temperature difference, there is very little exchange of water between the epilimnion and the hypolimnion and, therefore, water quality can be very different in each layer.

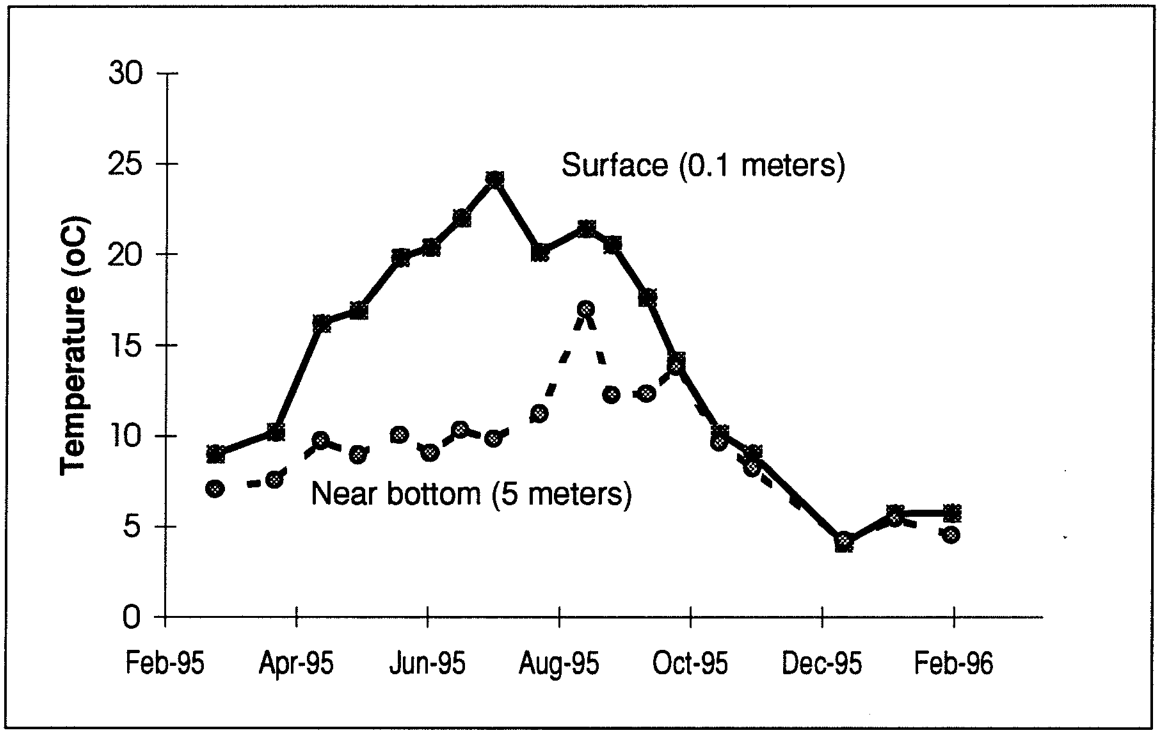

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Figure 4-1
Temperature Differences Between Surface and Bottom Waters in Lake Ketchum

In western Washington, thermal stratification is common in lakes during the late spring, summer, and early fall. After summer, the epilimnion will tend to cool, and by late fall or winter the temperature difference between the two water layers will be small enough so that the winds will mix the water throughout the lake. Lakes then stay fully mixed until the onset of stratification in late spring. Lake Ketchum follows this pattern of complete mixing in winter and stratification in summer (**Figure 4-1**).

The temperature profiles shown in **Figure 4-2** demonstrate the progression of thermal stratification in Lake Ketchum through the year. Lake Ketchum was completely mixed from late November 1995 until February 1996. The temperature in the lake was 4 to 9 degrees Celsius (39 to 48 degrees Fahrenheit) during the mixed period, with the coldest temperatures occurring in December. During the summer, the temperature in the surface reached 24 degrees Celsius (75 degrees Fahrenheit), while the hypolimnion was generally around 12 degrees Celsius (54 degrees

Fahrenheit). The metalimnion was generally located between 2 and 4 meters (6.6 to 13.1 feet) in depth.

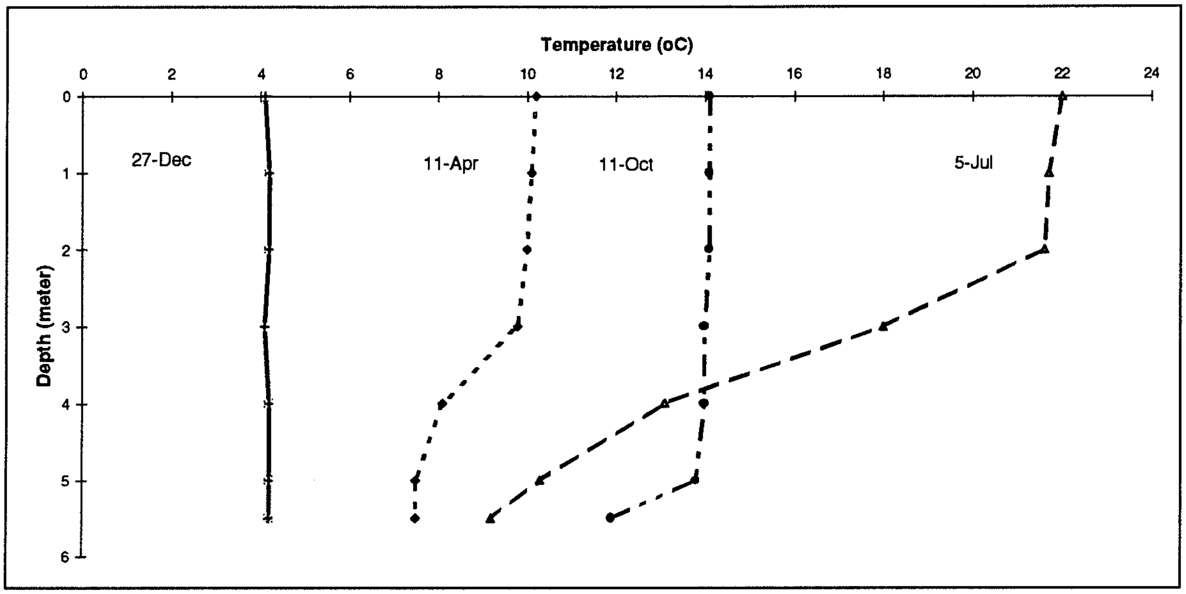

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Figure 4-2
Lake Ketchum Temperature Profiles

Water Clarity

Light is necessary for the growth of plants. Periods of more intense sunlight, such as late spring, summer, and early fall, stimulate the growth of aquatic plants and algae. The depth of sunlight penetration into a lake also affects the rate at which plants and algae grow and the associated aesthetic (visibility, turbidity, color, etc.) quality of the water (**Thomann and Mueller 1987**). Absorption and scattering are the two principal mechanisms for reducing light in water. Suspended sediments in the water column mainly scatter light, while dissolved organic matter from plant decay, which produces a brown color in water, absorbs light.

Secchi Depth

Water transparency is most often measured in lakes by a Secchi disk. The depth at which this black and white disk can no longer be seen is referred to as the Secchi depth. Secchi depths not only provide information on the transparency of the water and the depth of light penetration, but also provide information on trophic status, because the transparency of a lake often depends directly on the amount of algae suspended in the water.

The changes of Secchi depths in Lake Ketchum are shown in **Figure 4-3**. Secchi depths in the lake ranged from 0.8 meter (2.6 feet) during the algal bloom in summer (August 31st, when algal levels peaked) to 3.2 meters (10.5 feet) in April following the spring algal bloom. Secchi depths also were relatively high in winter during the period of low algal levels. The high winter Secchi depths reflect the low contribution of sediment and turbidity from the watershed (**Figure 4-3**).

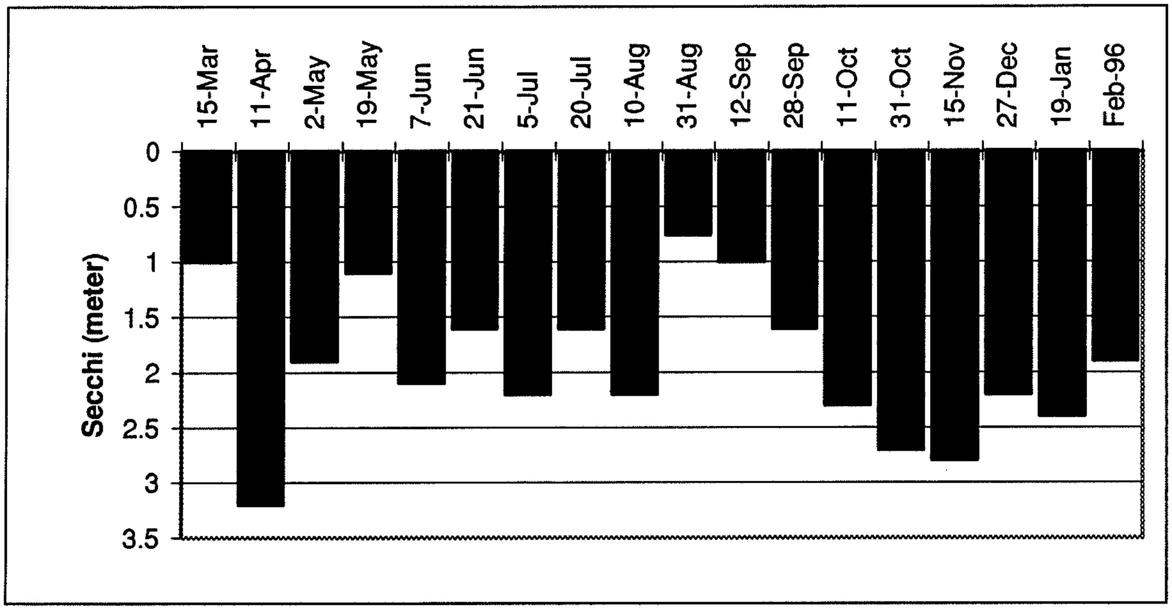

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Figure 4-3
Secchi Depths
March 1995 through February 1996

Euphotic Zone

The depth in a lake at which one percent of the surface light remains is referred to as the euphotic zone. Below the euphotic zone, there is insufficient light to allow photosynthetic production by algae and aquatic plants. Assuming that the euphotic zone is 1.2 times the Secchi depth, the euphotic depth in Lake Ketchum reached a maximum of about one-half the depth of the lake or 3.8 meters (12.5 feet). Therefore, no aquatic plant growth below 3.8 meters would be expected.

LAKE CHEMICAL CONDITIONS

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

Dissolved Oxygen

The level of dissolved oxygen (DO) in lakes affects the distribution and survival of different types of organisms, and also regulates the kinds and rates of natural chemical processes, such as the amount of nutrients released from lake sediments. Oxygen is added to lakes by atmospheric mixing and by the contribution of aquatic plants, through photosynthesis. Conversely, oxygen is removed from water by the respiration of aquatic organisms and plants, and the decomposition of organic matter by bacteria.

In Lake Ketchum, DO levels begin to decrease in the bottom waters during the spring (as shown on March 15 in **Figure 4-4**). Soon after Lake Ketchum becomes thermally stratified in May, DO levels in the hypolimnion fall to less than 2 mg/l (**Figure 4-5**). These levels, which are called anoxic, are too low for most fish and most animal life to survive. The DO levels remain low until the lake destratifies and mixes again in late fall.

As is common in lakes in western Washington, there is a large difference between the surface and bottom DO levels during the summer and early fall. Following turnover in the mid-fall, there is a rapid decline in DO concentrations in the surface layers as DO concentrations decrease to 2 mg/l throughout the top four meters. The low DO concentrations following turnover indicate a highly eutrophic lake with a large amount of oxygen demanding organic matter (such as algae).

Nutrient Limitation

A major focus of lake management is to control algae, because algal productivity, both directly and indirectly, influences a range of other water quality characteristics in lakes (**OECD 1982**). Nitrogen (N) and phosphorus (P) are the major nutrients that limit algal growth in most lakes. Because phosphorus is typically in shorter supply than nitrogen, relative to the needs of algae, the management of lake eutrophication usually involves phosphorus control. Most lakes in the Puget Sound Region are phosphorus limited (**Gilliom 1980**).

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

The average annual and summer (June through August) volume-weighted epilimnetic TN:TP ratio in Lake Ketchum indicates that algae are limited by nitrogen concentrations (**Figure 4-6**). The seasonal progression of TN:TP ratios indicate that nitrogen consistently limits algal growth in Lake Ketchum throughout the year under existing conditions.

Despite the fact that Lake Ketchum is presently nitrogen limited, phosphorus control is still proposed as the best eutrophication control strategy as discussed in Chapter 6.

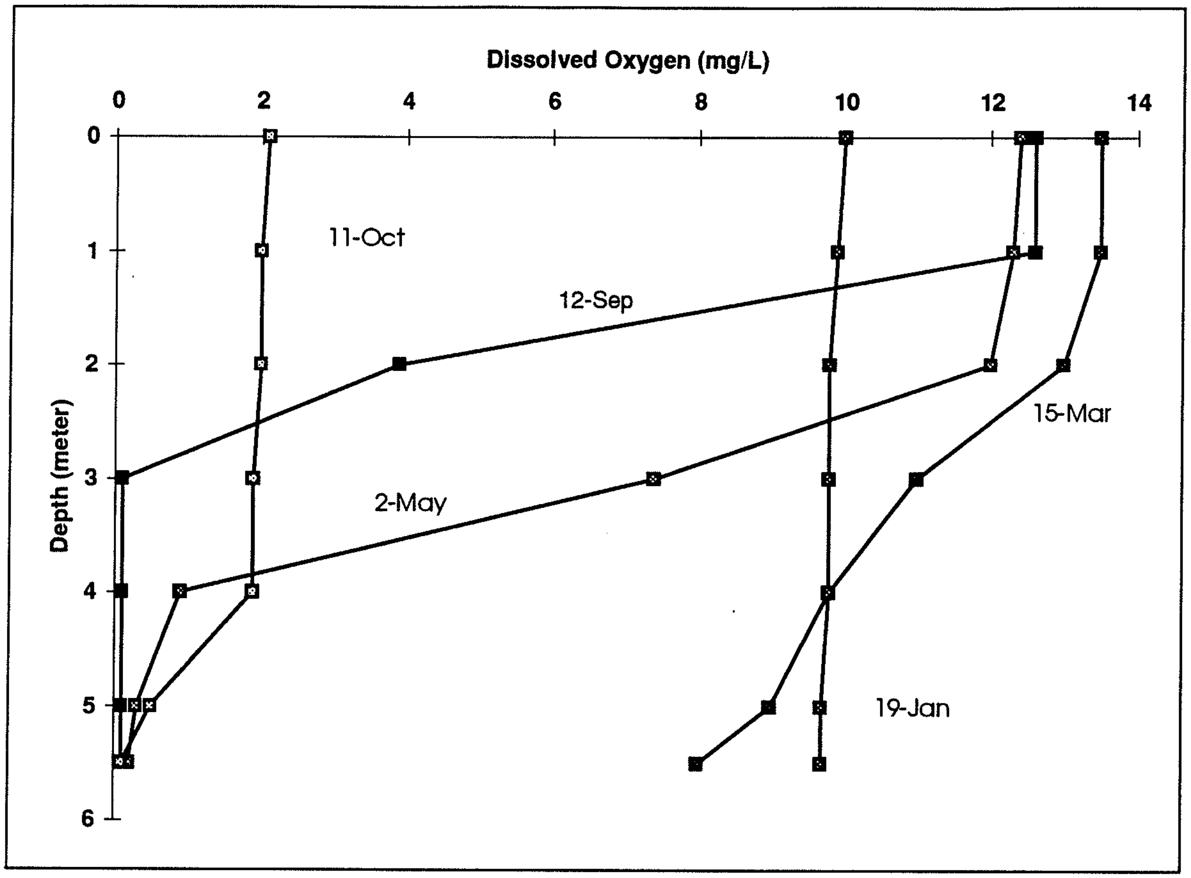

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Figure 4-4
Lake Ketchum Dissolved Oxygen Profiles

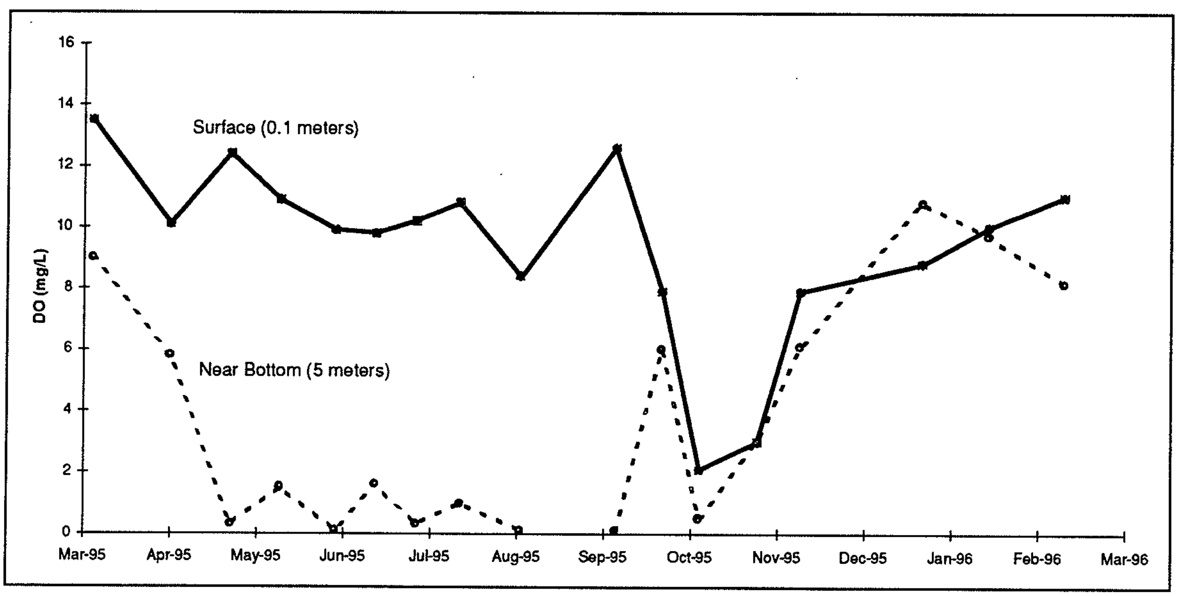

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Figure 4-5
Lake Ketchum Dissolved Oxygen
in the Surface and Bottom Depths

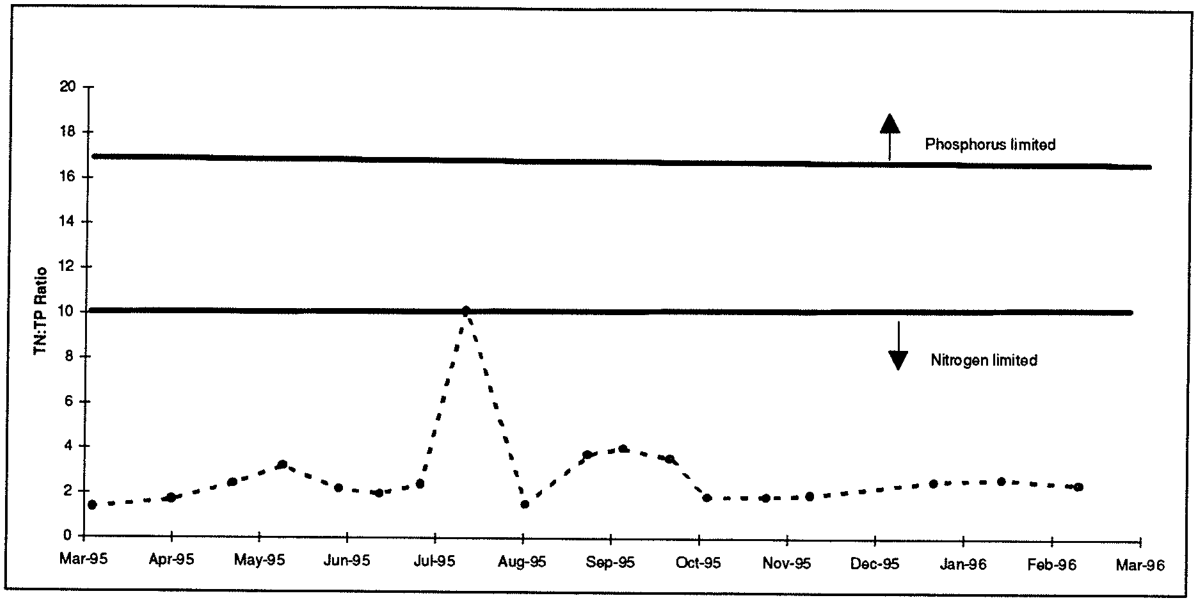

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Figure 4-6
Seasonal Progression of TN:TP Ratios in the Epilimnion

Phosphorus

Artificial increases in the concentration of phosphorus due to human activities in the watershed are the principal cause of eutrophication (**Chapman 1992**).

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

Concentrations of TP and SRP are summarized in **Table 4-2** and the changes in TP concentrations throughout the study year are shown in **Figure 4-7**. These phosphorus levels are very high when compared with most lakes and indicate a highly eutrophic lake. Concentrations of epilimnetic TP were highest in the late fall, following lake turnover. As shown by the steadily increasing hypolimnetic phosphorus concentrations in the summer, the sediments of Lake Ketchum release significant amounts of phosphorus (**Figure 4-7**). The maximum hypolimnetic concentrations of TP and SRP during the stratified period were 2,340 µg/l and 2,140 µg/l. Phosphorus is usually released from lake sediments under anoxic conditions. However, TP concentrations remained relatively stable in the epilimnion until turnover in October. This suggests that high hypolimnetic TP has little influence on lake algal growth, which reached its highest levels during the July–September period.

Table 4-2 Summary of Phosphorus Concentrations	TP (µg P/L)	SRP (µg P/L)
Annual		
Epilimnion	209–1,260	167–886
Hypolimnion	520–2,340	371–2,140
Summer (June–Sept)		
Epilimnion	209–635	167–325
Hypolimnion	1,100–2,340	712–2,140

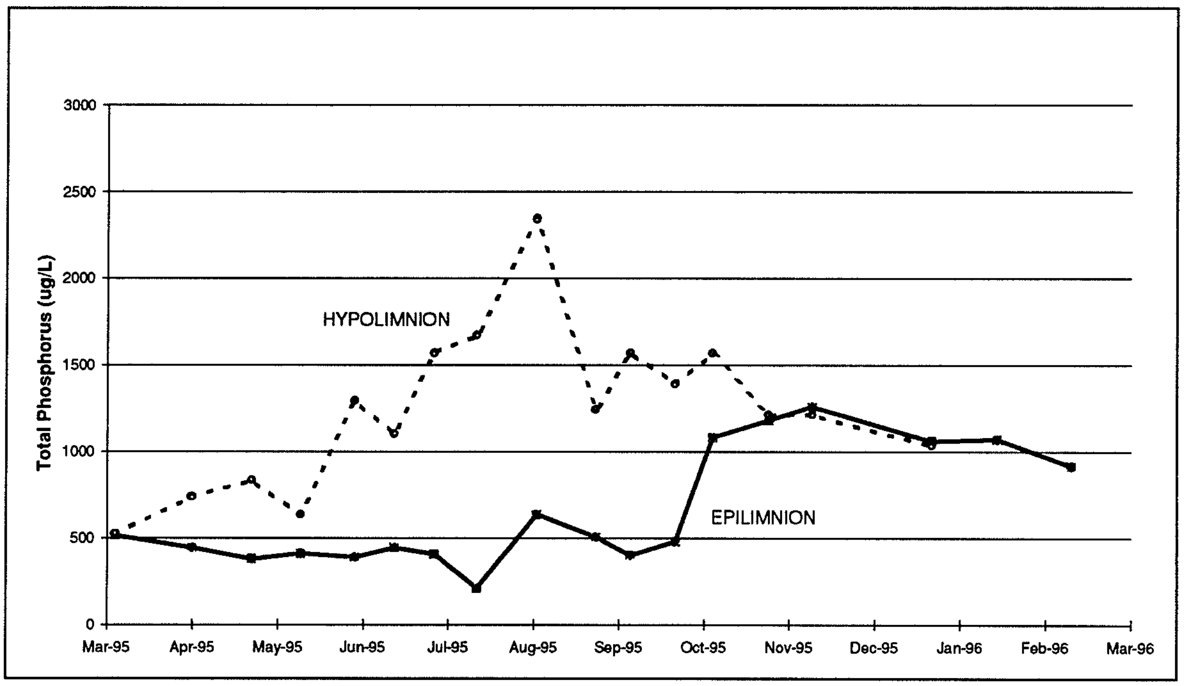

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Figure 4-7
Lake Ketchum Total Phosphorus Concentrations

Atypical for most lakes, phosphorus concentrations at the end of the monitoring period were significantly higher than at the beginning of the monitoring program. The increase in TP concentrations may indicate that the lake is out of equilibrium due to the recent changes in management or the unusually high TP contributions from the watershed.

