Newman Lake

Total Phosphorus
Total Maximum Daily Load

Water Quality Improvement Report

November 2007
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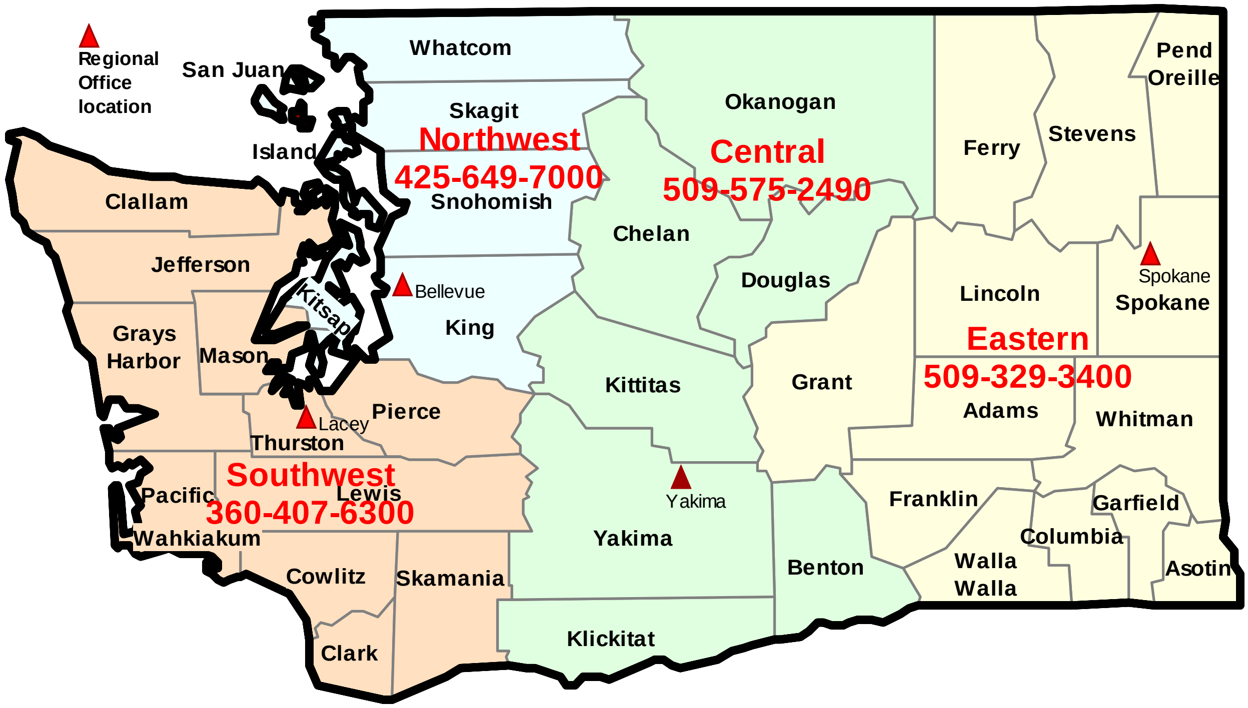

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Summary

The water quality of Newman Lake, located 26 kilometers northeast of Spokane, Washington, has been a focus of interest for over thirty years. During this period, several studies have been conducted by Washington State University's (WSU) Water Research Center and activities implemented by state and local governments and concerned citizens directed at both understanding and, ultimately, improving the lake's water quality. Much of this work was initiated due to community concerns regarding deteriorating water quality as indicated by high algal growth.

In lakes, one of the most evident effects to water quality due to increased availability of the nutrient phosphorus is elevated growth of algae during the summer months. Excessive algae growth reduces water clarity and results in chronic increased oxygen demand in the bottom sediments. This can severely affect coldwater aquatic habitat and, depending on the dominant algae present, pose a human health risk. Reportedly, Newman Lake experienced toxic blue-green algae blooms in 1983 and again in 1985 (Funk and Moore, 1988). The mechanism triggering toxic blue-green algae growth is not fully understood, though an environment with an elevated supply of phosphorus tends to favor the dominance of blue-green algae in relation to other types of phytoplankton.

For this reason, initial water quality investigations of Newman Lake (1974, 1986; both conducted by WSU) focused on quantifying phosphorus sources 1) within the lake, associated with sediments (internal sources) and 2) those external to the lake, such as phosphorus contained in surface water runoff. The results of that work indicated that the primary source stimulating algae growth was the release of phosphorus from sediments during the summer. To reduce this source, a whole lake alum treatment was conducted in 1989 and a hypolimnetic oxygenator installed in 1992. In 1997, the oxygenator system was modified with an alum injection system.

The water quality data collected as part of the initial investigation, as well as subsequent work, led to Newman Lake's inclusion on Washington State Department of Ecology's 1996, 1998, and 2004 303(d) lists for total phosphorus (TP). (Total phosphorus is the concentration of phosphorus present in both organic and inorganic forms.) Section 303(d) of the federal Clean Water Act requires that states compile a list of surface water bodies impacted by pollutants such as total phosphorus, where uses such as coldwater habitat, water supply, fishing, swimming, and boating are impaired. Once a water body is on the 303(d) list, a total maximum daily load (TMDL) study is required.

This TMDL addresses impairment of Newman Lake's characteristic uses and aesthetic qualities caused by the nutrient phosphorus. It examined and quantified the pathways that phosphorus is introduced to the water column of Newman Lake. By understanding these pathways, limits or allocations were defined on the amount of phosphorus that can be introduced to the lake in order to constrain algae growth and restore prior characteristic uses. The underlying strategy is that algae growth can be controlled by limiting the introduction of phosphorus.

Lakes can be characterized by their level of biological productivity, or trophic state. A lake's natural level of productivity is determined by factors such as its geologic setting, watershed size and relief, bathymetric characteristics, climate, and the quantity and quality of the water entering and leaving the lake. Increases in a lake's productivity over time, known as eutrophication, is a natural process. However for many lakes, such as Newman Lake, this process has been accelerated by human-related activities. Surface and groundwater inflow associated with nonpoint pollution sources, such as residential development and maintenance, agriculture, and forestry, are a few of the pathways present in the Newman Lake drainage area that contribute phosphorus either directly to the lake or to inflowing surface waters. This ultimately resulted in an increase in the lake's productivity.

In order to establish limits on phosphorus sources, an expectation of the maximum summer period phosphorus concentration for Newman Lake was first required. The target concentration is reflective of a condition where phosphorus sources are managed resulting in the restoration of the lake's characteristic uses. A target average summer period total phosphorus (TP) concentration of 20 micrograms per liter (ug/L) was set. The target concentration is defined as the average concentration observed during the summer period, June through August, within the upper water column (epilimnion), 0 to 3 meters below the water surface. The target was defined for the summer period because this is when environmental conditions favor algae growth coinciding with peak recreational use of the lake.

Central to the TMDL analysis is the determination of the load capacity and load allocations. The load capacity is defined as the maximum amount of total phosphorus that can be introduced to the upper water column from September to the following August while maintaining concentrations at or below the target concentration, 20 ug/L. Once defined, the load capacity is apportioned among the major phosphorus sources through the setting of load allocations. Load allocations were set for phosphorus sources that are observed at elevated levels though where some control is possible. A margin of safety must be considered throughout the analysis process so that when the allocations are achieved, the lake's water quality will have improved to a level where all previous characteristic uses are restored. A margin of safety that provided a 90 percent assurance that the target would be met in any given year was used to establish the load capacity.

During the analysis process, a phosphorus budget was constructed quantifying the amount of phosphorus introduced to the water column from various sources while also examining when the introductions occurred. Total phosphorus sources to Newman Lake can be divided into two categories: those internal to the lake, primarily through the release of TP from sediments under anaerobic conditions, and those external to the lake, such as TP present within surface water inflow. The external sources considered as part of this analysis include phosphorus associated with precipitation, surface water inflow, and on-site wastewater systems.

The focus of this TMDL is on establishing limits to external phosphorus sources because management measures to control in-lake phosphorus recycling are currently in place, and the concentration of phosphorus observed in the upper water column of Newman Lake is closely related to the level of external inflow (loading). This study assumes that over time, with control of external phosphorus sources, the impact to water quality from internal sources will also decline. The load allocation for phosphorus associated with internal recycling was set to an annual average level estimated for 1998 and 2005. Further reductions to achieve the target concentration will come from reductions in external sources.

Analysis results indicate that in order to meet the 20 ug/L target concentration, a 39 percent reduction in annual (September to the following August) external loading is required. Both the loads and concentrations are based on average levels observed over a 20-year period from 1986 to 2006. The load capacity has been set at 1167 kilograms TP: 903 kilograms attributed to external sources and 264 kilograms attributed to internal sources, September through August. A 39 percent reduction in external TP loading results in a 90 percent assurance that the target concentration will be achieved in any given year while providing a 50 percent assurance that summer phosphorus concentrations will remain below 14 ug/L. In comparison, without reductions in external loading, the 90^{th} and 50^{th} percentile concentrations predicted over the period 1986 to 2006 are 33 ug/L and 23 ug/L, respectively.

Based on historic relationships of phosphorus concentrations as they relate to chlorophyll (a), an indicator of algae growth levels, and Secchi depth, an indicator of water clarity, the achievement of the target concentration will decrease chlorophyll (a) concentrations to approximately 6 ug/L, increasing water clarity by 1 meter in relation to current average summer levels.

A summary of implementation strategies for achieving the TMDL targets focuses on external phosphorus loading control while assuming that internal loading will not be allowed to increase from existing conditions. The strategies identify the need to control road and shoreline erosion, improve forest practices, and significantly reduce near-shore septic system sources. Restoration of stream and flood plain functions are also an essential component of reducing external phosphorus loading from the watershed. Following the study, a detailed implementation plan will be developed with a stakeholders group to identify and prioritize the actions and monitoring to achieve the TMDL goal.

Introduction

Overview of the total maximum daily load study process

The federal Clean Water Act (CWA) requires each state to establish water quality standards to protect, restore, and preserve water quality. These standards have been set to protect designated uses such as drinking water supplies or cold water habitat, critical to the survival of certain organisms. Criteria, usually numeric, are used as a gauge to achieve those uses. When a lake, river, or stream fails to meet water quality standards after application of technology-based pollution controls, Section 303(d) of the CWA requires that states include it on a list of impaired water bodies and prepare an analysis called a **total maximum daily load** (TMDL). The United States Environmental Protection Agency (EPA) has established regulations (40 CFR 130) and developed guidance for establishing water clean up plans (USEPA, 1991).

Through the TMDL analysis, a **loading capacity,** or the maximum amount of a given pollutant that can be discharged to a water body, while still meeting water quality standards, is determined. That load capacity is allocated among the various sources responsible for the pollution problem. If the pollutant originates from a discrete source (point source) such as an industrial facility's discharge pipe, that facility's share of the loading capacity is called a **wasteload allocation**. If the pollutant originates from a diffuse source (nonpoint source) such as runoff from an agricultural operation, that facility's share is called a **load allocation**.

The TMDL analysis must also consider **seasonal variation** in pollutant concentrations and include a **margin of safety** that takes into account uncertainty about the causes of the water quality problem or a water body's specific loading capacity.

Newman Lake's inclusion on the 303(d) list

Newman Lake, located in Spokane County, 26 kilometers northeast of the city of Spokane, appears on Washington State Department of Ecology's 1996, 1998, and 2004 303(d) lists for total phosphorus (TP) (refer to http://www.ecy.wa.gov/programs/wq/swqs/index.html). (Total phosphorus is the concentration of phosphorus present in both organic and inorganic forms.)

Newman Lake has, at times, experienced chronically elevated phosphorus concentrations resulting in an accelerated growth of algae (blooms) during the summer months. These conditions have undermined the beneficial uses of the lake for activities such as fishing and swimming while importantly reducing the lake's overall biological health.

To address community concerns regarding the impaired use of Newman Lake due to poor water quality, Washington State University conducted studies of the lake in 1974 (Funk et al, 1976) and 1986 (Funk and Moore, 1988). The major objective of that work was to identify the principal sources of TP to the lake and to determine appropriate source control methods. Physical, chemical, and biological parameters were measured in the lake and its principal inflow sources. The Washington State Department of Ecology used the data collected during the 1986 study, and its principal findings, as the basis for including Newman Lake on the 303(d) list leading eventually to the initiation of this TMDL analysis.

Since the 1988 Feasibility Study Washington State University (Water Research Center) also completed additional water quality work in 1998, contained in the report titled: "Newman Lake Restoration Phase II." These studies indicated that lake sediments were a major source of the phosphorus stimulating algae growth. To reduce the release of phosphorus from sediments a whole lake alum treatment was conducted in 1989 and an oxygenator installed in 1992. In addition, an alum injection system was installed parallel to the oxygenator system in 1997. Both the oxygenator and alum injection system continue to operate.

As of 2006, both Washington State University and lake resident volunteers continue to monitor lake water quality. The data contained within the WSU studies, and subsequent data collection efforts, provides the base from which Ecology conducted this TMDL analysis.

Background

Newman Lake and its watershed

Newman Lake has a volume of 26,146,829 cubic meters, an average depth of 5.1 meters, and a maximum depth of 9 meters (30 feet) (Figure 1, Wolcott, 1961). Its surface area is approximately 515 hectares and greater watershed 7800 hectares (Figure 2). Thompson Creek, draining to the north lobe of the lake, comprises 40 percent of the watershed (3132 ha) and has a dominant effect on the lake's hydrology and water quality.

Forestry is the primary land use within the watershed representing approximately 78 percent of the area (Table 1). Cultivated pastureland represents six percent of the watershed area. Residential land use, while representing less than one percent of the watershed area, is concentrated along the lake shoreline. There are 486 residences located in close proximity to the lake shoreline with about 45 percent occupied year round. For this reason, the population within the watershed can vary considerably particularly during the summer months when use of the lake is the greatest. During the summer, the human population within the watershed is approximately 1,200.

The greater watershed is currently zoned as commercial forest lands and rural conservation. Within the rural conservation designated areas, residential development is restricted to one house per 20 acres (or one house per 10 acres with clustering). There are currently (2007) 744 parcels within 1000 feet (305 meters) of the lake shore with 231 or 31 percent of them undeveloped. With development restrictions in place for the greater watershed, development will continue to be focused on the near-shore parcels. Currently, approximately 85 percent of the residential development within the greater watershed occurs within 1000 feet of the shoreline.

The elevation of Newman Lake is 610 meters. Elevations within the watershed vary greatly, particularly for the Thompson Creek drainage. Excluding Thompson Creek, approximately 90 percent or more of the drainage area lies below 914 meters (Table 2). While the majority of Thompson Creek's drainage area is also situated below 914 meters (88 percent), 12 percent is situated above this elevation with upper elevations extending to 1676 meters. Thompson Creek's large size, representing 40 percent of the entire watershed, and relief, results in a disproportionate effect on Newman Lake's water quality. One of the primary factors is that during the winter months, precipitation is stored as snow in much of its drainage. As it will be discussed later, the level of snow accumulation and the timing of its eventual spring run-off are major determinants on Newman Lake's summer TP levels.

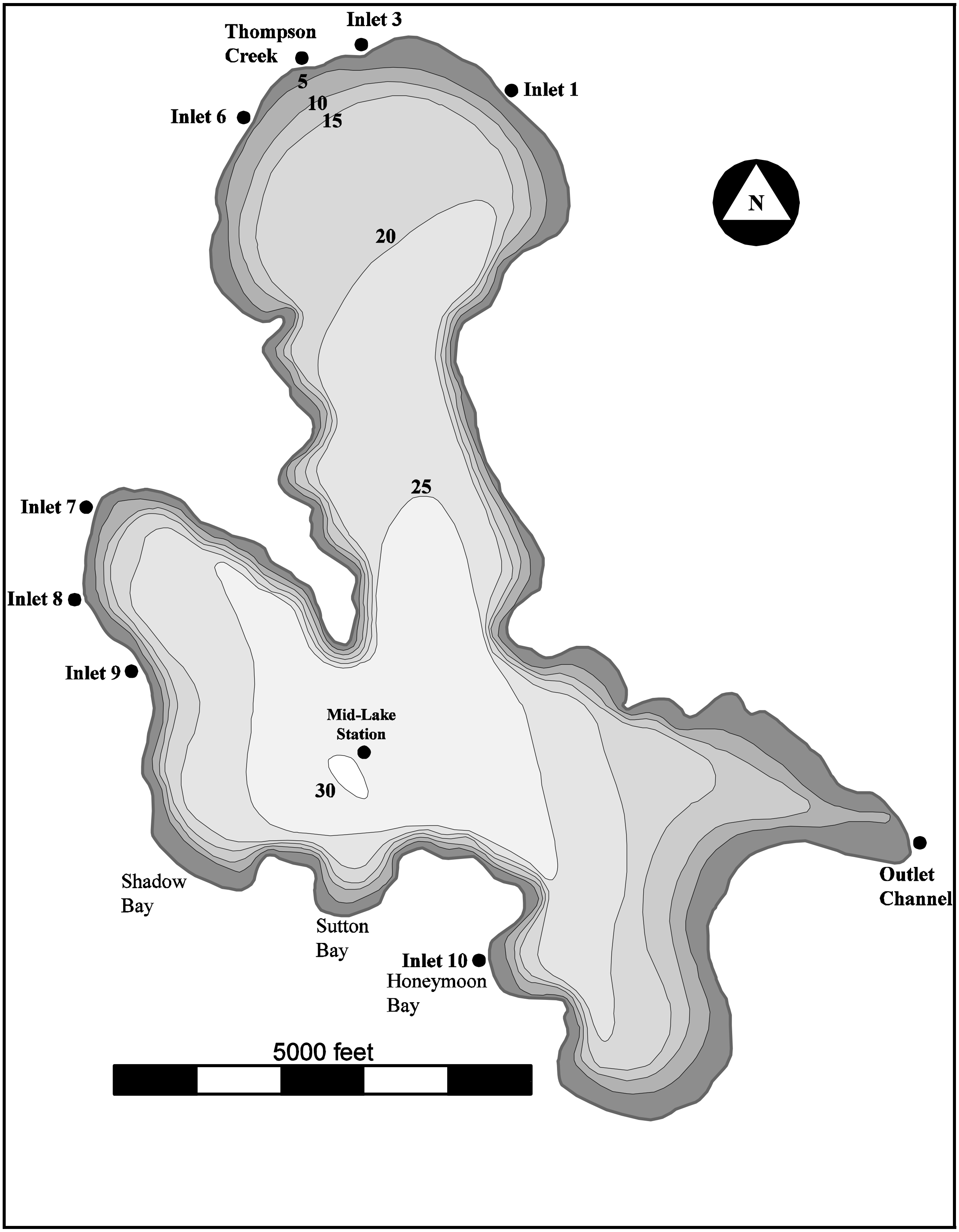

Figure 1. Newman Lake bathymetry along with monitoring locations (Depth isopleths in units of feet.)

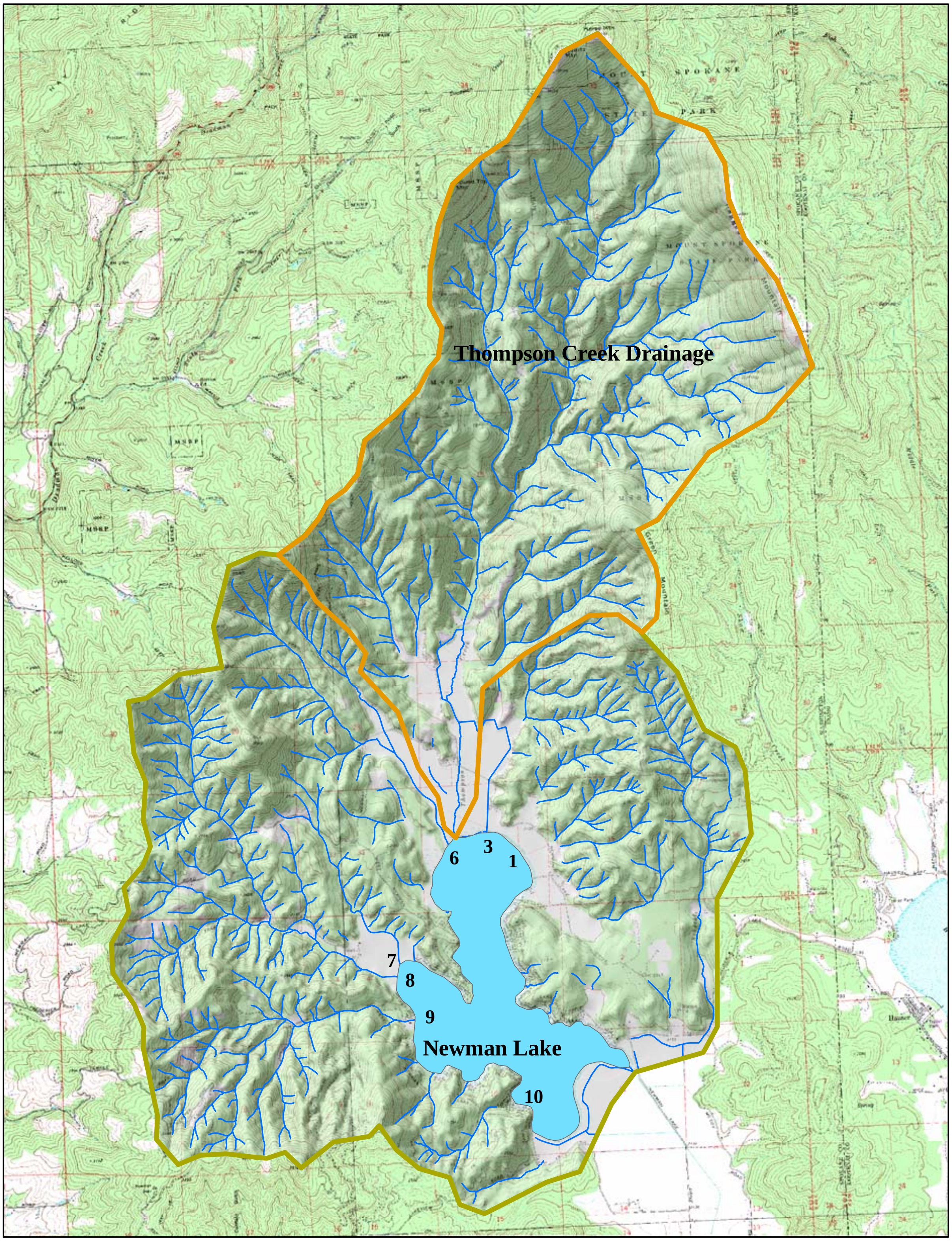

Figure 2. The Newman Lake watershed along with monitored inlet locations (numbered)

Table 1. Representation of land use within the Newman Lake watershed.

Land Use Description (1)	Land Use Description (2)	Percent Represented (1)	Hectares (1)	Percent Represented (2)	Hectares (2)
Openwater (Newman Lake)	Open Water	6.01	467.43	6.01	467.43
Low Intensity Residential	Developed	0.13	10.11	0.18	14.16
Commercial / Industrial / Transportation	Developed	0.05	4.05		
Bare Rock / Sand / Clay	Barren	0.01	0.41	10.15	789.17
Transitional (Clearcut)	Barren	10.14	788.76		
Deciduous	Forested Upland	0.03	2.83	67.98	5285.38
Evergreen	Forested Upland	58.57	4553.68		
Mixed Tree Species	Forested Upland	9.37	728.87		
Shrubland	Shrubland	8.10	629.31	8.10	629.31
Grasslands / Herbacous	Herbaceous Upland	1.18	91.87	1.18	91.87
Pasture / Hay	Herbaceous Planted / Cultivated	3.48	270.34	6.26	492.52
Row Crops	Herbaceous Planted / Cultivated	0.17	13.36		
Small Grains	Herbaceous Planted / Cultivated	1.56	121.01		
Fallow	Herbaceous Planted / Cultivated	1.06	82.15		
Urban / Recreational Grasses	Herbaceous Planted / Cultivated	-	0.41		
Woody Wetlands	Wetland	0.12	9.31	0.14	10.52
Emergent Herbaceous Wetlands	Wetland	0.02	1.21		

Table 2. The representation of various ranges in elevation within the greater Newman Lake watershed and its sub-watersheds.

Elevation Range (ft)	Watershed	Thompson Creek	Inlet 1	Inlet 3	Inlet 6	Inlet 7	Inlet 8	Inlet 9	Inlet 10
2001-2500	42.3	16.7	60.5	59.6	46.6	82.6	39.8	25.0	71.4
2501-3000	29.2	23.6	39.8	35.0	38.3	16.2	52.4	50.7	29.5
3001-3500	16.5	30.3	-	5.1	14.7	1.2	7.9	24.4	0.1
3501-4000	6.5	16.1	-	-	-	-	-	-	-
4001-4500	3.8	9.4	-	-	-	-	-	-	-
4501-5000	1.6	3.8	-	-	-	-	-	-	-
5001-5500	0.1	0.2	-	-	-	-	-	-	-

Water quality investigations and restoration activities

Due to concerns regarding Newman Lake's declining water quality, diagnostic studies were conducted by the Washington State University, Water Research Center in 1974 and 1986 (Funk et al, 1974; Funk and Moore, 1988). From this work, a series of recommendations were proposed to reduce phosphorus sources and their water quality impacts. Because lake sediments were found to be a significant phosphorus source, nutrient inactivation through the use of alum and hypolimnetic oxygenation were among the recommended options. In addition, watershed management measures to control external phosphorus inputs associated with forestry, residential development, and cattle grazing, among other activities, were presented.

Since completing these initial feasibility studies, several of the recommendations were implemented. In September 1989, a whole lake alum treatment was conducted and a Speece Cone-type hypolimnetic oxygenator installed in June 1992. Since 1992, the aerator has been operated most years between April and September, bracketing the period when the release of phosphorus from sediment is greatest. In 1997, the oxygenation system was modified with an alum injection system. Both the oxygenation and alum injection system are directed at reducing the release of phosphorus from sediments. Measures to control phosphorus sources within the watershed have been addressed, though less targeted, through the efforts of concerned lake residents, Spokane County Engineer's Office, Newman Lake Flood Control Zone District, the Spokane County Health Department, and public and private land owners.

Applicable Criteria

Water quality standards in Washington State are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW). Authority to adopt rules, regulations, and standards necessary to protect the environment is the responsibility of the Department of Ecology. Under the federal Clean Water Act, the EPA Regional Administrator must approve the water quality standards adopted by the state (Section 303(c)(3)). Through adoption of water quality standards, Washington designated certain characteristic uses to be protected and the criteria necessary to protect those uses [Washington Administrative Code (WAC), Chapter 173-201A). (For additional information on Washington State's water quality standards refer to http://www.ecy.wa.gov/programs/wq/swqs/index.html.)

This TMDL addresses impairment of Newman Lake's characteristic uses and aesthetic qualities caused by the nutrient phosphorus. Elevated phosphorus levels in lake systems can result in the onset of eutrophication which is typically characterized by excessive algae growth within the upper water column. Eutrophic conditions in lakes ultimately lead to severe habitat impairment affecting the majority of aquatic organisms originally present under less adverse conditions, while also leading to the loss of characteristic uses of the lake for activities such as swimming, fishing, and boating. Washington State laws relevant to the protection of water quality in Newman Lake include **Protection of characteristic uses [WAC 173-201A-030(5)]**:

Lake Class Characteristic uses shall include, but not be limited to, the following:

1) * Water supply (domestic, industrial, agricultural).
2) Stock watering.
3) * Fish and shellfish:
   - Salmonid migration, rearing, spawning, and harvesting.
   - Other fish migration, rearing, spawning, and harvesting.
   - Clam and mussel rearing, spawning, and harvesting.
   - Crayfish rearing, spawning, and harvesting.
4) * Wildlife habitat.
5) * Recreation (primary contact recreation, sport fishing, boating, and esthetic enjoyment).
6) Commerce and navigation.

*** Characteristic uses applicable to Newman Lake**

Target total phosphorus (TP) concentration

One of the primary goals of this TMDL analysis is to establish a load capacity or the maximum amount of phosphorus that can be introduced to Newman Lake from all identified sources, while limiting the in-lake TP concentration below a maximum or target level. The target concentration provides the foundation from which the load capacity and load allocations are determined. However, there are not specific water quality criteria that apply to total phosphorus for lakes in Washington. Instead, the Department of Ecology has suggested TP target concentrations based on an eco-regional framework. Newman Lake, situated within the Northern Rockies eco-region, has a suggested target phosphorus concentration of 20 micrograms per liter (ug/L) or less (Table 3).

The summer average TP concentrations used in this analysis were from data collected in 1986, 1992-94, 1998, and 2005. From this data, average summer (June-August) TP epilimnion concentrations have varied between 12 ug/L in 1994, to 29 ug/L in 1998. As will be discussed later in the report, model-predicted average summer period epilimnion TP concentrations, 1986 to 2006, are 25 ug/L. TP concentrations exceeding 20 ug/L are indicative of a mesotrophic-eutrophic level of productivity; in other words, a lake characterized by high levels of algae growth due to readily available phosphorus. For these cases, a lake specific study is recommended in order to establish the target concentration.

Table 3. Washington State's recommended total phosphorus lake criteria for the Pacific Coast range, Puget Sound lowlands, and Northern Rockies eco-regions.

Trophic State	Ambient TP Range (ug/L)	TP Criteria
Ultra-Oligotrophic	0 – 4	4 or less
Oligotrophic	>4 – 10	10 or less
Lower Mesotrophic	>10 – 20	20 or less
Mesotrophic – Eutrophic	>20	Lake Specific Study

Chapter 173-201A-030, Section 5(c) recommends the following be established by the lake specific study:

> Section ii – Determine appropriate total phosphorus concentrations or other nutrient criteria to protect characteristic lake uses. If the existing total phosphorus concentration is protective of characteristics uses, then set criteria at the existing total phosphorus concentration. If the existing total phosphorus concentration is not protective of the existing characteristic lake uses, then set criteria at a protective concentration. Proposals to adopt appropriate total phosphorus criteria to protect characteristic uses must be developed by considering technical information and stakeholder input as part of a public involvement process equivalent to the Administrative Procedure Act (Chapter 34.05 RCW).
>
> Section iii – Determine if the proposed total phosphorus criteria necessary to protect characteristic uses is achievable. If the recommended criterion is not achievable and if the characteristic use the criterion is intended to protect is not an existing use, then a higher criterion may be proposed in conformance with 40 CFR part 131.10.

This TMDL analysis uses the information contained within "*Investigation to Determine Extent and Nature of Non-Point Source Enrichment and Hydrology of Several Recreational Lakes of Eastern Washington, Parts I and II*" (Copp, 1976; Funk et al., 1976); "*Newman Lake Restoration Feasibility Study*" (Funk and Moore, 1988); and the "*Newman Lake Restoration Phase II Study*" (Funk et al, 1998) as the basis for the lake specific study. The results of those investigations indicated that a shift in the trophic status from mesotrophic/eutrophic to mesotrophic will result in the achievement of the lake's beneficial uses. A lower in-lake total phosphorus concentration, the result of source control, will further shift the environmental conditions which favor excessive algae growth, the major factor sited as impairing the characteristic uses of the lake.

A target TP concentration establishes a maximum level that should be observed, on average, within the epilimnion (0 to 3 meter depths) during the summer period (June through August), while remaining protective of the lake's characteristic uses. The reason why the target concentration applies to the summer period and the upper water column is that this is a period when the greatest recreational use occurs and when algae growth is at its peak. The upper portion of the water column is where both recreational use and algae growth are concentrated.

To achieve this trophic shift, a target average summer period (June through August) total phosphorus concentration for the epilimnion of Newman Lake is set at 20 micrograms per liter (ug/L).

Epilimnion Target Summer Period Total Phosphorus Concentration

- 20 micrograms per liter (ug/L)

In lake systems, increased growth of algae during the summer months is one of the most evident effects to water quality from the elevated introduction (loading) of phosphorus. Excessive algae growth reduces water clarity and results in chronic increased oxygen demand in sediments. This severely affects coldwater aquatic habitat and can, depending on the dominant algae present, pose a human health risk. The mechanism triggering toxic blue-green algae growth is not fully understood, though an environment with an elevated supply of phosphorus tends to favor the dominance of blue-green algae in relation to other types of phytoplankton.

The Trophic State Index (TSI) (Carlson, 1977) can be used as a gauge to indicate significant water quality improvements and the achievement of beneficial uses. The TSI uses the level of three parameters including total phosphorus; Secchi depth (a measure of water clarity); and chlorophyll(a), an indication of algae growth levels, to evaluate the trophic state, or productivity, of a lake. Ranges in the values for these parameters, (typically applying for the summer months) as they relate to the trophic state, are provided in Table 4.

Table 4. The range in trophic state index (TSI) parameters as they relate to lake trophic status.

Trophic State	Secchi Depth (m)	Chl(a) (ug/L)	TP (ug/L)	TSI
Oligotrophic	> 4	< 3	< 14	< 40
Mesotrophic	2 – 4	3 – 9	14 – 25	40 – 50
Eutrophic	< 2	> 9	> 25	> 50

Figures 3 and 4 provide box plots depicting the relationship between total phosphorus, chlorophyll (a), and Secchi depth observed in Newman Lake's epilimnion based on study data along with additional data collected by Spokane County and Washington State University between 1986 and 1992. (This is the only period chlorophyll (a) samples have been collected.)

In interpreting the box plots, the top and bottom of the vertical lines (blue open squares) represent the 90th percentile and the 10th percentile, respectively. The top and bottom of the main box depict the 75th and 25th percentile of the data, respectively. The median level is represented by the solid (red) square. As a comparison, the open circles in these figures are the results of similar relationships derived from a large dataset derived from North American lakes (Dillion and Rigler, 1974)

Based on these figures, with the achievement of the target TP concentration of 20 ug/L, a chlorophyll (a) concentration of approximately 6 ug/L can be expected resulting in a Secchi depth of approximately 3 meters. The trophic state index, based on these parameter values, will bring Newman Lake from 48, indicative of an eutrophic-mesotrophic state, to 44, indicative of a lower mesotrophic state.

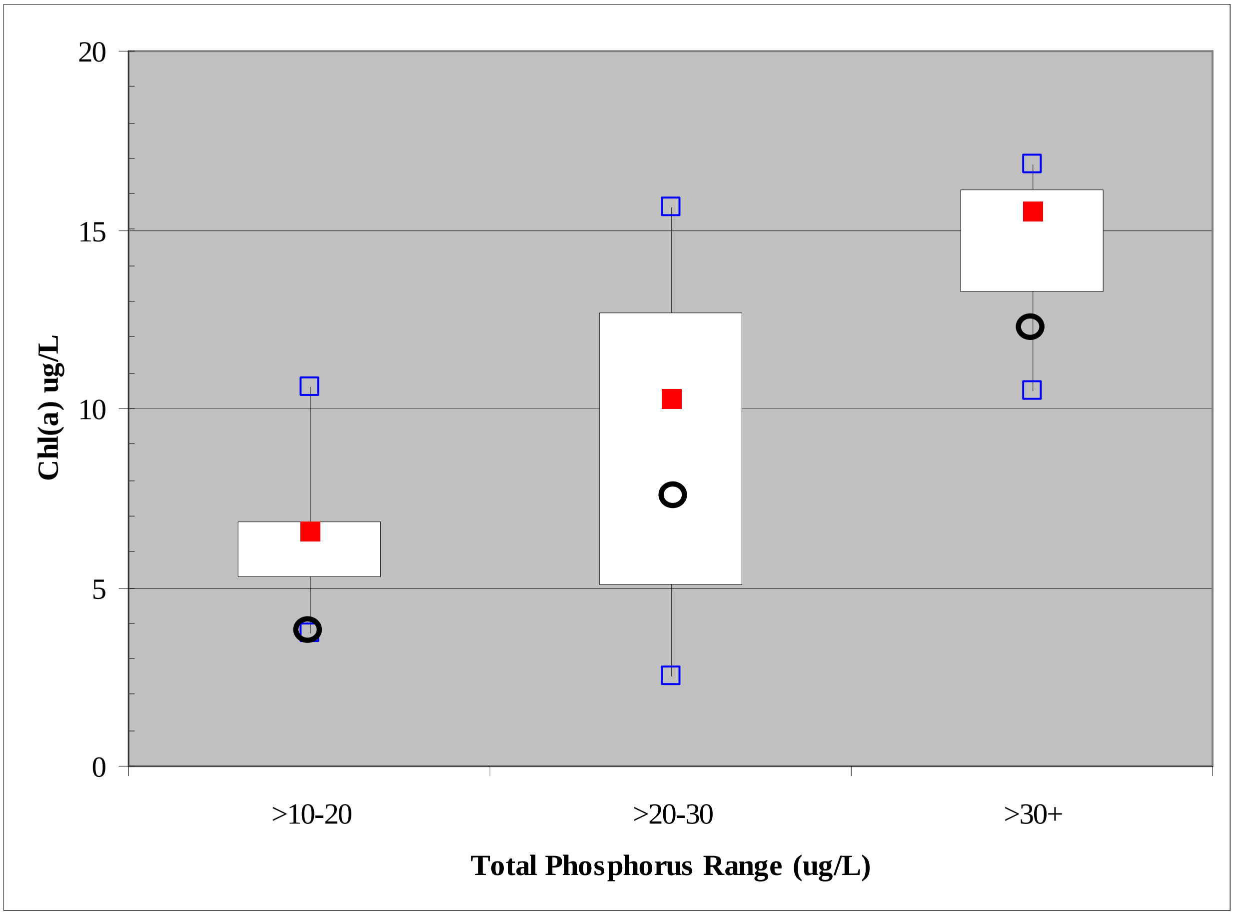

Figure 3. The relationship between TP and chlorophyll (a) concentrations observed for Newman Lake (1986-1992). (Circles are from Dillon and Rigler, 1974).

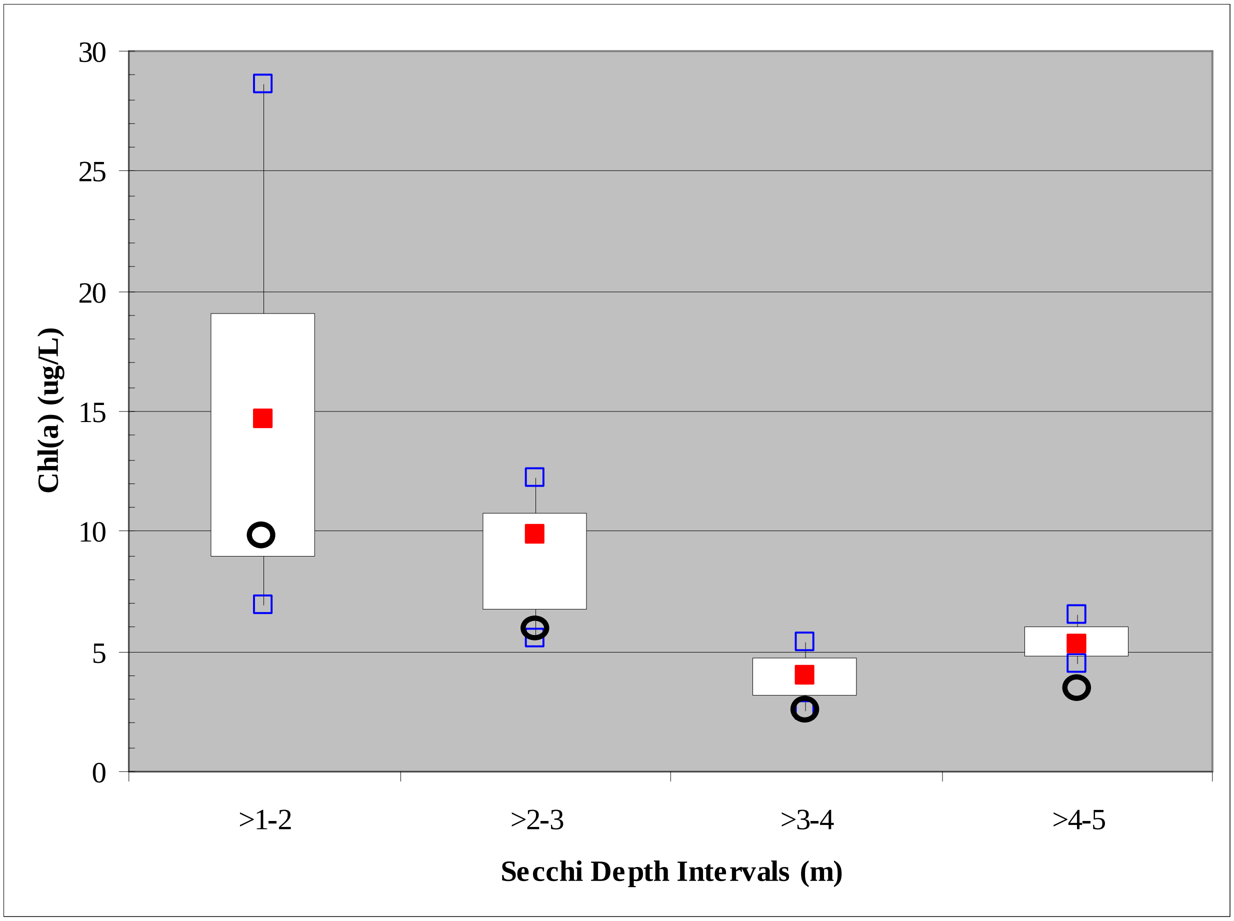

Figure 4. The relationship between Secchi depth and chlorophyll (a) concentrations observed in Newman Lake (1986-1992). (Circles are from Dillon and Rigler, 1974).

Water Quality and Resource Impairments

Lakes can be characterized by their level of biological productivity, or trophic state. A lake's natural level of productivity is determined by factors such as its geologic setting, watershed size and relief, bathymetric characteristics, climate, and the quantity and quality of the water entering and leaving the lake. Increases in a lake's productivity over time, known as eutrophication, is a natural process. However, for many lakes such as Newman Lake this process has been accelerated by human-related activities. Surface and groundwater inflow associated with non-point pollution sources, such as residential and commercial development and maintenance, are a few of the pathways present in the Newman Lake drainage area that contribute phosphorus either directly to the lake or to inflowing surface waters, ultimately increasing the lake's productivity.

Stratification, or the separation of the water column based on differences in temperature, is a process having a significant effect on the supply and distribution of total phosphorus in Newman Lake. For this reason, within this section of the report an overview of stratification will be presented followed by a discussion of its influence on total phosphorus dynamics.

The oxygenator is another major influence on Newman Lake's water quality. The oxygenator has operated since 1992 (at varying capacities), primarily between the months of April and September. The intended purpose of the oxygenator is to limit the release of phosphorus from sediments by maintaining higher dissolved oxygen concentrations at the bottom of the lake. Because of this influence, the effect that the oxygenator has on the lake's water quality was developed more fully. That analysis is contained in Appendix C. However, an overview of that work is also presented in this section.

Stratification - patterns to phosphorus enrichment and circulation

During the spring of each year, increased solar radiation levels selectively heat the upper water column of Newman Lake. Heat is primarily absorbed within the upper two-meters of the water column with greatly reduced heat transfer to the lower depths. The density of water (its weight per volume) is a function of temperature, with density decreasing with increases in temperature. For this reason, from May to September a warmer, less dense layer of the water column resides over a colder denser layer. This water column separation is known as stratification. The upper, warmer, and well-mixed layer is known as the epilimnion. The lower, colder layer is known as the hypolimnion. At peak stratification, in July, the epilimnion occupies the upper approximately three meters of the water column while the hypolimnion is situated from approximately six meters to the bottom (nine meters). Between three and six meters is the metalimnion, a transitional portion of the water column in terms of temperature and dissolved oxygen levels. This temperature gradient has a significant effect on the distribution of TP within the water column.

Within the epilimnion, dissolved oxygen concentrations are maintained through diffusion from surface air and primary production (photosynthesis). In contrast, the hypolimnion is isolated from the surface without a re-aeration pathway. Microbial decomposition of organic matter present within the sediments rapidly uses what available dissolved oxygen was present prior to the onset of stratification. Decomposition continues, though at a lower rate, without oxygen under anaerobic conditions. Because the hypolimnion is not in circulation with the surface, there is no mechanism to replenish dissolved oxygen levels. While stratification is a natural process, the rate in the decline of hypolimnetic dissolved oxygen is an indication of the level of organic enrichment of the sediments and, therefore, a measure of eutrophication.

Once dissolved oxygen levels decline below approximately 2 milligrams per liter (mg/L), phosphorus bound to sediment at higher dissolved oxygen levels is released into the water column in a dissolved state. This release of phosphorus is a process known as internal recycling. If a lake is strongly stratified and deep, phosphorus released from bottom sediments remains primarily within the hypolimnion. Lakes vulnerable to eutrophication, a condition characterized by elevated phosphorus levels and associated algae concentrations, are typically those with a shallow mean depth with higher organic content to the bottom sediments - conditions present within Newman Lake. In these types of lakes, there is a close proximity between high phosphorus concentrations in the hypolimnion (supply) and where algae grow (demand) within the euphotic zone. The mechanisms that move phosphorus from the hypolimnion to the epilimnion can occur through diffusion (movement from high to low concentration) and through water column mixing. Phosphorus introduction to the epilimnion through diffusion occurs at varying rates depending on the level of stratification. If stratification is strong, as indicated by a large temperature difference between the epilimnion and hypolimnion, the diffusion rate is low and phosphorus largely remains within the hypolimnion until the lake completely mixes in the fall (turnover). If stratification is weak, there is greater movement of phosphorus due to internal water column mixing. Mixing, or the disruption of stratification, can occur through a rapid loss of heat within the epilimnion associated with low pressure weather systems, high winds, or high surface water inflow levels. Within Newman Lake, the maximum release of dissolved phosphorus, from anaerobic sediments, occurs from mid-July until lake turnover.

By August, stratification begins to erode with decreasing solar radiation levels that result in surface cooling. When this occurs, the upper water column begins to mix to increasing depths as it gradually cools and becomes denser. This process is complete by mid-August to early-September with full lake turnover resulting in uniform temperatures throughout the water column (isothermal). As the upper water column begins to cool and mix to greater depths, it entrains water containing higher phosphorus levels situated within the lower water column. For this reason, phosphorus concentrations in the upper water column increase rapidly in September and October in comparison to levels observed during mid-summer. This will be further discussed in the section on Seasonal Variation.

Effect of oxygenator on lake water quality

A detailed analysis of the effect of the Speece Cone-type oxygenator on Newman Lake's water quality is contained in Appendix C. A synopsis of that analysis is discussed here. The analysis is based on temperature and dissolved oxygen profiles collected over 15 years during the stratification period. The data were collected both prior to and following the installation of the oxygenator in 1992. Changes in the temperature and dissolved oxygen levels as a consequence of the operation of the oxygenator indicate that it is causing unintended alterations to Newman Lake's water quality.

Differences in temperature and dissolved oxygen profiles collected prior to and following the operation of the oxygenator indicate that it is facilitating lower water column mixing. This is indicated in the rate and magnitude of temperature increases observed in the hypolimnion now in comparison to measurements made prior to its operation. Under current in-lake management, hypolimnion temperatures are greater and isothermal (uniform) with the rate of heat gained tied closely to the trend in epilimnion temperatures. It is believed that the hypolimnion gains heat from the upper water column through convection, or mixing.

At a design inflow rate of 21 cubic feet per second (cfs), the oxygenator pumps the entire volume of the lower 1.5 meters of the water column every 11 days. This level of disturbance is great enough to cause lower water column mixing and the transfer of heat to the hypolimnion. Increased hypolimnion heating has led to reduced water column stability resulting in an increased frequency of mixing events and, ultimately, to early lake turnover.

The oxygenator's influence on water column mixing is related to the level of spring surface water inflow. Two general patterns were identified, occurring most prominently at high and low spring inflow levels. Colder surface inflow during spring, primarily from Thompson Creek, being denser than the lake water, descends to the lowest portion of the water column. Years with higher spring inflow (related to the snow-pack level, the source of the inflow) maintain colder hypolimnion temperatures during the summer months. A colder hypolimnion results in a greater temperature difference between the surface and bottom resulting in a stronger level of stratification during the summer months (June-August).

Years with high spring inflow maintain a reservoir of colder water within the hypolimnion. During these years, while the oxygenator-induced mixing continues, the colder hypolimnion temperatures result in a stronger level of stratification. With stratification in place, dissolved oxygen concentrations plunge to anoxic conditions indicating no measurable effect of the oxygenator at maintaining dissolved oxygen concentrations in the hypolimnion. The sediment oxygen demand exceeds the level of oxygen supplied by the oxygenator. Recent examples of this scenario occurred in 1997, 1998, 1999, 2000, 2002, 2003, and 2006.

Years with low spring inflow have a reduced volume of cold water within the hypolimnion. Lower water column mixing results in the hypolimnion reaching higher temperatures sooner, resulting in an unstable water column. During these years, the dissolved oxygen levels in the hypolimnion appear to be maintained through disturbance as water high in dissolved oxygen in the upper water column is circulated with the lower water column. Recent examples of this scenario occurred in 2001, 2004, and 2005.

Given these patterns, it appears that the oxygenator is only able to maintain design (2 milligrams per liter [mg/L]) oxygen levels within the hypolimnion through water column disturbance. The ability of the oxygenator to facilitate water column disturbance, or mixing, is related to the rate of gain in heat within the hypolimnion which, in turn, is largely a function of the level of spring inflow. During high spring inflow years, the hypolimnion has a lower rate of heat gain than low spring inflow years. Less energy is required to facilitate water column mixing, the warmer the hypolimnion becomes. During low spring inflow years the water column is characterized by frequent mixing events; the upper water column is circulated with the lower water column, bringing with it higher dissolved oxygen concentrations.

During high inflow years, while the rate of heat gain in the hypolimnion is significantly greater than occurred prior to the oxygenator, stratification is still strong enough to limit the frequency and intensity of upper to lower water column mixing. During these years, the hypolimnion is largely anoxic, despite the operation of the oxygenator, indicating it does not deliver enough dissolved oxygen to overcome the sediment oxygen demand.

Seasonal Variation

Lake total phosphorus concentrations

June through August is a critical period for evaluating the trophic conditions of lakes in this region because environmental conditions supporting primary productivity are at their peak. The level of primary productivity is based on the amount and type of algae present. Both are indicators of the availability of nutrients, particularly phosphorus. Depending on its level of availability, phosphorus can stimulate the rapid growth of algae (phytoplankton) leading to "blooms." Lakes with chronically elevated levels of phosphorus tend to have a reduced diversity of phytoplankton dominated by cyano-bacteria or blue-green algae.

Monthly variation

Phosphorus concentrations observed in Newman Lake follow a seasonal pattern. As discussed previously, one of the major influences affecting the seasonal changes in phosphorus concentrations is stratification, or the division of the water column into distinct zones based on temperature. Stratification occurs due to the selective absorption of solar radiation within the upper 2-3 meters of the water column (epilimnion) with minimal heat transfer to the deepest portions of the water column (hypolimnion). Stratification is typically in place from May through September. However, until mid-June the water column remains weakly stratified and is vulnerable to whole water column mixing in response to disturbance factors such as low pressure systems and associated wind and cold air. Also, as previously discussed, the oxygenator has an additional significant influence on Newman Lake's stratification. Because of these varied influences, this discussion presents an average condition, recognizing that the annual variation of phosphorus in response to these influences can be great.

Once stratification begins and a hypolimnion forms, dissolved oxygen in the lower depths of the lake is rapidly consumed by microbial activity in the bottom sediments. As dissolved oxygen concentrations decline to minimal levels phosphorus, typically adsorbed to sediment under aerobic conditions, is released into the water column. This phosphorus is in a dissolved form that can be readily utilized by algae for growth.

The release of phosphorus from sediments within the hypolimnion (8 meters) can be observed in Figure 5. Beginning in June with the onset of stratification, TP concentrations begin to increase and separate from the levels observed at the surface and 4-meters. Phosphorus release continues through the stratification period though concentrations typically peak in July at about 50 ug/L. July is the period of peak stratification indicated by the largest difference in temperature between the epilimnion and the hypolimnion. With reduced solar radiation levels by August, the surface begins to cool, increasing in density, and mix to greater depths. With increased water column mixing, waters with higher TP concentrations (hypolimnion) are diluted with waters of lower TP concentrations (epilimnion). When this occurs, TP concentrations within the hypolimnion decline while concentrations within the epilimnion and metalimnion increase. TP concentrations at the surface and 4-meters increase in September due to this increased mixing. Prior to the oxygenator, full water column mixing (fall turnover) typically occurred in September. Now, with increased hypolimnion temperatures associated with lower water column mixing, lake turnover occurs sooner typically by mid-August. When full water column mixing occurs phosphorus levels throughout the water column are uniform.

