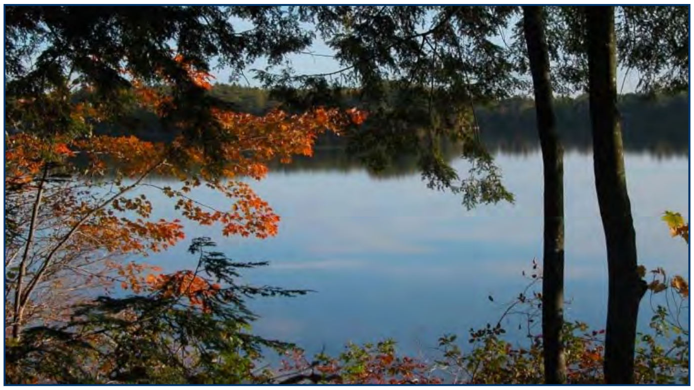
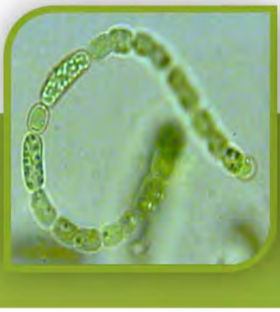


Mirror Lake Watershed Management Plan

May 2012



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EXECUTIVE SUMMARY

Mirror Lake (321 acres) is located in the Towns of Tuftonboro and Wolfeboro, NH. In 2008, Mirror Lake was included on the List of New Hampshire Threatened or Impaired Waters as an impaired waterbody due to recurring blooms of potentially toxin-producing cyanobacteria (blue-green algae). In 2010, the Mirror Lake Protective Association (MLPA) was awarded a Section 319 grant to develop a watershed management plan (WMP) focused on controlling sources of phosphorus entering the lake. Phosphorus (P) is usually the most important nutrient determining the growth of algae and aquatic plants in freshwater lakes. The primary goals of the WMP were to (1) identify and quantify sources of P to Mirror Lake, and (2) develop a management plan to reduce P loading to a level that would significantly improve in-lake conditions. A summary of the findings and recommendations from the WMP is provided below.

Water Quality

- Mirror Lake data from the early 1990's to 2010 show an increasing trend in total P concentrations of approximately 0.7 µg/L (micrograms per liter) every ten years during this period.
- Despite the increasing trend in P concentrations, the current water quality of Mirror Lake is very good. Both the Carlson Trophic Status Index and the New Hampshire Department of Environmental Services (NHDES) trophic classification system result in a "lower mesotrophic" classification for Mirror Lake.
- Cyanobacteria blooms have been a concern since Mirror Lake's first documented cyanobacteria bloom in 2007. Since 2007, 40 lake samples have been analyzed by NHDES for cyanobacteria and other algae. None of these samples have exceeded the current standard for beach advisories or lakewide warnings (cell count of 70,000 cells/ml or greater). The highest recorded level of microsystin (a toxin produced by some species of cyanobacteria) was 0.36 ppb, as measured during a 2008 cyanobacteria bloom. This microsystin level is three times lower than the World Health Organization (WHO) standard for drinking water and sixty times lower than the WHO standard for recreation.
- In New Hampshire, the water quality standard for mesotrophic lakes such as Mirror Lake is 12 µg/L of total P. To maintain at least a 10% reserve assimilative capacity, the maximum median epilimnetic (surface water) P concentration for Mirror Lake is 10.8 µg/L (12 µg/L - 1.2 µg/L). Mirror Lake's current median P concentration is 10.0 µg/L, indicating water quality that is better than the NHDES standard for mesotrophic lakes.

Annual Phosphorus Loading and Hydrologic Budget

- To estimate Mirror Lake's current annual P load, Geosyntec combined the loads from watershed land uses, internal loading, septic systems, atmospheric sources, and the Wolfeboro Wastewater Treatment Plant (WWTP). The estimated annual P load of 320 lb/year is summarized below.
  - Runoff from watershed land uses accounts for 52% (165 lb) of the annual load;
  - Septic systems account for 7% (23 lb) of the annual load;
  - Atmospheric deposition (wet and dry), accounts for 24% (78 lb) of the annual load;
  - Internal loading accounts for an estimated 17% (54 lb) of the annual load;
  - Runoff from the WWTP is estimated to account for only 0.6% (1.8 lb) of the current annual load. During full operation, the WWTF is estimated to have contributed 7.1% of the total load; and

  - New development projected for 2030 is estimated to increase the annual load by 26.4 lb/yr.

- The Mirror Lake hydrologic budget indicates that the lake has an estimated annual discharge of 3,955,000 m^3/yr. Based on this estimated discharge, the time required for complete lake flushing (hydraulic residence time) is 1.4 years. The hydrologic budget provides information that is required for the P concentration modeling discussed below.

Phosphorus Concentration Modeling Results

- Geosyntec developed two steady-state models, the Vollenweider Model and the Nürnberg Model, to predict the relationship between P loading and in-lake P concentrations for Mirror Lake.
- The Vollenweider equation predicts an in-lake phosphorus concentration of 13.9 μg/L, significantly higher than the observed 2010 average of 10.4 μg/L. The Vollenweider equation also only predicts one annual concentration that reflects the lake in a fully mixed state (i.e., during spring turnover), and does not predict peak concentrations in late summer and early fall when cyanobacteria blooms are more likely to occur. Due to these limitations, the Nürnberg Model appeared to provide a more accurate and useful predictive tool for Mirror Lake.
- The Nürnberg Model calculates an annual average P concentration (10.5 μg/L), a summer epilimnion P concentration (8.7 μg/L), and a fall P concentration (15.0 μg/L). P concentrations are typically highest in the late summer/fall due to mixing of internal P load that is either bound to sediment or retained in the hypolimnion during other times of the year. The Nürnberg results match well with the 2010 annual and summer observed averages, and somewhat overestimates the observed fall 2010 average.
- According to the Nürnberg Model, every P load increase or decrease of 30.4 lb/yr will result in a corresponding increase or decrease of 1.0 ug/L in the summer epilimnetic P concentration. New development anticipated for the Mirror Lake watershed by 2030 is predicted to yield an in-lake P concentration increase of 0.6 μg/L.
- Geosyntec used the Nürnberg model to analyze a variety of P loading scenarios in order to provide a framework for understanding the range of possible in-lake concentrations, and to aid in the selection of the MLPA's water quality goal. Based on review of these scenarios and discussion with NHDES staff, the MLPA adopted a water quality goal of a summer epilimnion P concentration of 8.5 μg/L. P concentrations below 10 μg/L are generally considered low enough to preclude summer cyanobacteria blooms in most lakes.
- According to the Nürnberg Model, the lake's current P load of 320 lb/yr must be reduced by approximately 7.4 lb/yr to achieve the water quality goal stated above. This equates to a target P load of 312.6 lb/yr, including both external sources and internal loading. However, based on 2030 buildout projections, it will be necessary to either prevent additional loading or reduce future projected loads by 33.8 lb/yr (7.4 lbs/yr plus an additional 26.4 lbs/yr from projected development) in order to maintain the water quality goal.
- In addition to the steady state models discussed above, Geosyntec developed a dynamic, rate-dependant model to investigate how long it takes for Mirror Lake's internal P load to respond to various changes in external P loading. For example, the model was used to investigate the lake's response to elimination of P loading impacts from the WWTF spray field operations in the Mirror Lake watershed. In that scenario, the model predicts that it will take roughly 10 years (from 2010 to 2020) for elimination of the WWTF spray field to achieve its full effect in reducing the in-lake P concentration. The dynamic model was also used to investigate the results of other potential changes to external P loading, such as P-load increases related to future development and P-load reduction due to sewering lakefront properties.

Watershed Management

- Geosyntec conducted a watershed survey to identify locations where P loading reductions could be achieved through storm water management improvements and other best management practices (BMPs). In general, the stormwater drainage in the watershed appeared to be in good condition and opportunities for storm water management improvements were limited due to the predominantly forested character of the watershed.

- The proposed storm water management BMPs would result in an estimated P load reduction of 5.2 lb/year, which is about 70% of the targeted phosphorus load reduction of 7.4 lb/year for Mirror Lake. These sites are representative examples of potential stormwater improvements and retrofits that could be implemented at numerous sites throughout the watershed. Significantly greater phosphorus load reductions could be attained from a watershed-wide effort to improve stormwater management through Low Impact Development practices (e.g. raingardens and other infiltrating BMPs) and other land management practices such as reduced fertilizer use, use of rain barrels and cisterns, improved septic system management, stabilization of erosion-prone areas, and proper management of domesticated and farm animal waste.

- Geosyntec identified five areas, including a total of 86 homes, as potential service areas for community septic systems. If all five community septic systems were constructed, the estimated annual reduction in P load ranges from 5.1 to 11.0 lb/yr. This range could achieve the targeted annual phosphorus load reduction of 7.4 lb/yr based on current conditions. For general costing purposes, a cluster mound system servicing 25 homes will cost about $458,000 to install ($18,320 per house). Annual maintenance costs are estimated at $5,000 ($200 annually per home).

- Model projections for 2030 indicate that potential lake shore development could result in an additional 10.3 pounds of annual P load to Mirror Lake, including 6.0 pounds due to land use changes and 4.3 pounds from new septic systems. This projected additional P load represents 30% of 34 pounds of annual P loading that must be prevented (based on current conditions) to maintain the water quality goal in 2030 . Recommended strategies to reduce this future phosphorus load include (1) protection of land either by fee acquisition or conservation easements and (2) regulatory and land planning tools such as zoning bylaws, watershed protection districts and Low Impact Development Bylaws.

- Based on the current condition of Mirror Lake with regard to P loading and in-lake P concentrations, in-lake treatment measures (e.g. alum treatments, dredging) are not recommended at this time. The current water quality of Mirror Lake is very good and Geosyntec recommends that priority should be given to maintaining and improving water quality through watershed source controls and non-structural practices such as land conservation, regulatory tools and public education.

1. INTRODUCTION

Geosyntec Consultants, Inc. (Geosyntec) was contracted by the Mirror Lake Protective Association (MLPA) to develop a Mirror Lake Watershed Management Plan (WMP). Financial support for this project was provided by a grant from the New Hampshire Department of Environmental Services (NHDES) funded by the U.S. Environmental Protective Agency under Section 319 of the Clean Water Act, the Tuftonboro Conservation Commission and the Mirror Lake Management Plan stakeholders.

Mirror Lake (321 acres[1]) and its 1,460-acre[1] watershed are located in the Towns of Tuftonboro and Wolfeboro, New Hampshire. The lake's watershed is comprised predominantly of forested and low density residential areas. The watershed also includes an approximate 22-acre portion of the Wolfeboro Wastewater Treatment Effluent Spray Fields and the Abenaki Ski Area. The lake drains to Lake Winnipesaukee, which is the largest lake in New Hampshire. Mirror Lake's 3.9 mile shoreline is bordered by approximately 105 lakefront homes, the majority of which are seasonal or vacation homes. The primary tributary to Mirror Lake is an unnamed tributary which flows westward from its headwaters at Abenaki Pond, a 2.2 acre pond in the eastern portion of the Mirror Lake watershed.

In 2008, Mirror Lake was included on the List of New Hampshire Threatened or Impaired Waters as an impaired waterbody with respect to contact recreation. The cause of the impairment was recurring blooms of potentially toxin-producing cyanobacteria. Due to this impairment designation and increasing public concerns about cyanobacteria, the MLPA successfully applied for a competitive Section 319 grant to develop a watershed management plan with respect to non-point source loading of phosphorus. In freshwater lakes, phosphorus is usually the most important nutrient determining the growth of algae and aquatic plants. Because phosphorus is typically relatively less abundant than nitrogen, it is considered the "limiting nutrient" for biological productivity. As such, increases in phosphorus levels tend to be strongly correlated with decreased water clarity, increased algal abundance and other indicators of declining water quality.

The primary purposes of this WMP are:

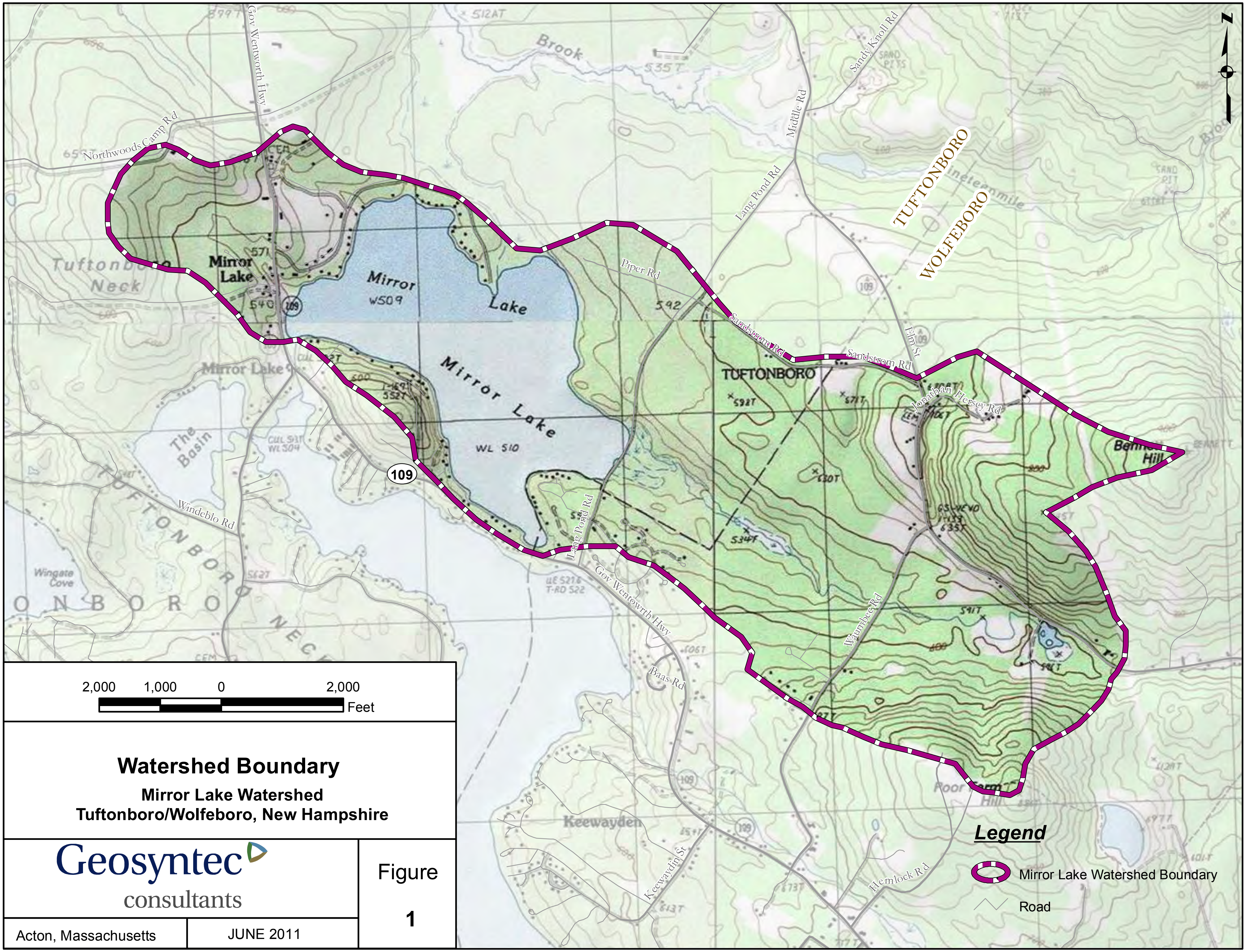
a. to identify and quantify specific sources of phosphorus contributing to the lake's water quality impairments; and

b. to develop a management plan to reduce phosphorus loading to the lake to a targeted level that would significantly improve in-lake conditions.

