LAKE KETCHUM ALGAE CONTROL PLAN

June 2012

Snohomish County WASHINGTON

Surface Water Management Division

Public Works Department

Snohomish County

3000 Rockefeller Avenue, M/S #607

Everett, WA 98201
425-388-3464

Prepared By:

Marisa Burghdoff
Gene Williams

With the assistance of

TETRA TECH, INC.

ACKNOWLEDGMENTS

Development of this plan was funded in part by a grant from the Washington State Department of Ecology Freshwater Algae Control Program. Local funds were provided by Snohomish County Surface Water Management service charges. Lake Ketchum citizens provided on-the-ground assistance and encouragement for this project.

Department of Public Works

Steve Thomsen, P.E., Director

Surface Water Management Division

Debbie Terwilleger, Director
Larry Matel, Manager
Kathy Thornburgh, Supervisor

Algae Control Plan Prepared By:

Snohomish County Surface Water Management

Marisa Burghdoff, Water Quality Analyst
Gene Williams, Senior Planner

Tetra Tech, Inc.

Dr. Harry Gibbons
Dr. Eugene Welch
Rob Plotnikoff
Shannon Brattebo
David Pizzi

Assistance from Lake Ketchum Citizens:

Special thanks to the following who provided access for or help with lake monitoring:

Miriam Lancaster
Bert and Judy Albert
Chris Sandys and Claudette Feather
Jack and Judy Green
Ken and Sheri Block
Darryl and Laurie Stoutsenberger

Table of Contents

TABLE OF FIGURES

LAKE KETCHUM ALGAE CONTROL PLAN

1 EXECUTIVE SUMMARY

PROBLEM STATEMENT

Lake Ketchum is a 25-acre public lake located in northwest Snohomish County two miles north of the City of Stanwood. The lake supports swimming, fishing, boating, aesthetic enjoyment, and wildlife habitat. Historically, it was the drinking water supply for the City of Stanwood.

ALGAE BLOOM AT LAKE KETCHUM

Although the lake setting is still beautiful, Lake Ketchum is now the most polluted lake in Snohomish County, if not the state. The lake suffers from thick growths, or blooms, of blue-green algae. The algae problems severely impair the public use and enjoyment of the lake. Furthermore, the algae blooms are also frequently toxic, threatening the health of people and pets that use the lake.

The algae problems are caused by extremely high levels of phosphorus in the lake. The original source of pollution was from a former dairy farm that drains to the Lake Ketchum inlet stream. Over time, phosphorus from the farm has accumulated in the lake bottom. The phosphorus stored in the lake sediments has now become the major source of pollution to the lake. The long-term summer phosphorus concentration at Lake Ketchum is 277 micrograms per liter (µg/l or parts per billion). This level of phosphorus is an order of magnitude higher than that found at all other lakes in Snohomish County and more than 13 times greater than the State phosphorus criterion of 20 µg/l for Puget Sound lowland lakes. For this reason, the Washington State Department of Ecology has officially listed Lake Ketchum as an "impaired" waterbody and as a regional priority for restoration.

LAKE KETCHUM WATERSHED

PROJECT BACKGROUND

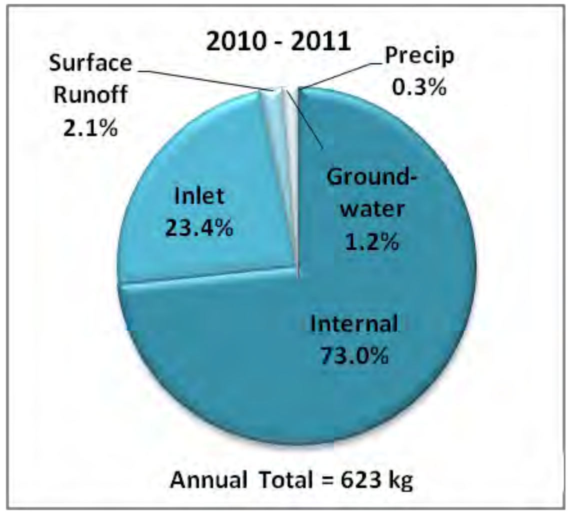
The water quality problems at Lake Ketchum have been ongoing for decades. In 1996, the Snohomish County Surface Water Management Division (SWM) completed an initial Phase I study that identified the farm soils and the lake sediments as the primary pollution sources. However, actions to clean up the lake were never taken due to lack of funding. In response to continued severe toxic algae blooms and the ongoing frustrations from Lake Ketchum residents, SWM initiated a new project in 2010 to work toward a feasible clean-up plan for Lake Ketchum.

The project goal is to achieve long-term restoration of Lake Ketchum. SWM was awarded a grant from the Department of Ecology to help fund a lake study to identify the best methods of reducing phosphorus and controlling future blooms of algae. The project objectives are to 1) identify current phosphorus amounts and sources; 2) identify effective treatment methods for both external and internal phosphorus; 3) develop an algae control plan, with costs and funding sources; and 4) work with citizens to gain support for the plan and begin steps toward implementation.

STUDY RESULTS

After a year of intensive water quality and hydrologic monitoring, a Lake Ketchum phosphorus model was developed to understand the sources and quantity of phosphorus flowing into and out of the lake. By far the largest source (73%) of the phosphorus which causes algae growth in the lake is the "internal" source. Internal refers to the phosphorus in the lake sediments which is re-released into the lake each year.

LAKE KETCHUM PHOSPHORUS SOURCES



The other major phosphorus source is from the main inlet stream, accounting for 24% of the total. The inlet drains from the former dairy farm. The current phosphorus levels in this stream are much lower than in 1996 during the original study. However, the phosphorus concentrations are still extremely high compared to other streams in the area. Runoff from the rest of the watershed (the land area that drains to Lake Ketchum – see photo above) and from shallow groundwater accounts for roughly 3% of the phosphorus, primarily from residential sources. Common residential phosphorus sources include lawn and garden fertilizers, poorly maintained septic systems, pet and animal wastes, stormwater runoff from roofs and driveways, and erosion from bare soils and shorelines (phosphorus is carried on soil particles).

LAKE RESTORATION ALTERNATIVES

Several lake restoration methods were evaluated to identify the most feasible and effective actions to reduce phosphorus levels in Lake Ketchum to a target of less than 40 µg/l during the summer. Achieving this target level of phosphorus will significantly reduce the frequency and duration of blue-green algae blooms and will restore the beneficial uses of the lake.

The most feasible method for inactivating the internal phosphorus from the lake sediments is one or more aluminum sulfate (alum) treatments of the lake sediments. Alum permanently binds phosphorus in the lake water and the sediments. Alum treatments are the most successful method used around the world to inactivate phosphorus to alleviate algae problems. Alum is also a safe treatment that is widely used to remove phosphorus and other impurities from drinking water supplies and to rehabilitate lakes.

The preferred method to address the main external source of phosphorus flowing from the farm through the inlet stream is to modify or remove the soils from the farm. However, this method cannot be pursued without the cooperation of the private land owners, which is currently not possible. In addition, much of the phosphorus from the farm is now sequestered in the soils of the wetlands that are located between the farm and the lake. Phosphorus in these wetlands cannot be removed without destroying the wetlands. Protecting the wetland area is critical to ensure that the wetlands continue to capture a portion of the phosphorus from the farm.

The only remaining option to control the external inflow from the main inlet stream is to intercept the phosphorus as it reaches the lake or soon after it enters the lake. Two methods were examined in detail to inactivate this inflowing phosphorus. The first method is to construct a small mechanical treatment plant that would inject alum into the stream as it enters the lake. The second method is to conduct small, annual alum treatments of the lake water (the water column). The annual alum treatments would be performed each spring to remove the phosphorus that has washed into the lake during the rainy period.

Four lake restoration alternatives involving combinations of these phosphorus control methods were developed. The alternatives were analyzed using the phosphorus model to predict the response of the lake to implementation of each alternative over a four-year time period. Only Alternatives #3 and #4 were shown to consistently meet the restoration target of 40 µg/l; however, Alternative #3 would cost $601,000 over four years while Alternative #4 would cost $338,000.

Based on the model results and the projected costs of each alternative, Alternative #4 is both effective and the most economical solution for Lake Ketchum. Therefore, Alternative #4 is the preferred restoration alternative.

LAKE RESPONSE TO POTENTIAL RESTORATION ALTERNATIVES

Lake Restoration Alternatives[1]	Upper Waters Summer Average Total Phosphorus Concentrations (µg/l)			
	Year 1	Year 2	Year 3	Year 4
Modeled Existing Conditions	173	175	175	175
Alternative 1 Whole-Lake Sediment Inactivation Alum Treatment	46	70	71	71
Alternative 2 Whole-Lake Sediment Inactivation Alum Treatment Repeated in Two Years	46	70	31	54
Alternative 3 Whole-Lake Sediment Inactivation Alum Treatment **AND** Alum Injection at Inlet	46	36	36	36
Alternative 4 Whole-Lake Sediment Inactivation Alum Treatment **AND** Annual Water Column Alum Treatments	41	39	39	39

[1]*Note: all alternatives would also include implementation of residential best management practices and wetland protection.*

RECOMMENDED ALGAE CONTROL PLAN

Five primary elements are included in the final recommended algae control plan. The first two elements are to implement Restoration Alternative #4 by conducting a whole-lake sediment inactivation together with annual water column alum treatments. These two elements will address the internal phosphorus as well as the primary external source of phosphorus from the lake inlet. The third plan element is to continue to protect the wetlands between the lake and the farm. Keeping these wetlands intact will allow for the continued capture of phosphorus from the farm runoff. The fourth element is to reduce residential phosphorus pollution. By making changes in household practices, less phosphorus will flow into the lake, helping the alum treatments be more effective. Finally, monitoring of lake conditions will be needed to evaluate results and allow for active management of lake treatments.

ELEMENTS OF RECOMMENDED ALGAE CONTROL PLAN

Element 1	**Element 2**	**Element 3**	**Element 4**	**Element 5**
Whole Lake Sediment Alum Treatment (Alternative 4)	Annual Water Column Alum Treatments (Alternative 4)	Continued protection of wetlands	Changes in residential practices	Water quality monitoring and plan updates as needed

COSTS & FUNDING

The estimated costs of each control plan element are outlined in the table below. The funding to implement the recommended Algae Control Plan will challenge the resources of the local residents and Snohomish County, especially for the large Year 1 and 6 costs. Funding assistance from the State through grants or other sources will be critical if the lake is to be restored. Potential funding sources for portions of the costs include:

- Lake shore property assessments through the existing LID (RCW 90.24).
- Formation of a Lake Management District (RCW 36.61).
- Snohomish County Surface Water Management funds.
- Department of Ecology Freshwater Algae Control Program grant.
- Department of Ecology Centennial Clean Water Fund grant.
- Department of Ecology Clean Water State Revolving Loan program.

COSTS FOR RECOMMENDED ALGAE CONTROL PLAN

Plan Elements	**Cost in $1000s (2011 dollars)**					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**4-Year TOTAL**	**10-Year TOTAL**
Whole-Lake Sediment Inactivation Alum Treatment	$194	0	0	0	$194	$368[1]
Annual Water Column Alum Treatments	$36	$36	$36	$36	$144	$324[2]
Residential BMPs and Wetland Protection	$20	$20	$8	$8	$56	$104
Monitoring/Adaptive Management	$14	$14	$12	$12	$52	$124
TOTALS	**$264**	**$70**	**$56**	**$56**	**$446**	**$920**

[1]*Sediment Alum Treatment may need to be repeated in Year 6.* [2]*No Water Column Treatment proposed in Year 6.*

CONCLUSION

The residents and users of Lake Ketchum have suffered with poor lake water quality for decades. Implementation of the Algae Control Plan will have major benefits for the health of Lake Ketchum. Controlling internal and external phosphorus sources will result in less frequent and less intense algae blooms. Fewer blooms will decrease the health risks from toxic algae and restore enjoyment of the lake for swimming, boating, fishing, and other uses.

2 PROJECT BACKGROUND

2.1 STUDY AREA AND WATER QUALITY HISTORY

Lake Ketchum is a 25.5-acre lake located two miles north of the City of Stanwood in northwest Snohomish County. The lake is relatively shallow, with a maximum depth of 6.4 meters (21 feet) and an average depth of 3.7 meters (12 feet). The lake is fed by one small stream that flows into the southeast corner of the lake, a wetland on the northeast shore, several small ditches, and groundwater. The lake drains west to Skagit Bay.

Lake Ketchum supports swimming, fishing, boating, aesthetic enjoyment, and wildlife habitat. The lake shoreline is developed with about 60 single family homes. There is a Washington State Department of Fish and Wildlife public boat launch on the south shore and a private community beach access on the northwest shore. The watershed—the land area that drains into the lake—covers 350 acres and supports mainly suburban and semi-rural residential development (Figure 2-1). A former dairy farm covers about 20 acres at the south end of the watershed.

Until the 1940s, the Lake Ketchum watershed was largely undeveloped and served as a drinking water source for the City of Stanwood. Since that time, the water quality has markedly declined. Lake Ketchum is now the most polluted lake in Snohomish County and possibly the region. The lake suffers from blooms of nuisance blue-green algae (cyanobacteria) caused by high phosphorus levels (Figure 2-2). The long-term average concentrations of total phosphorus during the summer are 277 µg/l in the epilimnion (the upper waters) and 1,746 µg/l in the hypolimnion (the bottom waters) (Snohomish County, 2012). (µg/l means micrograms per liter, which is equivalent to parts per billion.) Nitrogen levels are also very high, but phosphorus is the nutrient of major concern. Because of these high phosphorus levels, Lake Ketchum is listed in the Department of Ecology's 2008 Water Quality Assessment and 303d list as an "impaired" waterbody.

In 1995-1996, Snohomish County conducted a Phase I study for Lake Ketchum (Entranco, 1997). The study identified the main sources of phosphorus polluting the lake. At that time, 51% of the annual phosphorus loading came from the lake bottom sediments from which phosphorus was being recycled over and over again. (Loading refers to the contribution of phosphorus from a particular source.) The main external source of phosphorus was runoff entering the lake from the southeast stream, which drains from the former dairy farm. That sub-basin contributed 38% of the total phosphorus load to the lake in 1996. This farm pollution was also the original source of most of the phosphorus in the lake bottom sediments. All other sources combined contributed only 11% of the phosphorus.

FIGURE 2-1: LAKE KETCHUM AND ITS WATERSHED

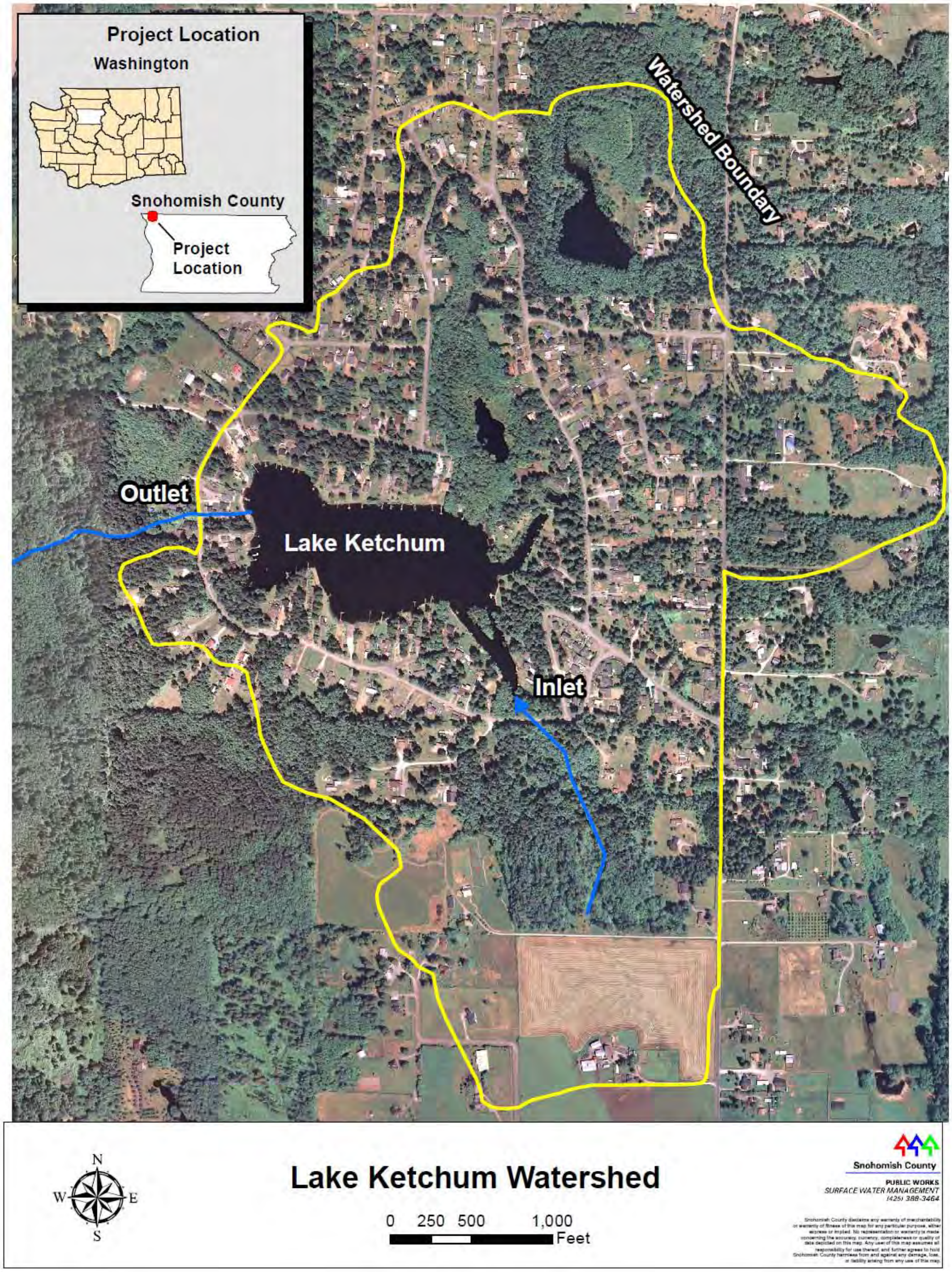
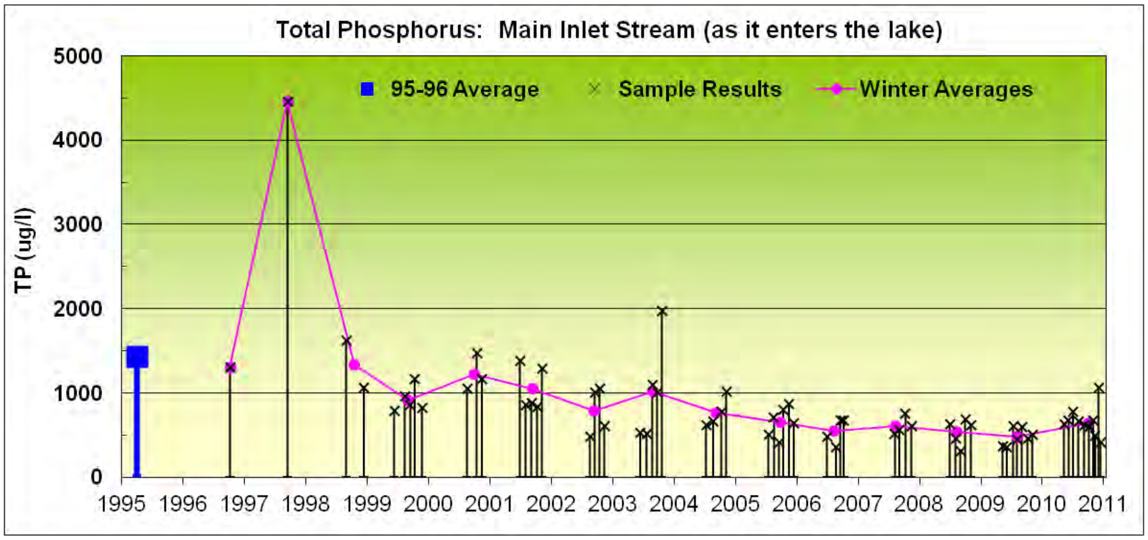


FIGURE 2-2: TOXIC ALGAE PROBLEMS AT LAKE KETCHUM

2.2 LAKE KETCHUM CURRENT CONDITIONS

Since 1996, several improvements have been made to runoff from the former dairy farm that have reduced the phosphorus flowing into the lake. Primarily, all cattle were removed from the portion of the farm draining to Lake Ketchum, and the land was converted to hay, which is cut and removed each year. These changes have significantly reduced the levels of phosphorus flowing to the lake. The average wintertime phosphorus concentrations at the point where the inlet stream reaches the lake have dropped from nearly 1,500 µg/l in 1995-96 to 646 µg/l in 2010-2011 (Figure 2-3). However, much greater reductions are needed to reduce phosphorus concentrations in the lake to levels that would limit algal blooms. Unfortunately, implementation of additional improvements on the farm to reduce phosphorus in runoff is not feasible because of the lack of cooperation from the current property owners. Efforts to explore the potential for soil treatments or soil amendments on the farm to neutralize phosphorus have been rejected**.**

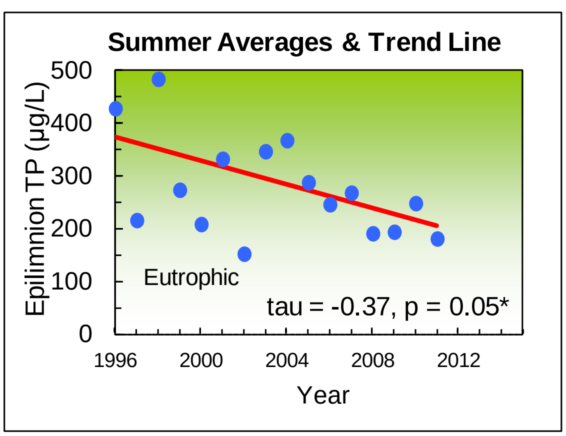
FIGURE 2-3: TOTAL PHOSPHORUS CONCENTRATIONS IN INLET STREAM TO LAKE KETCHUM



Phosphorus concentrations in the upper waters of the lake (the epilimnion) have also been slowly declining because of the lower levels of phosphorus coming from the farm (Figure 2-4). The 2011 summer average concentration of total phosphorus was 181 µg/l. However, the phosphorus levels are still significantly higher than all other lakes in Snohomish County (Snohomish County, 2012). The 1996-2011 long-term average of 277 µg/l is more than 200 µg/l higher than the next highest lake (Figure 2-5 – note the logarithmic scale of the graph).