Lakes with phosphorus concentrations greater than 24 µg/l are considered eutrophic (**Carlson 1979**). Lake Ketchum epilimnetic TP is 20 times greater than this amount and therefore can be considered very eutrophic. (Refer to the trophic state discussion on page 4-25.)

Nitrogen

Three forms of nitrogen were monitored in this study: ammonia-nitrogen (NH_3-N), nitrate+nitrite-nitrogen (NO_3+NO_2-N), and total nitrogen (TN). The dissolved inorganic forms of nitrogen (DIN), ammonia, and nitrate plus nitrite, are readily available for plant growth. Total nitrogen is the organic form plus the DIN. The ranges of these nitrogen forms are summarized in **Table 4-3.**

Table 4-3
Summary of
Nitrogen Concentrations

	TN (µg N/L)	**NO_3+NO_2-N** (µg N/L)	**NH_3-N** (µg N/L)
Annual			
Epilimnion	695–2,840	< 10–954	< 10–1,200
Hypolimnion	764–4,460	< 10–815	65–1,140
Summer (June–Sept)			
Epilimnion	843–2,120	< 10–27	5–386
Hypolimnion	1,030–4,460	< 10–17	148–926

For Lake Ketchum, ammonia was a relatively large proportion of DIN for most of the year. This indicates a highly eutrophic lake. More commonly, nitrate levels are the largest form of DIN, because nitrate dominates under less reducing conditions.

Ammonia-nitrogen concentrations typically increase in the hypolimnion during stratification as a result of nitrification and the release of this soluble form of nitrogen from sediments. This pattern occurred in Lake Ketchum.

High levels of un-ionized ammonia (a portion of ammonia-nitrogen which varies depending primarily on pH, temperature, and ammonia concentrations) are toxic to freshwater life. Ammonia toxicity is not a problem in lakes with a pH below eight and ammonia-nitrogen concentration less than 1,000 µg/l. Levels of ammonia-nitrogen were relatively high in Lake Ketchum when compared with other lakes in the Puget Sound—exceeding 1,000 µg/l in October and November, following turnover. Temperatures in Lake Ketchum are relatively low at this time of year, however, which reduces the likelihood of un-ionized ammonia toxicity.

Epilimnetic concentrations of nitrate peaked in winter to around 1,000 µg/l and declined to less than 10 µg/l through most of the summer. This is a common pattern in lakes, as ammonia and nitrate progressively decline in the epilimnion through uptake by algae during the growing season (**Harper 1992**).

Nitrate levels typically decrease in the lower waters of a lake during summer as DO concentrations decline and nitrogen remains in the reduced form of ammonia. If nitrate is not fully depleted in the sediment pore water, it may restrict the release of phosphorus from the sediments (**Harper 1992**). In Lake Ketchum, nitrate levels were essentially depleted in the summer, because nitrogen occurred in the more reduced form, ammonia-nitrogen. The depletion of nitrate may be another reason for the increased levels of sediment phosphorus release in the hypolimnion.

The TN concentrations increased throughout the year, so that, similar to phosphorus, TN concentrations were significantly higher at the end of the monitoring period. Again, this suggests a lake that is out of equilibrium or that watershed loading was unusually high this year.

Conductivity

Conductivity is a measure of water's ability to conduct an electrical current, and is an indicator of the amount of dissolved ions in the water. The conductivity of most freshwaters ranges from 10 to 1,000 µmhos/cm (**Chapman 1992**). The conductivity of a lake depends heavily on the type of soil and precipitation within the watershed. Lake Ketchum had relatively high conductivity levels for western Washington lakes. Conductivity (at 25°C) in Lake Ketchum ranged from 186 to 228 µmhos/cm during the monitoring year.

Alkalinity and pH

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

Similar to conductivity, total alkalinity in Lake Ketchum was relatively high for western Washington lakes, ranging between 49 mg/l to 64 mg/l as $CaCO_3$ in the epilimnion and 49 mg/l to 71 mg/l in the hypolimnion. Waters of low alkalinity (<24 mg/l as $CaCO_3$) have a low buffering capacity, and can therefore be more susceptible to wide fluctuations in pH (**Chapman 1992**). The low pH of organic acids from the wetlands within the Lake Ketchum watershed are somewhat offset by the moderate alkalinity in Lake Ketchum.

The pH of Lake Ketchum reached relatively high levels, particularly during the periods of algal blooms. The pH of most natural waters is between 6.0 and 8.5, whereas the pH in Lake Ketchum ranged between 6.5 and 10.4. The high pH levels occurred within surface waters during the late spring and summer due to the photosynthetic activity of algae. Such high pH levels may be detrimental to some fish life.

Sediment Chemistry

Phosphorus Fractions

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

The top five centimeters of the sediments from Lake Ketchum were sampled at three random locations in the deep portion of the lake. In this study, the following four fractions of sediment phosphorus were measured:

- **Loosely-bound phosphorus** (NH_4-Cl extractable-P): The fraction of phosphorus that is easily released into the lake.

- **Iron and aluminum-bound phosphorus** (NaOH extractable-P): The fraction of phosphorus that is sensitive to changes in pH or redox conditions in the sediment. This form of phosphorus becomes released under low redox environments, a typical condition found in the summer stratified period in the hypolimnion.

- **Calcium-bound phosphorus** (HCl extractable-P): The fraction of phosphorus that is tightly bound and unavailable for release under most conditions.

- **Organic-bound phosphorus**: The remaining form of phosphorus, which is highly refractory and rarely constitutes a source of phosphorus to lake water.

The results from the sampling are shown in **Table 4-4**.

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

Table 4-4
Sediment Phosphorus Fractionation Results

	Total Bound P	Inorganic P: Loosely Bound	Inorganic P: Iron+Al Bound	Inorganic P: Tightly Bound	Organic[a] P
Lake Ketchum	2,294	135	1,255	5	838
Lake Ketchum Percent		(6)	(53)	(2)	(38)
Mean from other studies[b]	1,693	(3)	(11)	(49)	(31)
Range from other studies[b]	662–4,700	5–76 (1–7)	13–380 (1–27)	4–2,550 (11–79)	110–1,600 (10–57)

Notes: Average concentrations in mg/kg of dry-weight
Percent of Total Bound P in parentheses
Results from three stations in Lake Ketchum and comparison with other studies

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

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

Copper

Copper samples were collected from the sediments of Lake Ketchum because of the past use of copper sulfate for the treatment of algae and the concern of toxicity to aquatic life. High copper concentrations in sediments have been shown to cause toxic effects to bioassay organisms in some cases. Past sampling of the lake's sediment for copper suggested levels that were sufficiently high to recommend that future copper sulfate treatments be discontinued (**Ecology 1994**). This is based on exceeding a "severe effect level" for copper of 110 ppm, as developed by the Ontario Ministry of the Environment, above which pronounced disturbances to benthic organisms can be expected. It should be noted:

- that there are no state standards for freshwater sediment copper levels and,
- the toxicity of copper does not depend on the total copper concentrations in the sediment, but rather the concentration of dissolved copper in the pore water (**Hart Crowser 1994**).

There are many factors which determine whether copper is biologically available. In addition, the rapid recovery of sediment biological communities following copper additions also has been reported (**Meador et al. 1993, as reported in Hart Crowser 1994**).

Copper samples in this study were significantly lower than sampling conducted two years earlier and less than the "severe effect level" of 110 ppm (**Table 4-5**). These copper levels also are considerably lower than the those recently measured in Lake Steilacoom, which has had repeated applications of copper sulfate (**Table 4-5**). The means (and ranges) of the past and present study were 480 mg/kg (260–600 ppm) and 78 mg/kg (52–112 ppm) dry weight, respectively. The apparent reduction in copper concentrations from 1993 to 1995 may be due to the greater depth of sampling in 1995 (top 5 cm) versus 1993 (top 2 cm) or the use of different sampling locations.

Table 4-5
Summary of Sediment Copper Concentrations (mg/kg)

	Mean	Range	Number of Samples
Lake Ketchum 1995 (Current study)	78	52–112	3
Lake Ketchum 1993[a]	480	260–600	5
NE Wetland Pond	18.5	NA	1
Lake Steilacoom [b]	760 (south) 470 (north)	13–1,100	NA

a. Source - Ecology 1994.
b. Source - Hart Crowser 1994.

Tributary Water Quality

Three tributary stations on two inlets to Lake Ketchum were monitored during the routine sampling (up to 12 trips over the course of one year) and three storm sampling trips (refer to **Figure 3-1** for station locations). The station at 308th Avenue NW is located along the main inlet, just downstream from the large farm draining to the lake. Inlet 1 is located at the mouth of the main inlet, just downstream of a large wetland. This creek, Inlet 1, is the major surface inflow to Lake Ketchum and was dry from June to October 1995. The only other clearly defined creek draining to the lake is Inlet 2, located just east of the public boat launch. Inlet 2 is relatively small and for much of the year it has very small or no flow.

The drainage basin of Inlet 1 is 92 acres (29 percent of the watershed area) and the land use is primarily agricultural and wetlands. Inlet 2 is 48 acres (15 percent of the watershed area) and is mainly low-density residential. The remaining watershed area (180 acres) drains to the lake in largely undefined channels.

Routine Sampling

Concentrations of selected water quality variables collected during the routine monitoring from the inlets are summarized in **Table 4-6**. Refer to **Appendix A**, for the complete water quality database.

Table 4-6
Concentrations of Water Quality Variables
Sampled in the Two Inlets to Lake Ketchum

Variable	Units	Sampling Location[a] 308th	Inlet 1	Inlet 2
Conductivity	µmhos/cm	575	210	241
Total Nitrogen	µg/l	10,100	2,100	3,715
Nitrate+nitrite-N	µg/l	1,450	667	1,930
Ammonia-N	µg/l	1,780	35	126
Total Phosphorus	µg/l	10,000	1,430	118
SRP	µg/l	5,780	1,047	32
pH[b]	s.u.[c]	6.9–7.8	5.9–7.9	6.1–6.9
Fecal Coliform	(#/100 ml)[d]	487	33	131
		(60–1,970)	(2–460)	(6–12,400)
Chloride	mg/l	29	14	9
Iron	mg/l	0.6	0.2	2.2
Temperature[e]	(C)	14.9	13.7	12.3
Dissolved Oxygen[f]	mg/l	8.4 (4.3)	9.2 (6.5)	7.5 (5.8)

Note: Values are median concentrations unless otherwise noted.
Sampling period: March 1995–February 1996.
a. Refer to **Figure 3-1** for station locations.
b. pH values listed are ranges.
c. Standard units
d. Fecal coliform values are geometric means, ranges are listed in parentheses.
e. Temperature values are maximums.
f. Numbers in parentheses are minimums.

The two main results from the routine sampling of Inlet 1 are:

- Inlet 1 is highly polluted as a result of contamination from the upstream farm area.
- The wetland located between the farm and the lake is reducing pollutant concentrations in the main inlet before it reaches the lake.

As can be seen from **Table 4-6** the concentrations of nutrients (total phosphorus and total nitrogen), at 308th are very high, even for agricultural runoff. There currently are no state standards for phosphorus or nitrogen, with the exception of nitrate. The TP concentration at 308th ranged between approximately 7,000 µg/l to 13,600 µg/l. Total phosphorus concentrations at Inlet 1 ranged between 736 µg/l and 2,390 µg/l. In addition, Inlet 1 had a large proportion (averaging 75 percent) of phosphorus in the soluble form, which is the form of phosphorus that is readily used by algae.

Total phosphorus concentrations measured at 308th are generally 60 times higher than typical agricultural runoff and also are higher than typical TP concentrations in wastewater effluent that has received primary treatment (**Table 4-7**).

Table 4-7
Phosphorus Concentrations Associated with Various Land Uses and Wastewater

Predominant Land Use	Average TP (μg/l)	Average SRP (μg/l)
Residential[a] (storm runoff)	199	21
Residential[a] (baseflow)	60	9
Forest[b]	28 (7–57)	
Agriculture[c]	161	71
Agriculture[d]	135	
Urban[e]	171 (45–490)	
Urban[f]	260 (2–3,600)	
Treated Wastewater Effluent[g]	8,710	
Untreated Wastewater[h]	18,000–29,000	

a. Martha Lake North Inlet. Source: Entranco 1991.
b. Source: Puget Sound Wetland Study numbers in parentheses are ranges (Patterson Creek)
c. Source: Cooke, et al. 1993
d. Based on 473 sites in an EPA study. Source: Reckhow and Chapra 1983
e. Source: Puget Sound Wetland Study (Bellevue Creek)
f. Source: Metro; January 9, 1990 storm data removed from analysis (Bellevue Creek)
g. Primary treatment and digestion. Source: Reckhow and Chapra 1983
h. Source: EPA 1980

Other parameters, such as ammonia, fecal coliform, chloride, conductivity, and total nitrogen, also indicate contamination at 308th.

Comparing the concentrations between stations upstream (308th) and downstream (Inlet 1), indicates water quality improves as the main inlet flows through the wetlands. For example, the average reductions in concentrations of the following parameters were observed:

- Total phosphorus and SRP–approximately 80 percent
- Total nitrogen–54 percent
- Ammonia-nitrogen–97 percent

- Fecal coliform–83 percent (The geometric mean of fecal coliform at 308th exceeds the State Class AA standard of 50 org/100 ml, while the station at Inlet 1 does not.)
- Conductivity–56 percent
- Chloride–50 percent

Although most of the reduction in pollutant concentrations in the main inlet is due to treatment by the wetlands, some of the water quality improvement is the result of dilution by low phosphorus groundwater.

Despite significant improvement in water quality downstream of 308th, the concentrations of phosphorus entering the main inlet to Lake Ketchum are still very high when compared with the ability of the lake to absorb TP without adverse impact. The TP concentration in Inlet 1 is 60 times higher than the eutrophic lake concentration of 24 µg/l.

Stormwater Sampling

The inlets to Lake Ketchum were sampled during three storms in February and March 1996 to characterize the water quality of storm flows (**Appendix A**). Concentrations of pollutants were not elevated when compared with the routine sampling; however, pollutant levels remained high. For example, TP concentrations ranged from 5,860 µg/l to 12,000 µg/l at 308th and from 1,240 µg/l to 2,600 µg/l at Inlet 1.

Total organic carbon levels also were very high, ranging between 22 and 43 mg/l at 308th, indicating high amounts of organic demanding wastes. For comparison, average total organic carbon (TOC) concentrations range from 2 mg/l in forested areas to 16 mg/l in urban areas.

Fecal coliform concentrations during the three monitored storms were highly variable in the main inlet, ranging from 6 org/100 ml at Inlet 1 to 8,400 org/100 ml at 308th. Geometric means for the three storms at Inlet 1 and 308th were 83 and 419 org/100 ml, respectively. Note that the geometric mean of stormwater values for both stations exceeded the State standard for Class AA streams of 50 org/100 ml and both stations exceeded the Class AA criterion of not more than 10 percent of the samples exceeding 100 org/100 ml.

Groundwater Quality

Shallow groundwater flows into the lake around the southeast end of the lake and flows out of the lake around the north and west ends of the lake. Quarterly water quality sampling results of four wells near Lake Ketchum are presented in **Appendix B**. For the flow entering the lake, the average SRP concentration was low, averaging 13 µg/l. Although the TP concentrations measured in the groundwater wells were occasionally high (>100 µg/l), high turbidity within these groundwater samples probably contaminated the samples. Therefore the measurements were considered an overestimate of the amount of phosphorus that actually moves through the ground and into the lake. The soluble form of phosphorus, SRP, gives a better estimate of the movement of phosphorus through the soil and the levels of phosphorus that may reach a lake.

Groundwater phosphorus data collected from the selected wells were used in the development of the lake's nutrient budget (refer to **Appendix C**).

Water quality parameters that are potential indicators of septic tank effluent are high concentrations of nitrate and chloride. Neither nitrate nor chloride are physically or chemically bound by soil particles and both move readily through the soil and groundwater environments. An indication of possible septic system failure or agricultural runoff contamination would be relatively high nitrate and chloride concentrations in groundwater samples. With the exception of three of the sixteen samples along the southern and eastern shore, groundwater samples did not indicate excessive concentrations of these parameters (**Appendix B**).

Results of Septic System Dye Survey

Conditions that prevent or interfere with proper function of septic systems include unsuitable soils (excessively drained or poorly drained), high water tables, the occurrence of soil fissures that allow rapid movement of effluent (**Chapman 1992**), and steep slopes, as well as poor design (system undersizing) or improper use. These soil conditions can occur around lakes (**Olem and Flock 1990**). At many lakes, older systems also were installed prior to approval of more environmentally sound siting and design criteria.

In addition to potential health effects, septic systems can also contribute to high in-lake phosphorus concentrations. Generally, phosphorus loading to a lake from septic tanks is low, because most soils retain phosphorus. However, higher levels of phosphorus loading may be associated with old nearshore systems where high groundwater levels reduce phosphorus removal efficiency during the winter and spring.

To assess the impacts of nearshore septic tanks on the water quality of Lake Ketchum a septic dye survey was conducted in March 1996. The spring survey was performed when groundwater levels were high, soils were saturated, and septic systems were considered most likely to fail.

The purpose of the survey was to determine whether any septic failures could be detected, rather than to quantify the septic tank loading to the lake. The dye survey was conducted by adding Rhodamine WT dye to 93 percent (38 homes) of the septic tank/drainfield systems along the shoreline of the lake. Two weeks later a continuous flow fluorometer was used to survey the entire lake shoreline for evidence of the dye.

The shoreline septic dye survey showed no evidence of a concentrated effluent plume entering Lake Ketchum. Concentrations of the dye were generally near the background concentrations in the lake. Absence of a verifiable plume does not necessarily indicate that leachate from septic systems is not entering the lake; rather, it indicates a lack of any major lakeshore septic tank failure. This finding was substantiated by very low in-lake fecal coliform counts (see **Table 4-9**, page 4-25).

LAKE BIOLOGICAL CHARACTERISTICS

This section describes the characteristics of Lake Ketchum's biological community. Topics include phytoplankton (algae), zooplankton, aquatic plants, and bacteria. Data collected for these biological elements are provided in **Appendix A.**

Phytoplankton

Phytoplankton are the small suspended algae (microscopic plants) of lakes and are dispersed mainly by wind and water currents. Like all other plants, phytoplankton are able to produce organic matter through the process of photosynthesis. The phytoplankton community consists of many groups of algae that have different biological, chemical, and physical requirements. Typically, several algal species coexist in a lake at the same time. Seasonal changes in environmental factors, primarily nutrient availability, and secondarily temperature and light, produce seasonal changes in algal abundance and dominance (**Wetzel 1983**).

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

Phytoplankton growth is controlled primarily by water temperature, light availability, nutrient availability, residence time (the amount of time that they inhabit a lake before being washed out of a lake's outlet or falling to the lake's bottom), and consumption by zooplankton (**Olem and Flock 1990**). When light is adequate for photosynthesis, the availability of nutrients usually controls phytoplankton growth.

Blue-green algae, which can form blooms (scums) on the surface, are most often associated with eutrophication. The summer biomass of blue-green algae depends most heavily on the epilimnetic concentrations of phosphorus (**Smith 1990**). Blue-greens are able to position themselves at or near the water surface by floatation using gas vacuoles. They also are able to "fix" or use atmospheric nitrogen and therefore are not limited by supplies available in the water as are other algal species.

Phytoplankton Composition and Biovolumes

The five major groups of algae and their relative annual dominance in Lake Ketchum are shown in **Figure 4-8.** (Refer to **Appendix A**, for a complete list of algal composition.)

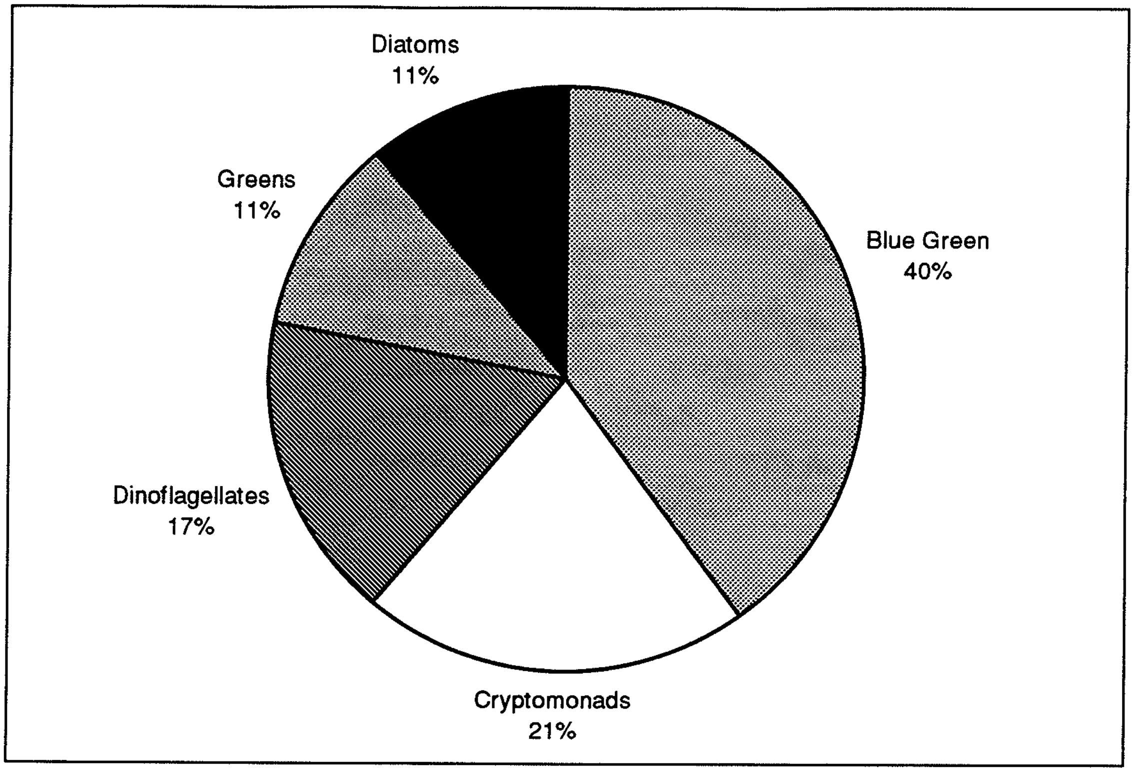

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Figure 4-8
Average Lake Ketchum Phytoplankton Composition

Figure 4-9 presents the changes in the relative composition of the major phytoplankton groups in Lake Ketchum throughout the study year. Only one species of diatom was present at significant levels—*Asterionella formosa*—which bloomed in early spring (March 15). Blue-green algae, *Aphanizomenon flos-aquae,* were a significant portion of the algal community through much of the year (**Figure 4-9**). *A. flos-aquae* can form large colonies on the surface which look like small grass clippings in the water. The greatest algal levels measured in Lake Ketchum, which occurred during the late summer, were dominated by a bloom of *A. flos-aquae* (see 12 Sept. on **Figure 4-9**).

Algal toxicity from blue-green algae was not evident in the samples submitted to the laboratory in July and September 1995. *A. flos-aquae* does not normally produce the toxins found in certain blue-green species.