To achieve the goals listed above, this WMP includes the following nine elements in conformance with the U.S. Environmental Protection Agency's guidance for watershed based plans:

1. Identify Pollutant Sources (WMP Sections 2, 3 and 4)
2. Pollutant Load Reduction Estimates (WMP Section 5)
3. Describe Nonpoint Source Pollution Management Measures (WMP Section 6)
4. Estimate Technical and Financial Assistance (WMP Section 7)
5. Public Information and Education (WMP Section 8)
6. Implementation Schedule (WMP Section 9)
7. Interim Milestones (WMP Section 9)
8. Evaluation Criteria (WMP Section 10)
9. Monitoring (WMP Section 10)

[1] Lake area calculated by Geosyntec by digitizing lake shoreline in ArcGIS from scanned U.S. Geological Survey topographic maps provided by ESRI, ArcGISOnline. Watershed area calculated by Geosyntec based on ArcGIS topographic watershed delineation shown in Figure 1.



Watershed Boundary

Mirror Lake Watershed
Tuftonboro/Wolfeboro, New Hampshire

Geosyntec consultants

Figure

1

Acton, Massachusetts

JUNE 2011

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2. LITERATURE REVIEW AND EXISTING WATER QUALITY

2.1 Water Quality Data

Total phosphorus (TP) is a measure of all organic and inorganic phosphorus forms present in the water. In freshwater lakes, phosphorus is usually the most important nutrient determining the growth of algae and aquatic plants. Because phosphorus is typically relatively less abundant than nitrogen, it is considered the "limiting nutrient" for biological productivity. As stated in the State of New Hampshire 2010 Section 305(b) and 303(d) Consolidated Assessment and Listing Methodology, the NHDES Aquatic Life Use Support criteria for total phosphorus by lake trophic class are as follows:

Oligotrophic < 8.0 mg/L
Mesotrophic ≤12.0 mg/L
Eutrophic ≤ 28 mg/L

Geosyntec has collected total phosphorus measurements in Mirror Lake from a variety of sources, including NHDES, University of New Hampshire Lakes Lay Monitoring Program (UNH LLMP), UNH Center for Freshwater Biology (UNH CFB) and New Hampshire Volunteer Lake Assessment Program (NHVLAP). The epilimnetic (surface water) data included measurements from the deep hole location as well as various locations around the lake, such as Hersey Cove, Mirror Lake Drive, Libby Cove, the Boat Launch, and Bowles Inlet (Figure 2, Sampling Location Map).

Epilimnetic phosphorus data collected by the UNH LLMP and CFB are presented in Figure 3 below. These epilimnetic data, which range from the early 1990's to 2010, seem to indicate an increasing trend in epilimnetic total phosphorus concentrations of approximately 0.7 µg/L (microgram per liter) every ten years.

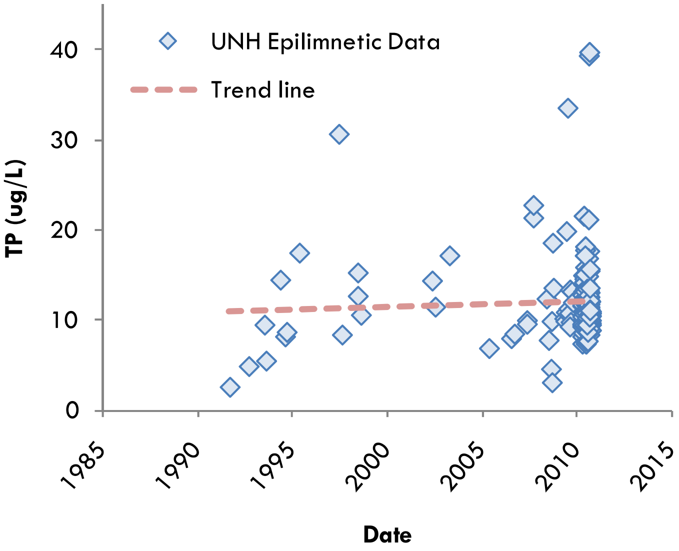
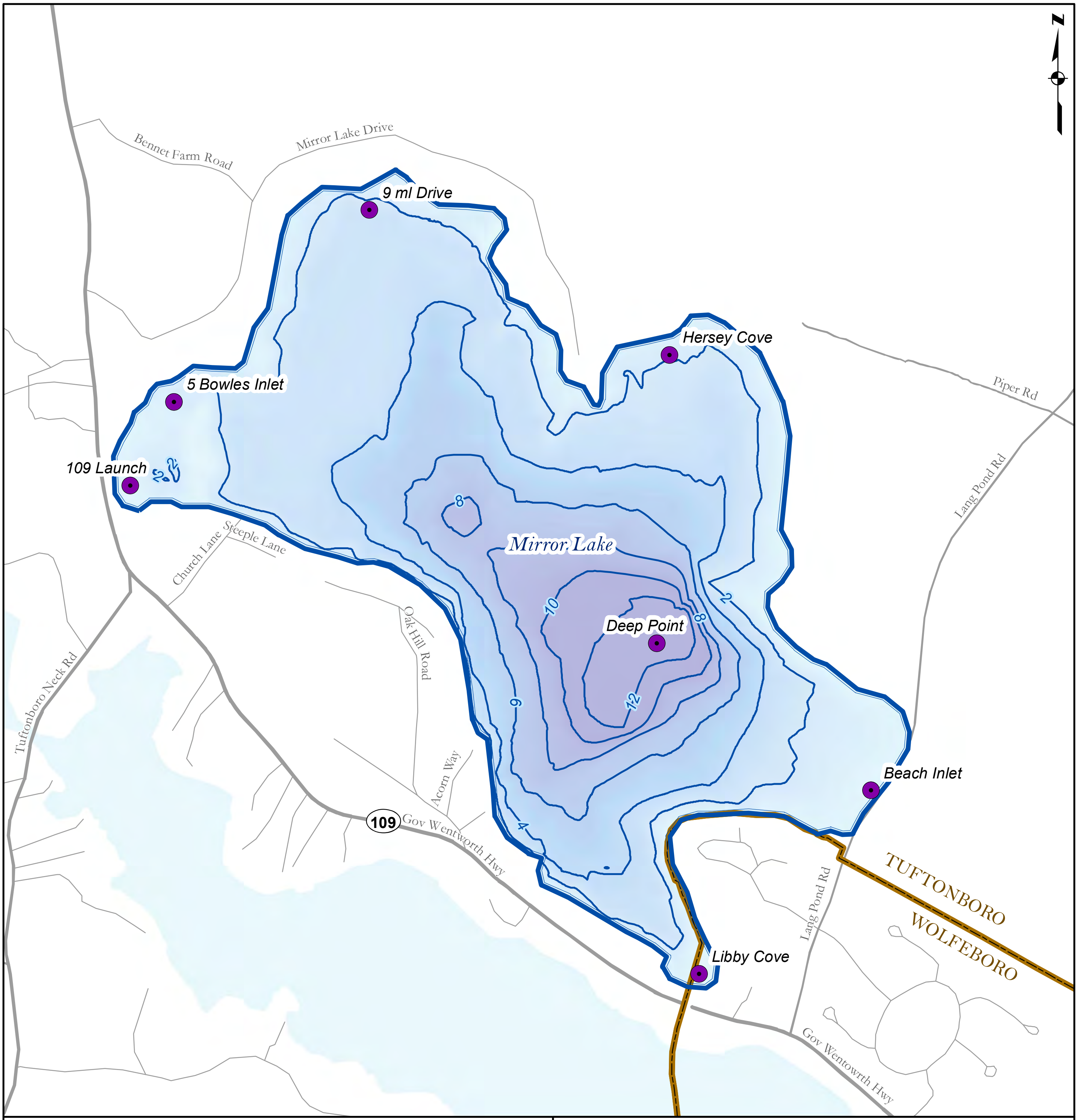


Figure 3. UNH LLMP and CFB epilimnetic total phosphorus data.



1,000 500 0 1,000 2,000

Feet

Legend

● Historic Sampling Locations

Bathymetric Contour (2m)

Mirror Lake

Town Boundary

Road

Note: Bathymetry data provided by NHDES (2010)

Historic Sampling Locations and NHDES 2010 Bathymetry

Mirror Lake Watershed
Tuftonboro/Wolfeboro, New Hampshire

Geosyntec
consultants

Figure

2

Acton, Massachusetts

JUNE 2011

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In addition to the UNH data, NHDES conducted a detailed weekly sampling program from April to October, 2010. The results of the epilimnetic concentrations (collected at a depth of 3m) are shown below. The average values varied seasonally, with summer concentrations (June through August), being 4 μg/L below the fall concentrations (September/October). The 2010 median epilimnetic phosphorus concentration was 10.0 μg/L, and the annual mean TP concentration was 10.4 μg/L.

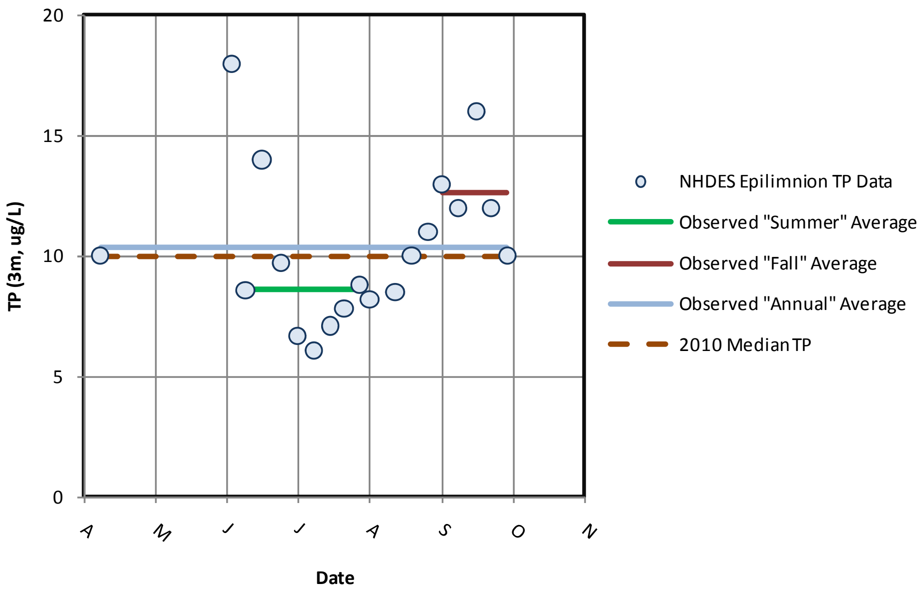


Figure 4. New Hampshire Department of Environmental Services 2010 epilimnetic phosphorus data.

According to the NHDES trophic classification system, a mean TP concentration of 10.4 μg/L places Mirror Lake on the cusp of the "Ideal" and "Average" categories for this water quality parameter. A complete analysis of Mirror Lake's trophic classification based on the NHDES system and the Carlson Trophic Status Index is presented in Section 2.2.

NHDES TP Categories	**TP (μg/L)**
Ideal	**<10**
Average	**11-20**
More Than Desirable	**>15**
Excessive	**>40**

⇨ **Mirror Lake annual mean 2010 TP = 10.4 μg/L**

Chlorophyll-*a* is a green pigment used by plants, phytoplankton and cyanobacteria to convert sunlight into the chemical energy needed to convert carbon dioxide into carbohydrates. The abundance of this pigment provides an indirect measure of algal biomass and is therefore an indicator of a lake's trophic status. For the period of 2008-2010, Mirror Lake's mean summer chlorophyll-a concentration was 3.0 ppb (parts per billion). In water, 1 ppb is equivalent to 1 μg/L. The median summer chlorophyll-a concentration for New Hampshire's lakes and ponds is 4.58 ppb and the mean is 7.16 ppb. NHDES categorizes chlorophyll-a results as follows:

NHDES Chlorophyll-a Categories	Chlorophyll-a (ppb)
Good	0-5
More Than Desirable	5.1-15
Nuisance Amounts	>15

Mirror Lake mean summer 2008-2010 chl-*a* = 3.0 ppb

The **Secchi disk** is a weighted black and white disk that is lowered into the water by a calibrated chain until it is no longer visible. This method provides a measure of water clarity (light penetration), which is primarily a function of algal productivity, water color, and turbidity caused by suspended particulate matter. Water clarity influences the growth of rooted aquatic plants by determining the depth to which sunlight can penetrate to the lake sediments. For the period of 2008-2010, Mirror Lake's mean summer Secchi disk clarity was 4.3 meters, which is on the high end of the "Good" category according to the NHDES trophic classification system.

NHDES Secchi Disk Categories	Water Clarity (m)
Exceptional	>4.5
Good	2 – 4.5
Poor	< 2

Mirror Lake mean summer 2008-2010 Secchi Disk = 4.3 m

2.2 Trophic Status Assessment

Surface water bodies are typically categorized according to trophic state as follows:

- **Oligotrophic:** Low biological productivity. Oligotrophic lakes are very low in nutrients and algae, and typically have high water clarity and a nutrient-poor inorganic substrate. Oligotrophic water bodies are capable of producing and supporting relatively small populations of living organisms (plants, fish, and wildlife). If the water body is stratified, hypolimnetic oxygen is usually abundant.

- **Mesotrophic:** Moderate biological productivity and moderate water clarity. A mesotrophic water body is capable of producing and supporting moderate populations of living organisms (plant, fish, and wildlife). Mesotrophic water bodies may begin to exhibit periodic algae blooms and other symptoms of increased nutrient enrichment and biological productivity.

- **Eutrophic:** High biologically productivity due to relatively high rates of nutrient input and nutrient-rich organic sediments. Eutrophic lakes typically exhibit periods of oxygen deficiency and reduced water clarity. Nuisance levels of macrophytes and algae may result in recreational impairments.

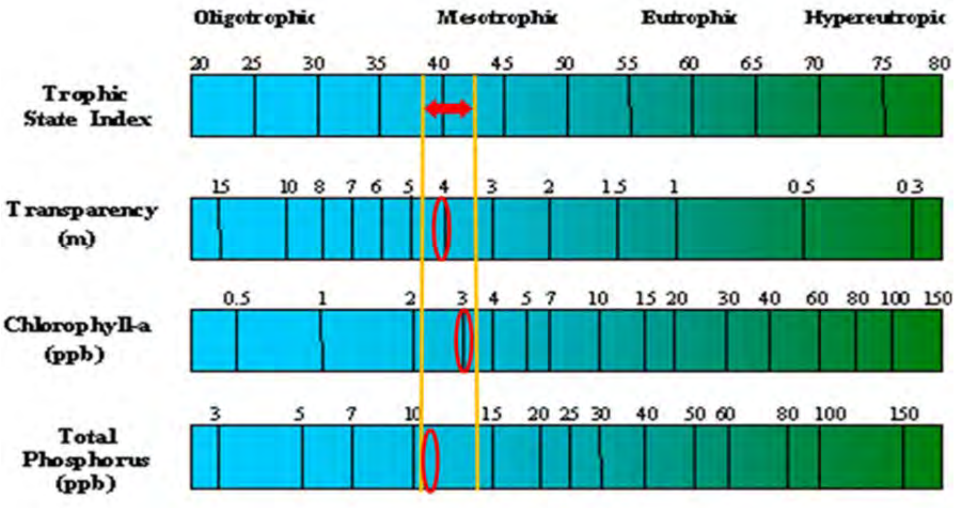
- **Hypereutrophic:** Dense growth of algae throughout the summer. Dense macrophyte beds, but extent of growth is light-limited due to dense algae and associated low water clarity. Summer fish kills are possible.

Geosyntec calculated the trophic status for Mirror Lake using both the Carlson Trophic Status Index and the NHDES trophic classification system. As described below, both methods resulted in a "lower mesotrophic" classification for Mirror Lake.

2.2.1 Carlson Trophic Status Index

The Carlson Trophic State Index (TSI) is one of the most commonly used means of characterizing a lake's trophic state. As illustrated in the Figure 5, the TSI assigns values based upon logarithmic scales which describe the relationship between three parameters (total phosphorus, chlorophyll-a, and Secchi disk clarity) and the lake's overall biological productivity. TSI scores below 40 are considered oligotrophic, scores between 40 and 50 are mesotrophic, scores between 50 and 70 are eutrophic, and scores from 70 to 100 are hypereutrophic. Figure 5 depicts the placement of Mirror Lake on this scale, based on the data discussed below.