The phosphorus concentrations in the lower waters of the lake (the hypolimnion) are also extremely high, with a 1996-2011 summer average of 1,746 µg/l. The 2011 summer average was 2,667 µg/l, ten times higher than any other lake in Snohomish County. The extremely high phosphorus levels in the hypolimnion suggest that phosphorus loading from the bottom sediments is a major problem.

FIGURE 2-4: LONG TERM CHANGES IN TOTAL PHOSPHORUS (TP) CONCENTRATIONS - EPILIMNION AND HYPOLIMNION



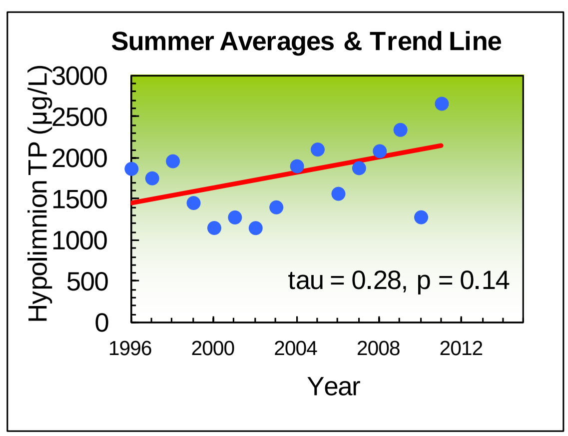
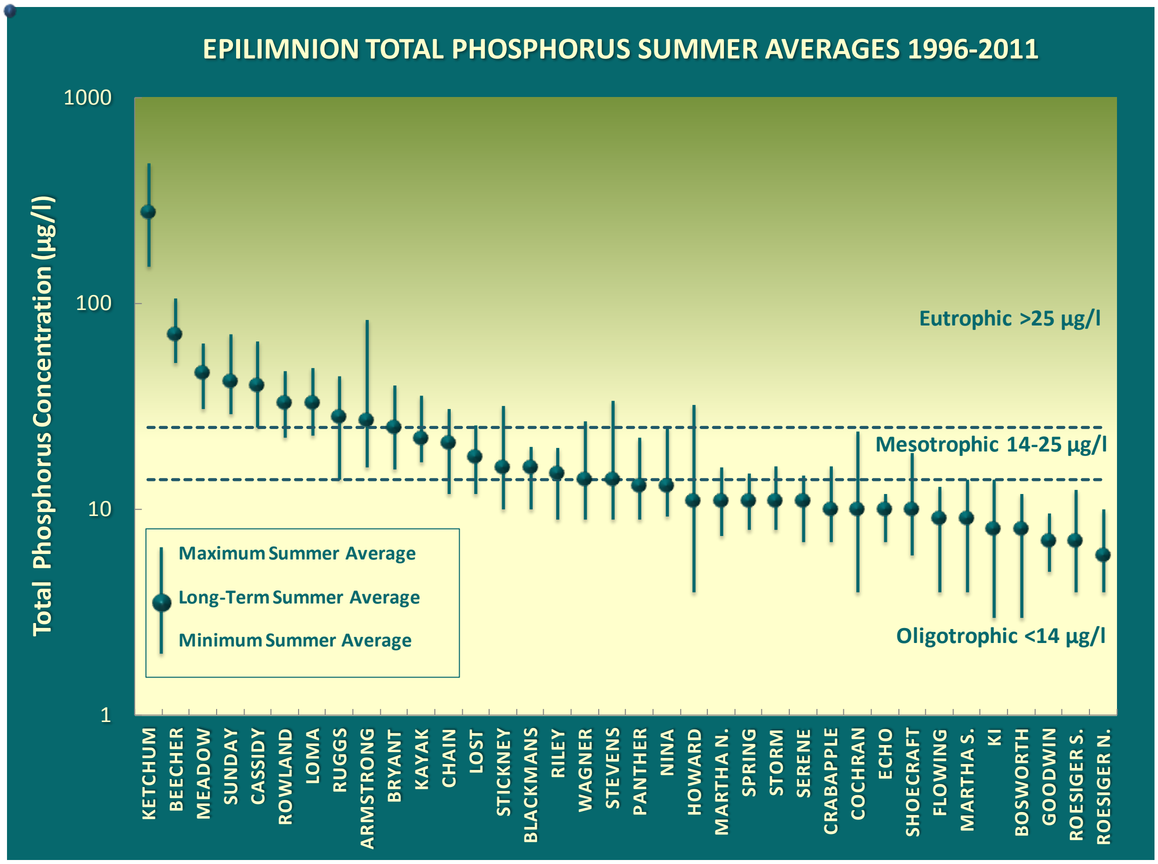


FIGURE 2-5: PHOSPHORUS CONCENTRATIONS FROM LAKE KETCHUM IN COMPARISON TO OTHER SNOHOMISH COUNTY LAKES– NOTE THE LOGARITHMIC SCALE



The extreme levels of phosphorus in the lake cause severe and persistent problems with aquatic plant and algal growth, in particular nuisance blooms of blue-green algae. Chlorophyll *a* is one measurement that indicates the amount of algae in the lake water. The long-term 2002-2011 summer average chlorophyll *a* concentration is 43 µg/l (Snohomish County, 2012). This is almost double other local lakes that have algae problems. Some individual chlorophyll *a* samples at Lake Ketchum have measured as high as 200 µg/l. Most alarming is that sometimes the algal blooms are toxic. Toxic algal blooms that endanger the health of lake users and pets have occurred every year since 2007. During 2011, tests showed that liver toxins were present in lake water every week from the beginning of June through the first week in November. For nine of those weeks, toxin levels were above the Washington State guidelines for safe recreational use.

3 PROJECT DESCRIPTION

3.1 PROJECT SUMMARY

The purpose of the Lake Ketchum Algae Control Plan project is to develop a feasible plan for reducing phosphorus and controlling nuisance and toxic blue-green algal blooms in the lake. The Algae Control Plan identifies the measures that have the highest potential for restoring healthy conditions in Lake Ketchum and that are also financially viable.

The Snohomish County Surface Water Management Division (SWM) worked with citizens at Lake Ketchum to develop this project. SWM secured a $39,300 grant from the Washington State Department of Ecology Freshwater Algae Program to fund approximately half of the project. SWM contracted with a limnology consulting firm, Tetra Tech, Inc., to perform detailed analyses of the lake water quality and help develop recommendations for restoring Lake Ketchum.

3.2 PROJECT GOALS, OBJECTIVES, AND TARGET

The overall goal of the project is the long-term restoration of Lake Ketchum. The more specific goal of this project is to develop a plan to reduce the amount of phosphorus in the lake in order to control future blooms of algae. This will require reducing both the internal loading from the lake bottom sediments and the external loading from the watershed. Both sources of phosphorus must be controlled to restore the lake. Because of the extremely high levels of phosphorus in Lake Ketchum, it will require many years of active intervention to re-establish a healthy ecological balance in the lake.

The objectives of this project are to:

- Identify the current amount and sources of phosphorus which are causing algal blooms in the lake.
- Identify the most effective methods to treat the phosphorus that is built up in the lake's sediments and to treat the phosphorus flowing into the lake from external sources.
- Develop an algae control plan to clean up Lake Ketchum, complete with projected costs and potential funding sources.
- Work with the Lake Ketchum citizens to secure support for the plan as the first step toward implementation.

Identifying the phosphorus sources requires development of a lake phosphorus budget that documents the seasonal timing and the amount of phosphorus coming into the lake. The first step in developing a phosphorus budget is to develop a water budget for the lake that measures the volume of water flowing into and out of the lake over the course of one year. The results of the water and phosphorus budgets are then used to evaluate the likely response of the lake to implementation of alternative methods of controlling phosphorus from the surrounding watershed and from the lake bottom sediments.

One requirement for developing a successful algae control plan is to set a target for phosphorus reductions. Based on monitoring studies of many lakes in Washington and the U.S., average total phosphorus concentrations of less than 30 µg/l are needed to avoid regular algal blooms. In addition, the criterion recommended by Washington State for lakes in the Puget Sound lowlands is a phosphorus average of 20 µg/l. However, these low levels of phosphorus are not realistically achievable given the extremely high levels of phosphorus already in Lake Ketchum.

A more realistic target for Lake Ketchum is to reduce the summertime average phosphorus concentrations in the upper waters to less than 40 µg/l. With this amount of phosphorus, the lake will still experience periodic blue-green algal blooms. However, the duration of the blooms will be shorter, and the blooms will not be as intense as currently experienced at Lake Ketchum. The algae species will also shift toward more beneficial diatoms and green algae during the spring and summer when lake recreation is most common.

4 MONITORING METHODS AND RESULTS

The following sections describe the monitoring methods used to develop the water and phosphorus budgets, as well as the results of the monitoring. Full details of the methodology, as well as the raw data, can be found in the Technical Appendix.

4.1 STREAM FLOW, LAKE LEVEL, AND PRECIPITATION MONITORING

SWM staff conducted hydrologic measurements of Lake Ketchum (lake level, precipitation, inflow, and outflow) for one full year (October 2010 through October 2011) to help develop the water budget for the lake. These data provide a picture of the movements of water in and out of the lake. The movement of water is a critical factor because phosphorus is carried by water as it moves through the system.

4.1.1 STREAM FLOW, LAKE LEVEL, AND PRECIPITATION MONITORING METHODS

The only channelized flow into Lake Ketchum is from a stream located at the southeast corner of the lake. Inlet flows were measured using a small wooden dam with a holding pool and a V-notch weir that was installed in 1995 for the previous Lake Ketchum study. Flows through the weir were measured using an absolute pressure transducer coupled with a data logger to measure water depths inside the pool. Another transducer/logger recorded barometric pressure that was used to adjust the water depth readings in order to compensate for changes in atmospheric pressure. The loggers recorded measurements every 15 minutes. Stream flows were later calculated based on the depth of the water flowing through the V-notch.

Measurements of the height of water in the lake (the lake level) are necessary for determining the total volume of water residing in the lake at any point in time. Lake levels were also measured at 15-minute intervals using an absolute pressure transducer/data logger installed in the lake not far from the lake inlet.

The lake outlet is located on the west shoreline (Figure 2-1). Water flowing out of the lake spills over a rectangular cement weir installed on the west shore of the lake by residents in early 2000. There is a notch in one side of the outlet weir to allow a small amount of water out of the lake when the lake level is lower. The outlet flow runs through a long underground pipe to a stream that flows out to Skagit Bay. The volume of flow out of the lake was calculated using the geometry of the outlet weir and the continuous lake level readings.

The timing and amounts of precipitation falling on the lake surface were measured with a recording rain gage installed near the northeast corner of the lake. The rain gage measured every 0.01 inch of rain that fell during the monitoring period.

Evaporation from the lake surface was estimated from regional evaporation data. Groundwater movements were also estimated based on data from the previous Lake Ketchum study.

The hydrologic monitoring methods are described in more detail in the Technical Appendix and in the *Quality Assurance Project Plan Addendum for Lake Ketchum Algae Control Plan Project – Appendix D.* (Snohomish County, 2011b).

4.1.2 STREAM FLOW, LAKE LEVEL, AND PRECIPITATION MONITORING RESULTS

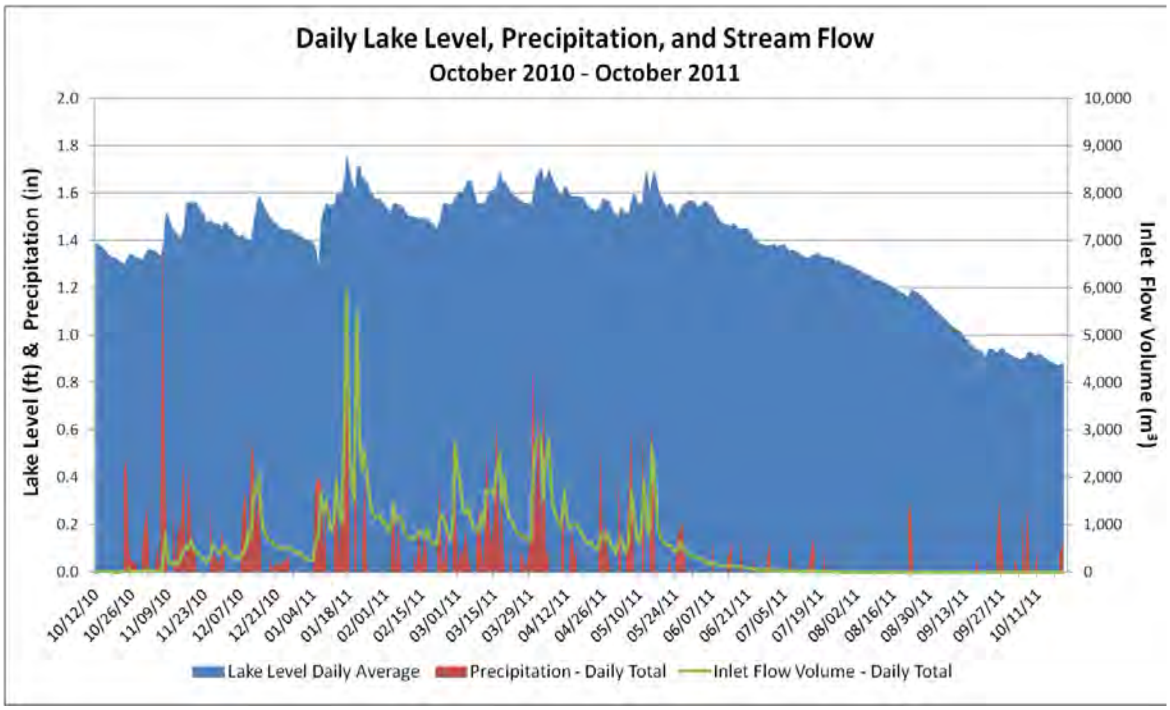
The year-long monitoring of stream flow showed that from October 2010 to October 2011 there was a total of 215,931 cubic meters of water flowing into Lake Ketchum from the main inlet stream at the southeast corner of the lake. This stream drains from the former dairy farm located south of the lake. (A cubic meter is equal to about 264 gallons of water.) The yearly water total is equivalent to almost seven feet of water over the entire surface of the lake. Of course, the lake did not rise seven feet because approximately the same amount of water flowed out of the lake outlet.

Figure 4-1 is a visual representation showing the results of the stream flow, lake level, and precipitation monitoring at Lake Ketchum. The green line shows the daily stream flow volumes in cubic meters. The highest peak flows happened during January 2011 when over 51,000 cubic meters (13.5 million gallons) flowed into the lake. The maximum flow rate for the inlet stream occurred on January 17th, when over a tenth of a cubic meter (31 gallons) of water per second were washing into the lake. Overall, there was steady flow in the inlet stream from December 2010 through May 2011. Because of wet conditions throughout the spring of 2011, some stream flow continued until July 27th. This is about three months later than the normal end of stream flow at Lake Ketchum.

Precipitation during the year of monitoring totaled 36.16 inches of rain. The highest daily rainfall total of 1.45 inches occurred on November 7, 2010. However, the wettest month was January 2011, and steady rain fell throughout the spring. Overall, the monitoring year was relatively wet. Although rainfall was similar to the amount that fell in 2009-2010, it was substantially more than occurred in any of the eight or nine previous years.

Inlet stream flow and precipitation have a large effect on the amount of water in the lake. Normally, the lake holds about 295 acre-feet of water (an acre-foot is one foot of water over one acre). The level of the lake fluctuated nearly one foot during the year (Figure 4-1). The highest daily lake level measured on a staff plate in the lake was 1.77 feet on January 17, 2011. At this height, the lake held about 307 acre-feet of water. The lowest lake level occurred at the end of the 2011 summer when the lake fell to 0.88 feet elevation and held about 282 acre-feet of water. By way of comparison, the top of the concrete weir at the lake outlet measures 1.49 feet elevation on the staff plate. The lake level was high enough that water flowed over the top of the weir and out the outlet almost continuously from early January through May 2011. A small amount of water flowed out through the notch in the weir until late August 2011.

FIGURE 4-1: LAKE KETCHUM DAILY LAKE LEVELS, PRECIPITATION, AND FLOW VOLUME



4.2 LAKE AND STREAM WATER QUALITY MONITORING

SWM staff also conducted water quality monitoring of the lake and the inlet stream for one full year. This monitoring documented the concentrations of phosphorus in the lake and stream, as well as changes in temperature, dissolved oxygen, and water clarity through the seasons. Together with hydrologic measurements, these data reveal the patterns of phosphorus flowing into and out of the lake and moving within the lake during the year.

4.2.1 LAKE AND STREAM WATER QUALITY MONITORING METHODS

Lake monitoring involved collection of water samples for laboratory analysis and field measurements of physical and chemical parameters. Monitoring took place every month from October 2010 through March 2011 and twice a month from April 2011 through October 2011. Water samples for total phosphorus and soluble reactive phosphorus (the portion of phosphorus that is available for algae) were taken in the deep portion of the lake at 1, 2, 4, and 5 meters deep. Samples were also taken for chlorophyll *a* from 1 meter deep to measure the concentrations of algae in the water. In addition, SWM staff took field measurements of temperature and dissolved oxygen at every meter depth from the lake surface down to the lake bottom. Water clarity was also measured using a Secchi disk.

For the inlet stream, SWM staff took grab samples of water from the downstream end of the culvert under South Lake Ketchum Road on the same dates as the in-lake sampling. These water samples were analyzed for total phosphorus and soluble reactive phosphorus. No separate samples were taken of water flowing out of the lake because the characteristics of that water would be similar to the water near the surface in the middle of the lake.

The water quality monitoring methods are described in more detail in the Technical Appendix and in the *Quality Assurance Monitoring Plan Snohomish County Lake Management Program* and the *Quality Assurance Project Plan Addendum for Lake Ketchum Algae Control Plan Project - Appendix D* (Snohomish County, 2011a and b).

4.2.2 LAKE AND STREAM WATER QUALITY MONITORING RESULTS

The dynamics of phosphorus in Lake Ketchum are related to the patterns of temperature and dissolved oxygen in the lake and the flow of phosphorus into the lake from the main inlet stream.

WATER TEMPERATURE

The temperature of lake water changes with the seasons and varies with depth. During spring and summer, the sun warms the upper waters. Because warmer water is less dense, it floats above the cooler, denser water below. The temperature and density differences create distinct layers of water in the lake, and these layers do not easily mix. This process is called stratification and occurs during the warm months. The warm, upper water layer is called the epilimnion. The colder, darker bottom zone is called the hypolimnion. These layers will stay separated until the fall when the upper waters cool, the temperature differences decrease, and the entire lake mixes, or turns over.

Figure 4-2 shows the profiles of water temperatures in Lake Ketchum from October 2010 through October 2011. Each line indicates the water temperatures in Celsius from the surface of the lake at the top down to the lake bottom near six meters. The profiles show that the temperature was uniform from top to bottom during December through March, ranging between 3° and 7°C (37° to 45°F). By May the surface water had warmed to about 15°C (59°F). During June through September, the water was around 20°C (68°F) at the surface. Over the same months, the water near the lake bottom remained around 9°C (48°F). This difference in temperature created a physical and chemical separation between the upper waters and the bottom waters. Then, by October 2011 the entire lake was cooling off again.

DISSOLVED OXYGEN

Profiles of dissolved oxygen show seasonal and depth changes similar to those seen in water temperature. Most of the dissolved oxygen in the lake comes from the atmosphere. During the warm months, the upper waters receive oxygen from the atmosphere and via photosynthesis by algae, but the lower waters cannot be replenished with oxygen because of the separation between water layers and because there is little algal growth in the lower waters where sunlight is limited. Meanwhile, bacteria in the lake bottom are consuming oxygen as they decompose organic matter. Eventually, oxygen is depleted in the bottom waters. Low dissolved oxygen in the bottom waters can allow phosphorus in the lake sediments to be released into the water. This process causes major problems in Lake Ketchum.

Figure 4-3 shows monthly profiles of dissolved oxygen from the top of the lake down to the lake bottom. Again, during December through March, dissolved oxygen levels were relatively uniform from top to bottom because the lake was well-mixed and not divided into temperature layers. By April, the bottom waters were losing oxygen. Then, from May through September, there was essentially no dissolved oxygen below two meters deep. These summer conditions were conducive for phosphorus in the lake sediments to be released into the lake water and made available for algal growth.