Chlorophyll a

In addition to the direct measurements of biomass levels derived from cell volume counts, the abundance of algae in Lake Ketchum was estimated by chlorophyll *a* concentrations. Chlorophyll *a* is the pigment in algae that makes it green and that is used as an indicator of algal levels because is it is relatively easy to measure.

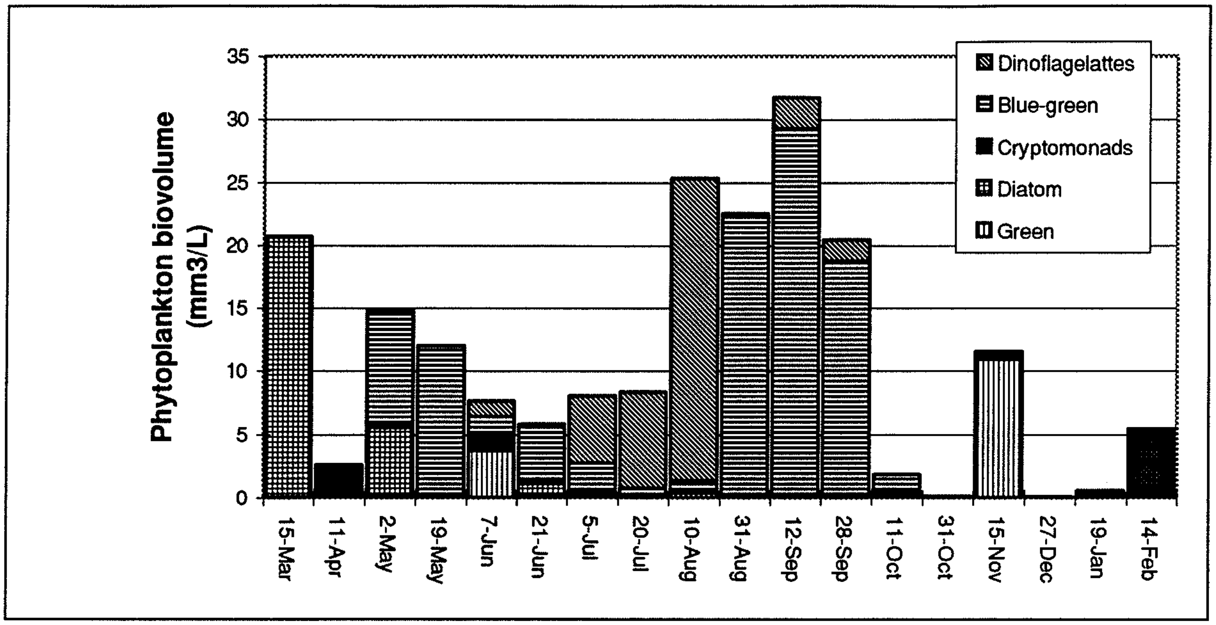

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Figure 4-9
Lake Ketchum Phytoplankton Composition and Biovolumes

Chlorophyll *a* concentrations in Lake Ketchum are high when compared with most lakes in western Washington, reflecting the high algal growth in the lake. The average annual and summer chlorophyll *a* concentrations in Lake Ketchum were 32 μg/l and 50 μg/l, respectively. High chlorophyll *a* levels (greater than 20 μg/l) persisted through the summer recreational period and peaked at 135 μg/l in late summer during the blue-green bloom (**Figure 4-10**). Typical of bloom conditions, chlorophyll *a* levels significantly decreased three weeks later following the bloom.

Zooplankton

Zooplankton are tiny aquatic animals, which are found suspended in the water column of lakes. Zooplankton play an important role in lakes, because they feed on algae, and in turn are eaten by fish. Zooplankton numbers decreased following the *Ceratium hirundinella* peak when blue-green algae once again dominated.

The zooplankton community in Lake Ketchum is well-mixed, without a single group dominating through most of the year, which is atypical for western Washington lakes. It is common for rotifers to dominate. Zooplankton numbers peaked in early August (**Figure 4-11**) corresponding to a bloom of *Ceratium hirundinella*. Blue-greens are generally considered to be a poor food source for zooplankton compared to other algal groups. (Zooplankton data, consisting of species composition and density, collected during the study are listed in **Appendix A.**)

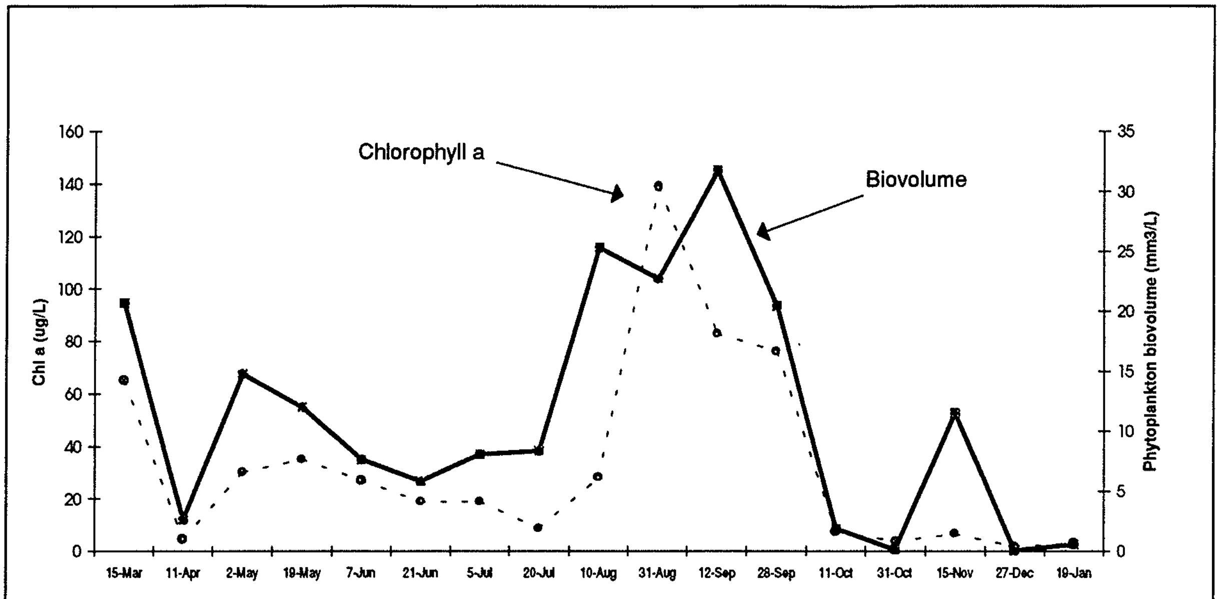

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Figure 4-10
Lake Ketchum Chlorophyll *a* Concentrations and Biovolumes

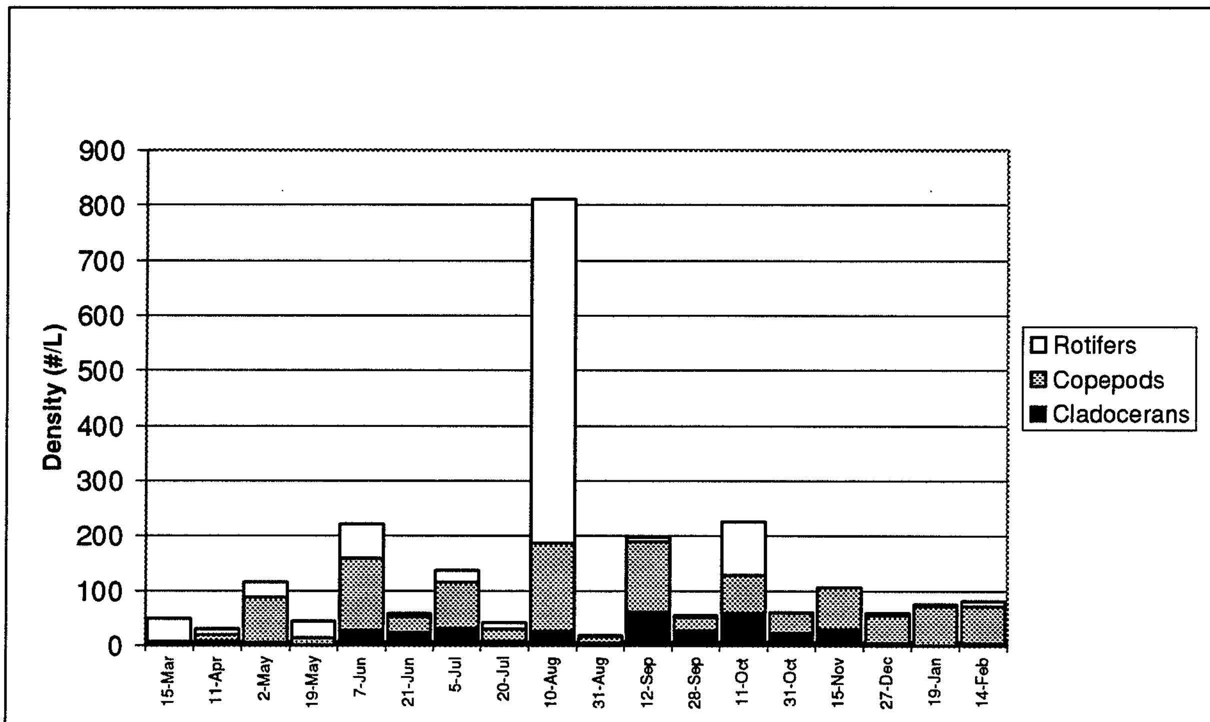

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Figure 4-11
Lake Ketchum Zooplankton Composition & Density March 1995 through February 1996

Aquatic Plant (Macrophytes) Community

Aquatic macrophytes are large submerged and/or floating-leafed plants located along the nearshore and the marsh areas of lakes. Macrophytes are adapted for growing totally or partially submerged in water and may grow to depths of 10 to 12 feet in Lake Ketchum. In most cases, macrophytes are a common component in lakes, and they serve as habitat for fish, waterfowl, and benthic invertebrates (bottom-dwelling organisms). Most rooted macrophytes obtain their nutrients from the bottom sediments rather than the water and are restricted by light penetration (**Olem and Flock 1990**). Duckweed, which floats on the water surface, and coontail, a non-rooted plant, both obtain their nutrients from the water.

The advantages of removing macrophytes from a lake for aesthetic reasons (e.g., unsightliness or interfering with recreational activities) must be weighed against the useful functions that these plants provide.

A survey of the aquatic plant community of Lake Ketchum was conducted in July 1995 to coincide with the peak of the growing season. (**Appendix A**, presents raw data from the aquatic plant survey). Approximately 7.2 acres, or 30 percent of the lake surface area, were covered by macrophytes. This is a moderate level of coverage, compared with other similarly sized lakes in this region. However, a more limited survey in August 1996 showed substantially more aquatic plants than during 1995. Plants covered about 40 percent of the lake area and were found in greater densities. Several species of aquatic plants were identified during the 1995 and 1996 surveys (**Table 4-8**).

Table 4-8
Lake Ketchum Macrophyte Species List
1995

Species	Common Name
Ceratophyllum demersum	Coontail
Elodea canadensis	Common waterweed
Lemna minor	Duckweed
Nitella spp.	Nitella
Nuphar polysepalum	Pond lily
Potamogeton pusillus	Pond weed
Potamogeton ampifolius	Pond weed

Macrophyte growth in Lake Ketchum follows a relatively consistent pattern throughout the lake (**Figure 4-12**). Because the water's clarity is low, light limitation results in the lack of rooted plant growth below a depth range of 10 to 12 feet. From six to ten feet, dense monoculture growths of *Nitella*, growing up to approximately one foot off of the bottom, exist throughout the lake. Between seven feet and five feet the *Nitella* community transitions into a community dominated by canopy species: *Elodea canadensis* and *Potamogeton pusillus.* The southern and southwestern portions of the lake are dominated by *E. canadensis,* while the northern and northwestern portions are dominated by *P. pusillus.* Although these species dominate, there is a sparse mix of each species in the area dominated by the other, and *Nitella* occurs as an understory beneath both the *E. canadensis* and *P. pusillus.* In 1996, *E. canadensis* was more dense than other species in all portions of the lakeshore. Also, small stands of *P. amplifolius* occur in scattered areas throughout the lake at depths of approximately three to seven feet.

The peninsula in the northeast corner of the lake is surrounded by a mixed community of wetland plants including *Typha spp.* (cattail), *Nuphar polysepalum* (pond lily), and spike rush (*Eleocharis palustris*). Inside the northeast inlet, the bottom has been dredged and the rooted macrophyte community is moderate, but the wind seems to have blown a large amount of floating plants and uprooted macrophytes into this area. Large quantities of *Ceratophyllum demersum (coontail)* and *Lemna minor* (duckweed) were observed in this location. Duckweed has covered a large portion of the lake in the past; however, during the monitoring year, duckweed was mainly restricted to the narrow embayments in the eastern portion of the lake.

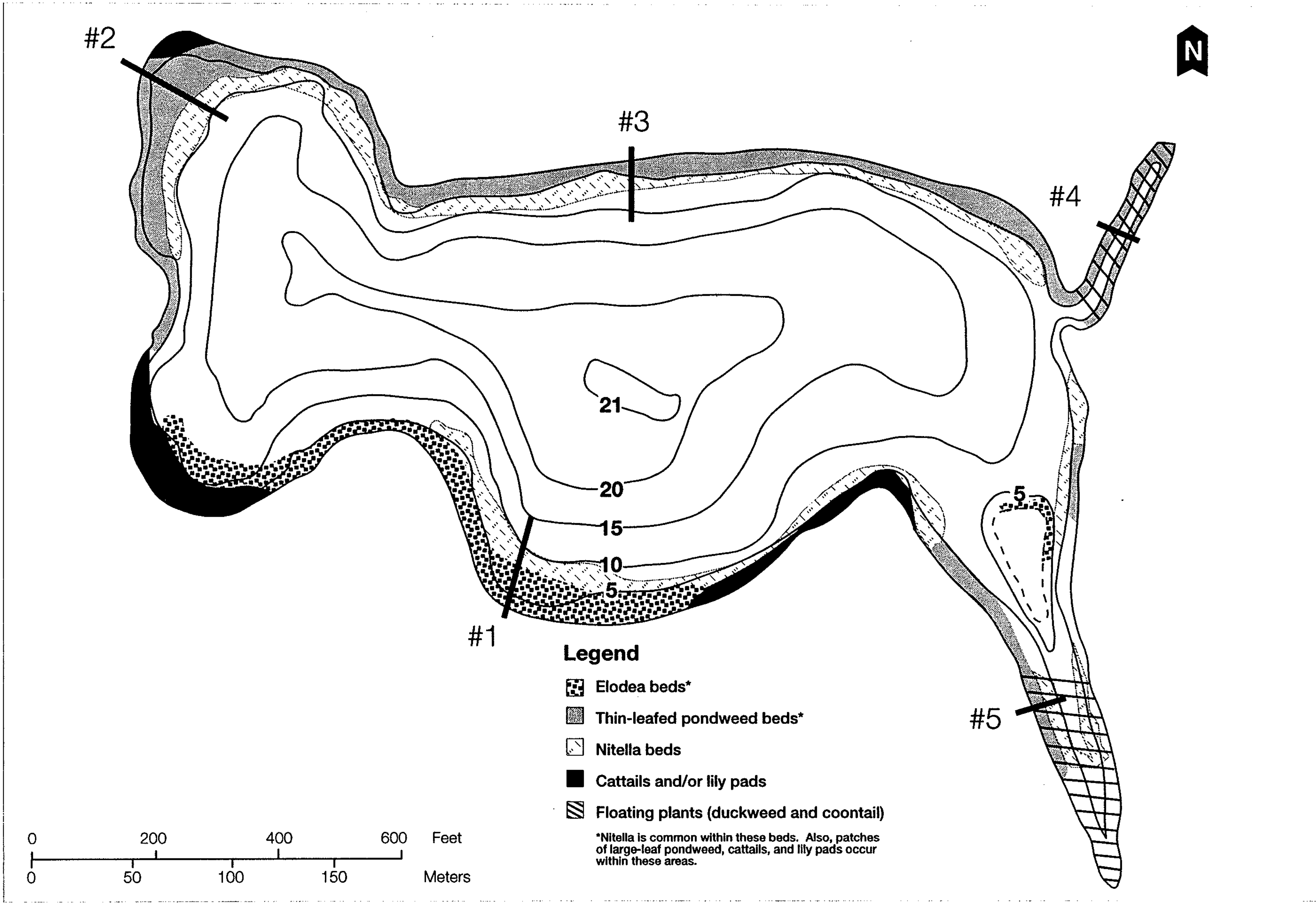
In the southeast corner of the lake, large mats of periphytic algae and duckweed dominate the overstory. In this area, the two communities exist, but the overstory community is more varied or mixed in this location than in any other location in the lake. In 1995, *C. demersum, P. pusillus,* and *Nitella* were moderately dense, and *E. canadensis* and *P. amplifolius* also occurred to some extent at this location. During 1996, *E. canadensis* and *C. demersum* were very dense throughout this corner of the lake.

Bacteria

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

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

1. Routine lake monitoring at the deep surface station in Lake Ketchum. A total of 18 samples were collected during the year-long study.
2. Nearshore samples collected at six locations between June and September on seven separate monitoring trips. A total of 42 nearshore samples were collected.



A679 Lake Ketchum (2/12/97) AGT

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Figure 4-12
1995 Lake Ketchum Macrophyte Survey

The bacterial data for the open lake stations and the shoreline sampling stations are summarized in **Table 4-9** and are presented in **Appendix A.**

Table 4-9
Summary of Lake Ketchum Fecal Coliform Data

	Lake Ketchum Mid-Lake	**Lake Ketchum Nearshore**
Annual Geometric Mean	4	NA
Summer Geometric Mean	2	4
Maximum	60	660
Number of samples	18	42

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

Open Water

The geometric mean of the open water station in Lake Ketchum was 4 org/100 ml, well below the state standard of 50 org/100 ml (**WAC 173-201-045**). The data indicate that, from a public health perspective, the lake is safe for contact recreation such as swimming.

Nearshore

Nearshore fecal coliform samples collected during the summer recreation period (June through September) similarly indicate that nearshore water quality is meeting the State standard. Two out of 42 samples had high values (480 and 660 org/100 ml), but the remaining samples were generally below 5 org/100 ml (contamination from waterfowl may have caused the high fecal coliform levels in these two samples). Geometric means also were calculated for each of the seven sampling events and the highest geometric mean was 20 org/100 ml, which is below the State standard.

TROPHIC STATE

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

Based on the trophic criteria, Lake Ketchum can be classified as eutrophic or hypereutrophic (**Table 4-10**). In addition to the traditionally-used trophic parameters, the presence of blue-green algae through most of the year and the extended period of hypolimnetic anoxia indicate a highly eutrophic lake.

Table 4-10
Annual and Summer Means of Lake Ketchum Trophic Parameters in Comparison with Trophic State Criteria

	Chl *a* (µg/l)	**TP** (µg/l)	**Secchi** (m)	**Result**
1. Trophic Parameters				
Trophic Classification				
Oligotrophic	< 2.6	< 12	> 4	
Mesotrophic	2.6 – 6.4	12 – 24	2 – 4	
Eutrophic	> 6.4	> 24	< 2	
Lake Ketchum				
Annual	32	655	2.0	Eutrophic
Summer	50	434	1.6	Eutrophic

Trophic Criteria: **Carlson 1977, 1979**

Comparison with Other Small Lakes in Snohomish County

Another way in which the condition of Lake Ketchum can be evaluated is to compare its trophic parameters with other lakes in this area. In general, Lake Ketchum has very high phosphorus and chlorophyll *a* concentrations in comparison with other Snohomish County lakes of similar size (**Table 4-11**).

Table 4-11
Comparison of Trophic Parameters (Summer Values) Between Lake Ketchum and Other Snohomish County Lakes

	Lake Ketchum	**Other Snohomish County Lakes**[a]
Trophic parameters		
Phosphorus (µg/l)	209–635	2–25
Chlorophyll *a* (µg/l)	9–139	0.1–51
Secchi (meters)	0.8–2.2	0.3–8.4

a. Sunday, Loma, Crabapple, and Goodwin lakes.

Generally, chlorophyll *a* concentrations give the most accurate classification of a lake's trophic state (**Carlson 1992; Jones and Lee 1982**). As shown in **Figure 4-13**, Lake Ketchum has much higher levels of algae in the summer compared with other Snohomish County Lakes.

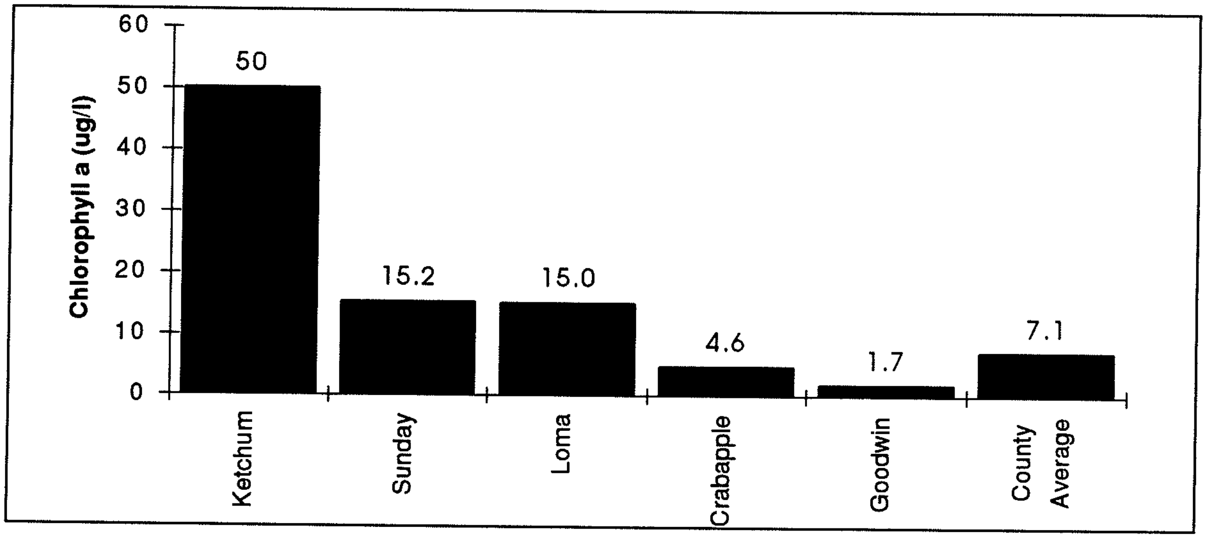

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Figure 4-13
Lake Ketchum Average Summer Chlorophyll *a* in Comparison with Other Snohomish Co. Lakes
Source: Snohomish County (unpublished data)

CHAPTER 5

WATER AND PHOSPHORUS BUDGETS AND THE LAKE RESPONSE MODEL

5. WATER AND PHOSPHORUS BUDGETS AND THE LAKE RESPONSE MODEL

WATER BUDGET

Lake Ketchum's water budget is an estimate of the sources of water entering and leaving the lake during the year. The U.S. Environmental Protection Agency (EPA) hydrologic model, Hydrologic Simulation Program - Fortran (HSPF), was used to develop the water budget for Lake Ketchum (refer to **Appendix C** for a description of the methods and assumptions used to calibrate the HSPF model). The model simulates daily totals of direct runoff (surface runoff and interflow) and direct precipitation (rain falling on the lake surface) entering the lake. The HSPF model was calibrated to the hydrological data collected during the study year.

The proportion of modeled annual inflow that each component contributes is summarized in **Figure 5-1**. The main inlet draining the farm land, contributes about one-quarter of the annual flow to Lake Ketchum, while the remaining basin, including Inlet 2, contributes approximately the same amount as groundwater—30 percent.

Figure 5-2 presents a monthly summary of simulated inflows to Lake Ketchum between April 1995 and March 1996. Seventy-one percent of the total annual simulated inflow to Lake Ketchum occurs over the 4-month period between November and February. Total annual inflow to the lake during the water year was 394 acre-feet. Assuming a lake volume of 296 acre-feet, Lake Ketchum has a fairly long retention time of 0.8 year (and conversely, a slow flushing rate of 1.3 $year^{-1}$). In general, the longer the retention time, the more susceptible the water is to phosphorus loading.