Figure 5. Carlson Trophic State Index for Mirror Lake
(Figure adapted from 1988 Lake and Reservoir Restoration Guidance Manual. USEPA. EPA 440/5-88-002.)



The TSI for Mirror Lake was calculated based on the data presented in Section 2.1as follows:

Transparency: Mirror Lake mean summer 2008-2010 Secchi Disk (m)= 4.3m;
TSI = 60 - 14.41ln Secchi Disk (m)
TSI = 39.0 (Mesotrophic)

Chlorophyll-a: Mirror Lake mean summer 2008-2010 chl-*a* = 3.0 ppb;
TSI = (9.81) (ln Chlorophyll-a) + 30.6
TSI = 41.4 (Mesotrophic)

Total Phosphorus: Mirror Lake 2010 mean annual TP =10.4 µg/L;
TSI = (14.42) (ln TP µg/L) + 4.15
TSI = 37.9 (Mesotrophic)

As shown in the calculations above, Mirror Lake has a TSI in the lower end of the mesotrophic range for each of the three parameters in the Carlson Trophic State Index.

2.2.2 *NHDES Trophic Classification System*

Geosyntec calculated Mirror Lake's trophic status using NHDES trophic classification system, which assigns points based on summer dissolved oxygen (DO) levels, Secchi disk transparency, aquatic plant abundance and chlorophyll-a. Summer DO levels are included in the classification system because DO is depleted by the respiration of organisms and decomposition of organic matter within the water column and sediments. Anoxic (oxygen depleted) conditions at the sediment/water interface are associated with the release of phosphorus from lake sediments back into the water column, fueling summer algae and plant growth. Aquatic vegetation information was based on the aquatic vegetation survey conducted by Geosyntec on July 31, 2010. The point total for all parameters is used to determine trophic class, as indicated below:

1. Summer Bottom Dissolved Oxygen Categories	**Mirror Lake Result**	**Points**
a. D.O. >4mg/L		0
b. D.O. = 1 to 4 mg/L & hypolimnion volume ≤10% lake volume		1
c. D.O. = 1 to 4 mg/L & hypolimnion volume >10% lake volume		2
d. D.O. <1mg/L in <1/3 hypo. volume & hypo. volume ≤10% lake volume		3
e. D.O. <1mg/L in ≥1/3 hypo. volume & hypo. volume ≤10% lake volume	✓	**4**
f. D.O. <1mg/L in <1/3 hypo. volume & hypo. volume >10% lake volume		5
g. D.O. <1mg/L in ≥1/3 hypo. volume & hypo. volume >10% lake volume		6
2. Summer Secchi Disk Transparency Categories		
a. > 7m		0
b. > 5m – 7m		1
c. > 3m – 5m	**4.3m**	**2**
d. >2m – 3m		3
e. >1m – 2m		4
f. >0.5 – 1m		5
g. ≤0.5m		6
3. Aquatic Vascular Plant Abundance Categories		
a. Sparse		0
b. Scattered	✓	1
c. Scattered/Common		2
d. Common		3
e. Common/Abundant		4
f. Abundant		5
g. Very Abundant		6
4. Summer Epilimnetic Chlorophyll-a (ppb) categories		
a. <4	**3.0 ppb**	**0**
b. 4 - <8		1
c. 8 - <12		2
d. 12 - <18		3
e. 18 - <24		4
f. 24 - <32		5
g. ≥32		6

NH Trophic Classification	**Stratified Lakes**	**Mirror Lake Score**
Oligotrophic	0-6	
Mesotrophic	7-12	**7**
Eutrophic	13-24	

Total Score = **7 points**
Trophic Classification: **Lower Mesotrophic**

Overall, the NHDES trophic classification system is consistent with the Carlson TSI for Mirror Lake, with both placing the lake within the lower mesotrophic range.

2.3 Cyanobacteria Data

The occurrence of cyanobacteria blooms has been a major concern for the MLPA and other stakeholders since Mirror Lake's first documented cyanobacteria bloom was observed by a UNH researcher in October 2007. Although cyanobacteria are commonly referred to as blue-green algae, they are actually a unique type of bacteria that is capable of photosynthesis. Cyanobacteria can be found in almost all upland and aquatic habitats on earth, and are found in a vast majority of New Hampshire lakes.

In lakes, some cyanobacteria species have the potential to produce toxins, which can be released into the water as the cells decompose. Even where potentially toxin-producing species are present, toxin levels are often are often either undetectable or at extremely low levels, well within accepted guidelines for safe swimming and water contact recreation. However, during cyanobacteria "blooms" (periods of rapid population growth) and subsequent mass die-off of cells, toxin levels can become high enough to present a health threat to humans, pets and other mammals. Cyanobacteria blooms can occur in lakes at any time, but are most common in late summer and early fall when many lakes are at their peak annual phosphorus concentration due to seasonal release of phosphorus from bottom sediments. Health threats are typically caused by ingestion of water, which can cause symptoms including stomach and intestinal illness, allergic responses, liver damage and neurotoxic reactions (e.g. tingling fingers/toes).

In New Hampshire, beach advisories are issued if more than 50% of the phytoplankton (plant algae, including cyanobacteria) cells in a water sample are cyanobacteria, although NHDES does have the authority to use discretion in cases where a sample has over 50% cyanobacteria but the total cell count is very low. As of 2008, NHDES began also issuing lakewide warnings for cyanobacteria. In 2008, these warnings were based on the same standard as the beach advisories (>50% cyanobacteria in a sample). In 2009, the standard was revised to be based on a total cell count of all phytoplankton species (70,000 cells/ml or greater). The total phytoplankton cell count guideline is not intended as a direct measure of cyanobacteria abundance, but is intended to indicate conditions in which excessive cyanobacteria levels could either exist or rapidly develop. As stated above, only some species of cyanobacteria are potentially toxin-producing, and the presence of these species does not imply that unsafe levels of toxin exist in the water. The World Health Organization (WHO) guidelines for cyanobacteria are based on a measured concentration of the toxin microcystin (1ppb for drinking water, 20 ppb for contact recreation). Microcystin is a liver toxin that is commonly found in cyanobacteria blooms.

Since 2007, 40 Mirror Lake samples have been analyzed by NHDES for cyanobacteria and other algae. Figure 6 provides a summary of these samples and relevant cyanobacteria guideline.

# of samples 2007-2010	# of samples > 50% cyano	Total Cell Count >70,000 cells/ml	Microsystin (ppb) WH0 guidelines: Drinking ≤ 1; Contact Recreation ≤ 20	Beach Advisories / Lakewide Warnings
40	20	**None** (Highest count was on 9/4/2009: 39,614 cells/ml)	4 samples **0.06 – 0.36 ppb**	**Aug. 2007 NHDES press release (no advisory)** **Aug.-Dec. 2008 (Beach Advisory/Lakewide Warning)**

Figure 6: Summary of Mirror Lake Cyanobacteria Sampling, 2007-2010

Figure 6 Notes:

1. Half of the samples taken since 2007 were comprised of >50% cyanobacteria cells. However, total cell counts were not performed on many of the samples because NHDES determined the overall abundance of cells to be very low.
2. The highest recorded level of microsystin (0.36 ppb) was measured during the 2008 beach advisory/lakewide warning. This level of microsystin is three times lower than the WHO standard for drinking water and sixty times lower than the WHO standard for recreation.

2.4 Assimilative Capacity

As defined by NHDES, assimilative capacity (AC) describes the amount of pollutant that can be added to a water body without causing a violation of the water quality criteria. New Hampshire requires that lakes maintain 10% of their AC in reserve. NHDES classifies Mirror Lake as a mesotrophic lake, and therefore the water quality standard used for determining total AC is 12 µg/L of total phosphorus (median epilimnetic concentration). The "reserve assimilative capacity" required for Mirror Lake is 1.2 µg/L, which is 10% of the 12 µg/L standard. This means that, to maintain at least a 10% reserve assimilative capacity, the maximum median epilimnetic phosphorus concentration for Mirror Lake is 10.8 µg/L (12 µg/L - 1.2 µg/L).

Using data obtained from the NHDES OneStop Environmental Monitoring Database (as required for AC calculations), Geosyntec calculated that Mirror Lake's current median epilimnetic phosphorus concentration is 10.0 µg/L (Figure 7). This median value is consistent with the 2010 median value presented above in Section 2.1.

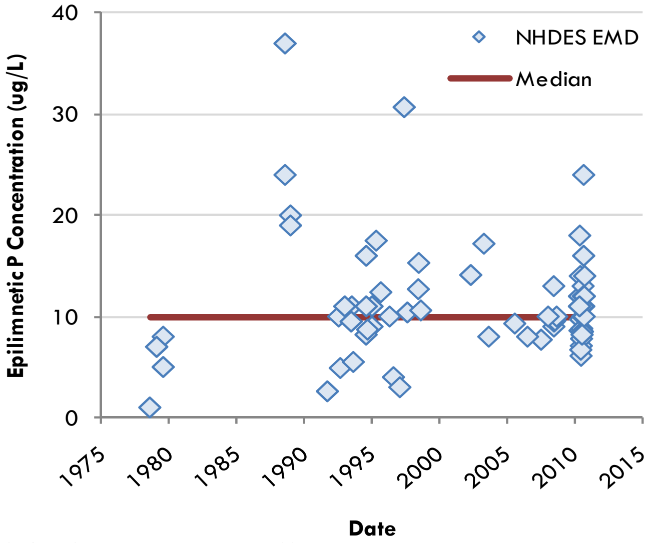


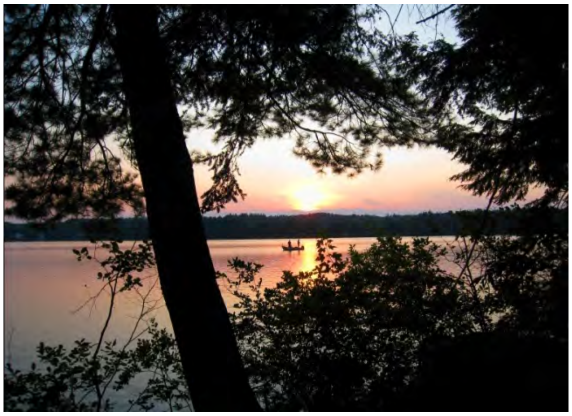
Figure 7. NHDES OneStop Environmental Monitoring Database epilimnetic phosphorus data.

To maintain the required 10% reserve assimilative capacity, the water quality goal for Mirror Lake must be equal to or below 10.8 µg/L. Based on a review of data and modeling scenarios developed by Geosyntec, and consultation with Andy Chapman of the NHDES Clean Lakes Program, the MLPA Water Quality Advisory Committee has selected a water quality goal of 8.5 µg/L (summer epilimnion P concentration). The modeling scenarios developed to aid in selection of the water quality goal are presented in Section 5.4 of this report.

2.5 Summary of Mirror Lake Water Quality

- Mirror Lake data from the early 1990's to 2010 show an increasing trend in total phosphorus concentrations of approximately 0.7 µg/L every ten years during this period.
- Despite the increasing trend in phosphorus concentrations, the current water quality of Mirror Lake is very good. Both the Carlson Trophic Status Index and the NHDES trophic classification system result in a "lower mesotrophic" classification for Mirror Lake.
- Cyanobacteria blooms have been a concern since Mirror Lake's first documented cyanobacteria bloom in 2007. Since 2007, 40 Mirror Lake samples have been analyzed by NHDES for cyanobacteria and other algae. None of these samples have exceeded the current standard for beach advisories or lakewide warnings (total cell count of 70,000 cells/ml or greater). The highest recorded level of microsystin (a toxin produced by some species of cyanobacteria) was 0.36 ppb, as measured during a 2008 cyanobacteria bloom. This level of microsystin is three times lower than the WHO standard for drinking water and sixty times lower than the WHO standard for recreation.
- In New Hampshire, the water quality standard for mesotrophic lakes such as Mirror Lake is 12 µg/L of total phosphorus. This means that, to maintain at least a 10% reserve assimilative capacity, the maximum median epilimnetic phosphorus concentration for Mirror Lake is 10.8 µg/L (12 µg/L - 1.2 µg/L). Mirror Lake's current median phosphorus concentration is 10.0 µg/L, indicating water quality that is better than the NHDES standard for mesotrophic lakes.

3. MIRROR LAKE PHOSPHORUS BUDGET



Geosyntec developed an estimate of the annual load of phosphorus that is delivered to Mirror Lake from watershed sources and internal sources (sediments). The sources included in this phosphorus budget are described below, and include phosphorus export from various land uses, septic systems, internal phosphorus loading, atmospheric deposition and the Wolfeboro Wastewater Treatment Plant (WWTP). An estimate of phosphorus loading was developed for current conditions and for conditions anticipated in the year 2030.

3.1 Land-Use Based Pollutant Modeling

Geosyntec performed a land-use assessment of the Mirror Lake watershed based on ground-truthing field investigations and review of aerial photography. The watershed was divided into nine land use categories. The area totals assigned to each land use category are summarized in Table 1. See Figure 8 for the land use map produced by Geosyntec.

Calculation of phosphorus export from the various land uses in the watershed was performed using a method outlined in Chapter 8 of the New Hampshire Stormwater Manual. The method multiplies a volume of runoff from each land use by an expected pollutant Event Mean Concentration (EMC) from the land use. Runoff volume from each land use is calculated using the equation:

$$R = P_{ann} \cdot P_j \cdot A \cdot (0.05 + 0.9 \cdot I_a) \cdot 3630$$

Where:

R is the runoff volume (ft^3/yr);

P_{ann} is the annual precipitation (in);

P_j is the fraction of precipitation events that cause runoff;

A is the total area of the land use in the watershed (acres); and

I_a is the fraction of impervious cover in the land use.

Geosyntec used a combination of remote sensing and field investigations provided by MLPA volunteers to generate an impervious surface map. Impervious surfaces have a significant influence on storm water runoff volume and quality because these areas rapidly shed water and do not allow for infiltration and associated pollutant attenuation. MLPA volunteers conducted field investigations of developed portions of the watershed to confirm and refine the accuracy of remote sensing imagery obtained by Geosyntec. Field investigations can typically provide more accurate mapping of impervious surfaces than remote sensing due to overhanging tree canopy, changes in land use not shown on the remote sensing images, etc. The location of impervious surfaces is shown in Figure 9 and these surfaces were used to calculate the I_a values presented in Table 1.