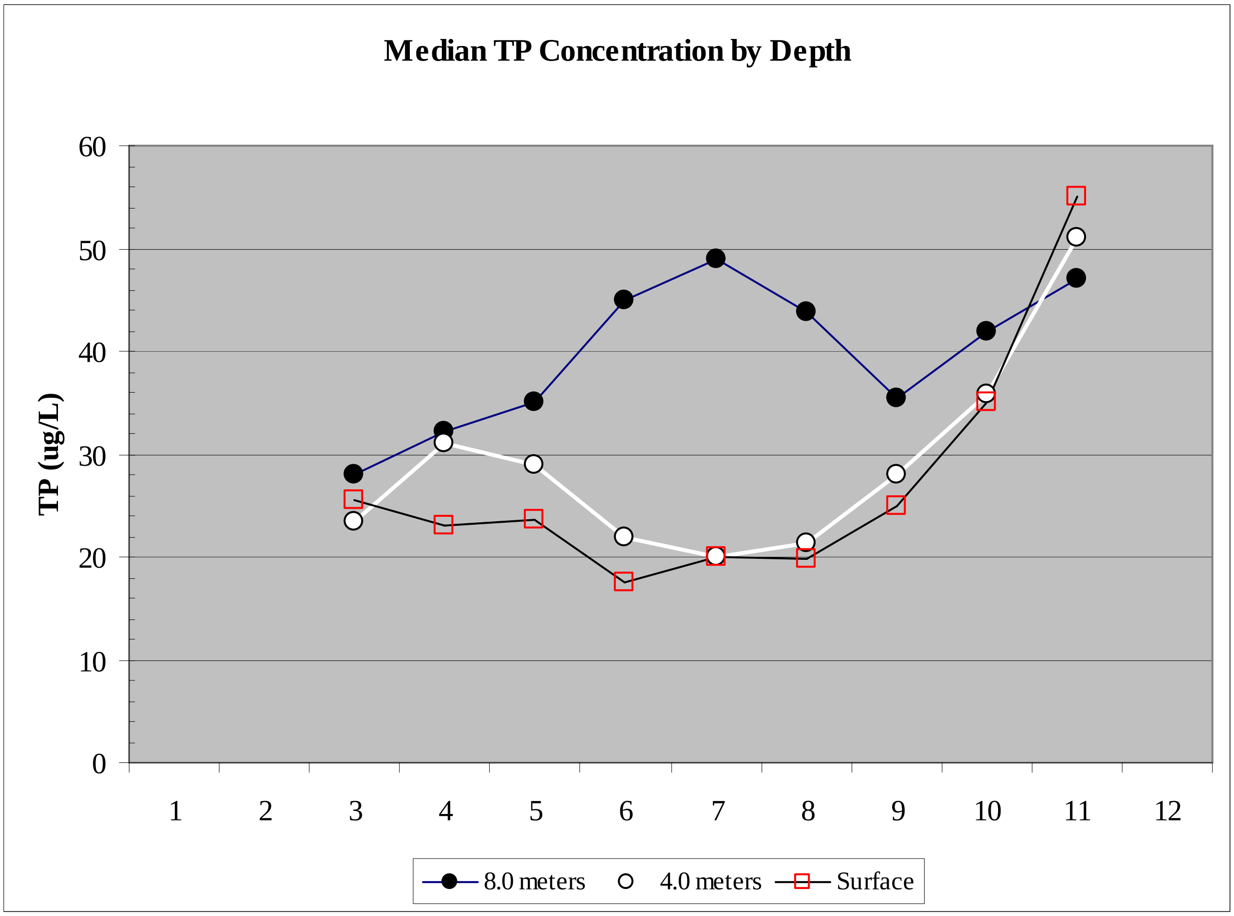

Figure 5. Median TP concentrations (ug/L) observed at the three monitoring depths at the mid-lake station for the period of record (excludes data not meeting quality screen. Refer to Appendix B.)

While TP concentrations in the hypolimnion increase, following the onset of stratification, concentrations within the epilimnion typically decrease. The lowest TP concentrations observed in Newman Lake occur during the June through August period at about 20 ug/L. This indicates that phosphorus released from sediments within the hypolimnion usually remain there until lake turnover. That the lowest TP concentrations occur at the surface and at four meters in the summer indicates the importance of external phosphorus sources in influencing lake concentrations.

Water column mixing can occur during the stratification period bringing phosphorus-rich water within the lower water column to the surface. This is usually associated with weather systems that bring a high level of disturbance (i.e., wind, elevated precipitation, cold air). These types of weather-related disturbances can cause water column mixing resulting in algae blooms. However, they are not common. Instead, surface TP concentrations are at their lowest level during the summer period as external loading (inflow) is at its lowest level and phosphorus released from sediments remains primarily within the hypolimnion.

Secchi disk - transparency

Average monthly Secchi disk readings, observed for the full dataset, are presented in Figure 6. From the data record, the majority of Secchi measurements have been collected April though October. Considering this period, average monthly readings are 2.1 meters with the greatest readings occurring in July at 2.6 meters. As discussed above, July is when total phosphorus levels are at their lowest during the year which, in turn, limits algal growth and increasing water clarity. The summer period, June through August, has among the highest transparency levels during the year. Following the July peak, transparency levels begin to decline, the result of increased water column mixing. As the surface layer begins to cool, and mix to greater depths, it entrains water with higher phosphorus concentrations stimulating phytoplankton growth which, in turn, reduces transparency.

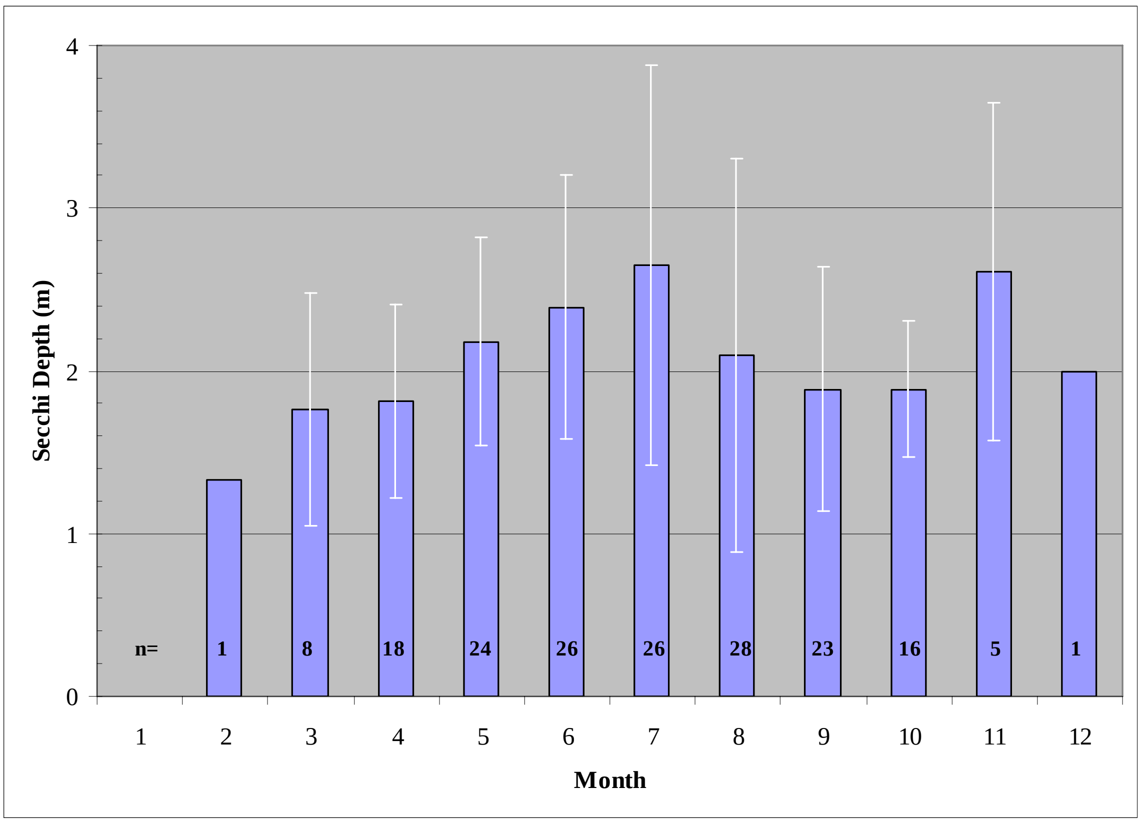

Figure 6. Average monthly Secchi readings along with the associated standard deviation. (n refers to the number of samples collected.)

Average summer period (June through August) Secchi disk readings are presented in Figure 7. Readings range from 3.6 meters in 1990 (a whole lake alum treatment was conducted in the fall of 1989) to 1.1 meters in 2000. The average summer Secchi level since 1992 is 2.0 meters, varying from the low of 1.1 meters in 2000 to 2.6 meters in 2001.

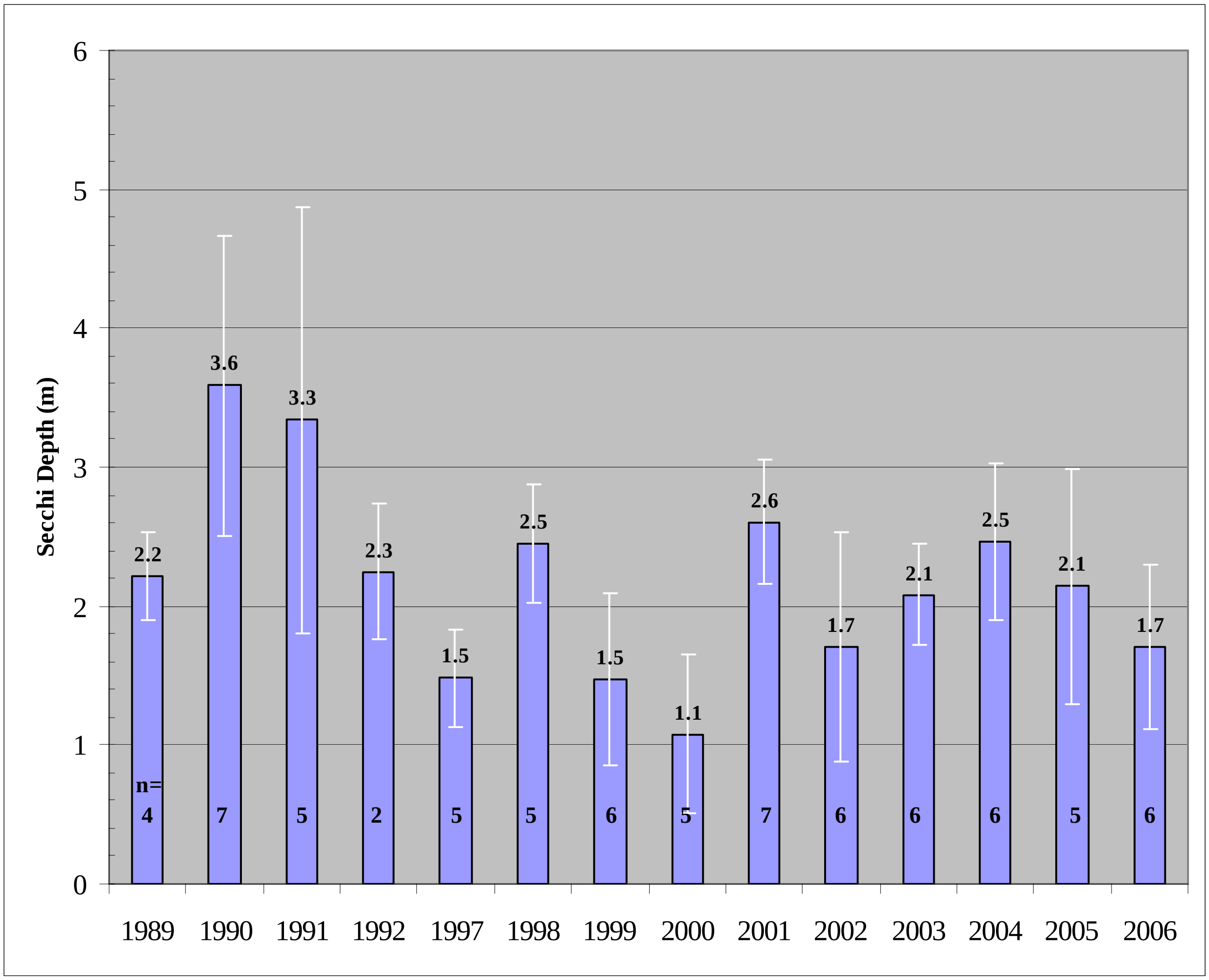

Figure 7. Average summer period (June-August) Secchi measurements by year along with the associated standard deviation. (n refers to the number of samples collected.)

Technical Analysis

Among the major objectives of this analysis is to identify and quantify the major TP sources to Newman Lake. Through this process, a phosphorus budget is constructed examining the various pathways phosphorus is gained and lost from the lake over time. The budget allows an examination of what pathways contribute a disproportionately high level of phosphorus to the lake. The budget also provides critical information for establishing the load capacity and load allocations, primary objectives of the TMDL analysis.

In this process, the first analysis step was to determine the level of inflow to the lake. The analysis period used in this study is 1985 to 2006. Sources of inflow include precipitation falling directly on the lake and surface water and groundwater inflow. Once inflow levels were defined, the TP concentrations associated with those inflows were examined. With an understanding of flow and concentration a load, or the mass of TP over time, can be calculated. The TP load is determined by multiplying the concentration of phosphorus observed in the water by the level of flow measured at the time the water sample was collected. In this study, the load is in units of kilograms (kg) of total phosphorus (TP) over time, typically by month or year. The calculation of loads is fundamental to the TMDL analysis.

TP sources to Newman Lake can be divided into two categories: those internal to the lake, primarily through the release of TP from sediments under anaerobic conditions, and those external to the lake such as TP present within surface water inflow. The external sources considered as part of this analysis include precipitation, surface water inflow, and on-site wastewater systems. The external TP loads were calculated on a monthly and annual basis from 1985 through 2006.

Based on an analysis of land use within the Newman Lake watershed, the primary source of TP to groundwater is residential on-site wastewater systems. For this reason, the influence of groundwater inflow on lake TP concentrations focused solely on the TP load associated with on-site systems. As will be discussed in the section on the report concerning the water budget, Newman Lake is a net exporter of groundwater; more groundwater leaves the lake than enters it.

Within this section of the report, initially the calculation of inflow levels associated with external sources will be discussed followed by the determination of TP concentrations associated with those inflows. The flows and associated total phosphorus concentrations were used to calculate loads entering the lake. The total phosphorus load estimations were used as input to a lake model. The model was used to better understand the link between variations in external TP loads and lake concentrations. The model also allowed the examination of how reductions in TP, from specific sources, affect in-lake TP concentrations. This, in turn, allowed the determination of the load capacity and source allocations.

Inflow

Thompson Creek

Measurements of discharge, collected between 1971 and 2006 (n=104), were compared with the daily average flow levels recorded at a nearby United States Geologic Survey (USGS) flow gauging station (12431000) located on the Little Spokane River at Dartford (Figure 8). The Little Spokane River watershed, while substantially larger than that of Thompson Creek, shares a similar geologic setting and, therefore, runoff characteristics. In addition, the USGS has maintained discharge monitoring at the Little Spokane River station since 1929 providing a substantial data record. As observed there is a close relationship between the daily average discharge at the Little Spokane River station and the instantaneous measurements taken at Thompson Creek (Figure 8). This relationship was used to estimate the daily average discharge for Thompson Creek for the analysis period, 1985 to 2006.

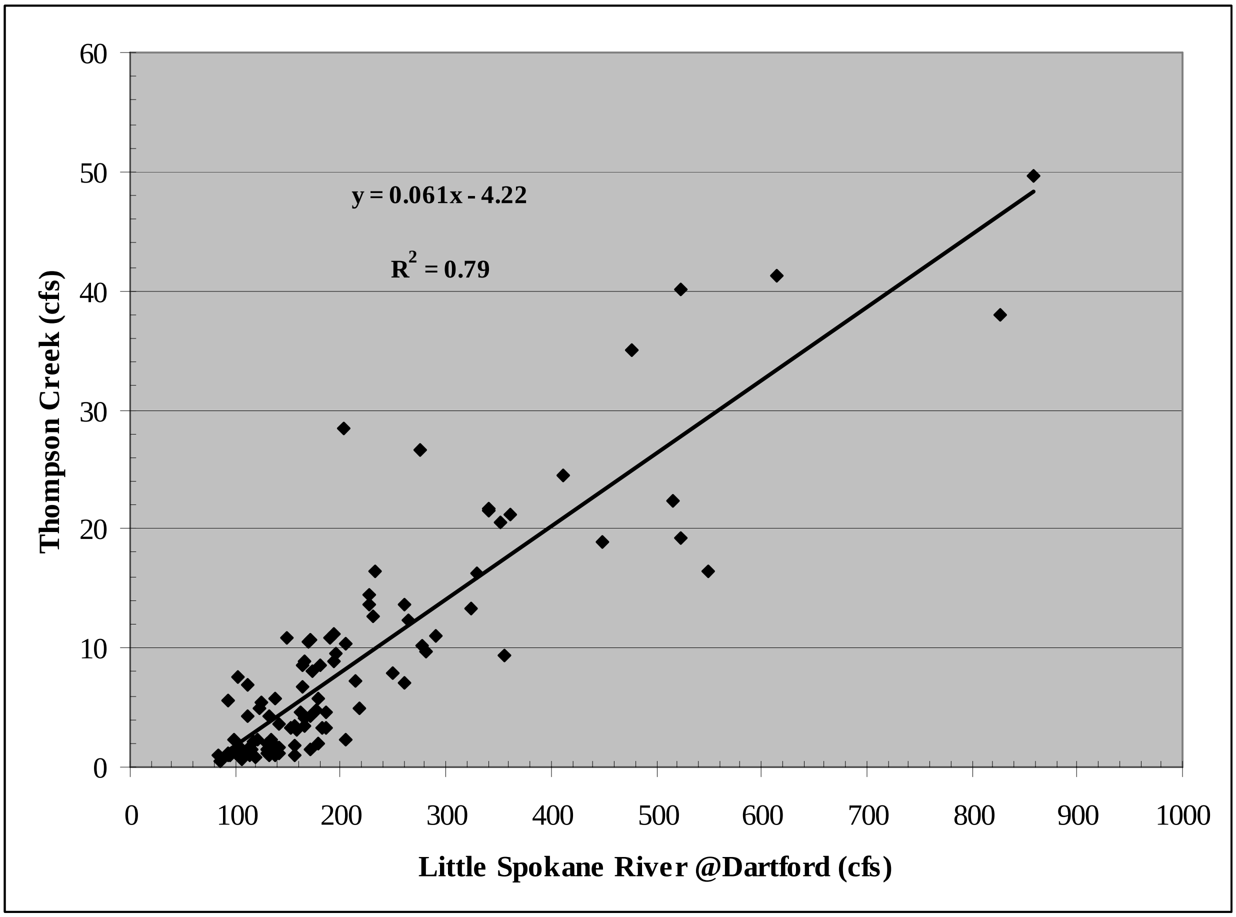

Figure 8. The relationship between the daily average flow recorded at the Little Spokane River at Dartford and that measured at Thompson Creek.

Based on the estimated daily average flow record, average monthly flows for Thompson Creek were determined (Figure 9). Monthly flow levels follow a distinct pattern. During the year, the highest average flows occur from March through May, associated with spring snow-melt. March has the highest average flow level at about 33 cubic feet per second (cfs). Annually, over 50 percent of the inflow occurs between March and May. (Worth mentioning here, and it will be discussed later, is that the magnitude of the spring inflow has a significant effect on the summer TP concentrations observed in Newman Lake.) From the March-April peak, flows decline steeply through June, with the lowest average flows occurring in August and September at 3 cfs.

On an annual basis from 1985 to 2006, the average inflow from Thompson Creek is 11,306,949 m^3 (Figure 10). There is high variability in annual inflow levels. Much of the variability is related to the level of winter snow-pack accumulation. From this period, the lowest annual inflows occurred in 1992 and 1994 at 4,256,018 m^3. From 1985 to 1994 the annual variability was low in comparison to 1995 to 2003. In 1997, inflows peaked at 31,245,561 m^3. Since then, the trend in the annual flow levels show a decline, though unsteady, back to more normal levels.

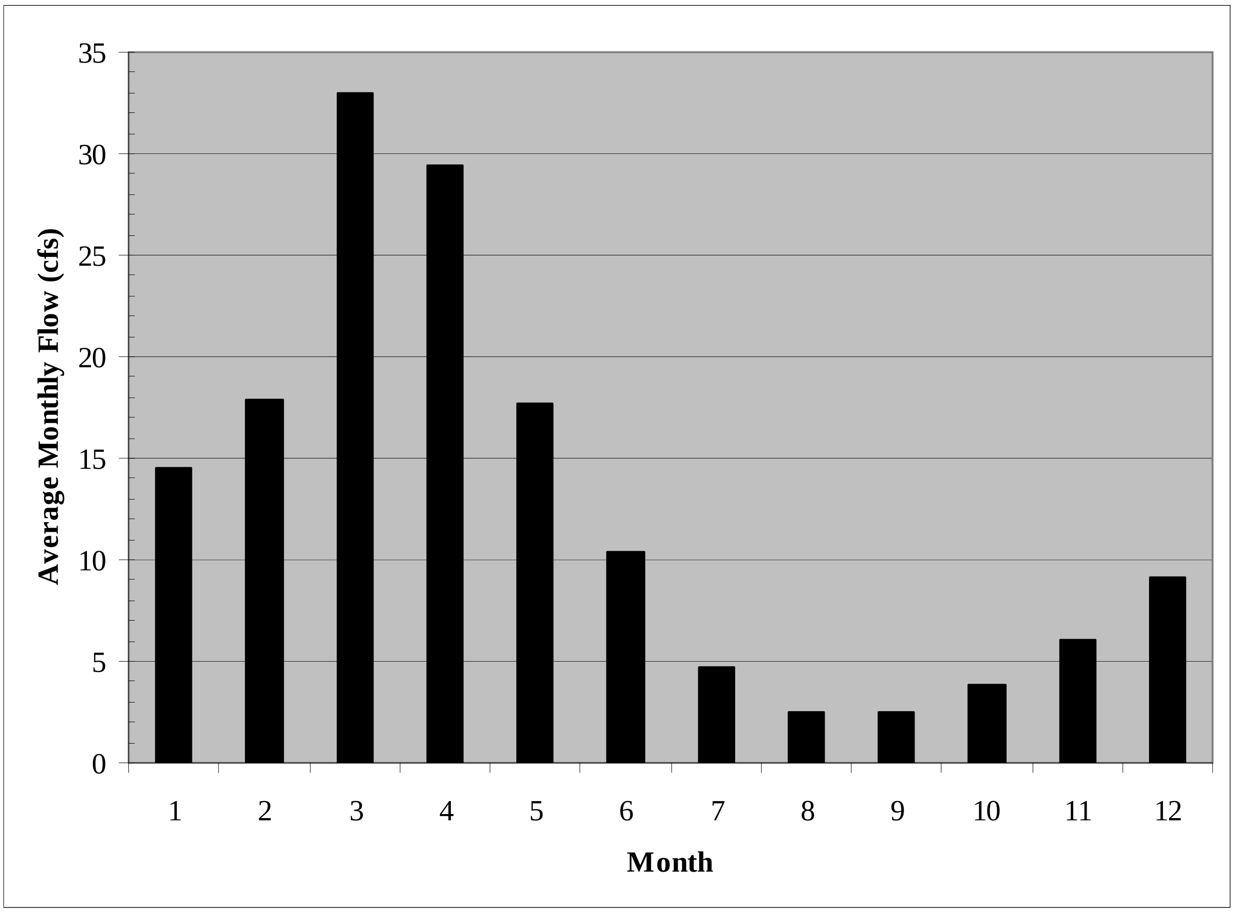

Figure 9. Thompson Creek median monthly flow levels (cubic feet per second) estimated from 1985-2006.

Watershed drainage

Watershed drainage in this report is defined as all surface water draining to Newman Lake outside of the Thompson Creek drainage. Historically, flow measurements have been collected at seven surface water inflow points surrounding the lake. These locations, known in previous reports as inlet stations, are indicated in Figures 1 and 2. Monthly flow estimates were determined for each of these drainages from July 1989 through December 1990 (Funk et al, 1998), providing the most regular flow monitoring information for these locations. To determine monthly average inflow levels from these tributary streams for the study period, the following methods were used.

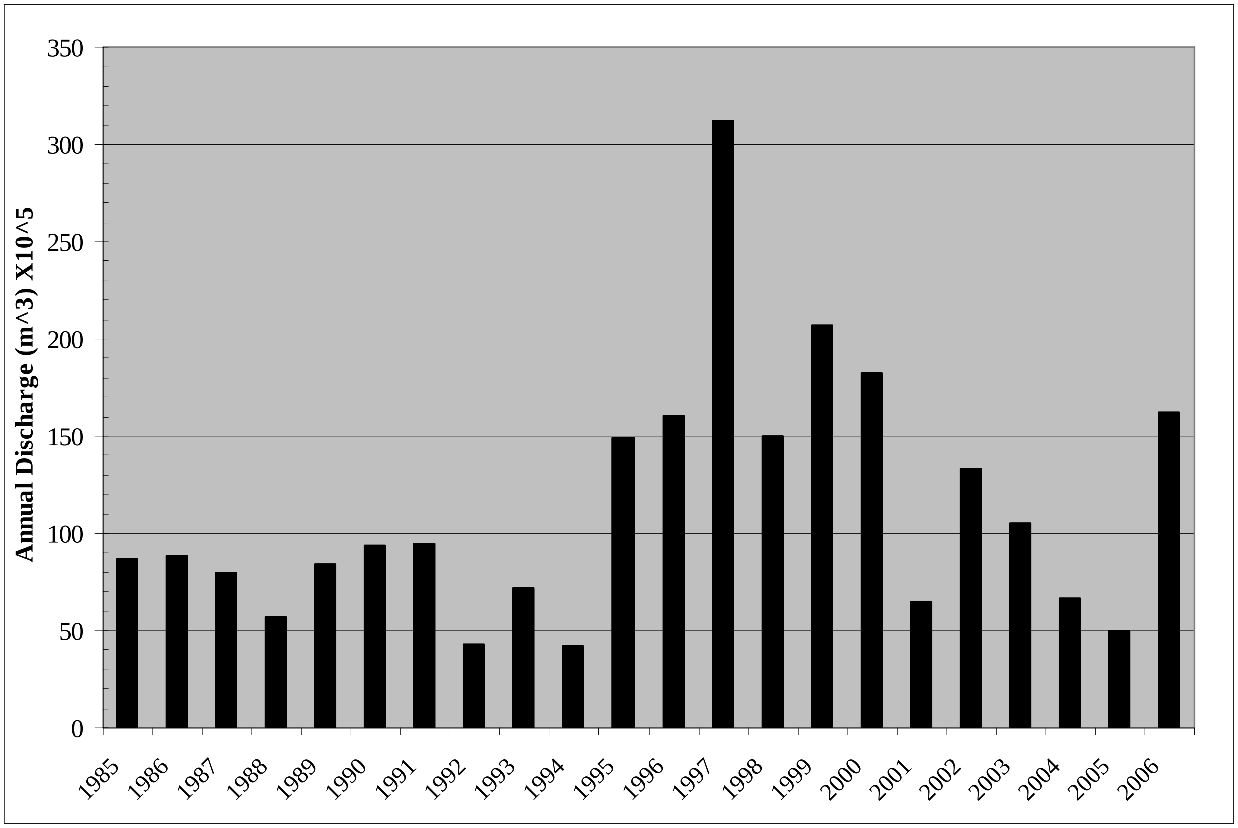

Figure 10. Annual discharge total (m^3/year *10^5) estimated for Thompson Creek (1985-2006).

The sum of the average monthly inflow levels measured for inlets 1 and 6-10 were determined for 1990. (Inlet 3 was excluded because it, at times, receives inflow from Thompson Creek.) It was assumed that the monthly variation in tributary inflow levels is directly proportional to the monthly variation in Thompson Creek flows. A ratio of average monthly flow levels, estimated for Thompson Creek from 1985 to 2006, were set relative to monthly levels observed in 1990. For instance, the April 1985 flow level estimated for Thompson Creek was 1.81 times greater than that observed in April 1990. Therefore, the average combined monthly flow level for inlets 1, 6-10 for April 1985 was estimated by multiplying the combined April 1990 inflow by 1.81. Each monthly inflow estimate was linked to its respective monthly 1990 flow level. This method provided an estimate of monthly tributary inflows from 1985 to 2006. Because this assessment of inflow was only for the monitored tributaries, flows were then scaled to the larger watershed. Inlets 1, 6-10 encompass 2404 hectares of the 4728 hectares that drain to Newman Lake, outside of the Thompson Creek drainage. For this reason, the combined monthly flows were multiplied by 1.97 to estimate the total watershed inflow.

Precipitation / atmospheric deposition

Monthly precipitation levels have been recorded by lake residents at about ten locations on the lake since 2003. From this data set median monthly totals were determined. To construct a record going back as far as 1985 (the beginning of the analysis period), the median monthly totals observed at Newman Lake were compared with monthly averages recorded at the National Weather Service station located at the Spokane International Airport. This weather station is located approximately 37 kilometers southwest of Newman Lake. In addition, monthly precipitation measurements collected during a prior lake study in 1974-5 (Copp, 1976) were also compared to the respective airport measurements. Both comparisons are included in Figure 11. Monthly precipitation levels observed at the lake are about 50 percent greater, on average, than observed at the Spokane Airport. This level of increase was consistent for both analysis periods.

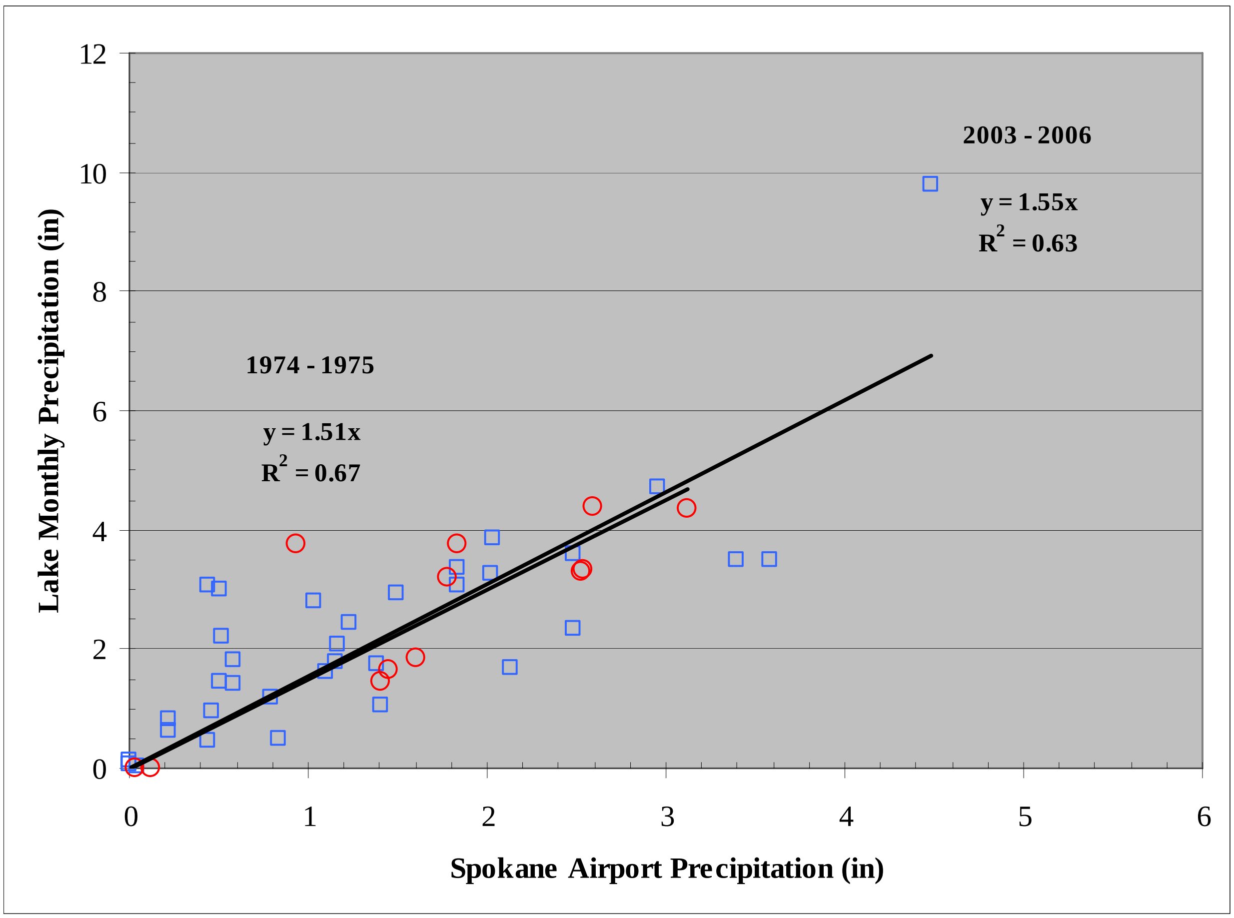

Figure 11. Comparison between monthly precipitation totals collected at Newman Lake and at the Spokane Airport, 1974-5 (circles) and 2003-6 (squares).

For this reason, monthly precipitation levels observed at the Spokane Airport from 1985 to 2006 were multiplied by a factor of 1.55 (factor determined for most recent dataset). To determine the direct inflow volume to the lake these monthly precipitation levels were multiplied by the surface area of the lake (515 hectares).

Groundwater

Groundwater inflow is not considered to be substantial in the Newman Lake watershed. This is because bedrock levels surrounding the lake are shallow, typically less than 2.5 feet below land surface (USDA, 1968). Not only is there shallow bedrock, but the overlying soils have low permeability. The geologic characteristics found in the near shore also apply to the greater watershed - there are not the geologic characteristics present that allow aquifer formation. The lack of groundwater storage within the watershed is evident in the variation of surface water flows observed in Thompson Creek. Despite its size of 3,132 hectares (12 square miles) and winter snow-pack, average flow levels during August and September are typically less than three cubic feet per second (refer to Figure 9). In addition, most of the inlet stations that drain the watershed outside of Thompson Creek are usually dry by June and remain that way until late fall. Average monthly inflow estimates for watershed drainage during August and September are typically less than 1 cfs despite its 4,728 hectare size. Another indication of the lack of available groundwater storage is the rapid increase and decline in surface runoff levels associated with precipitation events. For these reasons, as it will be discussed in the water budget section of the report, Newman Lake is a net exporter of groundwater.

Inflow overview

Figure 12 includes the percent representation of the average estimates of inflow to Newman Lake, 1985 to 2006. Of the sources, Thompson Creek provides almost half (49 percent) of the total inflow while watershed drainage (36 percent) and precipitation (15 percent) comprise lower levels. The water yield for Thompson Creek is approximately 0.4 m^3/m^2-yr while, in comparison, the yield for the greater watershed is half at 0.2 m^3/m^2-yr. The greater yield for Thompson Creek is associated with greater precipitation levels occurring within its upper elevations.

Based on the average annual inflow level (25,749,593 m^3/yr), the retention period for Newman Lake is approximately 1.2 years. The retention period is the amount of time for the volume of the lake to be replaced by inflow and is determined by dividing the lake volume (26,146,829 m^3) by the average annual inflow level (25,749,593 m^3/yr). Watershed characteristics are major determinants of the lake's retention time. Newman Lake has a large watershed size relative to its surface area and volume. For Thompson Creek, the magnitude of the annual inflow is closely tied to the level of snow-pack. For this reason, the majority of the inflow occurs within a relatively short period associated with the period of spring melt. Because of the close association between snow-pack and spring inflow levels, annual variations can be substantial. Over the analysis period, the retention time varied between 2.1 years in 1994 to 0.42 years in 1997. In other words, in 1997 the entire lake volume was replaced 2.4 times while in a more typical year the entire volume is replaced.

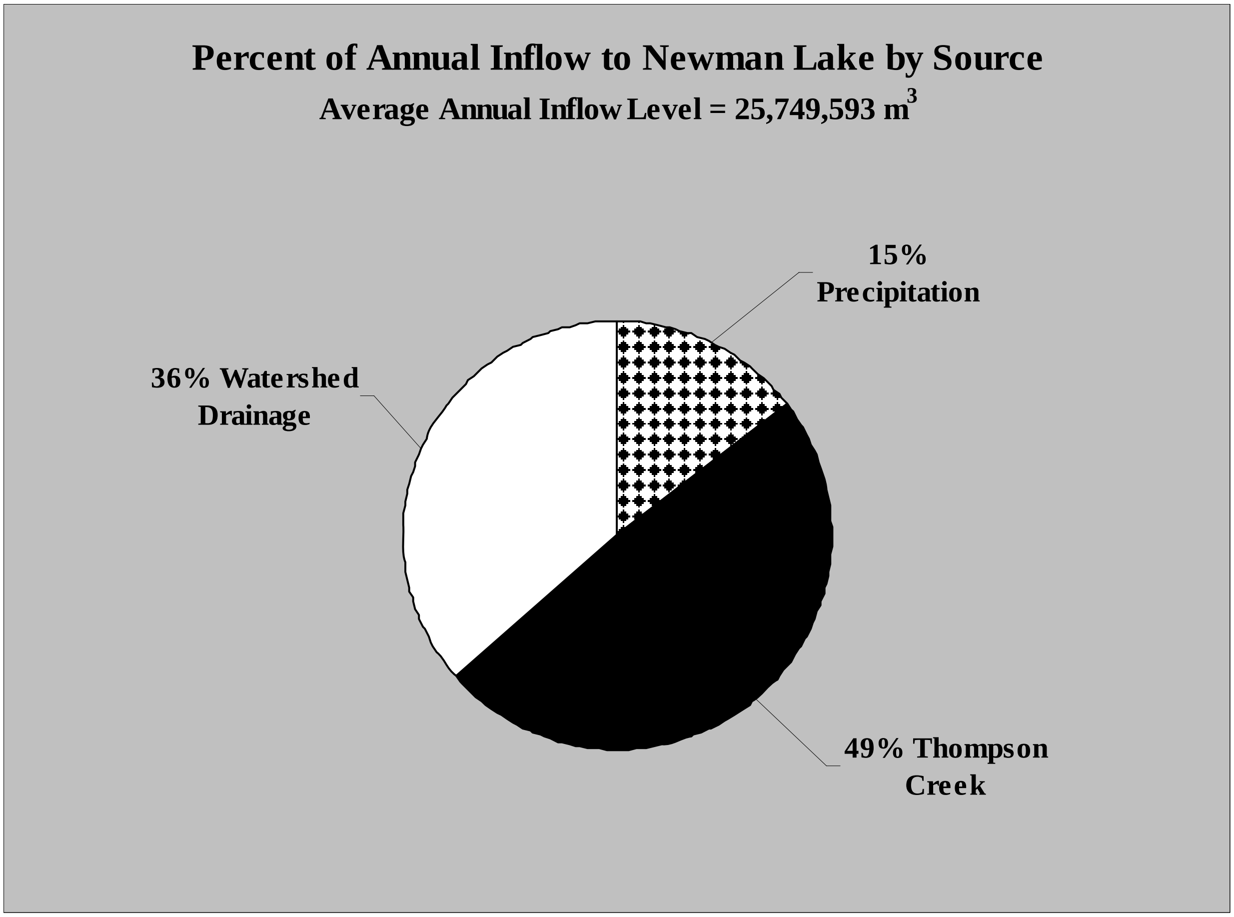

Figure 12. Percent of the average annual inflow to Newman Lake 1985-2006 by source.

Water budget

A water budget, or an accounting of the rate of inflows and outflows and their combined effect on the lake volume, was calculated for Newman Lake from 1997 to 2006. The determination of a water budget prior to 1997 is limited by the availability of surface outflow measurements. The water budget was calculated on a monthly time-step based on the following equation:

$$\textit{Change } (\Delta) \textit{ in Lake Volume} = \textit{Inflows} - \textit{Outflows} \quad (m^3/\textit{month})$$

From the equation, if more water leaves the lake than enters it, there is a loss in lake volume (the change in lake volume is negative) and in turn, if more water enters the lake than leaves, there is a gain in volume (the change in volume is positive).

Inflows include surface water runoff, direct precipitation to the surface of the lake, and groundwater. Outflows include surface outflow through the flow control structure located at the south end of the lake, evaporation, and groundwater. The change in lake volume is estimated by the relationship between water surface elevation (depth) and volume.

Most of the various pathways that water enters and exits the lake can be measured directly. For instance, surface water inflow can be measured with a flow meter; precipitation can be measured with a rain gauge; and the change in lake volume can be estimated through the recording of lake surface elevations over time. However, groundwater is difficult to measure directly and even if an attempt of measuring is undertaken its accuracy is low. For these reasons, the water budget equation is typically solved for groundwater; it is the unknown variable in the equation. Within the period of analysis (month), groundwater can simultaneously be entering and leaving the lake.

$$\Delta \mathit{Volume}\ (m^3) = (\mathit{Inflow}_{surface\ water} + \mathit{Precipitation} + \mathit{Groundwater}) - (\mathit{Outflow}_{surface\ water} + \mathit{Evaporation} + \mathit{Groundwater})$$

Solving for the amount of groundwater flow, equation becomes:

$$(+/-\mathit{Groundwater}) = \Delta\ \mathit{Volume} - (\mathit{Inflow}_{surface\ water} + \mathit{Precipitation}) + (\mathit{Outflow}_{surface\ water} + \mathit{Evaporation})$$

When the water budget equation is solved for the groundwater component, only a net change is calculated; either groundwater is entering the lake or leaving within the monthly analysis period.

Through this process, a monthly water budget was calculated from May 1997 through December 2006. The results are included in Appendix D. Within this section, the average flow and volume levels observed over years with a full data record (1998, 2000-02, 2004-06) are presented in order to gain an overall understanding of the general pattern in the movement of water and its effect on lake volume.

Lake stage and volume

Lake water surface elevation and, therefore, volume is managed by the Newman Lake Flood Control Zone District. Water surface elevations are manipulated through control of outflow levels. Through this management, the water surface elevation follows a fairly consistent annual pattern. Maximum water surface elevations occur late-May to early-June with minimum elevations tending to occur December through March, drawn down to accommodate the spring inflow. With annual maximum elevations averaging 25.6 feet and minimum levels averaging 23.8 feet, the lake has a variation in stage of about 2 feet (Figure 13).

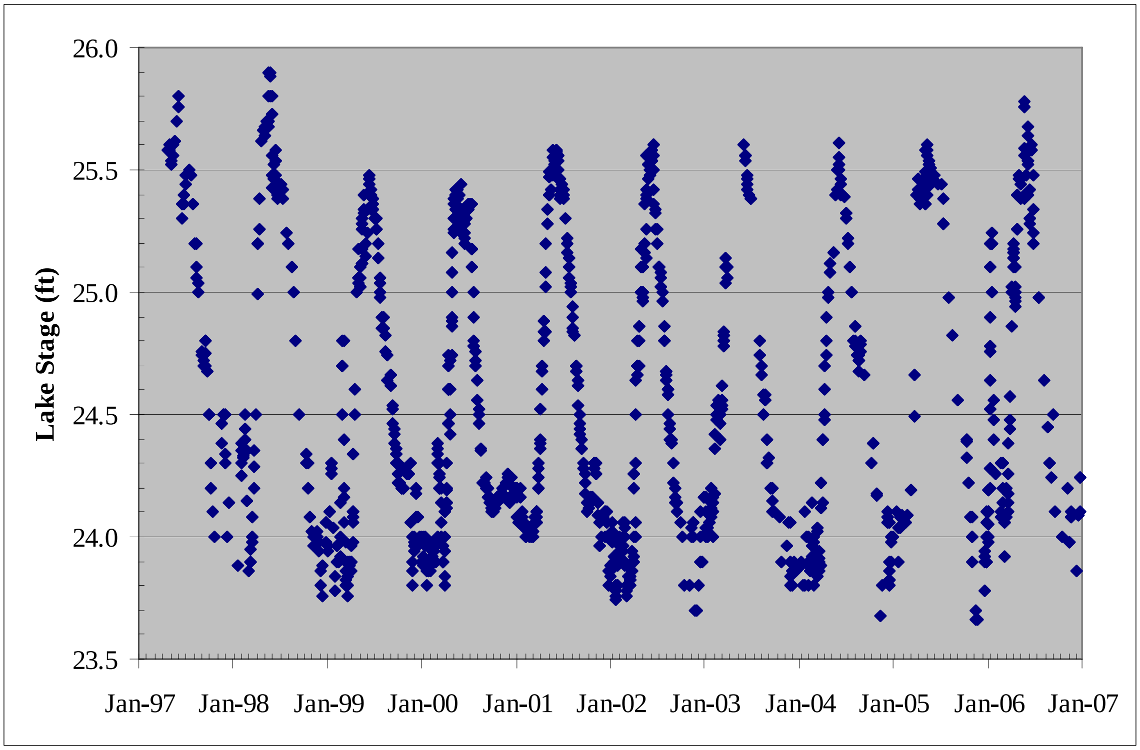

Figure 13. Change in lake stage 1997-2006 (in feet - add 2100' to determine relative elevation).

The average monthly change in lake volume is presented in Figure 14. Evident from Figure 14, the greatest increase in the lake volume occurs March through May associated with storage of spring snowmelt. However, by June the lake volume begins to decline which, over the analysis period, tends to continue until December with a major increasing trend not occurring again until the following March. Declining lake volume indicates that water losses through surface and groundwater flow and evaporation exceed the levels of inflow from precipitation, surface and groundwater inflow.

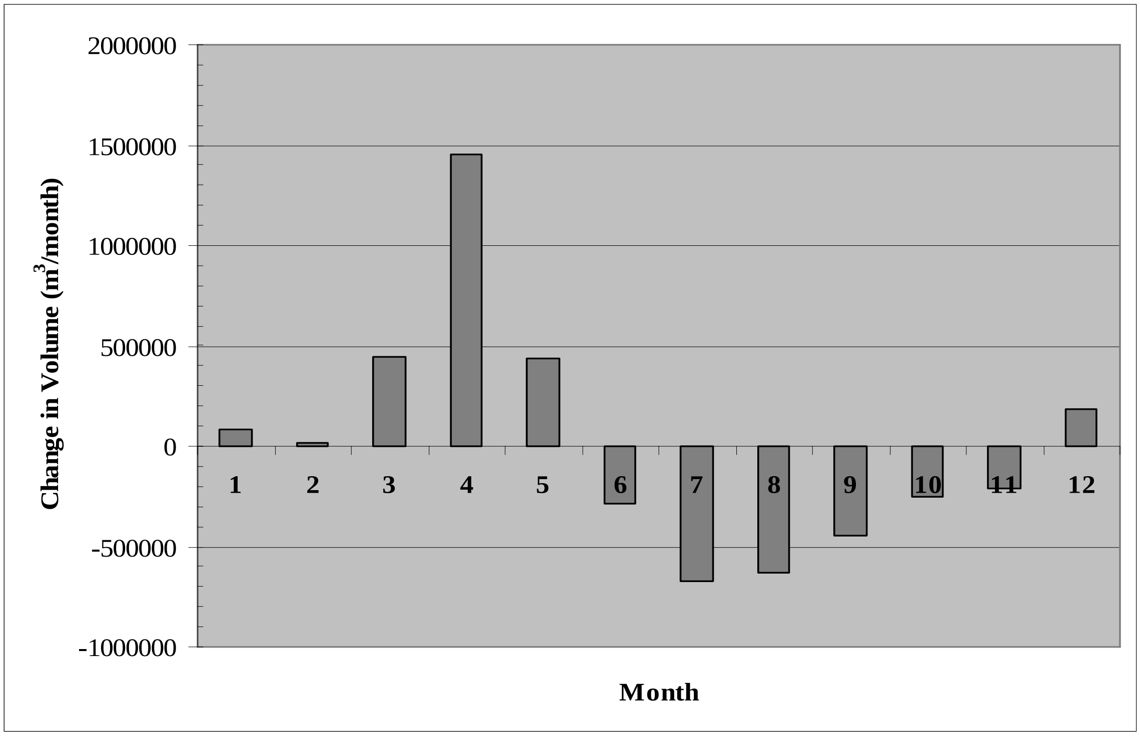

Figure 14. The average change in lake volume (m^3) by month, 1998, 2000-02, 2004-06.

Surface water inflow and outflow

About 60 percent of the annual surface water inflow to Newman Lake occurs between March and May primarily driven by melting snow-pack. Inflow peaks during March and April at approximately 4,450,000 m^3(Figure 15). Minimum inflow levels occur August and September at around 221,000 m^3, about 95 percent lower than observed during peak months. The low level of summer surface water flow indicates the low level of groundwater storage present within the watershed.

On average, about 20 percent of the March-May total inflow is captured to maintain summer lake levels. Annually, of all the inflow sources, surface water contributes approximately 85 percent of the total.

Lake surface water outflow occurs through a control structure situated at the lake's south end (refer to Figure 1) maintained by the Newman Lake Flood Zone District. Outflow is controlled through two, four-foot wide submerged gates and, since May 1997, gate opening levels have been recorded. Based on the gate openings and the difference in water surface elevations between the lake and directly below the structure, discharge can be calculated using the following equation:

$$Q = C_d(A)(2gH)^{0.5}$$

Q – discharge (ft^3/s)
C_d – coefficient of discharge (0.65)
A – orifice opening (ft^2)
g – gravitational acceleration (32.2 ft/s^2)
H – head, difference in surface water elevation between lake and outlet (ft)

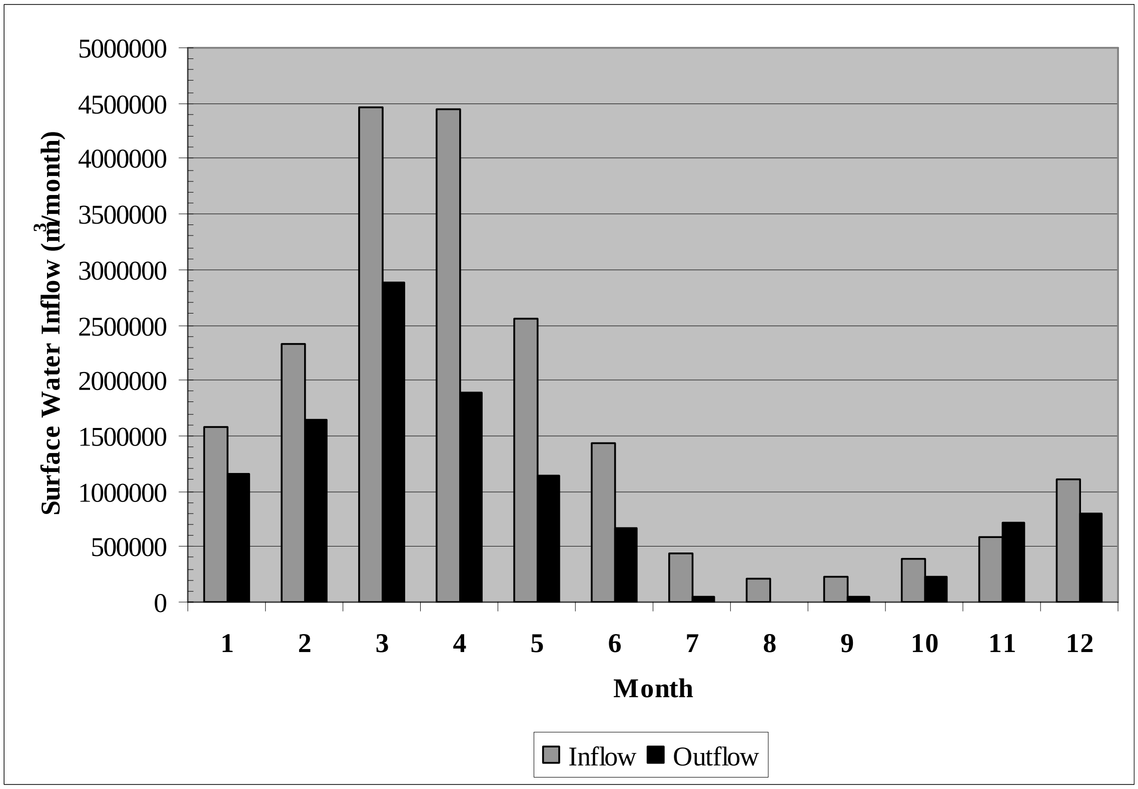

Figure 15. Average monthly surface water inflow and outflow levels (m^3/month) 1998, 2000-02, 2004-06.

Recordings of gate openings and downstream water surface elevations have not been observed at a sufficient frequency to allow a full extrapolation throughout the analysis period: May, 1997 to December, 2006. The following methods were used to estimate outlet discharge for periods when little data was available:

- The water budget equation was solved for the total outflow which included both the combined groundwater and surface water outflows.
- A linear regression was determined between monthly estimates of total outflow (groundwater + surface water) and the monthly estimates of surface water outflow determined from measurements (Figure 16).

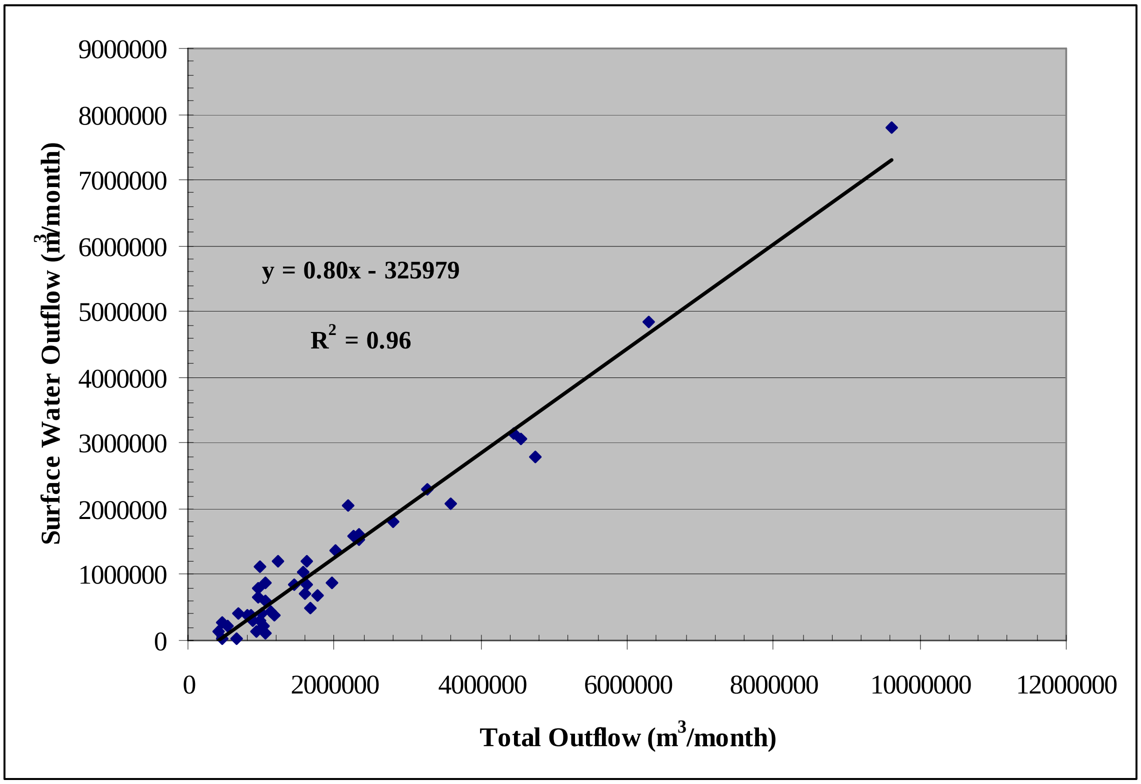

Figure 16. Relationship between total lake outflow (m^3/month) and the surface water flow exiting the lake via the outlet structure.