PHOSPHORUS BUDGET

The purpose of a phosphorus budget is to identify and quantify the major sources of phosphorus to a lake from the watershed and sources internal to the lake itself (e.g., phosphorus released from lake sediments). Phosphorus can originate from the watershed or within the lake through release from the lake's sediments and other mechanisms.

The phosphorus budget for Lake Ketchum was developed by combining the water budget estimated by the HSPF runoff model with the phosphorus concentration data measured in this study. Refer to **Appendix C** for the methods and assumptions used to develop the phosphorus budget for Lake Ketchum.

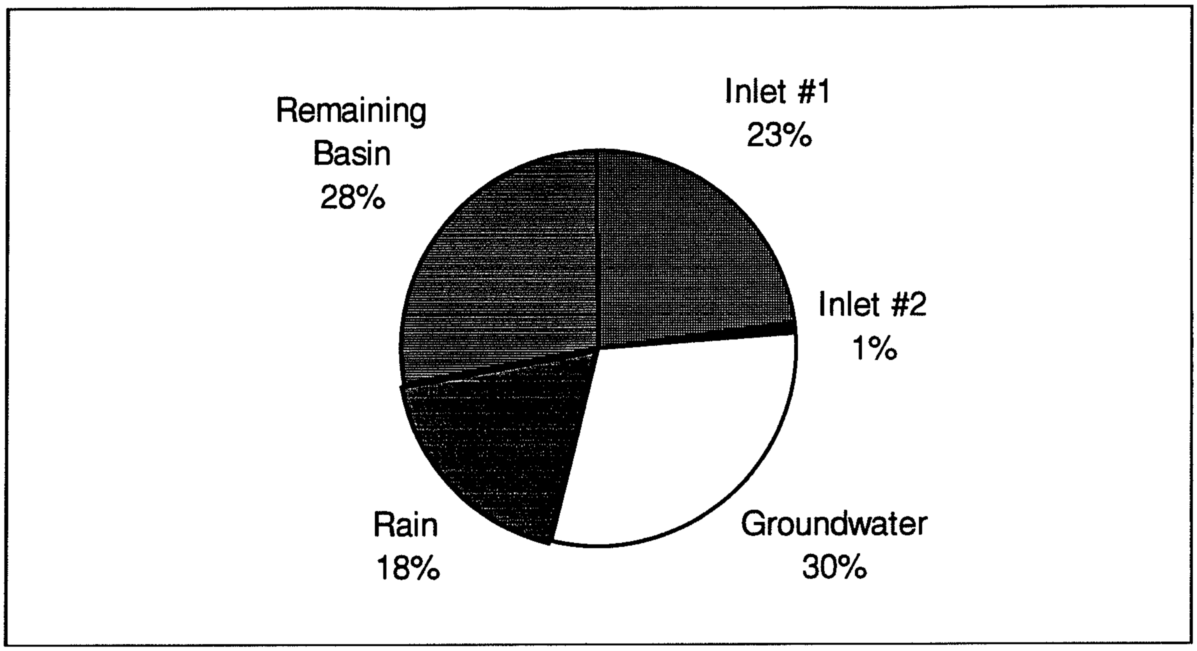

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Figure 5-1
Proportion of Annual Water Budget (Inflows) by Type

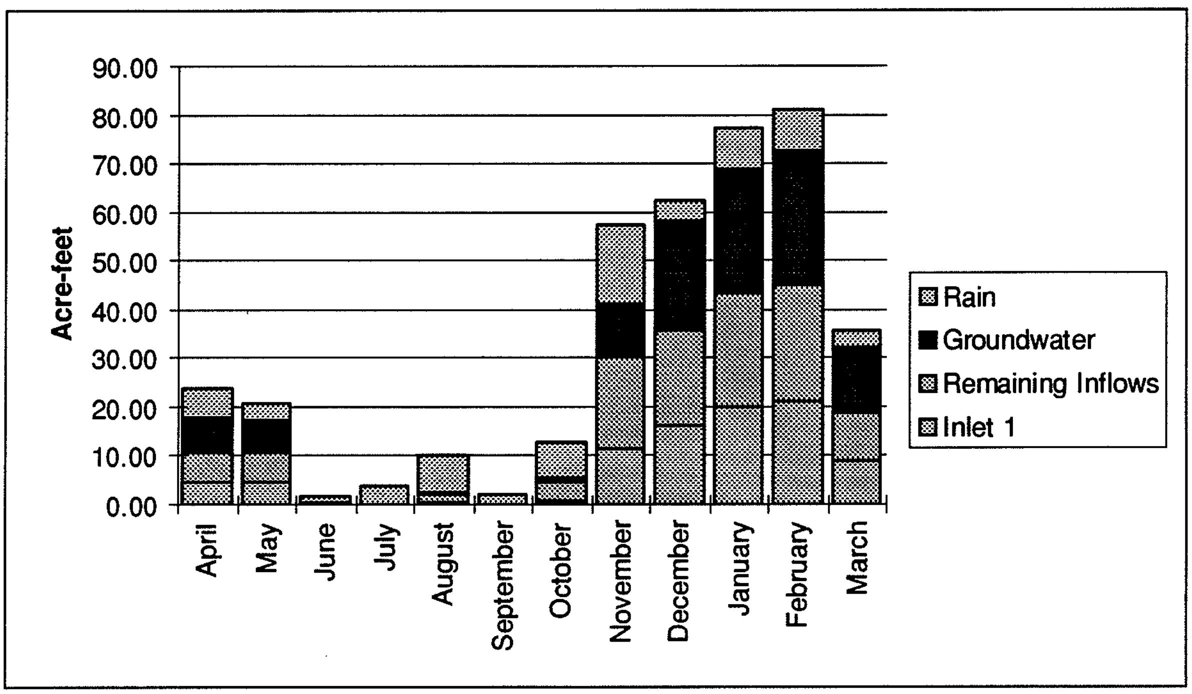

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Figure 5-2
Annual Water Budget (Inflows)
by Volume Through the Study Year

Sources of Phosphorus

Watershed (external) and in-lake (internal) sources of phosphorus to Lake Ketchum included in the phosphorus budget are shown in **Figure 5-3** and are described as follows:

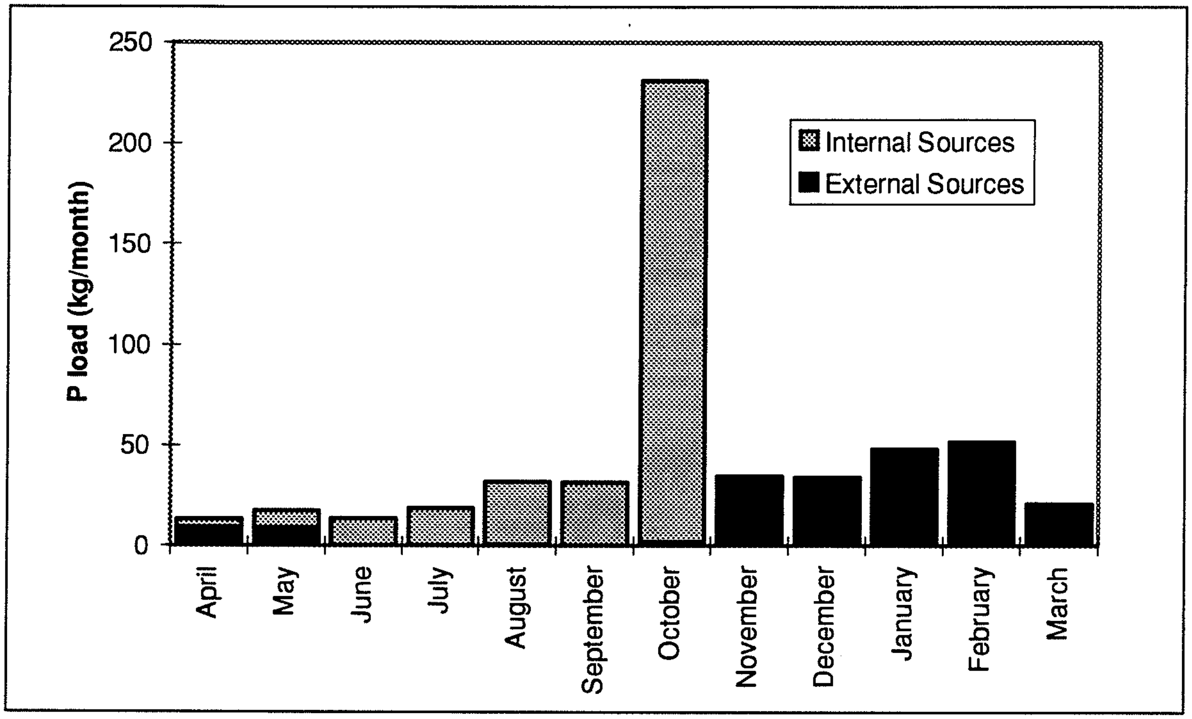

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Figure 5-3
Monthly Phosphorus Loading from External and Internal Sources to Lake Ketchum 1995–1996

Watershed Sources

- **Agricultural runoff -** phosphorus contribution (phosphorus loading) from Subbasin 6 and Subbasin 8, primarily from the cattle farm.
- **Other surface runoff -** phosphorus loading from the surface runoff in the remaining watershed area (Subbasins 2, 3, 4, 5, and 7).
- **Septic tanks -** phosphorus loading from the nearshore septic tanks in Subbasin 5. This loading occurs even though septic systems around the lake are not "failing".
- **Groundwater -** phosphorus loading from the shallow groundwater.
- **Direct precipitation -** phosphorus loading contained in rainfall and atmospheric deposition that falls directly on the lake surface.

In-lake Sources

- **Aquatic plants -** phosphorus taken up by plants during the spring and summer for their growth is released by the plants in the fall after the growing season.
- **Lake sediments -** phosphorus is released from the sediments during the stratified period in summer and fall. Phosphorus that enters the bottom of the lake from the sediments can then diffuse up to the epilimnion in the summer. Additionally, the higher levels of phosphorus in the hypolimnion enter the epilimnion when the lake mixes at turnover in late October.

Losses of Phosphorus

Losses of phosphorus from Lake Ketchum included in the phosphorus budget were:

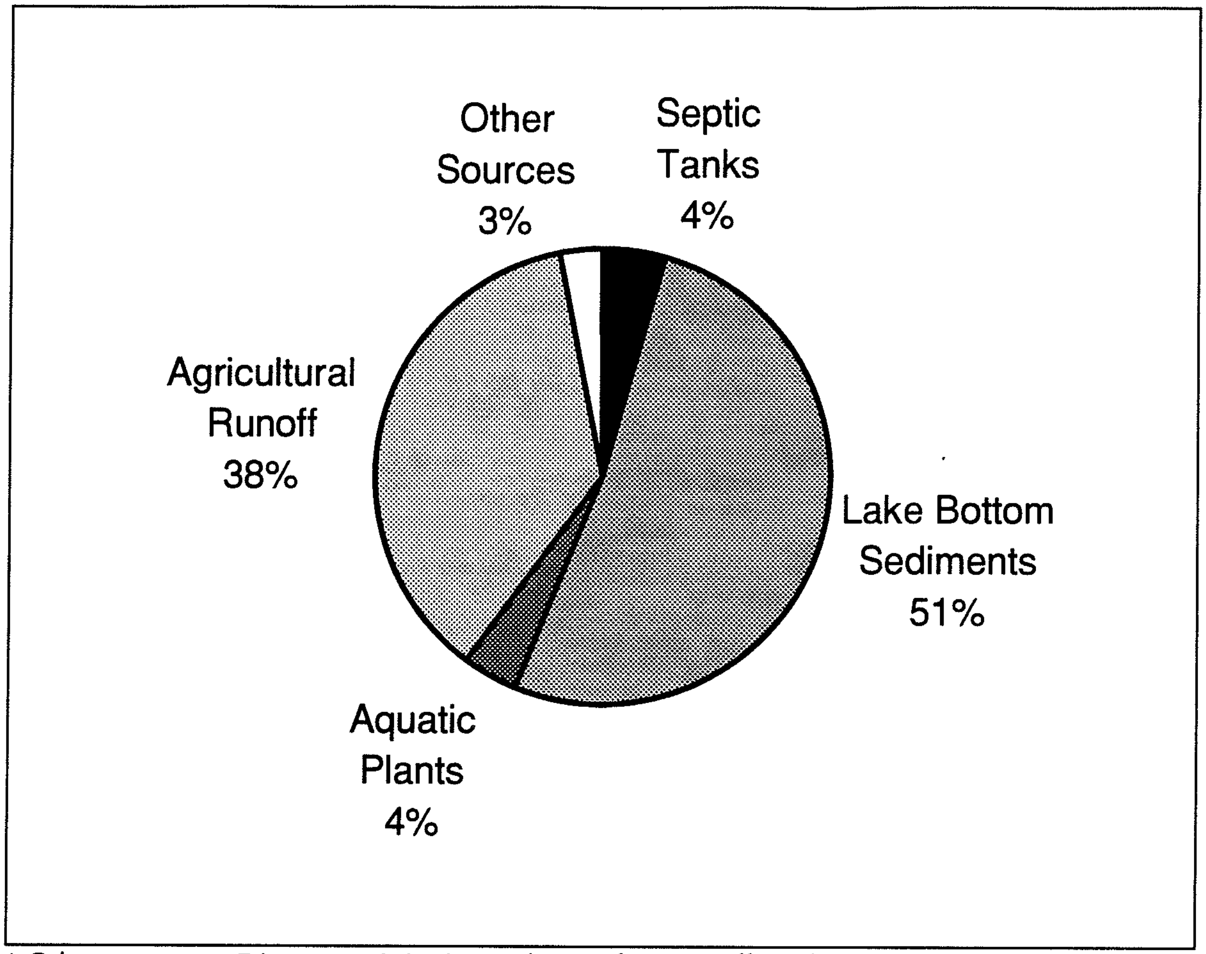
- Outflow from the lake's outlet.
- Discharge to the groundwater.
- Settling of phosphorus to the lake bottom.

Phosphorus Loading

The monthly phosphorus budget for Lake Ketchum during the study year is shown in **Figure 5-3**. The majority of the phosphorus loading occurs at turnover (October) as the relatively high phosphorus concentrations that have accumulated in the bottom waters mix with the surface waters. Normally, most of the phosphorus from the hypolimnion settles to the lake sediments following turnover as a result of mixing with the oxygenated water in the epilimnion. However, in Lake Ketchum, oxygen levels remain low throughout the water column following turnover and phosphorus stays in suspension.

The estimated annual phosphorus loading, from both watershed and in-lake sources, to the lake during the monitoring year was 1,129 pounds per year (513 kg/year). On an annual basis, phosphorus loading from watershed and in-lake sources are similar, however, the timing is different for these two sources. The watershed sources contribute phosphorus to the lake primarily during the high runoff period from November to March (**Figure 5-4**), while the phosphorus contribution from the lake's sediments takes place mostly at turnover.

The proportion of annual phosphorus loading from each source is shown in **Figure 5-4**. The two largest sources of phosphorus to Lake Ketchum are agricultural runoff from Subbasins 6 and 8 and the release of phosphorus from the lake's sediments. Watershed sources contribute approximately 43 percent of the annual phosphorus loading to the lake. Lake Ketchum's sediments contribute the majority (51 percent) of phosphorus to the lake.



* Other sources – Direct precipitation, other surface runoff, and groundwater

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Figure 5-4
Estimated Proportions of Annual Phosphorus Loading from the Major Sources to Lake Ketchum

To compare phosphorus loading rates between other local watersheds, the areal loading rate for Lake Ketchum was calculated. The areal loading rate is equal to the annual watershed loading rate divided by the watershed area. For example, the annual areal phosphorus loading to Lake Ketchum was 0.68 kg P/acre/year (219 kg P/year divided by a watershed area of 320 acres). This loading rate is more than ten times the background areal loading level of 0.049 kg P/acre/year estimated based on 25 lakes in western Washington with undeveloped watersheds (**Gilliom 1980**). In addition, Lake Ketchum's loading rate is more than five times higher than urbanized areas in western Washington (**Entranco 1991**).

For Subbasins 6 and 8, the areal loading rate is substantially higher—2.1 kg/acre/year. This loading rate is more than 40 times the background areal loading rate and sixteen times higher than urbanized areas.

LAKE RESPONSE MODEL

Following the development of the phosphorus budget, a mass-balance numerical model—the lake response model—was calibrated to phosphorus concentrations measured in the lake during the study year (refer to **Appendix C** for a summary of model assumptions and a presentation of the calibration results). The lake response model is a tool used to assess the results of different management scenarios on the lake's water quality. This is accomplished by simulating phosphorus levels in Lake Ketchum associated with potential restoration measures (see Chapter 6).

CHAPTER 6

LAKE AND WATERSHED RESTORATION PLAN

6.
LAKE AND WATERSHED RESTORATION PLAN

INTRODUCTION

The purpose of this chapter is to:

1. Summarize Lake Ketchum water quality status,
2. Set forth water quality goals, and
3. Identify the elements of a lake and watershed restoration plan.

LAKE WATER QUALITY SUMMARY

Lake Ketchum is very rich in nutrient content (especially nitrogen and phosphorus) and supports robust algal growth (suspended microscopic plant growth). Annual average total phosphorus (TP) and chlorophyll *a* levels were 655 µg/l and 32 µg/l, respectively, for the 1995–1996 study period. Peak chlorophyll *a* levels reached as high as 80 to 140 µg/l during August and September 1995. Visible blue-green algal blooms (*Anabaena* and *Aphanizomenon spp.*) dominated during these worst-case months. Water visibility was correspondingly low with average annual values of 1.9 meters (6.2 feet) and August/September values of 0.75–1.6 meters (2.5–5.2 feet). In some past years, the biological response of the lake has been even worse, with prolific duck weed growth out-competing algal species and covering the entire surface of the lake. Lake scientists refer to such nutrient-rich and productive lakes as eutrophic or hyper-eutrophic.

As the residents of Lake Ketchum know, this degree of nutrient enrichment and algal growth is not compatible with optimal aesthetic and recreational enjoyment of the lake, and has been the motivation for initiating this lake restoration study.

The lake also stratifies (develops two non-mixing layers) and becomes oxygen depleted (0 to 3 mg DO/l) at depths below ten feet (maximum depth is 21 feet) from May through October. This condition limits fish activity to the upper ten feet of the lake during this time period. The low levels of oxygen may have an adverse impact on the health of fish populations in the lake.

OBJECTIVES FOR ALGAE CONTROL

The citizens' lake water quality objective (page 1-2) is to "control excessive algal blooms and duckweed growth to levels acceptable to the citizens' needs and financial resources." This broadly stated objective has been restated in a more quantitative and scientific format below. By quantifying water quality objectives, the success of lake and watershed restoration activities can be monitored and verified following implementation.

Water quality objectives for Lake Ketchum are based on the eutrophic criteria of Carlson (**1977**) and the predicted water quality results of the recommended restoration alternative. The objectives for average summer TP, chlorophyll *a* and Secchi visibility are 30 µg/l, 6.4 µg/l, and 2 meters, respectively. Since the lake restoration strategy will be based on phosphorus control, and the existing summer lake TP level is 434 µg/l, over a 90 percent reduction in phosphorus loading is needed to reach this objective. This is a very ambitious objective that can only be achieved if each of the recommended techniques is as successful as predicted in reducing phosphorus loading.

Given that existing average summer Secchi values are about two meters, it is anticipated that major reductions in nutrients and algal levels could result in some improvement in Secchi visibility beyond the stated objective. In addition, major reductions in TP loading and corresponding reductions in algal growth could lead to improved oxygen conditions in the bottom of the lake during summer months.

PHOSPHORUS BUDGET AND PHOSPHORUS CONTROL STRATEGY

Understanding the relative magnitude of the various phosphorus sources to Lake Ketchum can help in deciding where the focus of lake and watershed restoration efforts should be directed. **Figure 5-4** provides this information in pie-chart format.

As indicated by the phosphorus budget, agricultural runoff and in-lake sediments, represent 38 and 51 percent of annual TP loading to the lake, respectively, and together represent 89 percent of the annual TP load. High agricultural TP levels are primarily due to intense dairy pasture use over a 20- to 40-year period and heavy chicken manure fertilization in recent years. This high-level, long-term TP load from agricultural activities also is suspected as a major contributor to the high internal load in Lake Ketchum.

Lake restoration techniques should focus on measures that have the greatest potential for reducing phosphorus from these two major sources. This assessment indicates that a combination of watershed and in-lake restoration measures will be necessary to achieve lake water quality objectives. In view of the relatively long history of poor water quality conditions at Lake Ketchum, members of the Ketchum Shores Improvement Club are eager to take action and are in favor of implementing both watershed and in-lake restoration measures concurrently. This is technically feasible as explained further below.

A critical assumption in developing the annual TP budget for the lake is that groundwater phosphorus is relatively low. This is based on soluble reactive phosphorus measurements of groundwater quality samples collected quarterly at four monitoring stations around the lake. Because this is a critical assumption, it is recommended that additional groundwater testing be performed to verify this assumption as a first step of implementation.

Another important assumption is that phosphorus control is the best restoration strategy even

Another important assumption is that phosphorus control is the best restoration strategy even though the lake is presently nitrogen limited (**Thomann and Mueller 1987**). Phosphorus control is recommended over nitrogen control for the following reasons:

- nitrogen control is typically more difficult and costly;
- some species of blue-green algae are able to obtain nitrogen supplies from the atmosphere, thus negating any advantage achieved through tributary or in-lake nitrogen reductions; and
- reducing nitrogen levels may favor the undesirable blue-green species over preferred green and diatom species.

Because Lake Ketchum is presently nitrogen limited, lake modeling analyses have been performed to assess whether TP can be reduced enough to become the limiting nutrient under post-restoration conditions. See the end of this chapter for modeling results.

PRELIMINARY SCREENING OF ALTERNATIVE LAKE AND WATERSHED RESTORATION APPROACHES

In the process of evaluating alternative restoration approaches for Lake Ketchum and its watershed, a total of 16 restoration techniques were reviewed for effectiveness, cost, environmental considerations and other factors (**Table 6-1**). Based on a review of these techniques by Snohomish County, the Lake Ketchum Citizen's Committee, and the Entranco study team, six of the 16 restoration measures were recommended for in-depth study and consideration. These six (techniques 1–6) are identified by an asterisk in **Table 6-1**. The other ten techniques were eliminated from further evaluation for reasons explained briefly below. An in-depth discussion of the six retained techniques is provided under the section Restoration Techniques Recommended for In-depth Evaluation.

Table 6-1
Preliminary Screening List of Potential Lake and Watershed Restoration Techniques

1. Farmland Soil Amendment*	7. Artificial Circulation	12. Dilution/Flushing
2. Wetland Treatment*	8. Sediment Oxidation	13. Lake Level Regulation
3. Inflow Diversion*	9. Hypolimnetic Aeration	14. Drawdown
4. Whole-lake Alum Treatment*	10. Stormwater Treatment	15. Dredging
5. Watershed BMPs*	11. Food Chain Manipulation	16. Hypolimnetic Withdrawal
6. Macrophyte Control*		

Alternatives Eliminated from Further Consideration

Artificial Circulation

This technique would involve addition of compressed air into the middle of the lake during the period of stratification from about May through October. This practice would prevent the lake from stratifying and would maintain good oxygen levels throughout the water column, thus improving fish habitat and possibly reducing internal phosphorus loading. This technique would be considered as a possible option to alum treatment if a non-chemical approach was desired. However, treatment benefits with artificial circulation would probably not be as great or reliable as those from whole-lake alum treatment. In some lakes, water quality actually deteriorates following whole-lake circulation, and there is no way of eliminating this possible outcome at Lake Ketchum.