Event Mean Concentrations (EMCs) are estimates of volume-weighted average concentrations of a pollutant in stormwater runoff. EMCs for each of the land uses in Mirror Lake Watershed are presented in Table 1. The values presented are averages of a range of EMCs that were collected from published literature and other technical documents. The phosphorus (P) load is calculated as follows:

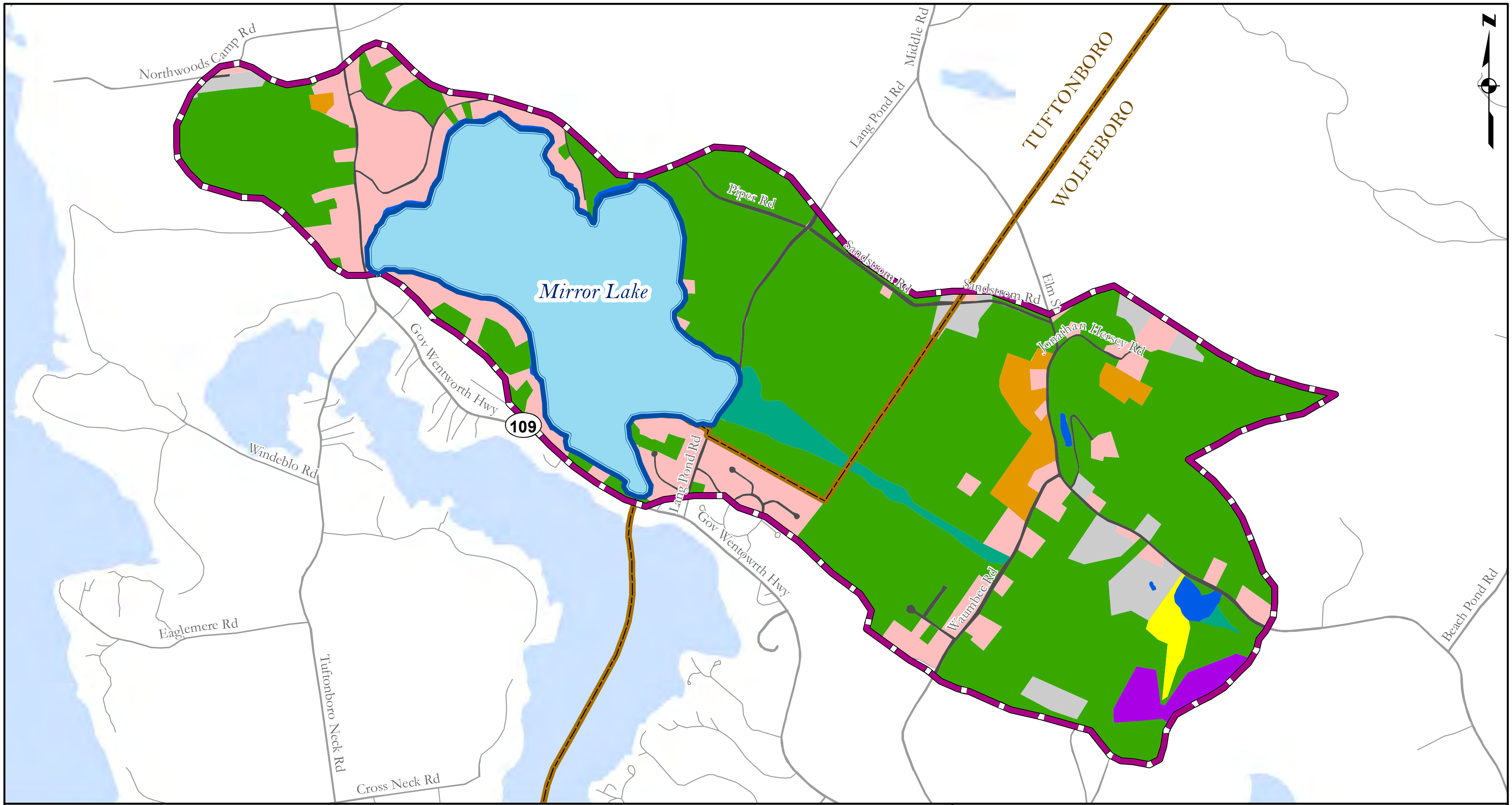
$$L = \frac{R \cdot EMC}{16018.5}$$

Where:

L is the P load (lbs);

R is the runoff volume (ft^3/yr); and

EMC is the event mean concentration (mg/L).



2,000 1,000 0 2,000 4,000
Feet

Legend

- Mirror Lake
- Mirror Lake Watershed Boundary
- Town Boundary
- Road

Land Use

- 🟩 Forest
- ⬜ Open
- 🟧 Pasture
- 🟨 Recreation
- 🟥 Residential
- ⬛ Road
- 🟪 Spray Field
- 🟦 Water
- 🟩 Wetland

Land Use

Mirror Lake Watershed
Tuftonboro/Wolfeboro, New Hampshire

Geosyntec consultants

Acton, Massachusetts

JUNE 2011

Figure

8

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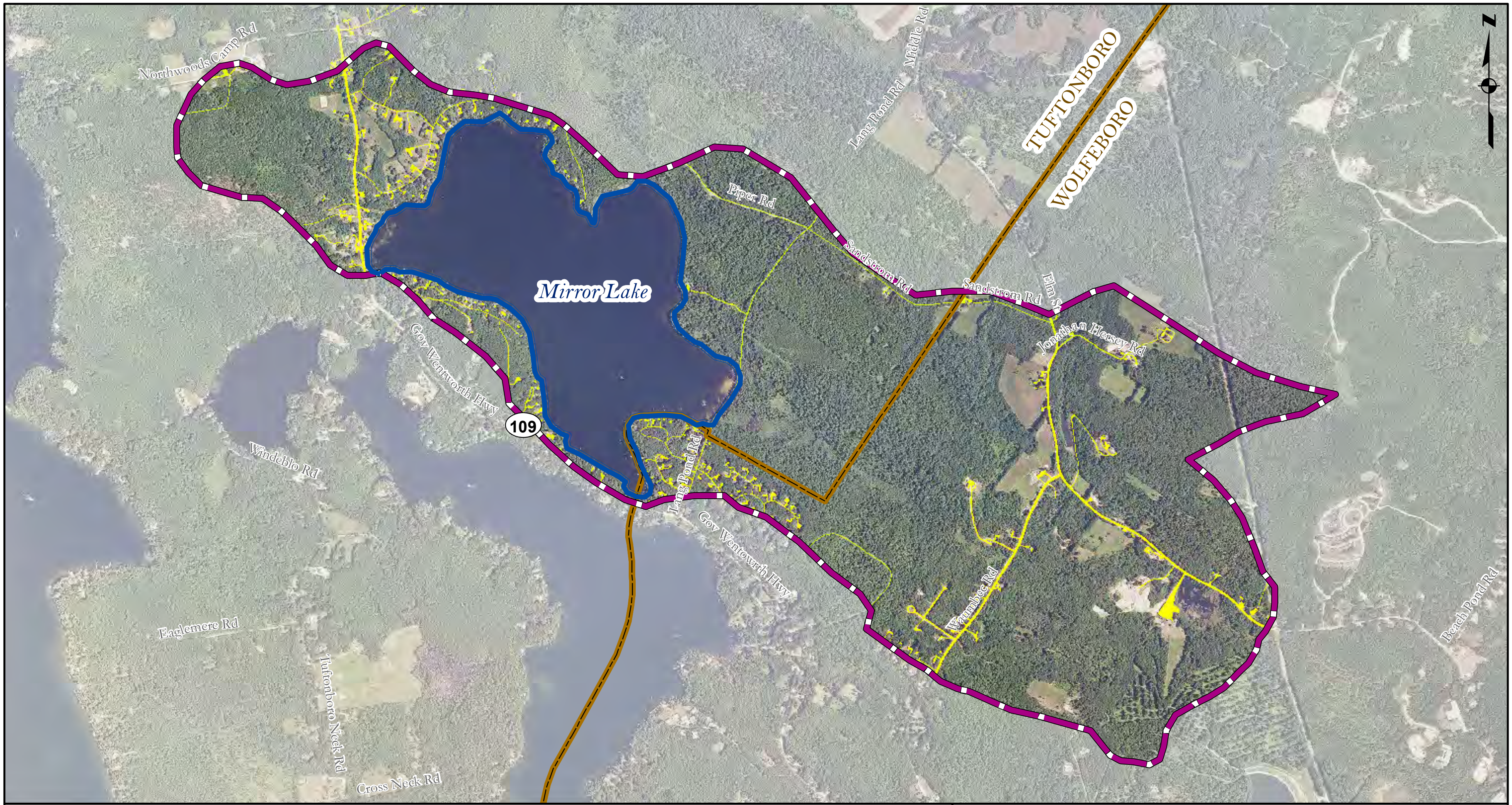

Legend

- Mirror Lake
- Mirror Lake Watershed Boundary
- Town Boundary
- 🟨 Impervious Surface

Impervious Surfaces

Mirror Lake Watershed
Tuftonboro/Wolfeboro, New Hampshire

Geosyntec consultants

Acton, Massachusetts

JUNE 2011

Figure

9

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Table 1. Land Use Pollutant Model Parameters and Results

Annual Rainfall, inches (P_{ann})	43.05
Fraction of rainfall that produces runoff (P_j)	0.9

	LAND USE	AREA (ac)	I_a	R (ft^3/yr)	EMC (mg/L)	L (lbs)
🟩	Forest	997.4	0.3%	7,428,065	0.12	**54.9**
⬜	Open	58.1	1.8%	541,036	0.11	**3.6**
🟧	Pasture	36.6	0.1%	262,918	0.31	**5.1**
🟨	Recreation	11.6	15.3%	307,047	0.11	**2.0**
🟥	Residential	241.4	8.4%	4,265,028	0.27	**72.1**
⬛	Road	35.4	54.2%	2,675,288	0.14	**23.4**
🟪	WWTF Spray Field	22.7	0.3%	169,196	0.17	**1.8**
🟦	Water	342.7	0.0%	2,410,221	0.00	**0.0**
🟦	Wetland	34.8	0.0%	245,053	0.11	**1.7**
	TOTAL	**1780.8**	**-**	**18,303,851**	**-**	**164.6**

3.2 Phosphorus Loading From Septic Systems

Geosyntec, in cooperation with MLPA volunteers, conducted an assessment to estimate phosphorus loads from on-site sanitary systems located within three tiers of parcels around the perimeter of Mirror Lake and its tributary. The first tier of parcels have water frontage, the second tier is separated from the water by another parcel, and the third tier is separated from the water by two parcels. On-site sanitary systems considered in the analysis included septic tanks with leaching fields, septic tanks with chambers, cesspools, holding tanks, chemical toilets, etc. MLPA volunteers collected data relevant to the watershed's septic systems, such as system volume, installation date, number of bedrooms, number of residents, etc. Approximately 90% of all homes included in the three tiers responded to the survey. The inventory results enabled a detailed estimation of the phosphorus load from septic systems within the Mirror Lake watershed; a quantity that is typically difficult to accurately estimate. The results of the septic system inventory data collection is presented in Appendix A.

Geosyntec calculated an annual phosphorus load from septic systems of 23 lb/yr, which equals an average annual load of 0.24 lb/year from each of the 96 homes within the three tiers of parcels This estimate was calculated using the following formula:

$$S = \sum_{i=0}^{h} B_i \cdot n_i \cdot Q_c \cdot m_i \cdot P_w \cdot \theta$$

Where:

S is the total P load from septic systems (lbs);

h is the total number of homes considered in the inventory;

B_i is the number of bedrooms served by the system;

n_i is the average number of persons per bedroom (0.905, determined from a subset of 71 homes that had information on both the number of bedrooms and the number of residents in the home);

Q_c is the per-capita daily water use (69.3 gal/person/day, from the USEPA Onsite Wastewater Treatment Systems Manual);

m_i is the number of months that the home is occupied;

P_w is the concentration of phosphorus in wastewater (10 mg/L, from the USEPA Onsite Wastewater Treatment Systems Manual);

θ is the fraction of phosphorus removal attributed to the septic system and leach field (0.94).

3.3 Internal Phosphorus Loading

Internal recycling of phosphorus can be a significant source of overall phosphorus load to a pond. Lake sediments contain phosphorus that is bound to the sediment particles. During periods of anoxia (oxygen concentration ≤ 1 mg/l), phosphorus can be released into the water from lake sediments in soluble form, making it biologically available to fuel increased algal productivity.

In 2010, NHDES conducted an intensive study of phosphorus concentrations within Mirror Lake to estimate the current rate of internal loading. Based on this study, NHDES estimated an internal P load of 54.4 lb P/yr. A copy of the study, "Mirror Lake, Tuftonboro, New Hampshire, Internal Phosphorus Loading and Cyanobacteria Response," is included as Appendix B of this report.

3.4 Atmospheric Deposition

Atmospheric deposition of phosphorus is an estimate of the load of phosphorus delivered through wet or "dryfall" precipitation depositing phosphorus-containing particles directly on the surface of Mirror Lake. Deposition rates were determined from published literature (Reckhow, 1980). The annual atmospheric deposition load was calculated assuming a deposition rate of 0.24 lb P/ac/yr, for a total atmospheric load of 77.7 lb P/yr.

3.5 Wolfeboro Wastewater Treatment Plant Spray Fields

As shown in Figure 8, approximately 22 acres of the Town of Wolfeboro Wastewater Treatment Plant (WWTP) Effluent Spray Fields exist within the Mirror Lake watershed. The spray field began operation in 1978 for the purpose of disposing wastewater treatment plant effluent. In 2005, NHDES issued an administrative order for WWTP violation of surface water quality standards. In 2009, Wolfeboro moved its effluent disposal to a series of rapid infiltration basins located outside of the Mirror Lake watershed. However, in 2010, the WWTP was re-permitted to allow limited spraying provided that the pipes and sprinkler heads were removed from the portions of the facility located in the Mirror Lake watershed. The effluent spray fields present a unique source of phosphorus to Mirror Lake, both from (1) nutrient-rich soil and sediment which can migrate to the lake via stormwater runoff and (2) the migration of nutrient-rich groundwater to tributaries and onward to the lake.

Phosphorus loading due to stormwater runoff from the spray fields was calculated using a method similar to the one described in Section 3.1. In the 2005 Administrative Order issued by NHDES to the Town of Wolfeboro, NHDES presented measurements of stormwater runoff from the spray fields which exhibited an average concentration of 0.17 mg P/L. As discussed in Section 3.1, this leads to an estimated 1.8 lb P/yr from stormwater runoff from the spray fields. Due to soil phosphorus adsorption in the spray field area, it was conservatively assumed that the estimated phosphorus load from stormwater runoff was the same for both the period of active spray field operation and current conditions (no spraying in Mirror Lake watershed).

The potential maximum phosphorus load entering groundwater from the spray field (during the period of spray field operation only) was calculated using the following formula:

$$G = \left[\left(A_{sp} \cdot D_{sp} \cdot C_{sp}\right) - L_{sp}\right](1 - \theta)$$

Where:

G is the P load entering the groundwater (lbs);

A_{sp} is the area of spray field within the watershed (acres);

D_{sp} is the depth of water sprayed per year (inches);

C_{sp} is the concentration of phosphorus in the effluent (mg/L);

L_{sp} is the P load removed via runoff (lbs);

θ is the soil adsorption factor (a similar value to that used in the septic system loading calculation).

Based on records obtained from the WWTP, Geosyntec determined that approximately 51.5 inches of water were typically sprayed per spraying season (May-October). Also, NHDES data presented in the 2005 Administrative Order indicate an average effluent concentration of 1.78 mg P/L. This leads to an estimated annual P load from spray field groundwater of:

$$G = \left[\left((22.7\,acre)\left(\frac{43{,}560\,ft^2}{acre}\right)(51.5\,in)\left(\frac{1\,ft}{12\,in}\right)\left(1.78\frac{mg}{L}\right)\left(\frac{1\,lb}{453592.4\,mg}\right)\left(\frac{28.32\,L}{1\,ft^3}\right)\right) - 1.8lb\right](1 - 0.95) = 23.5\,lb$$

This estimated load should provide a reasonable prediction of P concentrations observed at two sampling locations along the primary tributary from the WWTF to Mirror Lake; (1) at the outlet of Abenaki Pond, and (2) at the culverted inlet to Mirror Lake under Lang Pond Road. The table below summarizes a rough hydrologic and nutrient budget for these two locations, assuming that phosphorus is contributed by stormwater runoff from the spray fields, phosphorus rich groundwater from the spray fields, and stormwater runoff from the other portions of the watershed. Groundwater from other portions of the watershed is assumed to have negligible influence on the calculation. The methods used for calculating the hydrologic budget are discussed in Section 4.

Watershed	Total Watershed Area (ac)	Spray Field Area within Watershed (ac)	Q (m^3/yr)	Qsp (m3/yr)	Runoff Load (lb)	Groundwater P Load (lbs)	Estimated P Concentration (mg/L)	Observed P Concentration (mg/L)
Abenaki Pond Outlet	97.4	15.3	330,568	111,837	8.9	15.7	0.034	0.029
Mirror Lake Inlet	912.1	22.7	2,078,816	165,819	86.8	23.5	0.022	0.026

A sample calculation, for the Mirror Lake Inlet sampling location, is as follows:

$$C_i = \left[\frac{86.8\ lb + 23.5\ lb}{2{,}078{,}816\,\frac{m^3}{yr} + \ 165{,}819\,\frac{m^3}{yr}}\right] \cdot \left(\frac{453{,}592.4\ mg}{1\ lb}\right) \cdot \left(\frac{1\ m^3}{1000\ L}\right) = 0.022\,\frac{mg}{L}$$

The in-stream concentrations estimated by the model match closely with the observed concentrations, indicating that that the estimates of the P contribution from the spray field are not greatly over- or underestimated.