FIGURE 4-2: LAKE WATER TEMPERATURE AT VARIOUS DEPTHS DURING STUDY PERIOD

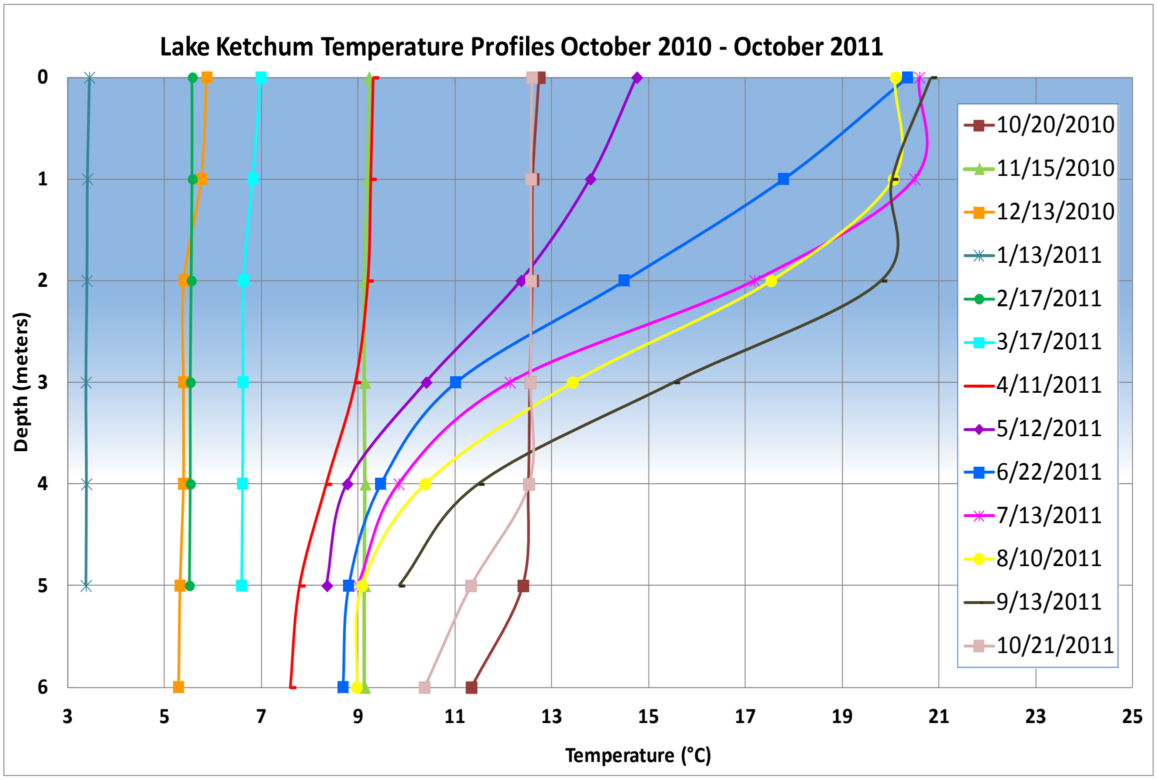
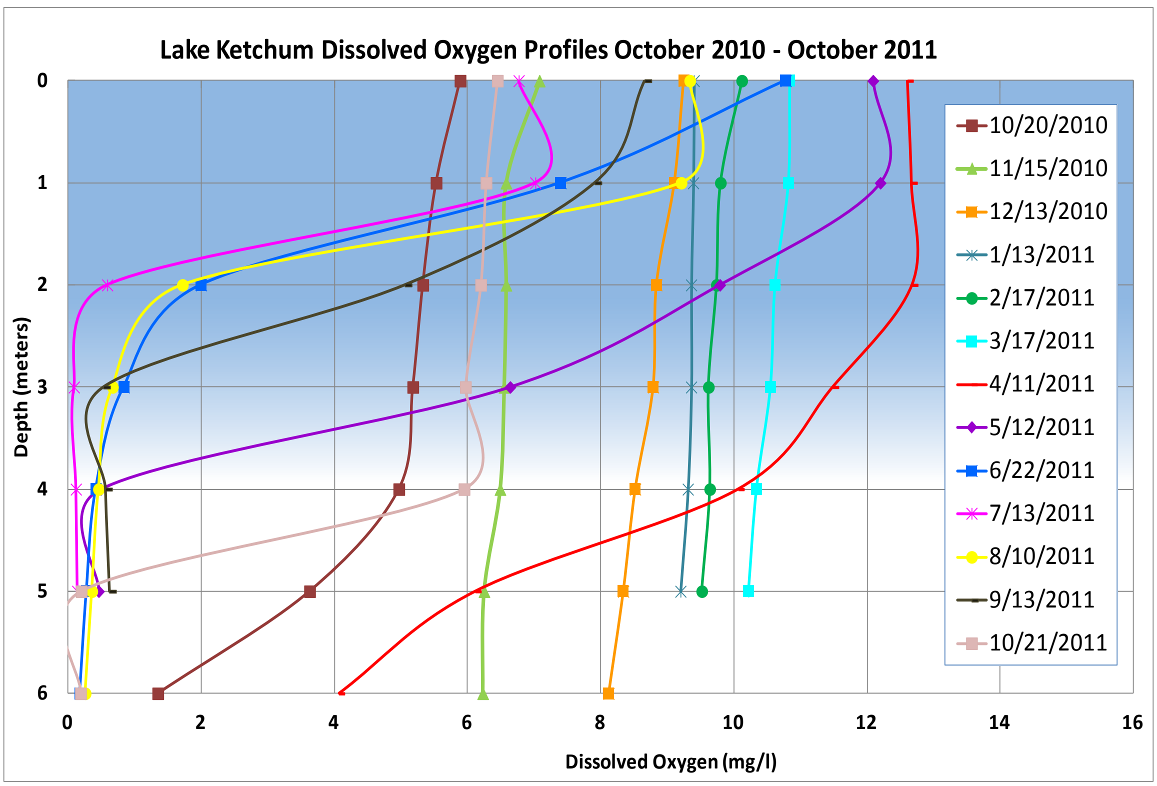


FIGURE 4-3: LAKE DISSOLVED OXYGEN LEVELS AT VARIOUS DEPTHS DURING STUDY PERIOD

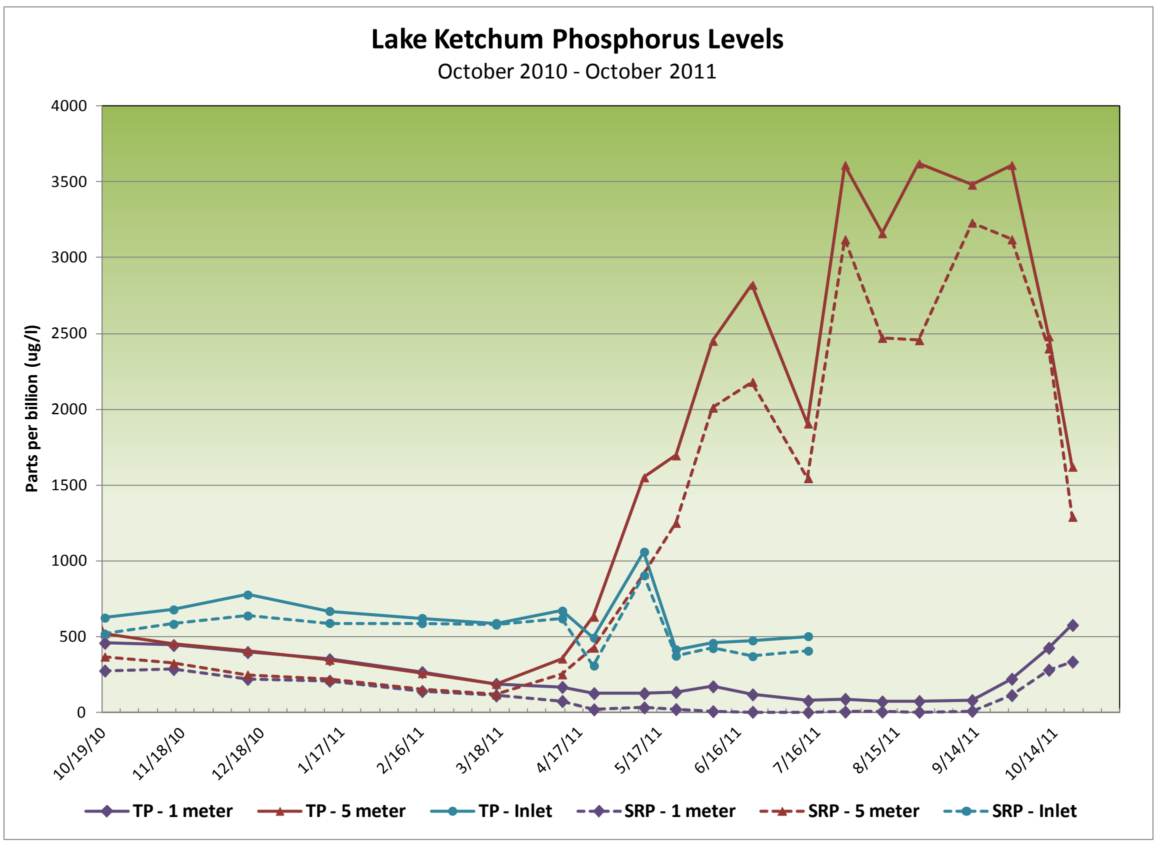


PHOSPHORUS

As described above, Lake Ketchum has extremely high phosphorus levels. This is the cause of the nuisance algae conditions in the lake. Water quality monitoring from May through October 2011 revealed that the summer average concentration of total phosphorus (TP) was 181 µg/l at one meter deep in the epilimnion (upper waters) and 2,667 µg/l at five meters deep in the hypolimnion (bottom waters).

Phosphorus concentrations in the lake and the inlet stream also varied through the seasons. Figure 4-4 illustrates the seasonal patterns of TP and soluble reactive phosphorus (SRP, the portion that is available for algae) at 1-meter and 5-meter depths in Lake Ketchum. In the winter and fall, when the entire lake was well-mixed, the 1 and 5-meter phosphorus concentrations were similar, and about two-thirds of the phosphorus was SRP.

FIGURE 4-4: PHOSPHORUS MEASUREMENTS AT 1 AND 5 METER DEPTHS DURING STUDY PERIOD



During the stratified period when the lake was divided into two layers (April through September), the 1-meter TP concentrations gradually declined, and the SRP concentrations were very low. This indicates that the algae were growing vigorously and using up nearly all the available phosphorus in the upper waters. In contrast, during the same April through September period, TP concentrations at five meters climbed steadily and dramatically, and nearly all the phosphorus was in the available SRP form. This clearly illustrates the high rate of phosphorus release from the lake sediments during the warm months when the lake is stratified into two separate layers. When the lake began mixing again in late September, this phosphorus spread throughout the rest of the lake and became available for algal growth.

Figure 4-4 also shows the patterns of TP and SRP concentrations in the main inlet stream. The phosphorus levels were quite high, above 500 µg/l from October 2010 until April 2011 when stream flow rates were also high, with another spike in May during a rain storm. The phosphorus loading from the stream helps fuel algal growth in the summer and then adds to the build-up of phosphorus in the lake bottom. Even though the levels in the stream are high, they are minimal in comparison to the high levels that are released into the bottom waters from the lake sediments during the summer.

CHLOROPHYLL *A*

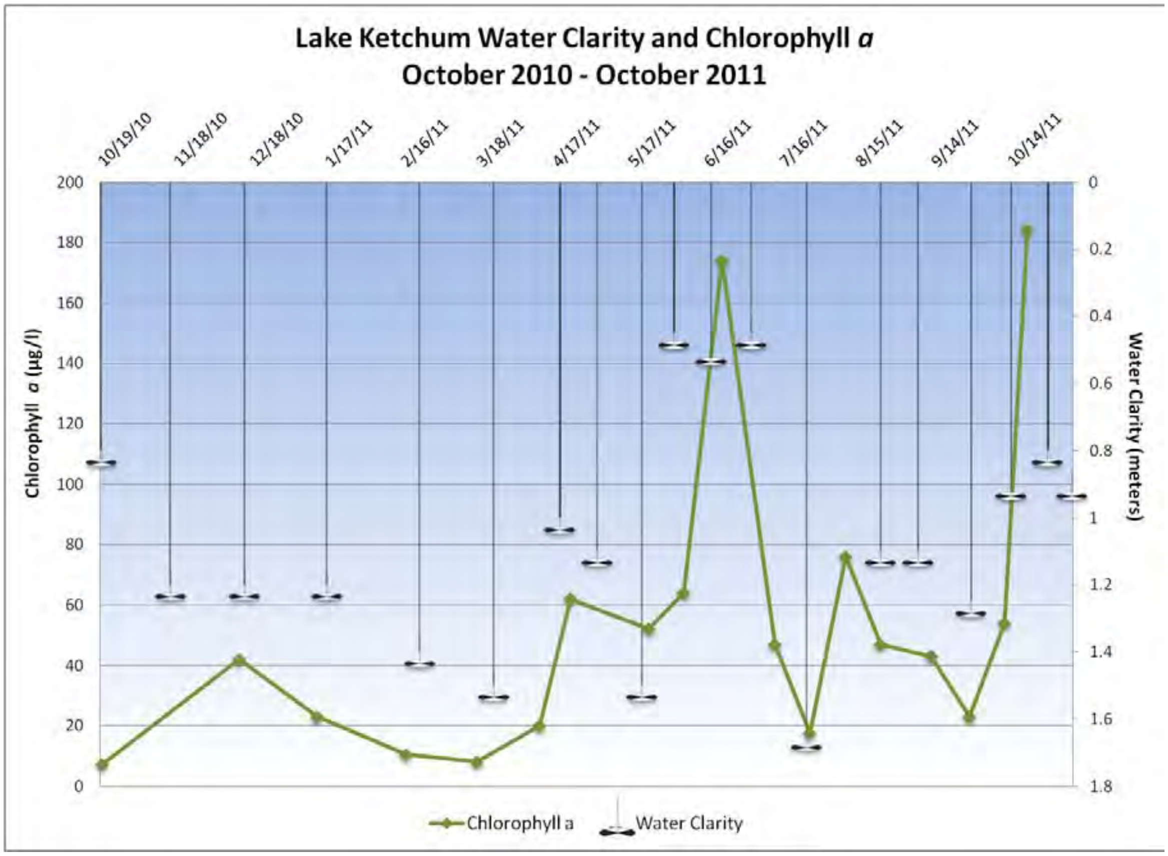
Lake Ketchum suffers from nuisance production of algae that impairs the use and enjoyment of the lake. Algal blooms are typical from late spring through mid-fall. Figure 4-5 illustrates the pattern of algal growth throughout the study year, as seen in chlorophyll *a* measurements. There was a large spike in the amount of algae in June 2011, with variable levels through the summer until another large spike in October. However, even the lower values during much of the summer were higher than algae levels seen in other lakes.

The types of algae in Lake Ketchum are also a concern. Detailed analyses of algae species were not undertaken during this study. However, blue-green algae (also called cyanobacteria) were dominant during much of the year, based on microscopic analysis. Blue-green algae are known for causing nuisance blooms and scums. Also, some blue-green algae can produce toxins that are threats to human and pet health. During 2011, liver toxins (microcystin) were detected almost continually from early June through early November. The peak toxin concentration occurred in mid-July when microcystin levels reached 555 parts per billion (ppb). The Washington State recreational guideline for microcystin is 6 ppb. These toxic algal blooms are a public health concern for Lake Ketchum.

WATER CLARITY

Lake water clarity—how far one can see into the water—is affected somewhat by the naturally brown/yellow color of Lake Ketchum. However, Figure 4-5 shows that water clarity is directly related to the amount of algae (chlorophyll *a*) in the water. In almost every case, when chlorophyll *a* levels rose, water clarity declined (the Secchi disk was less visible in the water). And, water clarity improved when chlorophyll *a* levels dropped. Water clarity of less than about 1.2 meters (4 feet) is usually perceived as poor water quality. This occurs during much of the year at Lake Ketchum.

FIGURE 4-5: WATER CLARITY COMPARED TO ALGAE LEVELS DURING STUDY PERIOD



4.3 LAKE SEDIMENT SAMPLING

The largest source of the phosphorus in Lake Ketchum is the sediments at the bottom of the lake. Over time, phosphorus from the surrounding watershed, primarily from the former dairy farm, has washed into the lake and settled to the lake bottom. There, it is available to be recycled back into the water column during the warm months of the year when dissolved oxygen levels decline in the bottom waters. Once the phosphorus is released back into the water, it can contribute to the growth of nuisance algae in the lake. The release of phosphorus from the lake sediments to the overlying water is called internal loading. In order to understand the magnitude of phosphorus present in the sediments and the portion of that phosphorus which is available to be released into the water column, SWM and Tetra Tech conducted a detailed analysis of the sediments in Lake Ketchum.

4.3.1 SEDIMENT SAMPLING METHODS

The analysis involved collecting sediment cores from three locations in the lake

- Mid-Deep: Center of the lake in 6 meters (20 feet) of water.
- East Shallow: East end of lake between the island and the south shore in 2 meters (6.6 feet) of water.
- West Shallow: West end of lake near outlet in 4.5 meters (15 feet) of water.

Each of the cores was 40 cm (16 inches) deep and was divided by the lab into 5-cm-thick sections and analyzed for 10 parameters. The sediment sampling and analysis methods are described in more detail in the quality assurance project plan for the Lake Ketchum sediment study (Snohomish County, 2011c).

4.3.2 SEDIMENT SAMPLING RESULTS

The results of the sediment analysis revealed that phosphorus levels are high in the Lake Ketchum sediments, especially in the top 10 cm (Figure 4-6). Total phosphorus concentrations in the upper sediments ranged from 700 to 2200 mg/kg (similar to parts per million or ppm) compared to 0.1 to 3.5 ppm in the lake waters. The levels were highest in the lake center because the finest, phosphorus-rich sediments tend to slowly slide to the deepest portion of the lake. The phosphorus levels in the Ketchum sediments (2200 mg/kg) are similar to or higher than phosphorus levels in several other Puget Sound area lakes that also have significant problems with internal phosphorus loading (Figure 4-7). Lake Washington had 4000 mg/kg before sewage diversion. The highest cited in literature is 10,000 mg/kg in a heavily waste loaded Danish lake (Cooke et al., 2005). Below 15 cm at the deep site, total phosphorus content in Ketchum is similar to most other Puget Sound lakes (between 500 and 1000 mg/kg).

FIGURE 4-6: LAKE KETCHUM SEDIMENT PHOSPHORUS CONCENTRATIONS

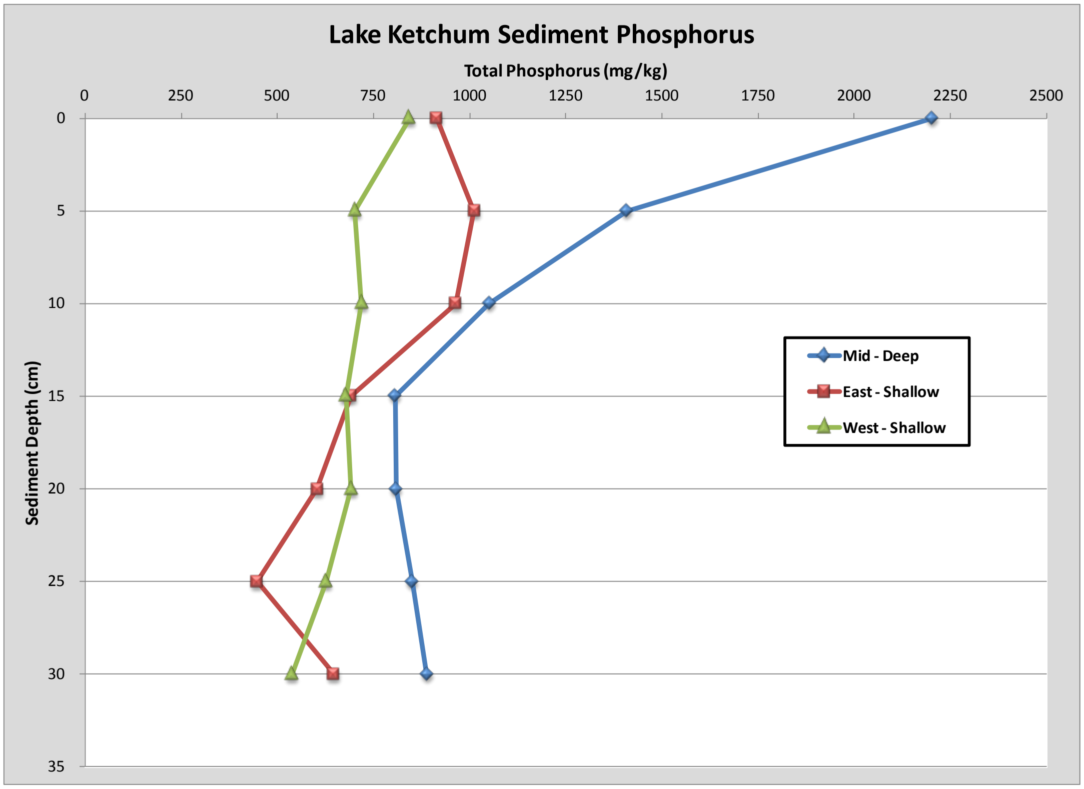
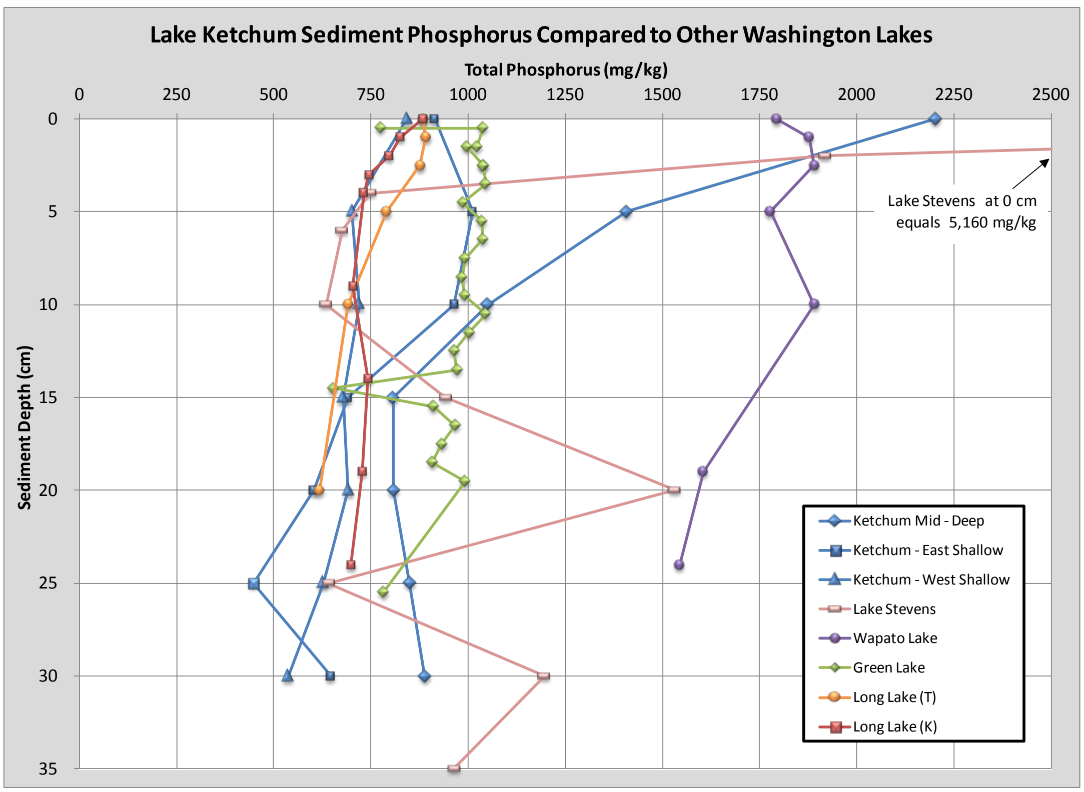
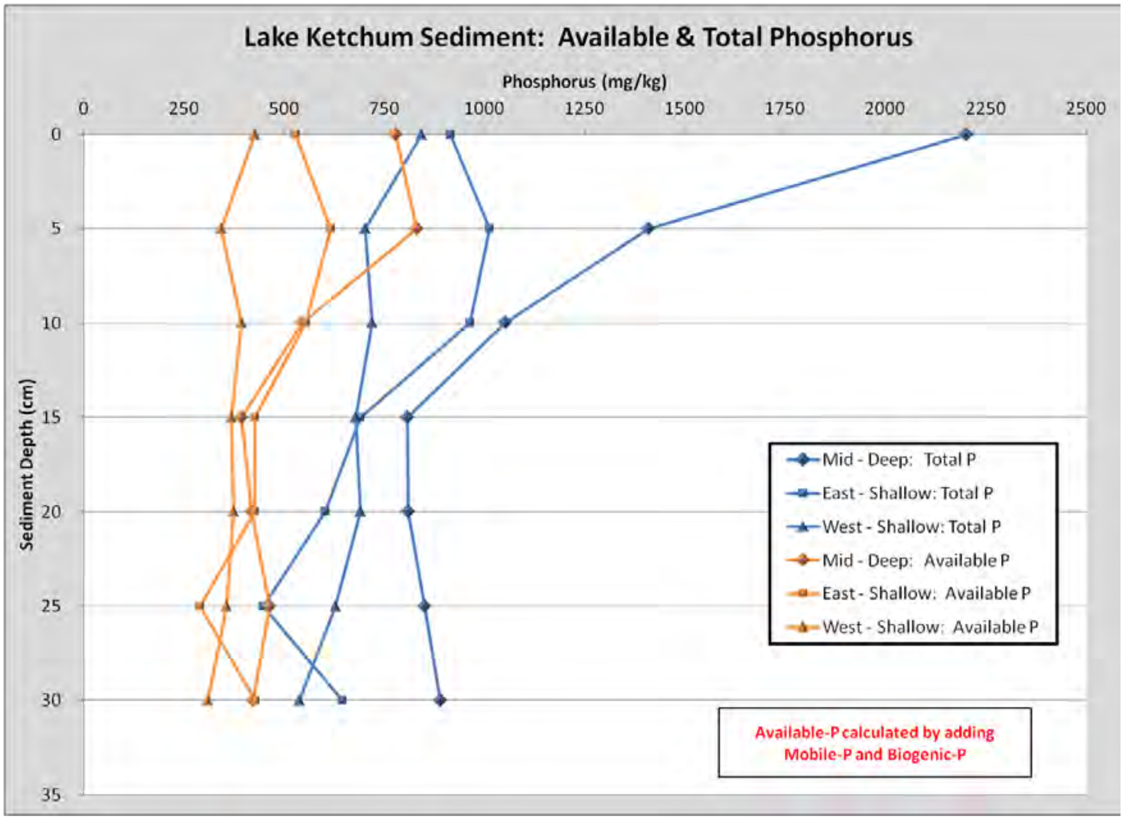