Sediment Oxidation

Although greater in cost than alum treatment, this approach may be a potential alternative to alum treatment for control of internal loading from the hypolimnion. This technique involves the addition of calcium nitrate, iron chloride, and lime to lake bottom sediments. Application costs would probably be higher than for alum treatment and case study results have been less consistent (one of four treated lakes showing benefit) than they have for the more widely used alum. At lakes that did not respond well to treatment there was a failure to provide adequate control of external loading or failure to apply an adequate dose of treatment chemicals. Because alum is viewed as a safe (when properly applied) and less costly treatment, this technique is not recommended for more detailed assessment.

Hypolimnetic Aeration

Experience with hypolimnetic aeration shows that this technique is able to produce improved oxygen conditions in the hypolimnion, but often times does not produce much change in summer TP concentrations or algal growth. Aeration can produce significant improvements in fish habitat for lakes with cold water fish species like trout, but that it has not proven to be an effective technique for eutrophication control.

Stormwater Treatment

Since stormwater runoff from non-agricultural sources is considered a minor contribution to the existing nutrient budget (only 1 percent of the total), no stormwater controls are recommended, except those being addressed for future development under watershed best management practices (BMPs).

Food Chain Manipulation

Food chain manipulation is an ecologically sound concept of water quality improvement. However, it is often difficult to predict the year to year trends in multiple, interdependent biological interactions, so that biological control methods are often less reliable than other common lake restoration techniques. We should not, however, discount the fact that biological control is likely to contribute to water quality improvements associated with other approaches. For example, reductions in aquatic plants using grass carp is a biological control technique that could result in corresponding reductions in internal phosphorus recycling from aquatic plants due to corresponding reductions in algal growth. Another possibility, however, is that large grass carp can disturb lake bottom sediments thus increasing internal loading and increasing algal growth. With whole-lake circulation there may be a shifting of algal species from blue-greens to diatoms, and this may favor increased zooplankton grazing (because they favor diatoms over blue-greens) with a corresponding reduction in algal growth. However, use of biological control as a primary restoration technique is not recommended.

Dilution/Flushing

Dilution or flushing may be a feasible restoration measure for some lakes where large volumes of low-nutrient water are plentiful. This is not the case in the Lake Ketchum watershed. Two phosphorus samples collected by the County from the local water purveyor (Wilderness Ridge Public Water Supply) had high soluble phosphorus concentrations (a mean of 102 μg/l). In addition, the cost for supplying the necessary dilution/flushing water ranged from $58,000 per year (to replace the amount of water from Inlet 1) and to approximately $500,000 per year (to replace the amount of water necessary for effective dilution—three lake volumes). Therefore, because of the high cost of and high phosphorus concentrations in the dilution water, this technique is not recommended.

Lake Level Regulation

Lake level regulation is usually important with respect to flood control and not water quality. Higher lake levels are sometimes recommended to prevent high-phosphorus groundwater from entering a lake. This is only feasible where near-shore groundwater levels are close to normal lake elevation. Since this is not the case at Lake Ketchum, this technique is not recommended for further analysis.

Drawdown

Lake drawdown has been used on a limited basis for control of aquatic plant growth through desiccation during summer months or freezing during fall or winter months. Since benefits are typically short-lived and more expensive than alternative plant control techniques, this technique is not recommended for further analysis.

Dredging

Dredging has been used on a limited basis for removal of nutrient-rich lake bottom sediments or to deepen shoreline areas to depths were aquatic plant growth becomes light limited. However, dredging is typically much more expensive (at $10 to $20 per cubic yard of material removed) than alternative control measures for internal phosphorus control or aquatic plant control. A planning level cost for dredging the entire lake surface down three feet (116,200 cubic yards) would be $1.1 to $2.3 million. At such a high cost, dredging is usually limited to maintaining navigational corridors in areas of high sediment deposition and is not commonly performed for eutrophication control. For these reasons, it is not recommended for further analysis.

Hypolimnetic Withdrawal

This technique is a variation of the dilution theme and requires a low-cost supply of high-oxygen, low-nutrient water to use in flushing the hypolimnion. Since there is no suitable water supply available, this technique is not recommended for further analysis.

RESTORATION TECHNIQUES RECOMMENDED FOR IN-DEPTH EVALUATION

Farmland Soil Amendment

High phosphorus concentrations in agricultural runoff are attributed to chicken and dairy cow manure that has been applied intensively in Subbasins 6 and 8 in recent years. Recent research by the USDA Agricultural Research Service and the University of Arkansas indicates that applying a combination of alum and lime or calcium carbonate can be effective in retaining these nutrients in the soil and reducing the amounts lost in watershed runoff. At rates of application used to date, phosphorus concentrations in runoff were reduced by 63 to 87 percent.

An estimated 187 kgP/year is being discharged to Lake Ketchum by the small stream which enters the lake from the southeast. It is important to note that 75 percent of this load is soluble reactive phosphorus. This stream drains Subbasins 6 and 8, but it is assumed that the majority of this very high phosphorus load is coming from Subbasin 8. The pasture land in Subbasin 8 has long been used for dairy farming and has received high loading of both dairy and poultry manure. Both dairy and poultry manure are high in phosphorus and nitrogen, and it is believed that the pasture is continuing to act as a source of high nutrient runoff.

Recent research by Shreve et al. (**1994 and 1996**) suggests that chemical amendment of heavily fertilized soils could result in significant retention of excess nutrients in Subbasins 6 and 8. Shreve et al. (**1994**) found that the addition of aluminum sulfate (alum) and ferrous sulfate to poultry manure, at a ratio of 1:5 (weight/weight), resulted in reductions in soluble reactive phosphorus (SRP) in pasture runoff of 63–87 percent and 48–73 percent, respectively, when compared with runoff from untreated poultry manure. This rate of application converts to approximately one dry ton of alum per acre. In the same study, Shreve et al. (**1994**) reported increased pasture yields of 28 percent and 7 percent, respectively, for alum-treated and ferrous sulfate-treated poultry manure. These increases were attributed, in part, to increases in available nitrogen resulting from reductions in ammonia-nitrogen volatilization.

In subsequent research, Shreve et al. (**1996**) measured soil retention of SRP under variable pH conditions (pH 4.0 to 8.0) following the addition of alum, iron, and calcium to poultry manure. Results indicated that soil retention of SRP was maximized within 100 days following application of treated manure and that the best performance was achieved with either ferrous sulfate or alum. Initial soil SRP concentrations ranged from 5 to 26 mgP/kg soil and were reduced to about 1 mgP/kg following 100 days under optimal conditions of either low (4.0) or high (8.0) pH. After 300 days, concentrations were reduced to less than 1 mgP/kg and were similar to native soil conditions.

Based on these results, it is recommended that aluminum sulfate and lime (to raise soil pH) be added to pasture soils in Subbasins 6 and 8 at a rate of approximately one dry ton per acre, each. A preliminary cost estimate for treating 22 acres would be $7,000 for alum, $3,500 for lime, $10,000 for soil testing, $3,000 for truck haul, and $15,000 for negotiations and permitting, for a total cost of $55,000. These costs include expenses for tractor rental, application, contingency, and sales tax. Application of dry chemicals could be done using conventional farm fertilizer spreading equipment.

Because this would be a new application of the soil amendment chemicals, we would consider this a research and demonstration best management practice. Two important questions are:

- How much phosphorus load reduction can be achieved, and
- How long would this kind of soil treatment last?

Performance monitoring of phosphorus and nitrogen at the 308th Street NW and Inlet 1 stations, on a monthly basis for a minimum of three years following initial treatment, is recommended to answer these questions. Monitoring needs are addressed later in this chapter for all project elements. If treatment benefits begin to decline prior to the end of the three-year period, consideration should be given to repeating soil treatment. It also may be necessary to extend the monitoring effort beyond three years to fully evaluate longevity and effectiveness of treatment.

Wetland Treatment

Aluminum sulfate could also be used to treat the existing 12-acre wetland in Subbasin 6 downstream of the farm. Although this wetland is currently filtering phosphorus out of the farmland runoff before it reaches Lake Ketchum, the wetland has probably become saturated with phosphorus over the years. Therefore, even if agricultural phosphorus sources are effectively controlled, high phosphorus concentrations from the wetland could continue to be flushed into the lake during periods of high runoff. Therefore, a separate phosphorus control program is recommended for the wetland.

Since alum has not been used in such an application elsewhere, this proposed use is experimental. Also, it will not be possible to apply alum in the wetland in the same manner as proposed for agricultural lands. Because of thick wetland forest and shrub communities, which should not be disturbed, agricultural equipment cannot be used to spread granular aluminum sulfate and lime as has been proposed in upstream pasture lands. For the wetland, it is recommended that a combination of aluminum sulfate and sodium aluminate (buffered alum treatment) be used similar to that proposed for the whole-lake alum treatment. To treat the wetland, however, the liquid slurry of aluminum sulfate and sodium aluminate should be sprayed onto the wetland. The spray should be applied to the floor of the wetland and not sprayed directly on shrub vegetation. The estimated cost of the wetland treatment (including alum, sodium aluminate, soil testing, easements, permits, and labor) is about $45,000.

This treatment may be relatively short-lived due to (1) the rapid flushing rate of the wetland, (2) the shallow water depths in the wetland, and (3) the high rate of leaf litter deposition in the wetland. Because of shallow water depths, alum floc could be flushed out of the wetland during periods of high runoff. This would be especially true in areas of high flow velocity toward the center of the stream channel. In addition, high rates of leaf litter accumulation in the fall could rapidly cover over the alum floc thus reducing the longevity of treatment benefit. However, combined with the farmland soil amendment, the wetland treatment should enhance the overall effectiveness of the lake restoration plan.

Inflow Diversion

Because the load reduction benefits of farmland soil amendment and wetland treatment are uncertain, it is recommended that this agricultural inflow be diverted directly through the lake to the outlet. This will make it possible to perform whole-lake alum treatment with the confidence that treatment success will not be jeopardized by failure or low percentage TP removal of the farmland soil amendment and wetland treatment. Based on this strategy, a primary benefit of farmland soil amendment and wetland treatment will be to mitigate adverse impacts to the Inlet 1 stream itself, and at the same time, to avoid adverse water quality impacts downstream of Lake Ketchum in the outlet stream. This is ecologically sound because streams are less sensitive to elevated phosphorus levels than are lakes, and the anticipated load reduction with farmland soil amendment and wetland treatment should make it possible to implement diversion without adverse downstream water quality impacts.

It is recommended that inflow diversion be implemented concurrently with farmland soil amendment, wetland treatment, other watershed BMPs, and whole-lake alum treatment. The plan will be to lay 2,300 feet of 12-inch, high-density polyethylene pipe on the bottom of the lake to divert flow from Inlet 1 to the outlet. The pipe would be anchored on the lake bottom so as to avoid interference with recreational activities. Implementation will include construction of a concrete flow control structure and groundwater flow cutoff trench where the inlet crosses South Lake Ketchum Road (see **Figure 6-1**). The intent of the cutoff trench is to intercept any groundwater that could be carrying high TP to the lake. The planning estimate for the cutoff trench is very preliminary due to lack of site specific soils information. It assumes a 50-foot-long trench, 15 feet deep and three feet wide, excavated and then back-filled with a low permeability silty-clay type soil material. This approach will need to be refined based on geotechnical analysis of the site during final design. A preliminary planning level cost for inflow diversion is approximately $320,000 (**Table 6-2**).

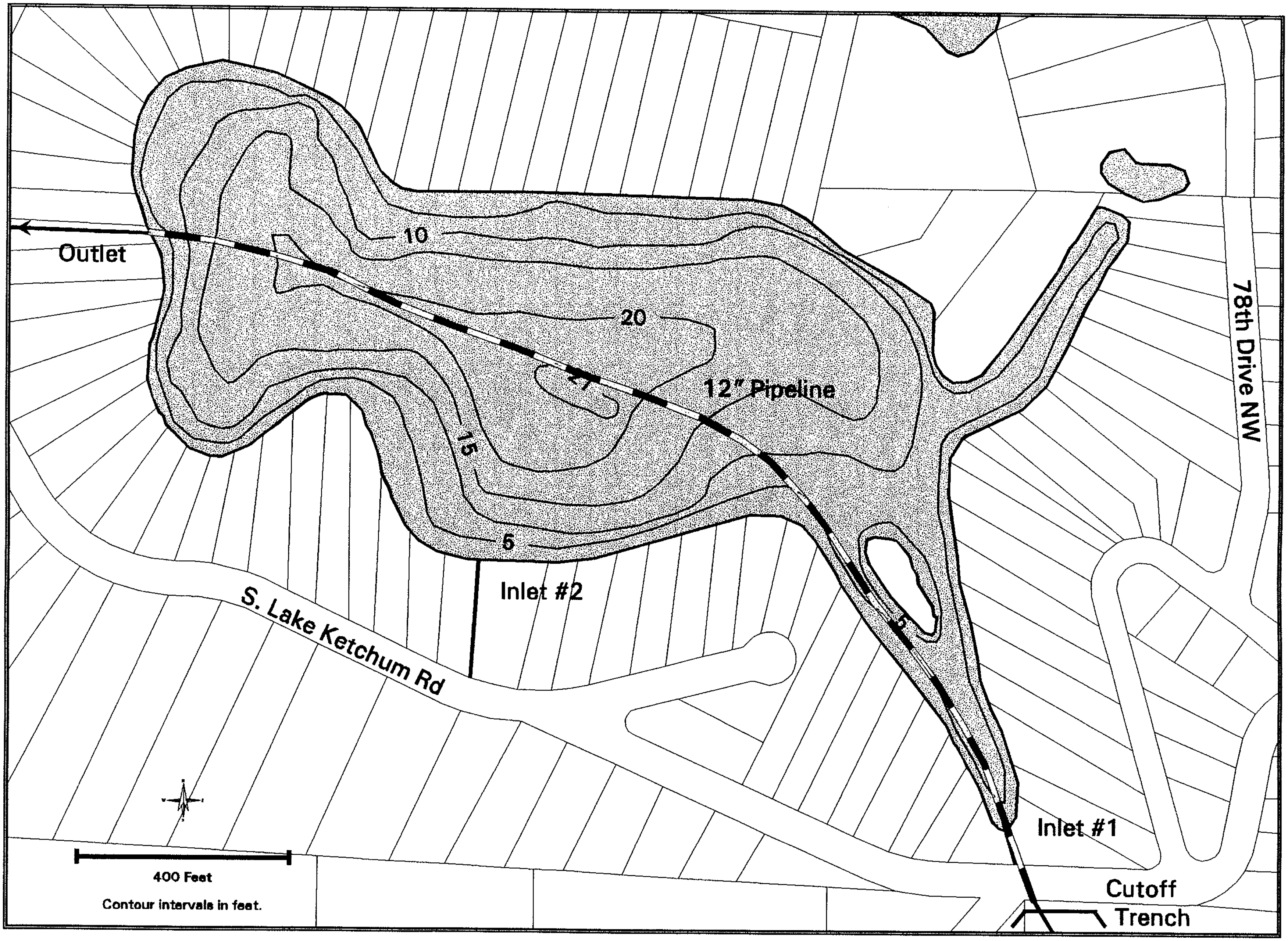

Figure 6-1. Proposed Inlet Diversion Pipeline

Table 6-2
Preliminary Planning Level Cost for Inflow Diversion

Item No.	Item Description	Quantity	Units	Unit Cost	$/Units	Cost
1	Mobilization	1	LS	10%	OF	$19,060
2	Traffic Control Labor (Assumed 10)	160	HR	$24	/HR	$3,840
3	HDPE Pipe, 12-inch Diameter (SDR 32.5)	2,300	LF	$50	/LF	$115,000
4	Concrete Class 4000 for Concrete River	28	CY	$350	/CY	$9,800
5	Steel rebar	11,050	LBS	$0.60	/LB.	$6,630
6	Diversion Structure	1	LS	$10,000	/LS	$10,000
7	Groundwater Cut-off Barrier	100	CY	$15	/CY	$1,500
8	Imported Controlled Fill Inc. Haul	100	CY	$15	/CY	$1,500
9	Temporary Erosion and Sediment	1	LS	$1,000	/LS	$1,000
10	Site Restoration	1	LS	$2,000	/LS	$2,000
11	Miscellaneous	1	LS	20%	OF	$30,254
12	Contingency	1	LS	5%	OF	$9,076
			Subtotal			$209,660
			Sales tax	8.2%		$17,192
			Total			$226,852
	Engineering/Design			25% of		$56,713
	Construction Administration			15% of		$34,028
	Grand Total					$317,593

Nationwide 404, Hydraulic Project Approval (HPA), and Temporary Water Quality Modification permits will be required along with easement acquisitions. These costs are included under the miscellaneous category in **Table 6-2**.

Assuming that the farmland soil amendment and wetland treatment provide some phosphorus reduction and that the whole-lake alum treatment is effective, downstream water quality will be better under post-implementation conditions than under existing conditions as discussed in the SEPA Environmental Checklist (**Appendix E**). This conclusion, combined with the fact that the outlet stream and Skagit Bay are much less sensitive to nutrient inputs than the lake, means that inflow diversion will protect Lake Ketchum without creating significant adverse impacts downstream. Another secondary impact issue is what impact will diversion of flow from Subbasins 6 and 8 have on summer lake levels. An HSPF analysis showed that summer lake levels would be lowered by less that 0.1 foot. This is considered an insignificant impact.

Whole-lake Alum Treatment

Whole-lake alum treatment can be performed using a variety of chemical treatment methods, but the method proposed for Lake Ketchum is buffered alum (a mixture of aluminum sulfate and sodium aluminate). As previously discussed, a successful alum treatment is predicated upon successful control of nutrients from the watershed using a concurrent combination of farmland soil amendment, wetland treatment, watershed BMPs, and inflow diversion.

Mitigating Measures for Potential Impacts - Jar tests are needed to determine proper dosage rates prior to application, and use of computerized dosing control systems can be used to accurately match the amount of aluminum sulfate with the volume of lake water at the point of application. Buffered alum (sodium aluminate) is used to reduce the risk of formation of toxic free aluminum and avoids potential toxicity to fish. The timing of application would be restricted to avoid periods of excessive algal production and to thus avoid oxygen depletion during or following treatment. Field monitoring of dissolved oxygen, pH and other parameters per the Ecology policy would be performed during application and be used as the basis for temporarily interrupting treatment if adverse water quality conditions occurred. Lime or soda ash could be made available as a contingency measure to restore pH balance, and aeration could be used to restore oxygen supplies in localized areas, if needed.

Treatment Mechanism - Buffered alum treatment is considered one of the more effective and long lasting in-lake nutrient and algal control techniques. Aluminum sulfate chemically binds with phosphorus and other particulates (e.g., algae and suspended sediment) in the water column as a "floc" (the floc forms somewhat like snowflakes in the water column) and settles to the lake bottom. Once on the lake bottom, the aluminum sulfate floc also binds phosphorus at the sediment-water interface, thus preventing the release of sediment phosphorus from contributing to algal bloom formation (**Cooke et al. 1993**). In addition to reducing the total amount of algae in lakes, there is evidence that alum treatments can result in shifts in the relative abundance of algal species, reducing the presence of one or two dominant blue-green species (like *Anabaena spp. or Aphanizomenon flos-aquae*), and favoring a more balanced and diversified mix of blue-greens, greens, and diatoms (**Welch and Cooke 1995**).

Reliability - Welch and Cooke (**1995**) report that six out of nine shallow (average depth of 12 feet or less), non-stratified lakes, and three, deeper stratified lakes (similar to Lake Ketchum) have been successfully treated with aluminum sulfate. Treatments were successful in lakes where external loading was either not a problem, or was adequately controlled. In the successfully treated shallow lakes, lake water column phosphorus concentrations declined by 29 to 75 percent. Reductions of internal phosphorus release can range from 72 to 100 percent (**Entranco 1987a and 1987b**).

Alum treatments failed in lakes with excessive, uncontrolled external loading, or extensive aquatic plant beds. Aquatic plants take up nutrients from sediment depths below the effective depth of the alum floc and use these nutrients to build new plant tissue. Later in the season, when the plants decay, these nutrients are recycled back into the water column. In some alum treated lakes, post-treatment water clarity improves sufficiently to encourage more extensive development of aquatic plants (**Entranco 1986**). This can lead to a rapid decline in water quality unless contingency aquatic plant control measures are implemented.

Either of these conditions—high external loading or excessive aquatic plant growth—could limit the effectiveness of alum treatment in Lake Ketchum. Measures to control external loading must be implemented concurrently with the alum treatment. Measures to control aquatic plants should be ready to implement at the first indication of increased aquatic plant growth following treatment.

Estimated Load Reduction Potential - Total load reduction potential for Lake Ketchum under present conditions would be 194–270 kgP/year (72–100 percent of the 271 kgP/year estimated existing internal loading). This load reduction would represent 36 to 50 percent of the total (external plus internal) existing phosphorus load of 540 kgP/year.

Longevity of Treatment - Treatment benefits are both immediate and long term, with benefits from a single application lasting at least eight years in shallow, non-stratified lakes, and as long as 13 to 19 years in deeper, stratified lakes (**Welch and Cooke 1993**). The longevity of treatment is likely to be shortened in cases where (1) high external loads (surface or groundwater) are not controlled, (2) high aquatic plant growth exists—or develops following treatment, or (3) external loads increase following treatment. As indicated above, these problems could limit the longevity of treatment in Lake Ketchum, making it difficult or impossible to predict how long an alum treatment will be effective. For planning purposes, it is best to assume that the alum treatment will need to be repeated in 5 to 10 years.

Engineering Feasibility - Aluminum sulfate has been applied on ten or more lakes in the State of Washington, and engineering feasibility has been clearly proven (**Funk et al. 1975; Entranco, Inc. 1980, 1986, 1987a and 1987b; Jacoby et al. 1994, Welch and Cooke 1995**). At Lake Ketchum, where internal loading is unusually high and lake sediment chemistry seems somewhat unique, jar testing with water overlying lake sediment is recommended. Jar testing under simulated anoxia also should be considered.

Estimated Cost - Aluminum sulfate treatment is relatively inexpensive compared to most other nutrient control techniques. The cost of whole-lake treatment for Lake Ketchum is estimated at $130,000 and assumes that sodium aluminate would be used for buffering (**Table 6-3**). There are no operation and maintenance costs per se, but treatments would have to be repeated periodically as noted above. Supportive aquatic plant control programs also may be necessary. This cost would include jar testing, permitting, environmental review (assumes environmental checklist) and field monitoring during application.

Table 6-3 Preliminary Planning Level Cost for Whole-Lake Alum Treatment	
56 dry weight tons of aluminum sulfate @ $160/ton	$9,000
Truck haul from Tacoma, Washington	$4,000
28 tons of sodium aluminate @ $310/ton	$8,700
Truck haul from Washougal, Washington	$3,300
Mobilization/demobilization	$10,000
Labor ($25/hour for two people for 60 hours)	$3,000
Monitoring/jar tests	$35,000
Engineering	$20,000
Environmental Review/Permits	$7,500
Subtotal	$100,500
Contingency @ 20%	$20,100
Subtotal	$120,600
Sales tax @ 8.3%	$10,000
Total Preliminary Planning Level Estimate	**$130,600**

Cost Effectiveness - To determine cost-effectiveness, the whole-lake alum treatment is assumed to last ten years, effectively preventing the loading of 1,940–2,700 kgP over the ten-year period. Based on the preliminary estimates, aluminum sulfate would cost $48–$67 per kgP removed.

Use Restrictions and Permits - Use of aluminum sulfate for whole-lake treatment requires a Short-Term Water Quality Modification permit and compliance with dosage determinations, monitoring programs and other elements of the Washington State Department of Ecology's (Ecology) Aluminum Sulfate Treatment Policy (**March 11, 1991**), including concurrent implementation of watershed controls for nonpoint nutrient sources. Application would require an HPA permit from the Washington State Department of Fish and Wildlife (WDFW).

Potential Adverse Impacts - The potential for fish kills with alum treatment is avoided with the use of buffered alum solutions, as proposed. Other potential adverse impacts include: (1) short-term reduction (about two months) in zooplankton numbers and diversity, (2) possible temporary adverse impacts on benthic fish food insects, (3) possible reduction in carrying capacity for fish following reduction in primary productivity (algal growth), and possible related food chain effects, (4) possible anoxia if the treatment causes too much algae to settle to the lake bottom at one time, and (5) possible adverse impacts to public health (**Cooke et al. 1993, Entranco, Inc. 1987a and 1987b, and Skagit County Planning Department 1984**).