This relationship was then applied to estimates of monthly total outflow to determine surface water outflows. The difference between the total outflow and surface water outflow was then attributed to groundwater. From this relationship, when the surface water outflow is 0 (gates are closed), the residual outflow, which is attributed to groundwater, is 325,979 m^3/month, or about 4.4 cubic feet per second. A previous water budget estimated seepage through the outlet structure at 2.4 cfs based on application of the Darcy equation to local conditions (Copp, 1976). Although the outlet structure present in the mid-1970s was replaced, the geologic conditions affecting seepage remain.

The level of monthly surface water outflow follows a similar pattern as observed for the inflow, though at a lower magnitude (refer to Figure 15). The annual peak outflow occurs during March at approximately 2,900,000 m^3. While the monthly pattern of outflow tends to mimic the inflows, the magnitude of outflow is considerably lower, resulting in a net increase in lake volume. Lake water surface elevations are kept at an annual low through the winter and early spring, maintaining storage capacity in order to capture the spring inflow. This is why the lake volume tends to achieve a maximum by late May.

To maintain this storage, regulated outlet flow is ramped down through the spring and summer. Typically, from June through September only minor levels of discharge occur from the outlet. Despite the lack of outlet discharge during the summer, the lake continues to lose volume primarily through evaporation. Annually, surface water outflow accounts for 49 percent of the water loss from the lake. It represents just 17 percent of the total water loss during the summer (June-August).

Precipitation

Inflow associated with precipitation falling directly on the lake surface follows a seasonal pattern: peak levels occurring in November and December with lows occurring July through September (Figure 17). Precipitation contributes approximately 14 percent of the total annual inflow.

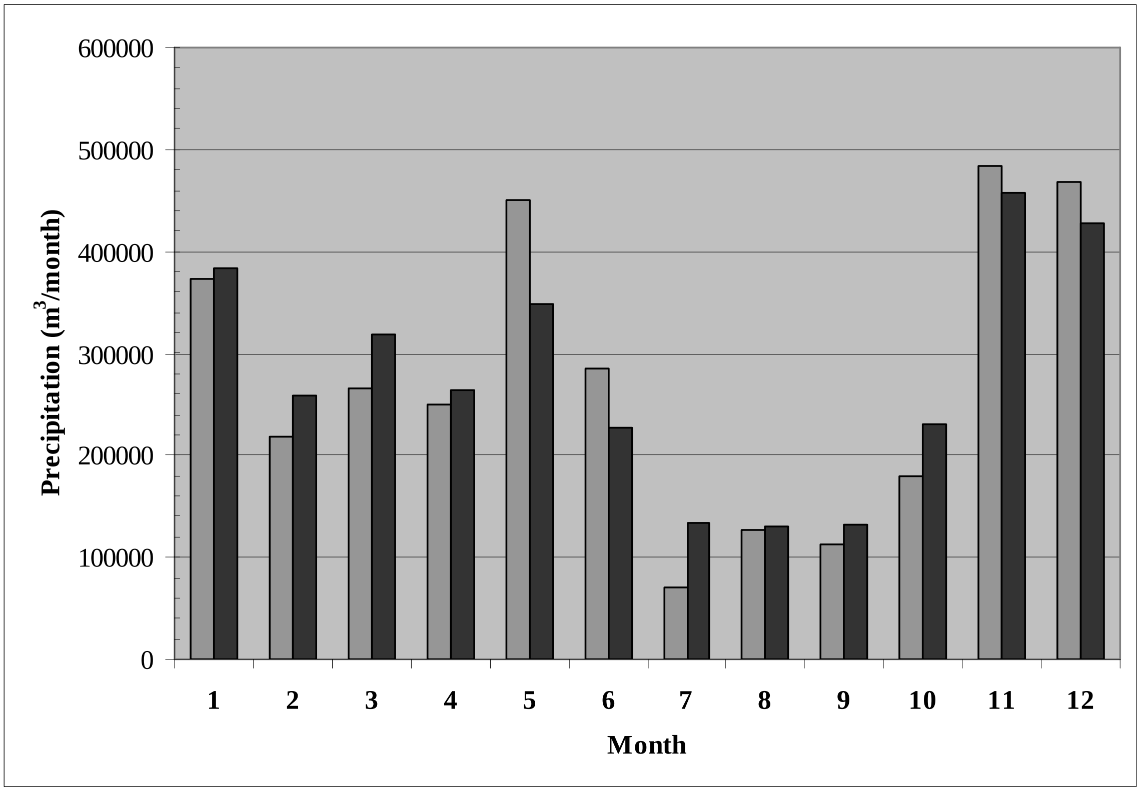

Figure 17. Average monthly precipitation volumes to the lake (m^3/month) 1998, 2000-02, 2004-06 (light grey) along with average monthly levels observed 1985-2006 (black).

Evaporation

Water loss through evaporation was estimated through application of the following equation (Gupta, 1989):

$$E = f(u)\,(e_s - e_a)$$

E = evaporation per day (inches)
f(u) = wind function
e_s = *saturation vapor pressure (in Hg)*
e_a = *vapor pressure of air (in Hg)*

The wind function has the form:

$$f(u) = a + NW^n$$

a, n = constants
N = mass transfer coefficient
W = wind speed (mph)

Typically, n is assumed to equal one for lakes and the constant *a* equal to zero. Reservoir evaporation studies derived the relation for the mass transfer coefficient (N) (Harbeck, 1962):

$$N=0.105(A_s)^{-0.05}$$

A_s = *lake surface area (acres)*

From this relationship, Newman Lake with a surface area of 1273 acres results in an N value of 0.073.

The air and saturation vapor pressure were determined from the following relationship (Raudkivi, 1979):

$$e\ (s,a) = 4.596(e^{(17.27(T))/(237.3+T))})$$

The air temperature observed at the Spokane International Airport was used as input to estimate the vapor pressure of air. The lake surface water temperature (derived from hourly predictions using the water temperature model rTemp (http://www.ecy.wa.gov/programs/eap/models.html) was used as input to estimate the saturation vapor pressure. Hourly wind speed observed at the Spokane Airport was also used in the evaporation model.

Water loss through evaporation follows a fairly well-defined pattern (Figure 18). Increased surface water heating, beginning prominently in spring (March) as a consequence of increased solar shortwave radiation levels, maintains a higher saturation vapor pressure in relation to the air vapor pressure leading to evaporative (heat) loss. Wind drives the rate of evaporative loss. Increasing rates of evaporation begin in March peaking in July at approximately 1,200,000 m^3. Following July, rates decline rapidly with relatively little evaporative loss November through February.

On an annual basis, evaporation accounts for 25 percent of the water loss from the lake. During the summer months (June-August), with outlet gates usually closed, evaporation accounts for 74 percent of the water loss.

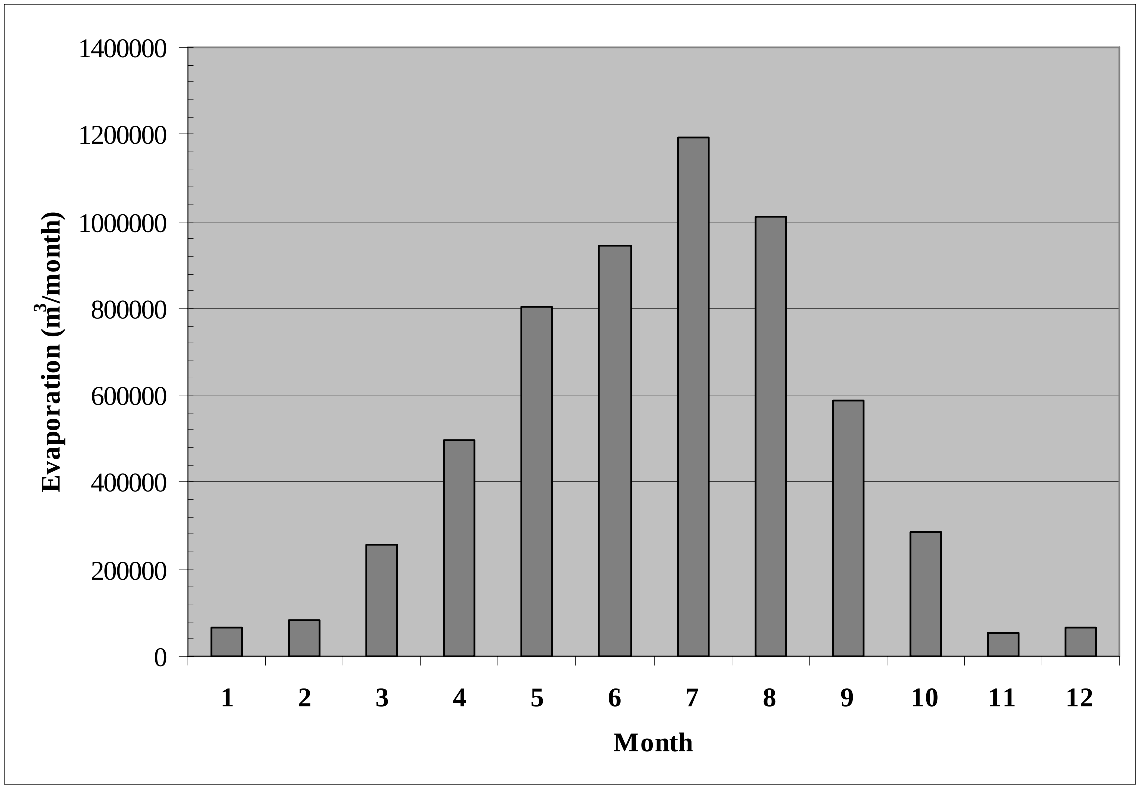

Figure 18. Average monthly evaporation levels (m^3/month), 1998, 2000-02, 2004-06.

Groundwater

Of the various sources of inflow and outflow from Newman Lake, groundwater is the most difficult to measure and, therefore, calculate accurately. Estimates were determined for all of the components of the water budget except groundwater. For this reason, the net inflow and outflow associated with groundwater was determined through application of the water budget equation. The resulting estimate provides a net level of groundwater flow.

A positive flow indicates that there is more groundwater inflow to the lake than outflow, while a negative flow indicates that there is a net greater outflow than inflow. Of course, this approach places a greater level of uncertainty to this estimate but it is the method most commonly used to estimate groundwater flow for lakes, short of a dedicated groundwater study.

Overall, there is a significantly greater groundwater outflow than inflow to Newman Lake consistent with prior water budget estimates (Copp, 1976). The only period when there is a net greater inflow occurs in July and August, though the amount is minor and within the range of error expected for this estimate. Groundwater outflow accounts for 26 percent of the water loss from the lake annually about equal to that lost through evaporation (Figure 19). During the summer months (June-August) it represents about 9 percent of the water loss.

The pattern of groundwater outflow levels follows that observed for surface water flow leaving the lake through the outlet; higher levels occurring in the spring and low levels occurring during the summer. This may indicate that a component of the groundwater outflow estimate incorporates the error in the surface water outlet estimates. For instance, surface water outflow may be underestimated and the difference then ascribed to groundwater. Unfortunately, the accuracy of the weir equation in estimating outlet flows has not been determined for the current outlet control structure (Marianne Barentine, Spokane County, personal communication April, 2007). A former outlet structure on Newman Lake was found to have significant deviations between the estimated flow, derived from a weir equation, and that measured (Copp, 1976). The differences were attributed to seepage around the outlet structure. At that time, in addition to the outlet seepage component, Copp estimated groundwater loss from the lake at a constant rate of 7.0 cfs. Methods used to determine this estimate were not contained in the report. While monthly groundwater outflow varied in this analysis, when the outflow is examined as an average instantaneous level it is determined to be 6.6 cfs, close to the prior estimate.

As speculated earlier in the discussion of surface water inflows, without the geological conditions for major groundwater storage Newman Lake is a net exporter of groundwater. Eventually, the south-shore wetlands and outlet channel drain to the Spokane Valley-Rathdrum Prairie Aquifer. This extensive aquifer, with an area of 830 square kilometers, has a lobe that extends from the valley to the south end of Newman Lake (MacInnis, 2004). In fact, the permeability of deposits intercepted by the outlet channel are great enough to infiltrate most outlet flows including, within this analysis period, average flows of 120 ft^3/s observed during March 1999. Extensive peat deposits, situated along the southeast shoreline, suggest a once larger lake surface area. The relatively shallow slope to the lake bottom (refer to Figure 1) in proximity to the peat deposits indicates that outflow, prior to the defined outlet channel, was diffuse across these deposits. Farming practices altered this flow pattern through the construction of dikes and drainage canals, which are still in place, and the outlet channel, which now serves as the principal outflow. The water table is shallow within the peat deposits and remains saturated throughout the summer months. These deposits likely serve as a plug impeding greater groundwater outflow levels.

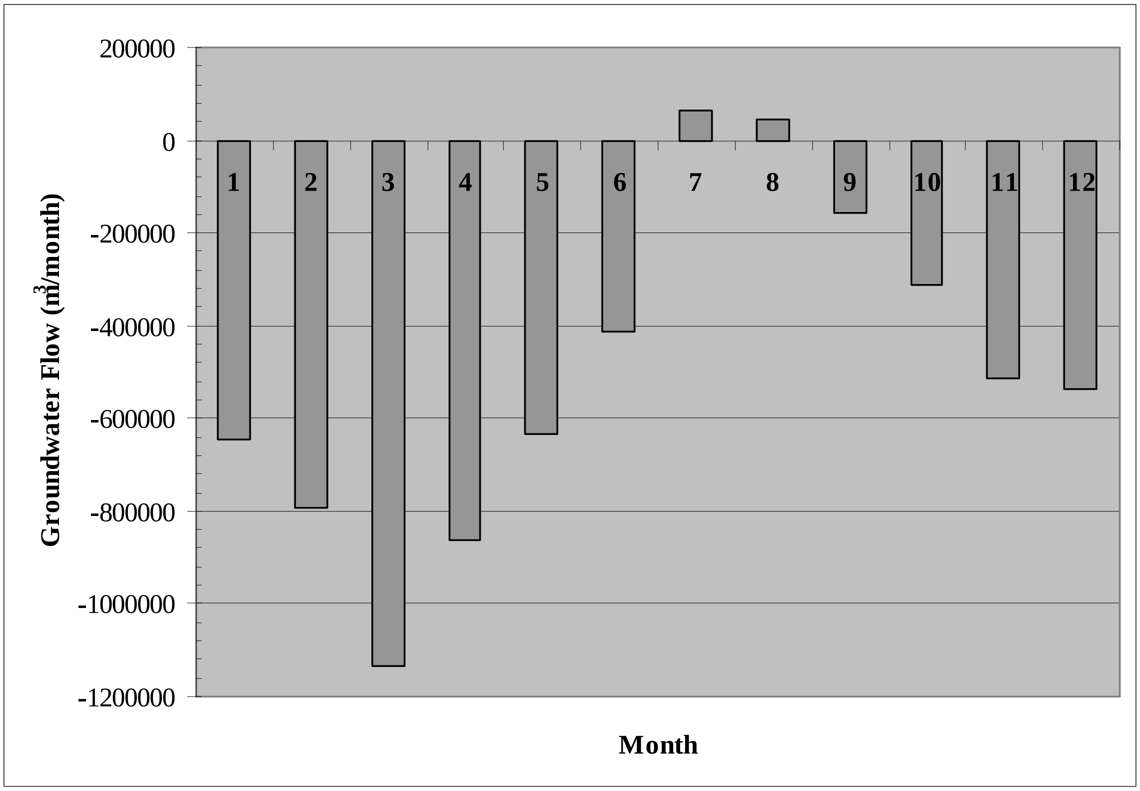

Figure 19. Average net groundwater outflow (-) and inflow (+) by month observed during 1998, 2000-02, 2004-06.

Outflow overview

Figure 20 includes the percent representation of the average estimates of outflow from Newman Lake observed during 1998, 2000-02, 2004-06. Of the loss routes, surface water leaving the lake via the outlet structure is the greatest at 49 percent of the average annual total of 22,949,937 m^3. The other water loss routes evaporation and groundwater are about equal at 25 percent and 26 percent, respectively, of the average annual total.

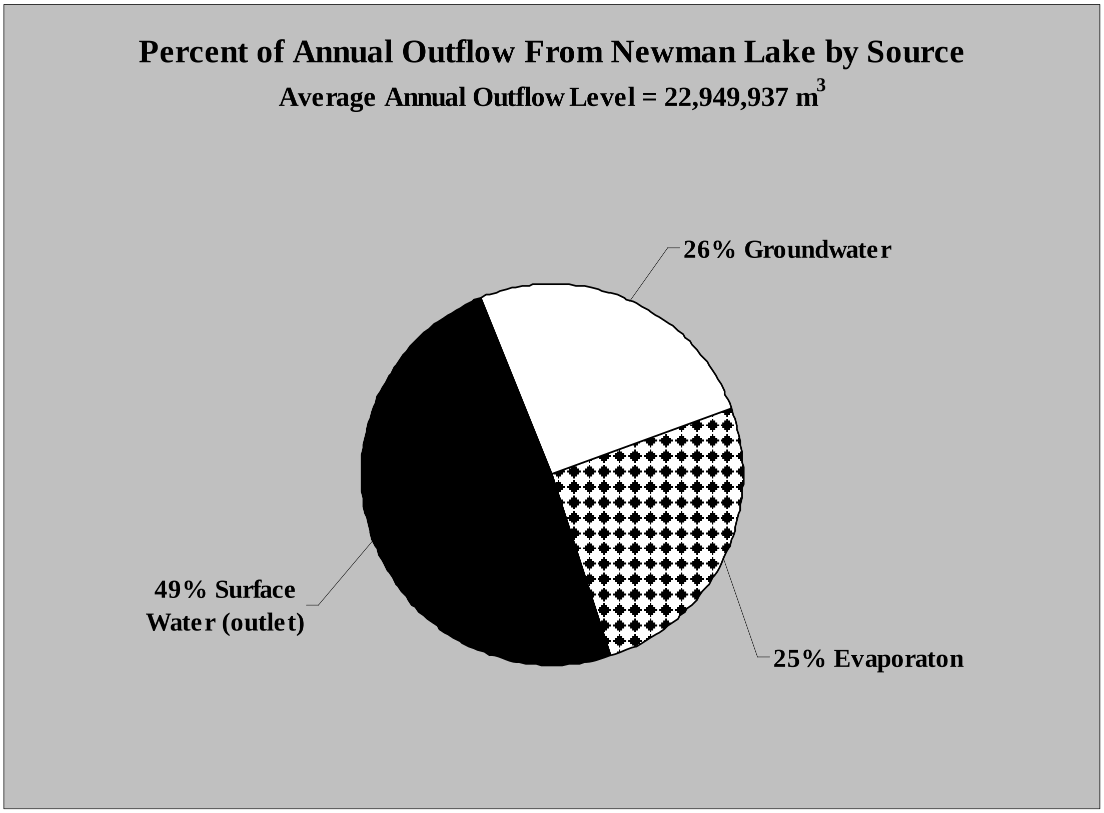

Figure 20. Average annual level of outflow associated with surface water, groundwater, and evaporation (1998, 2000-02, 2004-06).

External TP loads

Thompson Creek

Figure 21 shows the relationship between TP and flow for Thompson Creek. There is not a significant relationship between the level of flow and observed TP concentrations. Typically, in most surface waters, the variation in TP concentrations is closely related to the level of total suspended solids. Phosphorus is adsorbed to sediment particles so that when flow levels are higher, and sediment is mobilized, TP concentrations are also proportionally higher. In fact, the majority of the annual TP load is commonly attributed to just a few large storm-events that both deliver and transport, high suspended solids levels within surface waters (Hem, 1992). For this reason, the frequency and timing of sample collection, particularly during storm-events, is important in examining TP loads. However, for Thompson Creek there does not appear to be a relationship between flow (and associated suspended sediment levels) and TP. An explanation as to why this relationship does not occur is that typically the highest flow levels in Thompson Creek are associated with snowmelt during the spring. Flow derived from snowmelt may not generate as high of in-stream sediment levels in comparison to more erosive run-off processes such as those associated with heavy rain storms. Thompson Creek TP concentrations remain relatively constant despite varying flow levels with an overall median TP concentration of 43 ug/L.

Figure 22 displays median TP concentrations and discharge levels by month for Thompson Creek based on the data record. As observed, phosphorus concentrations are typically between 40 and 50 ug/L, with the annual average about 49 ug/L. For the period when the majority of the samples are collected, April through September, there is no significant difference in TP concentrations (log transformed concentrations ANOVA, p=0.96). In comparison, there are significant differences in flow levels observed over the same period (ANOVA, p=0).

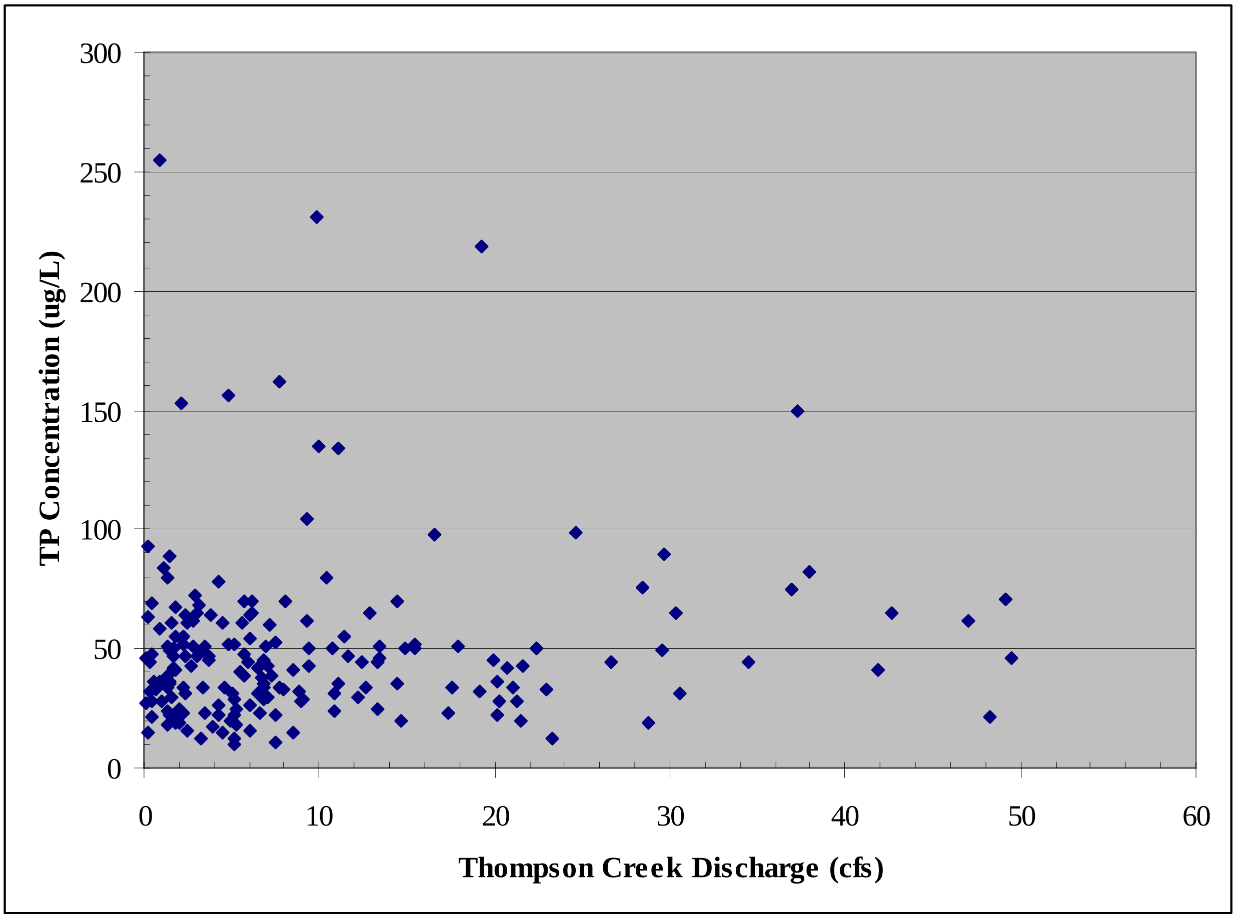

Figure 21. The relationship between discharge (cubic feet per second) and TP concentrations (ug/L) observed in Thompson Creek.

To determine annual loads for Thompson Creek, the Beale ratio estimator method was applied (Richards, 1998). The TP data used in this analysis was that collected since 1986. TP samples have been collected, with varying frequency, in 1986, 1989-92, 1999-2000, 2002-2005. The majority of the samples were collected between the months of April and September with few measurements collected for the other months. Of the data set, 1991 has the most TP measurements at 16 though loads where also calculated for 1989 when only 7 measurements were collected.

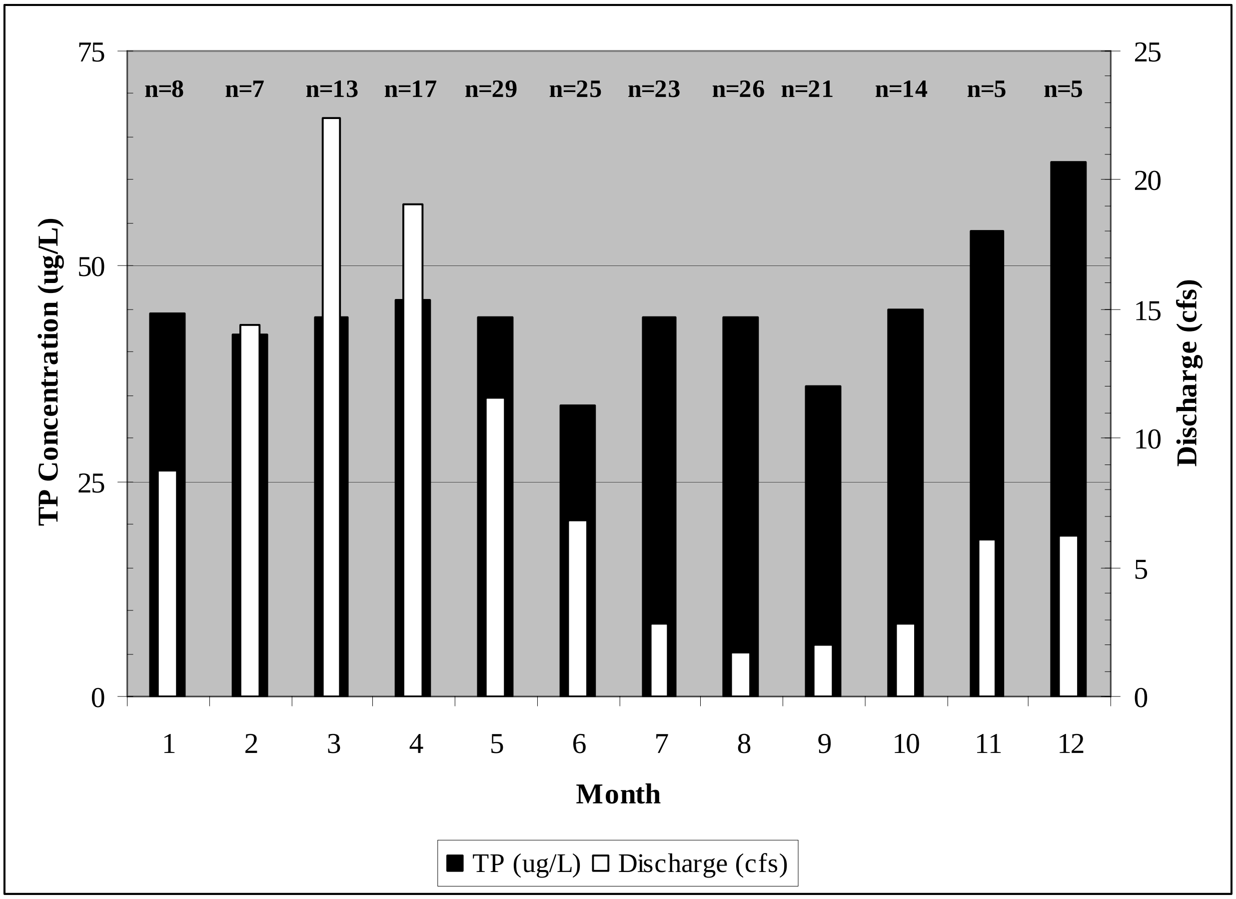

Figure 22. Median TP concentrations (ug/L) and discharge levels observed in Thompson Creek by month. (n refers to the number of samples collected.)

Data were not stratified because there are no seasonal patterns to the TP concentrations. The results of the load estimations are presented in Table 5 by year. From these estimates, Thompson Creek TP loads vary from 173 kg in 1992 to 1440 in 1999, with an overall average of 540 kg.

Table 5. Result of the application of the Beale ratio method of load estimation for Thompson Creek.

Year	n	Load (kg)	MSE	+/- 95 percent CI
1986	11	492	2858	105
1989	7	470	422	40
1990	14	435	5983	152
1991	16	760	37047	377
1992	9	173	602	61
1999	9	1440	32946	356
2000	8	960	987	90
2002	14	542	2251	93
2003	9	245	47	18
2004	30	274	114	24
2005	32	151	63	31

Recognizing the relatively consistent TP concentration observed in Thompson Creek, the loads were plotted against annual flow totals (Figure 23). As discussed in the section of the report concerning Newman Lake's surface inflow, since 1986 the estimated average annual level of inflow associated with Thompson Creek is 11,067,377 m^3. Applying this inflow level to the regression relation presented in Figure 23 results in an average TP load of 606 kilograms per year.

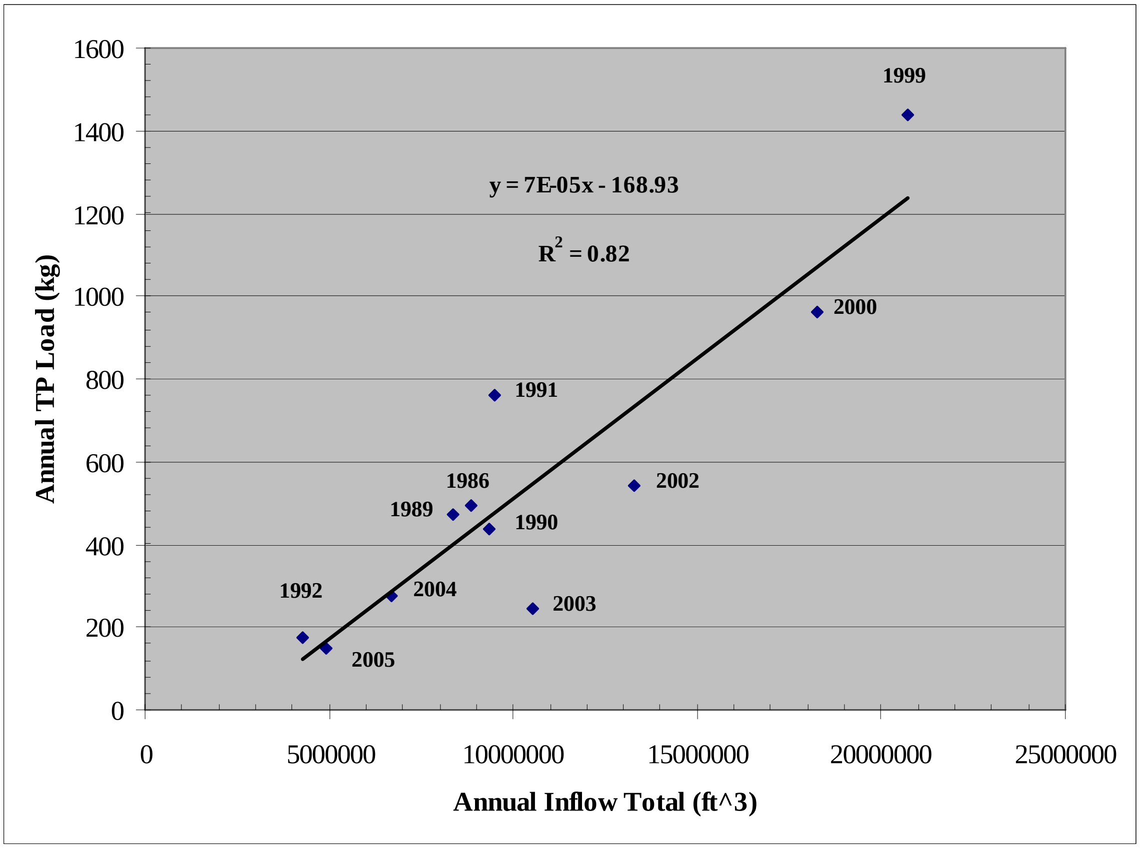

Figure 23. The relationship between the annual level of inflow (cubic feet) and the TP load (kg) observed in Thompson Creek.

From this relationship, the annual TP load from Thompson Creek to Newman Lake was estimated from 1985 to 2006 (Figure 24). The average TP load (600 kilograms) when divided by the drainage area (3132 hectares) results in a yield of 0.19 kg TP/ ha-yr. However, there is great variability in the estimated load levels from about 130 kilograms in 1992 and 1994 to over 2000 kilograms in 1997. As observed, the period from 1995 to 2000 had unusually elevated TP loads. During this period, the average annual TP load was 1,200 kilograms about twice the 1985 to 2006 average.

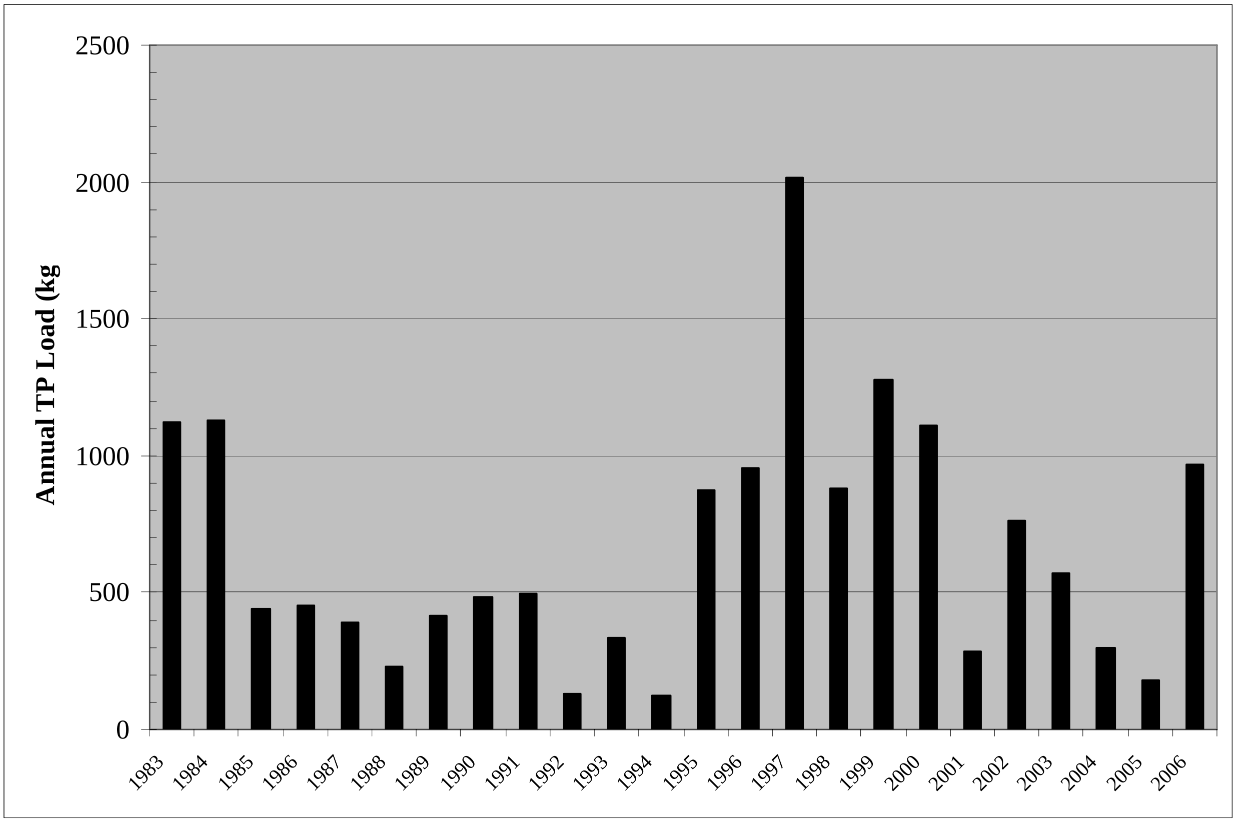

Figure 24. Estimates of annual TP loads from Thompson Creek, 1983 to 2006.

Precipitation

Insufficient data have been collected to characterize the level of TP present in precipitation falling to the surface of Newman Lake. Therefore, the level of TP entering the lake associated with precipitation was estimated through application of an export coefficient. To determine an appropriate TP export coefficient several lake studies, occurring throughout Washington, were consulted (Table 6). Among the studies examined, reported values range from 0.11 kg TP/ha-yr for Curlew Lake to 0.28 kg TP/ha-yr for Lake Chelan. Both lakes are located in central Washington. For each lake, yields vary annually depending on precipitation levels and the level of airborne material, among other factors.

Table 6. Precipitation export coefficients determined for several Washington lakes.

Lake	Study	TP Export Coefficient (kg/ha-yr)
Blackman	KCM, 1997	0.217
Chelan	Harper Owes, 1989	0.278
Curlew	WSU, 1988	0.112
Green	Herrera, 2003	0.192
Moses	Welch, E. B., 1989	0.185
Phantom	KCM, 1987	0.149

Typical TP export coefficients associated with precipitation range between 0.2 and 0.5 kg TP/ha-yr (Reckhow, 1983). From the reported values, an average level of 0.20 kg/ha-yr was applied to Newman Lake. Based on an average annual precipitation level of 64 centimeters (25 inches) falling over the lake surface (515 hectares), the average annual inflow volume associated with precipitation is 3,265,363 m^3. Multiplying the precipitation export coefficient by the lake surface area results in an estimate of the average annual level of TP associated with precipitation.

(0.20 kg TP /ha-yr) * (515 ha) = 103 kg TP/yr

When this annual load is divided by the annual precipitation volume the resulting concentration is 32 ug/L.

$((103 \text{ kg TP/yr})/(3,265,363 \text{ m}^3))*10^6 = 32 \text{ ug/L}$

This concentration level was then applied to all precipitation volumes over the analysis period 1985 to 2006.

Watershed Drainage

TP measurements have been collected at several surface water inflows to Newman Lake (refer to Figure 1). Data collection efforts for these locations over the analysis period, 1985 to 2006, have been sporadic with relatively few measurements taken in comparison to those collected on Thompson Creek. In addition, there tends to be substantial time gaps between sampling with the majority of the samples collected during the summer months. For this reason, the Beale ratio load estimation method, used for estimating the annual TP load for Thompson Creek, could not be applied to the inlet monitoring stations. Other methods were required.

Box plots of TP concentrations observed at the inlet locations along with Thompson Creek are presented in Figure 25. The box plots represent the total data set of TP observed at each station. In interpreting the box plots, the upper and lower squares represent the 90^{th} and 10^{th} percentile of each locations data set while the upper and lower edge of the central rectangle represent the 75^{th} and 25^{th} percentiles, respectively. Within the central rectangle is a solid square that represents the 50^{th} percentile or median. The median is an indicator of central tendency, similar to an average, where approximately 50 percent of the measurements are greater or less than its level.

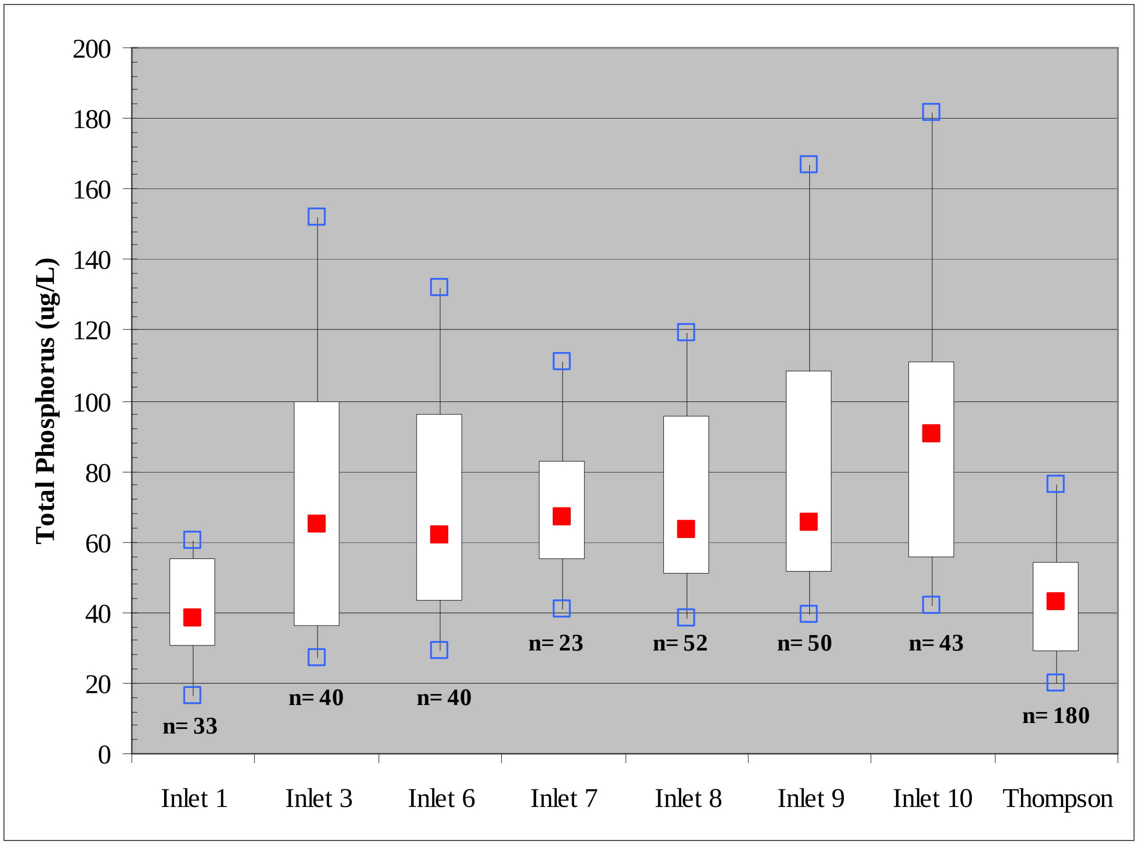

Figure 25. Box plots of TP concentrations observed at the inlet stations and Thompson Creek (n refers to the number of samples collected).

Exclusive of Thompson Creek, the median TP concentration among the inlet stations is 64 ug/L. In comparison, the median TP concentration observed at inlet 1 is about 40 percent less at 40 ug/L. It represents phosphorus levels expected for less impacted conditions. In contrast, the higher median TP level observed at inlet 10 is likely the influence of residential development located in proximity to Honeymoon Bay.

From this information, watershed loads were calculated by determining an area-weighted average TP concentration (64 ug/L) multiplied by the estimated monthly inflow levels from 1985 to 2006.

On-site wastewater systems

The contribution of residential on-site wastewater systems to the external TP load was estimated using the following methods:

- Using the geographic information systems software ArcView, a cover of Spokane County parcels (obtained from the Spokane County Assessor's Office) was intersected with a buffer set 1000 feet (305 meter) from the lake shore. The resulting intersection identified all parcels, or sections of parcels, situated within the buffer. The buffer distance of 1000 feet from the shoreline was chosen as a zone of potential impact from septic leachate while identifying the majority of the residential development situated around the lake.

- Spokane County Assessor's tables of ownership and value were joined to the parcel cover. The final table indicated owner's name and address, parcel number, its size, property use code, and land and home values among other attributes.

- The table was sorted initially by the land use code to provide a general description within the critical area. The full data set was then sorted by owner's mailing address into three groups: those located at Newman Lake, those located within the greater Spokane Valley, and those outside of Spokane County.

- For each of these address groups, the parcel data was sorted by land use codes to determine the number of residential structures present.

- Annual occupancy rates were based on the three groupings. It was assumed that home owners with a Newman Lake address used their residence as a primary one, occupying it year-round. Home owners with addresses within the greater Spokane Valley were assumed to have weekend occupancy May – September, while those located outside of Spokane County were assumed to occupy their lake homes for a two-week period annually.

The number of residences within the greater Newman Lake watershed was estimated in 2004 at 571 (Newman Lake Watershed Land Use Survey, 2004). Accounting for the total of the Spokane Assessor's office parcels with use codes 11, 14, 18, 19 and 75 (refer to Table 7) which total 486, indicate that approximately 85 percent of the residences within the watershed are located within 1000 feet of the shoreline.

Table 7. Overview of parcel land use designations and the area it represents within 1000 feet (305 meters) of the lake shore.

Code	Description	Parcel Number	percent of Total Parcels	Area (acres)	percent of Total Area
11	Single Family	399	53.6	285.7	27.7
14	Hotel / Motel	22	3.0	11.9	1.2
18	Other Residential	22	3.0	16.7	1.6
19	Vacation Home	42	5.7	20.5	2.0
44	Transportation – Marine	1	0.1	0.3	0.03
67	Service –Govern.	8	1.1	84.3	8.2
75	Resort – Camping	1	0.1	4.4	0.4
81	Agriculture – Not Classified	1	0.1	0.4	0.03
83	Current Use Agriculture	9	1.2	177.3	17.2
88	Designated Forest	8	1.1	71.2	6.9
91	Residential Land Un-Divided	231	31.1	357.6	34.7
Totals		**744**	**===**	**1030.3**	**===**

The 2004 land use survey indicated that residential use within the greater watershed was 39 percent primary and 61 percent seasonal. From the methods outlined above and, based on the total of parcels designated by codes 11, 14, 18, 19, and 75, those with a Newman Lake address total 221 (Table 8), Spokane Valley (209) (Table 9) and those outside of the county (56) (Table 10). On a percentage basis, of the 486 residential parcels, 45 percent are assumed to be a primary residence, with the combined inner and outer county ownership, assumed seasonal, at 55 percent. In many cases, it appears that the parcel codes used to indicate residential development by the County Assessor's Office, particularly 18 and 19, are more a reflection of the structure's assessed value than its level of use. For this reason, all of the structures are grouped together with the distinction of use based on the owner's address.

In assessing the contribution of on-site systems to TP loading to Newman Lake the following assumptions were used:

- Parcels with Spokane County Assessor's Office codes 11, 14, 18, 19 and 75 contributed to the TP loading to surrounding soils; all are assumed to have some type of on-site wastewater treatment method associated with the residence.

- The rate that development situated within each parcel contributes to TP loading to Newman Lake is based on the owner's address. If the parcel has a Newman Lake address, it was assumed that the residence is a primary one and that the home is used year round. In total, this matched 221 or 45 percent of the residentially developed parcels within 1000 feet (305 meters) of the lake (Table 8).

Table 8. Overview of parcel land use designations and the area it represents within 1000 feet (305 meters) of the lake shore for those with a Newman Lake address.

Code	Description	Parcel Number	percent of Total Parcels	Area (acres)	percent of Total Area
11	Single Family	182	61.1	194.3	51.5
14	Hotel / Motel	9	3.0	0.2	0.04
18	Other Residential	18	6.0	13.88	3.7
19	Vacation Home	11	3.7	2.1	0.6
75	Resort – Camping	1	0.3	4.4	1.2
83	Current Use Agriculture	5	1.7	104.3	27.7
88	Designated Forest	4	1.3	16.0	4.2
91	Residential Land Un-Divided	68	22.8	42.1	11.2

- If the parcel had a greater Spokane Valley address, the residence was assumed to be used seasonally. Because of the close proximity of the lake to the primary address, it was assumed that the lake residence was used during weekends, Friday through Sunday, May through September, or 46 days per year. This description applied to 209 of the 486 residentially developed parcels within 1000 feet of the shoreline (43 percent) (Table 9).

Table 9. Overview of parcel land use designations and the area it represents within 1000 feet 305 meters) of the lake shore for those with a Spokane Valley address.

Code	Description	Parcel Number	percent of Total Parcels	Area (acres)	percent of Total Area
11	Single Family	165	48.0	73.4	15.5
14	Hotel / Motel	12	3.5	11.7	2.5
18	Other Residential	3	0.9	2.8	0.6
19	Vacation Home	29	8.4	17.7	3.7
44	Transportation – Marine	1	0.3	0.3	0.1
67	Service –Govern.	7	2.0	82.3	17.4
81	Agriculture – Not Classified	1	0.3	0.4	0.1
83	Current Use Agriculture	4	1.2	72.9	15.4
88	Designated Forest	4	1.2	55.1	11.7
91	Residential Land Un-Divided	118	34.3	285.7	60.3

Use of lake residences by owners located outside of Spokane County was assumed to be two weeks per year, or 14 days. This description applied to 56 or 12 percent of the total number of residentially developed parcels within 1000 feet of the lake shore (Table 10).

Table 10. Overview of parcel land use designations and the area it represents within 1000 feet (305 meters) of the lake shore for those outside Spokane County.

Code	Description	Parcel Number	percent of Total Parcels	Area (acres)	percent of Total Area
11	Single Family	52	50.5	19.9	37.9
14	Hotel / Motel	1	1.0	0.01	0.02
18	Other Residential	1	1.0	0.01	0.02
19	Vacation Home	2	1.9	0.8	1.4
67	Service –Govern.	1	1.0	2.0	3.8
91	Residential Land Un-Divided	46	44.7	29.8	56.8

These occupancy rate estimates are conservative and could be substantially higher. For instance, land owners residing outside the Spokane Valley may lease property that could be potentially occupied year round. Or, owners residing in the Spokane Valley may have extended family or friends that have access to the residence resulting in a much higher level of occupancy. Given the wide variety of potential occupancy rates, quantifying them is difficult. Recognizing this limitation, a conservative approach to its estimates was used in this analysis. However, this method may under-estimate residential usage and, therefore, the potential introduction of TP to the lake from on-site wastewater systems.

It was assumed that the average population of each residence, when occupied, is 2.5. Therefore, during June through September when, at times, all residences could be occupied, the population can reach about 1200. For the rest of the year, the population is 553.

Typical residential wastewater flows are about 60 gallons (227 liters) per capita per day with average TP concentrations within the wastewater at 8 milligrams per liter (Metcalf and Eddy, 1991). From this flow amount and associated phosphorus concentration, an average annual per capita phosphorus load is 0.7 kg TP/capita-yr, or about 1 kg TP/capita-yr.

Applying the 0.7 kg TP/capita-yr (0.001819 kg TP/cap.-d) loading rate to the two seasonal and annual-based populations, results in a TP loading rate of 414 kg TP/yr associated with on-site systems. It is assumed that there is no decrease in the amount of phosphorus as wastewater passes through the settling tank to the soil absorption system.

Soil treatment varies in its effectiveness in adsorbing phosphorus and preventing it from entering the lake through groundwater transport. To express this process, a soil retention coefficient was applied. The coefficient can range from zero, indicating no retention, to one, indicating complete retention of phosphorus. Retention rates vary seasonally depending on soil saturation levels. For instance, lower levels of phosphorus migration and introduction to the lake would be expected during the dry summer months than following snowmelt and storm-events during the spring. This is particularly pertinent to Newman Lake where the majority of residential development is primarily situated in poor soil conditions for wastewater treatment. Depth to bedrock is shallow, typically less than 1.5 meters, with seasonally shallow water table elevations (Table 11). The very northern and southern sections of the lake are represented by wetland type soils, most prominently Semiahmoo muck (Sk, Se) which represents 26 percent of the soils found within 1000 feet of the shoreline (Figure 26). These are areas where frequent inundation occurs making these areas largely uninhabitable.

The Moscow series represents about 19 percent of the area within 1000 feet of the lake and is predominately located along the southeastern section of the shoreline from Shadow Bay to Honeymoon Bay (Figure 26). Residences located along the Honeymoon Bay section of the lake are situated within the Moscow Silt Loam soil series. The monitoring location inlet 10, at Honeymoon Bay had among the highest TP concentrations, likely associated with surface and groundwater drainage.

The majority of residential development located on the eastern shore is situated in the Spokane Rocky Complex (StC) type soils. Similar to the Moscow Loam soils, the Spokane soils also have shallow bedrock typically less than 1 meter below land surface. In fact the majority of the residential properties are located over either shallow bedrock, typically less than 1 meter below land surface, or perennially or seasonally shallow water table. Approximately 22 percent of the lake-side residences are located within the Moscow Silt Loam (MmC, MmD) series and 55 percent within the Spokane Rocky Complex (StC, StE) series both with shallow bedrock, typically within 0.7 meters of the land surface (Figure 26, Table 11).

The types of soil conditions present along the shoreline of Newman Lake provide poor wastewater treatment conditions and it is expected that there is a low attenuation of phosphorus migration. For this reason, a soil phosphorus retention level of 0.5 was used. This retention level assumes that 50 percent of the phosphorus load associated with residential wastewater eventually migrates to the lake. Therefore, on average 207 kilograms enters the lake each year associated with residential wastewater.

The TP load associated with wastewater was assumed to be constant each year at 207 kilograms and enters the lake at a level proportional to the monthly flows observed in Thompson Creek. For instance, if in a particular year the total April flow represented 20 percent of the total annual flow then it was assumed that 20 percent of the on-site TP load entered the lake at that time. Through this method, monthly TP loads were determined from 1985 to 2006.