FIGURE 4-7: LAKE KETCHUM SEDIMENT PHOSPHORUS COMPARED TO OTHER ENRICHED LAKES



The analysis also revealed that a large portion of the phosphorus in the Lake Ketchum sediments is present in forms that are potentially available for release into the water column as internal loading. The available phosphorus is a combination of iron-bound phosphorus and loosely-sorbed phosphorus (mobile phosphorus) and biogenic phosphorus. The available phosphorus in the upper 10 cm of sediment ranges from 343 to 830 mg/kg (Figure 4-8). This information is important because any sediment treatments proposed as part of the Algae Control Plan must be adequate to permanently inactivate the majority of this available phosphorus. The detailed results of the sediment analysis are described in the Technical Appendix.

FIGURE 4-8: TOTAL AND AVAILABLE PHOSPHORUS CONCENTRATIONS IN LAKE SEDIMENTS



5 WATER BUDGET

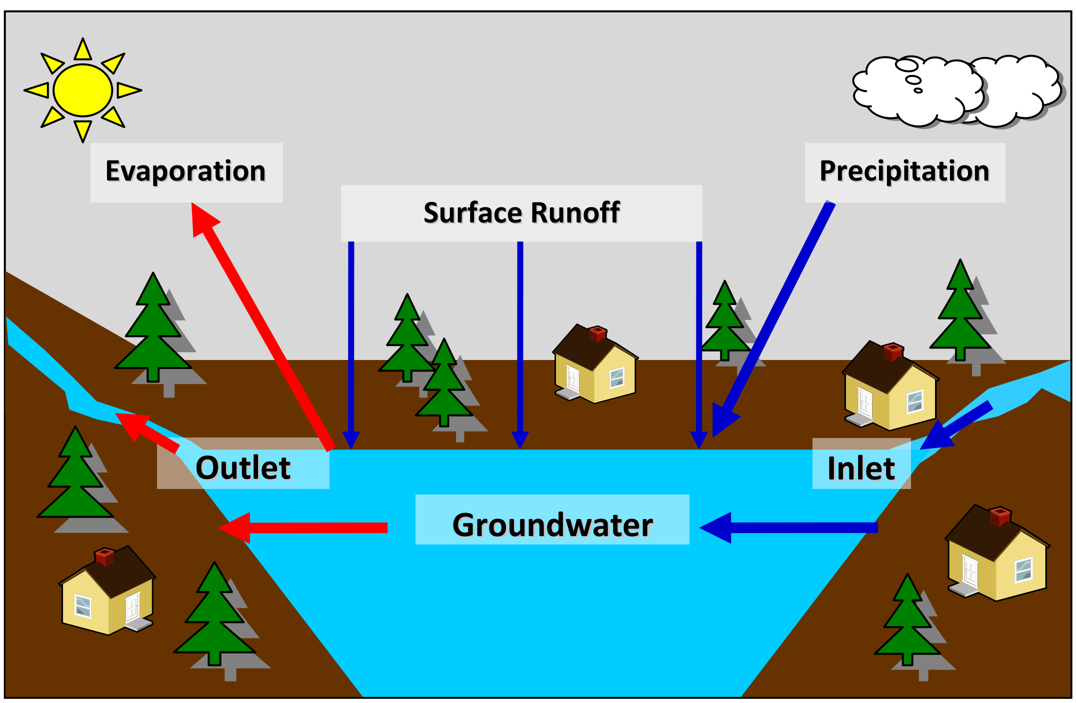
5.1 WATER BUDGET DESCRIPTION

A water budget was developed for Lake Ketchum in order to quantify all of the inflows and outflows to the lake over the one-year study period. The water budget serves as a key element for developing a phosphorus model that can be used to predict the lake's response to various restoration alternatives. A water budget must balance, meaning that all of the water flowing into the lake minus all of the water flowing out of the lake will equal the change in the volume of water held in the lake over the study period.

$$Change\ in\ Volume\ (\Delta V) = Inflows - \ Outflows$$

A conceptual model of Lake Ketchum is presented in Figure 5-1. The primary sources of water flowing into the lake include: 1) precipitation on the lake surface, 2) flow from the main inlet stream, 3) surface runoff from the rest of the watershed, and 4) shallow groundwater inputs. The outflows of water from Lake Ketchum include: 1) outlet flow, 2) evaporation, and 3) shallow groundwater losses. A two-week time step from October 10, 2010 through October 24, 2011 was used for the Ketchum water budget. The Technical Appendix contains detailed information on how each parameter of the water budget was measured or estimated.

FIGURE 5-1: CONCEPTUAL HYDROLOGIC MODEL FOR LAKE KETCHUM



5.2 WATER BUDGET RESULTS

The study found that the primary sources of water flowing into Lake Ketchum are shallow groundwater (33%) and flow from the main inlet stream (30%) (Figure 5-2; Figure 5-3). Runoff from the rest of the watershed (25%) and precipitation (12%) comprised the remainder of the water inflows. The total water flow into Lake Ketchum was 731,050 cubic meters of water, or 593 acre-feet, for the water year.

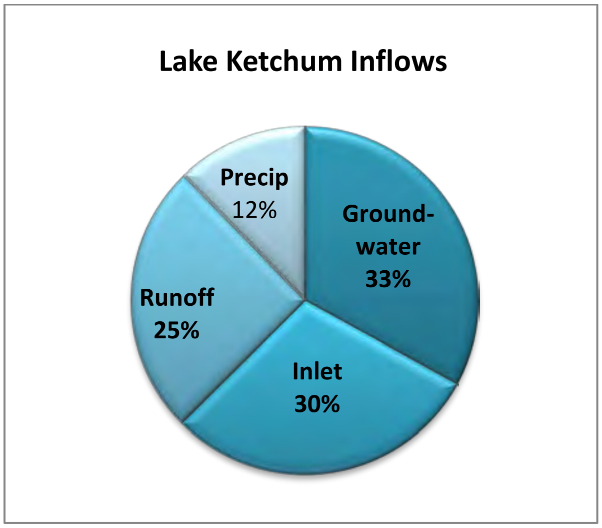
The lake outlet was the principle route for water leaving Lake Ketchum, accounting for over 88% of all outflows (Figure 5-2; Figure 5-3). Evaporation accounted for another 11%, while groundwater losses were less than 1%. Overall, the total outflows from the lake were 747,203 cubic meters, or 606 acre feet. Since there was more water that flowed out of Lake Ketchum than into Lake Ketchum during the study period, the lake volume decreased by 16,153 cubic meters, or 13.1 acre feet. This means that the lake water level was about six inches lower in October 2011 than in October 2010.

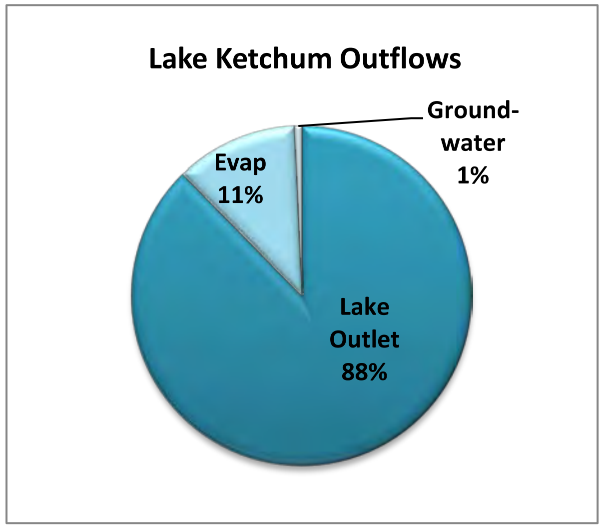
A similar water budget was developed in 1995-1996 as part of the original Lake Ketchum restoration study (Entranco, 1997). Although 2010-2011 was a slightly wetter year than 1995-1996, there was a high degree of similarity between the current study results and the historic investigation. (In 1995-96, the major inflows were groundwater-30%; runoff-29%, inlet-32% and precipitation-18%.) This similarity increases confidence that the new model is an accurate portrayal of the water flow patterns at Lake Ketchum. Additional details, including the seasonal distribution of flows, can be found in the Technical Appendix.

FIGURE 5-2: KETCHUM WATER BUDGET INFLOWS AND OUTFLOWS OCTOBER 2010-2011

Source	Total Inflow (m^3)	Total Inflow (ac-ft)	% of Total Inflow
Groundwater	241,247	196	33%
Inlet	215,931	175	30%
Surface runoff	184,343	149	25%
Precipitation	89,529	73	12%
Total	**731,050**	**593**	**100%**
Source	Total Outflow (m^3)	Total Outflow (ac-ft)	% of Total Outflow
Lake Outlet	655,234	531	88%
Evaporation	86,839	70	11%
Groundwater	5,130	4	1%
Total	**747,203**	**606**	**100%**

FIGURE 5-3: LAKE KETCHUM WATER INFLOWS AND OUTFLOWS OCTOBER 2010-OCTOBER 2011





6 PHOSPHORUS BUDGET AND LAKE MODEL

6.1 PHOSPHORUS BUDGET DESCRIPTION

Using the water budget as a foundation, a phosphorus budget was created for Lake Ketchum that accounted for all movement of phosphorus into and out of the lake and within the lake itself. The difference between the annual total phosphorus inputs and outputs equals the change in total phosphorus concentration within the lake over the study period.

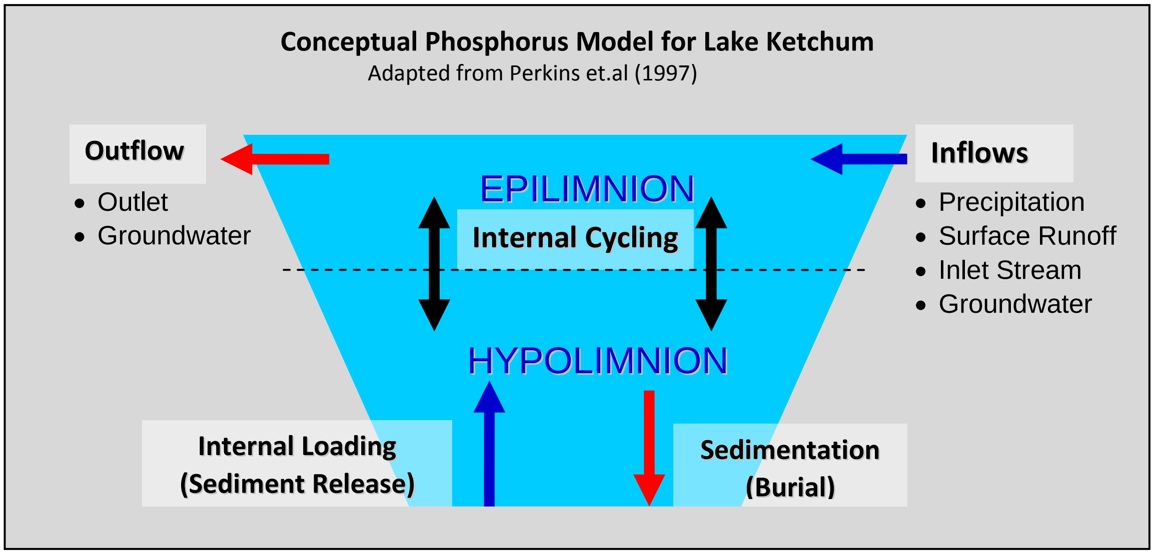
$$Change\ in\ Lake\ P\ Concentration(\Delta \mathrm{TP}) = Inflows\ of\ \mathrm{TP} - Outflows\ of\ \mathrm{TP}$$

The conceptual inflows and outflows of phosphorus for Lake Ketchum are presented in Figure 6-1. The primary external sources of phosphorus to the lake are 1) precipitation on the lake surface, 2) flow from the main inlet, 3) surface runoff from the rest of the watershed, and 4) shallow groundwater flow. Precipitation contains a small amount of naturally-occurring phosphorus. As the rain water washes across the ground, it has the potential to pick up dissolved phosphorus and particulate phosphorus from soil particles, fertilizers and animal wastes, which are laden with phosphorus. Shallow groundwater also carries in dissolved phosphorus from the surrounding soils.

Phosphorus can also enter the lake from the sediments at the bottom of the lake. This is known as internal loading. Internal loading primarily occurs during the stratified period when oxygen is depleted in the bottom waters, or hypolimnion. As discussed above, this occurs because the phosphorus, which is normally bound to iron or organic materials in the sediments, is released during low oxygen conditions.

Once phosphorus enters the lake, there are fewer ways for it to leave. For phosphorus to be completely removed from the lake system, it must flow out of the lake outlet or leave through shallow groundwater. Most of the phosphorus leaves the water column through sedimentation when particles settle to the lake bottom. However, phosphorus that has settled to the bottom of the lake may in the future be released into the lake through internal loading and become available again for algal growth. Please refer to the Technical Appendix for more details on the methods and assumptions used to develop the phosphorus budget for Lake Ketchum, as well as a more thorough description of internal phosphorus cycling.

FIGURE 6-1: LAKE KETCHUM CONCEPTUAL PHOSPHORUS MODEL



6.2 PHOSPHORUS BUDGET RESULTS

The annual load of phosphorus to Lake Ketchum from both external and internal sources is approximately 623 kg (1374 pounds) of phosphorous per year. Seventy-three percent of the total load, or 455 kg (1,000 pounds), comes from internal loading from the lake sediments. The lake inlet which drains the former dairy farm is the only other major source of phosphorus, contributing 146 kg (322 pounds), or 23.4% of the total. These loading values are extremely high for a lake. To put these amounts into perspective, there would need to be less than 15 kilograms of phosphorus in the entire lake to meet the target phosphorus concentration of 40 µg/l for the lake.

Another way to visualize the high loading rate is to think in terms of bags of fertilizer. One kilogram of phosphorus is the same amount found in a 50-lb bag of standard 10-10-10 lawn fertilizer. Therefore, the inlet stream carries in the equivalent of 146 bags of fertilizer each year. Meanwhile, the internal load from the sediments is equivalent to dumping 455 bags of fertilizer directly into the lake annually. In contrast, surface water runoff from the remainder of the watershed and from groundwater account for only 3.3% of the total phosphorus sources.

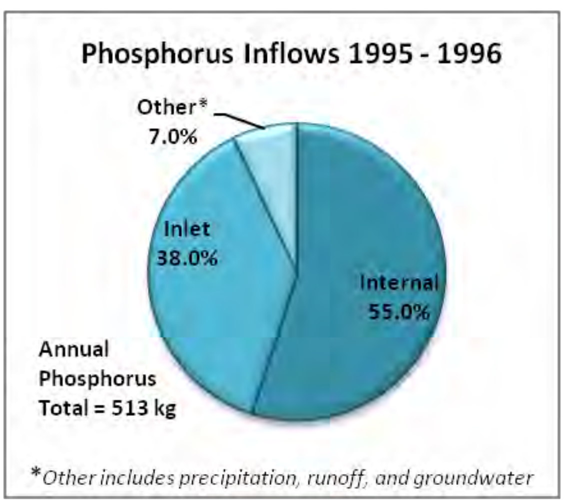
Of the 623 kg entering the lake, only 153 kg (337 pounds) left the lake through the outlet or through shallow groundwater. The remainder of the phosphorus settled out to the lake bottom where it is available as a potential future source of phosphorus to the lake. Over the entire year, there were 85 kg (187 pounds) more of phosphorus that settled to the lake bottom than were released from the lake sediments.

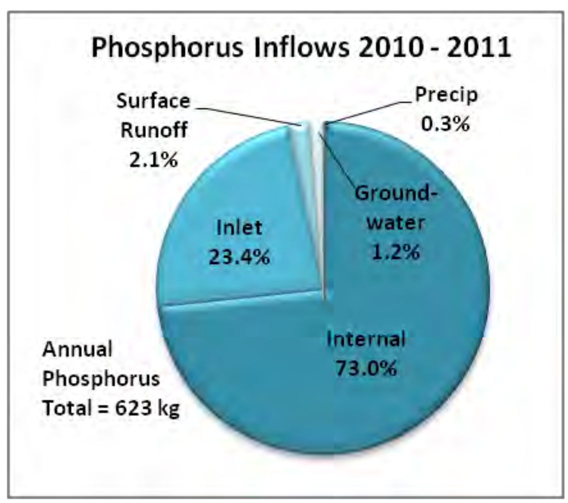
The current phosphorus sources can be compared to results found during the previous study conducted in 1995-1996 (Entranco, 1997). The relative share as well as the total amount of phosphorus coming from the inlet stream and the former dairy farm decreased markedly since the last study, going from 38% to 23% and from 195 kg to 145 kg. At the same time the total amount and the proportion of the phosphorus load attributed to internal loading has increased significantly, going from 262 kg to 455 kg and from 55% to 73%. As a result, the total amount of all loading has increased since 1995-1996, making the size of the total pie larger. This internal loading, not the loading from the inlet stream, is the primary cause of the nuisance algal growth in the lake. This dramatic increase in internal loading shows that the phosphorus in the lake sediments must be controlled in order to achieve any water quality improvements in Lake Ketchum.

FIGURE 6-2: PHOSPHORUS BUDGET INFLOWS OCTOBER 2010 – OCTOBER 2O11

Source	Total Phosphorus Inflows (kg)	% Phosphorus Load
Internal (Sediments)	455.07	73.0%
Inlet Stream	145.54	23.4%
Surface Runoff	13.13	2.1%
Groundwater	7.48	1.2%
Direct Precipitation	1.79	0.3%
Total	623.01	100.0%

FIGURE 6-3: CURRENT PHOSPHORUS INFLOWS COMPARED TO 1995-1996 INFLOWS





6.3 LAKE KETCHUM PHOSPHORUS MODEL

Using the conceptual framework outlined in Figure 6-1, a phosphorus model was developed for Lake Ketchum. This type of model is called a two-layer, seasonal mass balance model. Similar models have been developed for use in Lake Onondaga, New York and Lakes Sammamish, Pine and Jameson in Washington (Perkins et al., 1997; Auer et al., 1997; Tetra Tech, 2008; Tetra Tech, 2009). The purpose of the model is to simulate the impact of different restoration alternatives on the total phosphorus concentrations in the lake throughout the year. The summer phosphorus concentrations, in particular, will determine the frequency and severity of algal blooms during the most likely period of lake use and recreation.