Regarding effects on public health, aluminum is one of a number of suspected causative agents associated with Alzheimer's disease, a disease that causes loss of memory. However, aluminum sulfate has been widely used to treat drinking water supplies and there are no criteria for aluminum concentrations in drinking water at this time. Also, aluminum is found in quite high concentrations in the normal diet, since it is the third most abundant element in the earth's crust and is also an ingredient in certain foods (e.g., sweet pickles) and antacids. Therefore, the risk of ingesting large quantities of aluminum from lake or groundwater supplies seems very small compared to the amounts of aluminum that are ingested through normal diet and over-the-counter medications.

Impacts to benthic aquatic insects could be partially mitigated by establishing proper dosing rates using laboratory jar tests to ensure that dissolved aluminum remains below the EPA criteria of 87 µg/l for sensitive aquatic species (**EPA 1988**). Monitoring of aquatic insect populations before and after treatment also could be performed to assess impacts. If temporary impacts are clearly established by the monitoring program, they could be mitigated with artificial fish feeding programs and/or re-colonization of benthic insect populations from other lakes or untreated near-shore Lake Ketchum sediments.

In addition, the treatment would be phased over several days so as to limit impacts to given lake sectors at one time. However, if phasing is extended over a longer time frame, treatment cost would probably increase.

There is no known cure for Alzheimer's disease at the present time, nor are there any EPA or Washington State Department of Health drinking water criteria for aluminum. However, there is no conclusive evidence that aluminum sulfate treatment is a cause of Alzheimer's disease. Furthermore, since aluminum sulfate is still widely used in the treatment of public drinking water supplies, and because it is ingested in relatively large quantities in the normal diet, it has been concluded that the public health risk is small with the intended lake restoration use. Nevertheless, to ensure public health and safety, jar tests would be performed to determine proper dosage and buffered alum also would be used to limit the levels of dissolved aluminum in the water column following treatment. Monitoring of down-gradient domestic wells for total and dissolved aluminum before and after treatment also could be performed. Finally, a public health risk assessment could be performed by public health specialists.

Implementation of such monitoring and/or other mitigation measures could add significantly to the cost of treatment and is not covered in the planning-level cost estimate in **Table 6-3**.

Watershed Best Management Practices (BMPs)[1]

Land development, household practices, timber removal, and commercial and non-commercial agriculture generate pollutants and nutrients that flow into Lake Ketchum. Specific sources of

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[1] Many of the following descriptions are adapted from the *Blackman Lake Phase I Restoration Study,* KCM Inc., June 1994 and the *North Creek Watershed Management Plan,* Snohomish County Public Works, September 1994.

these pollutants include use of lawn and garden fertilizers, pesticides, and other common household chemicals; soil erosion from construction sites; animal wastes and fertilizers from farming; increased runoff from impervious surfaces; discharges from septic systems; increased waterfowl populations; and many "housekeeping" activities.

Although the impacts of agricultural runoff are many times grater than the cumulative impacts of other nonpoint pollution sources in the Lake Ketchum watershed, it is important to recognize and address all of the potential sources of pollution if the long-term health of the lake is to be protected. Establishing and maintaining good water quality in Lake Ketchum depends on the willingness and cooperation of everyone who lives, works, and plays within the watershed.

Watershed restoration requires sound land use, household construction, and drainage practices. To accomplish this, BMPs for households, agriculture, and development have been designed in recent years to prevent or reduce pollution from nonpoint sources. Many of these BMPs have no specific costs associated with them because they require changes in the behavior of individual residents or actions on individual properties around Lake Ketchum. Such costs cannot be easily quantified. However, the costs of public education to encourage these practices (PIE) is an identified cost of the restoration project.

The recommended BMPs for reducing watershed pollution in Lake Ketchum are described in detail in the following sections. These include a proposed Public Education and Involvement program; BMPs for septic systems, residential lots, households, new development, agriculture, forestry, roads, and waterfowl; and protection of existing wetlands. For each proposed BMP, the responsibilities and costs (to the extent that they can be identified as restoration project costs) also are summarized.

Predicting the positive impacts of BMPs on water quality is difficult. Each property in the watershed is unique; and the willingness or thoroughness of individual property owner actions is unknown. However, if all of the proposed BMPs are implemented in the Lake Ketchum watershed, nutrient pollution from these sources could be reduced by 5 percent to 20 percent. And, improvements on individual properties (such as reducing fertilizers on a lawn that used to be heavily fertilized or cleaning a septic system that was poorly maintained) could cut pollution from those specific properties by 50 percent or more. These projected ranges of pollution reduction are based on assumptions used in past lake studies in Snohomish County and on personal opinion. Therefore, they should be used with caution. However, it is clear that implementation of BMPs will result in a positive impact to the lake, even if the impact cannot be accurately predicted.

Public Involvement and Education

Effective, on-going public education is necessary to implement many of the recommended watershed BMPs described on the following pages. Citizen commitment is also necessary to sustain the lake restoration effort in the long run. Public education is most effective if it involves citizens in the actions to protect water quality and if it is fueled by citizen energy and enthusiasm. Therefore, the following goals and strategies are recommended with the assumption that citizens will have the primary responsibility for coordinating public education and motivating their neighbors to protect Lake Ketchum.

Goals of Public Education and Involvement:

1. Educate neighbors about their contributions to lake pollution and the actions (BMPs) they can take to improve lake water quality.
2. Involve neighbors in community activities to protect the lake.
3. Keep lake protection issues visible in the community.
4. Keep citizens aware of water quality problems and progress of the lake restoration project.

Recommended Public Education And Involvement Strategies:

The recommended public education and involvement strategies are listed and then described in detail on the following pages.

Community Organization:	Education Committee Club Meetings Watershed Watch
Ways to Get the Word Out:	Newsletters/Flyers Stationery/Logo Community Workshops Lake Festivals Educational Talks Signs/Posters Media Coverage Videos Welcome for New Residents
Ways to Involve the Community:	Septic Inspection and Pumping Program Clean-up Days School and Scout Outreach Home Parties Demonstration Homes

Community Organization

Education Committee: The Ketchum Shores Improvement Club should form a permanent Education Committee to coordinate on-going public education outreach efforts.

Ketchum Shores Improvement Club Meetings: The Ketchum Shores Improvement Club should serve as the primary community organization for coordinating overall implementation of the lake restoration plan. Lake water quality issues and restoration progress should be topics at the semi-annual Club meetings. These meetings could also be a forum for presenting new information about BMPs for individual homeowners to protect the lake. The Club should work closely with the Wilderness Ridge Community Club and other community organizations to maintain a broad base of support for the lake restoration.

Watershed Watch: The Club should designate one or more persons to serve on the Watershed Watch. These citizens would be trained by Snohomish County to watch for potential grading, drainage, clearing, and development activities that might threaten lake water quality, and to notify appropriate authorities for action. They also would be available for neighbors to call and report water quality problems. Members of the Watershed Watch would be knowledgeable about lake water quality issues and be able to answer citizens' questions about the lake.

Ways to Get the Word Out

Newsletters/Flyers: The Education Committee should be responsible for producing regular newsletters or flyers to keep citizens informed about lake water quality issues and ways they can help the lake. There should be at least two newsletters per year circulated to all watershed residents. Topics that should be covered in the newsletters or flyers include: 1) notice of community events addressing lake water quality; 2) BMPs, such as reducing lawn fertilizers, using non-toxic household products, planting native plant buffers along the shoreline, etc., and 3) progress of the lake restoration actions. Snohomish County staff should provide technical assistance to citizens for the technical topics in the newsletters.

Stationery/Logo: The existing logo developed for the Lake Ketchum Phase I study should be used for all newsletters and correspondence to maintain an identity for the lake restoration education efforts.

Community Workshops: At least one public workshop should be held each year to inform and educate watershed residents. Discussion topics should include progress of the lake restoration project and ways that homeowners can protect water quality. All watershed residents and lake users should be notified of these workshops.

Lake Festivals: Annual festivals could be held at the lake in the summer to bring neighbors together to celebrate the lake restoration and to learn about ways to protect the lake. Fun events, such as boating activities, could be included to attract more people for the festivals. A lake festival could also be held for the opening of Lake Ketchum Park if it is developed as part of the restoration efforts.

Educational Talks: Snohomish County staff and citizen volunteers should be available to talk to other citizens about specific BMPs techniques. These talks could be hosted in neighborhood homes. Snohomish County staff should provide technical information to be used in the talks.

Signs/Posters: Permanent signs or a changeable sign board should be designed and installed at the public boat launch. These signs should inform lake users about ways to protect the lake and about the problems of feeding waterfowl. Also, posters created by local school children could be displayed on such a sign board. Signs identifying the boundaries of the Lake Ketchum watershed should be placed along roads to help people identify with the Lake Ketchum watershed and recognize their role in protecting the lake. If the two large wetlands in the watershed are afforded permanent protection, signs should be posted there to explain the wetlands' importance in filtering out pollution and protecting water quality.

Media Coverage: Local newspapers, such as The Stanwood-Camano News and North Snohomish Weekly should be kept informed about lake restoration and education activities. Citizens could write articles for the newspapers or invite reporters to learn about lake activities.

Residents also could write letters to the editors of local papers to keep the lake water quality issues visible with the public.

Videos: Existing videos (about topics such as septic systems, landscaping with native plants, etc.) should be made available for citizens to view in their own homes or at home parties (see below). Residents also could tape their own videos showing steps they have taken to protect water quality around their homes.

Welcome for New Residents: Volunteers should work with local realtors to get information on BMPs to prospective and new property owners in the watershed. Volunteers also could meet with new residents to provide brochures and other information about lake protection. County staff should provide information packets of existing brochures.

Ways to Involve the Community

Septic System Inspection and Pumping Program: A voluntary septic system inspection and pumping program should be organized at Lake Ketchum. This program could be used as another educational activity for residents.

Clean-up Days: The Ketchum Shores Improvement Club should organize occasional clean-up days. Volunteers would work together to clean up the Lake Ketchum Park or streams and drainage ditches around the lake. This could be followed by a potluck dinner to build community.

School and Scout Outreach: Local school classes and scouting groups could be encouraged to learn about Lake Ketchum water quality and to participate in activities such as clean-up days and informational posters.

Home Parties: Neighbors could host parties in their homes to discuss their experiences with environmentally safe cleaning products, landscaping with native plants, and other BMPs.

Demonstration Homes: One or more local residents could restore or enhance the native vegetation along their lakeshore or make other improvements to protect water quality. Then, they could invite other citizens to tour their property and learn about successful techniques.

COSTS OF PUBLIC EDUCATION AND INVOLVEMENT STRATEGIES

Estimated annual costs for implementing the strategies described above are:

Community Organization	$2,500
Ways to Get the Word Out	$4,000
Ways to Involve the Community	$1,500

These costs include supplies, printing, postage, volunteer time, and County staff time.

Improved On-site Septic Systems

On-site waste disposal (septic) systems typically consist of a septic tank and a drainfield. Properly functioning septic systems effectively remove pathogens (bacteria and viruses) and parasitic microorganisms, as well as most nutrients. However, poorly functioning drainfields can be a significant source of nutrients. Septic systems currently contribute about 4 percent of the phosphorus to Lake Ketchum each year. This does not make septic systems one of the largest sources of pollution, but it does indicate that improvements to septic systems can have a positive effect on the lake.

The effectiveness of a septic system is first of all a function of local hydrology and soils. Some soils are poorly suited for on-site disposal systems because of extremely low or high permeability. Most of the soils in the Lake Ketchum watershed are highly permeable Everett and Winston soils which allow wastewater to percolate too quickly and may not provide adequate treatment. On the other hand, the Mukilteo muck soils near the boat launch and Terric Medisaprist soils near the northeast wetland are poorly drained wetland soils that do not allow water to percolate into the soil. Also, Tokul soils in the south end of the Lake Ketchum watershed have hard pan at depths of 20 to 40 inches which may limit the effectiveness of septic drainfields. In these areas, drainfield effluent can flow laterally above the hardpan and seep into nearby surface drainages.

In addition, the following factors also affect septic system performance:

- Age of the system
- Drain field location
- System design and sizing
- Construction techniques
- Inspection and maintenance practices
- User habits (water use, chemicals, etc.)

If poor maintenance causes septic tanks to fill up and drainfields to clog, effluent (what flows out into the drainfield) is no longer able to percolate into the soil. When the volume of effluent exceeds the soil's carrying capacity, effluent may pond at the soil surface, mix with stormwater runoff, and enter the lake. This situation is considered a septic system failure.

Fortunately, the septic system dye tests conducted as part of the lake restoration study did not find any failing septic systems at Lake Ketchum. However, because of the factors listed above, some systems may be contributing nutrients to the lake without showing obvious signs of drainfield failure.

To prevent water quality impacts from septic systems, the following BMPs should be implemented at Lake Ketchum. (The Snohomish County Health District can provide more specific guidance.)

BMP-1 Establish a volunteer managed septic system inspection and pumping program for the lake watershed. Sometimes, septic pumpers are willing to give discounts if several septic tanks are inspected or pumped on the same day.

BMP-2 Inspect each septic tank every two years and pump out the tanks when they are half-filled with solids. Typical costs for pumping a septic tank are $250 to $300. Generally, a septic tank will need to be pumped approximately every three to four years.

BMP-3 Limit the use of automatic dishwashing detergents that contain phosphates. Limit the use of chlorine bleach or other antibiotics that can harm septic drainfield bacteria performance. Septic system additives should not be used.

BMP-4 Do not use garbage disposals (food grinders). Residents should be informed of the detrimental effects of garbage disposals on septic systems and encouraged not to use disposals. Composting of organic wastes also should be encouraged.

BMP-5 Keep all vehicle and heavy foot traffic off drainfields to prevent soil compaction. Maintain low growing vegetation over drainfields. Large trees and shrubs can collapse pipes and interfere with infiltration.

BMP-6 Conserve water (especially considering the newly installed public water system around the lake) as a means of reducing the amount of water handled by the septic systems and thereby improving their performance.

	BMP Summary	**Responsibility**	**Cost**
BMP-1	Establish voluntary septic inspection and pumping program	Ketchum Shores Improvement Club to organize and manage	$750 per year
BMP-2	Inspect septic tanks every two years and pump out as needed	Individual private property owners encouraged through education	Individual property owners responsible for inspection/ pumping costs; Public Involvement & Education (PIE) program provides education
BMP-3	Limit use of automatic dishwashing detergents and chlorine bleaches. Do not use septic tank additives	Same as above	Part of PIE program
BMP-4	Do not use garbage disposals	Same as above	Same as above
BMP-5	Keep vehicle and foot traffic off drainfields	Same as above	Same as above
BMP-6	Conserve water to improve septic system performance	Same as above	Same as above

Alternative Landscaping and Residential Lot Restoration

As development has occurred in the Lake Ketchum watershed, native vegetation and trees have been replaced by houses, driveways, lawns, and gardens. These features of residential land use contribute the following impacts to the lake:

- Excess nutrients (e.g., nitrates and phosphates) from lawn and garden fertilizers, yard wastes, and burn piles;
- Toxic pollution from pesticides, herbicides, and paint products; and
- Increased stormwater runoff from impervious (hard) surfaces.

Proper landscaping and other site restoration practices can help control runoff, prevent erosion, and reduce water pollution. Property owners in the Lake Ketchum watershed are encouraged to implement the following maintenance practices as part of the long-term restoration of Lake Ketchum:

BMP-7 Preserve or replant native vegetation along wetlands, streams, and the lake shoreline. If vegetation must be removed, replant with native species of shrubs and ground cover. Plants help to intercept surface runoff and filter nutrients from the water. Where necessary, install fencing along stream and wetland buffers to prevent damage by livestock, people, or vehicles.

BMP-8 Limit the total amount of impervious surfaces on a site. Use gravel or stepping stones in place of concrete for patios and walks to increase soil absorption of runoff water. Rely upon straw, newspapers, or bark instead of plastic film for mulching.

BMP-9 Establish and maintain vegetated filter strips, berms, swales, or buffers downhill from houses, gravel parking areas, driveways, and other impervious areas. The vegetation will filter out pollutants and sediment.

BMP-10 Never pipe runoff from roofs or paved surfaces directly to the lake. Instead, direct downspouts and drains into french drains, detention basins, grass-lined swales, or vegetated filter strips. Ideally, runoff should be allowed to infiltrate back into the ground before it reaches the lake so it has more opportunity for natural filtration.

BMP-11 Dispose of grass clippings, tree cuttings, ashes, and other debris as far from the lake as possible. Try composting these materials and using the resulting humus for fertilizer.

BMP-12 Locate yard debris burn piles as far as possible from the lake. Move recreation fire pits back from the water at least 30 feet. Toxins and nutrients in ash residue contribute to lake degradation.

BMP-13 Use lawn and garden fertilizers sparingly and apply them accurately. Consider using no fertilizer at all within 25 feet of the water and only "no phosphate" lawn fertilizer during the summer.

BMP-14 Do not use pesticides and herbicides near the water. Away from the water, avoid spraying herbicides and pesticides on windy days. Read labels carefully and avoid using toxic products in excess or during poor weather. Apply pesticides sparingly and only when pests are seen.

BMP-15 Conserve water when irrigating lawns and gardens. This decreases runoff that can carry nutrients, pesticides, and sediment into the lake. Water thoroughly in the early morning or early evening, only once or twice per week. Mow grass at a height of 2 inches or more to help the grass protect its own water supply.

BMP-16 Wash vehicles at a commercial auto wash or on the lawn as far from the lake as possible, rather than the driveway or parking area, so the grass and soil can filter the wash water.

	BMP Summary	Responsibility	Cost
BMP-7	Preserve or replant native vegetation along lake shoreline, streams, and wetlands	Individual property owners encouraged through education	Individual owners pay for implementation; PIE program covers education
BMP-8	Limit impervious surfaces	Same as above	Same as above
BMP-9	Establish filter strips, berms, swales, or buffers downhill from impervious surfaces	Same as above	Same as above
BMP-10	Direct roof and driveway runoff into french drains or grassy areas rather than directly to the lake	Same as above	Same as above
BMP-11	Dispose of yard waste away from lake or try composting	Same as above	Same as above
BMP-12	Locate burn piles and fire pits as far from the lake as possible	Same as above	Same as above
BMP-13	Use lawn and garden fertilizers sparingly and none within 25 feet of water	Same as above	Same as above
BMP-14	Limit use of herbicides and pesticides and do not use near water	Same as above	Same as above
BMP-15	Conserve water when irrigating lawns and gardens	Same as above	Same as above
BMP-16	Wash vehicles on grass rather than driveways	Same as above	Same as above

Alternative Household Practices

Activities inside homes, garages, and storage sheds can also affect the water quality of Lake Ketchum when toxins and nutrients enter the septic system or spill onto the ground. Changing household practices to protect water quality is not easy. But, if residents realize the importance and potential benefits of responsible household practices, such changes can occur. The following actions should be encouraged through the on-going public education program for watershed residents:

BMP-17 Use biodegradable, low phosphate cleaning products. Use non-toxic substitutes for commercial cleaning products. Try to use products with the lowest phosphate content. Also, use low or non-phosphate brands of dishwashing detergents.

BMP-18 When handling paints, solvents, or preservatives, never wash containers or brushes in areas where the wash water will drain directly into the lake or to a drain pipe. Dispose of unused products through organized hazardous waste collection events.

Conserving water, as described earlier, is also an important household practice to improve septic system performance.

	BMP Summary	Responsibility	Cost
BMP-7	Use low phosphate cleaning products and dishwashing detergents	Individual property owners encouraged through education	Individual owners pay for implementation; PIE program covers education
BMP-8	Avoid washing paints, solvents, and other toxic products into the lake or drain pipe; dispose of these products properly	Same as above	Same as above

Improved Development Practices

Land use activities that replace natural vegetation with houses, driveways, and lawns typically result in increased runoff. Cumulatively, such changes from development throughout the watershed, whether it be a large complex or a single house, increase the volume of runoff and nutrients to Lake Ketchum.

The following principles for managing development in the Lake Ketchum watershed will protect water quality by reducing the quantity and velocity of runoff, controlling erosion and sedimentation, and filtering out pollution.

BMP-19 Adopt improved Snohomish County Drainage and Grading Codes (Titles 24 and 17) consistent with the 1992 Washington State Department of Ecology (Ecology) Stormwater Manual to control the rate of runoff, prevent soil erosion during construction, and provide water quality treatment of runoff. The revised codes should require new development to:

- limit the rate and amount of runoff to the lake;
- to the extent feasible, infiltrate all runoff into the soil;
- provide effective erosion and sedimentation controls during and after construction (e.g., biofiltration systems, retention ponds, sediment traps, and soil covers);
- control the timing of vegetation removal and exposure of soils during construction, particularly during the rainy season;
- immediately revegetate disturbed areas; and

- provide water quality treatment (biofiltration or infiltration) for runoff during all smaller storms.

(Adoption of revised drainage and grading codes is required as a condition of the County's new National Pollutant Discharge Elimination System (NPDES) permit. Optimistically, adoption will occur by the end of 1997.)

BMP-20 Require new development to provide 25- to 100-foot buffers of undisturbed soil and vegetation adjacent to streams and wetlands in accordance with Snohomish County rural area buffer requirements (SCC 32.10.520).

BMP-21 Limit clearing of vegetation adjacent to the lakefront during development.

BMP-22 Provide effective enforcement of County and State development regulations and permit conditions.

	BMP Summary	Responsibility	Cost
BMP-19	Adopt improved County Drainage and Grading codes consistent with 1992 Ecology Stormwater Manual	Snohomish County	Within existing work program
BMP-20	Maintain 25- to 100-foot buffers adjacent to streams and wetlands per County code	Snohomish County to enforce and private property owners to implement	Within existing County budget; for private owners, PIE program provides education
BMP-21	Limit clearing next to the lake	Individual property owners encouraged through education	Part of PIE program
BMP-22	Provide effective enforcement of development regulations	County enforcement staff with monitoring by citizens' Watershed Watch	Within existing County budget; part of PIE program

Improved Agricultural Practices

Pollutants most often identified with animal production and agricultural activities are sediments, nutrients, organic materials, pesticides, and bacteria. Activities that generate these pollutants include animal confinement, overgrazing of pastures, unrestricted livestock access to streams and wetlands, and improper application of animal wastes or irrigation to pastures or hay fields. Improper application of animal wastes to pasture lands has been identified as a significant source of nutrients in the Lake Ketchum watershed.

The Cooperative Extension Service and the Snohomish County Conservation District (SCD) offer advice and assistance in implementing agricultural BMPs. Farm owners, especially owners of the cattle from south of 308th, should implement the following BMPs to reduce discharge of nutrients and bacteria and to diminish the impacts to groundwater, surface water, streams, wetlands, and Lake Ketchum:

Pasture Restoration

BMP-23 Prevent overgrazing caused by too many animals in a given area. Divide pasture land into several areas for rotation, allowing adequate time for plant regrowth. Restrict grazing from late fall through early spring when grasses are vulnerable to overgrazing. (Animal traffic on wet soil can result in significant soil compaction, and subsequent erosion.)

BMP-24 Re-seed pastures with traffic-tolerant and grazing-tolerant grasses and legumes when the need is indicated by lack of adequate forage and ground cover.

BMP-25 Fence all livestock out of fragile riparian areas and seasonally wet areas. Do not allow grazing or access within 50 to 100 feet of streams and wetlands

BMP-26 Limit fertilization to only the amount needed for healthy pasture growth.

Waste Management

BMP-27 Avoid confinement of livestock within 100 feet of streams, wetlands, and seasonally wet areas. Divert runoff from barns, sheds, pens, and corrals away from natural surface waters and into biofiltration or infiltration facilities.

BMP-28 Locate waste storage areas at least 100 feet from wet areas, on a concrete floor with containment walls and a roof.

BMP-29 Spread manure on pastures or hay fields only during late spring and summer. Apply it evenly and not in excess of requirements.