Table 11. Soil types represented within 1000 feet (305 meters) of the shoreline.

Soil Description	Soil Type	Percent Representation with in 1000 feet (305 m) of Shoreline	Percent Representation of Near-shore Residences By Soil Type	Soil Attributes Relevant to On-Site Treatment
Bonner Loam	BvB	0.62		Well drained, 0-20 percent slopes
Clayton Fine Sandy Loam	CsB	0.05		Well drained, deep, 5-20 percent slopes
Clayton Loam	CtB	3.55	1.8	Similar to CsB w/ loam surface
Cocolalla Silty Clay Loam	Cw	4.03	0.9	Poorly drained, depth to water table fluctuates from 0 to 4 ft (0-1.2 m) below surface
Eloika Silt Loam	EkB	4.70	8.1	Well drained, gravel at 2.5-5 feet (0.8-1.5 m)
Freshwater Marsh	Fm	6.94		Fringing wetlands with fluctuating water table
Konner Silty Clay Loam	Kc	2.59	5.4	Poorly drained, depth to seasonally high water table 1.5-2.5 ft (0.5-0.8 m)
Konner Silty Loam	Kd	1.15		Poorly drained, depth to seasonally high water table 3-5 ft (1-1.5 m)
Moscow Silt Loam	MmC / MmD	18.5	21.9	Well drained, bedrock at 2.3 feet (0.7 m)
Moscow Rocky Complex	MsE	0.81	0.7	30-70 percent slopes, bedrock outcrop
Narcisse Silt Loam	NcA	1.16		Moderately well drained, depth to water table 3-5 feet (1-1.5 m)
Peone Silt Loam	PeA	1.18	0.4	Poorly drained, occurs on nearly level bottom lands along streams
Rock Outcrop	Ro	0.08		
Semiahmoo Muck	Se / Sk	26.4	0.6	Very poorly drained, water table within 1-foot (Se) or 1-4 feet (Sk) of surface
Spokane Loam	SpC / SpD /	8.40	5.6	Well drained, depth to bedrock 2.5-5 feet (0.8-1.5 m)
Spokane Rocky Complex	StC / StE	19.84	54.6	Depth to bedrock 1.7-2.5 feet (0.5-0.8 m)

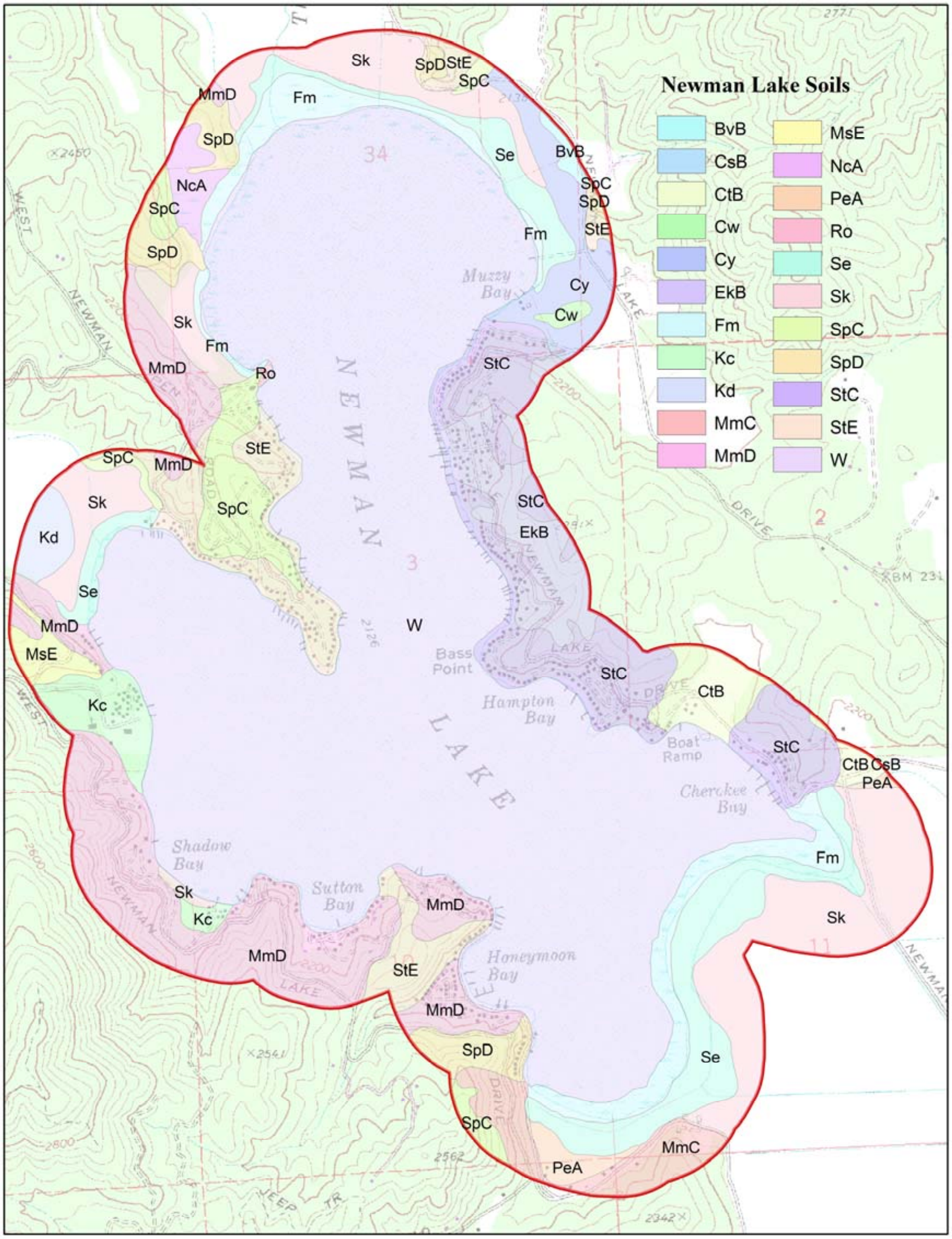

Figure 26. Soil types within 1000 feet of the shoreline (refer to Table 11 for soil description).

Groundwater

Land use for the majority of Newman Lake's watershed is forestry. This land use has a low level of influence on groundwater TP concentrations. For this reason, the only significant influence to groundwater quality is that associated with residential land use and, in particular, on-site systems. For this analysis, the contribution of on-site wastewater systems to the TP external load serves as an assessment of the groundwater component to the overall external load.

Overview of External TP Sources and Associated Loads

Of the external TP sources examined, Thompson Creek is the largest comprising, on average, 43 percent of the annual load to Newman Lake (Figure 27). The watershed outside of the Thompson Creek drainage, while comprising 60 percent of the drainage area to the lake, contributes a lower overall level at 36 percent. Precipitation and on-site systems contribute 7 percent and 14 percent, respectively to the average annual TP load.

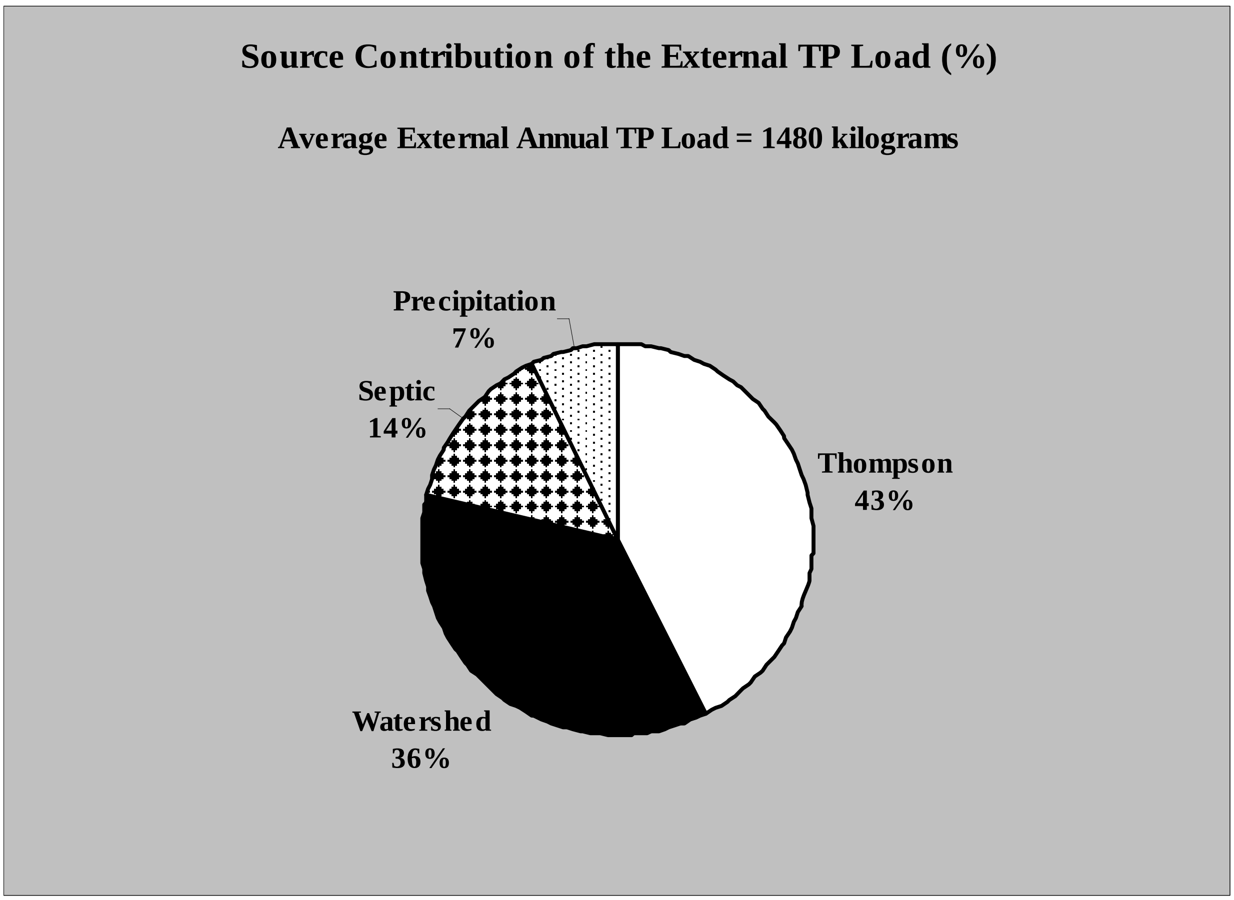

Figure 27. The percent contribution of the average annual external TP load, by source (1986-2006).

Nutrient Budget

A TP budget was constructed for the period May through September of 1998 and 2005. The period May through September was selected because these are months when annual TP data has been consistently collected. And, while TP data have been collected (to varying degrees) annually since 1997, only during 1998 and 2005 could the full dataset be used due to data quality concerns apparent in the other year's data sets (refer to Appendix B). For the TP budget, the period 1997 to present was analyzed congruent with the water budget analysis period based on the following relationship:

$$\Delta\ TP_{Lake\ Mass} = (TP_{Inflow}) - (TP_{Outflow})\ (kg)$$

TP is introduced to the lake water column associated with surface water inflow, precipitation, internal recycling (sediment release), and groundwater. TP is lost from the water column through surface water and groundwater outflow, and settling. Of these various pathways, the quantities associated with settling and internal recycling are difficult to measure or assess accurately. For this reason, the mass balance equation is typically solved for a combined quantity of internal recycling and settling. The result is a net quantity. If the resultant is negative (an outflow) then it is ascribed to settling while if it is positive (an inflow) then it is ascribed to internal recycling. It is a net amount because in any given month both settling and recycling of TP can occur though only the larger of the two is determined through the mass balance equation.

Solving for the unknown, settling and internal recycling, the budget equation becomes:

$$(+internal\ recycling\ /\text{-}settling) = \Delta\ TP_{Lake\ Mass} - (TP_{Surface\ Water\ Inflow} + TP_{precipitation} + TP_{Groundwater}) + (TP_{Surface\ Water\ Outflow} + TP_{Groundwater})\ (kg)$$

The analysis assumes that the water column is completely mixed during the analysis period, May through September, and the TP mass present in the water column is based on a whole lake, volume-weighted, average concentration. As discussed earlier in the section concerning stratification, this situation is never the case but the utility of applying this calculation is that it allows a rough assessment of the relative level of TP setting and internal recycling.

The TP concentration, determined for each sampling period, was multiplied by the surface and groundwater outflow levels to determine the mass of TP leaving the lake by these pathways. The mass of TP present within the water column for a particular month was determined by multiplying the average lake volume by the volume-weighted average monthly TP concentration. The change in the water column mass of TP for each month was determined by taking the difference in values between successive months. The methods used to determine the inflow TP loads was discussed in the previous section.

In comparing the two years, 1998 was a year of above-average spring surface water inflow, while 2005 had below-average inflow (refer to Figure 10). This difference in inflow was also reflected in the level of external loading. For the analysis period, the external load in 1998 was 2.6 times greater than estimated for 2005 (Figure 28). The lower spring inflow meant that in order to maintain lake volume, the outlet was closed from June through September. This limited TP outflow to just 18 kg TP in 2005 in comparison to 186 kg in 1998.

In 2005, there was a greater amount of TP that settled over the analysis period than calculated for 1998. In 1998, approximately 544 kg settled to sediments while in 2005 it was estimated at 744 kg.

Years with lower external loading, such as 1994 and 2005, tend to have lower summer average TP concentrations in comparison to high inflow years such as 1998. The summer average TP concentration in 1998 was 40 ug/L in comparison to 2005 at 15.9 ug/L. During low inflow years, lake TP concentrations are not maintained through external loading. In 2005, the lower external loading and increased settling resulted in the relatively low average epilimnetic summer concentration of 15.9 ug/L, below the TMDL target concentration. However, higher levels of TP settling may translate into higher internal recycling levels. While 2005 had lower external loading, its internal TP recycling level was 1.7 times greater than determined for 1998, 332 kg in comparison to 196 kg. Net internal recycling for both years analyzed was approximately 40 percent of the net TP settling level.

Important in interpreting these figures is that when calculating these TP pathways it is assumed that the lake remains completely mixed throughout the analysis period, a scenario with a very low probability of occurrence. The utility of calculating a budget by this method is that it provides a relative comparison in the sources and losses of phosphorus over the analysis period. Each summer the lake is stratified, to varying degrees, which limits the movement of phosphorus released by sediments, in the hypolimnion, to the upper water column. What more typically occurs is that TP associated with internal recycling is brought to the upper water column when deeper water column mixing occurs (lake turnover). Under the current in-lake management measures, this usually happens by mid-August.

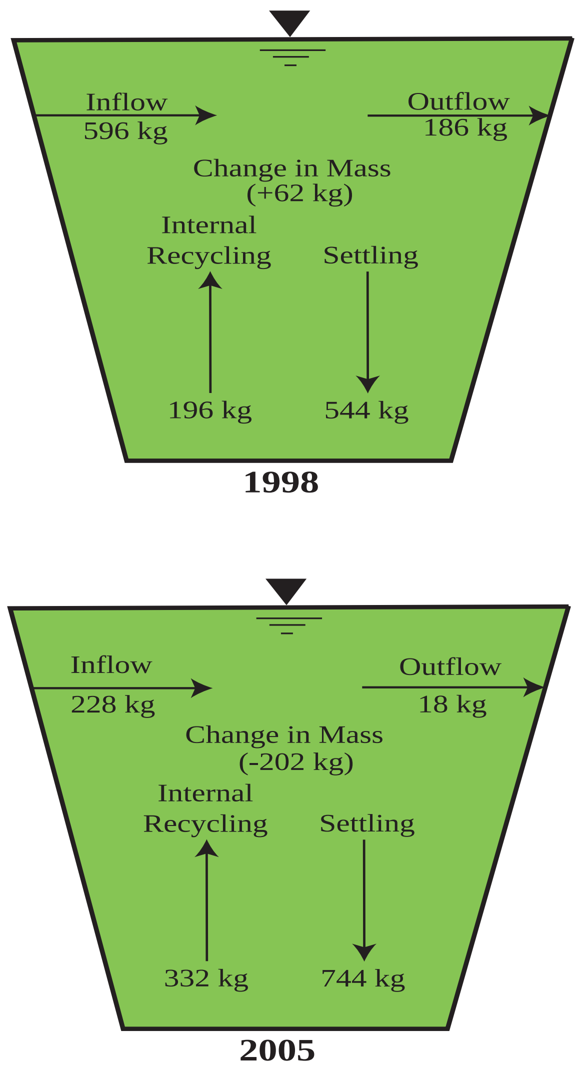

Figure 28. TP budgets (in units of kilograms) for 1998 and 2005 (May through September).

Assuming that the internal recycling levels estimated for 1998 and 2005 represent an average condition, then in terms of the annual TP budget, Thompson Creek and watershed drainage still represent the majority of the TP inflow at 36 percent and 28 percent respectively (Figure 29). Based on the average level observed for 1998 and 2005 (264 kg TP), internal recycling represents 15 percent of the average annual total with onsite wastewater systems and precipitation representing 12 percent and 6 percent, respectively.

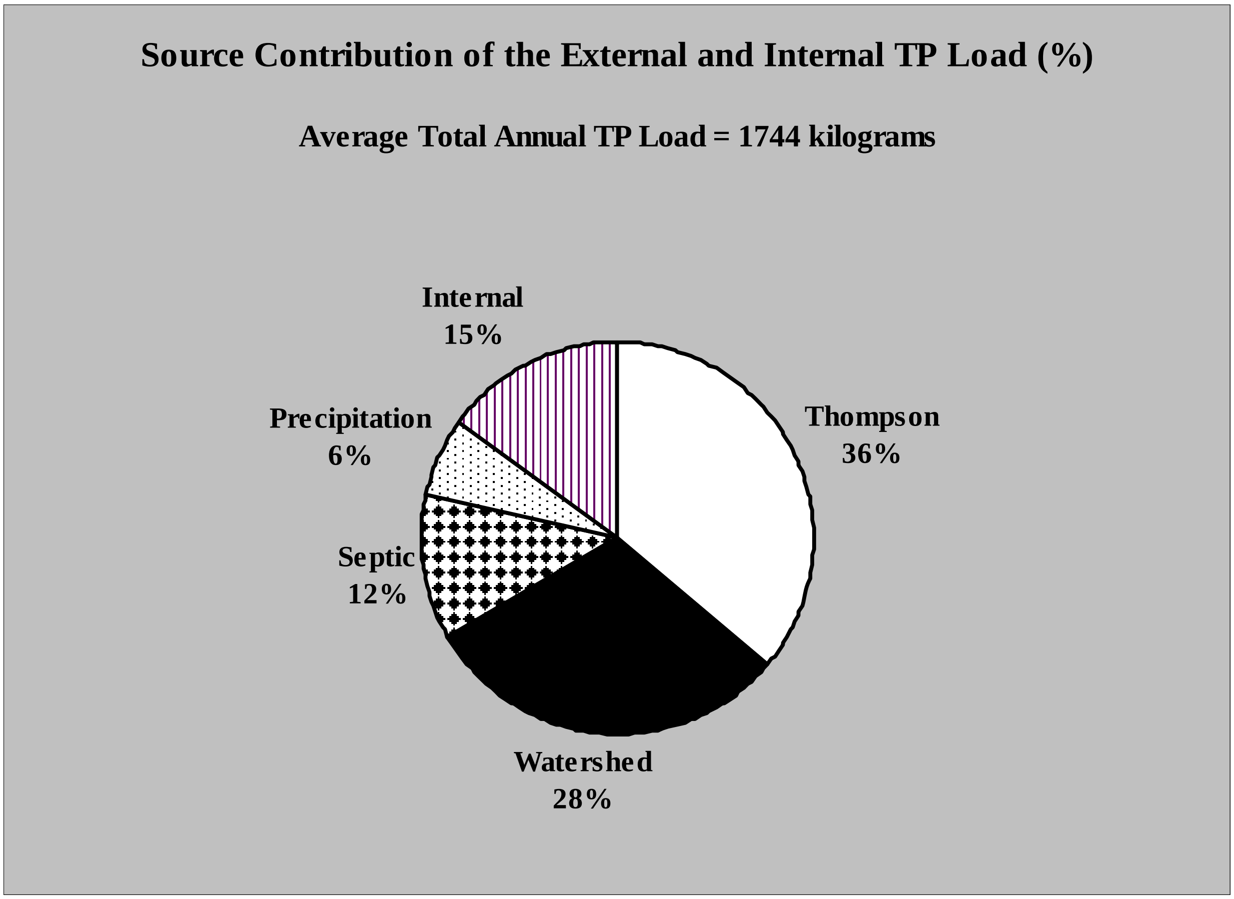

Figure 29. Percentage breakdown of the external and internal TP sources to the epilimnion based on the average annual load.

Loading Capacity

Establishing the load capacity

Within this TMDL, the load capacity is defined as the maximum amount of TP that can be introduced to the epilimnion annually (September to the following August) while maintaining concentrations at or below 20 ug/L. The target concentration is set at a level that is more protective of the beneficial uses of the lake such as aquatic resources and recreational activities. For this study, the critical period is June through August and the target concentration is the average epilimnion (0-3 meters) TP concentration observed during that period. Because a margin of safety is a required component of the TMDL analysis, the load capacity is set at a level that provides a 90 percent assurance that the target is achieved in any given summer period. The target concentration sets the ultimate water quality objective of the TMDL study. The load capacity and pollutant source allocations are all based on meeting the target concentration.

Model application for establishing the load capacity

Figure 30 displays the relationship between the summer and annual external TP loads from 1986 to 2006. The summer period is June through August while the annual load is the period from September to the following August and so it spans from lake turnover through the end of the following year's stratification period. As observed, there is a close relationship between the magnitude of the summer and annual external TP loads. Years with high spring inflow,(the result of increased snow-pack) maintain higher inflow levels during the summer. Deviations to this generalization occur most prominently in 1990 when inflow (loading) rapidly increased in June at a time when flow levels usually decline. Overall, approximately 11 percent of the annual TP load is delivered during the June through August period. However, 57 percent of the annual external load is delivered to the lake between March and May.

The relationship between the estimated annual external TP loads and observed lake TP concentrations is presented in Figure 31. The average summer epilimnion concentration, for the years included as part of this analysis (1986, 1993-4, 1998, and 2005), is 19.7 ug/L, about equal to the target concentration. The average annual external load for these years is estimated at 1088 kg TP. However, when considering the entire analysis period 1986 to 2006, the average annual TP load is 1480 kg ranging from 573 kg TP in 1992, to 3852 in 1997. Applying the linear relationship presented in Figure 31 to the average annual external load for the analysis period results in an average concentration of 25 ug/L.

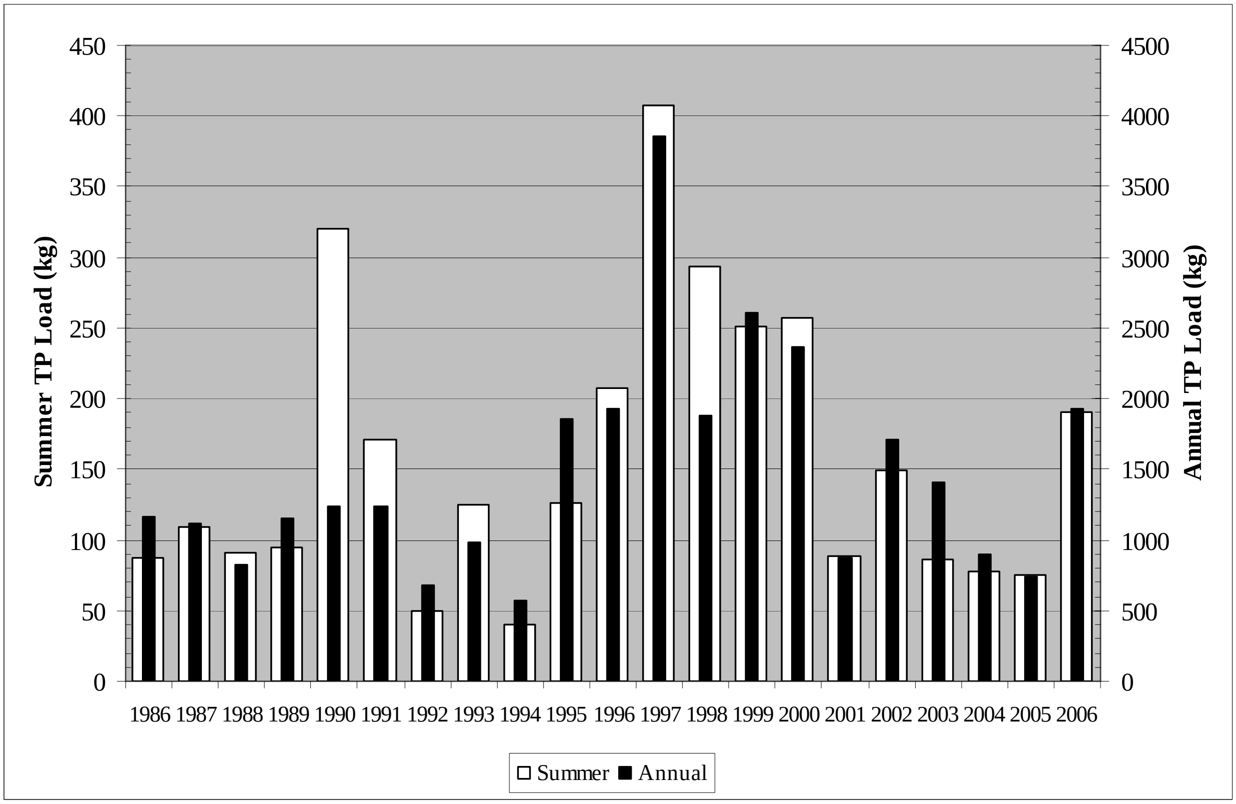

Figure 30. The relationship between estimated annual (September-August) and summer period (June-August) external TP loading to Newman Lake, 1986-2006

Recognizing these relationships, a simple model was used to predict the average summer period epilimnion concentration based on annual external load and inflow levels. The model is a modified version of a Vollenweider-type loading plot (Chapra, 1997). Application of the model was used to establish the TP load capacity for Newman Lake. The model equation and input parameters are provided below.

$$TP = [L_p / (q_s + v)] * 10^3 \text{ (ug/L)}$$

TP……average June-August epilimnion (0-3 meters) TP concentration (ug/L).
L_p……annual external TP load divided by the lake surface area (5,150,000 m^2) (g/m^2-yr).
q_s……annual inflow (m/yr) divided by the lake surface area.
v……..settling velocity (m/yr).

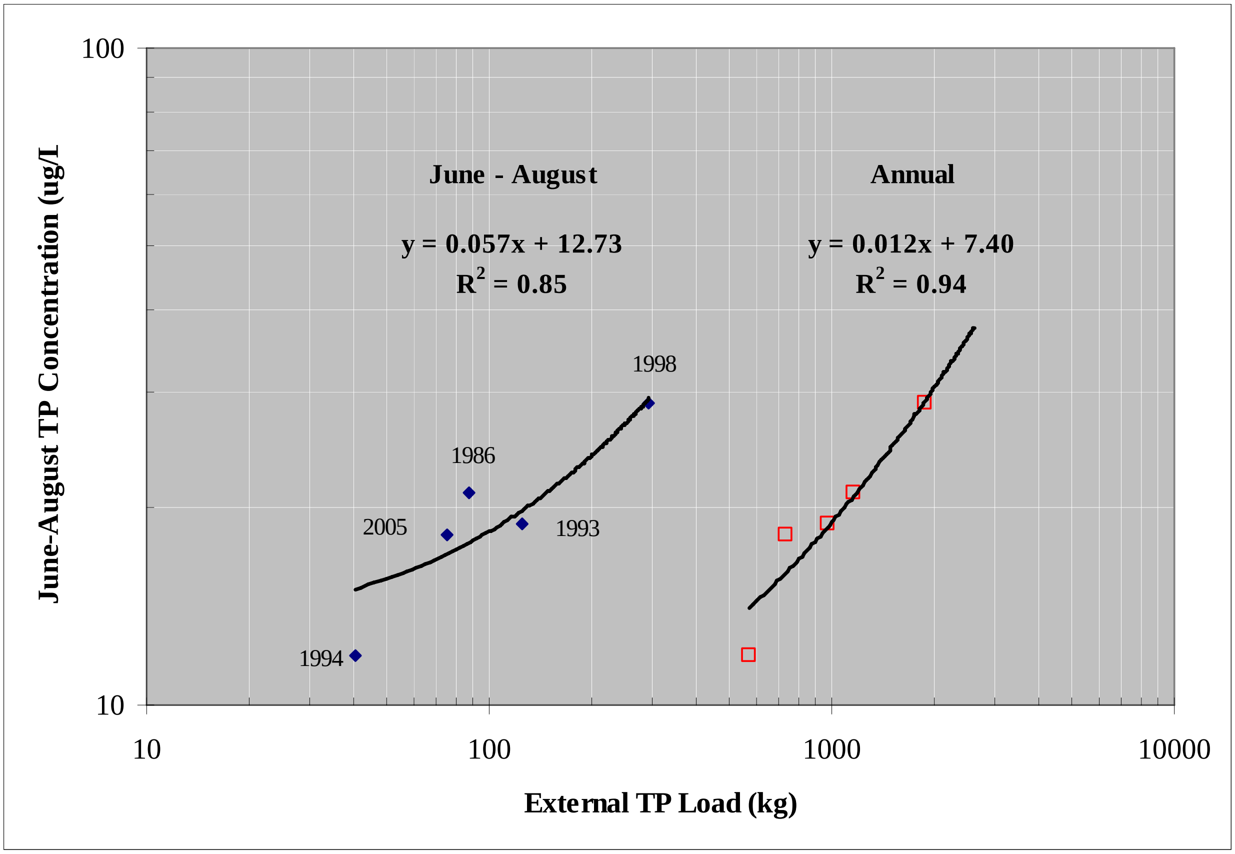

Figure 31. The relationship between summer period (June-August) epilimnion TP concentrations (ug/L) and the summer and annual external TP loads (kg).

Vollenweider examined the relationship between lake physical characteristics (mean depth, flushing rate) and the magnitude of the external TP load, to characterize lake trophic levels. Internal recycling of TP is also an important source to the epilimnion. This source was not incorporated into the model primarily because there is not enough available data to adequately calculate its annual variability. However, because (on average) the majority of internal recycling to the epilimnion occurs at lake turnover, at the end of the critical period, it is not as important a factor in driving average June through August TP concentrations. Instead, the major determinant is the level of external loading which is a function of inflow levels, both primary model variables.

A common gauge of a lake's trophic level is its average epilimnion summer TP concentration. Eutrophic, or high nutrient conditions, are typically found for lakes with TP concentrations above 20 ug/L while oligotrophic conditions are typically found at concentrations below 10 ug/L. A mesotrophic level lies between 20 and 10 ug/L.

Of the parameters in the model, only the settling velocity is unknown. Through application of the equation, a settling velocity of 6.8 m/yr provided the best fit line between observed and predicted epilimnion TP concentrations. The years evaluated were 1986, 1993-94, 1998, and 2005 resulting in an approximately 1:1 relationship with a coefficient of determination of 0.95. This settling velocity, along with the annual variation in external loading and inflow (1986 to

2006), was used to solve for the average summer period epilimnion TP concentration. The results are presented in Table 12.

From this information percentiles were determined for L_P , q_s, and the resulting predictions of average summer period epilimnion TP concentrations (Table 13). The criteria used to establish the load capacity are that, based on the percentiles (1986-2006), that there is a 90 percent assurance that in any given year the summer period epilimnion TP concentration will remain at 20 ug/L or less. The model was used to determine the load capacity by reducing external loading (Lp) to a level that achieved that criteria. The variable q_s, associated with the level of inflow, remained unchanged. (The load associated with precipitation also remained unchanged.) The results of this analysis are presented in Table 13.

Table 12. Model input parameters and estimated TP concentrations, by year.

Year	Annual External Load (kg)	L_P (g/m^2-yr)	Annual Inflow (m^3/yr)	q_s (m/yr)	TP-Estimated (ug/L)	TP-Measured (ug/L)
1986	1165	0.226	18466437	3.586	21.8	21.0
1987	1114	0.216	17759336	3.448	21.1	
1988	820	0.159	13214928	2.566	17.0	
1989	1157	0.225	18545335	3.601	21.6	
1990	1236	0.240	19731106	3.831	22.6	
1991	1241	0.241	19498806	3.786	22.8	
1992	678	0.132	10844062	2.106	14.8	
1993	976	0.190	15755011	3.059	19.2	18.9
1994	573	0.111	9039026	1.755	13.0	11.9
1995	1852	0.360	29194167	5.669	28.8	
1996	1932	0.375	30317611	5.887	29.6	
1997	3852	0.748	59126860	11.481	40.9	
1998	1883	0.366	29058755	5.642	29.4	28.8
1999	2605	0.506	39880471	7.744	34.8	
2000	2371	0.460	36342027	7.057	33.2	
2001	871	0.169	13533021	2.628	17.9	
2002	1711	0.332	26343379	5.115	27.9	
2003	1412	0.274	22004680	4.273	24.8	
2004	895	0.174	14515328	2.819	18.1	
2005	736	0.143	11983437	2.327	15.7	18.1
2006	2003	0.389	30068459	5.839	30.8	

Figure 32 presents this analysis graphically. Within the figure, the loading level (L_p) required to maintain an average summer period concentration of 20 ug/L and 10 ug/L, through variations of inflow, are presented. From Figure 32, for instance, at an inflow rate (q_s) of about 5 m/yr the maximum TP loading rate at which the summer period concentrations will be 20 ug/L and 10 ug/L are 0.236 g/m^2-yr and 0.118 g/m^2-yr, respectively. The data plotted as squares are the percentiles of q_s and L_p estimated for the lake from 1986 to 2006 (as presented in Table 13). Median levels of q_s and L_p for the 1986 to 2006 period are 3.79 m/yr and 0.240 g/m^2-yr resulting in a median summer period TP concentration of about 23 ug/L (Table 13).

A 39 percent reduction in the external loads (1986 to 2006) was required in order to achieve the criteria. With a 39 percent reduction, the 90th percentile summer period epilimnetic concentration is estimated at 19.9 ug/L with a median of 14.0 ug/L (Table 13). The effect of this reduction is presented in Figure 32.

Based on the 39 percent reduction, the annual load capacity for Newman Lake is 903 kilograms from external TP sources and 264 kilograms from internal sources for a total of 1167 kilograms per year. This load capacity, set for the epilimnion, represented by the upper 3-meters of the water column, will result in a 90 percent assurance that the summer period average concentration will be 20 ug/L or less. The total load capacity set on a daily basis is 2.47 kilograms for external sources and 0.72 kilograms for internal sources.

Table 13. Percentiles of the input parameters and resulting TP concentrations estimated, 1986 to 2006.

	1986 – 2006			Estimated TP w/ 39 percent Reduction in External Load	
Percentile	**Lp (g/m^2-yr)**	**qs (m/yr)**	**Estimated TP**	**Lp**	**Estimated TP**
100	0.748	11.48	40.9	0.446	24.4
95	0.506	7.74	34.8	0.302	20.8
90	0.460	7.06	33.2	0.275	19.9
85	0.389	5.89	30.6	0.239	18.8
80	0.375	5.84	29.7	0.228	18.1
75	0.366	5.67	29.3	0.220	17.7
70	0.360	5.64	28.9	0.220	17.7
65	0.332	5.12	27.9	0.201	16.8
60	0.274	4.27	24.8	0.167	15.1
55	0.241	3.83	22.7	0.149	14.0
50	0.240	3.79	22.7	0.148	14.0
45	0.226	3.60	21.7	0.140	13.4
40	0.225	3.59	21.6	0.140	13.4
35	0.216	3.45	21.1	0.134	13.1
30	0.190	3.06	19.2	0.119	12.0
25	0.174	2.82	18.1	0.109	11.4
20	0.169	2.63	17.9	0.104	11.0
15	0.159	2.57	17.0	0.100	10.7
10	0.143	2.33	15.7	0.091	9.9
5	0.132	2.11	14.8	0.083	9.3
0	0.111	1.76	13.0	0.070	8.1

Based on the period 1986 to 2006, a 39 percent reduction in the average annual external TP load will result in a decline from 1480 kg to 903 kg. The load capacity for the internal load is set at the annual average level estimated at 264 kilograms. It is assumed that the internal loading component will, however, decline with further reductions in external TP loading. Together, the TP load capacity to the epilimnion annually (September through the following August) is set at 1167 kilograms.

Epilimnon Load Capacity (September through August) = 1167 kilograms TP

- External Load = 903 kilograms
- Internal Load = 264 kilograms

Result of load reductions on water quality

A consideration in establishing a TP load capacity for Newman Lake is the effect that load reductions will have on water clarity. In some situations, rapid changes in water clarity, for instance, brought about by a whole lake alum treatment, can result in favorable conditions for excessive macrophyte growth, and so can result in establishing yet another water quality problem.

Figures 3 and 4, in the Applicable Criteria section, display the relationship between TP concentrations, chlorophyll (a) concentrations, and Secchi depth observed in Newman Lake. Currently, average epilimnion summer period TP concentrations are between 20 and 30 ug/L. A 39 percent annual external TP load reduction, and decrease in summer TP concentrations to a range between 10 to 20 ug/L, results in a shift in the median chlorophyll (a) concentrations from the current level within the 5-12 ug/L (defined by the inter-quartile range) to the 5-7 ug/L range (refer to Figure 3).

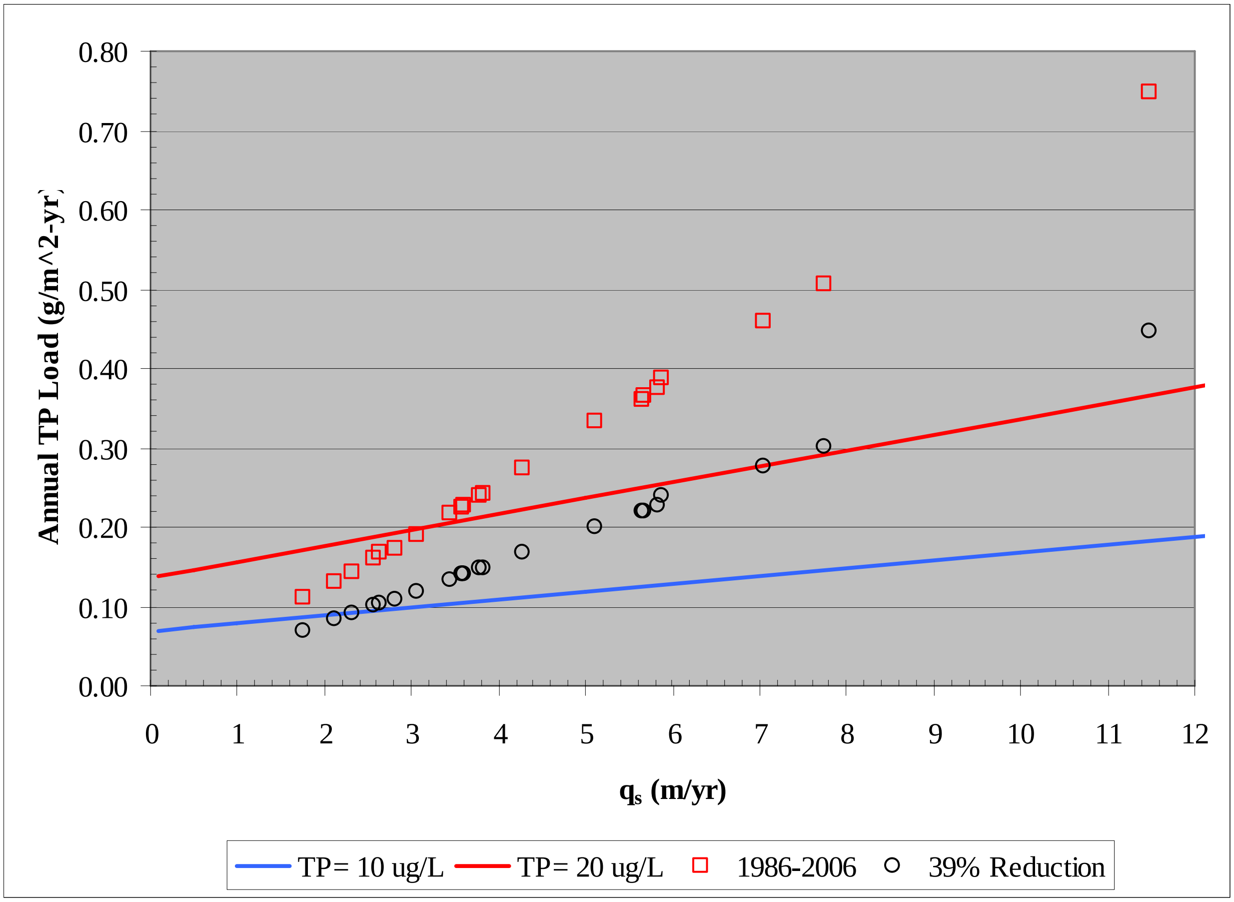

Figure 32. Percentiles of: external TP loading (Lp) estimated for Newman lake, 1986 to 2006; with a 39 percent reduction; and the level to achieve a 20 ug/L and 10 ug/L concentration through variations in inflow (qs).

This decrease in chlorophyll (a) levels results in an increase in water clarity, as indicated by Secchi depth, of approximately 1 meter from a range between 2 to 3 meters to one between 3 to 4 meters.

The ability of macrophytes (aquatic plants) to colonize various areas of the lake is dependent primarily on water clarity and depth. Increased water clarity allows macrophytes to colonize a larger area. For the majority of the lake's shoreline, the slope of the bottom sediments are relatively steep (Figure 1). The exception occurs at the south-end of the lake particularly towards the outlet. Here, an increase in water clarity exposes a significantly larger portion of the bottom sediments to light resulting in an increased vulnerability to macrophyte growth. The current average Secchi depth of 2 meters, or around 7-feet, will increase to around 10-feet (3 m) with the loading reduction. In examining the bathymetry of the lake, the 1 meter increase in clarity provides a good compromise because further increases in clarity result in substantially greater exposure of sediments to light, particularly at the lake's south end.

Load Allocations

Epilimnion Annual (September through August) Load Allocations

- Thompson Creek Drainage = 365 kilograms TP
- Watershed (outside of Thompson Creek drainage) = 310 kilograms TP
- On-Site Wastewater Systems = 121 kilograms TP
- Precipitation = 107 kilograms TP
- Internal Recycling = 264 Kilograms TP

A TP load capacity for Newman Lake has been established at 903 kg that can enter the lake from external sources, September through the following August, while maintaining the average summer period epilimnion concentration at or below 20 ug/L, 90 percent of the time. In order to meet these targets, an overall 42 percent reduction in the current (1986-2006) average external load is necessary. Among the external TP sources, precipitation is not a controllable one. Therefore, the average annual TP load estimated for the analysis period has been set as the allocation for precipitation. Because the phosphorus present in precipitation is not controllable, an increased level of reduction among the other sources is required. This is the reason why overall a 39 percent reduction is required to meet the load capacity while a slightly greater (42 percent) reduction is required among controllable sources.

The primary objective for establishing TP source allocations is to improve water quality to maximize the beneficial uses of the lake. There are, however, limits to the level of reduction possible. Total phosphorus is detectable in even the most pristine drainages. In addition, alteration to the natural landscape through, for instance, residential development, roads, agriculture, and forestry land use typically lead to increased introduction of phosphorus within surface water drainage. Recognizing that those land uses are present within the Newman Lake watershed and affect TP levels, the emphasis is not on establishing source allocations that are reflective of background loading levels. Rather, the emphasis is on setting realistic allocation targets with the understanding that through education and the implementation of best management practices, improvements can be made to reduce TP levels associated with these land uses.

The focus of this TMDL is on establishing limits to external phosphorus sources due to the fact that management measures to control in-lake phosphorus recycling are currently in place and that the concentration of phosphorus observed in the upper water column of Newman Lake is closely related to the level of external inflow (loading). This study assumes that over time, with control of external phosphorus sources, the impact to water quality from internal sources will also decline. The load allocation for phosphorus associated with internal recycling was set to an annual average level estimated for 1998 and 2005. Further reductions to achieve the target concentration will come from reductions in external sources.

Sources include surface water inflows and on-site wastewater systems. While precipitation is a source of phosphorus to Newman Lake it can not be controlled and so was not considered in setting load reductions. Surface water inflows were divided into those for Thompson Creek and the collective drainage exclusive of Thompson Creek within the greater Newman Lake watershed. The division here is due to the dominant influence of Thompson Creek on the lake hydrology and due to differing landscape influences on phosphorus concentrations. Thompson Creek largely drains managed forestlands in comparison to the majority of the other surface water drainages where residential development has a significant influence on phosphorus concentrations.

Thompson Creek allocation

Liberty Creek, the main surface water inflow to Liberty Lake, is located approximately 12 kilometers south of Newman Lake. It shares similar relief, soils, and geological characteristics with Thompson Creek (USDA, 1968). With the exception of alterations to its lower reach, the Liberty Creek watershed is relatively unmanaged with no road systems or industrial forestry practices. The water quality of Liberty Creek has been a focus for the Liberty Lake Sewer and Water District for a number of years with total phosphorus analyses being conducted as part of their data collection efforts (http://207.88.115.227/libertylakemonitoring/liberty_creek.htm). For these reasons, Liberty Creek serves as a good reference condition for comparison to Thompson Creek.

Flows measured in Liberty Creek (at the bifurcation) were compared to the daily average flows estimated for Thompson Creek. A least squares equation (with the y-intercept set to 0) determined that (on average) the flow in Liberty Creek is 0.45 times the level estimated for Thompson Creek (r^2=0.88). This relationship is expected because while the two creeks share similar geology and relief, Liberty Creek has about half the drainage area of Thompson Creek, 1565 ha in comparison to 3132 ha. For this reason, both drainages share a similar water yield. On average, from 1985 to 2006, the water yield for Thompson Creek and Liberty Creek are 0.35 m^3/m^2-yr, and 0.31 m^3/m^2-yr, respectively. While the two drainages share a similar water yield their total phosphorus concentrations and yields are quite different.

Figure 33 presents box plots of the total phosphorus concentrations observed in Liberty Creek along with those for Thompson Creek. The median TP concentration observed in Thompson Creek of 43 ug/L is about 3 times greater than observed in Liberty Creek (13 ug/L). Adequate TP measurements were collected from Liberty Creek from 1983 to 1985 allowing the calculation of annual loads using the Beale ratio method (Richards, 1998). From this method, the loads estimated for 1983 through 1985 were 101 kg, 103 kg, and 36 kg, respectively. In comparison, estimates for Thompson Creek for this same period were 1122 kg, 1127 kg, and 442 kg, respectively. Based on the average loads calculated for Thompson Creek and Liberty Creek 1983-1985 the annual yields, expressed on a per hectare basis, are 0.29 kg TP/ ha-yr and 0.05 kg TP/ha-yr, respectively. The annual per hectare yield estimated for Thompson Creek is about six times greater than estimated for Liberty Creek. As discussed earlier, the average TP yield for Thompson Creek for the period 1985 to 2006 is 0.20 kg TP/ ha-yr. Annual TP loads were estimated for Liberty Creek from 1985 to 2006 by multiplying the median TP concentration (13 ug/L) by annual flow levels. An overall average load for this period was estimated at 67 kg TP resulting in a yield of 0.04 kg TP/ ha-yr. So, on average, the TP yield for Thompson Creek is about five times greater than estimated for Liberty Creek.

While it is recognized that achieving the TP yield estimated for Liberty Creek would be difficult within the managed Thompson Creek drainage, a 42 percent reduction, resulting in a yield of 0.12 kg TP/ha-yr, is manageable and consistent with the overall load capacity reduction. A 42 percent reduction in the TP yield for Thompson Creek is still at a level that is about three times greater than estimated for Liberty Creek. This reduction level results in an average annual TP load allocation of 365 kg TP.

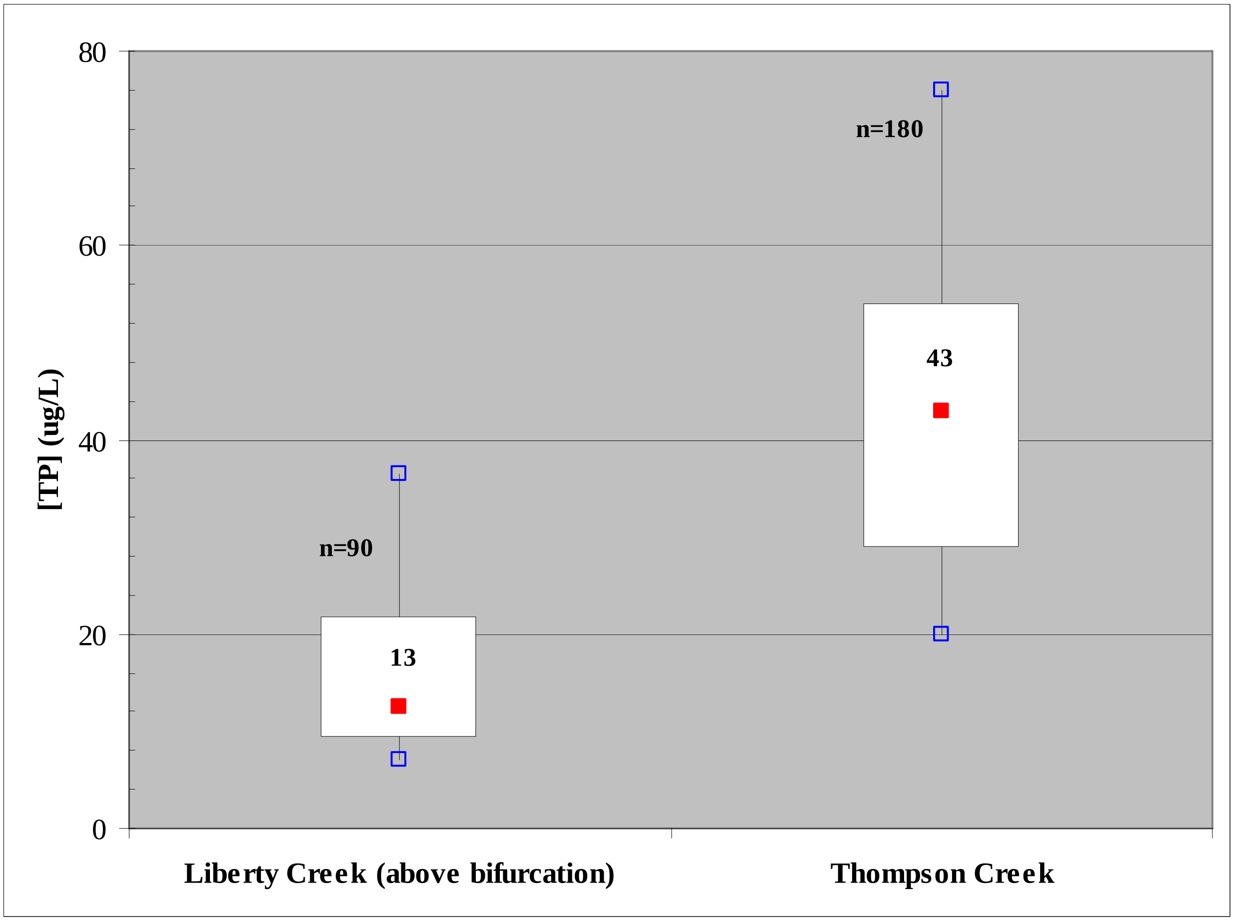

Figure 33. Box plots of total phosphorus (ug/L) observed at Liberty Creek and Thompson Creek.

Watershed allocation

To assess the potential level of reduction that can be achieved for the watershed drainage to Newman Lake, a reference condition is necessary. Referring to Figure 25, the median TP concentration observed at the inlet stations 6-9 is 64 ug/L. When this concentration is applied to the flows levels estimated from 1985 to 2006 the average annual TP load is 535 kg. This load results in an average yield of 0.11 kg TP/ha-yr. A 42 percent reduction in this yield level results in 0.06 kg TP/ha-yr.

The median concentration of TP observed in inlet 1 is 39 ug/L. This concentration is about 40 percent lower compared to those observed at the other inlet locations. Though among the lowest TP contributors, this drainage is not without its own non-point source impacts due to historic land use practices. But in comparison to the other inlets, this drainage has a lower level of residential, agricultural, and forestry-related impacts that effect TP levels. The lower level of non-point source impacts is evident in the reduced variability in TP concentrations. For this reason, the TP concentrations observed in inlet 1 serve as a reference condition for the surface water inflow from the watershed. The phosphorus allocation associated with surface water drainage is set at a 42 percent reduction from the current estimated levels resulting in a load allocation of 310 kg TP.

On-site wastewater allocation

In the Technical Analysis section of this report, it was estimated that annually 414 kilograms of phosphorus is associated with wastewater discharged to soils surrounding Newman Lake. Earlier studies set this estimate at 910 kg/yr, more than twice the level estimated by this analysis (Funk et al, 1974). Of the 414 kg of phosphorus discharged to soils, it was estimated half, or 207 kg, entered the lake annually, assuming a 50 percent soil retention rate. Given the soil conditions surrounding the lake, it is likely that the overall retention rate is lower meaning a greater amount of phosphorus enters the lake from this source.

Soils surrounding Newman Lake (primarily the Moscow and Spokane series) because of their shallow depth to bedrock and slope combine to make the lake particularly vulnerable to the export of phosphorus from on-site systems. Approximately 77 percent of the residences along the shoreline of Newman Lake are situated within the Moscow and Spokane soil series. While phosphorus loading associated with on-site wastewater systems was not found to be as great as that attributed to surface water sources, this and prior analyses identified sections of the lake with a high probability for system failures (NLWPC, 1990). Based on this vulnerability and estimates of phosphorus loading from this source that could be substantially higher, the allocation is also set at a 42 percent reduction from current estimated levels. The load allocation associated with on-site wastewater systems is 121 kilograms. This allocation results in an annual retention level of about 70 percent, an increase of 20 percent above the estimated level.