Additional monitoring, including groundwater phosphorus monitoring in the vicinity of the spray field, could aid in determining a more precise estimate of the contribution that elevated groundwater phosphorus concentrations may have on the current and future phosphorus budget of Mirror Lake.

3.6 Future Conditions Analysis

This section provides an analysis of estimated future land-use conditions in the Mirror Lake Watershed (MLW). Geosyntec's future conditions model estimates land-use changes based on year 2030 population projections from the Lakes Region Planning Commission (LRPC), as shown in the table below.

TOWN	2010 Population	2030 Population	% Increase
Tuftonboro	2490	3060	22.9%
Wolfeboro	6980	8710	24.8%

Based on available spatial data (tax maps, aerial images, etc), the total number of homes within the MLW was estimated for each town (H). The total number of homes was then multiplied by an average of 2.32 persons per household (N_H) to determine the population within the MLW. Finally, it was assumed that the portion of the town within the MLW would experience growth proportional to the rest of the town, and the current watershed population was multiplied by the projected town-wide population increase. (*Note: The projected % population increases listed above are expressed as fractions* (P_i) *in the formulas below.)*

For Tuftonboro, an increase in population was estimated as follows:

$$H \cdot N_H \cdot P_i = (80\ homes)\left(2.32\ \frac{persons}{home}\right)(0.229) = 43$$

Similarly, for Wolfeboro, an increase in population was estimated as follows:

$$H \cdot N_H \cdot P_i = (100\ homes)\left(2.32\ \frac{persons}{home}\right)(0.248) = 58$$

These population increases translate to approximately 19 and 25 additional homes for Tuftonboro and Wolfeboro, respectively.

The additional number of homes was next multiplied by a minimum lot size to determine the additional residential land use that would be introduced in the MLW, as follows:

- For Tuftonboro, it was assumed that the projected development would include full build-out of the remaining developable parcels along the lake's northern undeveloped shoreline ("Lakefront" zone minimum lot size = 1 acre).
- In Wolfeboro, the watershed includes three zoning classifications; Residential, General Residential, and Rural Residential. The minimum lot size of each zone was weighted by its proportion of the watershed to determine a weighted minimum lot size of 1.8 acres.

The number of homes was multiplied by the lot size to determine an increase in residential land of 19.0 and 46.3 acres for Tuftonboro and Wolfeboro, respectively.

The existing ratio of "road" land use to "residential" land use was used to project a future addition of 2.3 and 7.9 acres of road for Tuftonboro and Wolfeboro, respectively.

The total area increases in residential and road land uses were subtracted from "developable" land such as forest, pasture and open space. Overall, the adjustment of land uses resulted in an estimated additional 21.3 lb P/yr, as calculated using the method described in Section 3.1.

Because development in Tuftonboro was assumed to occur along the lake shore, an additional phosphorus load from these homes' septic systems will be contributed to Mirror Lake. In the septic system inventory (see Section 3.2), it was estimated that an average home contributes approximately 0.24 lb P/yr. A total of 19 homes along the lakefront would contribute an additional 4.3 lb P/yr to the Mirror Lake phosphorus budget.

3.7 Summary of the Mirror Lake Phosphorus Loading Budget

To estimate the current annual phosphorus loading budget for Mirror Lake, Geosyntec has combined the phosphorus load from internal loading, septic systems, atmospheric sources, and watershed loading estimates derived from the land use pollutant loading model. Because the available data is insufficient to determine the precise phosphorus load from the Wolfeboro Wastewater Treatment Plant, Geosyntec has presented a range of WWTP loads when investigating hypothetical loading scenarios in Section 5.4 of this report. For the purposes of estimating a current phosphorus budget, we have assumed that soil and sediment particles with elevated phosphorus may still be migrating toward Mirror Lake via stormwater runoff, as discussed in Section 3.5. In the absence of confirmatory data, we have assumed that a groundwater component from the WWTP is not included in the current phosphorus budget.

The estimated annual phosphorus budget of 320 lb/year is summarized below and presented in Figure 10. The estimated loads from this phosphorus budget are used in the water quality models presented in Section 5.

- The phosphorus load resulting from runoff from the varying land uses in the Mirror Lake Watershed accounts for 52% (165 lb/yr) of the annual phosphorus load to the lake.
- Phosphorus loading from septic systems is estimated to account for 7% (23 lb/yr) of the annual phosphorus load.
- Atmospheric deposition, including wet and dry deposition, is estimated to account for 24% (78 lb/yr) of the annual phosphorus load.
- Internal loading accounts for an estimated 17% (54 lb/yr) of the annual phosphorus load.
- Residual runoff from the WWTP accounts for only 0.6% (1.8 lb/yr) of the current annual phosphorus load. However, during full operation, the WWTF is estimated to have contributed 7.1% (24 lb/yr) of the total load.
- Compared to current conditions, new development projected for the year 2030 is estimated to increase the annual phosphorus load by 8.3% (26.4 lb/yr).

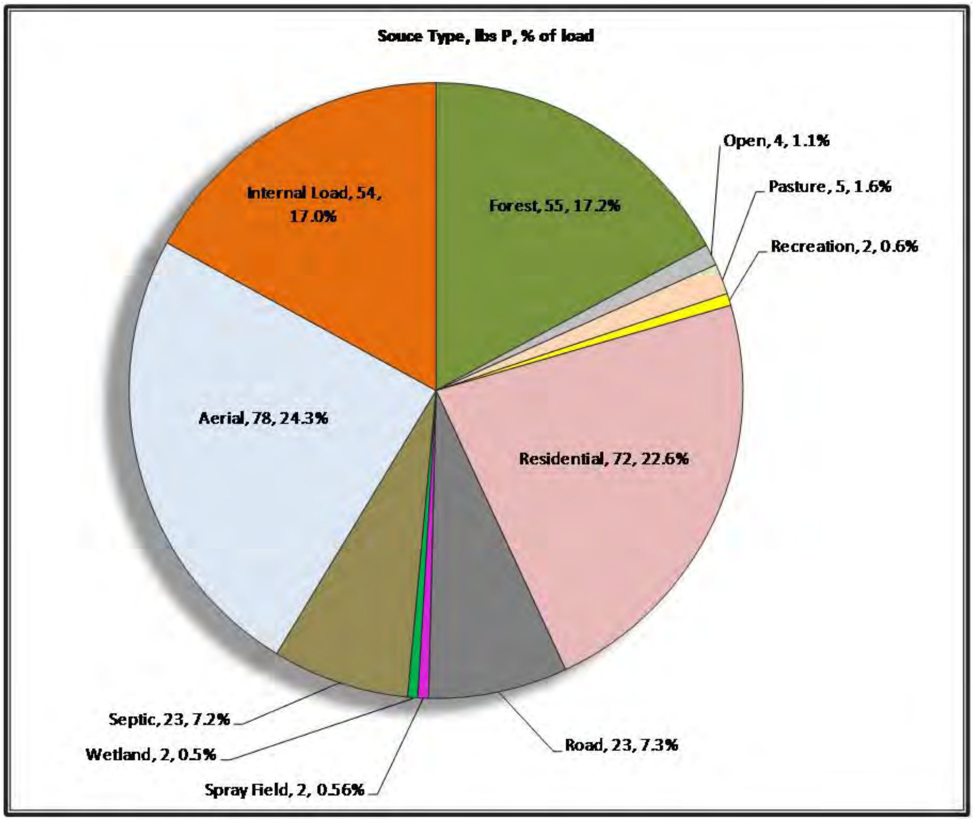


Figure 10. Current (2011) Mirror Lake Phosphorus Budget.

4. MIRROR LAKE HYDROLOGIC BUDGET

A hydrologic budget is an accounting of the inflow to, outflow from, and storage within a hydrologic unit, such as a lake watershed. Many methods are typically available for estimating an annual hydrologic budget for a lake watershed. Ideally, the optimal method involves direct measurement, i.e. installation of stream and precipitation gages to construct a full annual water budget. When time or budget prevents the use of direct measurement, other methods can be used. Geosyntec has performed two separate calculations of an annual water budget, presented below. The results of the hydrologic budget indicate that Mirror Lake has an annual discharge (Q) of approximately 3,955,000 m^3/yr which equates to a hydraulic overflow rate of 3.04 m/yr, and the time required for complete flushing (hydraulic residence time) is 1.4 years. The hydrologic budget provides information that is required for the phosphorus concentration modeling presented in Section 5.

The hydrologic budget is calculated as:

$$Q = Q_w + Q_d - Q_e = Q_w + (P \cdot A_s) - \left(\rho \cdot E_{pan} \cdot A_s\right)$$

Where Q is the annual discharge from the lake, Q_w is the annual discharge entering the lake from the watershed, Q_d is the water resulting from direct precipitation to the lake, and Q_e is the amount of water removed from the lake via evaporation, P is the annual precipitation, A_s is the lake surface area, E_{pan} is the pan evaporation rate (32 in/yr for New Hampshire), and ρ is the pan evaporation coefficient necessary to adjust pan evaporation to lake evaporation (0.75 for New Hampshire region).

Q_d is calculated as follows:

$$Q_d = P \cdot A_s = \left(43.05\ \frac{in}{yr}\right)\left(\frac{1\,ft}{12\,in}\right)(321.8\,ac)\left(\frac{43{,}560\,ft^2}{ac}\right) = 50.27 \cdot 10^6\ \frac{ft^3}{yr} = 1.424 \cdot 10^6\ \frac{m^3}{yr}$$

Q_e is calculated as follows:

$$Q_e = \rho \cdot E_{pan} \cdot A_s = (0.75)\left(32\ \frac{in}{yr}\right)\left(\frac{1\,ft}{12\,in}\right)(321.8\,ac)\left(\frac{43{,}560\,ft^2}{ac}\right) = 28.03 \cdot 10^6\ \frac{ft^3}{yr}$$
$$= 7.94 \cdot 10^5\ \frac{m^3}{yr}$$

Watershed discharge was calculated using two separate methods. The first method involved using a map of annual runoff amounts prepared by USGS (Randall, 1996). This method is the same as that used by New Hampshire DES in their Lake Trophic Reports and discussed in the "Sources of Information and Explanatory Data." For the Mirror Lake region, the Randall mean annual runoff value is approximately 21.5 inches, resulting in:

$$Q_w = \left(21.5\ \frac{in}{yr}\right)\left(\frac{1\,ft}{12\,in}\right)(1459\,ac)\left(\frac{43{,}560\,ft^2}{ac}\right) = 113.89 \cdot 10^6\ \frac{ft^3}{yr} = 3.23 \cdot 10^6\ \frac{m^3}{yr}$$

The second method incorporated stream gaging results from 94 New England stream gages (a total of 942 water-years) to develop a discharge-area relationship (Figure 11). Linear regression of these data resulted in:

$$\log[Q_{da}] = 0.9096 \cdot \log[A_w] - 2.2943$$

Where Q_{da} is an average daily discharge in ft^3/s and A_w is the watershed area in acres. For Mirror Lake,

$$Q_{da} = 10^{[0.9096 \cdot \log[1459] - 2.2943]} = 3.83\ \frac{ft^3}{s}$$

$$Q_w = Q_{da} \cdot \left(3.17\ \cdot \frac{10^7 sec}{yr}\right) = 120.95 \cdot 10^6\ \frac{ft^3}{yr} = 3.42 \cdot 10^6\ \frac{m^3}{yr}$$

Geosyntec used an average of the two methods to determine an estimate of Q_w of $3.325 \cdot 10^6\ m^3/yr$.

The total discharge, Q, is estimated to be

$$Q = Q_w + Q_d - Q_e = (3.325 + 1.424 - 0.794) \cdot 10^6\ \frac{m^3}{yr} = 3.955\ \cdot 10^6\ \frac{m^3}{yr}$$

The Mirror Lake hydrologic budget indicates that Mirror Lake has an estimated annual discharge of 3,955,000 m^3/yr. The hydrologic budget provides information that is critical for development of the phosphorus concentration modeling presented in Section 5.

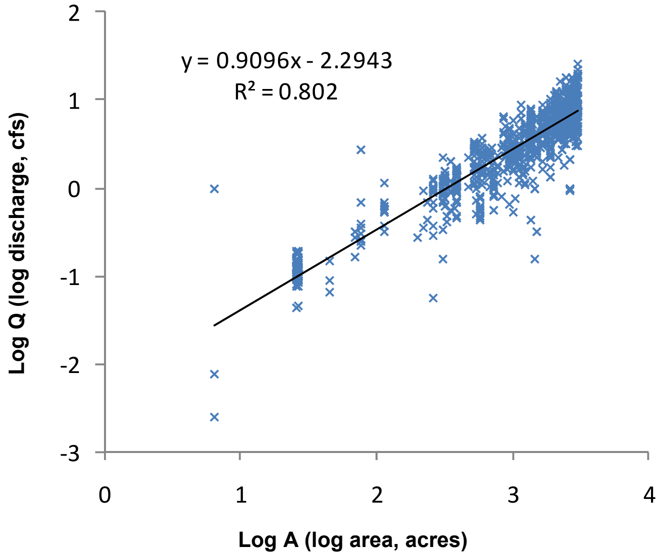


Figure 11. Area-Discharge Relationship for New England USGS Stream Gages (<3000 acres).

5. MIRROR LAKE PHOSPHORUS CONCENTRATION MODELING

5.1 Vollenweider Model

The Vollenweider model is commonly used to predict in-lake phosphorus concentrations as a function of annual external phosphorus loading, mean lake depth and hydraulic residence time (time required for entire lake volume to be "flushed" or replaced with new water inputs). Phosphorus concentrations predicted by the Vollenweider equation are based on an assumption that the lake is uniformly mixed, such as at spring turnover. The Vollenweider model is based on a five-year study of about 200 waterbodies in Europe, North America, Japan and Australia.

The Vollenweider Equation is provided below, with calculations for Mirror Lake based on the phosphorus loading estimate discussed in Section 3, including phosphorus from stormwater runoff, septic systems, and aerial deposition. Internal loading is not included in the Vollenweider phosphorus load because the model is an empirical relationship between in-lake phosphorus concentration and external load only. For this calculation, Geosyntec estimates annual external phosphorus loading to Mirror Lake to be 265.4 lb P/yr (120 kg P/yr).

Vollenweider Equation:

$$p_v = \frac{L_p}{\left(q_s\left(1 + \sqrt{\tau_w}\right)\right)}$$

where:

p_v = mean in-lake phosphorus concentration (mg/L) estimated by Vollenweider equation;

L_p = annual phosphorus load/lake area, (grams/m2/year);

τ_w = hydraulic residence time (yr);

q_s = hydraulic overflow rate=mean depth /hydraulic residence time (m/yr)= $z/\tau_{w;}$

z = average depth (m)

Hydraulic residence time reflects the results of the water budget that Geosyntec calculated for the Mirror Lake Watershed.

$$\tau_w = Q/V$$

where:

Q = annual discharge passing through the lake (m^3/yr);

V = lake volume (m^3)

Annual discharge, Q, was calculated as discussed in Section 4 of this report. Volume, V, was estimated based on a bathymetry map prepared by NHDES in 2010 (see Appendix B). Table 2 below summarizes the parameters used in the Vollenweider calculation.