	BMP Summary	**Responsibility**	**Cost**
BMP-23	Prevent over-grazing and restrict wet season grazing	Technical assistance from SCD; implementation may be required by Ecology as condition of potential enforcement action	Farmers responsible for costs of implementation; Ecology and SCD actions within current budgets
BMP-24	Reseed pastures as needed to maintain healthy grass	Same as above	Same as above
BMP-25	Fence livestock out of wet areas	Same as above	Same as above
BMP-26	Limit fertilization	Same as above	Same as above
BMP-27	Avoid livestock confinement within 100 feet of wetlands and streams	Same as above	Same as above
BMP-28	Locate waste storage more than 100 feet from wet areas	Same as above	Same as above
BMP-29	Spread manure only during dry seasons	Same as above	Same as above

Improved Forestry Practices

Timber removal is often one step in the land development process in a semi-rural area like the Lake Ketchum watershed. One of the most effective ways to mitigate adverse water quality impacts from forestry practices is to provide and preserve adequate buffer zones adjacent to streams, wetlands, and the lake.

The Washington State Department of Natural Resources (DNR) is responsible for oversight of forestry practices. DNR has authority to define no-harvest areas, such as 25- to 100-foot corridors along stream banks, to reduce water quality impacts. Forestry practices, especially plans for clear-cutting and conversion to non-forest uses, should be carefully reviewed and monitored in the Lake Ketchum watershed with the goal of protecting water quality.

In the Lake Ketchum watershed, the following principles for managing forestry-related runoff are recommended:

BMP-30 Maintain no-harvest buffer zones next to the lake, streams, and wetlands as required by DNR regulations.

BMP-31 Control sediment and erosion in logged areas.

	BMP Summary	Responsibility	Cost
BMP-30	Maintain no-harvest buffers adjacent to all streams, wetlands, and the lake as required by DNR regulations	Department of Natural Resources; citizens' Watershed Watch to monitor	Within DNR budget; part of PIE program
BMP-31	Control erosion and sediment in logged areas	Owners of forest lands encouraged by education; citizens Watershed Watch to monitor	Part of PIE program

Improved Road Drainage Maintenance Practices

Stormwater runoff is the primary means of transporting nonpoint pollution from roadways. Pollutants accumulate on shoulders and paved surfaces from vehicle emissions, atmospheric deposition, spills, and leaks. They are then washed off the roadways during storms and run off into nearby water bodies via ditches or into groundwater through permeable soils.

Maintaining vegetation in roadside ditches is critical to preventing erosion, filtering sediment, and removing pollutants through biofiltration. Biofiltration uses vegetation (such as grassy ditches) to "filter" the pollutants from runoff. Because most of the soils that line the ditches in the Lake Ketchum watershed are excessively well drained, most of the runoff in ditches infiltrates rapidly through the bottom of the ditch into the shallow groundwater. Together with biofiltration, this serves to filter many of the pollutants out of the runoff.

The following measures are recommended for managing runoff from roadways in the Lake Ketchum watershed:

BMP-32 Protect the existing system of open, vegetated roadside ditches in the Lake Ketchum watershed. Do not allow ditches to be enclosed in culverts or pipes, except to provide vehicular access to properties.

BMP-33 Maintain roadside ditches in a manner that minimizes soil disturbance and promotes a healthy layer of vegetation.

BMP-34 Inspect ditches and culverts annually for signs of erosion. Reseed as needed.

	BMP Summary	Responsibility	Cost
BMP-32	Protect existing open, vegetated roadside ditches; do not allow culverts or pipes except for vehicular access	Snohomish County through right-of-way permit and development review; individual citizens through education	Within current County budget; education part of PIE program
BMP-33	Maintain ditches to avoid bare soil and protect grass	Snohomish County road crews	Within current budget; education through PIE program
BMP-34	Inspect ditches annually and reseed as needed	Snohomish County road crews; citizens' Watershed Watch to help monitor	Within current budget; part of PIE program

Waterfowl Control

The waterfowl population at Lake Ketchum is not currently a concern. However, waterfowl do contribute nutrients to the lake through their fecal material. A single bird can contribute anywhere from 0.5 grams of total phosphorus per day (mallards) to 1.3 grams per day (geese). When birds are present in large numbers, their phosphorus contribution can be significant. Feeding waterfowl can cause them to stay in one location for longer periods than normal, or even stay at a lake year-round. Most human food is also harmful to the birds.

Waterfowl are also intermediate hosts of the parasites that cause one of the forms of "swimmer's itch." Keeping waterfowl populations in check will reduce the potential of a swimmer's itch outbreak.

To maintain the low, natural waterfowl populations at Lake Ketchum, the following actions should be taken:

BMP-35 If the public boat launch property is included in the development of a new park, design and post a sign to discourage the feeding of waterfowl.

BMP-36 Educate all watershed residents and lake users about the negative impacts of feeding waterfowl.

	BMP Summary	Responsibility	Cost
BMP-35	Design and post a sign at boat launch to discourage feeding of waterfowl	Snohomish County SWM	$400
BMP-36	Educate residents about problems of feeding waterfowl	Ketchum Shores Improvement Club with assistance from SWM	Part of PIE

Control of Invasive Non-native Aquatic Plants

Lake Ketchum is not currently infested with invasive non-native aquatic plants, such as Eurasian watermilfoil and Brazilian elodea. However, Lake Goodwin and Lake Shoecraft, south of Stanwood, as well as lakes in Skagit County, have serious problems with Eurasian watermilfoil. So, the potential for introducing one of these plants into Lake Ketchum exists.

Invasive non-native aquatic plants have the ability to out-compete native aquatic plants and form dense stands of vegetation, virtually eliminating boating, swimming, and fishing in a lake. Therefore, the following actions should be taken to prevent the spread of non-native aquatic plants to Lake Ketchum.

BMP-37 Educate watershed residents and lake users about non-native aquatic plants. Post available signs and additional information at the boat launch.

BMP-38 Train Watershed Watch volunteers to look for invasive non-native aquatic plants in the lake and on boat trailers.

	BMP Summary	Responsibility	Cost
BMP-37	Educate lake users about invasive non-native aquatic plants	Ketchum Shores Improvement Club with assistance from SWM	Part of PIE
BMP-38	Train volunteers to look for invasive plants	Snohomish County SWM	Within existing budget

Wetland Protection

Long-term preservation of the northeast and southeast wetlands is important in restoring Lake Ketchum. These wetlands provide water flow into the lake during much of the year. And, the wetlands serve to filter out nutrients before they reach the lake.

In the case of the southeast wetland, this filtering function is especially critical. Water quality monitoring data indicate that total phosphorus concentrations coming off the farm are reduced 60 percent to 90 percent by the time water passes through the southeast wetland on the way to Lake Ketchum.

Therefore, one recommended element of the restoration plan is to preserve the existing conditions of these two large wetlands and protect them from destruction, encroachment, or loss of function.

Both wetlands are on private property. Most of the northeast wetland is located in one large parcel and the owners state that they intend to maintain the wetland in its current condition. The southeast wetland sits on portions of at least four properties. In the last two years, tree cutting and some clearing have occurred on two edges of this wetland. So, there are no assurances that this wetland will be preserved in its natural condition.

In principle, State and County codes would prevent filling, grading, and development of the wetlands. However, codes require active enforcement and, if illegal activities occur, agencies may not be able to ensure complete rehabilitation of the wetlands. Also, under existing codes, logging and clearing may be allowed. Therefore, the only sure means of permanently protecting the wetlands are through conservation easements or purchase.

Conservation easements are agreements by the land owners to forego any rights to modify or develop a wetland by granting an easement to another party. The easements could be granted to Snohomish County, the Ketchum Shores Improvement Club, or a public land trust. Conservation easements can result in tax savings for the land owner.

Therefore, the first step to preserve these wetlands is for representatives of the Club and Snohomish County to approach the land owners to discuss the possibility of conservation easements. The costs of discussing and negotiating easements is estimated at $5,000.

Other methods to permanently preserve the wetlands are either to purchase exclusive easements or to purchase the properties outright. These options would be considerably more expensive, probably in the range of $30,000 to $50,000. Moreover, actual purchase of the southeast wetland might be difficult because the area is zoned for five-acre minimum parcels and some of the existing lots may be too small to subdivide out just the wetland portiòns of the lots.

Macrophyte (Aquatic Plant) Control Contingency Plan

Aquatic plants play an important role in lake ecology. They provide hiding, resting, and living space for fish and other aquatic organisms (everything from snails and frogs to butterflies and insects). They also provide food for these aquatic organisms, waterfowl, and small mammals. Plants also directly benefit the lake's human population through providing shoreline protection, reducing lake turbidity, and providing a counterbalance for lake algal populations. However, aquatic plants can reach nuisance levels that greatly hinder recreational use of lakes as well as negatively impact fish habitat. Aquatic plant control should support a diverse aquatic plant community that is in balance with these needs.

Existing Conditions

Under existing conditions, the aquatic plant community in Lake Ketchum consists largely of what would be considered desirable species. The shallow, nearshore portion of this lake and most other lakes provide excellent habitat for aquatic plants. Short of removing the habitat (through for example a dredging effort), this nearshore area will always support plants. Desirable plant species are those whose growth habit (the height and density the plants attain) minimizes impact on use of the lake. Currently, the majority of the nearshore area in Lake Ketchum is comprised of a mixture of submerged plants; thin-leaved pond weeds (*Potamogeton spp.*), common waterweed, and Nitella (*Nitella*). Thin-leaved pond weeds do not typically reach problem densities, and Nitella (which is actually a macroalgae) is a low-growing plant that grows in deeper waters and is often not even observed by lake users. Common waterweed can reach nuisance heights and densities, but usually does not. During 1995, common waterweed (*Elodea canadensis*) was present at moderate densities. However, the plant was dense enough in 1996 to create nuisance conditions. There are also at least three beds of floating-leaved plants (water lilies) and emergents (cattails) that are found around the lake shore that have not reached a nuisance size. Given this mix of native, desirable plant species, any actions taken to control the plants should be approached with caution, because upsetting the community may give a competitive advantage to less desirable species.

There are two notable problem areas in the lake; these are the narrow embayments located in the northeast and southeast corners of the lake. In addition to dense growths of common waterweed, these embayments have dense accumulations of duckweed (*Lemna spp.*), coontail (*Ceratophyllum demersum*), and periphytic algae. These latter three plants and algae remove nutrients directly from the water rather than from the sediments through root uptake. These plants flourish under conditions of high nutrients and calm or stagnant conditions. Duckweed is in fact so efficient at taking nutrients out of the water, that it has been used to treat wastewater effluents. Due to this direct relationship between high lake nutrient concentrations and the occurrence of these plants and algae, lake restoration and the resultant decreased nutrient concentrations is expected to cause changes in the composition of the plant community in this area.

Predicted Future Conditions

Restoration of Lake Ketchum can be expected to impact plant communities through the long-term increase in transparency caused by the reduction in lake nutrients and reduction in algae. Most rooted aquatic plants are highly dependent upon light for growth. For example, waterweed and the pond weeds in Lake Ketchum do not extend much past the five-foot depth contour. At depths greater than five to seven feet, there apparently is not enough light available to meet the needs of these plants. Nitella on the other hand, prefers somewhat deeper water (less light) and is growing in the 5- to 10-foot depth range. However, if the water was clearer or more transparent, light would penetrate to greater depths, thus allowing plants to colonize deeper areas.

It is difficult to predict how the submerged plant community in the main body of the lake, will change as a result of increased transparency in the lake. A reasonable assumption based on conditions in other lakes, is that the submerged plant community may extend to the 15-foot depth contour. If the community composition stays the same, Nitella should colonize the 10- to 15-foot depth intervals, while waterweed and pond weeds colonize the 0- to 10-foot zones, with a mix of all species within the 5- to 10-foot zone. (It should be noted that currently the plant stands are fairly well mixed, for example, waterweed may dominate in one area, but Nitella will also be found there. This should not change as a result of the increased transparency.) In addition to a lateral expansion of the plants, it is also possible that the submerged plant community will increase in density and height. Plant vigor (growth pattern and health) may be limited under existing conditions by the dense algal blooms, which not only shade out the plants, but also may produce toxins that discourage plant growth.

It is more difficult to predict the impact of the increased water clarity and reduced nutrient concentrations on the plants currently found in the shallow arms of the lake. The duckweed and coontail existing there now, are plants that remove nutrients directly from the water. Restoration is predicted to adversely impact these plants, both because they will not benefit from improved water transparency and because they will be adversely affected by the much lower lake nutrient concentrations. The plant community in this area is expected to change even more from plants that are dependent upon high water column nutrient concentrations, to plants which obtain their nutrients from the sediments (e.g., waterweed and pond weed). Because of these changes, duckweed and coontail are not expected to be problems after restoration and are therefore not a focus of this contingency plan.

Since the entirety of these arms consist of quite shallow water that is well within the colonization depth for many aquatic plants, some other plants or algae will replace the duckweed. Therefore, if these plants and algae are reduced or eliminated due to improved water quality, submerged plants, such as Elodea, will likely increase in density. As stated previously, these plants were already reaching nuisance density and height levels during 1996, so some plan for their control is necessary.

The floating-leaved plant community (water lilies) should not be affected by the increased water transparency. However, under normal circumstances these plant beds can be expected to continue to expand around the perimeter of the lake. These plants typically occupy the 0- to 2.5-foot depth interval, although as is apparent in Lake Ketchum, they can grow to depths of close to 10 feet.

Post Restoration Plant Control Recommendation

The project objectives identified by the steering committee that relate to aquatic plants are: 1) "Control excessive algal blooms and duckweed growth to levels acceptable to the citizen's needs and financial resources," and 2) "Control excessive plant growth that interferes with swimming, fishing, and boating. Maintain aquatic plants at moderate levels to allow a balance of human and fish and wildlife uses in Lake Ketchum." To achieve these objectives, aquatic plant control activities should be selected to ensure that existing desirable species are not replaced with more nuisance forms, especially under future conditions of improved water quality and clarity. Since major species shifts are often brought about by large manipulations of habitat; control tools that create major changes (e.g., herbicide applications or shoreline dredging) should be avoided. In the following plan, less intensive or disruptive techniques are recommended, at least in the short-term, to protect the existing species composition.

The plan includes control recommendations for control of the two major plant types: emergent/floating-leaved plants, and submerged plants. **Table 6-4** summarizes the costs associated with each of the control mechanisms selected.

Table 6-4
Aquatic Plant Control Contingency Plan and Associated Estimated Costs

Control	Year 1	Year 2	Year 3	Year 4	Year 5	10-Year Average Annual Cost
			(after initiation of contingency plan)			
Floating Leaved Plants						
Herbicide Appl.	$500			$500		$150
Submerged Plants						
Low Intensity						
Hand Control	$500					$100[1]
Bottom Barrier	$3,000					NA[2]
Weedroller	$2,000					NA[2]
Harvesting	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000
High Intensity						
Grass Carp	$5,000				$200	$540
Herbicides						
Sonar	$8,700		$8,700		$8,700	$4,350
Aquathol	$6,000	$6,000	$6,000	$6,000	$6,000	$6,000

1. Assumes equipment replacement every five years.
2. Costs for these controls are assumed to be carried by individual lakefront property owners and therefore are not included in the overall aquatic plant control plan costs.

Floating-Leaved Plants

As depicted in **Figure 4-13**, there are three different small to moderate size beds of floating-leaved plants in Lake Ketchum, totaling less that one acre. Since these beds are not too large and represent an important habitat type, no immediate control is required. However, these beds can quickly expand and colonize greater areas and are very difficult to navigate through, so these expansions can negatively affect recreational use of the lake. If the area of nuisance growth is small and localized, there are hand control tools available for property owners to use to aid in control of small patches of lilies. These range from familiar scythes or machetes to the more efficient Water Weed Cutter® and Lake Shaver®.

If these plant beds begin to expand too far, the extent of their expansion could be kept in check through applications of herbicides with glyphosate as the active ingredient (e.g., Rodeo®). Glyphosate is recommended due to its effectiveness, duration of control, low cost, and low environmental impact. Glyphosate is a systemic herbicide that is absorbed by foliage and passed throughout the plant. Since it kills the tubers, it results in long-term control of the plant community. This herbicide has low toxicity to bottom-dwelling organisms, fish, birds, and other mammals, and dissipates quickly; therefore it is considered to have a low environmental impact. It is assumed that two applications of the herbicide will be required in any treatment year to ensure application success.

Control should consist of treating the outer perimeter of the beds with herbicides, the goal being to reduce them to their former size. Treatment should not have to occur more than every three to four years. To treat one acre of plants two times costs approximately $500. Assuming plant beds had not reached too much beyond their existing configuration, $500 would represent the maximum cost. This would result in an annual cost of about $150–$200 when averaged over a 10-year period.

Submerged Plants

Low Control Intensity. Assuming the change in nutrient concentration and water clarity does not affect species composition, but affects the extent and density of the submerged plant beds, then the control plan needs to focus on maintaining this community at levels that do not excessively hinder recreational use of the lake. The following recommendation assumes that the existing plant community becomes problematic after the restoration.

A combination of hand control tools such as a "Waterweeder," "Water Weed Cutter," and "Lake Weed Shaver" should be purchased to provide lake residents with access to a few more effective tools for controlling plants located in their nearshore areas. Although these are fairly inexpensive tools ($100–$400 each) that could be purchased by individual property owners, purchasing them as a group would allow residents to select and have access to a number of different tool types. From an ecological perspective one of the advantages of these tools is that since they do require some work by the property owner, the amount of habitat removed is limited. This provides a "natural" constraint on the impact to the aquatic environment.

Use of bottom barrier and Weedrollers® also is recommended for use by property owners. Bottom barrier is similar to the synthetic weed barriers used in lawn and garden practice. It is installed over the sediment and keeps light from reaching the plants and forms a physical barrier the plants cannot grow through. Bottom barrier costs approximately $1 per square foot, installed. To protect a 30-foot by 100-foot area alongside a dock would then cost $3,000. A Weedroller is a mechanical device that is attached to docks and requires a power source. Basically, it consists of a long tube of aluminum that "sweeps" or rolls over the selected control area. The weedroller can be set to operate just a few hours during the night once each week, so there is no loss to recreational use and no safety hazard associated with the tool, and little electrical use. The continued disruption to the sediment surface keeps plants from establishing in the area. A basic Weedroller with a 30-foot reach costs approximately $2,000. This would control an area of 30 feet in diameter directly in front of the dock or mounting post.

If these tools are not effective, mechanical harvesting should be considered. Although many lake residents have been dissatisfied with mechanical harvesting as a control tool, these lakes have typically had Eurasian Watermilfoil problems. Eurasian Watermilfoil grows so fast and dense that harvesting must occur at least twice each summer to provide any relief. For larger lakes with large beds of the plants this has meant almost continual harvesting throughout the summer. Not only is this expensive, but it has not provided much relief from plants due to the high re-growth rate of the watermilfoil. However, due to the size of Lake Ketchum and the type of plants found, it is possible that a once per year harvest planned for late July would handle the plant problem. Since this work would be contracted out, it is possible for the lake residents to try using this technique for a few years, beginning with a once per year cut and moving to twice annually if it becomes necessary. (One problem to be aware of is that if watermilfoil is ever found in the lake, all harvesting operations should be stopped since harvesting will increase the colonization rate for this plant.) One of the greatest advantages of a lake plant harvesting program is that it is one of the few plant control alternatives that actually results in removal of the plant material from the lake. By this means the nutrients tied up in the plant material are also removed from the lake. Thus, the harvesting would work in combination with the lake and watershed nutrient control measures to reduce overall nutrient loading to the lake.

As described previously, the shallow bays located in the northeast and southeast corners of the lake, are likely to represent the largest challenge to aquatic plant control. With improved water clarity and assuming the existing duckweed is not as highly favored under lower phosphorus concentrations, these areas are likely to be completely overtaken by plants. It is possible that Nitella will colonize the deeper area, in which case the impact on use of the lake would be minimal. However, assuming this area is colonized by taller, denser growing plants, this area is even more likely to require harvesting.

Assuming the entirety of the two shallow bays are harvested (approximately 2.5 acres) and an additional 2.5 acres are harvested in the main body of the lake, a total of 5 acres might be slated for harvest. (This represents what would probably be a maximum harvesting scenario.) Harvesting costs approximately $400 per acre per cut, which would result in a yearly cost of $2,000 for a one-time harvest, and $4,000 for a twice per year harvest. (Costs shown in **Table 6-4** are based on the twice per year harvest rate to depict worse case scenario costs.)

Note: If duckweed did remain a problem, it could be controlled through either a removal program (e.g., the use of skimmers such as used in the petrochemical industry to skim the plant off the lakes surface [**Dutley, D. and E. Epps, 1973**]) or through increasing water movement or circulation (e.g., artificial circulation). A removal program would have the advantage of utilizing the duckweed to remove phosphorus; the duckweed takes up phosphorus which is then permanently removed from the lake when the duckweed is removed. The disadvantage is that duckweed is very fast growing and this removal might need to occur as much as once each week under optimum growing conditions. Increasing water movement also has disadvantages; depending upon design, it could enhance algal growth and it requires a mechanical structure and electricity which equates to operations and maintenance expense. Due to the potential problems associated with duckweed removal, in combination with the expectation that the existing problem may well be controlled through restoration activities, no specific control strategy for this plant is recommended.

High Control Intensity. If the plant population in the lake expands beyond the point of being controlled by the low intensity methods described, it may become necessary to resort to one of the more intensive control strategies. Caution should be used before moving to these strategies, because they each have some serious disadvantages and because as described previously, the use of these techniques may promote conversion of the plant community to more nuisance types.

Grass Carp Stocking. Grass Carp are a plant-consuming fish native to China and Siberia. They are raised commercially in the southeast U.S. for use in lake and pond plant control projects. These fish do not compete with other fish species for either food or spawning habitat and in that sense are a good biological control agent. The fish can reach sizes of 50 to 60 pounds and are said to eat twice their weight in plant matter each day. Thus, they can be very efficient grazers. The greatest advantage to using Grass Carp is their low cost especially when compared to the efficiency and duration of control achieved. In fact, the biggest problem with Grass Carp is that they can be far too effective and remove every submerged plant, leaving no cover for fish and other aquatic life.

The solution to this problem is to stock the fish at an appropriate rate. A great deal of research has gone into determining appropriate stocking rates, yet there is still no definitive answer. That means that there is a chance that either too few will be stocked and they will not make any inroads on the plant population, or that too many will be stocked and all plants will be removed. Removal of too many of the plants, is likely to cause large decreases in fish populations and waterfowl use of the lake. Removing the plants also means that shoreline erosion and sediment disruption can be greater. In other lakes, this has resulted in poorer water quality through increased turbidity. Another concern with the use of Grass Carp is that the plant material they consume is returned to the lake (via feces) in a soluble form that can then supply algae with a nutrient source. In this respect, the carp do not enhance the other lake restoration activities that are aimed at reducing nutrient loads. (It should be noted that the carp do not increase the overall nutrient load since the plant material would naturally decay and be released to the lake under normal conditions. The major difference is that normally the nutrients from decaying plants would be added during the late fall and winter months when algae are not likely to form nuisance blooms.)

Due to concerns about impact to fish and wildlife habitat, WDFW has placed a number of important restrictions on Grass Carp projects:

- A Phase I study of the lake is required.
- All inlets and outlets must be screened to ensure Grass Carp cannot move out of the lake.

Since Lake Ketchum will have completed a Phase I study, and the inlets and outlets could be fairly easily and inexpensively screened, these requirements should not be too difficult to achieve. The fact that there are no migratory fish that utilize the lake (i.e., salmonids) also reduces screening concerns. Thus, WDFW the permitting agency, might look more favorably on allowing Grass Carp in Lake Ketchum versus most other lakes.

Assuming a maximum cost of $15.00 per fish and a stocking rate of 20 fish per vegetated acre, and control of 10 acres of plants, the cost for stocking would be $3,000, plus an additional cost for screening the inlets and outlets, estimated at a maximum of $1,000 each. Every five years some effort should be made to replenish carp lost to mortality which would cost perhaps $200.