Important, in terms of this assessment, is some expectation of what future increases in TP can be expected from on-site systems primarily associated with future residential development. Some measure of this can be determined through an examination of the Spokane County Assessor's parcel designated code 91 or residentially undivided land (see Table 7). As of 2007, there are 231 parcels within 1000 feet of the shoreline that have this designation. Not all of these parcels can be developed due to site restrictions such as available water supply, wastewater treatment limitations, easements, proximity to sensitive areas among others. However, assuming conservatively that 50 percent of these parcels could be developed into residences and, applying the residential use scheme used in this TMDL, results in an increase of 70 kilograms TP per year or about a 17 percent increase in loading above the current estimate. This assumes that the residential seasonal use pattern does not change. Current increases in land values throughout the county and in proximity to lakeshores, in particular, may result in the transfer of property use from seasonal to primary due to the increased burden of property taxes and interest in realizing profits.

Over the past decade, residential development surrounding the lake has been steady. So it is not a question of whether the development will occur but rather to what extent and what will be its ultimate type of use. The greater Newman Lake watershed is zoned Rural Conservation and Forest Land. Residential development within the Rural Conservation designated zone is limited to 1 house per 20 acres (or 1 house per 10 acres with cluster-type development). This zoning limitation, of course, does not apply to the existing parcels smaller than 20 acres. For this reason, the only area within the watershed available for significant expansion of residential development is largely within the critical zone within 1000 feet of the lakeshore. This is why residential development (and the TP associated with it) represents the largest emerging source of TP to Newman Lake.

Margin of Safety

While the margin of safety was considered throughout the TMDL through conservative assumptions it was ultimately applied globally to the analysis through the setting of the load capacity. Establishing the load capacity is one of the primary objectives of the TMDL and its determination underlies the majority of the TMDL analysis. It is an endpoint of the analysis. With this in mind, its determination serves as an optimal point at which to apply a margin of safety. In this TMDL study the load capacity is defined as the maximum amount of TP that can be introduced to the upper water column (epilimnion) from September to the following August while maintaining a concentration at or below 20 ug/L. The load capacity was set based on providing a 90 percent assurance that the target TP concentration will be achieved in any given summer period. In addition, the 90 percent assurance level provides a high margin of safety because it incorporates the variability in TP loading estimated over a twenty year period, 1986 – 2006.

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Summary Implementation Strategy

What needs to be done

The intent of the TMDL implementation strategy is to formulate methods of source control to be applied on a watershed-wide scale for long term reductions of phosphorus loading to Newman Lake. The Newman Lake loading capacity analysis shows that the external phosphorus loading needs to be significantly reduced from estimates of post-1985 average levels to an annual load of 903 Kg/year. The allocation for an allowable external load assumes that the internal loading will not increase from the current estimates. Then the TMDL Advisory Group will develop a water quality implementation plan (formerly known as the detailed implementation plan). The advisory group will refine and prioritize the general strategy elements summarized by this document.

Past lake water quality restoration activities have been credited with significant reductions in internal phosphorus loading. The lake restoration process also funded the development of several documents containing common strategies for control of external nonpoint sources (Newman Lake Watershed Plan, 1992, Comprehensive Storm Water Control Plan, 1997). Improvements in forest harvest practices, forest road maintenance, and changes in livestock grazing management have occurred in portions of the watershed. However, lake water quality monitoring indicates that summer phosphorus in the upper layer of the lake (epilimnion) and average summer water clarity, as measured by Secchi disk, have not significantly improved since initiation of the lake restoration activities. This indicates that an emphasis should be placed on less implemented phosphorus control strategies to achieve significant in-lake phosphorus reductions.

Newman Lake has a relatively large area of forested watershed compared to its lake volume which results in 83 percent of the entire lake volume to be flushed out in a normal year. This means that during a normal or high run-off year, summer lake water quality is very dependant on the quality of the spring runoff event. This also means that seemingly small changes in land use and/or resource management over many acres of watershed can make a significant change in lake water quality. According to the last land use survey for the period 1997 through 2004, twenty-one miles of new road were constructed, logging occurred to some extent over about thirty four percent of the watershed, and more than 200 acres were permitted for conversion from forest to residential land use. The cumulative impacts of these activities make it important that the entire Newman Lake Watershed be managed in the future with a systematic approach. The watershed needs special resource protection so that focused, results-based nutrient control measures are put in place at a scale that will make a lasting difference.

The following implementation strategies to reduce phosphorus loading are divided into upland and near-shore categories to reflect the geographic character of the watershed. Several strategies are common to those previously identified and resolved by the Spokane County Commissioners in 1999 for implementation in the Newman Lake watershed. A few others have not been previously suggested for implementation. It is clear that extensive local government participation, public education, financial assistance, and regulatory enforcement will all be essential for successful implementation of strategies to restore and protect Newman Lake.

Upland phosphorus source reduction strategies

1) *Commercial forest management* – The land use survey reported that forestry land use comprises seventy-eight percent of the Newman Lake watershed. This results in tributary water quality being substantially affected by forest management practices. Logging and road building practices common throughout the intermountain region from the late nineteenth century through the most of the twentieth century have resulted in significant degradation of Newman Lake's watershed. Recently, implementation of more environmentally sound forest management practices has begun.

   The Forest Practices Act administered by the Washington Department of Natural Resources (Washington DNR) defines the minimum level of best management practices (BMPs) required to be implemented for commercial timber lands in Washington. It is anticipated that the new road maintenance and abandonment plans (RMAPS) along with other BMPs required by the revised forest rules will slowly reduce phosphorus export from harvested forests.

   Because of the sensitivity of Newman Lake water quality to cumulative forest land management changes, proposed timber harvest projects should be balanced with the watershed's rate of recovery from previous forest practices. This type of holistic forest planning is not considered under the Forest Practices Rules, but might be voluntarily considered along with more aggressive reforestation and accelerated road rehabilitation.

2) *Non-industrial forest management* – Small forest owners are also subject to portions of the Forest Practices Rules including requirements of RMAPS unless they are exempted due to size. The Washington Department of Natural Resources (DNR) provides technical and financial assistance to small landowners for forest management activities. The comprehensive Newman Lake implementation plan will need to address exemptions of Forest Practices Rules and timber harvest practices regulated by Spokane County. As forestry land is divided and sold in smaller parcels for residential land uses, planning of these conversions will need include to special road design for conversions of logging roads to permanent roads and account for cumulative impacts.

3) *Watershed-scale road planning and rehabilitation* – A watershed-scale management survey should inventory ownership and prioritize the total miles of erodible roads and road banks. Watershed specific implementation plan will be developed to reduce miles of erodible roads with more stringent regulations for road construction, road conversions, and maintenance. A watershed database of roads with tracking of BMP implementation is essential for determining success and accountability. The plan should identify opportunities to abandon and restore nonessential roads and correct existing roads that are poorly designed/maintained and contributing to obvious erosion problems.

4) *Control residential development storm water* – Resources needed to educate citizens and assure compliance with erosion and sediment control standards currently contained in county ordinance should be identified and funded specially for the Newman Lake watershed. Some of the construction sites will be subject to the new National Pollutant

Discharge Elimination (NPDES) construction storm water general permit when one acre or more of land is disturbed with potential for discharge to surface water.

5) *Restore sediment/phosphorus traps* – Opportunities will be identified and restoration plans implemented with cooperating land owners to restore natural riparian/wetland systems that have historically retained sediment and phosphorus in the watershed. These should include restoration of degraded natural riparian corridors that have been dredged and straightened. Engineered sediment ponds with annual maintenance should also be explored for mitigation of activities contributing to erosion.

Near-shore phosphorus source reduction strategies

1) *Eliminate shoreline septic system leachate where feasible* – Near-shore septic systems are estimated to contribute about 14 percent of the lake's annual external phosphorus load (207 Kg/Year). Most of this load is in the form of biologically reactive phosphorus and is readily available for immediate algal uptake upon reaching the lake. This source can be reliably eliminated by implementing wastewater management that exports the wastewater from the watershed or removes phosphorus from the wastewater before it is discharged. Economic and land use planning considerations can often prevent the removal of near shore septic systems in some places. However, removal of shoreline septic systems has been successfully implemented to reduce external phosphorus loading around other Eastern Washington and North Idaho lakes.

   New wastewater management alternatives, such as decentralized septic tank effluent pump (STEP) systems combined with new designs for small flow treatment technology, can achieve phosphorus concentrations near the target concentration for Newman Lake. A decentralized approach can minimize conveyance costs and allow phased implementation for cluster developments. This approach should be evaluated against other traditional wastewater designs previously rejected. The decentralized approach may also provide some alternative finance and governance solutions not previously considered.

2) *Restore degraded wetland/riparian functions* – Lowland streams and wetlands should be restored to more naturally functioning riparian systems. In a functioning system, high runoff events are dissipated into the wetland acting as a phosphorus filter by promoting sedimentation, phosphorus mineralization, and plant uptake. Financial incentives for landowners to participate restoration of these wetland areas should be identified and promoted.

3) *Reduce shoreline erosion* - Shoreline erosion from excessively high boat wakes has been raised as a concern by several citizens in public meetings. Potential methods of controlling shoreline erosion from wave action should be developed and implemented to reduce their impacts:

   - Consider controls on excessive boat wakes for sensitive areas of the lake.
   - The lake level management protocols should be reviewed with consideration of lowering the full-pool target to reduce shoreline erosion.

- To help dissipate wave energy, native emergent wetland plants should be reestablished on portions of the previously altered shoreline as part of shoreline restorations.

- Lakeshore homeowners should be provided focused technical assistance with shoreline landscape design. The departments of Ecology and Fish and Wildlife should work closely with Spokane County and others to develop an integrated template for acceptable shoreline landscape design and shoreline restorations. A well designed landscape should be aesthetically pleasing while enhancing aquatic habitat, reducing shoreline erosion, and act as a nutrient adsorbing buffer.

4) *Control construction erosion* – Identify resources needed to assure compliance with erosion and sediment control plans currently required by county ordinance. Develop corrections to the perceived lack of effective erosion control being implemented by Spokane County. Review of county ordinance should also be made to make sure that all BMPs are included. Because of the watersheds sensitivity to erosion and phosphorus, near-shore grading projects should be closely scrutinized regardless of size.

5) *Control storm water from shoreline roads and driveways* – Develop prescriptive design and maintenance standards including special bank stabilization and revegetation requirements. Identify mechanisms for assuring compliance and provide financial resources for education and enforcement. Existing driveways with erosion problems need to be identified and retroactively corrected with financial and technical assistance.

6) *Reduce Landscape runoff and phosphorus leaching* – Eliminate unnecessary use of phosphate fertilizer and significantly increase buffer distances between the lake and lawns. Well designed landscape buffers can take up excess nutrients and water while stabilizing the lakeshore. Develop specific landscape design recommendations with professional design assistance and possible financial incentives when integrated into a shoreline restoration project. Model shoreline gardens should be developed as examples of preferred designs with hosted public tours.

Internal phosphorus loading control

The control of excessive internal phosphorus loading is necessary for the continued success of the Newman Lake restoration and implementation of the TMDL. An independent peer review should be performed to assess the effectiveness of current practices for controlling of internal phosphorus loading and its relationship to summer epilimnetic phosphorus. The peer review should be conducted by a nationally recognized lake restoration expert and evaluate alternative methods to control internal phosphorus loading and reducing lake algae (phytoplankton) growth. The review should include a detailed economic analysis of the existing system compared to other alternatives including evaluations of both short and long term funding needs.

Who needs to participate

Private landowners

- Forest
- Agricultural
- Shoreline

Local governments

- Spokane County
  - Flood Control Zone District operates and maintain dikes, outlet gates and aerator
  - Issue erosion and sediment control permit
  - Issue approach road approach permits and maintain county roads
  - Administer shoreline protection ordinances
- Spokane Regional Health
  - Approve individual on-site septic systems with subsurface disposal
  - Issue public health advisory sometimes related to lake water quality
- Spokane County Conservation District
  - Natural resource education and assistance

State agencies

- Department of Ecology
  - TMDL Water Quality Implementation Plan (detailed implementation plan)
  - NPDES Permits for alum injections, nuisance aquatic plant control, construction storm water
  - Oversight of riparian and wetland projects
  - Approve and permit larger wastewater treatment systems
- Department of Fish and Wildlife
  - Issue hydraulic project approvals for work below the high water line
  - Manage fisheries
  - Maintain public access
- Department of Natural Resources
  - Issue forest harvest permits
  - Assure compliance with forest practices rules
  - Assistance to Small Forest Landowner
- Washington State Parks
  - Public land manager in northern portion of watershed
- Department of Health
  - Approve medium-size community on-site septic systems with subsurface disposal

Federal agencies

- Environmental Protection Agency
  - TMDL Approval and NPDES permit oversight
- USDA - National Resource Conservation Service
  - Resource enhancement cost-share and conservation easement programs

Schedule for achieving water quality standards

It is anticipated that ultimate reduction of nonpoint phosphorus sources will be a long term process (20 years) while establishing riparian restoration projects and reforestation of logged land.

It is foreseeable that the external phosphorus loading may be significantly and reliably reduced from current loading in the next ten (10) years by aggressive removal of near-shore septic system leachate, correcting the majority of the highest priority road erosion problems, and reducing shoreline erosion. The revised forest practices regulations require that all roads meet the construction and maintenance guidelines by 2016, so ultimate reductions in phosphorus export will be delayed.

Public education and focused implementation of effective erosion control programs for new projects should occur over the next two years with mechanisms identified for continued monitoring and enforcement.

Reasonable assurances

When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint sources) in the water body. For the Newman Lake Phosphorus TMDL, both nonpoint and storm water point sources exist. TMDLs (and related action plans) must show “reasonable assurance” that these sources will be reduced to their allocated amount. Education, outreach, technical and financial assistance, permit administration, and enforcement will all be used to ensure that the goals of this water clean up plan are met.

Ecology believes that the following activities already support this TMDL and add to the assurance that phosphorus in Newman Lake will meet the conditions provided by Washington State water quality standards. This assumes that the activities described below are continued and maintained.

The goal of the Newman Lake water quality improvement plan for phosphorus is for the lake to meet the state’s water quality standards. Based on past lake restoration efforts and financial commitments made by Newman Lake Flood Control Zone District, Spokane County, as well as citizen volunteer efforts of the Newman Lake Properties Owners Association, there is considerable interest and local involvement toward resolving the water quality problems in the Newman Lake.

The citizen associations, forest land owners, local government, and natural resource agencies will continue to actively pursue remedies identified in the water quality implementation plan. The following rationale helps provide reasonable assurance that the Newman Lake nonpoint source TMDL goals will be met by 2026.

1. The following ongoing nonpoint source control programs are currently being implemented:
    a. The revised forest practices rules have begun to be implemented on the commercial forest land including some recent changes in road management. New forest practices rules for roads also now apply. These include new road

construction standards, as well as new standards and a schedule for upgrading existing roads. Under the new rules, roads must provide for better control of road-related sediments, provide better stream bank stability protection, and meet current Best Management Practices. DNR is also responsible for oversight of these activities.

b. Inland Empire Paper Company has implemented a controlled access program at entrances to their forest property to reduce erosion caused off-road recreational vehicles.

c. Spokane County purchased 420 acres of conservation land with 3000 feet of water front along the northwest shore of Newman Lake for $1.54 million. The purchase of this land will prevent likely future erosion that would have been caused by residential development on the property.

d. Several private landowners have voluntarily reduced the amount of livestock grazing and confined feeding operations historically located along lower portions of the tributaries to the lake.

e. The flood control zone district is required to implement external phosphorus control strategies in order to receive a NPDES discharge permit for alum injection with the aerator.

2. The initial lake restoration project provided educational material to lake-shore homeowners. Ongoing environmental education to elementary school students and support of a Newman Lake world-wide webpage is occurring with financial assistance from an active grant project funded through Ecology.

3. Ongoing lake monitoring is funded by the flood control district. A grant project established a multi-year tributary monitoring effort that ended in 2006.

4. Ecology is responsible to insure that the TMDL is implemented and to issue construction stormwater permits to land-disturbing activities greater than one acre. Spokane County is responsible for implementing their erosion and sediment control ordinances and enforcement of shoreline protection and critical area ordinances. Department of Natural Resources is responsible for making sure the Forest Practices Act requirements are implemented.

While Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards, it is the goal of all participants in the Newman Lake TMDL process to achieve clean water through voluntary control actions where possible.

It is anticipated that water quality monitoring, combined with implementation tracking of phosphorus-controlling best management practices, will be reported annually and receive detailed evaluations every five years. This information will be used for adaptive management to revise implementation strategies or modify the requirements of the TMDLs where it is clearly shown that the load capacity can not be met after all achievable pollution remedies are implemented.

Ecology will consider and pursue formal enforcement, in accordance with the Regulatory Reform Act, in situations where no reasonable attempt is being made to implement best management practices and it is established that the resulting pollution is causing, or contributing to, non-attainment of load allocations and violations of water quality standards.

Monitoring plan

A monitoring plan will be developed as part of the detailed implementation plan, but Thompson Creek and one or two other tributaries representative of the northwestern watershed should be monitored year-round to track changes in external load tracking. Newman Lake should also be monitored (except for the lake when it is ice covered) to track changes in internal phosphorus loading, lake stratification, dissolved oxygen, and phytoplankton productivity (chlorophyll [a]). The lake monitoring plan may be revised and reduced in intensity to allow for diversion of funds for other types of monitoring, but should probably be monitored at least four times from June 1 through September 30.

Implementation of BMPs for roads and other high priority erosion control projects in the watershed will be tracked on an annual basis consistent with the detailed water quality implementation plan.

Entities with enforcement authority will be responsible for following up on any enforcement actions. Stormwater permit holders will be responsible for meeting the requirements of their permits. Those conducting restoration projects or installing BMPs will be responsible for monitoring plant survival rates and maintenance of improvements, structures and fencing.

The water quality implementation plan will describe the coordinated monitoring strategy.

Adaptive management

Phosphorus loading reductions required to meet the TMDL should be achieved by 2026. The upcoming development of the water quality implementation plan will identify interim targets. These targets will be described in terms of concentrations and/or loads, as well as in terms of implemented cleanup actions. State and local agencies, combined with private citizens, will work together to monitor progress towards these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the cleanup strategy as needed.

It is ultimately Ecology's responsibility to assure that cleanup is being actively pursued and water standards are achieved.

Summary of public involvement methods

Public workshops

Two workshops were conducted, coinciding with start of public comment period, to present and discuss the TMDL (June 17, and September 7, 2006). Ecology conducted four advisory group meetings to develop the summary implementation strategy and revisions to the TMDL technical report. A citizen group for detailed implementation planning will be responsible for developing the water quality implementation plan with Ecology. At least one workshop during the development of the water quality implementation plan will be held to gain input from the general public.

Public review and comment - draft TMDL

The announcement of the initial workshop and a formal public review and comment of the TMDL was published as a display ad in Spokane's largest newspaper, the Spokesman Review on June 16, 2006. After a request to extend the comment was received from the county, the comment period was extended to September 15 for a total of 90 days. The announcement of the extended comment period was published in weekly regional newspapers, the Spokane Valley News Herald and the Inlander on August 11 and August 17, 2006 respectively (see Appendix A). It was also included in the Fall 2006 issue of the Newman Lake Newsletter.

Printed copies of the draft TMDL were made available at the first public workshop and later by request. The draft TMDL could be reviewed electronically on Ecology's web site which was included with the display ads and Focus Sheet.

A revision of the original draft was made in consideration of comments. A second public comment period was conducted in August 10 – September 15, 2007 to provide input on the proposed final draft of the TMDL. The comment period was advertised in the Inlander and Spokane Valley News Herald newspapers August 10 and August 16, 2007, respectively (see Appendix A). Copies of the final draft were made available electronically on Ecology's website or mailed hard copy by request.

TMDL focus sheet and public mailing

A focus sheet was prepared prior to the second public workshop announcing the second workshop and mailed during the comment period to more than one thousand addresses using the mailing list provided by Newman Lake Flood Control Zone District. A notice of the second public workshop was also included in the Newman Lake Property Owners Association Fall 2006 newsletter which was distributed before the second public workshop. The newsletter will continue to be used for updating the watershed residents on progress of the detailed implementation plan development.

TMDL advisory group

A request for advisory group volunteers was made at the first public workshop and the group met four times on July 29, October 12, November 8, of 2006, and January 25, 2007. Members of the advisory group and their affiliation are:

Marianne Barrentine, Spokane County	*Linda Underwood, NLPOA*
Jane Takai for Bob Takai, NLPOA	*Lorne Burley, NLFZCD*
Jack Praxel, NLFZCD	*Lauretta Block, NLFZCD*
Warren Heylman, NLFZCD	*Barry Moore, WSU/NLFZCD*

Margo Wolf, Watershed Committee	*Linda Pool, Watershed Committee*
Dennis Parent, Inland Empire Paper	*Bob Warner, property owner*
Bruce Gallaher, property owner	*Sharon Cusic, property owner*
Mike Davis, property owner	*Chris Donley, Washington F&W*
Robert Anderson, Washington DNR	*Simone Ramel, property owner*
Bill Jarocki, Environmental Finance Center	

Potential funding sources

Multiple sources of financial assistance for water cleanup activities are available through Ecology's grant and loan programs, National Resource Conservation Service, local conservation districts, and other sources. The following table shows some of the potential sources of water cleanup funding. Ecology will be working with stakeholders and the Environmental Finance Center to identify funding sources and prepare appropriate scopes of work that will help implement this TMDL.

Possible funding sources to support TMDL implementation

Sponsoring Entity	Funding Source	Uses to be Made of Funds
Washington-Department of Ecology, WQP	Centennial Clean Water Fund, Section 319, and State Revolving Fund http://www.ecy.wa.gov/programs/wq/funding/	Facilities and water pollution control-related activities; implementation, design, acquisition, construction, and improvement of water pollution control. Priorities include: implementing water cleanup plans; keeping pollution out of streams and aquifers; modernizing aging wastewater treatment facilities; reclaiming and reusing waste water.
Washington-Department of Natural Resources	Small forest land owners office assistance http://www.dnr.wa.gov/sflo/resources/ http://www.dnr.wa.gov/sflo/frep/ http://www.dnr.wa.gov/sflo/resources/assistance.pdf	Assist non-industrial private forest owners in managing their properties for a variety of resource values. The Forest Riparian Easement Program compensates eligible small forest landowners for easements in riparian corridors. Other funding sources for forest protection.
USDA - Natural Resources Conservation Service	Wetland Reserve Program (WRP), Wildlife Habitat Incentives Program (WHIP) and others http://www.wa.nrcs.usda.gov/programs/index.html http://www.wa.nrcs.usda.gov/programs/wrp/wrp.html	WHIP - Landowners may receive cost-share to develop habitat for fish and wildlife on private lands. WRP - Provide easement lease incentives to enhance wetlands in exchange for land set aside and habitat restoration.
Private Funding	Land Trusts and conservation grants	

Next steps

Once EPA approves the TMDL, a water quality implementation plan (detailed implementation plan) must be developed within one year. Ecology will work with local people to create this plan, choosing and prioritizing the combination of possible solutions they think will be most effective to meet the TMDL's goal in their watershed. Elements of this plan will include who will commit to do what; how will we figure out whether it worked; what if it doesn't work; and potential funding sources.

Appendix A. Record of Public Participation

Summary of Comments and Responses

As part of the Newman Lake Total Maximum Daily Load study, the Department of Ecology conducted two public workshops, two formal public comment periods, and five advisory workgroup meetings to discuss the study's principal findings. Question-and-answer sessions followed each presentation. In addition, throughout this process presentations were given and comments sought from the Newman Lake TMDL technical advisory group.

An initial formal comment period occurred following a public workshop in June 2006. To address any additional questions or comments on the draft TMDL report, Ecology conducted a follow-up workshop for the Newman Lake community in September 2006. During this period, Ecology also met and sought comment from the TMDL advisory group in July 2006. Ultimately, the incorporation of these comments and suggested changes resulted in the following changes to the draft report: the inclusion of volunteer data (surface water flow and rainfall measurements) into the analysis; the examination of current in-lake restoration measures; the determination of a water and phosphorus budget; and a revision of the on-site phosphorus loading analysis. In addition, a new lake model was used to determine the phosphorus load capacity and source allocations. Together, these changes were significant enough that Ecology sought additional comment to the draft document. Presentations and comments were initially sought from the TMDL advisory group through a series of meetings occurring in October and November of 2006 and January and April of 2007. Further incorporation of those comments resulted in the final draft document released for public review and comment in August 2007. This section addresses those comments.

The format used in this section takes the form of a summarized comment (or question) followed by Ecology's response. The comments are in italics. In many cases, there was a commonality among the many comments received. For this reason, rather than addressing each comment individually the comments are grouped and addressed accordingly. The major groupings include the use of available water quality data in the TMDL analysis; methods used to determine target concentrations and load allocations; on-site systems; the analysis of the oxygenation system; and the summary implementation strategy.

This section of the report addresses comments seeking clarification or that point out a potential shortcoming of the analysis. In this sort of work, these types of comments tend to take precedence (and also tend to be more numerous). Importantly, they provide a check that the analysis is on a solid foundation. Lost in the process are the positive comments. However, at the risk of conceit, these have also been included (without comment) in a grouping titled: ☺ .

Regarding the Application of Available Data

Why weren't WSU studies and the associated data considered in the TMDL?

All available data were not used and TP data were rejected based on pre-conceived assumptions about concentrations and distributions in the lake.

Lake biological responses to current restoration were not considered.

Analysis and conclusions in the TMDL do not reflect local conditions and are inconsistent with previous studies.

Response: The majority of available water quality data historically collected on Newman Lake was brought together and collectively analyzed as part of this TMDL. No comprehensive analysis of this information had occurred prior to this effort. This information was gathered from numerous reports published by Washington State University, Washington State Department of Ecology, and the United States Geological Survey among others, as well as data from more current data collection efforts. However, not all of the previous data and analyses were used in the TMDL.

In particular, there were dates when total phosphorus concentrations collected and analyzed by Washington State University were not used (refer to comments regarding TP data in Appendix B). The Department of Ecology sought explanations from Washington State University for this unusual data through correspondence and meetings, though no formal response was forthcoming. In evaluating the TP data quality, patterns in internal and external factors that can affect phosphorus concentrations were considered. Among the factors considered included trends in surface water inflow quantity and quality, variation in weather characteristics (hourly temperature, wind etc.), the variation in water column temperature and dissolved oxygen levels, and Secchi transparency. Washington State University acknowledged problems with the reported TP values collectively, though they have not addressed issues with the data on a date by date basis. This is the level required for consideration in this TMDL analysis. Short of that, best professional judgment was required.

In some instances, the analysis methods and conclusions differed from previous work. Part of these differences lie in the unique analysis structure and goals of a TMDL study in comparison to more general lake studies. The TMDL is narrowly focused on determining pollutant source reductions necessary to meet target concentrations. Lake studies may include a broader approach examining, for instance, the assemblage and population of fishes or aquatic plants.

Methods differed from previous work reflecting changes in analysis objectives and tools. For instance, in the estimation of the phosphorus load associated with on-site systems geographic information systems analysis was used. Other differences were due to the discovery of errors in previous analysis methods. For instance, in several cases previously reported water budget estimates were not calculated correctly, so there are differences in the correction of those errors in the TMDL report. Also, previous reports were found to have errors in the units that data were recorded. For instance, Secchi measurements reported in the Phase I document (Funk and Moore, 1988) for 1986 were reported as meters though were later believed, by the study author, to have been erroneously reported and should instead have been feet (the original data collection notes are apparently not available).

Reporting errors are not usual and the detection and resolution to them is important if the data are to be considered for further analysis. The inclusion of poor quality data and analyses based solely on the fact that they were included in previously published documents would be remiss.

Analysis concerning the target concentration and load allocations

The use of 'averaging' in setting load allocations is simplistic and misses trends in lake ecology.

Response: This TMDL study used a summer period average TP concentration as the ultimate target from which pollutant source reductions were based. The average concentration applies to the epilimnion (surface to 3 meters depth) June through August. The period June through August was chosen because it is a critical period for aquatic resources, recreational use, and algal growth. Algae growth is at its annual peak coinciding with peak recreational use. For this reason, the use of a summer average epilimnion TP concentration is a standard limnological water quality metric and consistent with Washington State water quality standards.

It is more appropriate to base the target concentration on a series of measurements during the critical period (summer average concentration) rather than a single measurement. An average concentration incorporates the environmental variability expected over the summer period and so it provides a better foundation from which to assess the lake's overall phosphorus level.

Previous TP models were unsuccessful and dropped from the document and the final model only uses data from two years for phosphorus budget calculations used to determined external load reductions.

DOE has ignored all input regarding the TMDL.

Why have significant analytical changes occurred in each of the released TMDL draft reports?

Response: The analysis method used to determine Newman Lake's load capacity was changed between the draft and final-draft documents. A consequence of these changes is that the TP load capacity, the bottom-line objective of the TMDL analysis, also slightly changed. Rather than the result of failure, changes in methods occurred in response to both public comment as well as input from the technical advisory group.

The new (Vollenweider-type) model was chosen to address outstanding issues regarding the quality of various TP data. The Vollenweider-type model is relatively simple in that it uses as input annual loads to predict summer average concentrations as opposed to the previous model present in the initial draft report that used daily average loads to predict daily average lake TP concentrations. However, concerns were raised in the initial round of comments regarding data selectivity in the calibration of the former model. (As presented elsewhere in this response, the quality of certain reported TP concentrations has been a concern of the Department of Ecology and was the reason for the data exclusion [refer to appendix B].) The new model was chosen to address these concerns because the majority of the data for select periods could be used. This type of model has been applied to Newman Lake in previous studies and so it is not without precedent.

The model was calibrated using 5-years of summer period TP data. Once calibrated, the model was used to predict summer average TP concentrations from 1986 to 2006.

While two modeling approaches were used to analyze the connection between TP introductions to the lake and its effect on in-lake concentrations, they produced similar results. The model used in the draft report indicated that a 40 percent reduction in the external TP load was required, while the second model indicated that a 39 percent reduction was needed. This consistency increases the level of assurance that the final method used to determine the load capacity is sound.

Comments forwarded during the initial public comment period, and those from the technical advisory committee resulted in a number of changes to the initial draft TMDL report. In addition to the change in the lake model, the final draft report included a water budget; nutrient budget; re-examined the influence of on-site wastewater systems on phosphorus loading; examined the influence of the in-lake oxygenator system on the lake's water quality; and incorporated more recently collected data into the analysis. All of these additions were undertaken to address public and technical advisory comments.

Concerning On-Site Wastewater Systems

How was the contribution of phosphorus from on-site systems calculated?

Numerous assumptions underlying the estimate of on-site phosphorus loading are inaccurate resulting in an over estimation from this source. This applies specifically to the estimate of occupancy rates and types of on-site systems present.

Response: The effect of on-site wastewater disposal on phosphorus loading to Newman Lake was calculated based on the number of residentially developed properties situated within 1000 feet of the shoreline and their period of occupancy, along with flow and phosphorus levels typically associated with residential wastewater. It was assumed that no reduction in phosphorus occurred through settling (within the septic tank), though there was an assumed attenuation within the soil matrix of 50 percent following effluent discharge. In other words, due to poor soil treatment conditions, 50 percent of the phosphorus associated with wastewater is assumed to eventually migrate to the lake. Migration rates were set proportional to the level and timing of surface water flow, an indication of saturated conditions.

From these calculations, the TMDL estimated that 414 kilograms of phosphorus is discharged to surrounding soils from on-site systems per year, with half or 207 kilograms eventually migrating to the lake. Only one other estimate has been made for the Newman Lake community at an annual level of 910 kilograms of phosphorus per year, approximately twice that estimated by the TMDL (Copp, 1976). This estimate is now over 30-years old.

There is no current information on the type and condition of the various on-site systems present within the Newman Lake community. However, a survey of lake-side resident's water supply, wastewater treatment methods, and occupancy rates was conducted in 1989 (NLWPC, 1990). The results of that survey, along with analysis conducted during the Copp study, indicate the susceptibility of Newman Lake to phosphorus loading from on-site systems.

The 1989 survey noted, in reference to the build of on-site systems encountered for many Newman Lake properties and the poor soil conditions in which they are situated, that “infrequent use of the cabins connected to these sewage systems is the primary reason there is not any evidence of system failure.” The survey also noted, as indicated in the TMDL report, that soils surrounding the lake (primarily Moscow and Spokane series) provide poor wastewater treatment conditions because they are shallow (less than 30 inches to bedrock), with 20-50 percent of surface soils in many areas comprised of exposed bedrock, and are situated on slopes ranging from 30 to 70 percent.

Also, importantly, wastewater systems do not have to fail (noted by surfacing wastewater) for phosphorus migration to occur. Given the shallow soils it is likely that effluent from the on-site systems surrounding Newman Lake receives a low level of treatment (with poor phosphorus retention). The effluent is expected to flow at a relatively high rate to the lake once it meets the shallow bedrock surface. In 1975 elevated phosphorus levels, at two to four times background, were observed in soils down-gradient of residential development (Copp, 1976).

A further source of concern found from the 1989 survey was that 54 percent of the respondents indicated that their wastewater systems were within 100-feet of the lake shore. This zone is susceptible to periodic saturated conditions that would result in decreasing phosphorus soil retention. In addition, it indicates that effluent from the majority of on-site systems has a short migration pathway to the lake.

Unfortunately, while the survey provides a lot of useful information it is now almost 20-years old and other assessment methods were needed for the TMDL. Changes occurred in the demography and wastewater infrastructure since 1989 and a more current survey is necessary. Short of that, the TMDL sought to provide an estimate using best professional judgment, applying reasonable assumptions. A margin of safety was also incorporated into the assumptions and the ultimate estimate. Generalizations are necessary in this estimate, for instance through the assumption of typical wastewater flow and phosphorus levels. It is recognized that there are many intangibles. How often are people present at their residences? What is the population per residence? Of the phosphorus discharged to surrounding soils, how much migrates to the lake? In reality, no one knows, or will know, to a high degree of accuracy, many of these variables. Given this uncertainty a margin of safety in this estimate is necessary. Ultimately, the objective of the analysis is to provide a reasonable estimate for comparison with the other phosphorus sources present.

Regarding assumed residential occupancy rates:

Response: In order to calculate current residential occupancy rates, the TMDL assumed three groups present within the Newman Lake community based on each property owner’s address. The owners of residences on parcels with Newman Lake addresses were assumed to be occupied year-round. Those with a Spokane Valley address were assumed to be occupied 46 days per year, while those with an address outside of Spokane County were assumed to occupy their residence 14 days per year. Based on this analysis, of the 486 residentially-developed parcels within 1000 feet of the shoreline, 45 percent were determined to be primary. Of the seasonally occupied residences, 43 percent had a Spokane Valley address with the remainder (12 percent) located outside of the Spokane Valley.

The results of this analysis can be compared to two previous surveys. One is the 1989 survey of lake-side residential water supply, on-site systems, and occupancy rates (NLWPC, 1990). The other is a 2004 survey that provided an accounting of residences within the greater watershed and their occupancy rates. Results from the 1989 survey determined that of the respondents, about 33 percent occupied their homes year-round, 50 percent were occupied less than 36 days per year, and 17 percent were occupied between 90 and 120 days per year. (The survey divided seasonal use into these two categories.) Though applying to the greater watershed, the 2004 survey found that 39 percent of residences were primary while 61 percent were seasonal. (Seasonal use was not further defined beyond not being primary.)

In terms of estimating wastewater generation and phosphorus loading, the important factor is an overall estimate of the number of days per year residential properties are occupied. An estimate can be generated with the number of days of occupancy (category) weighted by the percent of the residential population it represents. For instance, from the 1989 survey 33 percent of the residences surveyed were occupied year round so it represents 0.33*365, or 120 days of the total weighted average. For occupancy rates defined by ranges, the mid-point was used in this calculation (18 days for x<36 days/yr and 105 days for 90-120 days/yr category from the 1989 survey). It was assumed that the percentage structure of occupancy rates present in 1989 also applies to 2004. This results in an average seasonal occupancy rate of 40 days per year ((0.75*18)+(0.25*105)). These calculations result in the following average annual occupancy rates per residence.

From the 1989 survey:
(18*0.5)+(105*0.17)+(365*0.33)=147 days per year.

From the TMDL:
(14*0.12)+(46*0.43)+(365*0.45)=186 days per year.

From the 2004 survey:
(40*.61)+(.39*365)=167 days per year.

By these comparisons the TMDL estimate exceeds these other estimates by between 10 and 20 percent. Assuming the upper range of the seasonal occupancy rates decreases these differences by 5 percent to between 5-15 percent.

While recognizing that neither survey is directly comparable, the 1989 survey does not reflect more current community changes and the 2004 survey applies to the greater watershed (though 85 percent of residences are within 1000 feet of the lake). However, accepting those limitations, and recognizing the wide range in seasonal occupancy rates selected by the 1989 survey, in comparison to the other measures, the TMDL estimate is close and within the range expected given recent demographic changes in the community.

Conservative assumptions in occupancy rates are also warranted provided some unknowns. For instance, seasonal occupancy rates do not properly account for higher use rental and recreational property. Land owners residing outside the Spokane Valley may lease property that could be potentially occupied year round. Or, owners residing in the Spokane Valley may have extended family or friends that have access to the residence resulting in a much higher level of occupancy.

Not all wastewater systems are contributing to phosphorus loading. Many residences utilize contained systems (holding tanks, composting toilets etc.) that have minimal effect.

Response: Unfortunately, there is no current accounting of the various types of on-site wastewater systems present around the lake. The 1989 survey, which is now almost 20 years old, provides the most current assessment. Since then the infrastructure has changed along with residential occupancy rates. For this reason, conservative assumptions that provided a margin of safety with this calculation were necessary. This was achieved by assuming that all of the on-site systems contributed phosphorus to surrounding soils with the level set based on annual occupancy rates. Despite its age, it is worth reviewing the results of the 1989 survey to gain an understanding of the on-site methods encountered then and why conservative assumptions were applied.

Of the survey respondents, the most common on-site systems encountered were septic tanks with drainfields (49 percent). A further 13 percent had septic systems but were not aware of what further treatment system was present, if any. Of concern, cesspools and privies comprised seven percent and 22 percent, respectively, of the respondents. Both provide a low level of treatment, particularly in terms of phosphorus migration as waste remains in contact with soils prone to periodic saturation. Residences with holding tanks comprised about nine percent of the respondents.

The survey noted that about 14-17 percent of the residences did not have plumbed toilets. This would comprise systems that contained waste such as incinerator toilets and other alternative methods but also potentially un-lined privies. Privies and cesspools that utilize direct discharge of waste to soil can be particularly problematic given the poor soil conditions for waste treatment surrounding the lake, and can continue to contribute phosphorus to the lake despite residential vacancy. Grey water (i.e. bath and sink water) from these properties was discharged to drywells or rock sumps (16 percent of the respondents). Grey water contains phosphorus, though to a lower level than typical wastewater, and so the residence remains a phosphorus contributor to the lake though to a lower extent.

Assuming that the holding tanks contained wastewater and were pumped, and half of the privies provide for containment of waste (a generous assumption), then about 80 percent of the properties responding to the 1989 survey discharged wastewater directly to, or with some form of treatment, to surrounding soils. (Holding tanks require periodic inspection to determine if leakage is occurring.) The majority of the residences with waste containment continue to be phosphorus contributors within the watershed through the discharge of grey water to surrounding soils. In addition, the survey indicated the high presence of unlined cesspools and privies where feces are in direct contact with soils. These systems remain a high source of phosphorus despite occupancy levels. Given these conditions, a conservative analysis approach was warranted.

Regarding future use of currently undeveloped parcels surrounding Newman Lake:

The discussion in the TMDL regarding the potential for future development on the lake recognized the existing Rural Conservation Zoning designation and its application to existing parcels, though it was not as clearly stated as it should have been. The report text has been changed to reflect this.

Also, the TMDL noted that not all of the parcels that are currently undeveloped could be in the future due to site restrictions such as available water supply, wastewater treatment limitations, easements, proximity to sensitive areas, among other factors. For this reason, in evaluating the potential for future development it was conservatively assumed that residential development could be realized on only 50 percent of the currently undeveloped parcels.

Aren't wastewater flows closer to 100 gallons per day per capita?

Response: Wastewater flows were assumed at 60 gallons per day per capita. Recent assessment of residential wastewater flows indicate levels around 71 gallons per capita per day (Metcalf & Eddy, 2002). Flow rates for cabins with seasonal use are between 40 to 60 gallons per day per capita with a typical rate of 50 gallons per day per capita. Assuming 71 gallons per capita per day applies to the permanent residents and the 50 gallons per day applies to the seasonal residents results in a weighed average flow of (0.45*71)+(0.55*50)=60 gallons per capita per day.

Regarding the analysis of the oxygenation system

Conclusions regarding dissolved oxygen levels in the summer hypolimnion are misrepresented. Dissolved oxygen has exceeded 1 mg/L throughout the summer period since 2001.

Response: Over 13-years of summer period measurements were used in the examination of dissolved oxygen trends in Newman Lake (refer to appendix B). No data were excluded. From this data record, dissolved oxygen concentrations reported in the hypolimnion have been below 1 mg/L on the following dates: 7/29-8/15/02; 6/16/03;7/23-8/6/03; 8/4/-8/12/04; 8/3/05; and 6/27-8/11/06 (refer to appendix B).

Only select days were used to examine temperature and dissolved oxygen variation.

Response: As mentioned above, over 13-years of temperature and dissolved oxygen data were considered in the TMDL analysis. All of the available data were used.

Climatological data was not considered in the examination of oxygenator performance.

Response: Hourly weather information recorded at Spokane's Airport during the summer months of 2001, 2002, 2003, 2004, 2005, and 2006 were used to examine the relationship between lake stratification and hypolimnetic dissolved oxygen levels (refer to appendix C). Meteorological data used to examine water temperature included air temperature, dew point temperature, wind speed, cloud cover, and short-wave radiation levels. This information was used to examine the variation in epilimnion water temperatures during the summer period. The oxygenator performance was examined in the TMDL, in part, based on the inter-relationship between the strength of stratification (indicated by the magnitude of the temperature differential between the epilimnion and hypolimnion) and dissolved oxygen concentrations present in the hypolimnion.

Concerning the Summary Implementation Strategy

The in-lake management and changes in water quality should not be included in discussions of the TMDL implementation strategies to control phosphorus.

Response: The goal of the TMDL is to achieve a summer target concentration of phosphorus in the epilimnion of the lake and restore all designated beneficial uses including a cold-water salmonid fishery. **All** potential actions for phosphorus control, with consideration of social/economic costs, need to be included in the detailed implementation planning with the actions being implemented by priority. The implementation plan should consider future anticipated changes in land use and development pressures that may lead to continued water quality degradation.

The goal of the TMDL is attainable and necessary for the future of Newman Lake, but the list of the advisory committee list should be updated to reflect actual participants.

Response: It is acknowledged that there has been participation from more than the original members of the TMDL advisory group. However, the list in the report is representative of the advisory group. The composition of the new TMDL implementation planning committee will be slightly modified to incorporate a broader spectrum in expertise for watershed restoration and land use planning.

The amount of new roads in the watershed described by the TMDL seems high and unusual and six times the rate that Inland Empire Paper built roads during the same years.

Response: The road information used in the TMDL was obtained from a 2004 survey required by the NPDES permit for chemical injection and was conducted by Newman Lake volunteers. It illustrates the potential threat to water quality that new road construction might exert in the watershed. The export of phosphorus has been shown, in many examples, to be highly influenced by the excess miles of erodible road present within the watershed. Although recent monitoring data has been very encouraging in Thompson Creek, the relatively high phosphorus export coefficients historically reported for the Newman Lake watershed suggests there may be opportunities for continued reduction of phosphorus loading with diligent road rehabilitation and construction planning.

Strategies to balance timber harvest with forest regeneration are a good idea, but would be extremely difficult in the Newman watershed due to even age timber stands and how to define the recovery rate.

Response: The lake is extremely sensitive to changes in the largely forested watershed. Management of the forest should consider potential water quality impacts to the lake. The character of canopy cover impacts, the rate of snowmelt, and the watershed's response to precipitation events all affect water quality. The health of the lake is directly related to the health of the forest, so harvest rates should be carefully planned with that consideration. The detailed implementation plan could include specific actions and tracking mechanisms developed to document changes in forest management including, for instance, forest canopy character. Many of the new forest practices implementation and tracking requirements will help watershed monitoring track forest practice changes and water quality improvements around the lake.

The forest practices act requires actions to be completed by 2015 not in 20-years as described in the TMDL.

Response: The 20-year period was used because the ultimate benefit realized through some of the implemented actions will take several years from when it is actually put in place on the ground.

The SIS should list all the ongoing BMPS being required by WADNR and that WADNR has already implemented road BMPs.

Response: The strategies about roads were mentioned in the Summary Implementation Strategy (SIS) because they are an important component of best management practices (BMP) implementation within the watershed. The actual amount of detailed implementation and tracking of the completed of actions will be developed in the implementation planning process. Many items currently outlined in Forest Practices BMPs should fit well into this process.

The timberland in the Newman Lake watershed is protective of the lake and if regulations get too stringent then the land could get converted to housing developments which would be worse for the lake. The Washington State forest practices are already second only to California in stringency.

Response: A healthy forested watershed has some of the lowest phosphorus export coefficients reported for this geographic eco-region. Ecology fully supports the commercial utilization of timber land with implementation of BMPs that protect water quality. Hopefully, the BMPs that are now being implemented under the Forest Practices Act will provide the protection needed for continued restoration of the lake's forested watershed. Regardless of the land use, diligent implementation of erosion and phosphorus control strategies will continue to be essential to realize full restoration of Newman Lake.

Miscellaneous Reporting Information

Why use descriptions of barren and clear-cut for transitional areas (table 1)?

Response: A. Land use composition within the Newman Lake watershed was determined through the application of geographic information systems analysis. A 30-meter resolution grid of land use descriptions, produced as part of a cooperative project between the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (USEPA), was used (refer to http://gisdata.usgs.net/index.php). The land use descriptions present in Table 1 are consistent with those present in the land use grid.

The report underestimates the distance of Newman Lake to Spokane at 10 kilometers.

Response: The distance, as the crow flies, is actually about 26 kilometers and this has been changed in the document.

☺

The current draft Newman Lake TMDL is complete and thorough in its evaluation of the data.

The SIS supports a systematic and holistic approach for resource protection and planning.

List of public meetings

- First Public Workshop to present and discuss the first draft of the TMDL Report - June 17, 2006.
- Second Public Workshop to allow a second presentation and discussion of the first draft of the TMDL Report – September 7, 2006 .
- Advisory Group Meetings were held – July 29, 2006, October 12, 2006, November 8, 2006, January 25, 2007, and April 11, 2007.

Public Outreach and Announcements

Item 1. Initial public display ad placed in the Spokesman Review announcing the first public workshop and public comment period on the first draft of the TMDL.

Page B8 • Friday • June 16, 2006

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The Spokesman-Review

NORTHW

Officials trace to Bingham C

ASSOCIATED PRESS

POCATELLO, Idaho – A 45-acre field in Bingham County has been pinpointed as the source of the potato cyst nematodes whose discovery last April caused foreign markets to stop importing Idaho potatoes.

Frank Muir, executive director of the Idaho Potato Commission, said the southeast Idaho field was identified after inspectors tested two fields they considered likely sources.

Officials declined to name the owner of the field, whose field has been quarantined. The quarantine restricts moving plants and soil and includes sanitizing equipment used in the field.

Inspectors are examining other nearby fields as well as fields that used shared equipment, had common seed sources and had common irrigation water.

"Farmers have been extremely cooperative with us," Wayne Hoffman, of the Idaho Department of Agriculture, told the Post

"Farmers have b
extremely cooper
with us. They're
aware of the
implications."

Wayne Hoffman
Idaho Department of Agri

Register. "They're k
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In April, Japan
fresh U.S. potato imp
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Department of Ecology seeks comments on

The draft Newman Lake Total Maximum Daily Load (TMDL) for phosphorus and potential clean-up strategies

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Efforts continue on Newman Lake to restore water quality degraded by excessive phosphorus. The proposed TMDL or water-quality improvement plan sets a lake phosphorus target and allowable pollution loads based on current and historical trends in lake and tributary water quality. A detailed implementation plan for meeting the TMDL will be developed over the next year with the help of an advisory group made up of interested local residents, businesses, and agencies.

We welcome your comments on the draft TMDL plan and invite you to a public workshop June17, 2006 to learn more about the TMDL and potential clean-up strategies.

Public comment period June 18th through July 21st, 2006

Public Workshop
June 17th from 7:00 p.m. – 9:00 p.m.
Tri-Community Grange Hall (Starr Road)

You can review the draft TMDL at:

- http://www.ecy.wa.gov/programs/wq/tmdl/watershed/tmdl_info-ero.html#newman
- Or call to request a copy at (509) 329-3515 (copies available at workshop)

Please send written comments to Ken Merrill, Dept. of Ecology, 4601 N. Monroe St, Spokane, WA 99205 or email at kmer461@ecy.wa.gov by July 30, 2006.

Please call Ken at (509) 329-3515 if you need special accommodations.

Chinook salmon was late, but siz

BY JOSEPH B. FRAZIER
Associated Press

PORTLAND – For a while, it looked like the Columbia River's spring chinook salmon run might give 2006 a miss. Fishing seasons were curtailed and tribal fisheries were reduced as fish biologists waited – and waited – for the fish to arrive at Bonneville Dam.

But then the fish arrived – in bigger numbers than last year.

When the counting season closed on Wednesday nearly 124,000 chinook had passed the dam, more than the 88,000 expected and more than last year's return of 95,000.

"This year's spring run took its time but it crossed the finish line with a very respectable showing," said Bob Lohn, head of the Northwest region of the Nation-

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Item 2. Announcement of the First TMDL workshop and public comment period in the Spring-06 Newman Lake Newsletter.

SPRING 2006 NLPOA/NLWSC NEWSLETTER PAGE 3

Engineer to replace me soon We will also be making use of a seasonal technician to assist especially for the milfoil control work So if you see some new faces out on the pontoon boat this summer wave and introduce yourself I know they will be looking forward to introducing themselves and working with all of you in the coming years I know I have enjoyed working with all of you to help solve the challenges of operating the District facilities and improving Newman Lake Water Quality I've been Newman Lake's engineer for the past 9 years Thanks to all of you for your help over these years Time does fly when you're having fun and working with a great group of dedicated people This move is made easier for me knowing that I'll still be nearby though not involved on a day to day basis I know the new Newman Lake Engineer will do a great job for Newman Lake, but if you do need to contact me I will still be available at the same phone number and email.

If you have any questions or concerns on the above or any District activity, please contact me at 509-477-7443 or mbarrentine@spokanecounty.org Have a great summer at the Lake!!

Marianne Barrentine,
Spokane County Engineering

NEWMAN LAKE TDML WORKSHOP

As we have talked about in previous newsletters, the Washington State Department of Ecology (Ecology) has been working on a Total Maximum Daily Load (TMDL) study for Newman Lake. This study is now almost complete and Ecology plans to hold a workshop to explain the results and take input from Newman Lake area residents. This TMDL workshop will be held Saturday, June 17th at 6:30 pm at the Grange, in conjunction with the NLPOA/NLFCZD Annual Summer meeting. Tony Wiley from Ecology's Lacey office, who has prepared the study based on WSU and volunteer monitoring data over the last 20 years will be there to explain his results. Please make plans to attend!! The public will have 30 days to comment after this date. The report will be posted on the Ecology's TMDL website in early June if you would like to preview before the meeting (see web site noted below).

What exactly is a TMDL? The terms Water Cleanup Plan and TMDL are often used to mean the same thing. However, it is often best to think of a Water Cleanup Plan as a process to return water bodies to a healthy condition and a TMDL as the technical piece of that process. TMDLs are technical studies that describe the type, amount and sources of water pollution in a water body and develop targets and recommendations to control the pollution. The ultimate purpose of the TMDL study at Newman Lake is to determine how much phosphorus needs to be reduced to have a healthy lake. This is the piece that Tony will be presenting in June. The Water Cleanup Plan that will follow the completion of this study is the actual public process in which local organizations and citizens plan actions to reduce phosphorus levels in the Lake. This process will build upon the extensive Newman Lake restoration efforts of the last 20 years and will be coordinated out of the Ecology's Eastern Regional Office here in Spokane.

Why Newman Lake? Newman Lake was listed on the 1998 US Environmental Protection Agency's (EPA) 303(d) list for elevated phosphorus levels. Section 303, part d of the Clean Water Act requires that each state provide a list of streams and lakes that do not meet water quality standards. Water quality standards are set to protect water for the things we want to use it for. The Clean Water Act requires a TMDL study of all water bodies listed on the 303(d) list. Typically, increased phosphorus in lakes leads to higher algae concentrations during the summer months impairing recreational uses such as fishing, swimming, and boating while also impacting the habitat, diversity, and distribution of plants, fishes, and aquatic invertebrates.

For more information on TMDLs in general you can look at Ecology's TMDL web page at http://www.ecy.wa.gov/programs/wq/tmdl/index.html. For questions on the Newman Lake TMDL project please contact me or Ken Merrill in Ecology's Eastern Regional Office at 509-329-3515.

Item 3. Announcement flyer for the second workshop and extended comment period mailed for the first draft TMDL directly to Newman Lake citizens August 26, 2007 (mailing list provided by Spokane County Engineers).