The Vollenweider equation contains an implicit assumption that particulate phosphorus becomes sequestered in lake sediment via settling to the lake bottom. The formula makes the assumption that settling velocity can be approximated as:

$$v = q_s\sqrt{\tau_w}$$

Typical measured values of settling velocity range from 5 to 20 m/yr (Chapra 1975). For Mirror Lake (q_s=3.04 m/yr, τ_w=1.41 yr),

$$v = q_s\sqrt{\tau_w} = 3.04\frac{m}{yr} \times \sqrt{1.41\ yr} = 3.61\ m/yr$$

or 3.61 m/yr (lower than the typical range). Using a low settling velocity value could lead to an erroneously high modeled in-lake P concentration. To provide a better representation of conditions specific to Mirror Lake, Geosyntec used an additional modeling approach (Nürnberg Model), discussed in Section 5.2 of this report.

Table 2: Vollenweider model parameters

VOLLENWEIDER MODEL PARAMETERS			
W	Total P Loading Rate	120	kg/yr
V	Volume	5,573,700	m3
z	Average Lake Depth	4.28	m
Q	Annual Discharge	3,950,380	m3/yr
As	Lake Area	1,301,900	m2
L	Areal Loading Rate	92.3	mg/m2
q_s	Hydraulic Overflow Rate (m/yr)	3.04	m/yr
τ_w	Hydraulic Residence Time (yr)	1.41	yr

$$\text{In-lake P concentration} = \frac{L_p}{\left(q_s\left(1+\sqrt{\tau_w}\right)\right)} = \frac{92.3}{3.04\left(1+\sqrt{1.41}\right)} = 13.9\ \mu g/L$$

Based on the estimated annual external phosphorus load of 265.4 lb/yr (120 kg/yr), the Vollenweider equation predicts an in-lake phosphorus concentration of 13.9 µg/L.

NHDES measurements of 2010 in-lake phosphorus concentrations suggest an average annual phosphorus concentration of 10.4 µg/L. The Vollenweider equation appears to overestimate the in-lake phosphorus concentration, most likely because the implicit assumption about settling velocity (noted above) is not applicable to a lake such as Mirror Lake. The Vollenweider model, including the settling velocity assumption, was developed based on a set of empirical data, within which much variation existed. While the assumptions may hold true over a large set of lakes, its predictive power for any individual lake may be limited. Additionally, the model only predicts one annual concentration, despite the fact that concentrations can vary seasonally. Because of these limitations, Geosyntec utilized a second modeling approach known as the Nürnberg Model.

5.2 Nürnberg Model

Nürnberg's model utilizes a parameter, R, which describes the fraction of sediment retained by the lake each year. This fraction is then applied to different subsets of the annual P load to determine an in-lake phosphorus concentration at various times of the year. Nürnberg estimates the value of R to be:

$$R = \frac{15}{18 + q_s}$$

For Mirror Lake, the estimate of R is:

$$R = \frac{15}{18 + 3.04} = 0.713$$

The Nürnberg model uses the following three equations to calculate an annual average P concentration (p_{ann}), a summer epilimnion P concentration (p_{epi}), and a fall P concentration (p_{fall}):

$$p_{ann} = \left[\frac{(L_{ext} + L_{int})}{q_s}\right](1 - R)$$

$$p_{epi} = \left[\frac{(L_{ext})}{q_s}\right](1 - R)$$

$$p_{fall} < \left[\frac{(L_{ext})}{q_s}\right](1 - R) + \frac{L_{int}}{q_s}$$

The three equations describe a situation where the retention factor, R, is applied to different combinations of internal and external P load to represent in-lake conditions during various seasons of interest. For an annual average, the retention factor is applied to the complete annual load, as the internal load will be able to mix throughout the year and be available for uptake, settling, and flushing. The retention factor is applied to the external load only to obtain a summer epilimnion concentration, when any internal P loading is sequestered in the hypolimnion during stratification and is not available for uptake, settling, and flushing. Finally, the internal load is added to the epilimnion concentration and only subjected to flushing (by being divided by q_s, the hydraulic overflow rate) to represent the relatively rapid mixing of the pulse of soluble phosphorus from the hypolimnion into the epilimnion during fall turnover (Nürnberg states that this third equation will tend to overestimate actual fall epilimnion concentrations).

The Nürnberg model parameters and results for current (2010) conditions are provided below:

Table 3. Nürnberg Model Parameters

NÜRNBERG MODEL PARAMETERS			
W_{ext}	External P Loading Rate	120	kg/yr
W_{int}	Internal P Loading Rate	21.6	kg/yr
V	Volume	5,573,700	m^3
Q	Annual Discharge	3,950,380	m^3/yr
As	Lake Area	1,301,900	m^2
L_{ext}	External Areal Loading Rate	92.3	mg/m^2
L_{int}	Internal Areal Loading Rate	19.0	mg/m^2
R	Retention Factor	0.713	
q_s	Hydraulic Overflow Rate (m/yr)	3.04	m/yr

$$p_{ann} = \left[\frac{(L_{ext} + L_{int})}{q_s}\right](1 - R) = \left[\frac{(92.3 + 19.0)}{3.04}\right](1 - 0.713) = 10.5\ \mu g/L$$

$$p_{epi} = \left[\frac{(L_{ext})}{q_s}\right](1 - R) = \left[\frac{(92.3)}{3.04}\right](1 - 0.713) = 8.7\ \mu g/L$$

$$p_{fall} < \left[\frac{(L_{ext})}{q_s}\right](1 - R) + \frac{L_{int}}{q_s} = \left[\frac{(92.3)}{3.04}\right](1 - 0.713) + \frac{19.0}{3.04} = 15.0\ \mu g/L$$

Figure 12 shows the above model results plotted against 2010 epilimnion (3m deep) phosphorus concentrations measured by NHDES. The Nürnberg results match well with the annual and summer observed averages, and as Nürnberg, the p_{fall} model result overestimates the actual observed fall average.

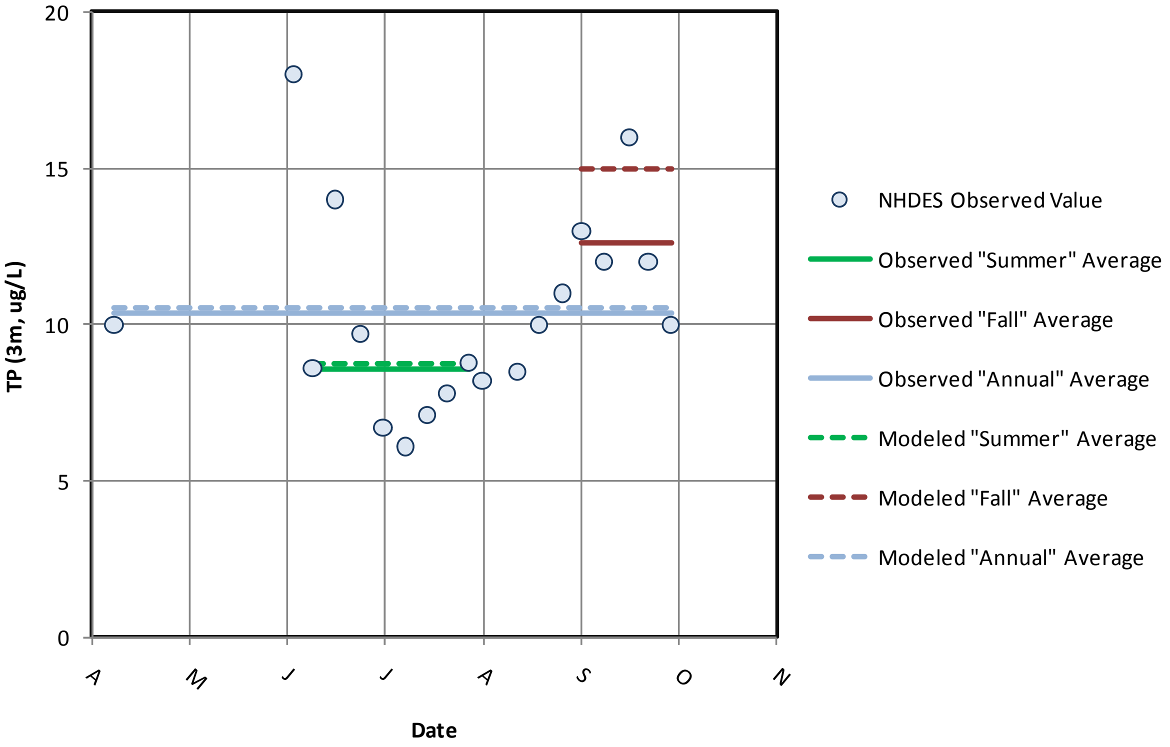


Figure 12. Nürnberg model results vs. observed epilimnion data for year 2010.

5.3 Monte Carlo Simulation

A Monte Carlo Simulation is a technique in which a deterministic model, such as the Vollenweider model or Nürnberg model discussed above, is repeatedly re-calculated using unique sets of randomly selected input variables. The resulting distribution of results can be used to assign likelihoods and uncertainties to model results.

A Monte Carlo simulation was performed for the Vollenweider and Nürnberg models of Mirror Lake phosphorus concentrations. Table 4 describes the various model input parameters that were randomly adjusted, and the distribution that was used to select the values of those parameters.

The selection of parameters adjusted in the simulation effect almost all aspects of the phosphorus dynamics. Not only are external phosphorus loads varied by adjusting phosphorus EMC values, aerial deposition rates, and septic system loading factors, but physical flushing is also affected by adjustment of precipitation values, thereby varying the hydrologic budget for the lake.

Table 4. Monte Carlo Simulation Input Parameters

Input Parameter	Distribution Type	Unit	Mean	Standard Deviation	Min.	Max.	Source
Precipitation	Normal	inches	43.05	5.84	-	-	1
Aerial Deposition Rate	Normal	lb/ac/yr	0.24	0.11	-	-	2
EMC - Forest	Normal	mg/L	0.12	0.02	0	-	3,4,8
EMC – Open	Normal	mg/L	0.11	0.06	0	-	3,6,7,8
EMC – Pasture	Normal	mg/L	0.31	0.12	0	-	3,4,6,7,8
EMC – Recreation	Normal	mg/L	0.11	0.06	0	-	3,6,7,8
EMC – Residential	Normal	mg/L	0.27	0.09	0	-	3,5,6,7,8
EMC - Road	Normal	mg/L	0.14	-	-	-	3
EMC – Spray Field	Normal	mg/L	0.17	0.08	0	-	9
EMC – Wetland	Normal	mg/L	0.11	0.07	0	-	3,6,8
Per Capita Water Use	Lognormal	gal/day	69.3	39.6	-	-	10
Concentration of P in Wastewater	Normal	mg/L	10	1	-	-	10,11,12
P Reduction Factor for Septic Systems	Normal	-	0.94	0.033	-	1	13,14,15
Buildout: Land Use	Uniform	lb/yr	10.65	-	0	21.3	-
Buildout: Septic Load	Uniform	lb/yr	2.28	-	0	4.56	-

Source:

1. National Climate Data Center
2. Reckhow (1975)
3. NHDES Stormwater Manual
4. STEP-L Model
5. NSWQ Database
6. Lin 2004
7. Adamus and Bergman
8. Philadelphia Water Department
9. NHDES Consent Order to Wolfeboro WWTP
10. EPA Onsite Wastewater Treatment Systems Manual
11. Gillom and Patmont, 1983
12. Barnstable County Health Department
13. Sikora et. al. 1976
14. Kerfoot and Skinner
15. Jones and Lee

Figure 13 below displays the results of the current-conditions Monte Carlo Simulation. The simulation was run for 1000 iterations, and results were tabulated for the Vollenweider model P concentration and the Nürnberg P_{ann}, P_{epi}, and P_{fall} concentrations. The boxes of the box/whisker plots shown below represent the range which included 50% of the model iterations. The whiskers represent the range into which 80% of the model iterations fell. The Monte Carlo simulation results indicate that 50% of the possible modeled summer epilimnion concentrations (P_{epi}) fell within the range of 7.7 to 9.8 ug P/L. Half of the modeled annual average P concentrations (P_{ann}) fell within a range of 9.3 to 11.4 ug P/L.

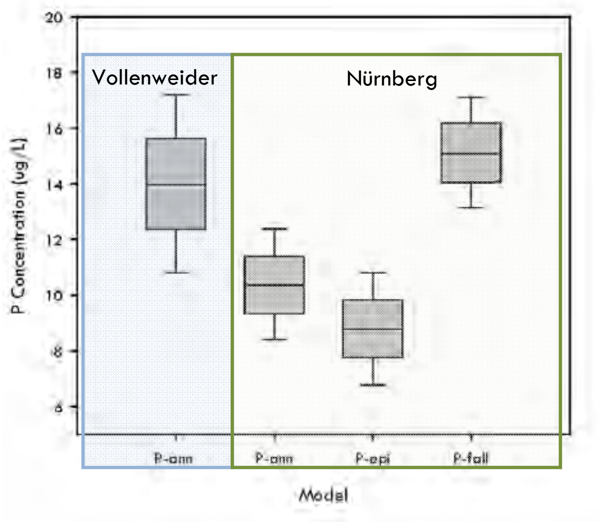


Figure 13. Box/whisker plots representing Monte-Carlo results for current conditions as estimated by the Vollenweider and Nürnberg models.

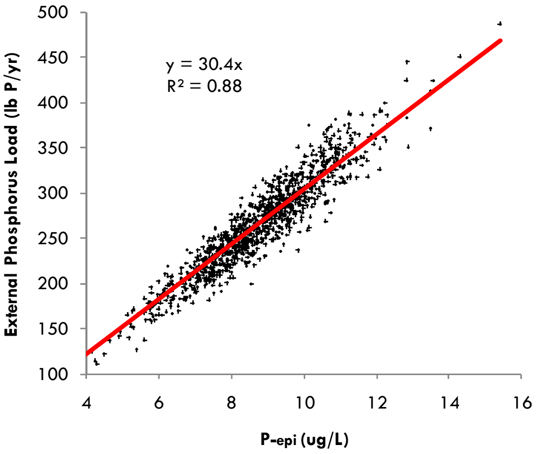


Figure 14. Nürnberg p_{epi} Monte-Carlo results scatter-plot and linear regression

The results of the Monte Carlo current-conditions simulation can also be used to form a relationship between external load and in-lake concentration. A linear regression was performed on the Nürnberg P_{epi} Monte Carlo simulation results. As shown in Figure 14, the linear regression suggests that every increase or decrease of 30.4 lb P/yr of the external P load will result in a corresponding increase or decrease of 1 ug P/L in the summer epilimnion concentration.

The Monte-Carlo analysis was also run for year 2030 buildout conditions (as described in Section 3.6). In this case, the additional external load from potential buildout was also varied along with the other model parameters. Figure 15 below shows box/whisker plots comparing the results of the current and buildout Monte-Carlo results. The results predict that, according to Vollenweider, in-lake concentrations at 2030 buildout will most likely increase by 0.9 µg/L, and according to Nürnberg, will most likely increase by 0.6 µg/L. While 50% of the modeled external loads during current conditions fell between 231 and 301 lb/yr, 50% of the modeled external loads for the 2030 buildout fell between 245 and 317 lb/yr.

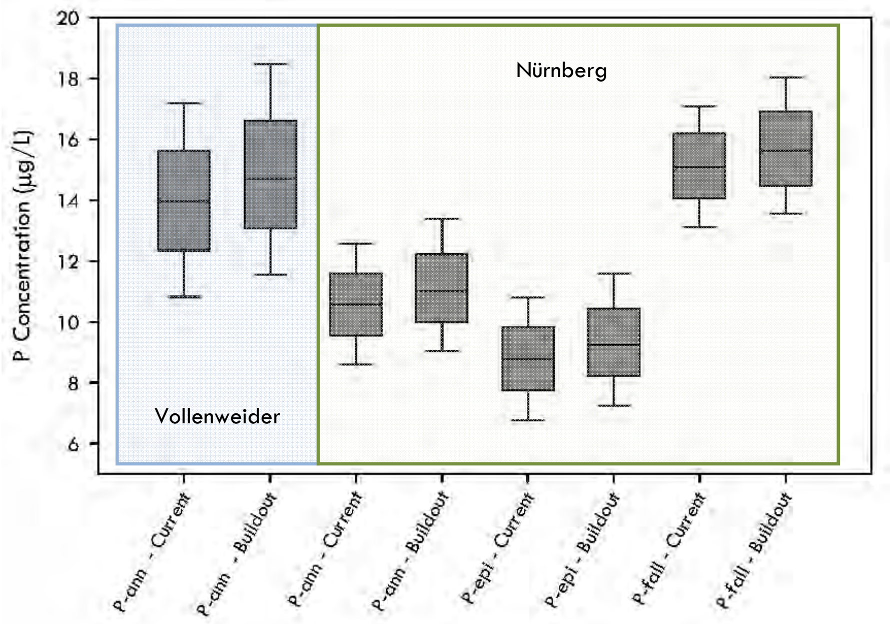


Figure 15. Current conditions and year 2030 buildout conditions box/whisker plots for the Vollenweider and Nürnberg models.