If Grass Carp are stocked in the lake at a reasonable rate, it should take three to five years before any significant impact occurs. However, control should continue for another five to ten years or indefinitely if the carp are replenished every few years. There is a concern that the three- to five-year interval before the carp take affect might adversely affect the longevity of the alum treatment. This is due to the large load of nutrients that could be added over this time period if the plant biomass becomes very large. If Grass Carp are selected as the control tool, stocking might be used in conjunction with a herbicide application to first reduce the plant biomass and allow for more control in selecting a stocking rate. These decisions would need to be made at the time of application.

The feasibility of this alternative is entirely dependent upon WDFW policy at the time of application. New information developed in the next few years may result in changes to the WDFW policy and the basic level of acceptability of this control technique. The WDFW policy and approach should be reviewed to determine feasibility.

Herbicide Applications. There are a number of herbicides that might be appropriate for use in Lake Ketchum, each of which has advantages and disadvantages and different application procedures. Probably the greatest disadvantage to using any of these herbicides is that associated with the use of chemicals or toxins in natural environments. Although all herbicides approved for use in aquatic environments must pass stringent toxicity tests, and have been approved by both the EPA and Ecology, their use still remains a concern by many.

Possibly the most common herbicide for use on submerged plants is Sonar®, which contains fluridone as the active ingredient. Sonar® was specially formulated to kill Eurasian Watermilfoil and is not as effective on other plants. (Native plants may die back the first year but because they leave a seed bank in the sediments, some regrowth occurs the following year.) Sonar® has at least two advantages over other herbicides; 1) It kills the plant and its roots so it has a higher duration of control, and 2) Sonar® has no lake use restrictions due to its low toxicity. A third advantage is that it does not impact Nitella, so this beneficial plant type might be favored by Sonar® use. The only use restriction is on using treated water to water plants for the obvious reason that it could be expected to kill plants. Other than general chemical use concerns, the largest disadvantage to using Sonar is the cost. The product itself is expensive and the application can be expensive as well. Sonar® comes in both a liquid form (for treating large volumes of water) and a pellet form for treating smaller areas. In Lake Ketchum, liquid Sonar® might be used to treat the two shallow bays, while the pellet form might be used to treat select areas of plants in the main body of the lake.

It is difficult to estimate cost because use of the liquid is based on volume not surface acres. Based on estimates from other shallow lakes, it would cost approximately $1,200 each treatment year to treat the 2.5 acres that comprise the shallow arms. Use of the pellet form in the main body of the lake would cost approximately $1,000 per acre. Assuming a maximum of 7.5 acres is treated with Sonar® pellets (this number was selected to allow direct comparison with Grass Carp costs) this would cost an estimated $7,500 per treatment year. Treatments should need to occur at a maximum of every other year, but may be as infrequent as every third year. The total cost on any treatment year is estimated at $8,700. Thus, the annual average cost would range from $3,480-$4,350 per year, if averaged over a 10-year period.

A second option is to use a herbicide such as Aquathol® that contains endothall as the active ingredient. Aquathol® is a contact herbicide that works rapidly to kill the leaf and stem portions of plants. It does not kill the roots and root crowns and therefore control lasts for one season at the most. This means treatment needs to occur at least annually to achieve desired control. Aquathol® affects a broad spectrum of plants, including those found in Lake Ketchum (with the exception of Nitella). Aquathol® does have some label restrictions. In Washington State, there is an eight-day swimming restriction, and a three-day fish consumption restriction, and a 35-day irrigation or potable water use restriction. The largest advantage to using Aquathol® is the lower chemical cost and the ability to spot treat problem areas. It costs approximately $600 per acre to treat with Aquathol®. In Lake Ketchum, each of the shallow bays could be treated for $1,500 and the additional lake shoreline (7.5 acres) for an additional $4,500 for an annual cost of $6,000.

Residents of Lake Ketchum have expressed interest in using Diquat to control nuisance growths of common waterweed (*Elodea spp.*). This is because of its reduced costs and potential effectiveness. However, Diquat is not currently approved for aquatic use in the State of Washington.

Because of the anticipated improvement in water clarity following implementation of the recommended alternative, it is likely that controls for aquatic plants will be required. As a planning level estimate approximately $10,000 per year should be budgeted for aquatic plant control.

Algae Control

From 1981 until 1993, Lake Ketchum was treated regularly with copper sulfate to control algal growth. Treatments ceased in 1994 because of the on-going Phase I restoration study and because a 1994 Ecology study recommended that permits no longer be issued for the use of copper in Lake Ketchum.

Algae control is a primary objective of the proposed lake restoration plan. The plan is intended to reduce phosphorus concentrations in Lake Ketchum to a level where nuisance algal blooms will no longer cause a problem. Toward that end, both watershed and in-lake restoration measures are proposed to be implemented concurrently. However, if the recommended measures cannot be implemented in a timely manner because of costs or permitting issues, the lake residents may desire to re-apply for permits to use copper compounds on an interim basis to control algae.

Performance Evaluation Monitoring

To determine whether the recommended alternative techniques are successful, performance evaluation monitoring should be conducted. Performance monitoring is normally required for all grant-funded restoration programs.

Table 6-5 shows the proposed routine performance evaluation monitoring program for one year. The annual cost is estimated at $30,000 including data management, interpretation, quality control, and report (up to 20 pages) preparation (see **Appendix F** for cost spreadsheet). Performance evaluation monitoring is proposed for three years, including the year of implementation, so the total cost for monitoring over this period would be $90,000. An additional $15,000 is needed to install four new monitoring wells. Limited monitoring (about $7,500 per year) would be continued in years four and five to evaluate the long-term effectiveness of the restoration techniques.

This is the proposed annual performance monitoring cost and does not include the one-time monitoring cost associated with implementation of the whole-lake alum treatment. Monitoring required for the alum treatment is included with the alum treatment cost estimate.

Table 6-5
Performance Evaluation
Monitoring Program for One Year

Component	Sampling Frequency	Stations/Depths	Parameters
In-Lake	12/year	Deep Station/Epilimnion and hypolimnion composites (2 samples)	pH, SRP, TP, NO_2+ NO_3-N, NH_3, TN
	12/year	Deep Station/ 1 meter intervals	DO, Temp
	12/year	Deep Station	Secchi disk transparency
	12/year	Deep Station/ Euphotic zone composites	Chlorophyll *a*, Phaeophytin *a*, phytoplankton species biovolume, and identification
	12/year	Deep Station/ vertical tow	Zooplankton species enumeration and identification
	Quarterly	Deep Station/ epilimnion and hypolimnion	Total and dissolved Al
Inlets	9/year	2 inlet stations (Subbasins 6 and 8)	Temp, pH, DO, Cl, SRP, TP, TN, NO_2+NO_3, NH_3, fecal coliform
Flow	Continuous	1 inlet (continuous),	Flow records
Lake Level	Continuous	1 station	Lake level record
Groundwater	Quarterly	4 existing wells, 4 new wells, and 7 residential: total = 15 wells	SRP, TP, NO_2+NO_3-N, NH_3, TN, Cl
Benthic Invertebrates	Annually for 3 years	5 stations	Identify to order and count
Macrophytes	Once July/Aug.	5 transects with recording fathometer plus oblique aerial photos	Area mapping

PREDICTED LAKE RESPONSE

Table 6-6 summarizes the modeling results for three of the restoration techniques that are recommended for further analysis (listed in **Table 6-1** with an asterisk). Note: Modeling was not performed for aquatic plant control or watershed BMPs (Other Runoff and Septic Systems) because these restoration techniques focus on the elements which contribute a relatively small portion (a total of 7 percent) of the phosphorus budget. Watershed BMPs would target the surface loading not associated with agriculture (6 kg TP/yr) and with control of phosphorus loads from septic systems (18 kg TP/yr), while aquatic plant control would reduce phosphorus loading by only 20 kg TP/yr (assuming total eradication). In addition, there is less certainty that plant controls and watershed BMPs would be as effective in controlling TP loading from these sources. Wetland treatment also was not included in the modeling because of its experimental nature and the difficulty of estimating its effectiveness. Based on past experience, there is a much greater degree of certainty that farmland soil amendment, inflow diversion, and whole-lake alum treatment will produce the specified ranges in TP load reductions.

Table 6-6
Predicted Phosphorus Loading to Lake Ketchum and Phosphorus Concentrations of the Selected Restoration Alternatives

Alternative	Total Phosphorus (kg/yr)	Phosphorus Load From Agricultural Runoff[1] (kg/yr)	Annual Average In-lake Phosphorus (µg/l)	Summer Average In-lake Phosphorus[2] (µg/l)
Recommended Alternative				
Farmland Soil Amendment, Alum Treatment and Diversion[3]	65–123	0–19	22–29	29–32
Other Alternatives Considered				
No Action	513	194	668	389
Farmland Soil Amendment and Alum Treatment[3]	85–181	19–78	27–45	30–35

1. Subbasins 6 and 8
2. June through September
3. Includes wetland treatment, watershed BMPs, and aquatic plant control. Assumes the following percent effectiveness: farmland soil amendment (60 to 90%); alum treatment (80 to 94%); and inflow diversion (75 to 100%).

Note: The amount of phosphorus load reduced by aquatic plant control, wetland treatment, and watershed BMPs was not included because these restoration techniques focus on the elements which contribute a relatively small portion of the phosphorus load to the lake and there is less certainty that these techniques would be as effective in controlling phosphorus loads from these sources. Wetland treatment is experimental and would enhance the effectiveness of the alternatives, but not beyond the ranges shown.

The specified load reduction ranges are based on the following assumptions:

- Farmland soil amendment will provide agricultural TP load reductions of 60 to 90 percent.
- Inflow diversion will provide agricultural TP load reductions of 75 to 100 percent.
- Whole-lake alum treatment will provide internal load reductions of 80 to 94 percent.

As shown in **Table 6-6**, the recommended alternative provides the greatest reduction of in-lake phosphorus concentrations. In addition, the recommended alternative includes inflow diversion, therefore, this alternative is more likely to reduce phosphorus loading to the lake than the other alternatives. (Inflow diversion is less experimental than the farmland soil amendment and wetland treatment, but these measures address reducing the source of nutrients and mitigate downstream water quality impacts.) The alternative that includes farmland soil amendment, wetland treatment, and alum treatment (without diversion) could reduce phosphorus levels in the lake almost as much as the recommended alternative, however, there is much more uncertainty as to the effectiveness of the farmland soil amendment and wetland treatment. The no action alternative does not improve water quality and therefore does not meet the goals and objectives established for the lake.

RECOMMENDED RESTORATION PLAN

Table 6-7 provides a summary of recommended lake and watershed restoration elements, costs and responsibilities. This is the recommended restoration plan. The location of key restoration actions is shown in **Figure 6-2**.

Funding Strategy

The recommended restoration plan is an aggressive program that will stretch the funding capabilities of Snohomish County and the citizens at Lake Ketchum. To implement this lake restoration plan, a combination of watershed resident funding, County funds, State grant funds, and farm owner investments will be needed. Watershed resident and County funds will be targeted toward watershed BMPs, the lake alum treatment, aquatic plant control, performance monitoring, park development/maintenance, and administration. State grant and loan funds will be targeted for each element of the restoration plan except for aquatic plant control and park development/maintenance. The farmland soil amendment, wetland treatment, and inflow diversion should be funded by Ecology in conjunction with the farm owner or other outside funding sources as part of an on-going water quality enforcement action.

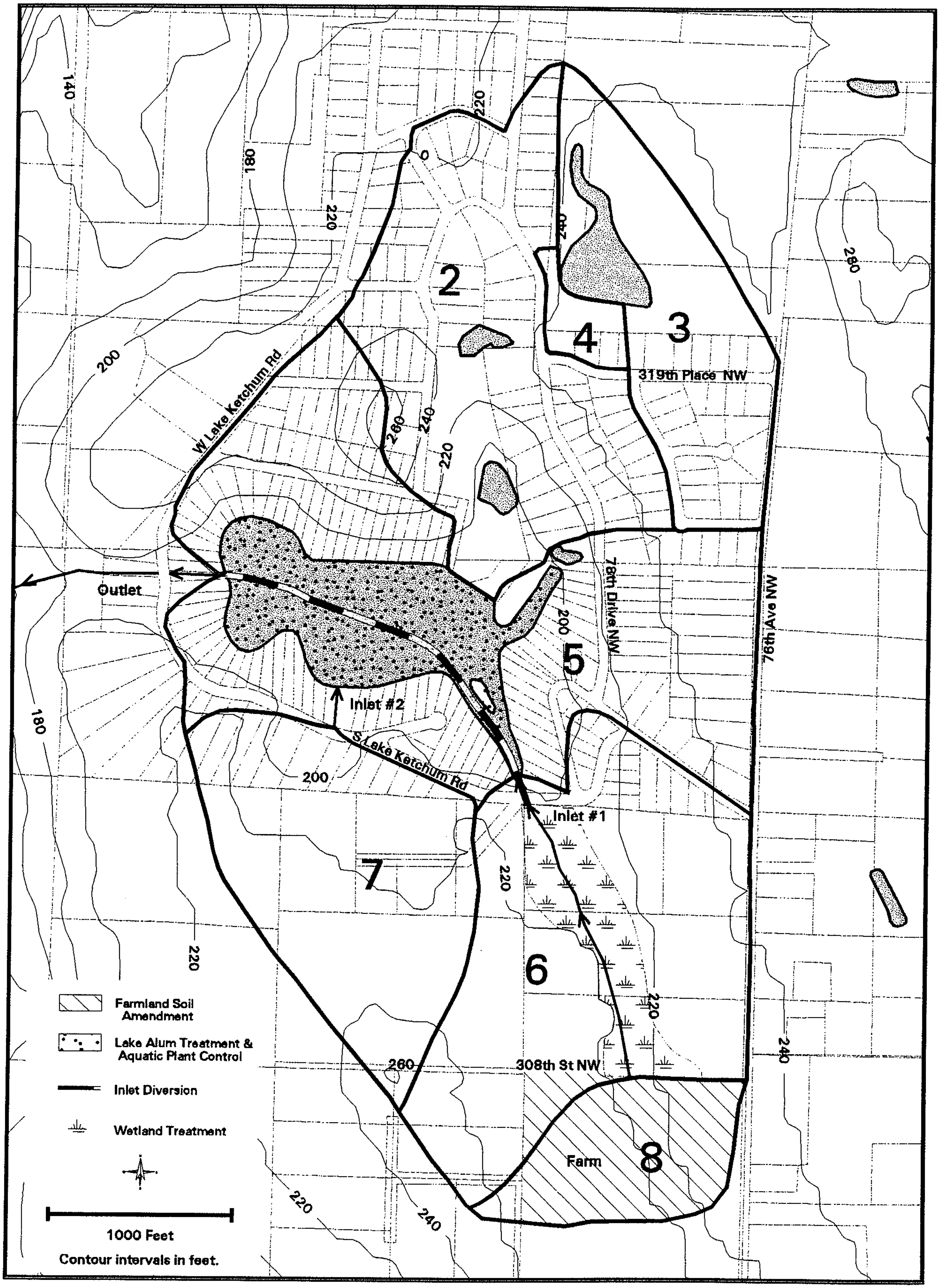

Figure 6-2. Recommended Restoration Actions With Watershed and Sub-Basin Boundaries

Table 6-7
Summary of Recommended Lake and Watershed Restoration Elements

Restoration Element	Estimated 5-Year Cost	Estimated Annual Cost	Implementing Organization
1. Farmland Soil Amendment	$55,000	$11,000	Snohomish County/DOE[2]
2. Wetland Treatment	$45,000	$9,000	Snohomish County/DOE[2]
3. Watershed BMPs[1]	$45,000	$9,000	Snohomish County/KSIC[3]
4. Whole-lake Alum Treatment	$130,000	$26,000	Snohomish County
5. Inflow Diversion	$320,000	$64,000	Snohomish County/DOE[2]
6. Aquatic Plant Control	$50,000	$10,000	Snohomish County/KSIC[3]
7. Performance Monitoring	$120,000	$24,000	Snohomish County
8. Administration	$80,000	$16,000	Snohomish County
9. Park Development/ Maintenance[4]	$50,000	$10,000	Snohomish County/KSIC[3]
Total	**$895,000**	**$179,000**	

1. Includes public involvement and education for 5 years plus conservation easements for wetlands.
2. Washington State Department of Ecology.
3. Ketchum Shores Improvement Club.
4. Development of a park on the lake (about $35,000) and on-going park maintenance ($3,000/year) will be required if state grant funds are received for implementation of the restoration plan.

Watershed Resident Funding

Lakeshore residents have historically funded lake-related work through collection of dues from the members of the Ketchum Shores Improvement Club or through shorefront property assessments under RCW 90.24. They have been able to generate up to $10,000 per year with these programs. However, at the present time, there are a substantial number of retired residents who can no longer assume these costs. In addition, there may be some restrictions on the use of funds collected under RCW 90.24. For example, park development and maintenance are probably ineligible uses for these funds. Also, there may be a need to go back to Superior Court for authorization, if the proposed uses are substantially different than the uses specified under the original authorization.

Another option available for generating local matching funds would be to form a Lake Management District (LMD). The LMDs are special districts authorized under RCW 36.61 and 35.21.403. The law requires that the nature of improvements be specified along with their cost and that some reasonable procedure be developed to assess costs to individual property owners within LMD boundaries. Boundaries would be determined cooperatively between Snohomish County and citizens of the area. The LMD could collect fees for specified uses for a period of up to 10 years. Prior to approval, a public hearing must be held to provide opportunity to discuss the purpose, boundaries, cost, method of assessment, and benefits of the LMD, and a majority of affected property owners must subsequently vote in favor of the LMD formation. Drawbacks of this option are that the LMD process is long (12 to 18 months) and somewhat costly.

Snohomish County Surface Water Utility

Another source for funding a portion of the recommended restoration plan is Snohomish County Surface Water utility fees. Existing fees have been contributing about $15,000 to $20,000 per year as matching funds for the Phase I grant. A similar level of funding may be available for implementing the restoration plan. One method for raising additional Surface Water utility funds would be to establish a surcharge on top of the current fees to be paid by all developed properties in the watershed. The surcharge would be for a specified length of time and would be collected in the normal manner with regular property taxes. While not requiring a formal vote, this option would only be chosen if supported by residents of the Lake Ketchum watershed.

Ecology/EPA 319 Nonpoint Source Grant

Phase II Lake Restoration projects, which would include many elements of the recommended alternative (farmland soil amendment, wetland treatment, other watershed BMPs, inflow diversion, and whole-lake alum treatment), have recently been authorized under Ecology guidelines for 319 funds. Preliminary discussions with Ecology staff indicate that 75 percent grant funding may be available for all lake restoration elements. The next cycle to apply for funding will extend from January 2, 1997, through the end of February 1997.

Ecology Centennial Clean Water Grants or Loans

Another source of grant or loan funds is the Centennial Clean Water Program. This program may provide up to 75 percent funding (in the case of grants) or more for Phase II implementation projects. The application process is combined with the EPA 319 grant process. The current application period closes February 28, 1997.

Farm Owner

The financial capabilities of the farm owner are unknown. However, agricultural runoff, affected by the former dairy farm, is contributing a large percentage of the nutrient pollution to Lake Ketchum. Therefore, Ecology should work with the farm owner and together address the costs of the farmland soil amendment, wetland treatment, and inflow diversion. Some of these costs could include donated labor and equipment use by the farm owner. These restoration measures are specifically designed to control nutrient and bacteria loading from the farm, which currently violate state water quality standards. Without these agricultural controls, the proposed lake restoration plan will not be effective.

Ecology Aquatic Plant Control Grant Program

This grant program gives preference to projects involved in eradication of plants on the state list of noxious weeds. However, control of other aquatic plants may also be eligible.

Roles and Responsibilities

Snohomish County should take the lead in preparing grant applications, coordinating with Ecology, and managing the implementation of farmland soil amendment, wetland treatment, alum treatment in-lake, inflow diversion, and performance monitoring. Ecology should coordinate with the County and farm owner in implementing the farmland soil amendment, wetland treatment, and inflow diversion. The County also should continue to maintain close coordination with the Ketchum Shores Improvement Club for all restoration elements. The watershed citizens, through the Ketchum Shores Improvement Club, should have primary responsibility for implementing watershed BMPs and aquatic plant control.

Planning Schedule for Implementation

The actions required to implement the restoration plan for Lake Ketchum are listed **Table 6-8**. The table provides a start and completion date for each action and lists them in the order they should occur.

Table 6-8
Planning Schedule for Implementation

Implementation Action Items	Starting Date	Completion Date
Grant Applications/Negotiations	February 1997	November 1997
Supplemental Monitoring, Design	November 1997	May 1998
Environmental Review and Permits	November 1997	May 1998
Restoration Plan Implementation:		
Farmland Soil Amendment	July 1998	October 1998
Wetland Treatment	July 1998	October 1998
Watershed BMPs	July 1998	On-going
Alum Treatment In-lake	July 1998	October 1998
Inflow Diversion	July 1998	October 1998
Aquatic Plant Control	July 1997	On-going as needed
Performance Evaluation Monitoring	July 1998	November 2003

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GLOSSARY OF TERMS

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Aerobic	Condition characterized by the presence of oxygen.
Algae	Single- or multi-celled, nonvascular plants containing chlorophyll. Algae form the base of the food chain in aquatic environments.
Algal bloom	Heavy growth of algae in and on a body of water as a result of high nutrient concentrations.
Alkalinity	The acid binding capacity of a (carbonate) solution, its buffering capacity.
Anaerobic	Absence of oxygen (Gr. *an* without, *aer* air).
Anoxic	Lack of oxygen.
Biomass	The total organic matter present (Gr. *bios* life).
Chlorophyll	The green pigments of plants (Gr. *chloros* green, *phyllon* leaf).
Drainage basin	The area drained by, or contributing to, a stream, lake, or other water body.
Ecosystems	Any complex of living organisms together with all the other biotic and abiotic (non living) factors which affect them.
Epilimnion	The surface layer of a lake (Gr. *epi* on, *limne* lake).
Euphotic zone	That part of a water body where light penetration is sufficient to maintain photosynthesis.
Eutrophic	High algal productivity; lake suitability for most recreational uses is often impaired by frequent and intense algal blooms which may form floating scums. The water often takes on a "pea soup" color and is extremely murky. Fish kills may be common because of depleted oxygen, especially in shallow lakes.
Fall turnover	A natural mixing of thermally stratified waters that commonly occurs during early autumn. The sequence of events leading to a fall turnover includes 1) cooling of surface waters, 2) density change in surface water that produces convection currents from top to bottom, and 3) circulation of the total water volume by wind action. The turnover generally results in a uniformity of the physical and chemical properties of the water.

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

Hypolimnion The deep layer of a lake and removed from surface influences (Gr. *hypo* under, *limne* lake).

Limiting nutrient Essential nutrient which is the scarcest in the environment relative to an organism's needs.

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

Littoral The shoreward region of a body of water.

Mesotrophic Moderate algal productivity; generally compatible with all recreational uses. Algal blooms are occasional, but generally of low to moderate intensity. Oxygen depletion is common in the bottom waters and cold water fisheries may be endangered in some shallow lakes. In many lakes, however, the fishery may be enhanced by the increased productivity.

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

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

Oligotrophic Low algal productivity; high suitability for all recreational uses. Algal blooms are rare and the water is extremely clear.

Periphyton The biological community attached to substrate (such as rocks, sediments, aquatic plants) that is primarily composed of algae.

pH The negative logarithm of the hydrogen ion activity.

Photosynthesis Production of organic matter (carbohydrate) from inorganic carbon and water in the presence of light (Gr. *phos*, *photos* light, *synthesis* placing together).

Phytoplankton Free floating microscopic plants (algae) (Gr. *phyton* plant).

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

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

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

Sediment Solid material deposited in the bottom of a basin.

Stratified period The period of time in which through warming (or cooling) from above, a density stratification is formed that prevents a mixing of the water mass (Lat. *stagnum* a piece of standing water).

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

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

Watershed See drainage basin.

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

Zooplankton The animal portion of the plankton (Gr. *zoion* animal).