2nd Public Workshop - Newman Lake TMDL
September 7th, 6-8 pm, Tri-Community Grange Hall

Draft Newman Lake Water Quality Improvement Plan (TMDL) to Manage Phosphorus and Algae

Newman Lake has had many years of study and millions of dollars spent to restore water quality from toxic blue-green algae blooms referenced in the initial lake restoration plans. The research and initial lake restoration methods focused on reducing phosphorus, which is the limiting essential nutrient for algae growth. Whole-lake addition of a chemical (aluminum sulphate, also called alum) to the lake was completed in 1989 and later an aerator, augmented with annual aluminum sulphate injection, was used to provide more control of internal recycling of phosphorus from lake sediments.

The information gathered during the initial lake studies and subsequent monitoring clearly shows that water quality has improved since initial chemical treatments. However, water quality is still degraded by pollution sources causing it to be placed on the State's list of waterbodies whose beneficial uses such as swimming, fishing, healthy aquatic habitat, and water supply have been impaired by pollution.

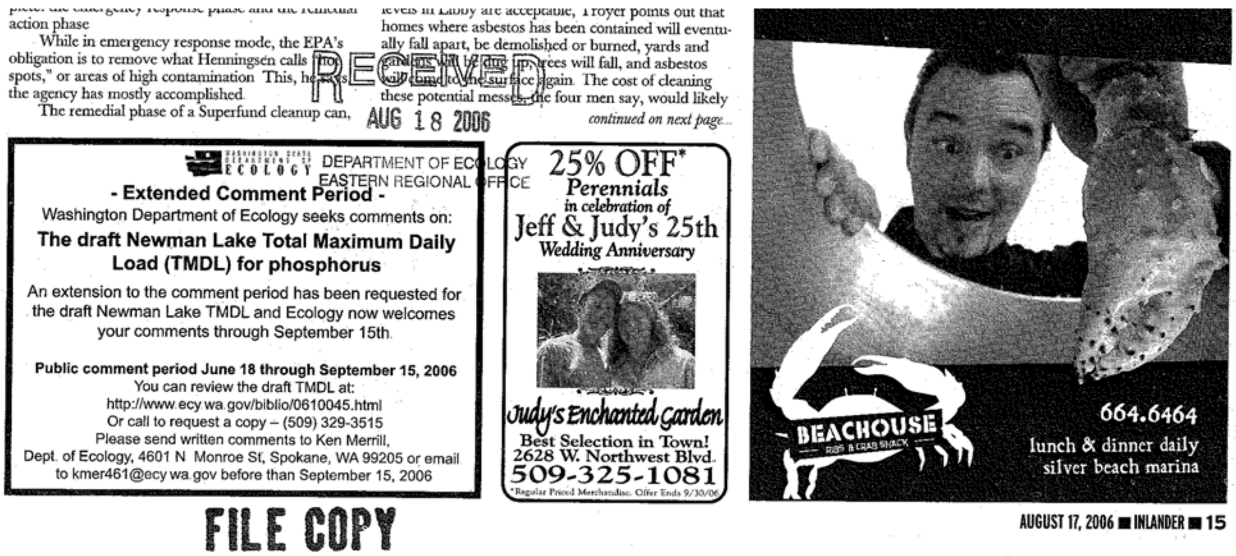
The listing of impaired waterbodies is required under section 303(d) of the Federal Clean Water Act, which also requires States to develop long term, watershed-based water quality improvement plans (total maximum daily loads) for those waterbodies. The ultimate goal is to implement sustainable pollution controls on controllable sources so that all designated beneficial uses are once again fully realized.

The Washington Department of Ecology has drafted a Water Improvement Plan that proposes a summer target concentration of 20 micrograms per liter phosphorus in the upper layer of the lake to control excessive algae growth. It is estimated that this would increase summer water clarity by about 3 feet. Selection of the target concentration was based on water quality characteristics and uses of other lakes that are geographically similar and have not been significantly impacted by pollution. The plan estimates that about a 40 percent reduction in external phosphorus sources is needed in order to meet the target concentration.

Ecology will be working with a community-based advisory group over the next year to develop clean-up strategies for achieving the target concentration. For more details, please refer to the Draft Newman Lake Phosphorus Total Maximum Daily Load Report on Ecology's web site at http://www.ecy.wa.gov/biblio/0610045.html or request a printed copy at 509-329-3515.

The public comment period on the draft TMDL (Improvement Report) has been extended to September 15, 2006. You are welcome to attend the workshop to learn more about the water improvement plan and ask questions. Please send written comments to Ken Merrill by email at kmer461@ecy.wa.gov, or by postal mail to WA Dept of Ecology, Attn: Ken Merrill, 4601 N. Monroe St., Spokane, WA, 99205-1295.

Item 4. Public display ad in the Inlander newspaper announcing the extended public comment period for the first draft of the TMDL.



plete: the emergency response phase and the remedial action phase

While in emergency response mode, the EPA's obligation is to remove what Henningsen calls "hot spots," or areas of high contamination. This, he says, the agency has mostly accomplished.

The remedial phase of a Superfund cleanup can,

levels in Libby are acceptable, Troyer points out that homes where asbestos has been contained will eventually fall apart, be demolished or burned, yards and gardens will be dug up, trees will fall, and asbestos will come to the surface again. The cost of cleaning these potential messes, the four men say, would likely

continued on next page...

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

- Extended Comment Period -

Washington Department of Ecology seeks comments on:

The draft Newman Lake Total Maximum Daily Load (TMDL) for phosphorus

An extension to the comment period has been requested for the draft Newman Lake TMDL and Ecology now welcomes your comments through September 15th.

Public comment period June 18 through September 15, 2006
You can review the draft TMDL at:
http://www.ecy.wa.gov/biblio/0610045.html
Or call to request a copy – (509) 329-3515
Please send written comments to Ken Merrill,
Dept. of Ecology, 4601 N. Monroe St, Spokane, WA 99205 or email
to kmer461@ecy.wa.gov before than September 15, 2006

FILE COPY

AUGUST 17, 2006 ■ INLANDER ■ 15

Item 5. Public display ad in the Spokane Valley News Herald newspaper announcing the extended public comment period for the first draft of the TMDL.

12 — Spokane Valley News Herald

ICB Bank signs lease for new branch site

Intermountain Community Bank of Washington has signed a long-term lease for a new branch site at 5600 East Sprague, near the Costco store.

Bank officials say they plan to develop a one-story, 8,000-square-foot facility on the site. It will include two drive-up lanes and a drive-up ATM. The bank plans to move from its current Spokane

FILE COPY

- Extended Comment Period -

Washington Department of Ecology seeks comments on:
The draft Newman Lake Total Maximum Daily Load (TMDL) for phosphorus

An extension to the comment period has been requested for the draft Newman Lake TMDL and Ecology now welcomes your comments through September 15th.

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Please send written comments to Ken Merrill, Dept of Ecology, 4601 N. Monroe St., Spokane, WA 99205 or email to kmer461@ecy.wa.gov before September 15, 2006

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Item 6. Announcement of the second public workshop and extended comment period on the first draft of the TMDL in the Newman Lake Newsletter Fall-06

under grants from Washington state's Department of Ecology. This summer was no exception, as we used both liquid and granular 2-4,D to stem the growth of the invasive aquatic vegetation.
Thanks to some observant residents, we were able to treat a large area at the south end of the lake that appeared to have escaped treatment the last couple of years. Recent surveys of the lake have shown the treatments to have been very successful, as plant fragments have greatly decreased and the plants themselves appear to have all but disappeared from most areas. Our continued success will be reliant upon early detection of problem areas, so community input is valued and encouraged. If you have any questions about identifying milfoil, or have any tips on plant locations, please call me at (509) 477-7262 or e-mail jmccann@spokanecounty.org.
2: The other item of business is of great importance to the lake and its surrounding watershed: The Newman Lake Total Phosphorous TMDL. Under the guidance of the Department of Ecology, this process will fine tune many of our efforts towards improved lake water quality. Aimed at controlling the contributing watershed, rather than the internal loading that has dictated many of our past efforts, the TMDL aims to reduce Phosphorous inputs and thus keep the water clear and free of large-scale algal blooms. This added focus, paired with the monumental efforts of WSU and the Newman Lake Watershed Volunteer Monitoring, will help assure that this limiting nutrient is indeed kept at levels appropriate for all beneficial uses of Newman Lake.

Though the two items above have dominated Summer 2006, I anticipate that other news of interest will occur over the coming years. We will do our best to keep you informed of all activities that relate to Newman Lake and the surrounding community. It is truly a remarkable environment that we all share around this beautiful lake in Eastern Washington. I look forward to working with all of you, and I am always happy to say "Hi"; so give a wave if you see the NLFCZD pontoon boat out and about! Thank you!!!

Newman Lake Flood Control Zone District has a official web site -**www.nlfczd.org**- it can be used to access information about various and a sundry issues like:
Mission and Goals
Water Quality
Lake Level
Milfoil
Policies and Procedures

2ND PUBLIC WORKSHOP - NEWMAN LAKE TMDL
SEPTEMBER 7TH, 6-8 PM - TRI-COMMUNITY GRANGE HALL

Draft Newman Lake Water Quality Improvement Plan (TMDL) to Manage Phosphorus and Algae

The Dept. of Ecology will be working with a community-based advisory group over the next year to develop clean-up strategies for achieving a target concentration for phosphrus in the lake. For more details, please refer to the Draft Newman Lake Phosphorus Total Maximum Daily Load Report on Ecology's web site at http://www.ecy.wa.gov/biblio/0610045.html or request a printed copy at 509-329-3515.

The public comment period on the draft TMDL (Improvement Report) has been extended to September 15, 2006. You are welcome to attend the workshop to learn more about the water improvement plan and ask questions. Please send written comments to Ken Merrill by email at kmer461@ecy.wa.gov, or by postal mail to WA Dept of Ecology, Attn: Ken Merrill, 4601 N. Monroe St., Spokane, WA, 99205-1295.

Item 7. Public display ad announcing public comment period for the final draft TMDL in Valley News Herald published August 10, 2007.

Washington Department of Ecology seeks comments on:

The draft Newman Lake Total Maximum Daily Load (TMDL) for phosphorus

Ecology has revised the Newman Lake TMDL report in response to comments and input from the TMDL Advisory Group. This is the second and final comment period for the Newman Lake TMDL. Ecology welcomes your comments through September 15th.

Public comment period ends September 15, 2007

You can review the draft TMDL at:

- http://www.ecy.wa.gov/biblio/0610045.html
- Or call to request a printed copy – (509) 329-3515

Please send written comments to Ken Merrill, Dept. of Ecology, 4601 N. Monroe St. Spokane, WA 99205 or email to kmer461@ecy.wa.gov no later than September 15, 2007

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Item 8. Public display ad announcing public comment period for the final draft TMDL in the Inlander published August 16, 2007.

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Washington Department of Ecology
seeks comments on:

The draft Newman Lake Total Maximum Daily Load (TMDL) for phosphorus

Ecology has revised the Newman Lake TMDL report in response to comments and input from the TMDL Advisory Group. This is the second and final comment period for the Newman Lake TMDL. Ecology welcomes your comments through September 15th.

Public comment period ends September 15, 2007

You can review the draft TMDL at:
http://www.ecy.wa.gov/biblio/0610045.html
Or call to request a printed copy – **(509) 329-3515**

Please send written comments to Ken Merrill, Dept. of Ecology, 4601 N. Monroe St, Spokane, WA 99205 or email to kmer461@ecy.wa.gov no later than September 15, 2007

AUGUST 16, 2007 INLANDER 15

Appendix B. Water Quality Data

Table B-1. Water temperature (in degrees Celsius) observed at the mid-lake monitoring station by sampling date and depth (m).

	Temperature (C)								
	Sample Depth (m)								
Date	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
7/3/85	20.8	20.8	20.5	19.8	19.0	17.0	13.8	11.8	10.5
1/23/86	-2.2	-1.5	-0.5	-0.2	0.2	1.0	1.5	1.5	1.5
3/30/86	7.0	7.0	7.0	6.7	6.5	6.0	5.5	5.2	5.0
4/19/86	7.0	7.0	6.9	6.5	6.5	6.2	5.2	4.3	
5/22/86	13.8	13.8	13.8	13.7	12.5	11.5	10.5	10.8	10.6
6/11/86	19.5	18.5	18.0	17.5	14.0	11.5	9.5	8.5	
6/27/86	23.0	23.0	22.0	22.0	21.0	17.0	14.0	13.0	12.0
7/18/86	21.5	20.3	20.0	19.5	19.3	19.2	19.0	16.0	14.5
8/20/86	25.0				23.0				16.0
9/6/86	20.0	20.5	20.0	20.0	20.0	20.0	20.0	20.0	16.0
9/28/86	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.8
10/17/86	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
7/7/89	22.0	22.0	22.0	21.0	19.0	16.0	14.0	12.0	
8/2/89	20.3	20.5	20.5	20.5	20.5	17.0	15.5	13.0	
8/11/89	21.5	21.2	20.9	20.6	19.2	16.8	15.3		
8/25/89	17.8	17.2	17.1	17.0	17.0	17.0	15.9	13.5	11.1
10/7/89	11.5	11.3	11.3	11.3	11.3	11.3	11.2	11.2	11.1
10/21/89	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
11/16/89	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.9	6.9
12/9/89	4.2	4.5	4.5	4.5	4.5	4.5	4.3	4.3	4.3
4/27/90	11.5	11.5	11.5	11.5	11.3	10.8	9.5	8.3	7.5
5/14/90	12.5	12.5	12.5	12.3	11.8	10.4	9.8	9.0	8.2
6/5/90	15.1	14.8	14.0	14.0	13.9	13.5	12.5	11.8	11.0
6/19/90	19.0	18.0	17.5	15.5	14.5	13.5	12.5	12.0	
6/27/90	23.0	22.0	21.0	21.0	17.0	14.5	13.0	12.0	11.5
7/11/90	25.8	24.2	23.5	22.1	19.0	15.9	13.8	13.2	12.2
7/26/90	22.0	22.5	23.0	23.0	23.0	17.8	16.4	14.0	13.5
8/8/90	26.0	25.0	25.0	25.0	24.0	21.0	18.0	16.0	14.5
8/22/90	21.0	21.0	21.5	21.5	21.5	21.5	19.0	15.5	
9/5/90	22.0	21.3	21.0	20.7	20.2	20.1	19.7	17.3	13.8
9/22/90	19.0	18.5	18.5	18.3	18.2	18.2	18.2	18.0	15.2
10/6/90	16.1	16.1	16.1	16.8	16.8	17.0	17.1	17.1	17.1
11/10/90	7.5	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
11/27/90	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
4/13/91	9.1	8.9	8.8	8.5	8.3	8.3	8.3	7.5	7.1
4/27/91	11.9	11.9	11.4	11.0	11.0	10.0	9.3	9.1	9.0
5/30/91	14.8	15.2	15.5	15.5	15.8	14.0	13.0	13.0	11.5
6/11/91	19.0	19.0	18.0	17.0	16.5	15.0	14.0	12.0	12.0
6/25/91	19.0	18.5	18.0	17.0	16.0	16.0	15.0	14.0	13.0
7/10/91	24.0	23.5	23.0	21.5	20.5	18.0	17.0	15.0	14.0
7/25/91	23.5	23.5	23.5	23.0	22.0	21.0	22.0	15.0	14.5
8/20/91	25.0	25.0	24.5	24.0	23.0	22.5	20.0	17.5	16.0

Temperature (C)									
	Sample Depth (m)								
Date	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
9/20/91	20.0	19.0	19.0	18.5	18.0	18.0	18.0	18.0	
10/18/91	14.5	14.0	14.0	14.0	14.0	14.0	13.9	13.9	
11/9/91	6.3	6.2	6.1	6.1	6.1	6.1	6.1	6.1	6.0
12/1/91	4.0	4.0	4.0	4.0	4.5	4.5			
1/23/92	0.0	1.0	1.0	1.0	2.0	2.0	4.0		
3/28/92	10.0	10.0	9.2	9.1	8.3	8.0	7.5	7.1	6.5
4/25/92	13.2	12.2	11.8	11.8	11.8	11.0	10.5	5.0	2.6
5/27/92	18.5	18.5	18.0	18.0	18.0	15.0	15.0	13.0	13.0
6/24/92	26.0	25.0	24.0	24.5	20.0	19.0	18.5	18.5	18.0
7/14/92	19.0	19.0	19.0	19.0	19.0	19.0	19.5	19.5	19.0
7/28/92	23.1	22.8	22.8	22.5	22.2	22.0	21.8	21.7	21.5
8/18/92	24.4	24.0	23.6	23.3	23.0	22.2	22.1	22.0	
1/30/93					3.6				4.2
2/28/93	1.1				4.0				4.3
4/24/93	9.0				8.2				7.3
5/21/93	19.6				11.9				11.1
6/18/93	20.1				15.9				12.6
7/22/93	19.6				18.6				14.3
8/13/93	22.2				20.5				17.2
9/17/93	17.4				17.1				17.1
10/22/93	12.0				12.0				11.9
4/10/94	7.6				7.4				7.2
4/29/94	13.9				11.7				10.1
5/27/94	17.0				14.8				13.5
6/29/94	20.1				17.5				16.0
7/12/94	22.8				20.1				18.6
8/2/94	27.1				20.1				18.6
9/2/94	20.1				19.7				19.6
9/14/94	18.3				18.1				18.1
10/7/94	15.0				14.4				14.4
11/7/94	6.2				6.2				6.2
4/14/95	7.2				7.2				7.2
5/6/95	14.6				14.4				13.4
5/25/95	17.7				13.1				12.3
7/29/95	22.0				21.3				18.9
5/6/97	10.4	10.4	10.3	9.8	9.6	9.3	9.3	9.3	9.2
5/22/97	17.5	16.7	16.2	15.6	13.1	12.2	11.5	11.3	11.3
6/4/97	17.0	17.0	16.8	14.8	13.1	12.9	12.4	12.2	12.0
7/8/97	21.9	21.0	21.0	18.3	17.0	16.0	16.0	16.0	15.8
7/31/97	24.0	23.2	23.0	21.5	19.5	18.0	17.5	17.5	17.5
8/4/97	28.0	26.0	24.0	21.0	18.5	18.5	18.0	18.0	18.0
3/20/98	7.5	7.0	6.0	6.0	5.5	5.5	5.5	5.5	5.5
3/27/98	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
4/10/98	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
5/14/98	17.0	17.0	17.0	15.0	13.5	12.5	11.5	11.2	11.0
5/27/98	13.2	13.2	13.2	13.2	13.1	13.1	13.0	13.0	13.0
6/24/98	20.5	20.5	20.3	20.0	17.0	16.5	16.0	16.0	16.0
7/8/98	24.4	24.0	24.0	21.0	19.0	18.0	17.8	17.4	17.0
7/22/98	25.0	25.0	24.5	23.9	21.0	19.5	18.6	18.2	18.0
8/5/98	26.1	26.0	25.9	24.5	22.0	21.0	20.1	20.0	19.8

Temperature (C)									
	Sample Depth (m)								
Date	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
8/27/98	22.0	21.6	21.6	21.6	21.5	21.5	21.5	21.5	21.5
9/10/98	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
9/24/98	18.9	18.8	18.8	18.8	18.9	18.8	18.8	18.8	18.8
10/8/98	15.2	15.1	15.1	15.2	15.1	15.1	15.1	15.1	15.1
3/31/00	7.9	7.5	6.3	6.0	6.0	5.6	5.5	5.3	5.3
4/27/00	12.3	12.0	11.3	10.4	10.2	10.1	10.0	9.4	9.2
5/11/00	11.9	11.7	11.7	11.7	11.7	11.7	11.6	11.6	11.5
5/25/00	17.7	17.7	16.9	13.4	13.8	13.0	12.0	12.1	12.0
6/15/00	16.2	16.2	16.2	16.2	16.2	16.2	15.7	15.4	
7/6/00	20.1	20.1	20.0	19.4	19.0	17.2	16.4	15.9	15.7
7/13/00	23.6	23.4	22.0	20.6	18.9	17.9	16.5	15.8	15.6
7/26/00	23.4	22.9	22.6	21.2	19.8	17.5	16.7	15.8	15.7
8/10/00	25.0	24.7	24.5	22.4	19.6	17.8	16.9	16.2	15.8
8/24/00	21.7	21.4	21.2	20.5	19.9	19.1	17.5	17.2	16.6
9/7/00	17.7	17.7	17.7	17.6	17.6	17.6	17.6	17.6	17.5
9/21/00	16.7	16.8	16.8	16.8	16.8	16.8	16.8	16.7	16.6
10/5/00	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	
4/14/01	6.0	6.1	6.0	6.0	6.0	6.0	6.0	6.0	5.9
4/23/01	8.6	8.5	8.6	8.6	8.5	8.5	8.4	8.4	8.2
5/11/01	14.2	14.1	13.4	13.1	12.9	12.6	11.4	11.3	10.5
5/23/01	19.0	17.7	17.2	15.1	14.2	13.8	13.2	13.1	13.0
6/6/01	15.9	15.9	15.9	15.9	15.7	15.5	15.3	15.1	14.8
6/13/01	15.8	15.9	15.8	15.8	15.8	15.8	15.8	15.8	15.8
6/20/01	19.2	18.8	18.6	18.1	17.1	16.8	16.3	16.1	16.1
6/27/01	19.5	19.4	19.2	19.1	18.6	17.0	17.0	16.8	16.7
7/11/01	24.1	24.1	24.0	22.7	21.3	19.3	18.7	18.5	18.5
7/25/01	23.1	22.7	22.2	21.5	21.2	20.9	20.8	20.6	20.4
8/8/01	23.0	22.9	22.4	22.3	22.0	21.5	21.0	21.0	20.8
8/22/01	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.0
9/6/01	20.3	20.3	20.3	20.2	20.2	20.2	20.2	20.1	20.0
9/20/01	19.2	19.1	19.1	19.0	19.0	19.0	19.0	19.0	19.0
10/5/01	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2
10/26/01	10.3	10.1	9.9	9.8	9.8	9.8	9.8	9.8	9.7
4/12/02	6.8	6.8	6.9	6.8	6.8	6.8	6.7	6.6	6.7
5/3/02	11.6	11.4	11.4	11.2	11.0	10.8	10.4	10.3	9.8
5/15/02	12.7	12.4	12.1	12.2	12.0	11.5	11.4	11.1	10.9
5/29/02	16.1	16.1	15.8	13.6	12.4	12.4	12.4	12.2	11.9
6/12/02	17.2	16.1	15.7	15.5	15.0	14.2	13.8	13.7	13.6
6/26/02	23.0	21.9	20.2	18.5	15.7	15.1	15.0	14.7	14.7
7/16/02	25.7	24.9	23.7	19.3	17.8	17.4	17.3	17.2	17.2
7/29/02	23.3	23.3	23.0	22.5	19.5	18.8	18.4	18.1	17.9
8/15/02	22.3	22.2	22.1	21.6	21.0	20.5	20.4	20.2	
8/29/02	22.6	22.4	22.0	21.4	21.1	20.8	20.7	20.7	20.6
9/12/02	19.6	19.4	19.3	19.2	19.1	19.1	19.1	19.1	19.0
9/27/02	16.7	16.7	16.6	16.6	16.5	16.5	16.5	16.5	
10/8/02	14.9	14.6	14.5	14.3	14.3	14.3	14.2	14.2	14.2
10/22/02	11.6	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
11/15/02	5.4	5.4	5.3	5.3	5.3	5.3	5.3	5.3	5.3
2/7/03	2.9	2.9	2.9	2.9	2.9	2.9	2.9	3.0	3.0
3/28/03	6.7	5.9	5.7	5.6	5.6	5.6	5.5	5.5	5.5

	Temperature (C)								
	Sample Depth (m)								
Date	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
4/16/03	10.0	9.7	9.5	9.4	9.0	8.9	8.1	7.8	7.5
5/2/03	12.7	11.9	11.2	10.8	10.4	10.0	9.6	9.2	8.7
5/14/03	15.1	14.3	13.6	13.5	12.8	11.8	11.6	11.1	10.9
5/28/03	18.9	18.2	17.9	15.1	13.2	12.6	12.5	12.4	12.2
6/4/03	20.7	18.6	18.1	17.6	16.2	13.9	13.2	13.1	12.9
6/16/03	21.7	21.0	20.6	19.9	17.9	16.2	14.7	14.1	14.0
7/9/03	21.7	21.5	21.3	21.1	20.3	19.2	17.6	17.4	17.2
7/23/03	25.7	25.5	24.6	23.2	20.6	19.6	19.4	19.1	19.0
8/6/03	24.5	23.9	23.6	22.7	22.1	20.6	20.4	20.3	19.8
8/20/03	22.8	22.7	22.3	22.0	21.8	21.6	21.4	21.4	21.3
9/4/03	22.4	21.9	21.7	21.5	21.3	21.3	21.3	21.0	20.8
9/18/03	17.4	17.4	17.3	17.4	17.3	17.3	17.2	17.2	17.2
10/2/03	16.9	16.8	16.8	16.7	16.7	16.7	16.7	16.7	16.7
10/24/03	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
3/26/04	6.5	6.4	6.3	6.3	6.4	6.3	6.3	6.3	6.3
4/16/04	11.1	11.1	11.0	10.3	10.1	9.9	9.5	9.4	9.2
5/27/04	16.0	16.0	15.9	15.5	15.3	15.1	15.0	14.7	14.8
6/10/04	16.6	16.6	16.6	16.4	16.1	16.0	16.0	16.0	15.8
6/24/04	22.8	22.9	20.9	18.9	18.4	17.6	17.4	17.1	16.6
7/14/04	23.4	22.8	22.7	21.8	21.1	20.7	20.1	20.0	19.7
8/4/04	24.5	24.3	23.9	23.8	23.6	22.8	22.6	22.4	22.1
8/12/04	24.1	23.9	23.7	23.2	22.6	22.4	22.2	22.1	22.1
8/26/04	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
9/9/04	19.5	19.5	19.4	19.4	19.3	19.3	19.3	19.3	19.3
9/23/04	16.0	16.1	16.0	16.0	16.0	16.0	16.0	16.0	16.0
10/8/04	15.9	15.8	15.8	15.7	15.7	15.8	15.7	15.7	15.7
10/27/04	11.2	11.2	11.1	11.0	11.0	11.0	11.0	11.0	11.0
3/17/05	6.7	6.7	6.7	6.7	6.7	6.8	6.7	6.7	6.7
4/8/2005	8.0	7.8	7.5	7.3	7.1	7.1	6.9	6.8	6.7
4/22/2005	10.6	10.6	10.3	10.3	10.2	10.1	9.8	9.1	8.5
5/3/2005	13.9	13.6	13.5	13.2	12.7	12.3	12.0	11.9	11.6
5/19/2005	15.6	15.6	15.2	14.9	14.6	14.3	13.9	13.8	13.6
6/2/2005	18.1	18.1	18.1	18.1	16.9	16.3	15.8	15.5	15.2
6/16/2005	17.6	17.3	17.1	16.9	16.8	16.8	16.8	16.7	16.7
7/8/2005	21.8	21.7	21.5	21.3	21.2	20.3	19.1	18.8	18.5
7/21/2005	23.7	23.4	22.9	22.8	22.6	22.1	20.7	20.6	20.4
8/3/2005	23.6	23.5	23.5	23.4	23.4	23.0	22.2	21.9	21.6
8/18/2005	22.2	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.0
8/30/2005	21.3	21.3	21.1	20.9	20.8	20.8	20.8	20.8	20.7
9/16/2005	18.4	18.3	17.9	17.9	17.9	17.8	17.8	17.8	17.8
9/30/2005	15.8	15.8	15.7	15.7	15.7	15.7	15.7	15.7	15.7
10/11/2005	13.5	13.5	13.3	13.3	13.4	13.3	13.3	13.3	13.3
4/7/2006	8.3	7.8	7.5	7.5	7.5	7.3	7.1	6.7	6.4
4/21/2006	11.3	10.7	9.9	9.2	8.4	8.3	8.2	8.1	7.8
5/6/2006	14.6	13.7	13.5	12.8	12.1	11.1	11.1	10.7	10.6
5/18/2006	21.5	18.7	15.0	13.6	12.8	12.2	12.1	12.0	11.6
6/1/2006	19.7	18.8	16.0	15.3	14.5	13.2	13.0	11.0	
6/13/2006	20.0	20.0	19.7	15.9	14.5	14.0	13.7	13.5	13.5
6/27/2006	24.2	23.7	22.1	19.1	17.1	15.2	15.0	14.8	
7/13/2006	23.1	23.1	23.1	23.1	18.8	16.7	16.4	16.0	

Temperature (C)									
	Sample Depth (m)								
Date	0.5	1	2	3	4	5	6	7	8
8/11/2006	23.6	22.7	22.3	22.2	21.9	20.9	20.5	20.0	19.7
8/24/2006	22.1	22.0	21.8	21.5	21.5	21.3	21.2	21.2	20.9
9/7/2006	21.7	20.7	20.4	20.3	20.2	20.1	19.9	19.7	19.6
9/21/2006	16.8	16.8	16.7	16.7	16.7	16.7	16.7	16.7	16.7
10/5/2006	15.8	15.8	15.6	15.6	15.6	15.5	15.5	15.5	15.5

Table B-2. Dissolved oxygen levels (in milligrams per liter (mg/L)) observed at the mid-lake monitoring station by sampling date and depth (m).

Dissolved Oxygen (mg/L)									
	Sampling Depth (m)								
Date	0.5	1	2	3	4	5	6	7	8
7/3/85	11.0	10.4	10.4	10.8	11.0	11.0	7.2	2.8	1.0
1/23/86	11.8	11.2	9.4	8.8	6.6	3.7	1.9	1.2	0.6
3/30/86	10.0	10.0	10.0	9.8	9.6	9.0	8.4	7.8	7.2
4/19/86									
5/22/86	8.1	8.1	8.1	8.1	8.0	7.3	5.0	4.1	3.6
6/11/86	7.6	7.6	7.5	8.0	8.7	9.6	5.2	1.2	
6/27/86	7.1	7.2	7.3	7.3	7.7	6.7	2.4	0.6	0.1
7/18/86	7.2	7.2	7.1	6.9	6.9	6.8	6.4	1.4	0.6
8/20/86	7.0	7.3	7.4	7.4	7.4	7.3	2.2	0.2	0.2
9/6/86	7.9	7.7	7.8	7.9	7.9	7.9	7.9	7.5	0.5
9/28/86	7.5	7.5	7.5	7.4	7.2	7.1	7.0	7.0	6.9
10/17/86	9.8	9.8	9.7	9.7	9.6	9.5	9.5	9.4	9.0
7/7/89	10.2	10.5	10.0	9.6	3.2	0.4	0.3	0.3	
8/2/89	6.2	6.1	6.1	6.1	2.2	1.2	0.2	0.1	
8/11/89	9.5	9.7	9.9	9.4	5.1	1.3	0.3		
8/25/89	7.1	7.0	6.9	6.8	6.7	6.0	0.7	0.2	0.2
10/7/89	10.7	10.8	10.9	10.5	10.6	10.5	10.4	10.2	9.9
10/21/89	8.5	8.6	8.5	8.4	8.3	8.2	8.2	7.6	7.6
11/16/89	10.0	10.0	10.0	9.8	9.6	9.6	9.6	9.6	9.5
12/9/89	11.3	11.1	11.1	10.9	11.0	11.0	11.0	10.8	10.8
4/27/90	10.6	10.7	10.7	10.7	10.6	9.0	8.0	5.8	4.5
5/14/90	9.9	9.8	9.8	9.7	9.4	8.0	6.4	4.2	2.8
6/5/90	9.2	8.9	8.9	8.9	9.0	7.2	4.0	1.0	0.0
6/19/90	9.0	9.0	9.0	9.5	8.7	6.7	3.9	0.4	
6/27/90	8.1	8.0	8.3	10.0	10.2	7.4	1.6	0.3	0.0
7/11/90	7.6	7.9	8.0	8.2	9.7	4.9	0.5	0.2	0.0
7/26/90	11.4	11.5	11.6	11.4	11.4	8.6	2.0	0.6	
8/8/90	7.4	7.5	7.6	7.5	7.4	5.3	1.3	0.5	0.2
8/22/90	6.9	6.6	6.7	6.4	6.6	6.3	1.1	0.2	
9/5/90	7.8	7.8	7.8	7.7	7.4	6.4	4.3	0.8	0.2
9/22/90	7.6	7.6	7.6	7.4	7.4	7.3	7.3	5.1	0.3
10/6/90	6.7	6.7	6.7	6.7	6.6	6.6	6.6	6.5	6.4
11/10/90	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
11/27/90	10.2	10.2	10.2	10.2	10.0	10.0	10.0	10.0	
4/13/91	12.0	12.0	12.2	12.2	12.0	12.0	12.0	11.6	11.2
4/27/91	10.6	10.8	10.9	11.0	11.0	10.2	9.6	8.0	6.9

Dissolved Oxygen (mg/L)									
	Sampling Depth (m)								
Date	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5/30/91	8.6	8.7	8.6	8.8	8.7	8.0	6.4	5.7	2.1
6/11/91	9.2	9.3	9.4	9.4	8.8	6.8	4.7	2.2	0.4
6/25/91	9.4	9.5	9.5	9.5	8.7	6.3	3.4	0.8	0.5
7/10/91	7.8	7.9	7.9	8.4	8.7	6.8	5.7	3.5	0.5
7/25/91	7.4	7.3	7.2	7.6	7.6	6.8	5.0	0.6	0.5
8/20/91	9.2	9.2	9.2	9.3	9.0	6.2	1.4	0.3	0.1
9/20/91	7.2	7.1	7.1	6.9	6.6	6.3	6.4	5.7	
10/18/91	8.4	8.2	8.3	8.1	8.2	8.3	7.8	7.8	
11/9/91	10.5	10.5	10.4	10.3	10.2	10.2	10.2	10.2	10.2
12/1/91	11.5	11.5	11.5	11.2	11.2	11.2	10.8	10.8	10.8
1/23/92	6.8	6.8	4.1	4.0	4.0	4.0	1.0		
3/28/92	11.7	11.8	11.8	11.9	11.3	10.6	10.2	8.2	4.4
4/25/92	10.7	10.7	10.6	10.8	10.8	10.6	10.2	9.9	9.3
5/27/92	8.8	8.8	8.7	8.7	8.7	8.6	8.2	7.8	6.0
6/24/92	6.6	7.8	7.9	8.4	7.7	6.3	5.7	5.2	4.2
7/14/92	8.4	8.2	8.1	8.1	7.9	7.8	7.4	7.4	7.2
7/28/92	8.0	8.0	8.0	8.0	8.1	7.2	5.7	5.1	3.4
8/18/92	8.8	8.8	8.6	7.5	6.4	3.2	2.9	2.5	
1/30/93	9.6				4.3				3.5
2/28/93	9.4				4.1				0.5
4/24/93	9.3				9.4				8.7
5/21/93	10.1				9.4				8.0
6/18/93	8.0				4.0				0.5
7/22/93	9.0				8.6				0.1
8/13/93	8.3				6.0				0.1
9/17/93	9.1				8.4				8.1
10/22/93	9.3				9.1				8.9
4/10/94	11.3				11.3				10.4
4/29/94	11.1				10.5				7.7
5/27/94	10.3				10.3				2.1
6/29/94	10.6				7.6				2.1
7/12/94	10.4				5.9				2.4
8/2/94	7.8				1.7				0.6
9/2/94	8.0				7.8				3.0
9/14/94	7.6				7.2				2.3
10/7/94	8.6				7.1				7.4
11/7/94	7.8				7.8				2.2
4/14/95	12.2				11.0				10.9
5/6/95	11.0				11.0				9.0
5/25/95	11.1				5.9				2.4
7/29/95	8.5				5.5				0.3
5/6/97	12.1	12.4	12.0	11.0	10.2	9.4	9.4	9.2	8.0
5/22/97	9.2	9.6	10.2	10.0	9.4	8.2	7.8	7.8	7.6
6/4/97	9.0	9.3	9.2	8.4	6.4	5.4	4.8	4.5	3.4
7/8/97	10.4	10.7	10.5	6.6	2.9	2.0	2.0	1.6	0.5
7/31/97	10.0	10.4	9.8	6.2	1.6	0.6	0.5	0.3	0.3
8/4/97	9.4	10.0	10.4	8.0	1.0	0.7	0.4	0.4	0.4
3/20/98	11.4	11.4	11.2	10.8	10.6	10.8	10.4	10.5	10.0
3/27/98	11.2	10.8	11.0	10.8	10.9	11.0	11.0	11.0	11.0
4/10/98	12.5	12.2	12.3	12.3	12.2	11.6	12.0	12.1	12.0

Dissolved Oxygen (mg/L)

Date	Sampling Depth (m)								
	0.5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5/14/98	8.6	8.4	8.6	8.5	8.4	8.2	6.4	5.6	5.3
5/27/98	8.4	8.0	8.1	8.0	7.6	6.4	5.7	5.3	3.9
6/24/98	9.4	9.4	9.5	9.3	4.0	2.8	2.2	2.0	1.5
7/8/98	8.2	8.5	8.5	8.6	4.8	2.2	1.8	0.7	0.3
7/22/98	8.1	8.0	7.8	8.2	9.0	4.2	0.7	0.3	0.2
8/5/98	7.5	7.6	7.6	8.2	5.7	1.0	0.5	0.3	0.2
8/27/98	7.2	6.5	6.6	6.7	6.6	6.4	6.5	6.3	6.1
9/10/98	7.1	7.2	7.1	7.3	6.7	6.5	6.6	6.9	7.0
9/24/98	8.4	8.4	8.4	8.4	8.3	8.2	7.9	8.0	8.0
10/8/98	8.2	8.1	8.2	8.4	8.4	8.2	8.3	8.3	8.2
3/31/00	11.1	10.3	10.6	10.4	10.3	9.7	9.7	8.5	7.8
4/27/00	10.8	10.0	10.0	9.0	8.7	8.4	7.9	6.3	4.5
5/11/00	8.6	8.3	8.0	7.8	7.6	7.5	7.4	7.2	6.6
5/25/00	8.2	8.0	7.5	6.5	5.5	4.9	3.7	3.5	3.4
6/15/00	8.4	7.7	7.7	7.6	7.6	7.6	6.3	4.8	
7/6/00	10.2	9.4	9.6	8.6	7.4	2.6	0.7	0.5	0.4
7/13/00	10.6	10.4	10.7	10.5	5.3	2.2	0.5	0.4	0.4
7/26/00	10.6	9.3	9.3	4.4	1.8	0.4	0.4	0.4	0.4
8/10/00	8.6	8.1	7.8	1.1	0.4	0.4	0.4	0.4	0.4
8/24/00	8.0	8.0	7.3	6.1	3.5	3.2	1.9	1.2	0.7
9/7/00	4.2	4.0	4.0	3.7	3.4	3.3	3.4	3.2	3.1
9/21/00	7.4	9.7	6.6	6.5	6.6	6.6	6.5	6.0	2.6
10/5/00	8.1	8.0	7.5	7.3	7.3	7.6	7.3	7.8	
4/14/01	10.1	10.1	10.0	9.8	9.5	9.5	9.8	9.6	9.2
4/23/01	10.1	9.6	9.7	9.6	9.2	9.4	9.2	9.1	8.4
5/11/01	9.1	9.2	9.2	9.5	8.9	9.0	9.2	7.5	6.5
5/23/01	8.2	8.3	8.2	8.3	8.5	8.1	6.5	6.2	6.2
6/6/01	7.6	7.5	7.5	7.4	7.2	6.9	6.5	4.4	3.9
6/13/01	8.8	8.8	9.0	8.9	8.6	8.2	8.1	8.0	7.9
6/20/01	9.8	9.4	9.0	8.3	7.6	7.2	6.2	5.6	5.5
6/27/01	9.6	9.5	9.4	9.2	8.2	5.4	5.3	5.1	4.5
7/11/01	8.8	8.7	8.3	8.5	8.5	6.1	4.7	3.6	3.3
7/25/01	9.5	9.3	9.2	8.3	6.5	5.7	5.7	4.4	3.4
8/8/01	8.4	8.2	8.2	8.5	6.6	5.1	3.8	3.4	3.0
8/22/01	7.1	6.8	6.5	6.3	6.3	6.2	6.3	6.0	5.1
9/6/01	8.3	8.2	8.1	7.6	7.7	7.5	7.5	7.6	7.5
9/20/01	8.2	7.8	7.6	7.6	7.3	7.5	7.3	7.2	7.3
10/5/01	7.7	7.7	7.6	7.6	7.5	7.5	7.5	7.2	7.4
10/26/01	8.2	7.9	7.9	7.7	7.7	7.6	7.7	7.8	7.8
4/12/02	11.4	10.8	10.6	10.5	10.2	10.2	9.7	9.4	9.2
5/3/02	10.9	11.1	10.8	10.4	9.7	9.2	8.4	8.3	7.5
5/15/02	11.0	10.5	10.4	10.3	9.9	9.6	9.6	9.0	8.7
5/29/02	11.2	10.1	9.5	8.7	7.8	7.3	7.4	7.3	6.3
6/12/02	9.5	9.4	9.1	8.7	7.5	5.4	4.8	4.2	3.8
6/26/02	9.3	9.6	9.4	10.5	5.4	2.9	2.7	2.0	1.7
7/16/02	8.8	8.8	8.6	3.1	2.1	1.7	1.7	1.4	1.1
7/29/02	8.4	8.0	8.1	7.2	1.5	0.6	0.4	0.3	0.2
8/15/02	8.9	8.8	7.8	7.6	6.1	4.5	3.5	2.1	0.5
8/29/02	9.1	9.2	7.8	5.1	4.0	2.9	1.9	1.4	1.3
9/12/02	8.3	8.2	7.6	7.1	7.2	6.9	6.4	6.4	5.9

Dissolved Oxygen (mg/L)									
	Sampling Depth (m)								
Date	0.5	1	2	3	4	5	6	7	8
9/27/02	8.8	8.5	8.1	8.2	8.1	8.2	8.3	7.8	
10/8/02	11.8	10.0	9.0	9.1	9.0	8.8	8.5	8.0	7.9
10/22/02	9.8	9.8	9.7	9.8	9.8	9.8	9.5	9.7	9.6
11/15/02	11.0	10.9	10.7	10.7	10.5	10.6	10.4	10.4	10.6
2/7/03	12.2	12.0	11.9	11.9	11.8	11.6	11.6	11.6	11.4
3/28/03	11.9	12.0	11.9	11.7	11.9	11.8	11.6	10.5	10.9
4/16/03	11.6	11.6	11.3	11.1	10.9	10.7	9.3	8.8	8.0
5/2/03	10.9	10.3	10.6	9.4	8.7	7.7	7.0	6.3	4.6
5/14/03	10.1	10.2	10.1	9.5	8.6	8.0	7.9	5.1	6.0
5/28/03	9.4	9.2	8.9	8.2	7.5	5.9	5.7	5.3	4.4
6/4/03	8.0	8.1	7.8	7.7	7.6	5.5	4.8	4.4	3.9
6/16/03	7.5	7.6	7.3	7.8	7.3	5.1	2.6	1.0	0.6
7/9/03	8.3	8.0	7.7	7.7	6.7	4.7	2.2	1.6	1.1
7/23/03	8.8	8.9	8.6	8.0	3.1	1.3	0.9	0.5	0.5
8/6/03	8.8	8.6	8.3	4.8	2.6	0.3	0.3	0.3	0.2
8/20/03	7.6	7.1	6.5	5.7	4.1	3.2	2.0	1.8	1.0
9/4/03	7.4	7.6	7.3	7.3	6.1	6.4	6.3	3.9	2.4
9/18/03	7.7	7.4	7.3	7.3	7.1	7.5	6.9	6.8	7.0
10/2/03	8.0	7.5	7.4	7.1	7.3	7.6	7.3	7.6	7.4
10/24/03	7.2	6.8	6.6	6.6	6.5	6.4	6.4	6.3	6.2
3/26/04	7.0	7.1	7.1	7.1	7.1	7.2	7.2	7.2	7.1
4/16/04	10.6	11.2	10.8	10.3	9.5	9.1	9.2	8.6	7.8
5/27/04	9.3	8.8	8.5	8.3	8.1	7.8	6.9	6.6	5.8
6/10/04	8.8	8.1	8.1	7.4	6.3	6.4	6.0	5.9	4.8
6/24/04	8.2	8.2	8.7	9.0	8.5	7.9	6.8	4.3	1.4
7/14/04	7.9	7.5	7.6	6.8	6.7	5.3	3.3	2.2	1.5
8/4/04	7.5	6.9	6.7	6.6	5.3	3.0	1.6	1.1	0.5
8/12/04	7.6	7.6	7.4	5.5	4.9	3.6	1.5	0.7	0.2
8/26/04	8.7	8.8	8.7	8.6	8.6	8.2	8.4	8.7	8.6
9/9/04	8.0	7.6	7.3	7.3	7.0	6.9	6.6	6.5	6.0
9/23/04	7.4	7.0	7.2	6.9	7.1	7.0	7.1	6.8	6.7
10/8/04	8.1	7.9	7.7	8.0	7.9	7.8	7.6	7.8	8.0
10/27/04	7.8	7.5	7.4	7.2	6.9	6.8	6.9	6.7	3.3
3/17/2005	11.6	11.4	11.7	11.2	11.1	10.7	10.1	9.9	8.3
4/8/2005	10.4	10.0	9.9	9.6	9.6	9.7	8.6	7.8	7.3
4/22/2005	10.7	10.3	10.3	10.1	9.8	10.0	9.8	8.4	6.9
5/3/2005	9.8	10.1	9.7	9.4	9.3	8.6	8.0	7.5	6.9
5/19/2005	9.3	9.0	8.8	7.9	6.9	6.4	5.4	5.2	4.4
6/2/2005	9.1	8.5	8.2	8.5	7.3	6.6	5.3	4.0	3.0
6/16/2005	9.3	9.0	8.6	8.5	8.1	7.9	8.1	7.5	7.0
7/8/2005	8.3	8.2	8.4	8.1	7.6	5.8	3.5	2.8	1.6
7/21/2005	8.4	8.2	8.1	8.1	7.6	6.5	3.5	2.5	1.8
8/3/2005	7.9	7.4	7.1	7.1	6.8	6.0	2.2	1.3	0.3
8/18/2005	7.7	6.2	6.1	6.2	6.1	6.3	5.8	6.3	5.6
8/30/2005	6.5	6.5	6.2	5.8	5.9	6.0	5.9	5.8	5.9
9/16/2005	8.0	7.6	7.8	7.5	7.8	7.0	7.4	7.8	7.4
9/30/2005	8.3	8.0	8.1	8.1	7.7	8.0	8.0	7.9	7.7
10/11/2005	9.7	8.8	8.5	8.3	8.3	8.3	8.2	8.1	7.8
4/7/2006	11.3	10.6	10.3	10.7	10.5	9.8	9.2	8.5	6.9
4/21/2006	11.4	11.3	11.4	11.1	9.9	9.5	9.4	9.1	7.3

Dissolved Oxygen (mg/L)									
	Sampling Depth (m)								
Date	**0.5**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5/6/2006	11.0	10.8	10.3	9.2	8.7	7.4	7.3	6.5	6.0
5/18/2006	8.4	7.7	9.5	9.1	8.2	6.4	6.0	5.8	4.1
6/1/2006	9.7	9.5	8.8	7.0	5.7	3.9	3.6	3.0	
6/13/2006	9.2	8.9	8.3	5.5	3.3	2.2	1.8	1.2	1.3
6/27/2006	8.2	8.1	8.7	9.2	4.8	1.7	1.1	0.8	
7/13/2006	7.7	7.2	7.5	7.1	6.4	2.5	1.4	0.7	
8/11/2006	8.9	9.1	8.9	8.7	7.8	3.9	2.0	0.4	0.2
8/24/2006	7.7	7.5	7.4	6.7	6.0	4.3	3.7	3.5	1.1
9/7/2006	8.8	9.0	8.8	8.0	7.8	7.3	4.7	2.8	0.9
9/21/2006	7.9	7.9	7.8	7.7	7.7	7.7	7.7	7.7	7.5
10/5/2006	8.7	8.7	8.7	8.5	8.4	8.3	8.2	8.1	7.6

Table B-3. Total phosphorus (TP) concentrations (in micrograms per liter (ug/L)) observed at the mid-lake monitoring station by sampling date and depth (m). Highlighted data were excluded from analysis (refer to enclosed comments below).

Sampling Date	Total Phosphorus (ug/L)		
	0.5 m	4 m	8 m
07/03/85	18	49	49
01/23/86	14	27	84
03/30/86	40	45	44
04/19/86	23	31	36
05/22/86	29	43	42
06/11/86	10	16	20
06/27/86	18	22	45
07/18/86	20	20	196
08/20/86	25	13	256
09/06/86	32	32	548
09/28/86	38	56	52
08/02/89	20	24	220
08/11/89	26	29	188
08/25/89	21	25	336
09/02/89	16	16	181
09/19/89	24	19	25
10/07/89	40	40	39
11/16/89	21	37	37
12/09/89	24	24	53
03/10/90	32	16	101
03/31/90	22	30	35
04/14/90	76	109	427
04/27/90	112	128	130
05/14/90	141	128	104
06/05/90	156	206	148
06/19/90	150	118	84
06/27/90	145	133	104
07/11/90	108	101	129
07/26/90	165	183	186
08/08/90	74	23	71
08/22/90	18	15	56
09/22/90	123	20	341
10/16/90	18	18	58
11/10/90	78	137	77
01/18/91	109	100	92
04/13/91	23	39	39
04/27/91	13	18	23
05/20/91	16	27	51
05/30/91	16	22	27
06/11/91	18	21	31
06/25/91	15	25	63
07/10/91	10	15	58
07/25/91	15	15	15
08/20/91	11	10	43
09/20/91	15	15	62
10/18/91	26	27	35
11/09/91	15	20	20

Sampling Date	Total Phosphorus (ug/L)		
	0.5 m	4 m	8 m
12/01/91	15	15	15
01/23/92	39	77	452
02/14/92	97	1	1
03/28/92	29	14	21
04/25/92	21	21	33
05/27/92	20	21	27
06/24/92	16	27	66
07/14/92	28	144	52
07/28/92	25	31	41
08/18/92	18	24	70
09/19/92	27	42	33
01/30/93	19	28	162
02/28/93	73	50	19
04/24/93	23	27	32
05/21/93	16	31	40
06/18/93	18	20	32
07/22/93	19	20	76
08/13/93	20	17	45
09/17/93	27	37	30
10/15/93	33	32	33
03/11/94	10	17	12
04/10/94	18	16	18
04/29/94	15	12	12
05/27/94	9	16	21
06/29/94	12	14	22
07/12/94	14	20	27
08/02/94	11	18	19
09/02/94	24	20	79
09/14/94	40	40	26
10/07/94	56	80	70
11/07/94	58	58	47
04/14/95	47	31	33
05/25/95	24	28	28
05/06/97	46	20	24
05/22/97	11	11	31
06/04/97	27	6	35
07/08/97	20	40	51
07/31/97	23	23	13
08/05/97	13	37	23
09/04/97	13	8	25
09/11/97	36	18	4
10/10/97	35	47	53
03/21/98	13	30	21
03/28/98	38	19	39
04/11/98	23	32	19
05/15/98	13	16	27
05/28/98	24	49	71
06/25/98	22	49	42
07/09/98	34	67	65
07/23/98	30	53	33
08/06/98	42	x<DL	12

Sampling Date	Total Phosphorus (ug/L)		
	0.5 m	4 m	8 m
08/28/98	29	35	41
09/11/98	24	29	38
10/09/98	41	40	42
10/23/98	36	53	51
04/06/99	74		51
04/23/99	32	39	30
05/07/99	53	53	80
05/27/99	16	30	8
06/16/99			39
06/30/99	63	66	93
07/14/99	62	58	69
07/28/99	32	25	26
08/11/99	22	30	31
08/26/99	16	19	18
09/09/99	16	19	37
10/07/99	26	33	30
10/21/99	26	33	30
03/24/00	86	67	86
03/31/00	11	68	55
04/27/00		32	50
05/11/00	38	41	43
05/25/00	8	27	38
06/15/00	10	24	12
07/13/00	x<DL	6	44
07/26/00	9	3	69
09/21/00	4	12	7
04/14/01	74	61	65
04/23/01	37	31	24
05/11/01	==	75	81
05/23/01	64	70	83
06/06/01	x<DL	20	40
06/20/01	10	20	30
07/11/01	20	20	30
07/25/01	10	30	10
08/08/01	10	20	20
08/22/01	10	20	20
09/06/01	10	20	20
09/20/01	40	30	30
10/5/01	22	23	19
04/12/02	30	29	30
05/03/02	29	29	29
05/15/02	30	29	40
05/29/02	35	35	32
06/12/02	29	38	49
06/26/02	26	44	90
07/16/02	42	46	49
07/29/02	48	56	81
08/15/02	77	86	101
08/29/02	39	58	114
09/12/02	43	47	48
09/27/02	44	49	48

Sampling Date	Total Phosphorus (ug/L)		
	0.5 m	4 m	8 m
10/08/02	40	560	58
10/22/02	47	101	100
11/15/02	55	51	59
03/28/03	15	17	18
04/16/03	13	14	17
05/02/03	7	8	9
05/14/03	x<DL	7	20
05/28/03	12	19	25
06/04/03	11	16	45
06/16/03	13	14	38
07/09/03	16	19	29
07/23/03	20	23	33
08/06/03	14	13	17
08/20/03	18	14	21
09/04/03	21	22	31
09/18/03	26	27	30
10/02/03	23	27	22
10/24/03	34	30	28
03/27/04	33	36	39
04/17/04	38	41	42
05/28/04	34	30	52
06/11/04	34	18	29
06/25/04	92	84	123
07/15/04	19	10	19
08/05/04	36	34	95
08/13/04	9	11	37
08/27/04	21	23	15
09/10/04	14	16	20
09/24/04	18	20	18
10/09/04	17	18	20
10/26/04	7	7	8
03/17/05	23	23	21
04/08/05	26	24	27
04/22/05	28	26	28
05/03/05	30	27	31
05/19/05	33	28	34
06/02/05	11	11	37
06/16/05	10	12	39
07/08/05	8	12	29
07/21/05	9	11	28
08/03/05	10	12	26
08/18/05	50	20	28
08/30/05	29	18	31
09/16/05	25	27	26
09/30/05	11	10	17
10/11/05	7	5	11
4/7/2006	14	12	12
4/21/2006	29	28	23
5/5/2006	29	16	32
5/18/2006	24	23	34
6/1/2006	15	19	29

Sampling Date	Total Phosphorus (ug/L)		
	0.5 m	4 m	8 m
6/13/2006	11	12	34
6/27/2006	9	18	17
7/13/2006	9	12	28
8/10/2006	8	10	16
8/24/2006	7	10	14
9/6/2006	10	13	14
9/21/2006	8	9	6
10/5/2006	7	11	13

Comments regarding total phosphorus data quality: Inclusion or exclusion of various data.