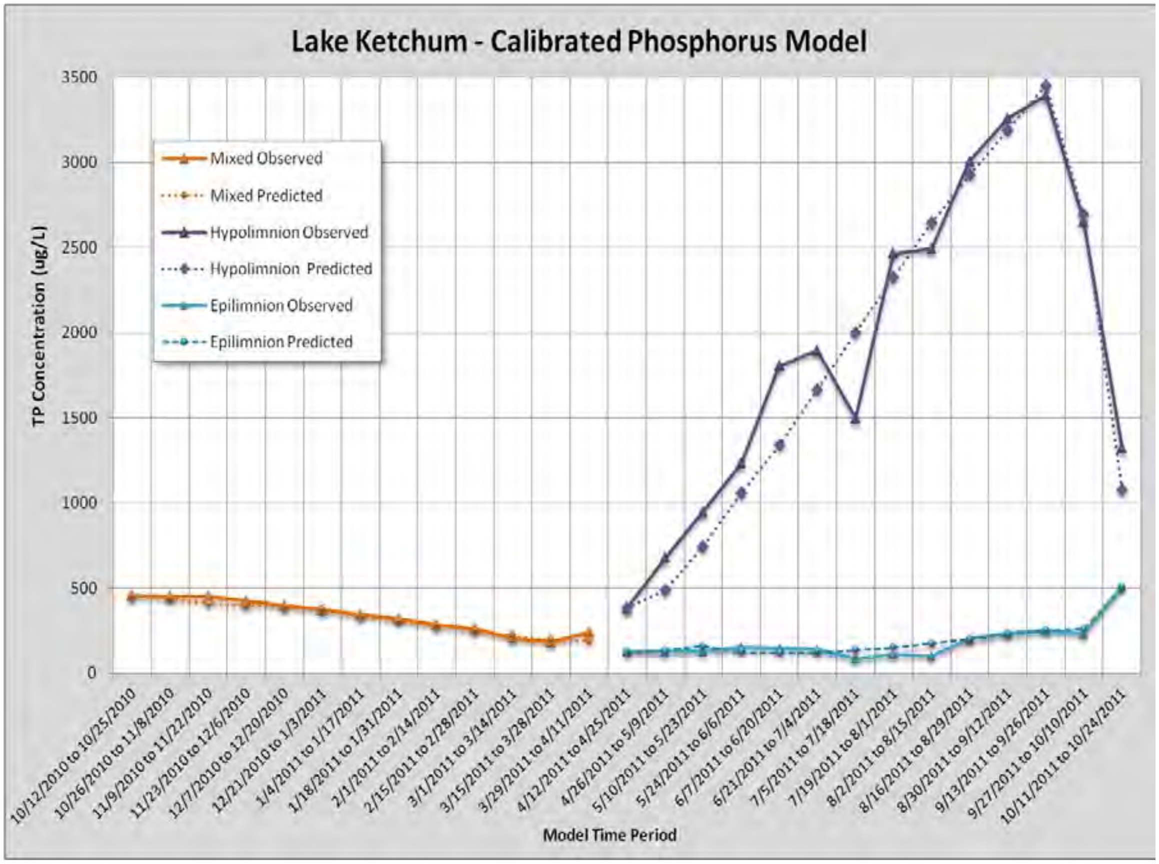
A two-layer seasonal approach is needed because of the effects of thermal stratification on phosphorus movements, as described in Section 4.2. Unlike the phosphorus budget that just looks at the net internal load, or sediment phosphorus release, during the study period, a model attempts to quantify the rate at which internal loading and sedimentation occur during the stratified and mixed periods. It also takes into account the movement of phosphorus between the hypolimnion (bottom waters) and the epilimnion (upper waters) during the stratified period.

The two main processes of phosphorus movement within the lake during the stratified period are diffusion and entrainment. Diffusion entails the movement of phosphorus from the phosphorus-rich hypolimnion to the less-rich epilimnion because of the differences in concentration. Entrainment is the capture of phosphorus by the epilimnion from the phosphorus-rich bottom waters that occurs as the depth of lake stratification descends during the fall prior to lake mixing.

To calibrate the model, the predicted changes in phosphorus concentrations over time were compared to the actual weekly changes observed during the study year (Figure 6-4). The model was calibrated so that during the seasons, the error, or the difference between the observed total phosphorus (TP) concentrations (the solid lines in Figure 6-4) and the predicted lake TP concentrations (the dashed lines) was minimal and within 6.5 % of the observed.

After calibration, the model was run for a period of four years for each restoration alternative to better understand the effects of various lake clean-up strategies over a longer time period. The model's predicted effects of the restoration alternatives on the lake are described below in Section 9.6. A thorough description of the assumptions made to estimate internal loading, sediment release, and internal phosphorus movement, as well as details of the model performance, can be found in the Technical Appendix.

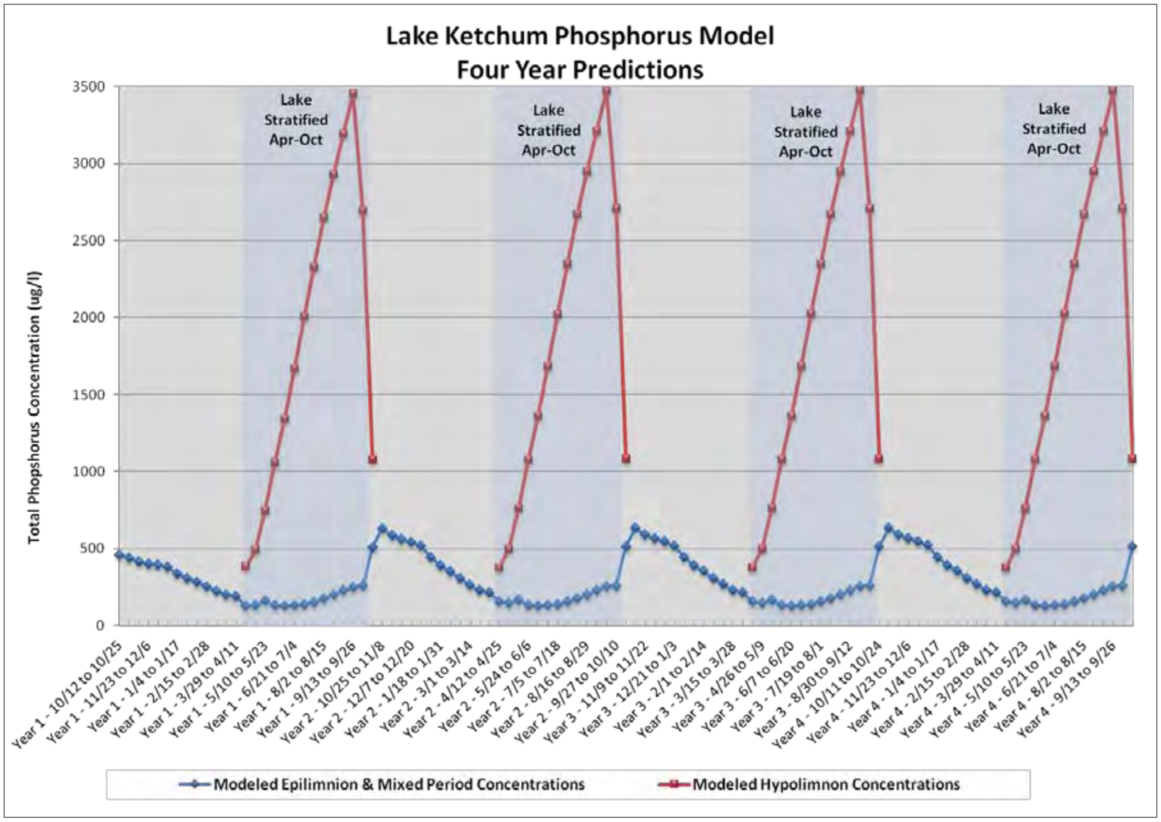
FIGURE 6-4: MODELED LAKE PHOSPHORUS CONCENTRATIONS COMPARED TO OBSERVED CONCENTRATIONS DURING MIXED AND STRATIFIED PERIODS



6.4 MODEL RESULTS

Several conclusions come from the Lake Ketchum phosphorus model. The most significant conclusion is that the internal loading that occurs through phosphorus release from the lake sediments is extremely high, as shown by the steep slopes and high peaks of the lines showing phosphorus levels in the hypolimnion during the stratified period (Figure 6-4 and Figure 6-5). The sediment-release rate (SRR) at Lake Ketchum was found to be 32 mg/m² per day on average during the stratified period, with a maximum of 42 mg/m² per day. Such high sediment release rates have been found in only hyper-eutrophic lakes that have long been polluted. Pine and Sammamish lakes, both highly affected by surrounding residential development, only reach phosphorus concentrations in the bottom waters of around 100 µg/l, with SRR rates of less than 5 mg/m² per day. Reducing the extremely high levels of internal loading is essential to the success of controlling algae and restoring the lake.

FIGURE 6-5: MODELED PHOSPHORUS CONCENTRATIONS FOR LAKE KETCHUM FOR FOUR YEAR PERIOD IN THE ABSENCE OF LAKE TREATMENTS

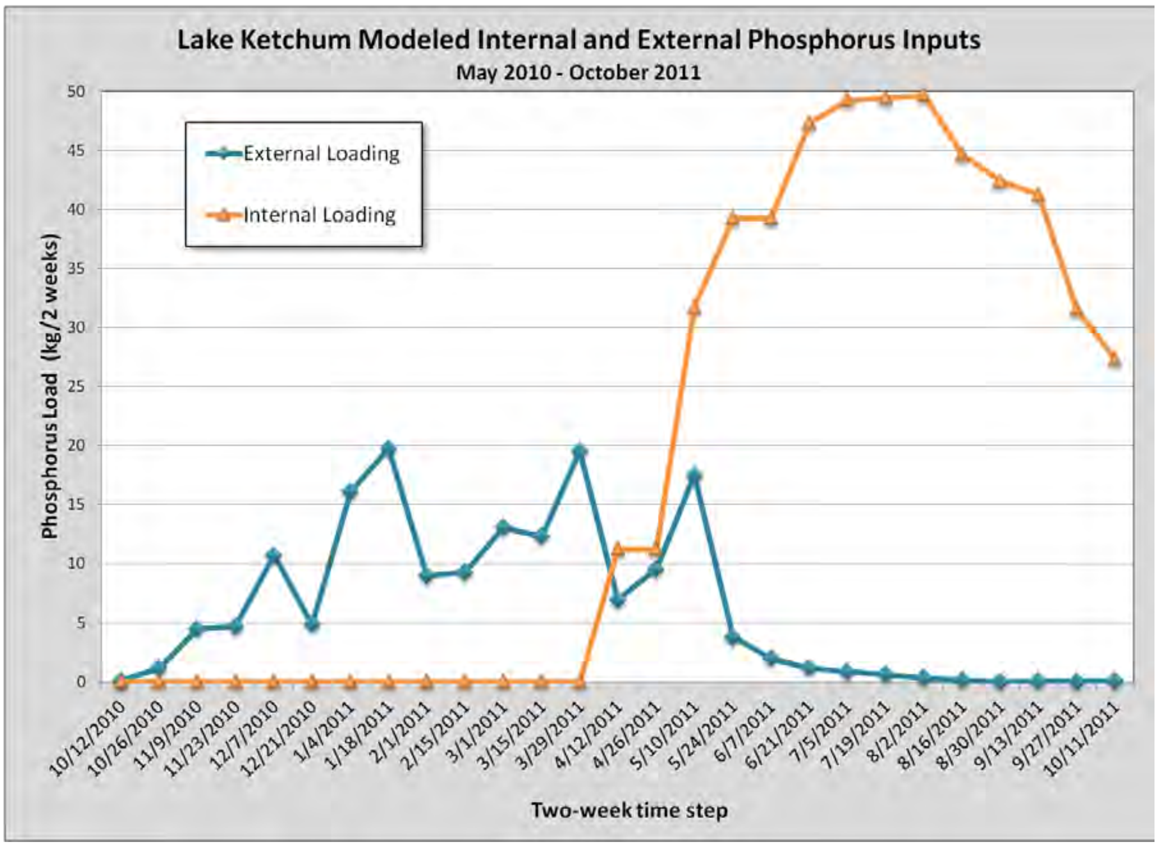


The largest benefit of reducing internal phosphorus loading will be preventing the persistent high levels of phosphorus that occur throughout the lake following fall turnover. The immediate impact of the high internal loading rate each year is extremely high phosphorus concentrations in the hypolimnion. Fortunately, summer stratification helps prevent these high phosphorus concentrations from reaching the upper waters and being available for algal growth during much of the summer. However, a large amount of this phosphorus is entrained into the epilimnion as the lake begins to mix in October (Figure 6-5). The high phosphorus concentrations following turnover do not fully settle out in the short term, likely due in part to a lack of iron in the lake sediments. Instead, high phosphorus levels persist into spring and remain available for algal growth during the next summer. Every year more phosphorus builds up in the lake bottom, magnifying this problem.

Furthermore, curtailment of internal loading will help to reduce summer phosphorus concentrations in Lake Ketchum by decreasing the amount of diffusion of phosphorus from the hypolimnion to the epilimnion during the summer months. Phosphorus concentrations in the hypolimnion are six to ten times greater than in the epilimnion. Therefore, some of the phosphorus from the hypolimnion diffuses into the epilimnion during the stratified period because of the large concentration gradient. Without this diffusion process, the model indicates that average summer phosphorus concentrations in the upper waters would be only 37 µg/l, as opposed to 173 µg/l with the existing rates of diffusion. Controlling internal loading will reduce this concentration gradient and lower the overall amount of diffusion.

Finally, the Lake Ketchum model shows that the source of phosphorus loading at Lake Ketchum varies significantly with the seasons (Figure 6-6). During the rainy season (October through May), external loading from the main inlet stream is the primary source of phosphorus for the lake, accounting for over 23% of the yearly total. However, as the lake begins to stratify in mid-April, internal loading from the sediments becomes the primary source of phosphorus for the lake. The seasonality of the phosphorus loading helps determine the most appropriate control methods, as well as the timing of clean-up actions.

FIGURE 6-6: SEASONAL CONTRIBUTIONS OF EXTERNAL AND INTERNAL PHOSPHORUS LOADS



7 MANAGEMENT METHODS FOR ALGAE CONTROL

The following methods were evaluated for controlling excess algae in Lake Ketchum. The methods either control algal growth directly or address one of the two main sources of phosphorus entering the lake—the internal phosphorus loading from the lake sediments or the external loading from the main inlet. Control of phosphorus from residential pollution is discussed further in Section 0.

7.1 DIRECT ALGAE CONTROL METHODS

There are several possible methods for directly controlling algal growth rate and quantity. These methods were briefly evaluated to determine if any might be appropriate for long-term algae control at Lake Ketchum. The conclusion of this evaluation was that, because none of these methods address the phosphorus that feeds algae, they are temporary or partial solutions and not appropriate for Lake Ketchum.

ALGAECIDES/CHEMICALS

There are several products that may be able to kill algae or limit its growth.

- Sodium carbonate peroxyhydrate is a fast-acting compound that, in some cases, can inhibit algal growth or prevent the formation of algal blooms. However, there is limited evidence that products containing this compound can control algal growth in a lake system.
- Another chemical that is sometimes used to control algae is endothall-amine salt (Hydrothol 191™). This chemical can kill algae; however, it has high toxicity to fish, so can only be applied at low concentrations. It would take repeated applications of endothall-amine at Lake Ketchum, and the algae would keep returning because of the high phosphorus concentrations in the lake.
- Bales of barley straw have been used in England to limit algal growth in ponds and some lakes. The decaying barley apparently releases chemicals that slow down algal growth. However, experience in the U.S. has not shown any consistent benefits from the use of barley straw.

PHYSICAL INHIBITORS

- The growth of algae can sometimes be controlled by adding shading products (dyes) to the water. The dyes make the water dark and limit the amount of light available for algae. Shading products may be successful in controlling algae in small ponds. However, they are not as effective and would likely not be allowed in a lake.
- Ultrasonic devices have been used to disrupt algal cells and control algal growth. The citizens at Lake Ketchum have deployed a number of the SonicSolution® brand of these devices in an attempt to control the algae. Although algal growth has seemed less in some years, testing in 2008 and 2009 did not find any statistical evidence that the units reduced algal growth in Lake Ketchum.

7.2 INTERNAL LOADING CONTROL METHODS

7.2.1 METHODS CONSIDERED AND REJECTED

There are several methods that could be implemented to control internal loading from lake sediments. Because of high costs and predicted ineffectiveness, the following methods were eliminated from detailed consideration for Lake Ketchum:

DREDGING

Dredging could be used to remove the most phosphorus-rich sediments from the lake bottom, thus reducing internal loading and improving water quality. However, the cost of dredging is extremely high. The estimated cost to remove three feet of sediment from Lake Ketchum (over 120,000 cubic yards) would exceed $4 million. Also, any dredging project would have to be followed by an aluminum sulfate treatment to clear the water of suspended particles.

HYPOLIMNETIC AERATION

Adding oxygen to the bottom waters of the lake could be used to bind some of the phosphorus in the bottom sediments and prevent it from becoming available for algal growth. This technique is expensive, depends on long-term maintenance, requires adequate iron in the sediments to bind all the phosphorus, and may not be effective in Lake Ketchum.

ARTIFICIAL CIRCULATION/WHOLE-LAKE AERATION

This technique would use air pumped into the lake to continuously circulate the water and disrupt algal growth through induced light limitation. However, traditional circulation/aeration would mix the entire lake, bringing the large volume of phosphorus in the bottom waters to the surface, making more phosphorus and light available to algae. This would result in even worse algae conditions in the lake. Some systems, such as SolarBee®, can circulate water without mixing, but are not appropriate for Lake Ketchum because increased lake circulation would increase algal production due to increased light and phosphorus exposure. In addition, there are no third-party peer-reviewed studies that demonstrate the effectiveness of this approach for lake systems of this size.

HYPOLIMNETIC WITHDRAWAL

This technique involves withdrawing phosphorus-rich water from the bottom of the lake and sending it downstream through the lake outlet. This removes phosphorus from the lake, but requires a supply of low-phosphorus water to offset all or part of the lost water. However, there is no available supply of low-phosphorus water for Lake Ketchum to offset the loss of water volume during summer withdrawal.

INFLOW DIVERSION

Diverting the inflow would involve piping the water from the main inlet through the lake and out the outlet without ever emptying into the lake. This would eliminate the phosphorus currently flowing into the lake from the former dairy farm. The 1995-1996 study recommended this method for implementation. However, the cost is very high, permitting would be difficult, and the lake level would drop substantially without another source of water.

CHEMICAL ADDITION OF IRON

Chemical formulations of iron could be applied to the lake sediments to bind with phosphorus and make it unavailable for algal growth. The addition of iron is not appropriate at Lake Ketchum, however, because iron requires adequate dissolved oxygen levels at the sediment surface to maintain the bond with phosphorus. Through much of the year, dissolved oxygen levels are near zero in the lower waters of Lake Ketchum. Therefore, iron addition would not effectively bind the phosphorus.

LANTHANUM TREATMENT

Lanthanum (sold commercially as Phoslock®) can be applied to a lake to bind soluble phosphorus in the water column and sediments, with minimal impacts to lake chemistry and biology. However, the use of lanthanum for phosphorus control is still in its developmental stages, and the material must be shipped from Australia and China, so the costs are high. Lanthanum is not yet approved for normal use in the State of Washington. Also, there has been no demonstrated advantage over the buffered alum treatments discussed in the next section.

7.2.2 METHOD SELECTED FOR CONTROL OF INTERNAL LOADING— WHOLE-LAKE ALUM TREATMENT

The only method determined to be appropriate for controlling internal loading in Lake Ketchum is the use of aluminum sulfate (alum) to inactivate phosphorus in the sediments. Applying alum to a lake is the most successful method used around the world to inactivate phosphorus in lake sediments, reduce internal loading, and mitigate algae problems. Alum treatments have been used successfully in numerous lakes in Washington and have been proposed for Lake Stevens. Inactivation of sediment phosphorus with alum is a best management approach for controlling the sediment phosphorus source.

7.2.2.1 Description of Method

Alum is applied as a slurry to the lake surface, usually from a boat or barge with long arms to spread the alum into the lake from nozzles or trailing tubes. The treatment is typically done using computerized dosing control to apply the appropriate amount of alum for the water depth and volume at any point on the lake. Some of the aluminum in alum combines with the phosphorus in the water column as an aluminum hydroxide polymer forms. The result is a floc that resembles snowflakes which settle to the lake bottom. There the alum combines with available phosphorus in the sediments and forms a permanent bond to prevent the phosphorus from being released into the water column even in low or no oxygen conditions.

The addition of alum to a lake can rapidly lower pH levels of the water, making the lake more acidic, especially in lakes with soft water and low buffering capacity. For this reason, alum treatments are often buffered by adding another chemical, such as sodium aluminate, to balance the pH and prevent negative impacts to organisms living in the lake.

7.2.2.2 Effectiveness and Longevity

A whole-lake alum treatment to inactivate phosphorus in lake sediments can be a very effective management tool. In one analysis (Welch and Jacoby, 2001), over 80% of the projects proved successful, reducing internal loading by an average of 54%. However, these earlier projects typically did not supply a high enough dose of alum to fully inactivate the available phosphorus. Another analysis of four lakes showed an average of 90% reduction in internal loading (Cooke, et. al., 2005). For the purposes of the Lake Ketchum plan, the assumption is that a whole-lake alum treatment will reduce internal loading by 85%.