5.4 Nürnberg Modeling Scenarios and Water Quality Goal

Sections 7.1 - 7.3 provide a detailed discussion of the modeling approach used to estimate current phosphorus loads and in-lake concentrations, as well as potential future phosphorus loads. Geosyntec also used the Nürnberg model to analyze several loading scenarios in order to provide a framework for understanding the range of possible in-lake concentrations, and to aid in the selection of the MLPA's water quality goal. The scenarios analyzed include pre-development forested conditions with a variety of internal loads, as well as current conditions with a range of phosphorus loads deriving from the WWTP spray fields. Table 5 below summarizes the results of the various scenarios, with additional information (i.e. phosphorus load charts) for each model scenario provided on the pages that follow.

Geosyntec worked in cooperation with the MLPA water quality advisory committee and NHDES staff to analyze existing data and the modeling scenarios presented below for the purpose of establishing a water quality goal for Mirror Lake. This process has included:

- Gathering and review of water quality data from NHDES and the UNH-VLAP programs, including meetings, phone discussions and sharing of information via mail and email;
- Public meetings held at the Tuftonboro Old Town House on 6/26/2010 and 10/16/2010 to discuss data trends and analysis with regard to historic and current lake phosphorus concentrations; and
- A teleconference including the MLPA water quality advisory committee, Geosyntec staff, and NHDES staff on 2/11/2011discuss the modeling scenarios and reach consensus on a water quality goal for in-lake phosphorus.

Based on the 2/11/2011 teleconference and preceding discussions described above, the MLPA has adopted a water quality goal of a summer epilimnion P concentration of 8.5 µg/L. P concentrations below 10 µg/L are considered low enough to preclude summer cyanobacteria blooms in most lakes.

Table 5: Nürnberg Model Results

Scenario	Assumptions	Phosphorus Budget (lb/yr)		Predicted Total Phosphorus (µg/L)		
		External Load	Internal Load	Annual whole lake mean (p-ann)	Summer epilimnetic mean (p-epi_summer)	Fall epilimnetic maximum (p-epi_fall)
Example 1: Current Conditions	• External P load based on current conditions. • Internal P load based on current conditions.	265.4	54.4	10.53	8.74	14.99
Example 2a: Full Effluent Spray Field Operation	• External P load based on current land use conditions plus an estimated avg. additional load from full effluent spray field operation. • Internal P load based on current conditions.	287.7	54.4	11.27	9.48	15.72
Example 2b: Spray Field Effects Eliminated	• External P load assumes residual effects of spray fields have been eliminated (area converted to forest). • Internal P load based on current conditions.	264.8	54.4	10.52	8.72	14.97
Example 3: Undeveloped Watershed; Current Internal Load	• External P load assumes all watershed land uses are forest or wetland. • Internal P load based on current conditions.	156.7	54.4	6.95	5.16	11.41
Example 4: Undeveloped Watershed; 50% Internal Load	• External P load assumes all watershed land uses are forest or wetland. • Internal P load assumes current load reduced by 50%.	156.7	27.2	6.06	5.16	8.28
Example 5: Undeveloped Watershed, No Internal Load	• External P load assumes all watershed land uses are forest or wetland. • Assumes no internal P loading.	156.7	0	5.16	5.16	5.16
Example 6: 10% Reduction from BMPs	• External P load assumes (1) effects of spray fields have been eliminated and (2) 10% reduction in residential, road and septic load due to BMPs. • Internal P load based on current conditions.	253.0	54.4	10.13	8.34	14.58
Example 7: Future Conditions (year 2030)	• External P load assumes (1) land use and septic system changes discussed in "Future Conditions Analysis" section and (2) residual effects of spray fields have been eliminated. • Internal P load based on current conditions.	291.8	54.4	11.39	9.59	15.84
				Range: 5.16 – 11.39	**Range:** 5.16 – 9.59	**Range:** 5.16 – 15.72

Table 5 Notes:

1. Mirror Lake is categorized by NHDES as a mesotrophic lake. The NHDES total phosphorus (TP) criteria for mesotrophic lakes is 8 - 12 µg/L (based on "summer" epilimnetic median for the period of May 24 – Sept. 15).

2. Mirror Lake's 2010 summer (May 24-Sept. 15) epilimnetic median was 9.25 µg/L , based on NHDES data. The 2010 fall epilimnetic (non-stratified, Oct. 10) concentration was 13.6 µg/L . The 2010 mean spring whole lake (non-stratified, April 10) concentration was 10.35 µg/L .

3. The median summer TP concentration for "unimpaired" NH lakes is 9.0 µg/L , based on an assessment of 233 lakes (NHDES, 2009). This assessment included all impairments that would trigger inclusion on the Section 303(d) Impaired Waters list, including primary contact recreation impairment due to cyanobacteria. 80% of all unimpaired lakes had median summer TP levels below 11.5 µg/L .

4. Cyanobacteria and toxins produced by bacteria (e.g. microcystins) have been found to be ubiquitous in New Hampshire lakes of all types and trophic classes. In a study of over 50 New Hampshire lakes (Haney and Ikawa (2001), all of the lakes had detectable quantities of microcystins. The lakes investigated were distributed throughout New Hampshire, including the southern, coastal plain, western rural, White Mountains lakes region and the Northern Forest regions. The study lakes represented a wide range of sizes, depth and trophic conditions, from ultra-oligotrophic to eutrophic lakes.

5. Dr. James Haney at the University of New Hampshire have developed the "Tens Rule", which suggests that lakes should avoid total phosphorus concentrations above 10 µg/L since it appears that eutrophication rates and toxicity of phytoplankton increase markedly at this level (Haney, 2010). The "Tens Rule" is based on Haney's ongoing research, and publications on the topic: Sasner (date not specified), Haney and Ikawa (2000), EPA (2000), and Haney and Ikawa (2001). Data presented in these publications indicate that the microcystin concentration in lake phytoplankton, which is a measure of toxicity, increases sharply at mean summer epilimnetic TP concentration of 9.5 µg/L.

6. The Maine Department of Environmental Protection set a limit of 15 µg/L total phosphorus in lakes in its *Description of Nutrient Criteria for Fresh Surface Waters (Chapter 583)* (2009). This threshold concentration is "based on the prevention of nuisance algal blooms" and is derived from an empirical analysis of a state-wide limnological database.

7. In 2009, the Wisconsin Department of Natural Resources published a guide that covers physical and chemical compositions of different trophic classes of lakes. This guide states that "a concentration of total phosphorus below 20 µg/L for lakes, and 30 µg/L for impoundments, should be maintained to prevent nuisance algal blooms."

8. In 2010, the International Joint Commission published the *Beneficial Use Impairment Delisting Targets – Savern Sound, Ontario*, which set a TP goal stating "a total phosphorus concentration that limits the growth of algae should be no more than 10-20 µg/L ".

EXAMPLE #1:

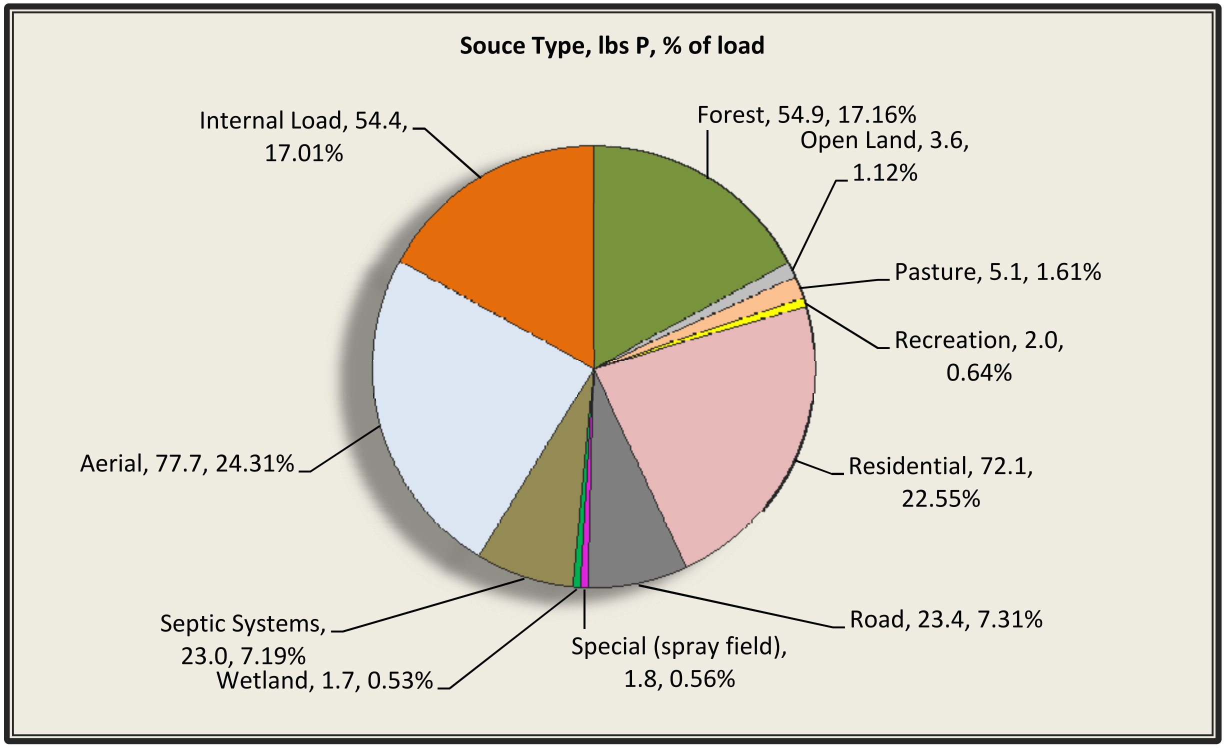
Sources:	lb/yr
Forest	54.9
Open Land	3.6
Pasture	5.1
Recreation	2.0
Residential	72.1
Road	23.4
Special (spray field)	1.8
Wetland	1.7
Septic Systems	23.0
Aerial	77.7
Internal Load	54.4

Nürnberg Model Results	
p-ann	**10.53 ug/L**
p-epi (summer)	**8.74 ug/L**
p-fall	**14.99 ug/L**

Assumptions:

1. External P load (265.4 lb/yr) based on current conditions.

2. Internal P load (54.4 lb/yr) based on current conditions.



EXAMPLE #2a:

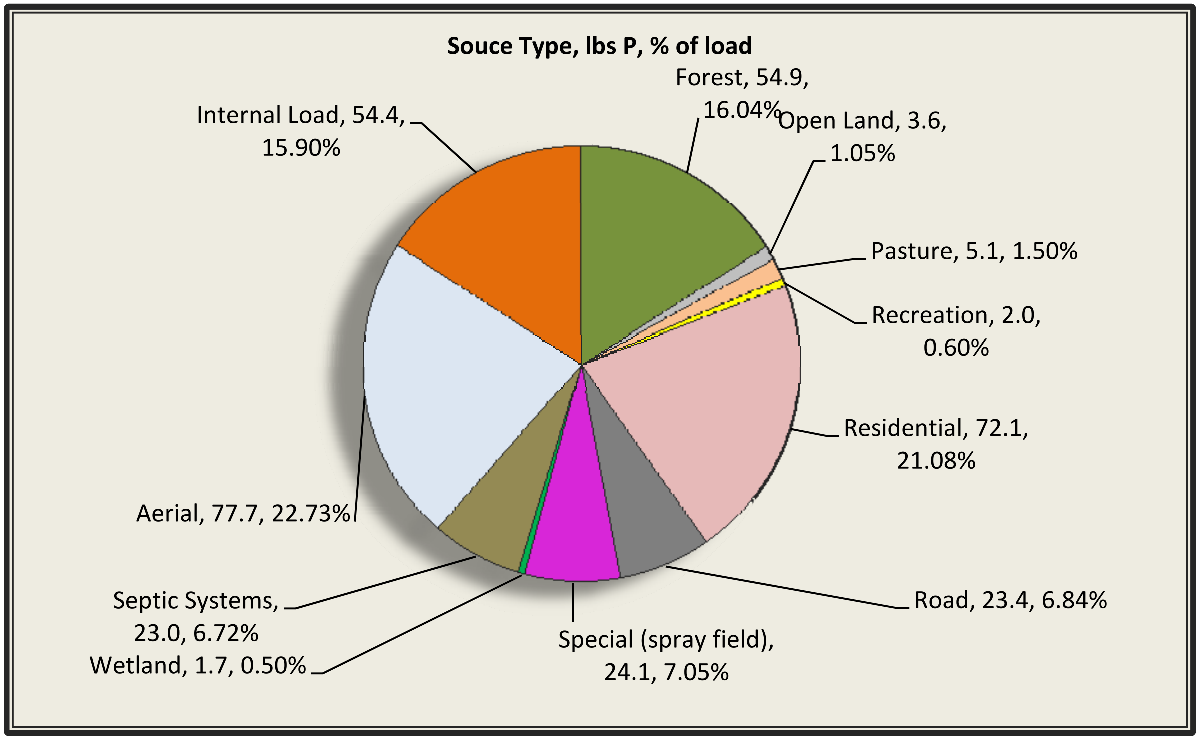
Sources:	lb/yr
Forest	54.9
Open Land	3.6
Pasture	5.1
Recreation	2.0
Residential	72.1
Road	23.4
Special (spray field)	24.1
Wetland	1.7
Septic Systems	23.0
Aerial	77.7
Internal Load	54.4

Nürnberg Model Results	
p-ann	**11.27 ug/L**
p-epi (summer)	**9.48 ug/L**
p-fall	**15.72 ug/L**

Assumptions:

1. External P load (287.7 lb/yr) based on estimated average during full effluent spray field operation.

2. Internal P load (54.4 lb/yr) based on current conditions.



EXAMPLE #2b:

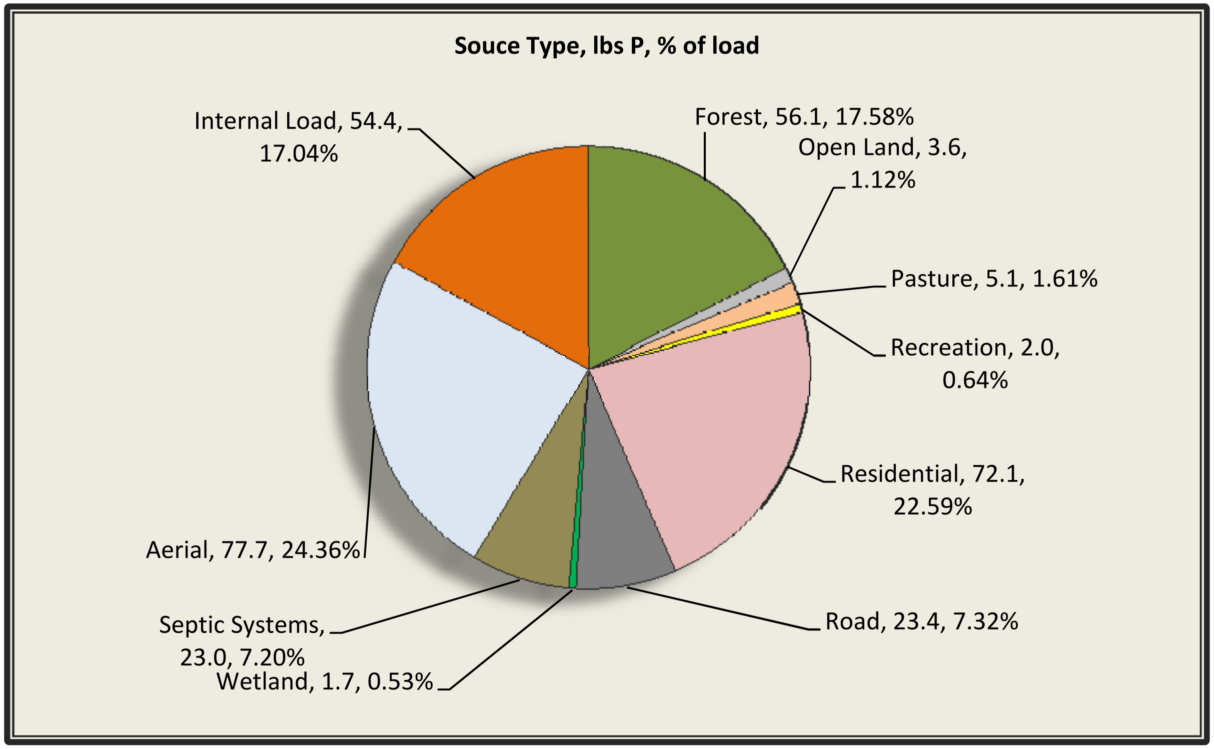
Sources:	lb/yr
Forest	56.1
Open Land	3.6
Pasture	5.1
Recreation	2.0
Residential	72.1
Road	23.4
Special (spray field)	0.0
Wetland	1.7
Septic Systems	23.0
Aerial	77.7
Internal Load	54.4

Nürnberg Model Results		
p-ann	**10.52**	**ug/L**
p-epi (summer)	**8.72**	**ug/L**
p-fall	**14.97**	**ug/L**

Assumptions:

1. External P load (264.8 lb/yr) assumes all residual effects of spray fields have been eliminated (area converted to forest).