6/11/86

Common throughout this data set are rapid and improbable changes in TP concentrations occurring at times throughout the water column or at other times only at select depths. An example of this are the TP concentrations reported on 6/11. The TP concentrations observed on the prior sampling date (5/22) were reported at levels approximately 2 to 3 times greater. The reported values on 6/27, the sampling data following 6/11, were about two times higher (18 ug/L). So within a short period, there is a rapid decline in TP concentrations throughout the water column. Surface water inflow levels during this period were steady and declining at normal levels. The Secchi reading for 6/11 was reported at 4 meters (m), which would be in-line with this low phosphorus concentration. However, it was communicated that the Phase I study (containing 1986 data) erroneously reported Secchi readings as meters when they were actually in units of feet. If this is the case, then the Secchi transparency was really only 1.2 m despite this very low phosphorus concentration, further highlighting this unusual data.

4/14/90 – 9/22/90

A whole lake alum treatment was conducted in the fall of 1989. The following summer (June-August) the average Secchi transparency was reported at 3.6 meters, extending to 5.4 meters on 8/8/90. During the summer of 1990 the highest recorded Secchi readings observed for the lake were recorded. Water clarity was at a maximum. However, TP concentrations during this period were reported in the hundreds of micrograms per liter for the upper water column, the highest reported concentrations for the lake. For instance, on 7/26/1990 a surface TP concentration of 165 ug/L was recorded. This is the highest TP level recorded for this depth during the summer period. In 1990, the average summer (June-August) TP concentration within the epilimnion was 114 ug/L. On August 8 when clarity was at a maximum (5.4 m), the reported TP concentration was 74 ug/L. The average TP concentration of Thompson Creek was 55 ug/L during the summer period. While there was unusual spike in inflow from May 27 to June 3 , lake TP concentrations were already elevated and the increase in inflow (loading) was not reflected in lake phosphorus concentrations at that time.

The Department of Ecology collected TP samples in Newman Lake on two occasions in 1990, 5/26 and 8/9 (Rector, 1993*). The TP samples were a composite, or equal mixture of water collected from 1, 2, and 4 meter depths. On 5/26, the epilimnion sample had a TP concentration of 23 ug/L while on 8/9 the concentration was 24 ug/L. WSU sampling dates prior to and following the 5/26 Ecology sampling effort are 5/14 and 6/5. On these dates the average epilimnion TP concentration (0.5 and 4 m depths) was reported at 135 ug/L and 181 ug/L, respectively. The WSU values are a factor of 6 to 8 times greater. The WSU reported TP concentration for 8/8 was 49 ug/L while the Ecology reported value, collected the previous day (8/8), was about half at 24 ug/L.

*Rector, J., David Hallock. 1993. Lake Water Quality Assessment Project, 1990. Washington State Department of Ecology. Environmental Investigations and Laboratory Services Program, Ambient Monitoring Section. Publication 92-124.

11/10/90

Similar to 6/11/86, on 11/10/90 there is an unusual deviation in TP concentrations (137 ug/L at 4 m). This TP concentration is not congruent with levels observed on prior or following sampling dates or within the concentration pattern present within the water column. For instance, on 11/10/90, the water column of the lake was fully mixed with surface and bottom TP levels at about 77 ug/L yet, at 4 m, the TP concentration was twice as high at 137 ug/L.

7/25/91

TP concentrations are uniform throughout the water column despite the fact that the lake was stratified. TP concentrations recorded at 8 m prior to and following this sampling date had recorded TP concentrations that were 3 (8/20) to 4 (7/10) times greater.

2/14/92

TP concentrations at the surface increased by a factor of three from the prior sampling date (1/23) from 39 ug/L to 97 ug/L while concentrations at 4 and 8 meters were reported at 1 ug/l, a level typically below the limit of detection. These are the lowest reported TP concentrations for the lake.

7/14/92

A TP concentration spike was recorded at 4 m. TP concentrations reported prior to (6/24) and following (7/28) the 7/14 sampling date were 80 percent lower; 30 ug/L as opposed to 144 ug/L. In addition, the water column on this date was fully mixed with uniform water temperatures and among the highest recorded dissolved oxygen levels for July.

5/6/97-3/28/98

During the spring and summer of 1997, surface water inflow to Newman Lake was at unusually high levels (associated with above average of snow-pack and precipitation levels). (No TP measurements were measured for Thompson Creek for this period.) The average summer (June-August) Secchi transparency was low at 1.5 m, among the lowest recorded for Newman Lake. The lower transparency probably reflects the high organic and inorganic suspended matter within the water column associated with the elevated surface water inflow and an expected increase in algal productivity. These conditions typically translate into higher observed TP concentrations. However, TP concentrations recorded during the summer of 97 were among the lowest observed for the lake. TP was recorded at 6 ug/L at 4 m on 6/4, 8 ug/L at 4 m on 9/4, and 4 ug/L on 9/11 at 8 m. In addition to the unusually low overall TP concentrations, the distribution of phosphorus within the water column is unusual.

For instance, on 6/4 while the TP concentration is 27 ug/L at the surface, and 35 ug/L at the bottom, it is 6 ug/L at 4 meters, about 5 times lower. On 9/11, the 8 m TP concentration was recorded as 4 ug/L while the surface and 4 m concentrations were 36 ug/L and 18 ug/L, respectively. During the summer period, until the water column is fully mixed, TP concentrations at 8 m are usually higher than concentrations observed in the upper water column (surface and 4 m) due to algae settling to the lake bottom and the release of phosphorus from sediments. When the lake is fully mixed, TP concentrations will be relatively uniform throughout the water column not declining toward detection limit levels as reported for 9/11.

8/6/98

TP concentration was reported below detection at 4 m on 8/6 while at the same depth, two weeks prior, a concentration of 53 ug/L was recorded. The TP concentration at 8 m is also abnormally low at 12 ug/L, the lowest observed during August. Two weeks following the 8/6 sampling date (8/28), TP concentrations returned approximately to the levels observed previously. Inflows during August were steady and declining. In addition, on this sampling date, the lake was stratified with dissolved oxygen concentrations below 1 mg/L from 5 m depth to the bottom circumstances that typically lead to the release of phosphorus from sediments.

5/27/99

An unusually low TP concentration occurs on 5/27 at 8 m (8 ug/L). By May the lake is usually weakly stratified. (The temperature and dissolved oxygen data for 1999 have apparently gone missing, so the level of stratification cannot be determined for this date.) The higher TP concentration recorded at 8 m on 5/7 (80 ug/L) suggests the release of phosphorus from sediments. During this period, inflow levels are declining steadily with no rapid increases. Given the TP concentrations recorded on 5/27, if the water column mixed, phosphorus levels would have increased throughout the upper water column, becoming more uniform in magnitude. This did not occur. So this type of event is probably unlikely. Instead, concentrations declined dramatically through the lower water column with no real plausible explanation.

10/7/99 & 10/21/99

The same TP concentrations, for each depth, are reported for these two sampling periods, a situation that has a low probability of occurring, and is likely the result of reporting error. (Reported TP concentrations at 0.5 m and 4 m for 8/26 and 9/9 also follow the same pattern.)

3/31/00

For this sampling date, within the upper water column (surface), TP concentrations rapidly decline to an unusually low level, in 7-days, from 86 ug/L (3/24/00) to 11 ug/L (3/31). Proportional decreases in TP were not observed at 4 and 8 meter depths despite the lake being weakly stratified at these times.

5/25/00 – 9/21/00

During this period phosphorus concentrations were unusually low particularly on 7/13 when TP concentrations at the surface were below detection (typically 1 or 2 ug/L) and on 7/26 when a concentration of 3 ug/L was recorded at 4 m. From the reported values, the average summer period epilimnion TP concentration was 10.2 ug/L, the lowest since records have been kept. The summer of 2000 was also a period when the oxygenator was only functional in June.

Total phosphorus concentrations at this low a level are not consistent with the observed Secchi transparency readings recorded for the same period. During July 2000, Secchi readings averaged 1 m. The summer average level was 1.1 m, among the lowest recorded for Newman Lake. The low TP concentrations observed throughout the water column despite a largely in-operative oxygenator would suggest its low level of influence with reducing in-lake phosphorus concentrations.

6/6/01 – 9/20/01

These data have a low level of analytical resolution with TP concentrations reported only to the nearest tens of micrograms per liter. Due to the low reporting resolution, on three consecutive sampling dates 8/8, 8/22, and 9/6, at each depth, a constant TP concentration is maintained, an unusual pattern in comparison to past data.

7/15/02 – 8/15/02

The TP concentrations observed at the three monitoring depths on 7/16 are nearly uniform at approximately 45 ug/L. In comparison, on the previous sampling date 6/26, TP concentrations at the surface were approximately half this level (26 ug/L). During both these sampling dates, temperature and dissolved oxygen profiles indicate that the lake was stratified with inflow levels (Thompson Creek) steady and declining. For this reason, the apparent redistribution of TP throughout the water column is difficult to explain. While the lake remained stratified during this period, again with steady and declining surface water inflow, TP concentrations increased throughout the water column.

Increases in TP concentrations at 8 m are expected, due to stratification and the resulting anoxic hypolimnion that causes the release of phosphorus from sediments. However, there is not a defined TP source for the increase in concentrations at the surface and 4 m.

10/8/02

A large spike in TP concentrations occurs at 4 m (560 ug/L) on this date. The concentration is about 10 times greater than observed at the surface or 8 m despite the lake being fully mixed at the time.

3/28 – 8/20/03

TP concentrations, overall, are much lower than environmental conditions would suggest. The average summer TP concentration was about 16 ug/L yet the average Secchi transparency was 2.1 m, indicating low water clarity. A 2.1 m average is more indicative of a situation where there is more suspended organic and inorganic matter within the water column resulting in higher TP concentrations. TP concentrations declined to levels below detection ($x<2$ ug/L) on 5/14 a very unusual situation. On 8/6, when the TP concentration within the upper water column was reported to be about 14 ug/L (among the lowest reported levels for August), the Secchi transparency was low at 1.5 m.

6/11 – 10/26/04

This period, in contrast to 2003, had more elevated TP concentrations than would be expected based on environmental conditions. Surface water inflow (and associated phosphorus loading) was low relative to other years data have been collected and the Secchi transparency levels reflect this reduced level of loading with a summer average of 2.5 m, among the highest observed since the oxygenator was installed. In fact, among the highest Secchi readings were recorded during the summer of 2004 for Newman Lake on 6/25 at 3.5 m. On this same date, TP concentrations within the upper water column were reported at 92 ug/L, typical of a hyper-eutrophic lake. With surface water inflow low and steady, TP concentrations at this level would be indicative of a substantial algae bloom yet water clarity was high.

6/1-10/5/06

During the summer of 2006, TP concentrations were reported at exceptionally low concentrations. Based on this data, the summer average for 2006 was 11.4 ug/L, among the lowest reported for Newman Lake. However, during the spring of 2006, a higher than normal snow-pack resulted in significantly increasing phosphorus loading to the lake in comparison to the previous 5 years. As a consequence of this increased loading, the average summer Secchi transparency was less than 2 m at 1.7 m. During the month of August, when the upper water column had an average reported TP concentration of 8 ug/L, (an exceptionally low level for Newman Lake) the average Secchi transparency was low at 1.4 m, reflective of substantial suspended matter within the water column (algae).

Table B-4. Secchi transparency measurements (in meters) and chlorophyll (a) concentrations (in micrograms per liter) observed at the mid-lake monitoring station by sampling date. (Chlorophyll (a) data shaded grey was used to generate Figures 3 and 4.)

Sampling Date	Secchi Transparency (m)	Chlorophyll (a) (ug/L)		
		0.5 m	4 m	8 m
7/3/85	4.9		17.8	19.3
1/23/86			6.5	
3/30/86	2.0	19.1	13.2	7.8
4/19/86	1.9	19.1	13.2	20.6
5/22/86	2.8	9.8	18.9	11
6/11/86	4.0	3.8	6.3	71.4
6/27/86	4.5	5.8	7.3	8.1
7/18/86	4.5	4.8	6.1	29.1
8/20/86	4.8	4.4	7.8	67.7
9/6/86	2.0	5.2	11.1	76.5
9/28/86	2.8	11.0	20	18.7
10/17/86	2.5			
7/7/89	1.2	42.9	19.6	4.4
8/2/89	3.8	2.0	2.9	58.1
8/11/89	1.9	28.0	16.8	51.5
8/25/89	2.0	9.6	11	51.5
10/7/89	1.7	14.7	17.4	17.4
10/21/89				
11/16/89	2.3	13.4	16	13.4
12/9/89	2.0	15.4	13.4	14.3
4/27/90	1.8	14.2	29.7	24.3
5/14/90		10.3	19.5	18.9
6/5/90	1.4	7.2	7.1	6.2
6/19/90	2.0	2.7	8	2.7
6/27/90	3.3	1.3	8.1	6.7
7/11/90	4.3	3.3	10.1	30.7
7/26/90	5.3	4.1	7.1	30.7
8/8/90	5.4	1.5	4.9	80.1
8/22/90	3.5	15.1	21.0	88.1
9/5/90	4.3	2.0	5.6	81.4
9/22/90	3.0	5.1	6.8	49.8
10/6/90	2.3	12.1	11.8	11.5
11/10/90	3.5	9.6	9.6	11.5
11/27/90	3.5	8.4	10.0	8.1
4/13/91	2.0	8.1	16	16
4/27/91	2.1	6.7	14.5	20.7
5/30/91	2.5			
6/11/91	3.4			
6/25/91	2.5	3.2	10.7	46.1
7/10/91	3.5	2.7	4.7	38.1
7/25/91	3.5	3.2	4	34.7
8/20/91	3.8	4.2	18.7	84.1
9/20/91	2.9			
10/18/91	2.2	15.0	16	17.8
11/9/91	2.8	17.7	16.7	12.4
12/1/91		20.4	19.8	16.7

Sampling Date	Secchi Transparency (m)	Chlorophyll (a) (ug/L)		
		0.5 m	4 m	8 m
1/23/92				
3/28/92	3.2	4.7	8	12.7
4/25/92	2.8	10.0	11.4	10
5/27/92	4.0	4.8	5.3	4.7
6/24/92		2.3	2.7	16.7
7/14/92		8.7	19.7	17.7
7/28/92	2.0	12.7	32	16.7
8/18/92	2.5	10.7	14.7	20
5/6/97	1.0			
5/22/97	2.3			
6/4/97	2.2			
7/8/97	1.5			
7/31/97	1.3			
8/5/97	1.0			
8/11/97	1.5			
3/20/98	1.5			
3/27/98	1.5			
4/10/98	1.5			
5/14/98	2.5			
5/27/98	2.3			
6/24/98	2.3			
7/8/98	2.5			
7/22/98	3.0			
8/5/98	3.0			
8/27/98	1.5			
9/10/98	1.5			
9/24/98	1.5			
10/8/98	2.0			
4/6/99	1.5			
4/23/99	1.3			
5/7/99	1.5			
5/27/99	2.5			
6/16/99	2.0			
6/30/99	2.0			
7/14/99	1.8			
7/28/99	1.5			
8/11/99	0.8			
8/26/99	0.8			
9/2/99	1.0			
9/9/99	1.3			
3/31/00	1.0			
4/27/00	1.5			
5/11/00	1.5			
5/25/00	2.5			
6/15/00	1.8			
7/6/00				
7/13/00	1.2			
7/26/00	0.8			
8/10/00	0.6			
8/24/00	1.1			

Sampling Date	Secchi Transparency (m)	Chlorophyll (a) (ug/L)		
		0.5 m	4 m	8 m
9/7/00	1.5			
9/21/00	2.0			
10/5/00	1.3			
4/14/01	1.5			
4/23/01	1.5			
5/11/01	2.3			
5/23/01	2.5			
6/6/01	2.5			
6/13/01	1.5			
6/20/01	2.5			
6/27/01				
7/11/01	3.8			
7/25/01	3.5			
8/8/01	2.8			
8/22/01	1.8			
9/6/01	1.8			
9/20/01	1.5			
10/5/01	1.8			
10/26/01	1.8			
4/12/02	1.5			
5/3/02	1.3			
5/15/02	1.8			
5/29/02	2.3			
6/12/02	1.5			
6/26/02	2.3			
7/16/02	2.0			
7/29/02	1.8			
8/15/02	1.3			
8/29/02	1.5			
9/12/02	1.3			
9/27/02	1.3			
10/8/02	1.5			
10/22/02	1.0			
11/15/02	1.0			
2/7/03	1.3			
3/28/03	1.3			
4/16/03	1.3			
5/2/03	1.8			
5/14/03	2.3			
5/28/03	2.5			
6/4/03	2.8			
6/16/03	2.5			
7/9/03	2.5			
7/23/03	1.8			
8/6/03	1.5			
8/20/03	1.5			
9/4/03	2.3			
9/18/03	1.8			
10/2/03	2.0			
10/24/03	2.3			

Sampling Date	Secchi Transparency (m)	Chlorophyll (a) (ug/L)		
		0.5 m	4 m	8 m
3/26/04	1.8			
4/16/04	1.8			
5/11/04				
5/27/04	2.3			
6/10/04	3.0			
6/24/04	3.5			
7/14/04	3.0			
8/4/04	2.3			
8/12/04	1.5			
8/26/04	1.5			
9/9/04	1.5			
9/23/04	1.8			
10/8/04	1.8			
10/27/04	2.0			
3/17/2005	1.9			
4/8/2005	3.5			
4/22/2005	2.5			
5/3/2005	2.5			
5/19/2005	2.5			
6/2/2005	2.3			
6/16/2005	1.8			
7/8/2005	2.5			
7/21/2005	3.0			
8/3/2005	2.5			
8/18/2005	1.3			
8/30/2005	1.8			
9/16/2005	2.0			
9/30/2005	2.0			
10/11/2005	2.5			
4/7/2006	1.3			
4/21/2006	1.5			
5/6/2006	1.0			
5/18/2006	2.3			
6/1/2006	1.3			
6/13/2006	1.8			
6/27/2006	2.0			
7/13/2006	2.5			
8/11/2006	1.5			
8/24/2006	1.3			
9/7/2006	1.5			
9/21/2006	1.3			
10/5/2006	1.8			

Appendix C. Water Quality Issues Concerning Oxygenator

In 1992, a Speece Cone-type oxygenator was installed in Newman Lake designed to provide sufficient dissolved oxygen to the hypolimnion to reduce the period of anoxia when the lake is stratified. By supplying sufficient oxygen to the hypolimnion, and maintaining aerobic conditions at the sediment-water interface, it was believed that the oxygenator could significantly reduce the release of phosphorus into the water column. However, based on the analysis of temperature and dissolved oxygen profiles, collected over 15 years during the stratification period, it appears that the oxygenator is not functioning as designed resulting in unintended alterations to Newman Lake's water quality.

Stratification and phosphorus recycling

Phosphorus is typically adsorbed to sediment under aerobic conditions. Following the onset of stratification, the supply of dissolved oxygen to the hypolimnion, through circulation, is stopped and microbial decomposition of organic matter, present in sediments, rapidly uses up all available oxygen. For this reason, hypolimnetic dissolved oxygen levels during stratification are negligible. Newman Lake is typically stratified (to varying degrees) from May through August, with the strongest period of stratification late-June through July. As dissolved oxygen levels decline to anaerobic conditions, phosphorus is released into the water column. As a consequence, phosphorus concentrations are usually significantly higher in the hypolimnion than in the epilimnion, in part due to this sediment release, or recycling pathway. Problems arise if this source of phosphorus is able to migrate to the epilimnion where algae grow. Prior studies indicated that this pathway was a major driver stimulating summer period algal growth resulting in the installation of the oxygenator. The primary objective of the oxygenator was to maintain high enough dissolved oxygen levels within the hypolimnion to significantly reduce this phosphorus recycling pathway.

Newman Lake, on average, has uniform water column temperatures from September through March indicating that the entire water column is fully circulating (Figure C-1). (The exception during this period is January when the surface of the lake tends to be frozen.) Beginning in March, with increased levels of solar radiation the surface of the lake begins to heat at a greater rate than the lower water column, resulting in the onset of stratification.

July is typically when stratification is the strongest. There is a maximum temperature difference between the upper and lower portions of the water column. The greater the temperature difference, the stronger the level of stratification. June and September are transitional months when the lake is vulnerable to de-stratification, or full water column mixing, because there is a lower temperature difference between the surface and bottom temperatures. Further analysis focuses on temperature and dissolved oxygen levels observed within the water column during July at peak stratification.

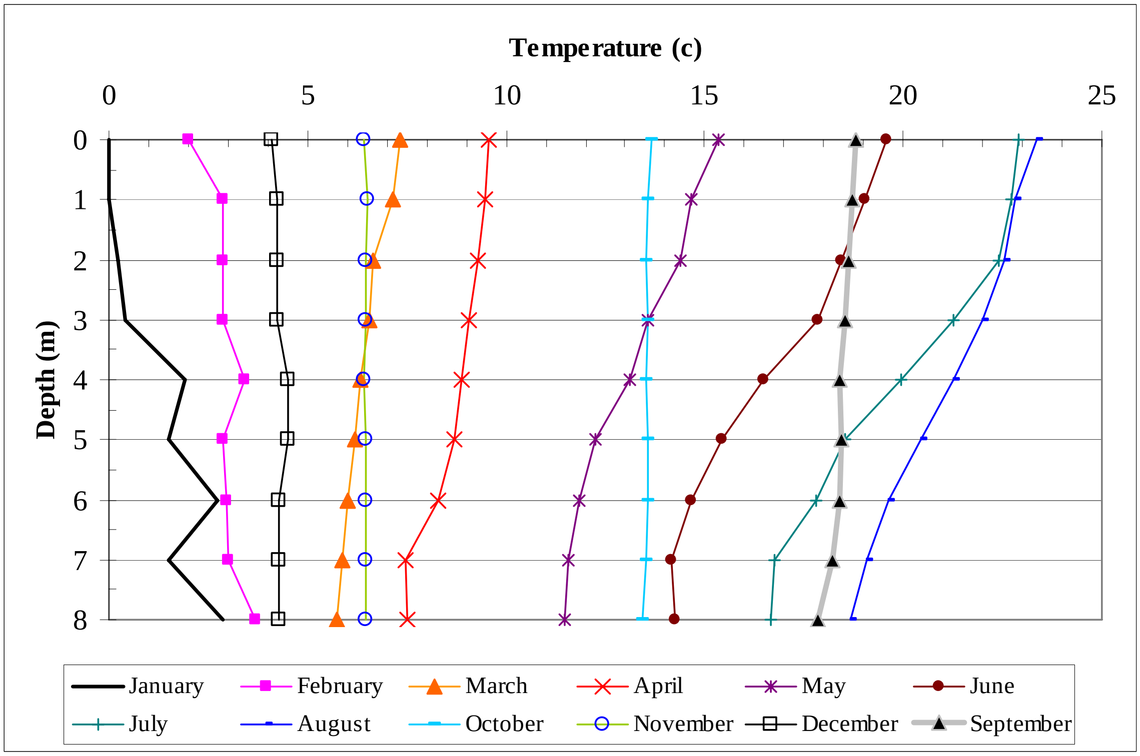

Figure C-1. Average water temperatures observed in Newman Lake by depth and month, 1985-2004. (years without temperature profiles: 1987, 1988, 1993, 1995, 1996, 1999.) Both pre and post-oxygenator periods are analyzed together.

Comparison of July temperature profiles

Figure C-2 presents average July temperature profiles observed during the years temperature has been recorded for Newman Lake. The profiles in red (bold) are those collected prior to the installation of the oxygenator and the thin lines (black) are following its installation (1992+).

Average July temperatures are highly variable in both surface and bottom temperatures. For instance, in 1992 the lake was completely unstable with nearly uniform water temperatures throughout the water column. (This highly unusual temperature profile may be associated with the start-up of the oxygenator.) Due to this variability there does not appear to be a significant difference in surface water temperatures (0 to 4-meters) prior to and following the installation of the aerator. However, below this depth, deviation in the former temperature pattern is apparent.

Hypolimnion temperatures (6+ meters depth) were colder prior to the installation of the oxygenator. In particular, over the period 2003 to 2005, average hypolimnion temperatures approached, and at times exceeded 20^{o}C during July. In comparison, prior to the oxygenator average July temperatures at 8-meters depth were approximately 13^{o}C. The coldest hypolimnion temperatures occurred prior to 1991. Also of note are the uniform, isothermal, temperatures now observed within the hypolimnion extending from 5-meters depth to the bottom. Prior to the oxygenator, hypolimnion temperatures continued to decline through this portion of the water column (Figure C2).

As water temperatures increase within the hypolimnion (below approximately 6-meters) the more unstable the water column becomes. This is because it takes a lower amount of energy to completely mix the stratified lake. The reason full water column mixing is a concern is that the release of phosphorus from bottom sediments and its introduction to the upper water column through full water column mixing can stimulate high algal growth rates.

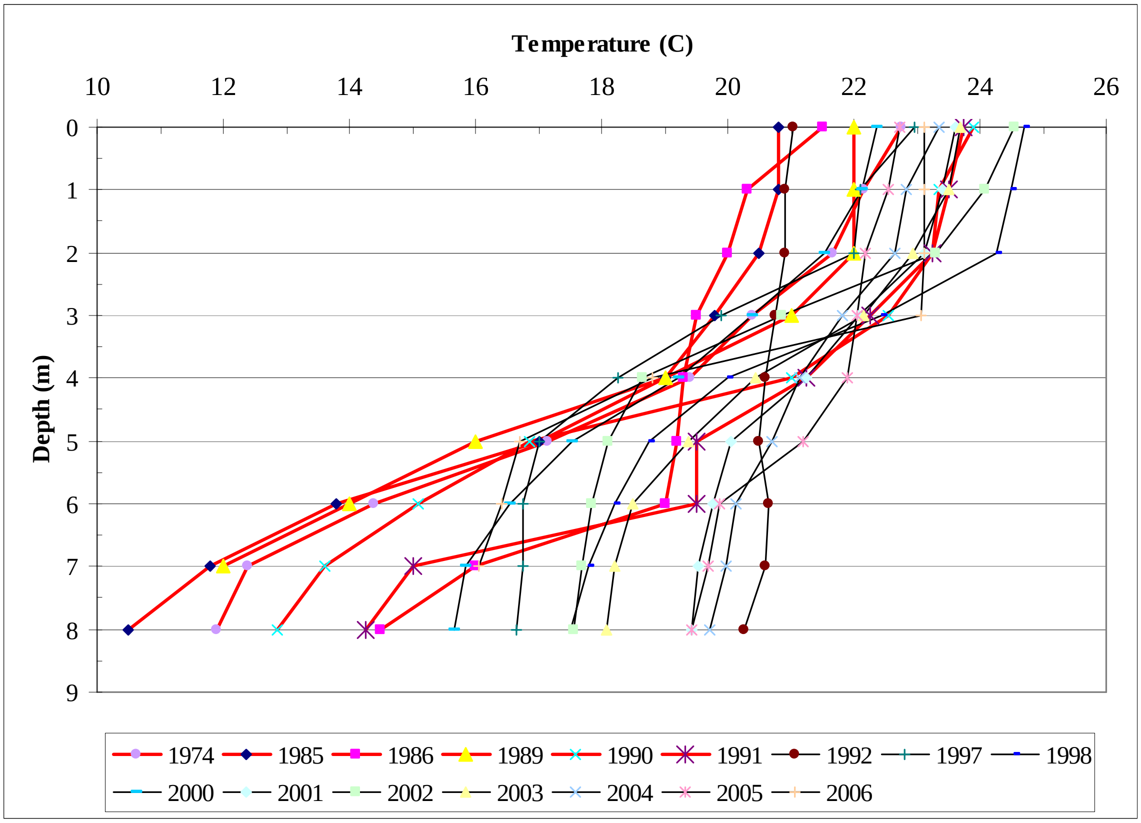

Figure C-2. Average July temperatures observed in Newman Lake, by depth and year. (Red profiles indicate years prior to aerator installation.)

Figure C-3 is a synthesis of these profiles. The red profile (black dots) represents the average July temperature based on observations made prior to the oxygenator and the black profile (white dots) is the average of the observed data following the installation of the oxygenator. Again, the upper portion of the water column (0 to 4-meters depth) pre and post oxygenator is similar, varying by less than 1^{o}C. In contrast, significant temperature divergence occurs below 5-meters depth. Pre-oxygenator temperatures continue to decline to approximately 13^{o}C at 8-meters while post-oxygenator temperatures are uniform through this portion of the water column, at over 18^{o}C. So on average, a 5^{o}C increase has occurred within the hypolimnion following the installation of the oxygenator.

The effect of the oxygenator on hypolimnion heating can be observed for the profile of July 2000 temperatures (depicted in Figure C-2). In 2000, the oxygenator's pumping system was shut down following June. Without this influence, July 2000 hypolimnion temperatures were the coldest since the initiation of the oxygenator, conforming to former temperature patterns. Recognizing the changes in the temperature profiles; both the increase in observed hypolimnion temperatures and the fact that they are also isothermal (uniform), suggest that the oxygenator is causing lower water column mixing.

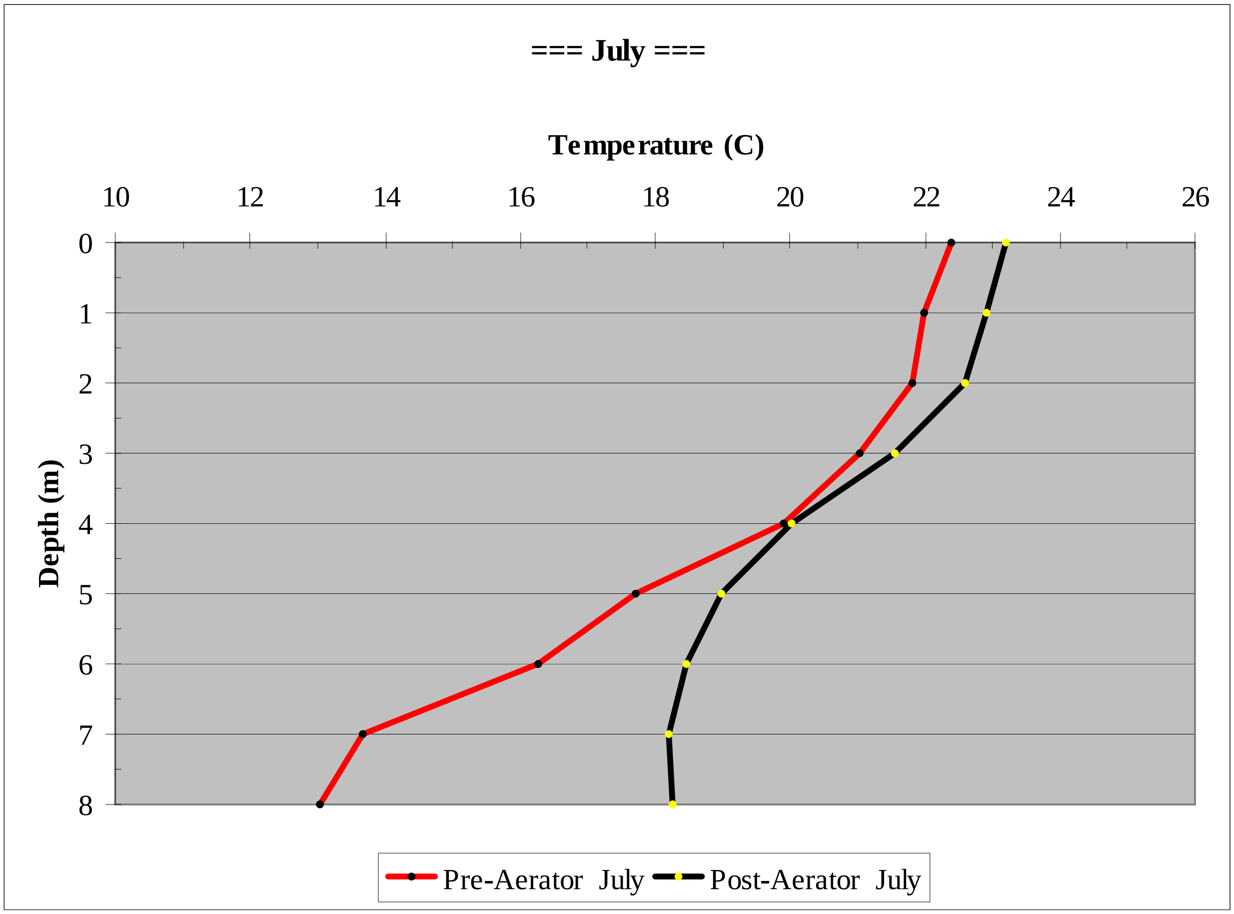

Figure C-3. Average July temperatures observed for the pre and post-aerator periods.

Lower water column mixing

It is believed that the oxygenator is facilitating lower water column mixing primarily as a result of the magnitude and velocity of inflow to the Speece-cone. When operating, the oxygenator's 60 horsepower pump circulates approximately 21 cubic feet per second (cfs) (0.6 m3/s) of hypolimnetic water through the cone. This flow is directed through a 2-foot diameter entrance resulting in the acceleration of flow from 0 to about 7 feet per second.

To provide some perspective to this pumping rate, the maximum average monthly flow in Thompson Creek occurs in March at about 33 cubic feet per second (cfs). At an inflow rate of 21 cfs, the lower 1.5 meters of the water column (depth below the center of the intake) is circulated through the cone every 11 days.

Factors influencing oxygenator mixing

Annually, there are varying levels in the strength of stratification as indicated by the difference in temperature between the hypolimnion and epilimnion. And, while meteorological factors have a role they do not appear to be the dominant one in effecting the temperature variability in the hypolimnion. They primarily affect the variation in temperature within the epilimnion; temperatures within the hypolimnion are largely buffered from surface meteorological factors. Instead, heat is passed from the surface to the lower water column primarily through conduction. For this reason, as it will be shown, epilimnion temperatures display greater summer period variability in comparison to those observed in the hypolimnion. The trend in lower water column temperatures, over the stratification period, is one of steady and gradual increase, peaking at the time of lake turnover.

However, as observed from Figure C-2, even following the operation of the oxygenator there is annual variability in July hypolimnion temperatures. Because the pumping rate is fixed when operational, the oxygenator provides a fairly constant influence on lower water column mixing. So, some other influence must be affecting this annual variability. It is believed that while the oxygenator provides the major influence on the rate of heat gain in the hypolimnion, the annual variability in hypolimnion temperatures is a function of the level of spring inflow.

Effect of spring inflow on water temperatures

Spring surface water inflow, occurring between March and May, provides about 50 percent of the annual total. Thompson Creek, due to its relief and higher snow-pack accumulation, is the main source of spring inflow to Newman Lake. The largest factor driving the variation in spring inflow levels in Thompson Creek is the level of snow-pack within its drainage. Average March-April snow-water equivalent levels, recorded at the National Resource Conservation Service's SNOTEL monitoring station Quartz Peak (17B04S), are closely tied to the level of spring (March-June) inflow observed (Figure C-4). (Quartz Peak data are available at: http://www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=707&state=wa)

The level of spring inflow (March-June total) varies annually from about 20 x 10^5 m^3 in 1992 and 1994 to about 200 x 10^5 m^3 in 1997 (Figure C-5). The overall average, 1985-2006, is 67 x 10^5 m^3. The period 1995 to 2000 experienced above average inflow while that occurring 1985-1991 was about average. More recently, 2001, 2004, and 2005 have had below average inflow levels.

The effect that inflow has on influencing oxygenator-induced hypolimnion heating can be examined through two general scenarios: high and low spring inflow levels. Recent examples of high spring inflow years are 2002, 2003, and 2006. Examples of low spring inflow include 2001, 2004, and 2005. Figure C-6 displays the average monthly inflow levels for these two flow groups for the previously mentioned years. The average spring (March – June) inflow for Thompson Creek from 1985 to 2006 is 67 x10^5 m^3. In comparison, the general high and low spring inflow groups have average spring inflow levels of 88 x10^5 m^3 and 33 x10^5 m^3, respectively. Therefore, the average for these groups is about +30 percent and -50 percent in comparison to the overall average for the period.

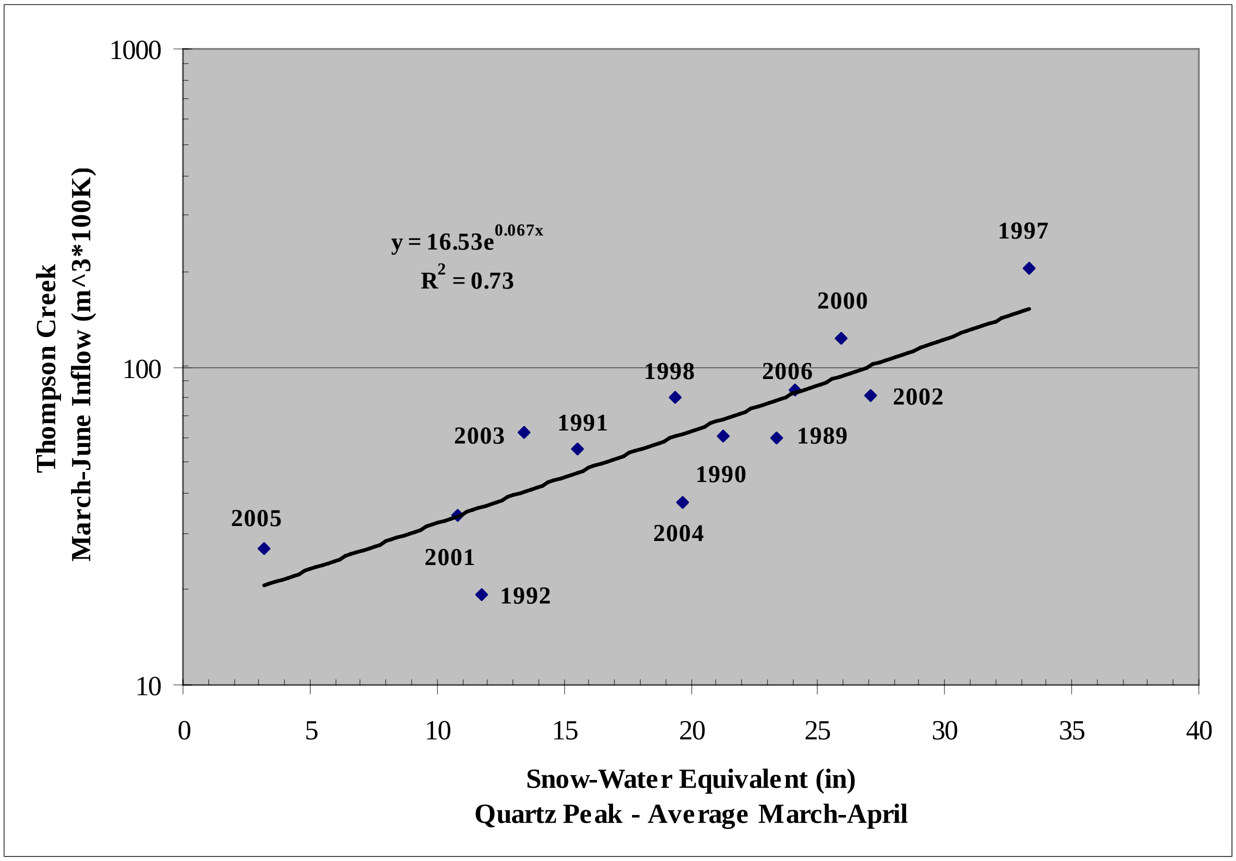

Figure C-4. Relationship between the March-June level of Thompson Creek inflow and the snow-water equivalent observed at Quartz Peak.

Average monthly water temperatures observed in Thompson Creek in relation to the average temperature observed at 8-meters depth is presented in Figure C-7. Thompson Creek's water temperatures are lower by approximately 1.5°C in comparison to those observed at 8 meters during the period, March through May. This temperature difference peaks in June when Thompson Creek's water temperature is lower by approximately 3°C. Because the spring inflow is derived primarily from snowmelt it is colder and, therefore, denser than Newman Lake water and would tend to flow to the lowest portion of the water column (hypolimnion) during the peak inflow period (March-May).

For this reason, years with high spring inflow result in a colder hypolimnion. The colder the hypolimnion, in relation to the epilimnion, the stronger the level of stratification. Years of low inflow, in contrast, result in warmer hypolimnion water temperatures and weaker stratification. The role the oxygenator plays in modifying water temperatures is most noticeable during low inflow years.

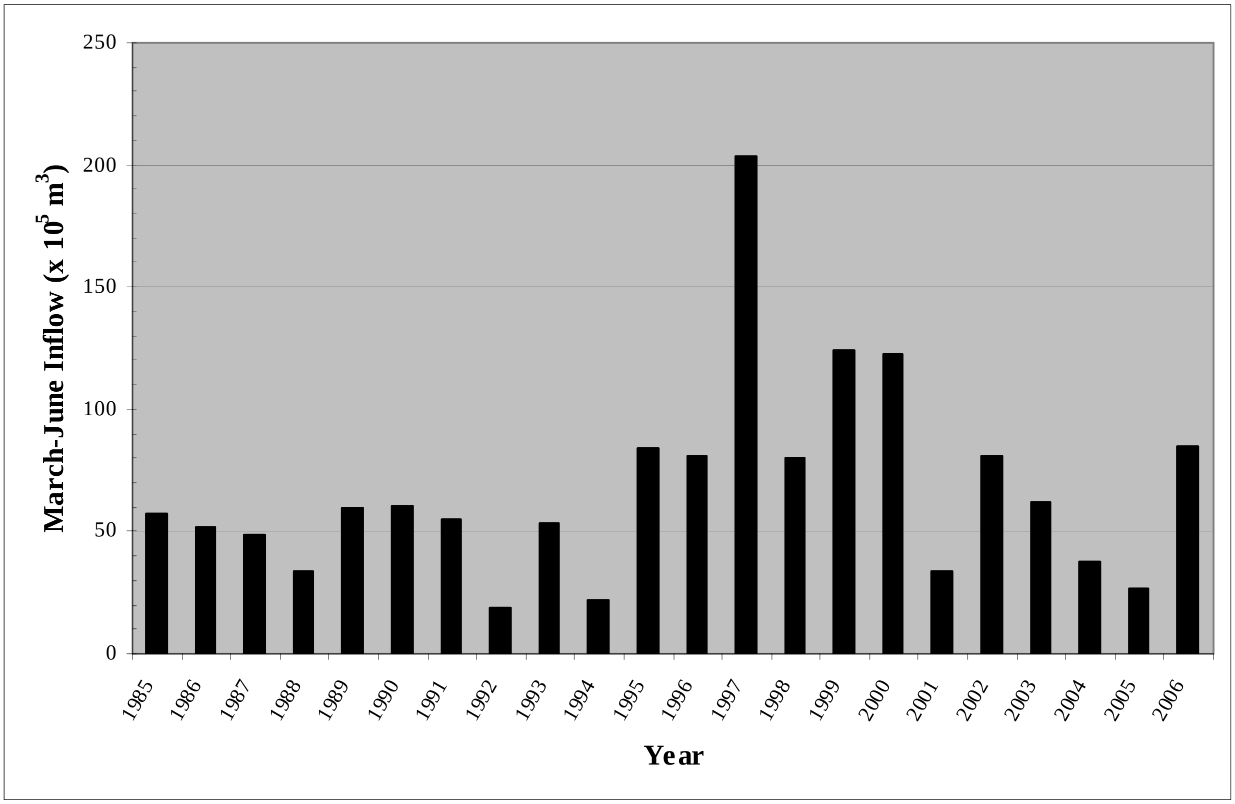

Figure C-5. The variation in Thompson Creek's spring (March-June) inflow to Newman Lake. (Flows in 100,000 cubic meters).

With weaker stratification, less energy is required to mix the lower water column. Lower water column mixing results in increasing hypolimnion temperatures as the warmer mid-water column is integrated with the hypolimnion. The passage of heat to the hypolimnion is greater during low inflow years, as opposed to high inflow years. However, under all conditions the passage of heat to the lower water column is evident by the warmer water temperatures under the current management scenario when compared prior to the installation of the oxygenator.

Table C-1 presents average July water temperatures, by depth, for the following categories: prior to the oxygenator (1985-86, 1989, 1990-91); those observed following the installation of the oxygenator (1997-98, 2001-06); and by the relative level of spring inflow observed since 2001: high (2002-03, 2006) and low (2001, 2004-05).

As noted earlier, temperatures in the hypolimnion have increased when the pre and post-oxygenator periods are compared. While the upper 2-meters are similar for the pre (22.4^{o}C) and post-aerator (23.6^{o}C) periods, hypolimnion (6 m+ depth) average temperatures have increased by about 4^{o}C from an average of 14.3 ^{o}C to 18.3 ^{o}C.

When the post-oxygenator period is examined, for the upper two meters, the average epilimnion temperature for the high and low inflow groups is again similar at 23.6^{o}C and 22.7^{o}C, respectively (Table C-1). In comparison, the hypolimnion temperatures (6-8 meters) for the high and low inflow periods are 17.1^{o}C and 19.9^{o}C, respectively. Both still well above temperatures observed prior to the oxygenator.

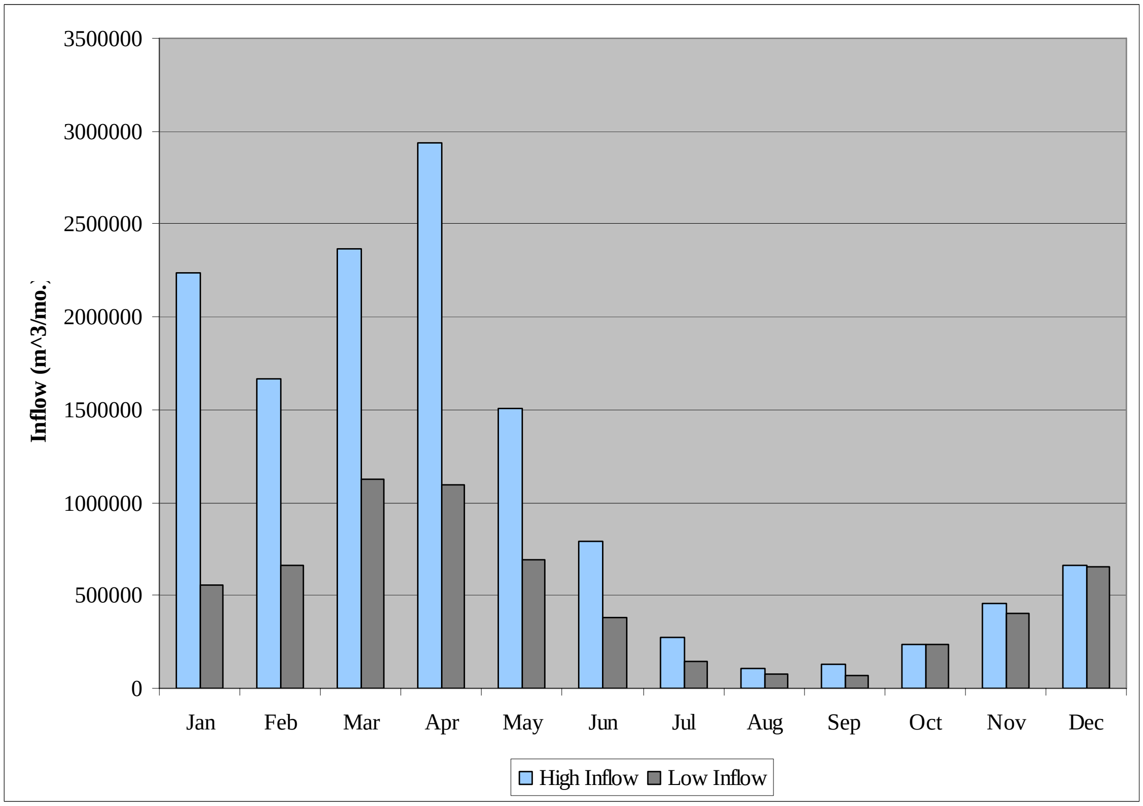

Figure C-6. Comparison in average monthly inflow between years with high (2002, 2003, 2006) and low (2001, 2004, 2005) spring inflow for Thompson Creek.

Table C-1. Average July temperatures (C) by depth and category for Newman Lake.

Depth (meters)	Pre-Aerator Prior to 1992	Post-Aerator 1997-8, 2001-06	Relative Spring Inflow Level	
			High Inflow 2002, 2003, 2006	Low Inflow 2001, 2004, 2005
Surface	22.4	23.6	23.6	22.7
1	22.0	23.3	23.2	22.4
2	21.8	22.9	22.9	22.2
3	21.0	21.8	21.5	21.7
4	19.9	20.1	19.2	21.2
5	17.7	19.0	17.9	20.6
6	16.3	18.4	17.4	20.1
7	13.7	18.2	17.1	19.9
8	13.0	18.0	16.9	19.7

Also evident in Table C-1, for the categories: post-oxygenator, high and low inflow groups, from 5-meters depth to the bottom, temperatures differ by less than 1^{o}C indicating isothermal conditions (as presented in Figure C-2). In comparison, for the pre-aerator period, temperatures varied from an average of about 18^{o}C, at 5-meters, to 13^{o}C at 8-meters, a 5^{o}C gradient. As mentioned earlier, it is believed that the uniform water temperatures, observed within the hypolimnion, indicate that the oxygenator is facilitating lower water column mixing.

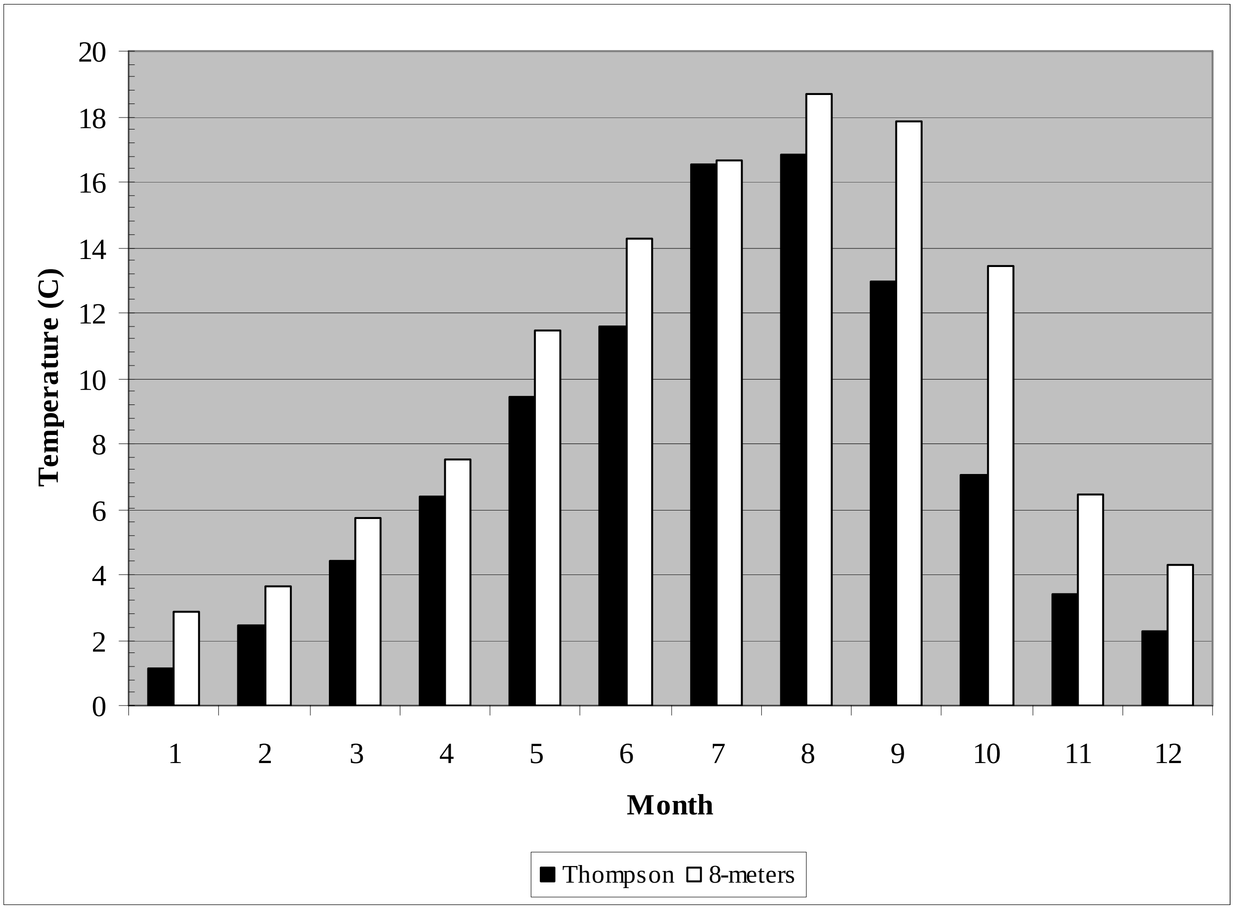

Figure C-7. The relationship between the average monthly temperature observed in Thompson Creek (black) and that observed at 8-meters (white) within Newman Lake.