Whole-lake alum treatments can typically be effective for 10 to 15 years (Welch and Cooke, 1999) if properly designed and dosed. However, the effectiveness and longevity of an alum treatment also depends on the amount of external loading that continues to flow in from the lake watershed. Over time, continued high external loading will provide enough phosphorus to overcome the benefits of a single alum treatment. In addition, the alum floc layer gradually sinks deeper into the sediment and is no longer able to bind new phosphorus. The phosphorus flowing into Lake Ketchum from the main inlet, calculated at 146 kg per year, is high enough to grow nuisance amounts of undesirable algae in the lake even if an alum treatment has controlled the majority of the internal loading. In addition, even with an 85% reduction in internal loading, the rate of internal loading from the sediments of Lake Ketchum is so high in comparison to other lakes that there will still be a significant amount of phosphorus released into the lake each year.

Therefore, a single alum treatment, by itself, will provide only short-term water quality improvements in Lake Ketchum. A whole-lake alum treatment would need to be combined with measures to control external phosphorus loading from the main inlet stream or would need to be repeated at frequent intervals. On the other hand, external watershed controls without in-lake sediment phosphorus inactivation will have no effect on algal production for the predictable future. Repeated whole-lake alum treatments would cost about 10% less than the first treatment because of lower costs for design and testing, and assuming no inflation.

7.2.2.3 Potential Adverse Impacts

The primary potential impact of an alum treatment is lowered pH that can harm aquatic life and kill fish. This is a serious risk, but can be avoided with the use of a buffer solution such as sodium aluminate. Also, lab tests would be done in advance to check for any possible pH concerns and adjust the alum dosing accordingly.

Another impact that may occur from an alum treatment is a short-term reduction in zooplankton and benthic (bottom-dwelling) organisms. However, bottom sediments that are devoid of oxygen, such as Lake Ketchum, are already nearly uninhabitable. Experience with other alum treatments shows that these components of aquatic life will re-populate in a relatively short time following alum treatments (Cooke et al. 2005).

In addition, alum treatments result in dramatically clearer water within a few hours and greater water clarity long-term. The clear water will allow more light into the lake and may lead to an increase in the growth of rooted aquatic plants. As long as these are native plants, this change will provide a healthier balance in the lake. However, Lake Ketchum currently has virtually no aquatic plants, so some citizens may perceive the increased aquatic plants as unwelcome.

Alum is sometimes perceived as a threat to human health because of the aluminum. However, alum is safe. It is used extensively in treatment of drinking water supply systems. Even if people drank water from Lake Ketchum, the levels of aluminum after an alum treatment would be within drinking water standards. The form of aluminum in alum is also the same as in over-the-counter antacids. And, contrary to past suspicions, recent studies have not found links between aluminum and Alzheimer's disease. In summary, alum is safe for the lake and for humans.

7.2.2.4 Treatment Dosing

A whole-lake alum treatment must be appropriately sized and designed to inactivate the majority of the available phosphorus in the sediments of Lake Ketchum. Tetra Tech used the results of the sediment analysis and the most recent scientific guidelines to determine the amount of aluminum sulfate necessary to inactivate the available phosphorus in the sediments of Lake Ketchum.

First, it was determined that the dose should be sufficient to bind all the phosphorus in the top 10 cm of sediments, which is the zone of sediments most likely to release phosphorus into the water. Second, it was determined that a ratio of 20 parts aluminum to 1 part available phosphorus was needed to effectively bind the phosphorus. Using these parameters, the calculated alum dose rate would be 24 mg Al per liter of lake water. Tetra Tech also calculated that an additional dose of 4 mg Al/liter would be necessary to remove the phosphorus residing in the lake water column. This brings the total alum dose to 28 mg Al/liter, which works out to 20,400 gallons of liquid alum for the lake. At a standard ratio of 2:1 for alum to the sodium aluminate buffer, approximately 10,200 gallons of buffer would also be needed for the treatment.

7.2.2.5 Costs

The total cost of a whole-lake alum treatment in Lake Ketchum would be approximately $194,000 in 2011 dollars. This includes the cost of the aluminum sulfate and the sodium aluminate at $2.50 to $4.00 per gallon, in addition to costs for treatment design, pre-treatment testing, trucking, application from a boat or barge, and permitting.

7.3 EXTERNAL LOADING (FROM MAIN INLET) CONTROL METHODS

7.3.1 METHODS CONSIDERED AND REJECTED

There are also several methods that could be implemented to control the phosphorus flowing into Lake Ketchum from the main inlet. Of these methods, the following were eliminated from detailed consideration because of high costs or inability to achieve implementation.

FARM BEST MANAGEMENT PRACTICES (BMPS) AND FARM SOIL TREATMENT

The preferred method of reducing external phosphorus loading to a lake is to control the phosphorus at its source, in this case on the former dairy farm. To some extent, this has been done. Most of the farm lands draining to Lake Ketchum are no longer used for dairy or cattle farming. The land is planted in grass and harvested for hay. This change has resulted in significant reductions in the amount of phosphorus flowing into the inlet stream compared to the situation in 1996. As described above under Project Background, the concentrations of phosphorus leaving the farm have declined 81% since 1996. However, the levels of phosphorus reaching Lake Ketchum are still very high, providing 23% of the total phosphorus load to the lake. Unfortunately, opportunities to implement additional BMPs on the farm or to apply alum to the farm soils to bind phosphorus are not feasible because the farm owners have rejected all attempts to discuss potential actions on the farm. There is no possibility of controlling phosphorus at the source at this time.

ALUM TREATMENT OF WETLAND

The 20-acre wetland located between the former dairy farm and the southeast corner of Lake Ketchum traps some of the phosphorus flowing in the inlet stream before it reaches the lake. After passing through this wetland, phosphorus levels in the stream, though still very high, are only one-third as high as the phosphorus levels that flow into the wetland. This means that large amounts of phosphorus are sequestered in the soils of the wetland. Over time, much of this phosphorus may be released and flow into the lake. One method to inactivate phosphorus in the wetland would be to add alum to the wetland soils, permanently binding the phosphorus. Unfortunately, this would require cutting down all the vegetation in the wetland and plowing alum into the wetland soils. This would destroy the wetland and still might not capture a large percentage of the phosphorus. For this reason, a wetland alum treatment is not recommended. However, long-term preservation of this wetland is critical to continue trapping phosphorus and helping to protect lake water quality.

CONTINUOUS ALUM INJECTION IN THE LAKE

Injecting alum into the lake would involve a small mechanical plant on the shore that would continuously pump alum through an extensive array of pipes anchored in the lake. The alum would be disbursed throughout the lake where it would combine with phosphorus in the water column and sink to the lake bottom. Alum injection is sometimes implemented in conjunction with an aeration system in order to use the same piping system. Lake injection is expensive, requiring detailed design, permitting, and construction costs, as well as on-going operations and maintenance costs. For these reasons and because of the large array of piping required, this management method is not considered appropriate for Lake Ketchum.

7.3.2 FIRST METHOD SELECTED FOR DETAILED CONSIDERATION -- ALUM INJECTION AT MAIN INLET STREAM

7.3.2.1 Description of Method

Alum injection involves the continuous addition of aluminum sulfate to the inlet stream near where it flows into the lake. The aluminum in the alum would combine permanently with the phosphorus in the water, making it unavailable for algal growth in the lake. This technique would require a small treatment plant that mechanically adds alum to the stream water. High pressure air would then be mixed with the treated water, forming a microfloc. The stream water and microfloc would be discharged into the lake, either near the southeast corner of the lake or farther out near the north end of the island. The microfloc of alum and phosphorus would slowly settle to the lake bottom.

An alum injection system would include a large tank, an air compressor, mechanical pumps, an injector, piping, and electrical service. The components of the system would fit within two covered 10' x 10' concrete vaults. The system would operate continuously during the wet months when water is flowing in the inlet stream.

7.3.2.2 Effectiveness and Longevity

Alum injection would be highly effective in reducing the external phosphorus load coming from the former dairy farm through the main inlet stream. Based on experience with similar systems in the U.S., it is estimated that alum injection would remove 85% of the phosphorus, provided the system is working continuously and maintained properly. This benefit would continue as long as the injection system operates. As with any mechanical system, however, occasional repair and operational problems can be expected. Another benefit is that, as the microfloc slowly migrates to the deeper portions of the lake basin after it is discharged into the lake, any aluminum in the floc that has not already become bound to phosphorus will be available to bind with additional phosphorus in the lake sediments.

7.3.2.3 Potential Adverse Impacts

There would be very limited adverse impacts to be expected from alum injection. Compared to a whole-lake alum treatment, the amount of alum used for injection would be much less. The pH in the lake water would drop because alum makes the water more acidic. However, this impact would occur only in a tiny area around the discharge pipes, and any impacts to zooplankton and benthic organisms would also be localized. Depending on the location of the discharge pipe(s), the microfloc will settle and may gradually fill in a portion of the lake. Piping the inflow farther into the lake would provide more lake volume to accommodate the floc build-up and allow the floc to slowly drift along the bottom toward the deepest part of the lake.

7.3.2.4 Injection Dosing

Stream monitoring revealed that the average total phosphorus concentration in the main inlet stream is 635 µg/l, with the vast majority being soluble reactive phosphorus that is available for algal growth. The ratio of aluminum required to bind available phosphorus in the stream flow is 20 to 1. This translates to an aluminum dose of almost 13 mg per liter of water. Based on the total annual flow expected through the main inlet stream, the total volume of liquid alum needed would be about 12,760 gallons per year. Because of the small amount of alum injected into the stream compared to the volume of the lake, there is no need for a buffer of sodium aluminate in the injection system.

7.3.2.5 Costs

The capital cost of an alum injection system at the lake inlet is estimated to be $212,000. This includes detailed engineering design, permitting, materials, and construction. Annual maintenance and operation, including electricity, alum, staffing, and seasonal upkeep, would cost about $65,000 in 2011 dollars. These figures do not include any costs for land acquisition.

7.3.3 SECOND METHOD SELECTED FOR DETAILED CONSIDERATION -- ANNUAL WATER COLUMN ALUM TREATMENTS

7.3.3.1 Description of Method

Repeated application of alum over the surface of the entire lake is another method that could be used to inactivate the external loading of phosphorus from the inlet stream. This method would be similar to a whole-lake sediment inactivation treatment except that it would treat just the water column of the lake using a much smaller amount of aluminum sulfate and sodium aluminate.

Water column alum treatments would be performed each spring after the rainy season. The purpose of water column treatments would be to remove the phosphorus that has washed into the lake during the rainy season and prevent it from being available to feed summer algal growth. In the first treatment year, a fall water column treatment would also be performed. Because a whole-lake sediment inactivation alum treatment is predicted to bind 85% of available phosphorus in the sediments, an initial fall treatment will help to bind any residual phosphorus that is released back into the water column during the low oxygen summer period.

The water column treatments would work by stripping phosphorus and suspended particles from the lake water. The alum would form an aluminum hydroxide floc where aluminum combines with phosphorus. The floc would sink to the lake bottom, leaving much lower concentrations of phosphorus in the water column and restricting summer algal growth. However, the amount of alum used would not be enough to bind the large amounts phosphorus that already reside in the lake sediments. Instead, water column treatments would inactivate most of the new phosphorus and would then settle down to the lake sediments and help to inactivate more phosphorus there.

As with whole-lake sediment inactivation treatments, the alum and buffer would be applied using a boat or barge with large tanks and long arms to disburse the alum. The amount of alum would be metered out by computer to account for the volume and depth of the water at each point around the lake.

7.3.3.2 Effectiveness and Longevity

Water column alum treatments would be effective at removing the phosphorus that exists in the water column at the time of treatment. It is estimated that each treatment would bind about 85% of the phosphorus in the lake water. However, water column treatments do not prevent phosphorus from getting into the lake in the first place. And, depending on the timing of treatments, they may be too late in some years to prevent early season algal blooms or they may take place too early to catch runoff from late spring storms and neutralize the new phosphorus that these storms bring into the lake. Although water column treatments would not remove all the phosphorus flowing into the lake, they could control a significant portion of the new phosphorus that flows in each year and help to bind some of the additional phosphorus still being released internally.

Because the main inlet stream continues to bring large amounts of phosphorus into Lake Ketchum each rainy season, water column alum treatments would likely need to be repeated every year.

Assuming that water column treatments are conducted at opportune times to inactivate most of the phosphorus washed into the lake during the previous rainy seasons, they should provide effectiveness throughout the following summer season. However, unless combined with a whole-lake sediment inactivation alum treatment prior to any water column treatments, the water column treatments by themselves would not maintain acceptable lake water quality through the summer and fall. Instead, phosphorus released from lake sediments into the bottom waters would diffuse into the upper waters or be mixed throughout the lake at fall turnover, leading to algae problems in the late summer, fall, and the following spring.

7.3.3.3 Potential Adverse Impacts

The potential impacts of water column alum treatments would be the same as for a whole-lake sediment inactivation alum treatment, but of lesser magnitude. The primary potential impact of a water column alum treatment is lowered pH that can harm aquatic life and kill fish. This risk can be avoided with the use of a buffer solution such as sodium aluminate. Also, lab tests would be done in advance to check for any possible pH concerns and adjust the alum dosing accordingly.

Another impact is a short-term reduction in zooplankton and benthic (bottom-dwelling) organisms. As discussed previously, the affected populations are minimal in Lake Ketchum due to the low oxygen environment, and the organisms should quickly recover. The repeated water column alum treatments will also result in dramatically clear water within a few hours and greater water clarity long-term. The clear water will allow more light into the lake and may lead to an increase in the growth of rooted aquatic plants. Some citizens may perceive the increased aquatic plants as unwelcome. The plants, however, will compete with algal growth by taking up some of the available phosphorus.

As stated above, alum is sometimes perceived as a threat to human health because of the aluminum. However, water column alum treatments are safe. The amount of aluminum discharged to the lake would not exceed drinking water standards, and there would be no human health impacts.

7.3.3.4 Dosing

The dose of alum needed to treat the water column would be 4 mg AL/liter in the first year. The doses in subsequent years would be somewhat higher in order to bind both the phosphorus flowing in that year plus any phosphorus left over from previous years. A dose of 4 mg AL/liter would require almost 3000 gallons of liquid aluminum sulfate and 1500 gallons of sodium aluminate buffer.

7.3.3.5 Costs

The total cost of a water column alum treatment in Lake Ketchum would be approximately $36,000 in 2011 dollars. This includes the cost of the aluminum sulfate and the sodium aluminate at $3.50 to $4.80 per gallon. These unit costs are higher than for a sediment inactivation alum treatment because of the smaller volumes that would be manufactured and purchased. Other costs included in the total are for treatment design, pre-treatment testing, trucking, application from a boat or barge, and permitting.

7.3.4 THIRD METHOD SELECTED – WETLAND PROTECTION

As described above, the wetland located between the former dairy farm and the southeast corner of Lake Ketchum traps some of the phosphorus flowing in the inlet stream before it reaches the lake. Large stores of phosphorus are sequestered in the soils of the wetland. Because removal or inactivation of the phosphorus in the wetland is not practical, it is critical to preserve the wetland in its natural condition to prevent erosion of the soils and release of the phosphorus.

Snohomish County's Critical Areas Regulations provide some standards for protecting wetlands from the impacts of land clearing and development. However, working with property owners to make them aware of the value of preserving the wetland portion of their properties is also important.

8 METHODS TO CONTROL RESIDENTIAL PHOSPHORUS SOURCES

In Lake Ketchum, nonpoint residential pollution from the surrounding watershed accounts for around 3% of the total phosphorus sources to the lake. Although the impacts of agricultural runoff are many times greater than the cumulative impacts of residential pollution sources in the Lake Ketchum watershed, it is important to recognize and address all of the potential sources of pollution to protect the long-term health of the lake. Any decrease in phosphorus entering the lake will make the in-lake alum treatments more effective and last longer. In addition, when actions are implemented to reduce phosphorus from the lake sediments and from the main inlet stream, the remaining 3% of phosphorus sources will then contribute a much higher percentage of phosphorus to the lake. So, addressing these residential sources will become more important. Therefore, the long-term health of Lake Ketchum depends on the willingness and cooperation of everyone who lives within the Lake Ketchum watershed.

The primary residential sources of phosphorus from around the watershed are poorly maintained septic systems, lawn and garden fertilizers, pet and animal wastes, stormwater runoff from roofs and driveways, and erosion from shorelines and bare soils. Many sources of residential phosphorus pollution can be significantly reduced or even eliminated with small changes in household practices by watershed residents. Lakeshore landowners can also make a significant contribution by protecting or re-establishing shoreline vegetation. Shoreline vegetation acts like a sponge and filters pollution out of storm runoff and shallow groundwater before it reaches the lake.

In many cases, residents do not recognize that their household practices may be contributing to lake pollution or do not see their contributions as having significant adverse impacts on water quality. Therefore, a well-planned and robust outreach program is the only viable solution for encouraging changes in household practices that will lead to a reduction in phosphorus pollution at Lake Ketchum. The following section outlines some practices that residents can employ to reduce phosphorus pollution, describes a potential outreach program being developed by SWM, and provides additional recommendations specific to the Lake Ketchum community.

8.1 PHOSPHORUS REDUCTION BEST MANAGEMENT PRACTICES (BMPS)

8.1.1 SEPTIC SYSTEM CARE AND MAINTENANCE

Septic systems that are failing are clearly a source of phosphorus pollution, as well as bacteria and pathogens that can threaten the lake's and residents' health. However, even septic systems that are not failing but are poorly maintained can contribute to increased phosphorus pollution in the lake. Employing the following set of septic system practices will help to minimize the amount of phosphorus coming from septic systems and protect the health of Lake Ketchum:

- Attend a septic system care workshop.
- Regularly inspect septic system (every 3 years).
- Pump as needed (when septic system is ½ full).

- Repair septic system when failures occur.
- Protect the septic system drainfield.

8.1.2 LAWN CARE PRACTICES

Lawn care practices, particularly the use of phosphorus-containing fertilizers, can have a significant impact on phosphorus reaching the lake. Lawn fertilizers typically contain a high amount of phosphorus and are easily washed into the lake. One alternative to phosphorus fertilizers is to employ natural lawn care practices to eliminate the need for fertilizers. If fertilizers must be used, there are phosphorus-free options. Because the majority of soils in this region have more than ample phosphorus required for a healthy lawn, there are virtually no negative impacts from using phosphorus-free products. In fact, starting in 2013 the sale and application of phosphorus-containing lawn fertilizers, except in limited circumstances, will be banned in the State of Washington as an effort to protect lake water quality statewide. Recommended practices include:

- Attend a workshop on natural lawn care.
- Eliminate fertilizer use and replace with natural lawn care practices which include:
    - Mow high and leave the clippings.
    - Do not use weed-n-feed products; instead spot treat weed problem areas.
    - Water deeply and less frequently.
    - Improve poor lawns with aeration.
    - Use lawn alternatives for slopes, shady areas, or near streams and lakes.
- If fertilizer is used – use only phosphorus-free or organic slow release products.

8.1.3 SHORELINE LANDSCAPING

The last line of defense for preventing phosphorus from reaching lake waters is the zone of vegetation along the shoreline. These vegetated buffer zones stabilize the lake shore, intercept stormwater runoff, and remove phosphorus from water before it reaches the lake. Without shoreline vegetation, there is little or no filtering and removal of phosphorus flowing toward the lake. Furthermore, lake shorelines without a zone of native vegetation also frequently suffer from erosion. Eroding shorelines can serve as additional sources of sediment and phosphorus. Since shoreline vegetation buffers capture the phosphorus that run off from other sources, providing intact shoreline vegetation may be the most important step that lakeshore property owners can take to protect lake water quality. Recommended practices include:

- Leave existing shoreline vegetation intact.
- Re-establish shorelines that have grass or minimal vegetation by one of the following options:
    - Stop mowing near the shoreline and allow vegetation to be re-established on its own.
    - Re-plant lake shorelines with grasses, trees, or shrubs. A mix of plants can be chosen that are attractive and low-lying to preserve views of the lake.

8.1.4 PET WASTE

Many people do not consider the impacts of pet waste on water quality. Not only does animal waste have a high load of phosphorus that can be washed into the lake, it also can transmit harmful microorganisms, such as roundworms, *E. coli,* and *Giardia.* Even though it may seem like a small factor, pet waste adds up. On average 37.4 percent of Washington State households own dogs, with an average of 1.5 dogs per dog-owning household. With approximately 350 households in the Lake Ketchum watershed, this means almost 200 dogs. It is estimated that 1/3 pound of solid waste is produced daily per dog. Therefore, about 65 pounds per day could be deposited in the Lake Ketchum watershed. Recommended practices to mitigate potential impacts from pet waste include:

- Pick up pet waste, bag it, put it in the trash.
- Do not bury or compost dog waste (it doesn't kill bacteria and phosphorus still ends up in the lake).

8.1.5 STORMWATER RUNOFF FROM ROOFS AND DRIVEWAYS

Reducing and slowing runoff from rain can help prevent phosphorus and other pollutants from entering the lake. As land around Lake Ketchum has been developed, hard surfaces such as driveways, houses, patios, and walkways (also known as impervious surfaces) prevent rain water from infiltrating into the ground. Instead, the rain runs off these surfaces and picks up phosphorus that is washed directly into the lake. Even worse, runoff from driveways and roofs is sometimes piped directly into the lake instead of being directed away from the lake. Any actions that can be taken to slow and capture runoff will help reduce the amount of phosphorus going to the lake. Recommended practices include:

- Disconnect pipes from downspouts or driveway runoff that run to the lake and re-route water into vegetated areas or dry wells (but not on to septic drainfields).
- Minimize the amount of paved or concrete services for driveways and patios.
- Start a rain garden, which is a garden planted with the intention of capturing rain water from rooftops, driveways, and patios. Rain gardens are planted in small depressions and act like a native forest that collects, absorbs, and filters runoff.

8.1.6 EROSION FROM BARE SOILS AND SHORELINES

One of the ways that phosphorus washes into a lake is through soil erosion. Phosphorus attaches readily to individual soil particles. So, if rainfall erodes bare soils, the soil particles that are picked up by the water bring the phosphorus along. Preventing erosion and covering bare soils helps stop this pollution pathway. Recommended practices include:

- Covering all bare or eroding soil areas with mulch.
- Using effective erosion control measures during construction and landscaping projects.
- Planting grasses, shrubs, or trees on eroding shorelines. A buffer of intact vegetation along the shoreline helps prevent erosion and traps soil particles before they can reach the lake.

8.2 POTENTIAL OUTREACH PROGRAM APPROACH

Snohomish County's Lake Management Program is in the process of developing a pilot outreach project, called LakeWise, that aims to produce phosphorus-reducing residential behavior changes and improve lake shoreline protection and restoration. Although the LakeWise project is still in its pilot phase, it has a strong potential to be successfully applied at Lake Ketchum to encourage the important BMPs recommended above.

SWM is taking an investigative approach to develop the new program. The idea is to go beyond simply providing information to landowners about water quality and ways to improve it. Instead, the approach is to first identify the barriers that people have in making those changes (such as time, knowledge, costs, etc) as well as the benefits and incentives that might encourage behavior changes. The program can then be tailored with messages and incentives that highlight benefits and overcome barriers. The desired end result is not just an increase in awareness but actual behavior changes.

The following steps have already been taken by SWM to develop an effective outreach program:

- Performed a nationwide search to identify existing lake shoreline restoration and phosphorus reduction programs (such as the Maine LakeSmart program, Wisconsin shoreline improvement project, and the Liberty Lake, WA Pledge program).
- Conducted a telephone interview survey which included 50 lake and watershed residents to identify the current understanding of lake water quality pollution and sources. The survey also assessed the barriers to and willingness to implement the key BMPs.
- Held two citizen focus groups to provide feedback on outreach program names, slogans, and logos, as well as potential program elements including a landowner recognition program, site visits, etc.

The information obtained is currently being shaped into the final LakeWise program that will be piloted at Lake Howard in the summer of 2012. The initial outreach messages will focus on septic system maintenance and lawn care, followed by shoreline protection and restoration. The strategies that will be incorporated in the program include:

- Certification program for properties where Best Management Practices have been implemented;
- One-on-one site visits;
- Specialized workshops on septic system care and natural lawn care;
- Demonstration shoreline improvement projects;
- Landowner incentives for attending workshops, performing septic system maintenance, and implementing shoreline restoration.

Based on similar program results, the project aims to have 60-70% of the landowners take at least one action to reduce phosphorus sources and at least 15% of participants restore or protect their shorelines. After the initial efforts at Lake Howard, the intent is to expand the most effective elements of the LakeWise program to other lakes in the County.

The outreach project will be adapted for Lake Ketchum and integrated into the implementation of this Algae Control Plan. Strong involvement from the residents living on and near Lake Ketchum will be pivotal to the success of the outreach program.

8.3 LAKE KETCHUM COMMUNITY COMMITMENTS

The residents living in the Lake Ketchum area have a higher interest in cleaning up and keeping their lake clean than do most lake communities. After years of struggle with poor water quality, citizens have a heightened awareness of lake problems and are motivated to take all possible steps to improve their lake. Furthermore, strong commitments by the community to take actions to reduce phosphorus from residential properties could be a powerful justification to help leverage funding from the State and Snohomish County for Lake Ketchum restoration. Below are potential actions that could be taken at Lake Ketchum specifically to help increase funding opportunities for implementation of this algae control plan.

COMMUNITY PLEDGE PROGRAM

Strong community commitment to reducing phosphorus sources from the residential areas around the lake could significantly increase the likelihood of receiving grant or state agency funding for alum treatments in the lake. One way to illustrate commitments is to implement a pledge program at Lake Ketchum. A pledge program would entail having residents sign on or commit to make some of the most important changes on their properties that could reduce phosphorus. It would also be a way for people to show that activities are already being done to minimize phosphorus pollution. A high percentage of landowners showing commitments would be a compelling message for funding agencies. The difficulty with pledge programs is ensuring that commitments are kept. The SWM outreach program described above includes a certification program that could be used to acknowledge residents who are taking steps for their lake health and could serve as a follow-up to the pledge program.

LAKE SHORELINE RESTORATION

As described previously, shoreline restoration is one of the most beneficial activities that landowners can do to help protect lake water quality. Furthermore, funding agencies often view on-the-ground restoration as the most visible and most important commitments for landowners to take for long-term phosphorus reduction. Written commitments from numerous shoreline landowners to either protect or restore their shorelines would be highly compelling for funding in-lake treatments.

Recognizing that shoreline restoration may be difficult for many landowners, a successful outreach program could include incentives for encouraging restoration. Several example planting plans could be developed that provide a mix of attractive plants that help water quality while maintaining shoreline access and views. Financial assistance could also be provided to help alleviate the costs of plants or other materials. The community could also host planting parties to help with the actual physical work.

SEPTIC SYSTEM INSPECTION AND PUMPING PROGRAM

Septic system inspection and pumping is also important for protecting Lake Ketchum and can help prevent failing systems and costly septic repairs. Commitments from local residents to regularly maintain their septic systems would be another demonstration of the dedication of the community to restoring the lake. Residents could work with local septic system providers to develop an ongoing voluntary septic inspection and pumping program. Providers may be able to provide discounted services in exchange for groups of customers signing up from one area.

9 LAKE RESTORATION ALTERNATIVES

9.1 LAKE RESTORATION STRATEGY

The proposed strategy to restore Lake Ketchum is to implement methods to control phosphorus coming from the bottom sediments of the lake and phosphorus coming from the main inlet. These are by far the largest sources of phosphorus contributing to nuisance algal growth in the lake. As described above under the phosphorus budget, 73% of the phosphorus in the lake comes from internal loading—the release of phosphorus from the bottom sediments in the lake. Another 23% of the phosphorus comes from the main inlet which drains the former dairy farm. The remaining sources account for less than 4% of the phosphorus in the lake.

In order to improve the water quality of Lake Ketchum, it is necessary to implement actions targeting both the in-lake internal loading and the main external loading source. If the Algae Control Plan fails to address the internal loading, the lake water quality will not improve. And, if the Plan does not address the external loading, any improvements from in-lake methods will be short-lived. In addition, the remaining external sources of phosphorus should be addressed because they will become more important as the two main sources are reduced.

Several management methods to control the two primary sources of phosphorus at Lake Ketchum were selected for further analysis as described in the section above. These methods include a whole-lake aluminum sulfate treatment to bind phosphorus in the sediments, alum injection into the inlet stream to bind phosphorus flowing into the lake, and whole-lake alum treatments to remove phosphorus just from the water column. Each of these methods can be used individually, can be combined with other methods, and/or can be repeated as needed. And, each of the methods would be coupled with Best Management Practices around the shoreline and in the watershed to reduce other nonpoint pollution sources.

Tetra Tech and SWM examined numerous combinations of management methods and selected four alternatives for further analysis. The alternatives are:

1. Whole-lake sediment inactivation alum treatment.
2. Whole-lake sediment inactivation alum treatment repeated in two years.
3. Whole-lake sediment inactivation alum treatment with alum injection at inlet.
4. Whole-lake sediment inactivation alum treatment with annual water column alum treatments.

Tetra Tech evaluated each of these alternatives using the calibrated phosphorus model to predict the response of the lake over four years. The lake responses, efficacy, and costs of each alternative are discussed below.

It should be noted that the phosphorus model is an approximation of the present and future conditions in the lake. There are a number of assumptions underlying the model. These assumptions are based on the best available science. However, the model cannot provide exact predictions of lake conditions in future years because the model is calibrated for the 2010-2011 year only. The lake is a dynamic ecosystem, and there are natural variations in lake and weather conditions from year to year. The phosphorus model as calibrated predicts slightly worse conditions than may be expected under each alternative. But, the predictions are within the range of variations that could occur in the lake.

For each of the treatment alternatives described below, the response of lake phosphorus concentrations is shown. The focus of the predictions is the phosphorus concentrations found in the upper waters where the majority of algal growth is occurring. From April through October, the lake is stratified into epilimnion and hypolimnion layers. During the remainder of the year, the lake is fully mixed. The impact of treatments on the hypolimnion (lower waters) is discussed in the Technical Appendix.

9.2 ALTERNATIVE 1 – ONE-TIME WHOLE-LAKE SEDIMENT INACTIVATION ALUM TREATMENT

Alternative 1 involves a one-time whole-lake aluminum sulfate treatment for the purpose of controlling the internal phosphorus loading from the lake sediments. The application of aluminum sulfate, with a buffer of sodium aluminate to minimize impacts to water pH, will inactivate phosphorus in the lake sediments and reduce the amount of phosphorus available for algal growth. Although this alternative does not address the continuing inflow of phosphorus from the main inlet stream, it was evaluated for lake response because the internal phosphorus loading is such a large portion of the overall phosphorus loading to the lake. The assumption is that a whole-lake treatment will reduce the internal loading by 85%, at least in the first year.

Figure 9-1 illustrates concentrations of phosphorus that may be expected in the upper waters of Lake Ketchum with this alternative according to the lake phosphorus model. Note that the low concentrations occur during summer stratification, and the very high levels (600 µg/l) take place during winter when the phosphorus-rich bottom waters are mixed throughout the lake. Compared to existing lake conditions, total phosphorus concentrations in the epilimnion (upper waters) would drop significantly during the first summer, to an average of 46 µg/l. However, by the second summer, phosphorus concentrations would rise to an average of 70 µg/l. This is because the original alum treatment is estimated to control only 85% of the internal loading from the sediments and also because large amounts of phosphorus will continue to flow into the lake from the main inlet stream. The model also predicts that total phosphorus concentrations in the hypolimnion (bottom waters) will begin to build up after the first year, providing more phosphorus that is available to algae in the epilimnion in future years.

With summertime concentrations of about 70 µg/l total phosphorus in the epilimnion during Years 2 through 4, Lake Ketchum would have better conditions that at present. However, the lake would still be eutrophic, and there would still be nuisance blue-green algal blooms during many years. The duration of the blooms would likely be shorter than current blooms. There may also be a shift toward diatoms or green algae in the early part of the warm season instead of blue-green algae. Overall, there would be some improvement in lake conditions, but there would not be a dramatic improvement in lake water quality.

The cost of a one-time whole-lake sediment inactivation alum treatment would be approximately $194,000 in 2011 dollars.

9.3 ALTERNATIVE 2 – WHOLE-LAKE SEDIMENT INACTIVATION ALUM TREATMENT REPEATED IN TWO YEARS

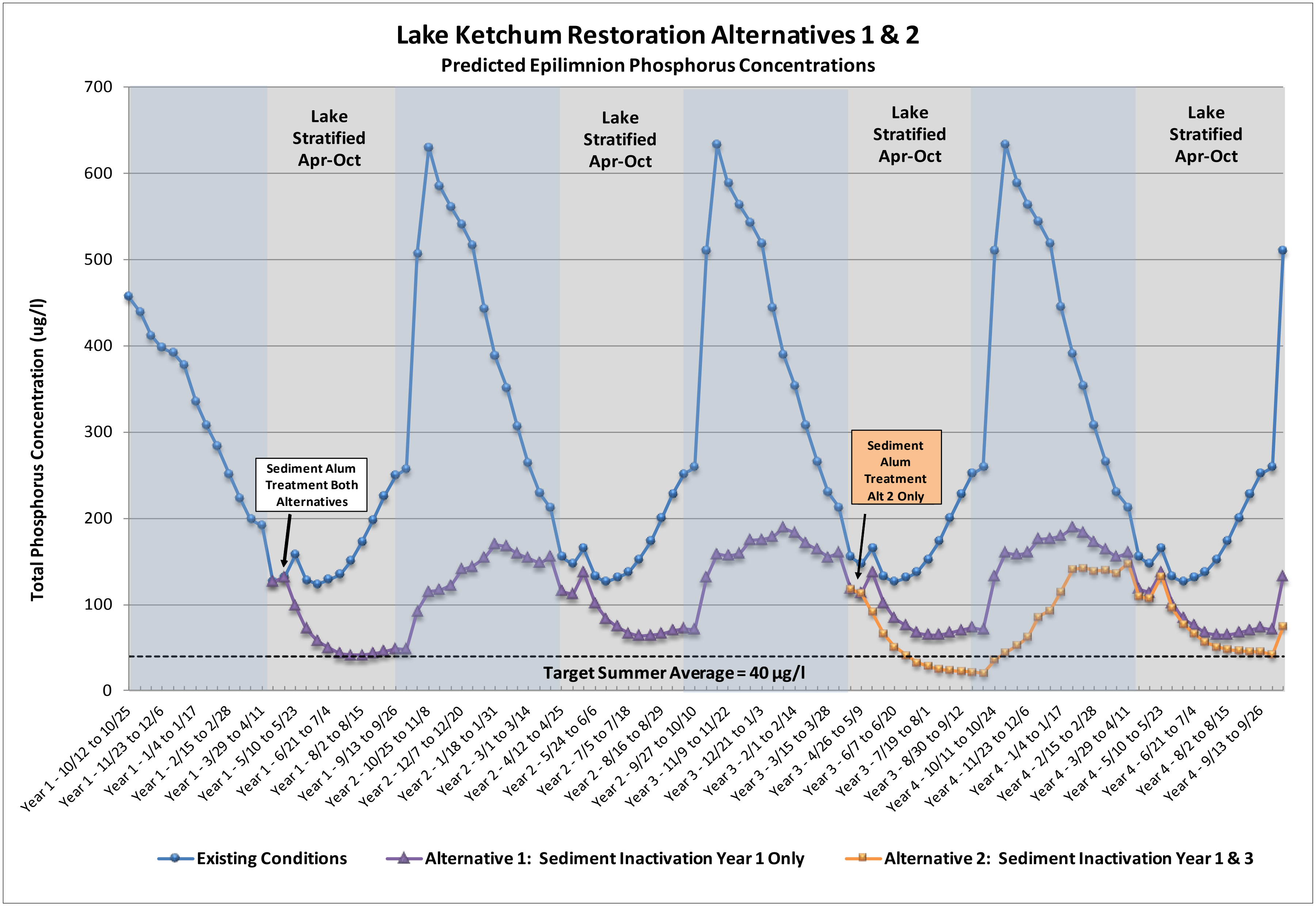
This alternative is exactly the same as the first alternative, but it assumes that the whole-lake sediment inactivation alum treatment will be repeated two years after the first whole-lake treatment. The purpose of repeating the treatment is to inactivate the portion of the phosphorus internal load that would still be released from the lake bottom sediments after the first whole-lake treatment in addition to some of the external phosphorus load that would continue to flow in from the main inlet. The assumption is that the first treatment will reduce the internal load by 85% and that the repeated treatment will reduce the remaining internal load by another 85%. However, the uncontrolled external loading from the main inlet will continue to deliver phosphorus that promotes algal growth in the short term, and that phosphorus will eventually sink to the lake bottom where it adds to future internal loading.

Figure 9-1 illustrates the lake response to implementation of Alternative 2. The lake response to Alternative 2 during the first two years is exactly the same as for Alternative 1—the average summertime total phosphorus concentration in the epilimnion would drop to 46 µg/l in Year 1 but rise to 70 µg/l in Year 2. There would be significant improvements to lake water quality, with only occasional blue-green algal blooms. Phosphorus levels in the hypolimnion would also drop.

Then, in the spring of Year 3, the second whole-lake alum treatment would take place. The lake response in the summer of Year 3 would be dramatic (see orange line in Figure 9-1). Average phosphorus concentrations in the epilimnion would drop to approximately 31 µg/l. At this level of phosphorus, Lake Ketchum could be expected to have only occasional blue-green algal blooms, most likely during the late summer or early fall. The perception would be of a lake with much clearer water and few impediments to swimming and other water activities.

Unfortunately, because of the continuing inflow of phosphorus from the main inlet stream and because of the portion of the internal loading that is not controlled by alum treatments, lake conditions will decline in Year 4 (Figure 9-1). The average phosphorus concentration in the epilimnion during the summer of Year 4 will climb back to approximately 54 µg/l. At this level, the lake will be better than current conditions, but will not meet the lake water quality target and may not meet residents' expectations. The lake will likely experience routine blue-green algal blooms off and on throughout the summer and early fall. Implementation of Alternative 2 will result in improvements at Lake Ketchum, but less than desired conditions. Additional alum treatments would be needed every two to four years into the future to bring the lake back to desired conditions and offset the impacts of continued external loading from the main inlet stream.

FIGURE 9-1: LAKE KETCHUM PHOSPHORUS RESPONSE TO RESTORATION ALTERNATIVES 1 & 2



The cost of the Year 1 whole-lake alum treatment is estimated at $194,000. The Year 3 alum treatment would cost approximately $174,000 in 2011 dollars. The lower cost of the second treatment is because the planning, design, and permitting work would take somewhat less resources the second time.

9.4 ALTERNATIVE 3 – WHOLE-LAKE SEDIMENT INACTIVATION ALUM TREATMENT WITH ALUM INJECTION AT INLET

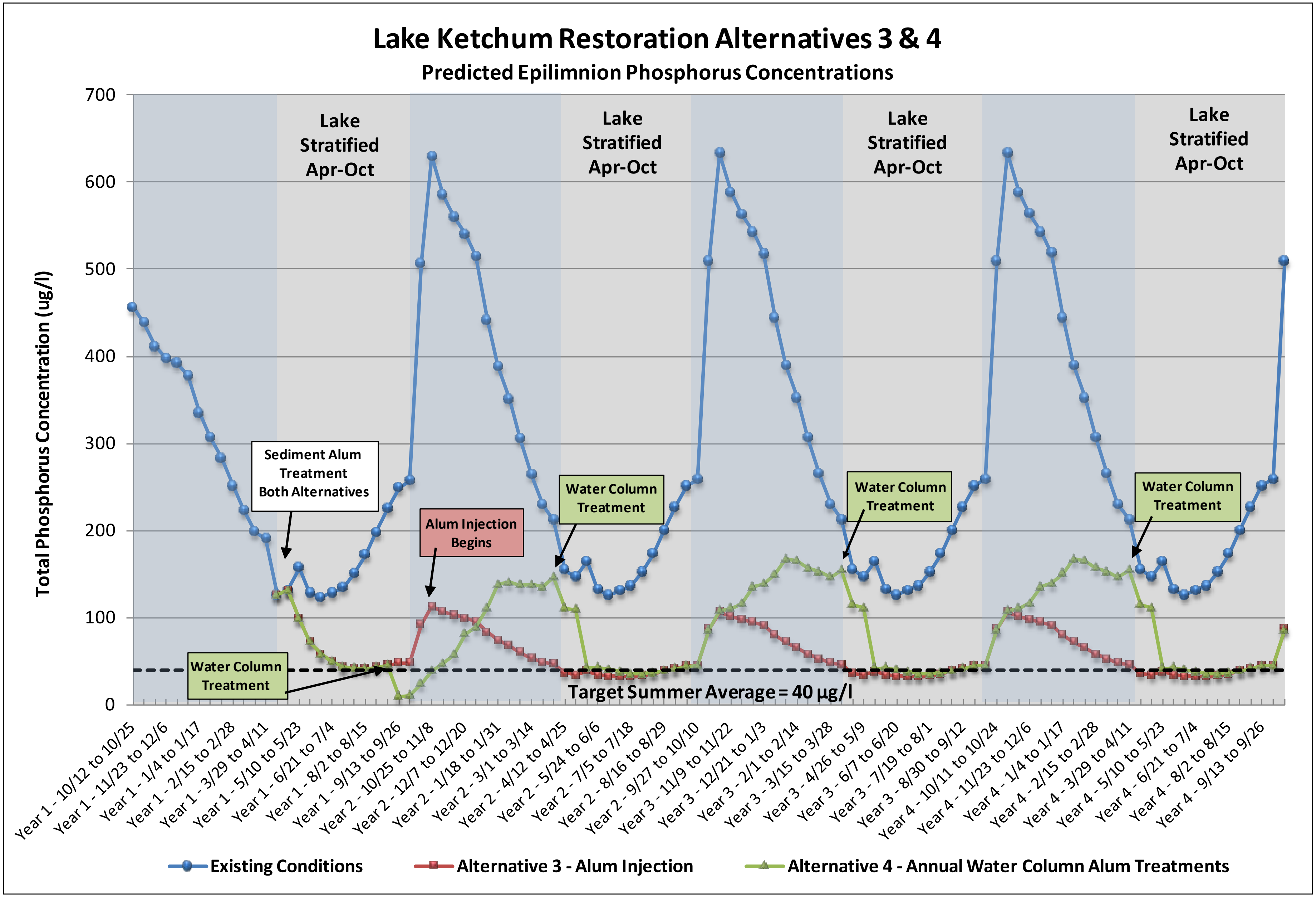
Alternative 3 involves implementation of a whole-lake sediment inactivation alum treatment in Year 1, followed by implementation of an alum injection system at the main lake inlet for the winter at the end of Year 1 and beginning of Year 2. The alum injection system would then operate every year into the future during the wet months of the year. The combination of an alum treatment and alum injection would control approximately 85% of the internal loading from the lake sediments and 85% of the external loading from the inlet stream.

Results from the phosphorus model indicate that this alternative will have the best long-term water quality results for the lake. As shown in Figure 9-2, the average total phosphorus concentration in the epilimnion during the first summer would drop to approximately 46 µg/l. This is the same amount of improvement as seen during the first year of Alternatives 1 and 2.

However, the benefit of adding the alum injection system at the main lake inlet before the beginning of the wet season at the end of Year 1 is continued improvements in lake conditions in Year 2 and beyond. The alum injection system will inactivate much of the external loading from the main inlet stream during each wet season and prevent the phosphorus concentrations in the hypolimnion from building progressively each year. The summertime average phosphorus levels in the epilimnion would drop to about 36 µg/l in Year 2 and remain at that level into the future (Figure 9-2). In the hypolimnion, the phosphorus concentrations would build gradually each summer until the phosphorus is entrained into the epilimnion in late summer. However, the concentrations would decline again the next spring.

At the level of approximately 36 µg/l of total phosphorus in the epilimnion, Lake Ketchum quality would be significantly improved from current conditions. There would be occasional blue-green algal blooms, especially in late summer when phosphorus is brought up from the hypolimnion. However, the severity and length of blooms would be reduced. And, algae populations would likely switch to less bothersome diatoms and green algae in spring and early summer. Over a period of seven to ten years, the uncontrolled phosphorus in the lake sediments and the portion of the external phosphorus load that is not inactivated by the injection system would gradually build up in the lake sediments. By that time, another whole-lake sediment inactivation alum treatment may be needed.