Increased rate of heating

A colder hypolimnion maintains a stronger level of stratification. As observed from Figure C-8, when spring inflow is relatively low, the strength of stratification is weak: there is only a minor difference in temperature between the epilimnion and hypolimnion. July is the month when epilimnion temperatures tend to reach a peak and is, therefore, when stratification is typically the strongest. From Figure C-8, the temperature profiles for years with high spring inflow have a defined epilimnion (indicated by the uniform temperatures within the upper 2 meters of the water column), metalimnion (temperature transition between 2.5-5.5 meters) and hypolimnion (6+ meters). In contrast, years with low spring inflow have weak levels of stratification with poorly defined water column temperature strata. At these times, with hypolimnion temperatures approaching 20^{o}C, the lake is vulnerable to full water column mixing. An indication of the strength of stratification is indicated by the difference between the average epilimnion and hypolimnion temperatures during peak stratification in July; the smaller the difference the weaker the level of stratification. When considering the high and low spring inflow levels these temperature differences are 6.1^{o}C and 2.5^{o}C, respectively. In comparison, prior to the oxygenator the temperature difference was 7.8^{o}C.

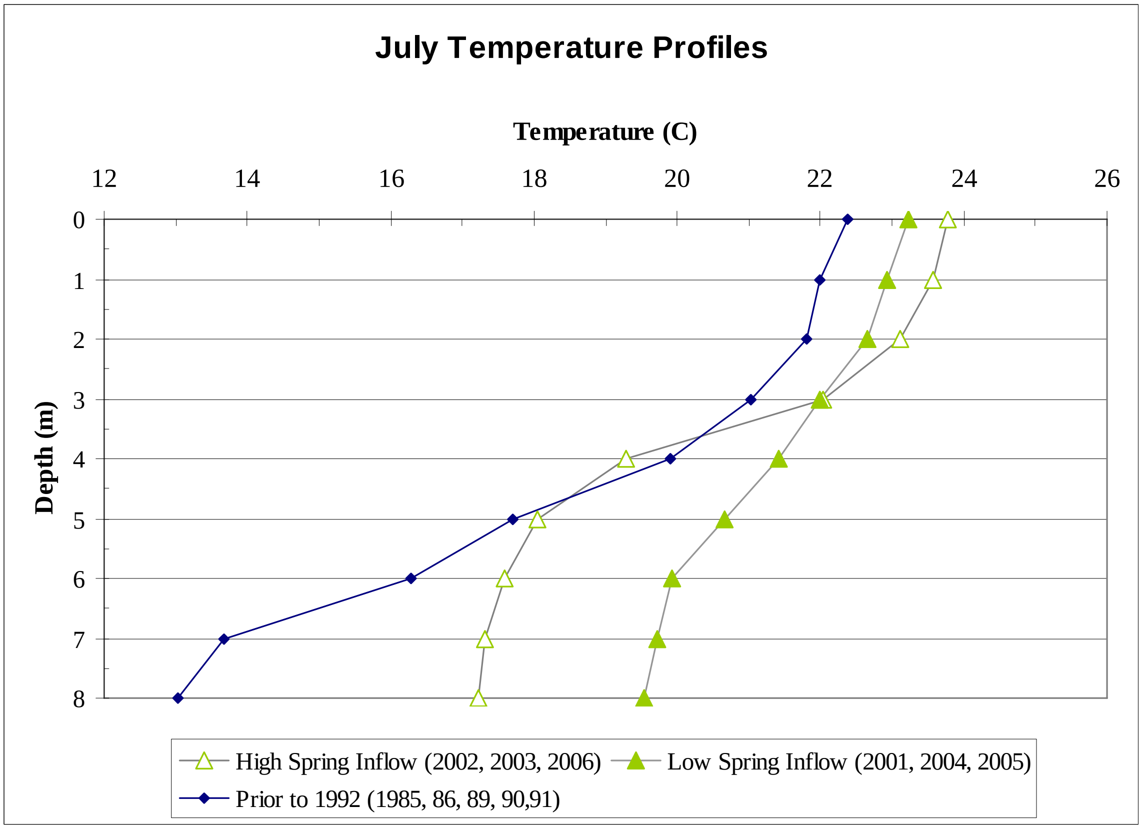

Figure C-8. Average temperature profiles for the low and high spring inflow years

The result of lower water column circulation is that the hypolimnion gains heat from the upper water column through convection. The connection between the upper and lower water column is evident when the pump is operating, by the close association between the temperature of the hypolimnion and that of the epilimnion. Prior to the oxygenator, the hypolimnion was largely buffered from the heating and cooling processes present in the upper water column. Then, heat transfer to the hypolimnion, from the upper water column, was primarily driven by conduction, a slower heat transfer process.

An effect of lower water column circulation on water temperature is presented in Figure C-9. The figure displays average hypolimnion (6-8 meters) temperatures through the stratified period for data collected since 1986. The trend in hypolimnion temperatures for the low and high spring inflow groups are indicated by the red line and blue line, respectively. The trend in hypolimnion temperatures observed prior to the operation of the oxygenator is displayed by the yellow line. The trend lines are derived from a least squares regression relationship between time and temperature observed during the stratification period based on data groups representing the pre-oxygenator (1986, 1990, 1991), high (2002, 2003, 2006) and low (2001, 2004, 2005) inflow years.

As observed, following the operation of the oxygenator, the increase in hypolimnion temperatures over the stratified period is linear. Years with high spring inflow provide a larger volume of cold water to the hypolimnion which has the effect of reducing the magnitude of the temperature gain in the hypolimnion. Based on the least squares line for this group, by mid-July the average hypolimnion temperature is about 17^{o}C. In comparison, for years represented by the low spring inflow years, the mid-July average is 3^{o}C warmer at 20^{o}C.

Prior to the operation of the oxygenator, the trend in hypolimnion temperatures was quite different. Then, the trend in temperature was linear up until June, when the onset of a stronger level of stratification occurs. Once this happened, the passage of heat through convection, or the movement of water, was significantly reduced. Instead, the gain in heat in the hypolimnion was largely from conduction, a much slower heat transfer process. In fact, while now mid-July hypolimnion temperatures are in the range of 17^{o}C to 20^{o}C (depending on spring inflow levels), prior to the oxygenator they were around 14^{o}C (Figure C-9). From Figure C-9, by mid-August, with the oxygenator operating, hypolimnion temperatures are, on average, greater than 20^{o}C. Prior to its installation, mid-August hypolimnion temperatures were 16^{o}C, an average temperature that now occurs by mid-June to early-July. There are no records, prior to the operation of the oxygenator, of hypolimnion temperatures reaching 20^{o}C, the level reached in mid-July for the low spring inflow years. Temperature profiles collected from prior studies indicate a significantly colder hypolimnion.

Measurements collected on August 25, 1911, late into the stratification period, observed a temperature of 14.9^{o}C at 8 meters (Kemmerer et al, 1923). On July 19, 1971 a temperature of 13^{o}C was recorded at 8 meters with an average temperature of 14.2^{o}C through the hypolimnion (6 to 8 meters) (Bortleson et al, 1974). And, on June 28, 1974, a temperature measurement of 10.8 ^{o}C was recorded at 8 meters (Dion et al, 1976).

One of the consequences of increased heating of the hypolimnion is that the lake de-stratifies or ‘turns over’ sooner than it did historically. Newman Lake now largely de-stratifies by mid-August, an event that typically occurred (prior to the oxygenator) in late-September. This early de-stratification confirms the influence of lower water column mixing and, as a consequence, increased heating of the hypolimnion. Prior to the oxygenator, hypolimnion (6-8 meters) temperatures in August were 16^{o}C. Average August hypolimnion temperatures are now over 20^{o}C, close to the epilimnion (0-2 meters) average of 23^{o}C. For this reason, since 1992, the lake is well on its way to complete turnover by mid-August almost one month earlier than average historic occurrences.

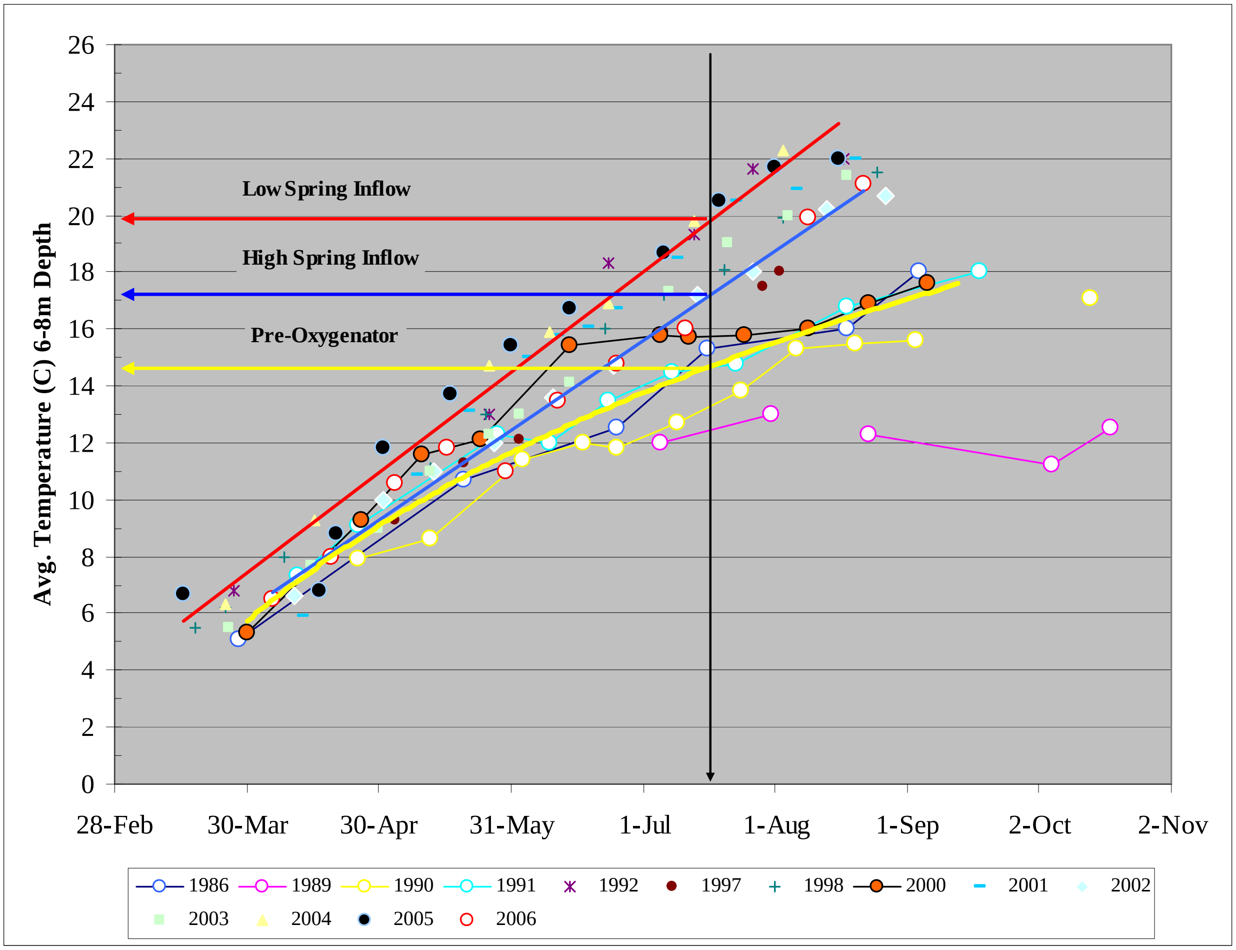

Figure C-9. The trend in observed average hypolimnion (6-8 meters) temperatures for monitored years based on three datasets: pre-oxygenator (1986, 1990, 1991), and years with high (2002, 2003, 2006) and low (2001, 2004, 2005) spring inflow levels.

Effect on dissolved oxygen

Profiles of dissolved oxygen concentrations by depth observed during July (for years observations have been made) are presented in Figure C-10. As previously discussed, in July 1992 water temperature profiles indicated near complete water column mixing. This mixing is evident in Figure C-10 where the dissolved oxygen levels in the lower water column are unusually elevated in relation to observations made in other years. (The instability may be related to the oxygenator start-up in June 1992.) Worth noting here (and it will be discussed later) is that at 8-meters, the years with the more elevated temperatures (2001, 2004, 2005) also tended to have greater dissolved oxygen levels.

Even with the oxygenator in place, with the exception of July 1992, dissolved oxygen levels, on average, remain at low levels within the hypolimnion. In fact, the average dissolved oxygen concentration observed at 7 and 8 meters for the period prior to the oxygenator's installation (1985, 1986, 1989, 1990, 1991) and following its installation (1992+) are 1.4 mg/L and 1.1 mg/L, respectively, showing relatively little influence on hypolimnion levels.

For most depth intervals dissolved oxygen concentrations were slightly higher prior to the installation of the oxygenator indicating that it is having a minimal effect on altering dissolved oxygen concentrations within the lower water column. Average pre- and post-aerator dissolved oxygen concentrations at 8-meters (0.7, 1.2 mg/L), 7 to 8-meters (1.1, 1.4 mg/L), 6-8-meters (2.1, 1.7 mg/L), 5-8-meters (3.2, 2.2 mg/L), and 4-8-meters (4.1, 2.8 mg/L) indicate that while dissolved oxygen levels have slightly increased in the lowest depths of the lake (8+ meters), for much of the water column levels have declined. This may be due to lower water column mixing as water with lower dissolved oxygen is circulated further up into the water column.

Newman Lake's sediments have a high oxygen demand. Even in 1992, when the lake was largely de-stratified, there was still a dissolved oxygen gradient. However, even with the oxygenator operating, dissolved oxygen levels are typically low enough most years, resulting in conditions conducive to sediment phosphorus release. The intended purpose of the oxygenator is to maintain dissolved oxygen concentrations at levels high enough (above approximately 2 mg/L at 8 meters depth) to maintain aerobic conditions at the sediment water interface limiting phosphorus release. (The original design oxygen level for the hypolimnion from oxygenator operation was 4-6 mg/L.).

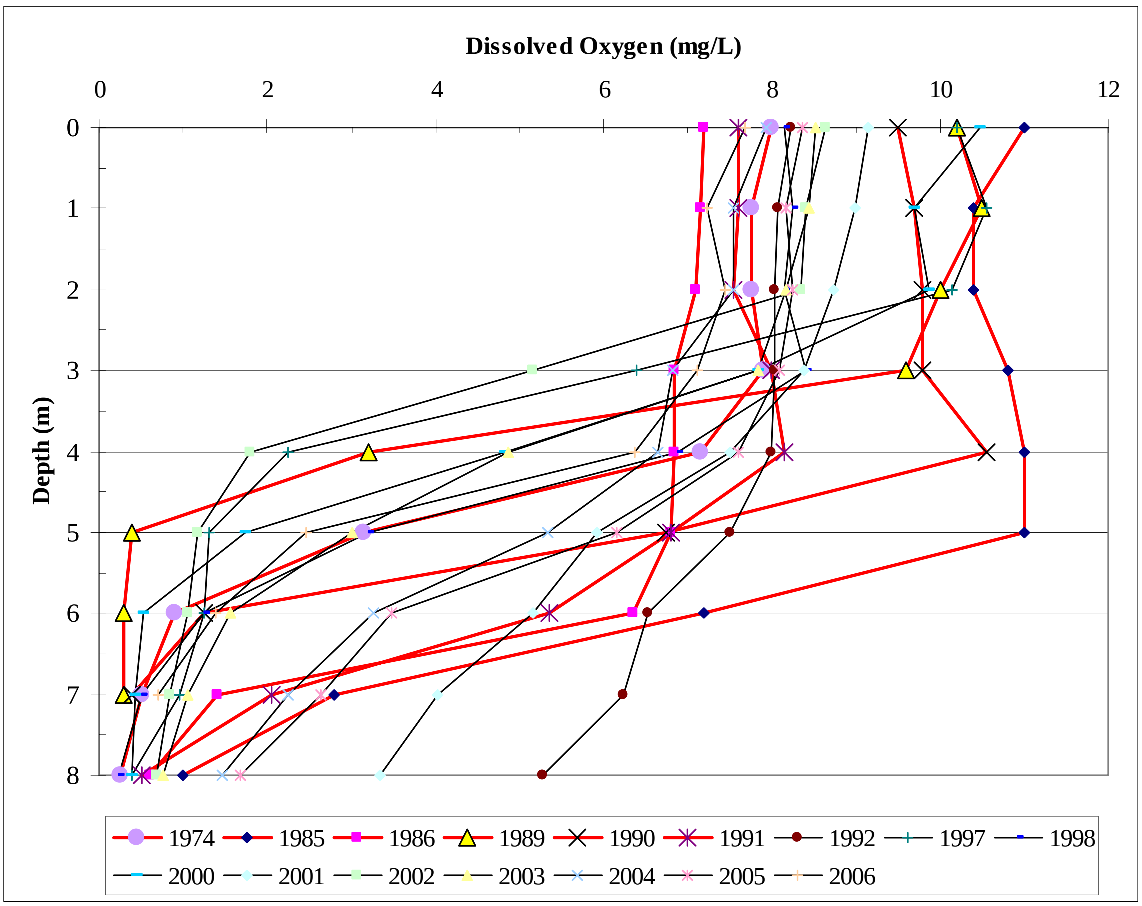

Figure C-10. Average July dissolved oxygen observed in Newman Lake, by depth and year. (Profiles in red indicate years prior to aerator installation.)

Table C-2 presents a similar treatment as presented in Table C-1 but for dissolved oxygen. Average July pre- and post-oxygenator dissolved oxygen levels observed in the epilimnion (0-2 meters) are similar at 9.1 mg/L and 8.5 mg/L, respectively. Pre- and post-oxygenator hypolimnion (6+m) dissolved oxygen levels are also similar at an average level at 2.1 and 1.7 mg/L, respectively.

Dissolved oxygen concentrations in the epilimnion during high and low spring inflow levels are similar at 8.1 mg/L and 8.3 mg/L, respectively. In comparison, within the hypolimnion (6-8 meters), average July dissolved oxygen levels for high and low spring inflow levels are 1.0 mg/L and 3.1 mg/L, respectively. This indicates that only during periods of low spring inflow, and weak stratification conditions, are dissolved oxygen levels at a sufficient concentration (above 2 mg/L) to reduce internal phosphorus recycling. During years with higher levels of spring inflow and stronger levels of stratification, the oxygenator cannot provide sufficient oxygen transfer.

Table C-2. Average July dissolved oxygen levels (mg.L) by depth and category for Newman Lake.

Depth (meters)	Pre-Aerator Prior to 1992	Post-Aerator 1997-8, 2001-06	Relative Spring Inflow Level	
			High Inflow 2002, 2003, 2006	Low Inflow 2001, 2004, 2005
Surface	9.1	8.6	8.3	8.5
1	9.1	8.4	8.0	8.2
2	9.0	8.4	8.0	8.2
3	9.0	7.3	6.7	7.8
4	8.0	5.5	4.3	7.3
5	6.4	3.6	2.2	5.8
6	4.1	2.3	1.3	4.0
7	1.4	1.6	0.9	3.0
8	0.7	1.2	0.7	2.2

With the oxygenator in place, the level of stratification has a significant effect on dissolved oxygen concentrations in the hypolimnion. There are defined differences in dissolved oxygen concentrations between years with high and low spring inflow. This has to do with the level of stratification. Hypolimnion temperatures for years with low spring inflow achieve higher temperatures sooner than years with high spring inflow. The oxygenator facilitates a greater heat transfer for low spring inflow years than high spring inflow years. The result of increased hypolimnion temperatures is that the water column is less stable. For this reason, mixing events occur frequently during years with low spring inflow. In comparison, for years with high spring inflow, the hypolimnion is slightly colder and, as a result, the water column is more stable, with a lower frequency of water column mixing. Recent examples of these scenarios are presented in Figures C-11 and C-12 for 2005 and 2006, respectively.

The spring inflow level in 2005 was low in comparison to historic levels, while 2006 had a relatively high spring inflow level. Within the figures, the average measured epilimnion (0-2 meters) temperature is represented by white dots and hypolimnion (7-8 meters) temperatures represented by open circles. Also plotted are the average hypolimnion (7-8 m) dissolved oxygen concentrations (right axis, black dots with connected line). The continuous line in the figures (blue) represents predicted epilimnion temperatures based on the input of hourly meteorological data (Spokane International Airport) using the water temperature model, rTemp (www.ecy.wa.gov/programs/eap/models.html).

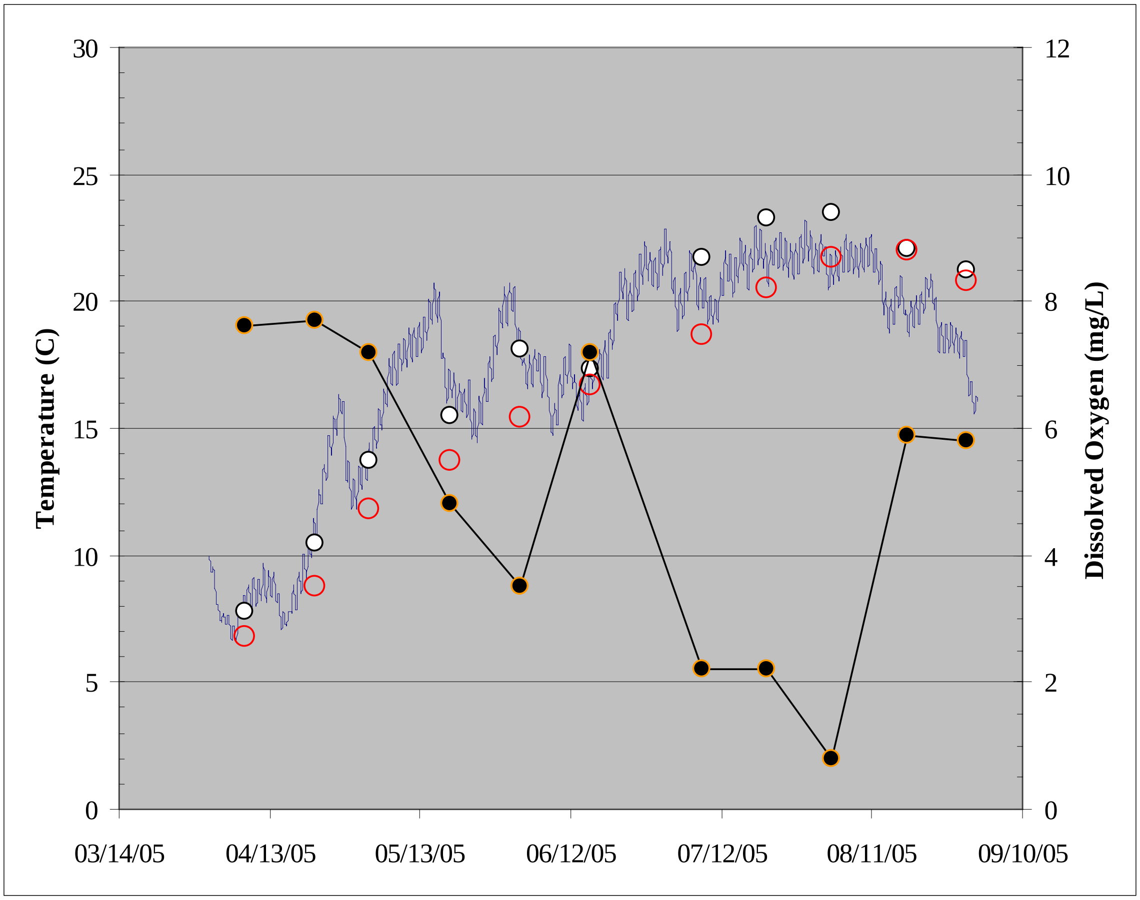

Figure C-11. Predicted hourly epilimnion temperatures (blue line) along with measured epilimnion (white dots, 0-2 m) temperature, hypolimnion temperatures (circles, 7-8 m) and hypolimnion dissolved oxygen concentrations (black dots) for 2005.

As observed from Figure C-11, in 2005 hypolimnion temperatures closely track temperatures in the epilimnion. Epilimnion temperatures respond to varying meteorological conditions which, at times, can result in rapid cooling by several degrees. When there is relatively little difference between epilimnion and hypolimnion temperatures, the lake is vulnerable to deep water column mixing. This occurs when the epilimnion cools rapidly in response to changing meteorological conditions. (In interpreting these figures, a water column mixing event is indicated when hypolimnion temperatures intersect the predicted and measured epilimnion temperatures.) In 2005, this is most evident in mid-June when the epilimnion and hypolimnion temperatures coincide. This event resulted in deep water column mixing, bringing water with higher dissolved oxygen levels at the surface to the lower water column resulting in the spike in the hypolimnion dissolved oxygen level. Throughout the summer of 2005 the water column remained unstable with the hypolimnion reaching 22^{o}C by early August, resulting in permanent full water column mixing by mid-August. When this occurred, dissolved oxygen concentrations increased rapidly from less than 1 mg/L to 6 mg/L.

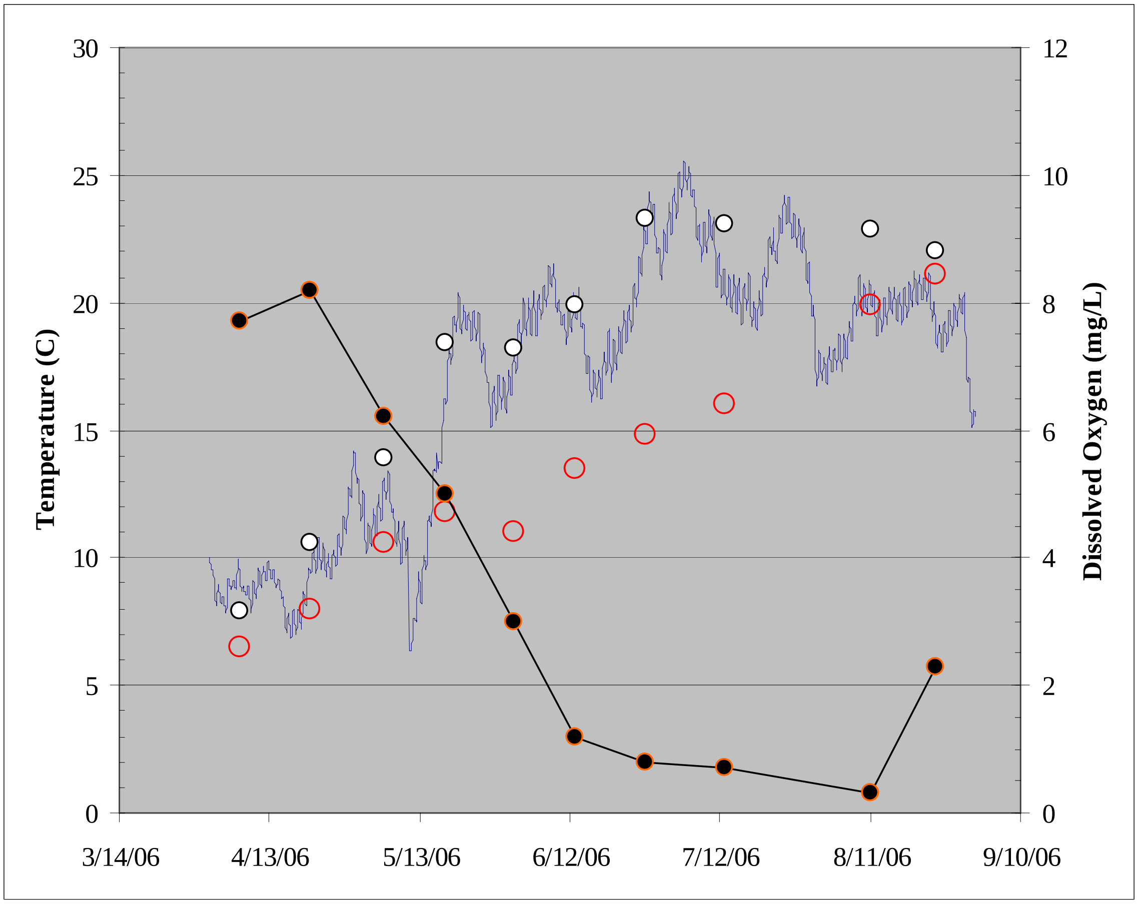

Figure C-12. Predicted hourly epilimnion temperatures (blue line) along with measured epilimnion (white, 0-2 m) temperature, hypolimnion temperatures (circles, 7-8 m) and hypolimnion dissolved oxygen concentrations (black dots) for 2006.

In contrast to 2005, 2006 had relatively high spring inflow. As a consequence, hypolimnion temperatures were colder and the water column more stable. During the stratified period, there was a greater difference between the magnitude of hypolimnion temperatures and those observed in the epilimnion. With a stronger level of stratification in place, between early-June through mid-August, there were no significant water column mixing events. As a result, hypolimnion dissolved oxygen concentrations were not replenished through water column mixing. For this reason, from mid-June to mid-August dissolved oxygen concentrations in the hypolimnion (6-8 meters) were less than 1 mg/L only increasing when deep water column mixing occurred in mid-August.

Similar relationships were observed for 2004, 2003, 2002, and 2001 (Figures C13-16 below). The spring inflow for 2004 and 2001 was low and, with oxygenator-induced hypolimnion heating, the water column was unstable and frequently mixed. Due to these factors, the dissolved oxygen levels during the stratification period remained at detectable concentrations. This was particularly evident in 2001 when dissolved oxygen concentrations remained above 3 mg/L for the entire summer (Figure C-16).

The spring inflow for 2003 and 2004 was, in contrast, relatively high and as a consequence, stratification was stronger. With less oxygen transfer to the hypolimnion through mixing, dissolved oxygen concentrations remained below 2 mg/L from mid-June until lake turnover in August.

These relationships indicate that the oxygenator is only able to maintain adequate dissolved oxygen concentrations that limit the release of phosphorus from sediments, through water column disturbance. Mixing brings waters high in dissolved oxygen present in the upper water column to the hypolimnion. However, when the lake remains stratified and the oxygenator is the sole source of dissolved oxygen to the hypolimnion, concentrations plunge to low concentrations (x<2 mg/L), a condition conducive to sediment phosphorus release.

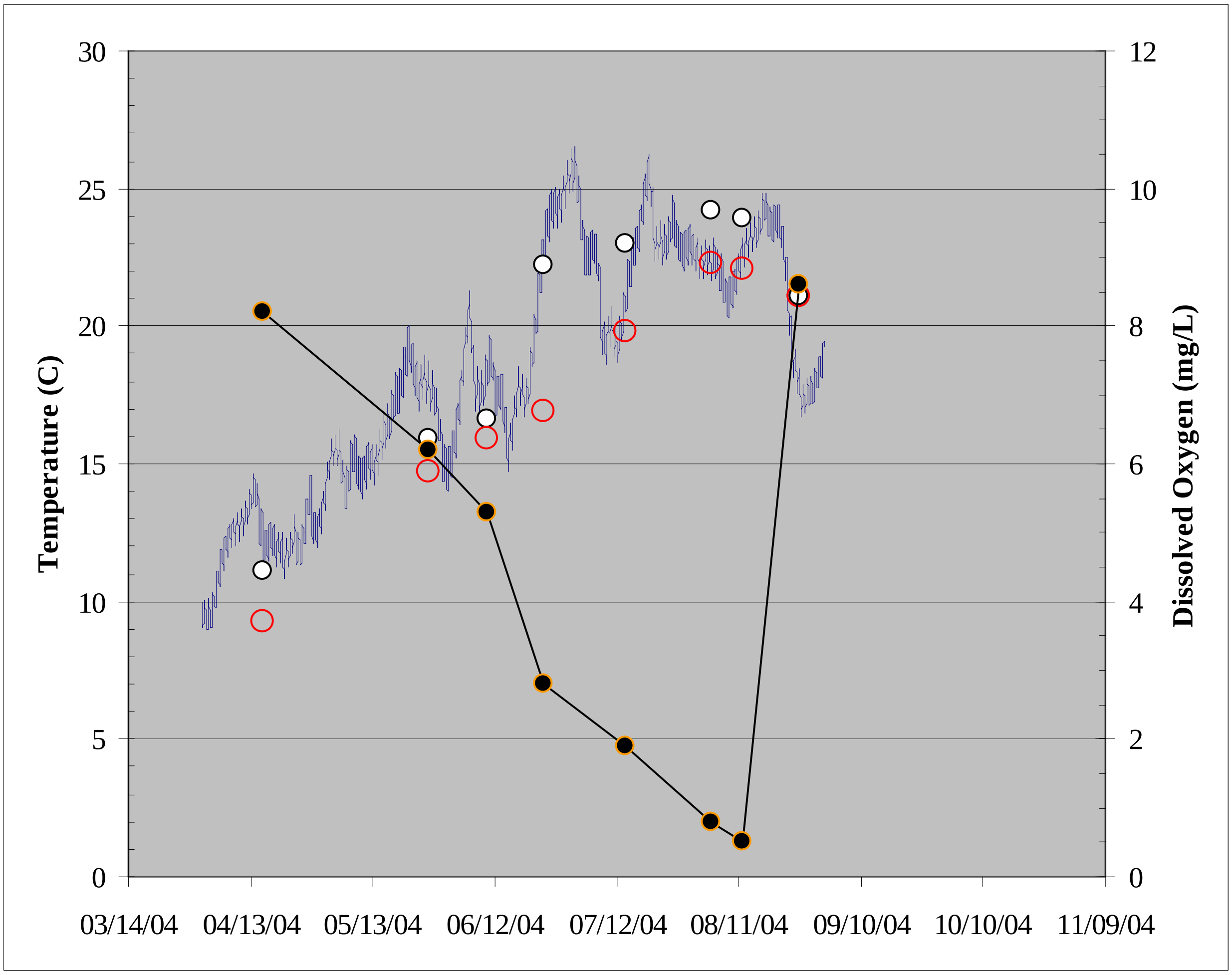

Figure C-13. Predicted hourly epilimnion temperatures (blue line) along with measured epilimnion (white, 0-2 m) temperature, hypolimnion temperatures (circles, 7-8 m) and hypolimnion dissolved oxygen concentrations (black dots) for 2004.

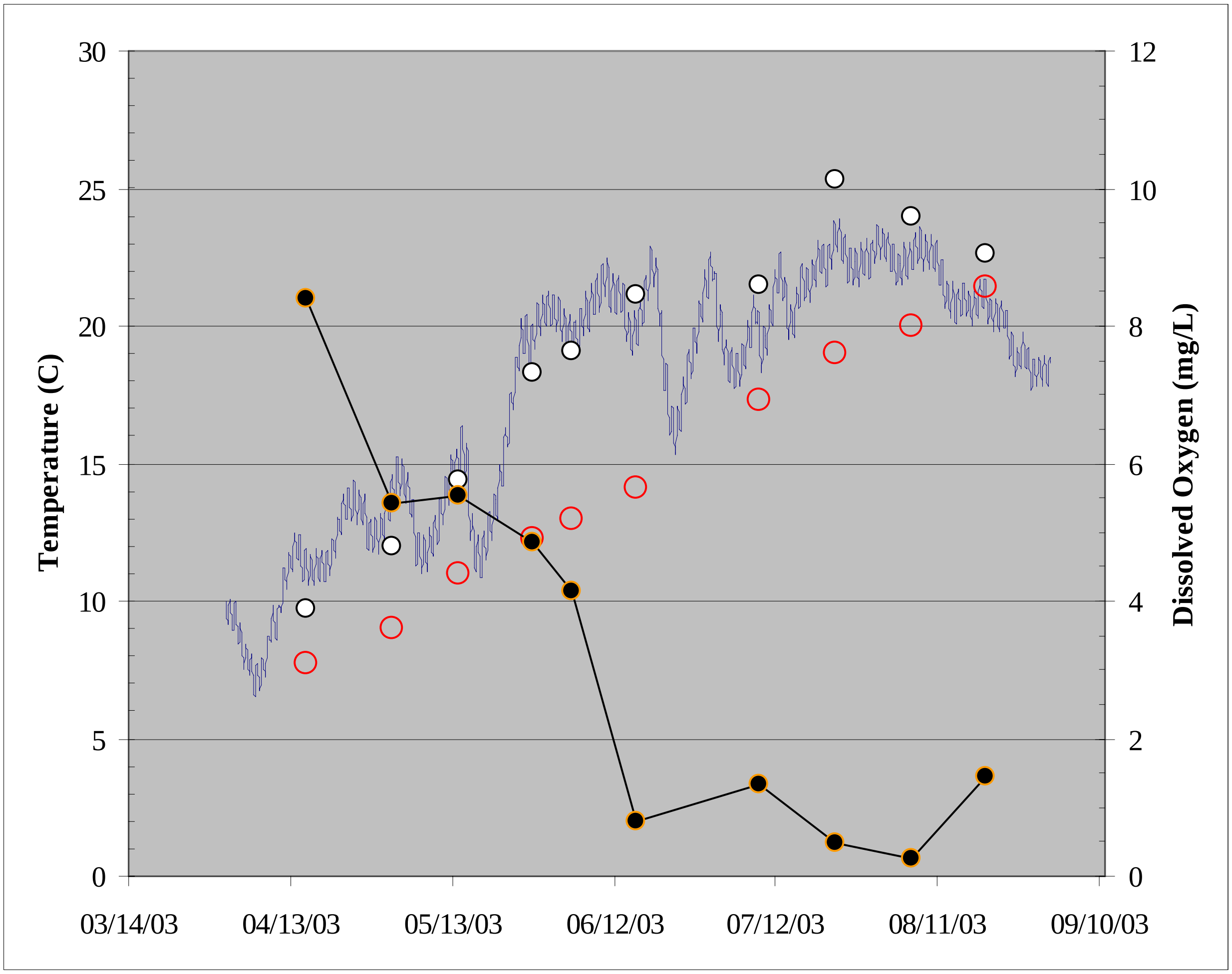

Figure C-14. Predicted hourly epilimnion temperatures (blue line) along with measured epilimnion (white, 0-2 m) temperature, hypolimnion temperatures (circles, 7-8 m) and hypolimnion dissolved oxygen concentrations (black dots) for 2003.

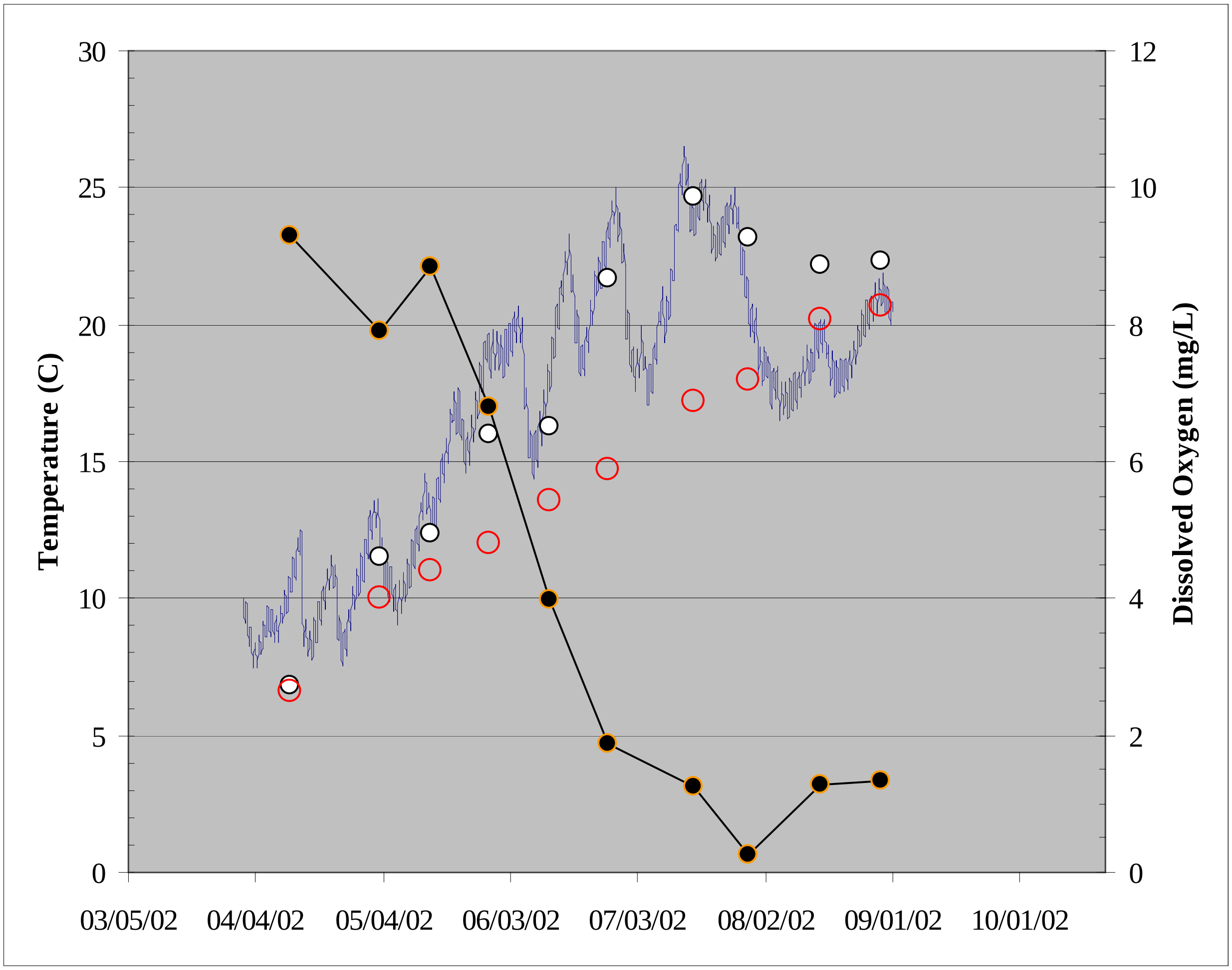

Figure C-15. Predicted hourly epilimnion temperatures (blue line) along with measured epilimnion (white, 0-2 m) temperature, hypolimnion temperatures (circles, 7-8 m) and hypolimnion dissolved oxygen concentrations (black dots) for 2002.

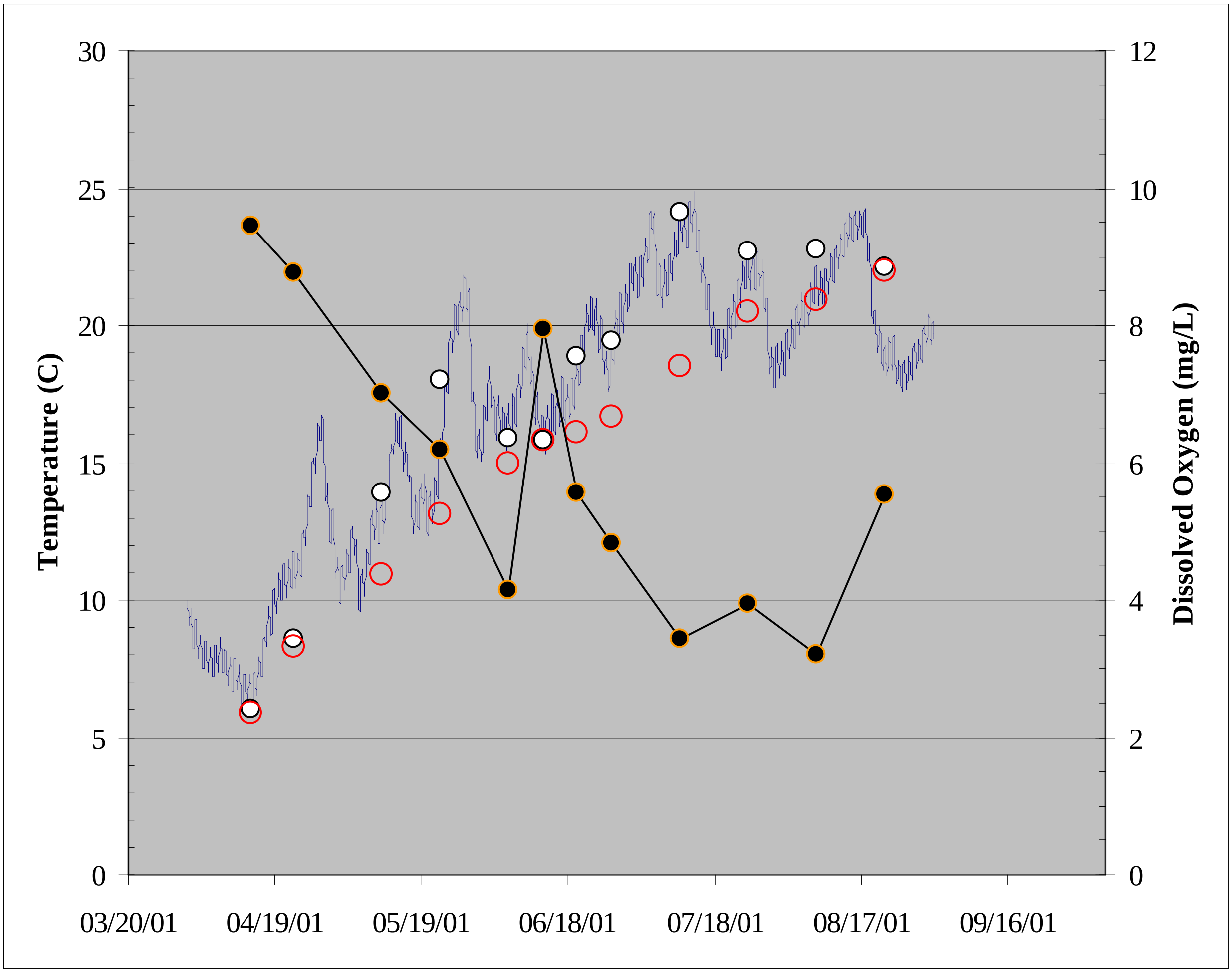

Figure C-16. Predicted hourly epilimnion temperatures (blue line) along with measured epilimnion (white, 0-2 m) temperature, hypolimnion temperatures (circles, 7-8 m) and hypolimnion dissolved oxygen concentrations (black dots) for 2001.

Summary

Differences in temperature and dissolved oxygen profiles collected prior to and following the operation of the oxygenator indicate that it is facilitating lower water column mixing. This is indicated in the rate and magnitude of temperature increases observed in the hypolimnion now in comparison to measurements made prior to the operation of the oxygenator. Under current in-lake management, hypolimnion temperatures are greater and isothermal with the rate of heat gained tied closely to the trend in epilimnion temperatures. It is believed that the hypolimnion gains heat from the upper water column through convection. At a design inflow rate of 21 cfs, the oxygenator is pumping the entire volume of the lower 1.5 meters of the water column every 11 days. This level of disturbance is great enough to lead to lower water column mixing and the transfer of heat to the hypolimnion. Increased hypolimnion heating has led to reduced water column stability resulting in an increased frequency of mixing events and ultimately to early lake turnover.

Currently, the water column stability is related to the magnitude of spring inflow. Years with high spring inflow maintain a reservoir of colder water within the hypolimnion. During these years, while the oxygenator induced mixing continues to occur, the colder hypolimnion temperatures result in a stronger level of stratification. With stratification in place, dissolved oxygen concentrations plunge to anoxic conditions indicating no measurable effect of the oxygenator at maintaining dissolved oxygen concentrations in the hypolimnion. The sediment oxygen demand exceeds that supplied by the oxygenator.

Years with low spring inflow have a lower volume of cold water within the hypolimnion. Lower water column mixing causes the hypolimnion to gain heat at an increased rate. This results in an unstable water column. During these years, the dissolved oxygen levels in the hypolimnion appear to be maintained through disturbance as water high in dissolved oxygen in the upper water column is circulated into the hypolimnion.

Appendix D. Water Budget

Table D-1. Change in lake volume in cubic meters per month

Month	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		203783	-377509	-76576	-215854	-61050	-30856	250155	80110	425968
2		-59178	1423544	91907	-92208	336771	558484	-161140	65946	-79540
3		543058	-1240272	-244683	431848	-214590	881674	397448	1469579	756951
4		1854573	1713651	1708133	1446619	1903043		1347241	682434	1219253
5	234637	216299	278223	796489	513124	720791		773455	-6127	42903
6	-470898	-646221	282965	-96241	-136800	-465673	510877	-254664	-21438	-407913
7	-117726	-296163	-656224	-952476	-630960	-730001		-784287	-567511	-766262
8	-807626	-517884	-458225	-810872	-724925	-756628	-1548337	-213929	-707989	-703437
9	-552844	-753428	-544266	-154382	-634094	-395449	-469950	-499349	-303916	-357350
10	-652215	-581938	-30997	61693	198033	-398263	-292275	-517582	-683412	131638
11	652215	-79851	-646297	123626	-380891	-152275	-9183	-254972	-482647	-220233
12	-687663	71655	137747	-61853	-326958	704619	-35424	98650	444281	366302

Table D-2. Precipitation (cubic meters per month)

Month	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	338585	421711	383189	397381	127730	233157	689335	287899	233157	908300
2	283844	322366	662978	326420	133812	210855	105428	296009	8110	235185
3	486589	245322	139894	332503	277761	206801	431848	135840	411574	249377
4	519029	180444	89208	437931	346695	178416	285871	115565	160169	328448
5	460233	626484	148004	450095	160169	223020	302091	744076	725829	220993
6	127730	170306	275734	184499	223020	304118	44604	212883	279789	626484
7	162196	52714	26357	70961	56769	50686	0	16220	223020	20275
8	28384	54741	216938	0	52714	251405	89208	381162	93263	50686
9	186526	42577	0	227075	34467	111510	117592	139894	170306	64879
10	338585	54741	180444	129757	425766	36494	103400	214910	208828	188553
11	403464	766378	417656	229103	529166	334530	373052	229103	409546	888026
12	202746	665006	458205	188553	411574	662978	502809	271679	600127	480507

Table D-3. Surface water inflow (cubic meters per month)

Month	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	4072198	1416370	2160470	1235570	726913	2120398	1660824	595004	678022	4328540
2	4275105	3589941	4807572	3096147	937466	2564449	2817723	1570305	1005363	3502323
3	15524446	5205693	10771147	9261284	2002137	4366952	4669444	3400795	1493445	5462795
4	12762899	3898821	7028548	8094118	2079241	6650621	4253089	2206138	2058347	6138115
5	7891993	3365797	4506239	4247199	1734639	3433901	2323254	1120485	1105283	2913390
6	3444880	2788248	1945451	2291719	728728	1258501	883777	635645	542297	1843060
7	1485398	817578	915859	857055	238375	410059	198693	130019	180393	442340
8	854717	484934	530298	440402	121602	191105	89139	57717	4237	145116
9	922632	451147	480601	521967	113289	213838	137545	124550	51564	173122
10	968296	554491	557040	675887	271887	270711	239136	376417	220309	359747
11	1038033	776866	761906	723303	538233	510344	368309	507758	374404	719609
12	1357005	1961378	1762893	889605	1364551	1019947	767724	831523	617946	1064994

Table D-3. Evaporation (cubic meters per month)

Month	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	85022	45781		98103	62786	66710	36625	82406	86330	17004
2	65402	64094		48397	95487	90254	92871	48397	94179	143884
3	291692	231522		231522	236755	234138	245911	347938	311313	204054
4	457813	431652		533679	469585	463045	483973	504902	540219	525831
5	706340	812290		820139	905161	753429	763893	841067	779590	703723
6	1000648	1000648		991491	920857	982335	1054277	877692	930014	899929
7	996724	1179849		1072590	1143224	1243942	1296264	1259639	1172000	1274027
8	1005880	1081746		1092210	958791	940478	1038581	992799	1035965	974487
9	542835	633090		517982	698491	664482	680179	536295	572920	499670
10	283844	268147		240679	291692	247219	419880	304772	239371	415956
11	58862	24853		81098	0	20929	90254	23545	85022	133420
12	51013	107259		100719	99411	23545	66710	23545	27469	69326

Table D-4. Surface water outflow (cubic meters per month)

Month	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		992562	1967337	1010201	545341	1577284	1574585	193167	342853	3460682
2		2778095	2816103	2296747	591763	1577579	1518687	1293277	426482	2597741
3		3370259	8943615	7166753	1010102	3276141	2829158	1918665	0	3427802
4		1150044	3557906	4612886	161898	3205876		130965	536218	3404943
5	5476066	2051446	2538656	2141517	136327	1450084		0	583794	1607976
6	2112406	1774582	505436	986748	0	574791	0	0	0	1292101
7	361223	0	91720	391489	0	0		0	0	0
8	296737	0	0	0	0	0	299244	0	0	0
9	631163	242232	117403	66194	0	0	0	0	0	0
10	1059348	480131	142574	156924	0	122256	0	388590	441751	0
11	331827	1000051	1129992	345119	884588	521094	277827	514986	679217	1074129
12	1460632	1653955	1322217	569660	1312231	504570	723625	524780	344073	624007

Table D-5. Groundwater inflow (+) and outflow (-) (cubic meters per month)

Month	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1		-595955	-887121	-601224	-462369	-770612	-769806	-357175	-401886	-1333185
2		-1129296	-1140649	-985516	-476236	-770700	-753109	-685779	-426866	-1075424
3		-1306176	-2970945	-2440194	-601194	-1278063	-1144549	-872583	-124127	-1323364
4		-642995	-1362226	-1677350	-347834	-1257075		-338595	-459644	-1316536
5	-1935183	-912245	-1057775	-939149	-340196	-732617		-250039	-473855	-779780
6	-930454	-829545	-450450	-594218	-167690	-471166	636773	-225500	86490	-685427
7	-407373	13395	-326872	-416414	217119	53196		329113	201076	45151
8	-388111	24187	-199581	-159064	59550	-258660	-388860	339992	230476	75247
9	-488005	-371830	-334544	-319248	-83358	-56315	-44909	-227499	47133	-95681
10	-615904	-442891	-342062	-346349	-207928	-335993	-214932	-415548	-431427	-707
11	-398593	-598192	-637005	-402563	-563703	-455127	-382462	-453302	-502358	-620319
12	-735768	-793514	-694423	-469633	-691441	-450191	-515623	-456228	-402250	-485867