FIGURE 9-2: LAKE KETCHUM PHOSPHORUS RESPONSE TO RESTORATION ALTERNATIVES 3 & 4



The main drawbacks of Alternative 3 are the high initial costs and the on-going maintenance and operation responsibilities and costs. The cost of the whole-lake alum treatment would be $194,000, and the cost of the injection system would be approximately $212,000. Combined with a portion of the operational costs for the first winter, the total Year 1 costs for this alternative would be $428,000. In addition, yearly operation and maintenance costs for the injection system would be $65,000 per year indefinitely into the future.

9.5 ALTERNATIVE 4 – WHOLE-LAKE SEDIMENT INACTIVATION ALUM TREATMENT WITH ANNUAL WATER COLUMN ALUM TREATMENTS

The last alternative combines a whole-lake sediment inactivation alum treatment with much smaller annual water column alum treatments. The initial whole-lake alum treatment would reduce internal phosphorus loading from the sediments by 85%. The annual water column alum treatments would be designed to remove the phosphorus that flows into the water column from the main inlet stream each winter, as well as a portion of the phosphorus from internal loading that is not controlled by the whole-lake alum treatment. Each water column alum treatment is anticipated to remove approximately 85% of the phosphorus in the water column (in both the epilimnion and hypolimnion) at the time of the treatment.

Except during Year 1, the water column alum treatments would occur in late spring each year in order to inactivate the phosphorus that has washed into the lake during the prior winter. During Year 1, there would be an initial water column alum treatment in the early fall. The purpose of this initial treatment would be to remove the 15% of internal loading not captured by the spring whole-lake sediment inactivation alum treatment as well as any phosphorus that may have washed into the lake after the sediment treatment. Without this fall water column treatment, phosphorus levels in the lake will rise at the end of the first summer as the lake cools off and mixes. This phosphorus would then carry over to Year 2 without the fall treatment.

Figure 9-2 illustrates the lake response in the epilimnion under this alternative. Because of the combination of a whole-lake sediment treatment and an initial early fall water column treatment, the average total phosphorus concentration in the epilimnion would drop to 41 µg/l during Year 1. In the early fall of Year 1, phosphorus concentrations in both the epilimnion and hypolimnion would drop dramatically because of the initial water column alum treatment. In Years 2 through 4, the model indicates that the average summertime phosphorus concentrations in the upper waters would be approximately 39 µg/l.

At phosphorus levels of 39 µg/l to 41 µg/l, Lake Ketchum would have significantly better conditions than at present. There would still be periodic blue-green algal blooms, especially in late summer and early fall. However, the blooms would be shorter and much less severe than currently. There would also likely be more diatoms and green algae in spring and early summer instead of the nuisance blue-green algae.

It should be noted that phosphorus levels in the lake are likely to gradually increase through the years under this alternative. Within five to ten years, the combined effects of the uncontrolled fraction of the sediment phosphorus and the portion of the external loading not inactivated by the water column treatments will drive phosphorus levels higher. Also, it is possible that late spring rain storms may occur after the annual water column treatments, so the phosphorus from those storms would not be treated. The model is not sophisticated or sensitive enough to illustrate gradual increases in phosphorus through Year 4. However, it is likely that lake conditions will slowly decline and another whole-lake sediment inactivation alum treatment will be needed within five to seven years.

The cost of the Year 1 whole-lake alum treatment is estimated at $194,000. The Year 1 fall water column alum treatment would cost $36,000. Each subsequent spring water column alum treatment would cost approximately $36,000 in 2011 dollars.

9.6 COMPARISON OF ALTERNATIVES

As described above, there are both benefits and drawbacks for each of the lake restoration alternatives. Figure 9-3 is a table comparing the responses of Lake Ketchum under each alternative. In comparison to the lake water quality target of maintaining summer phosphorus concentrations at less than 40 µg/l, Alternative 1 does not meet the objective. Alternative 2 does meet the target, but only for Year 3 after implementation of the second whole-lake alum treatment. The model concludes that both Alternatives 3 and 4 will lower phosphorus concentrations to near the target in Year 1 and will meet the target beginning in Year 2 when either the alum injection system or annual water column alum treatments begin controlling the external phosphorus load from the main inlet stream. However, the model indicates that Alternative 3 is somewhat more likely to keep the phosphorus concentrations below 40 µg/l.

FIGURE 9-3: LAKE WATER QUALITY RESPONSES—COMPARISON OF ALTERNATIVES

Lake Restoration Alternatives[1]	**Epilimnion Summer Average Total Phosphorus Concentrations (µg/l)**			
	Year 1	**Year 2**	**Year 3**	**Year 4**
Modeled Existing Conditions	173	175	175	175
Alternative 1 Whole-Lake Sediment Inactivation Alum Treatment	46	70	71	71
Alternative 2 Whole-Lake Sediment Inactivation Alum Treatment Repeated in Two Years	46	70	31	54
Alternative 3 Whole-Lake Sediment Inactivation Alum Treatment with Alum Injection at Inlet	46	36	36	36
Alternative 4 Whole-Lake Sediment Inactivation Alum Treatment with Annual Water Column Alum Treatments	41	39	39	39

[1]Note: all alternatives include implementation of residential best management practices and protection of the wetlands.

Figure 9-4 is a graphical representation of the lake responses to each of the four alternatives. The graph shows that Alternative 4 gives the most improvement in early fall of the first year. In Years 2 through 4, Alternatives 3 and 4 consistently provide the most water quality improvements, with Alternative 3 giving slightly better conditions. Alternative 2 results in the best conditions for Year 3, but conditions decline in Year 4.

FIGURE 9-4: LAKE PHOSPHORUS CONCENTRATIONS IN RESPONSE TO RESTORATION ALTERNATIVES

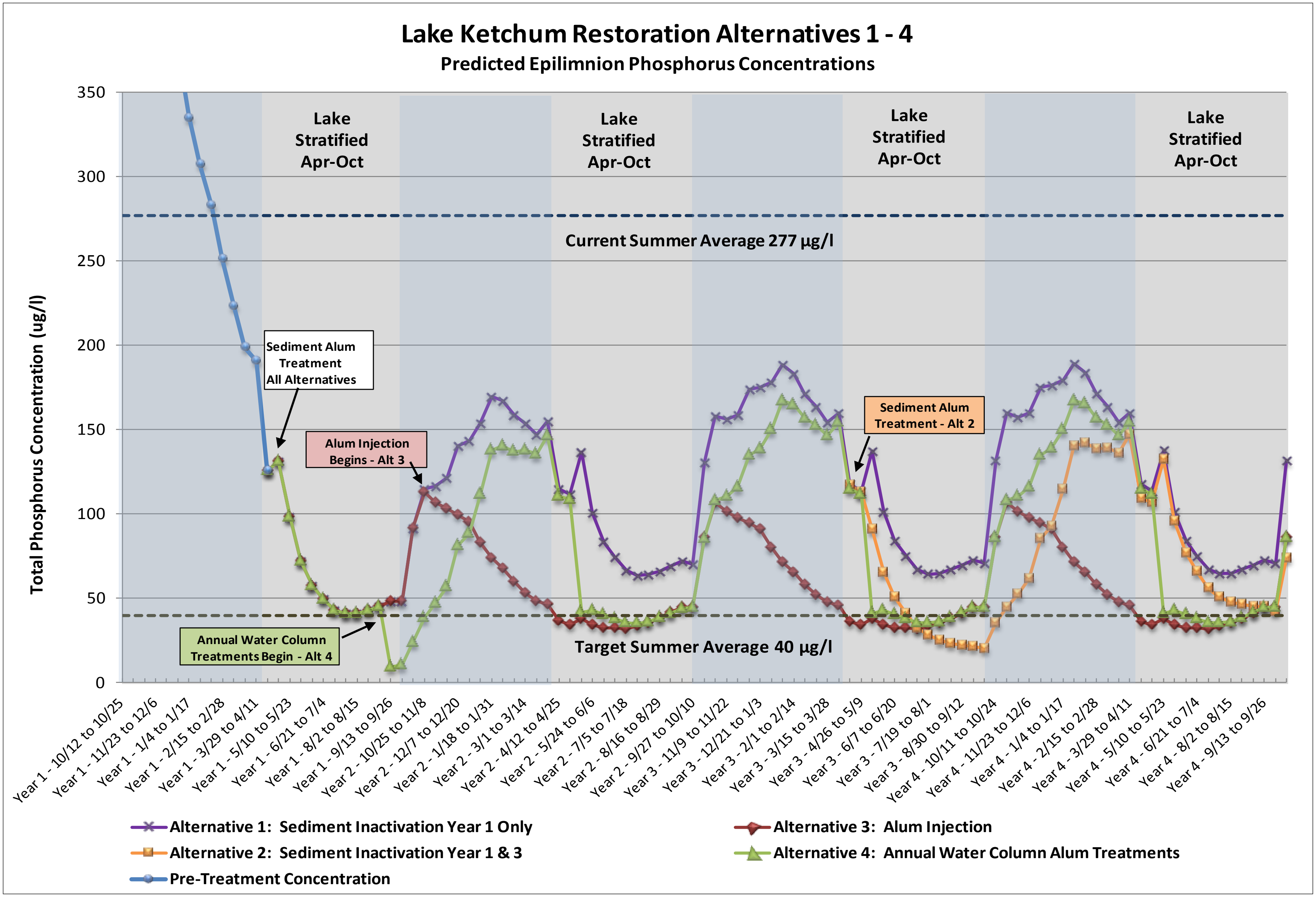


Figure 9-5 compares the annual costs of the lake restoration alternatives, the 4-year total costs, and the total costs over 10 years. The most expensive alternative is Alternative 3, both within the first four years and over ten years. However, as discussed above, Alternative 3 is also the option that is most likely to meet the water quality target for Lake Ketchum.

Alternative 4 is the least expensive alternative of the options that can meet the water quality target, and considerably less expensive over four years than Alternative 3. However, over ten years, the relative cost of Alternative 4 goes up because there is more uncertainty about its long-term benefits. It is also likely that the whole-lake sediment inactivation alum treatment will have to be repeated within five to seven years with Alternative 4. This assumption is incorporated into the 10-year cost estimate.

FIGURE 9-5: COST COMPARISON OF ALTERNATIVES

Lake Restoration Alternatives	Cost in $1000s (2011 dollars)					
	Year 1	Year 2	Year 3	Year 4	4-Year TOTAL	10-Year TOTAL
Alternative 1 Whole-Lake Sediment Inactivation Alum Treatment	$194	0	0	0	$194	$194[1]
Alternative 2 Whole-Lake Sediment Inactivation Alum Treatment Repeated in Two Years	$194	0	$174	0	$368	$890[2]
Alternative 3 Whole-Lake Sediment Inactivation Alum Treatment with Alum Injection at Inlet	$428	$43	$65	$65	$601	$991[3]
Alternative 4 Whole-Lake Sediment Inactivation Alum Treatment with Annual Water Column Alum Treatments	$230	$36	$36	$36	$338	$692[4]

ASSUMPTIONS:
[1]No repeated treatments in first 10 years.
[2]Sediment treatments repeated every two years.
[3]Sediment treatment will not need to be repeated until after 10 years.
[4]Sediment treatment will need to be repeated in Year 6.

It should be noted again that alum treatments will result in dramatically clearer water within a few hours and greater water clarity long-term. The clear water will allow more light into the lake and may lead to an increase in the growth of rooted aquatic plants. As long as these are native plants, this change will provide a healthier balance in the lake. However, Lake Ketchum currently has virtually no aquatic plants, so some citizens may perceive the increased aquatic plants as unwelcome.

9.7 MONITORING AND ADAPTIVE MANAGEMENT

With any of these alternatives, it is important that water quality monitoring of the lake and inflowing stream continue on a regular basis. This monitoring will track conditions in the lake and help the County and citizens evaluate the effects of implementing the preferred alternative. Monitoring will show the differences in phosphorus levels before and after any alum treatments and will document the abundance of algae in the lake.

At a minimum, the lake water quality should be monitored every month on a year-round basis for phosphorus, chlorophyll *a*, and water clarity. The inlet stream should be sampled for phosphorus at least monthly. Water levels and stream flows should be monitored on a continuous basis for the first two years after implementation begins.

Monitoring will also support adaptive management for this project. This is a fancy term for tracking the success of the project and making changes as needed to improve the outcomes of each element of the project. For example, under Alternative 4, monitoring results could be used to adjust the frequency and concentrations of water column treatments.

9.8 PREFERRED RESTORATION ALTERNATIVE

Based on the comparisons described above, the recommended in-lake restoration alternative for controlling algae and restoring Lake Ketchum is Alternative 4 (Whole-lake Sediment Inactivation Alum with Annual Water Column Alum Treatments). Although Alternative 4 does not lower the summer phosphorus levels in the lake quite as much as the alum injection Alternative 3, Alternative 4 is considerably less costly and provides more flexibility to respond to changing conditions. Therefore, the most cost effective restoration alternative for Lake Ketchum is Alternative 4. This alternative is recommended for adoption by the lake community and Snohomish County.

10 RECOMMENDED ALGAE CONTROL PLAN

There are five elements in the recommended Algae Control Plan for Lake Ketchum. These are 1) a whole-lake alum treatment to inactivate phosphorus in the lake sediments, 2) annual water column alum treatments to inactivate phosphorus from the main inlet stream, 3) implementation of residential BMPs by lakeshore and watershed landowners, 4) protection of the wetlands located between the former dairy farm and the lake, and 5) on-going monitoring and adaptive management to ensure the plan is working.

The ideal lake restoration plan for Lake Ketchum would also include work on the soils of the former dairy farm to remove or inactivate phosphorus. However, work on the farm soils is not feasible, so it is not a component of the plan. Instead, the phosphorus that flows into the lake from the main inlet stream will be addressed by annual water column alum treatments and protection of the wetland. If work on the farm ever becomes viable in the future, the plan will be revisited and potentially revised.

10.1 RECOMMENDED PLAN ELEMENTS, TIMING, AND COSTS

Figure 10-1 is a table showing the elements, timing, and costs of the recommended algae control plan.

FIGURE 10-1: COST OF RECOMMENDED RESTORATION STRATEGY

RECOMMENDED LAKE KETCHUM ALGAE CONTROL PLAN						
Plan Elements	**Cost in $1000s (2011 dollars)**					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**4-Year TOTAL**	**10-Year TOTAL**
Whole-Lake Sediment Inactivation Alum Treatment	$194	0	0	0	$194	$368[1]
Annual Water Column Alum Treatments	$36	$36	$36	$36	$144	$324[2]
Residential BMPs and Wetland Protection	$20	$20	$8	$8	$56	$104
Monitoring/Adaptive Management	$14	$14	$12	$12	$52	$124
TOTALS	**$264**	**$70**	**$56**	**$56**	**$446**	**$920**

ASSUMPTIONS:
[1]Sediment Alum Treatment may need to be repeated in Year 6.
[2]No Water Column Treatment proposed in Year 6.

10.2 FUNDING STRATEGY

Implementation of the restoration plan for Lake Ketchum will be expensive both in the short term and long term. The total costs will stretch the capabilities of the local residents and Snohomish County. Therefore, every effort should be made to secure outside funding for a portion of the implementation costs. However, clean-up of Lake Ketchum is a high priority and must be accomplished, with or without outside funding, to ensure the future use and enjoyment of the lake. Snohomish County SWM and the lake residents will have to work together to develop a feasible funding strategy to implement the restoration plan.

10.2.1 LOCAL PROPERTY OWNER FUNDING

Owners of lakeshore properties have been funding lake management work for years through collection of assessments under the authority of RCW 90.24. Property owners vote to approve the assessments each year. The citizens have generated $5,000 to $15,000 per year through this mechanism. Members of the lakeshore community have indicated a willingness to assess themselves for a portion of the costs of the proposed lake restoration. However, no specific commitments have yet been made as to the level of funding for lake restoration.

Another option available for local funding is formation of a Lake Management District (LMD) under the authority of RCW 36.61. An LMD could be formed for the specific purpose of funding Lake Ketchum restoration and could include properties around the lakeshore and within the larger watershed. An LMD would collect fees annually for a specific length of time. An LMD also allows bonding of large upfront costs that could be paid back over several years by annual assessments. There are numerous procedural steps in forming an LMD, including at least two public hearings. Most importantly, the owners of every property included within a proposed LMD have the opportunity to vote to approve or not approve the LMD. Each owner gets one vote for every dollar they would be assessed. A majority of votes is required to establish the LMD. Drawbacks of the LMD process are that it is long (12 to 18 months) and costly to set up.

10.2.2 SNOHOMISH COUNTY SURFACE WATER MANAGEMENT

Another source for funding a portion of the recommended restoration plan is Snohomish County SWM funds. SWM funding comes from fees that are currently paid by all developed properties within unincorporated Snohomish County. This funding has already paid for much of the work at Lake Ketchum to date. Snohomish County may be able to continue providing a similar level of funding to assist with implementing the restoration plan.

Another possible option for local funding is for Snohomish County to establish a surcharge on top of the current SWM fees to be paid by all developed properties in the watershed. The surcharge would be for a specific length of time and would be collected in the normal manner with the property taxes. A similar SWM fee surcharge has been established for all properties around Lake Goodwin and Lake Shoecraft to fund work to control Eurasian watermilfoil, an invasive aquatic plant, and at Lake Stevens to fund water quality protection. This option would not require a vote of affected property owners, but would have to have strong support from property owners for the County Council to approve such a surcharge.

10.2.3 WASHINGTON DEPARTMENT OF ECOLOGY CENTENNIAL CLEAN WATER FUND GRANTS OR LOANS AND EPA 319 FUNDS

Another potential source of grant or loan funds is the Centennial Clean Water Fund and EPA 319 funds managed by the Washington State Department of Ecology. These funds support a wide variety of water quality improvement projects. However, preliminary indications from the Department of Ecology are that alum treatments are considered “short-term” and “palliative” rather than providing long-term pollution source control. Therefore, alum treatments may be ineligible for grants unless Ecology can be convinced that the alum treatments in Lake Ketchum are not palliative and that every effort is being made to reduce shoreline/watershed phosphorus sources. The eligibility of alum treatments for State loans is not clear.

10.2.4 WASHINGTON DEPARTMENT OF ECOLOGY FRESHWATER ALGAE CONTROL PROGRAM GRANTS

The Department of Ecology also offers grant funding as part of the Freshwater Algae Control Program. Grants of up to $50,000 are possible for algae control projects. Development of the algae control plan for Lake Ketchum is partially funded by one of these grants.

10.3 ROLES AND RESPONSIBILITIES

The primary responsibilities for the actual work of implementing the restoration plan will lie with the lake residents and Snohomish County SWM. The citizens and SWM should work together to develop a feasible funding strategy. SWM should be responsible for preparing grant applications and working with citizens to track progress and costs. SWM should have the lead for implementation of the whole-lake sediment inactivation alum treatment and the annual water column treatments. This includes final design, permitting, contracting, and directing the actual treatments. The citizens should be responsible for implementing residential BMPs, including motivating property owners to participate. SWM should provide outreach materials, site visits, and workshops related to BMPs. Finally, SWM should be responsible for water quality monitoring activities to track lake conditions and the success of the restoration plan, and work with citizens to determine if the plan should be revised to increase success.

11 CITED REFERENCES

1. Auer, M.T., Doerr S.M., and Effler, S.W. 1997. A zero degree of freedom total phosphorus model: 1. Development for Onandaga Lake, New York. Journal of Lake and Reservoir Management. 12(2):118-130.
2. Cooke, G.D., E.B. Welch, S.A. Peterson and S.A. Nichols. 2005. Restoration and Management of Lakes and Reservoirs. 3rd Ed. CRC Press, Boca Raton, FL.
3. Jensen, H.S., P. Kristensen, E. Jeppesen and A. Skytthe. 1992. Iron-phosphorus Ratio as an Indicator of Phosphorus Release from Aerobic Sediments in Shallow Lakes. Hybrobiologia. 235/236:731-743
4. Entranco. 1997.Lake Ketchum: Lake Restoration Plan. Prepared for Snohomish County Public Works Surface Water Management. February 1997. and technical appendices.
5. Perkins, W. W., Welch, E.B., Frodge, J., and Hubbard, T. 1997. A Zero Degree of Freedom Total Phosphorus Model; 2. Application to Lake Sammamish, Washington. Journal of Lake and Reservoir Management. 13(2):131-141.
6. Snohomish County - Surface Water Management. 2011a. Quality Assurance Monitoring Plan-Snohomish County Lake Management Program.
7. Snohomish County - Surface Water Management. 2011b. Appendix D: Quality Assurance Project Plan Addendum for Lake Ketchum Algae Control Plan Project.
8. Snohomish County - Surface Water Management. 2011c. Quality Assurance Project Plan for Lake Ketchum Sediment Study.
9. Snohomish County - Surface Water Management. 2012. Lake Ketchum 2011 State of the Lakes Update.
10. Tetra Tech. 2008. Jameson Lake Phosphorus Model Results: Two-layer phosphorus mass balance model. Prepared for Water Quality Engineering, Inc. January 2008.
11. Tetra Tech. 2009. Management of Pine Lake Water Quality, Final Report. Prepared for City of Sammamish Public Works. March 2009.
12. Welch, E.B. and G.D. Cooke. 1995. Internal Phosphorus Loading in Shallow Lakes: Importance and Control. Lake and Reservoir Management. 11:273-281
13. Welch, E.B., C.A. Rock, R.C. Howe and M.A. Perkins. 1980. Lake Sammamish Response to Wastewater Diversion and Increasing Urban Runoff. Water Res. 14:821-828.
14. Welch, E.B. and Jacoby, J.M. 2001. On Determining the Principal Source of Phosphorus Causing Summer Algal Blooms in Western Washington Lakes. Lake and Reservoir Management. 17:55-65.