2. Internal P load (54.4 lb/yr) based on current conditions.



EXAMPLE #3:

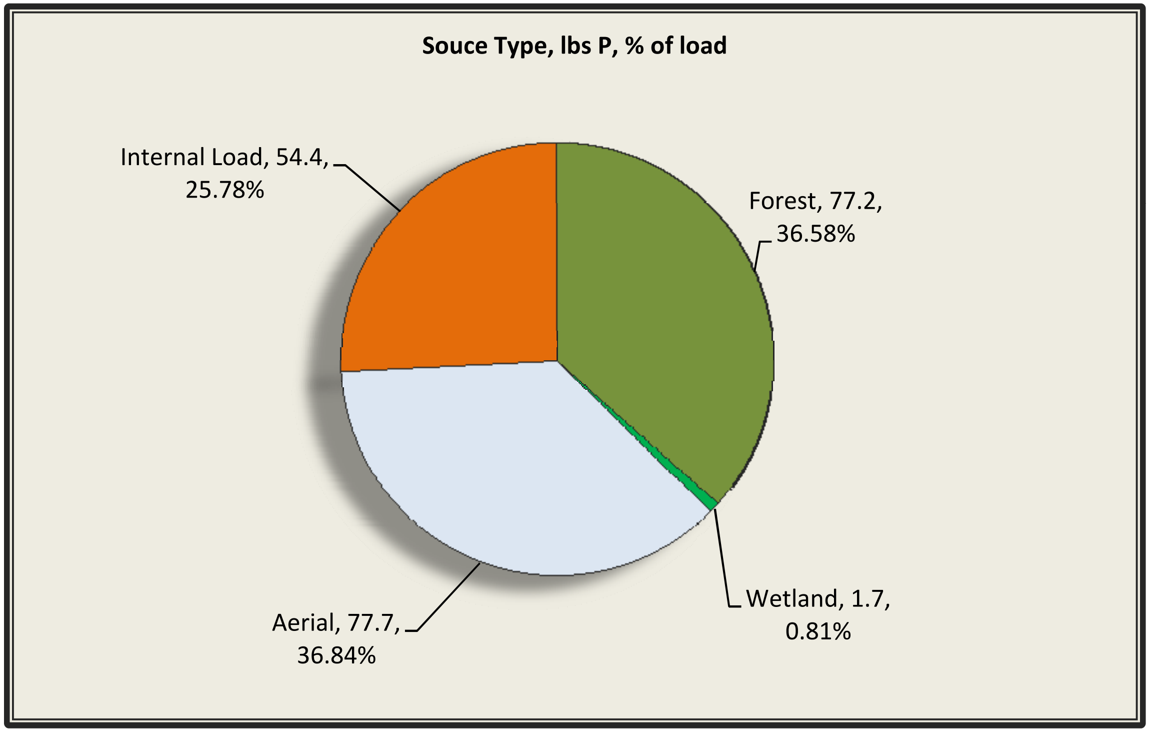
Sources:	lb/yr
Forest	77.2
Open Land	0.0
Pasture	0.0
Recreation	0.0
Residential	0.0
Road	0.0
Special (spray field)	0.0
Wetland	1.7
Septic Systems	0.0
Aerial	77.7
Internal Load	54.4

Nürnberg Model Results	
p-ann	**6.95 ug/L**
p-epi (summer)	**5.16 ug/L**
p-fall	**11.41 ug/L**

Assumptions:

1. External P load (156.6 lb/yr) assumes all watershed land uses are either forest or wetland.

2. Internal P load (54.4 lb/yr) based on current conditions.



EXAMPLE #4:

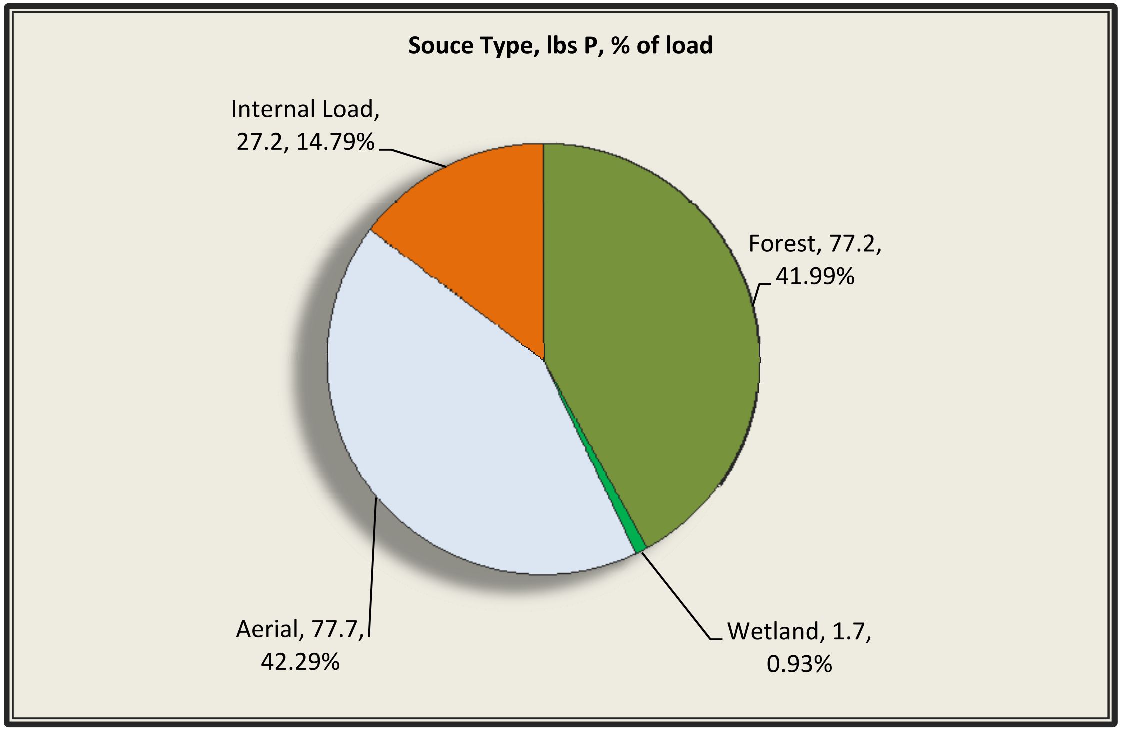
Sources:	lb/yr
Forest	77.2
Open Land	0.0
Pasture	0.0
Recreation	0.0
Residential	0.0
Road	0.0
Special (spray field)	0.0
Wetland	1.7
Septic Systems	0.0
Aerial	77.7
Internal Load	27.2

Nürnberg Model Results	
p-ann	**6.06 ug/L**
p-epi (summer)	**5.16 ug/L**
p-fall	**8.28 ug/L**

Assumptions:

1. External P load (156.6 lb/yr) assumes all watershed land uses are either forest or wetland.

2. Internal P load (27.2 lb/yr) assumes current load reduced by 50%.



EXAMPLE #5:

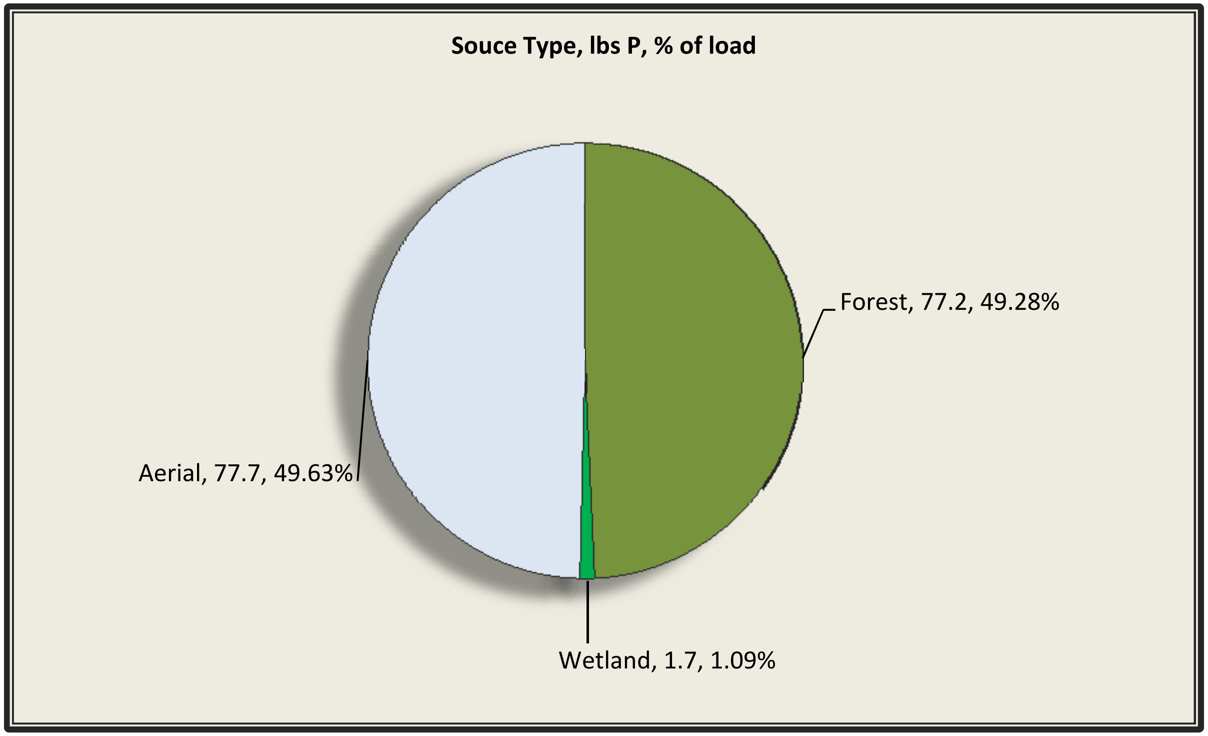
Sources:	lb/yr
Forest	77.2
Open Land	0.0
Pasture	0.0
Recreation	0.0
Residential	0.0
Road	0.0
Special (spray field)	0.0
Wetland	1.7
Septic Systems	0.0
Aerial	77.7
Internal Load	0

Nürnberg Model Results	
p-ann	**5.16 ug/L**
p-epi (summer)	**5.16 ug/L**
p-fall	**5.16 ug/L**

Assumptions:

1. External P load assumes all watershed land uses are forest or wetland

2. Assumes no internal P loading



EXAMPLE #6:

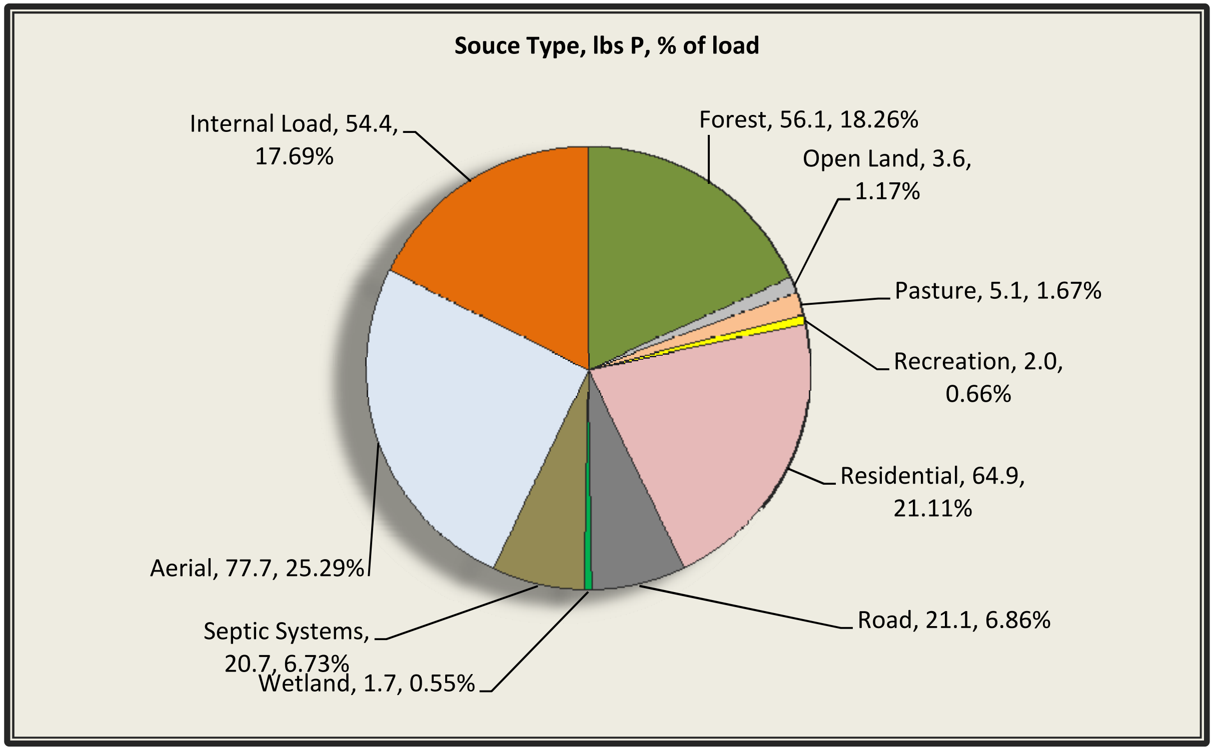
Sources:	lb/yr
Forest	56.1
Open Land	3.6
Pasture	5.1
Recreation	2.0
Residential	64.9
Road	21.1
Special (spray field)	0.0
Wetland	1.7
Septic Systems	20.7
Aerial	77.7
Internal Load	54.4

Nürnberg Model Results	
p-ann	**10.13 ug/L**
p-epi (summer)	**8.34 ug/L**
p-fall	**14.58 ug/L**

Assumptions:

1. External P load (253.0 lb/yr) assumes (1) all residual effects of spray fields have been eliminated (area converted to forest), (2) 10% reduction in load from residential, road and septics due to BMPs.

2. Internal P load (47.6 lb/yr) based on current conditions.



EXAMPLE #7:

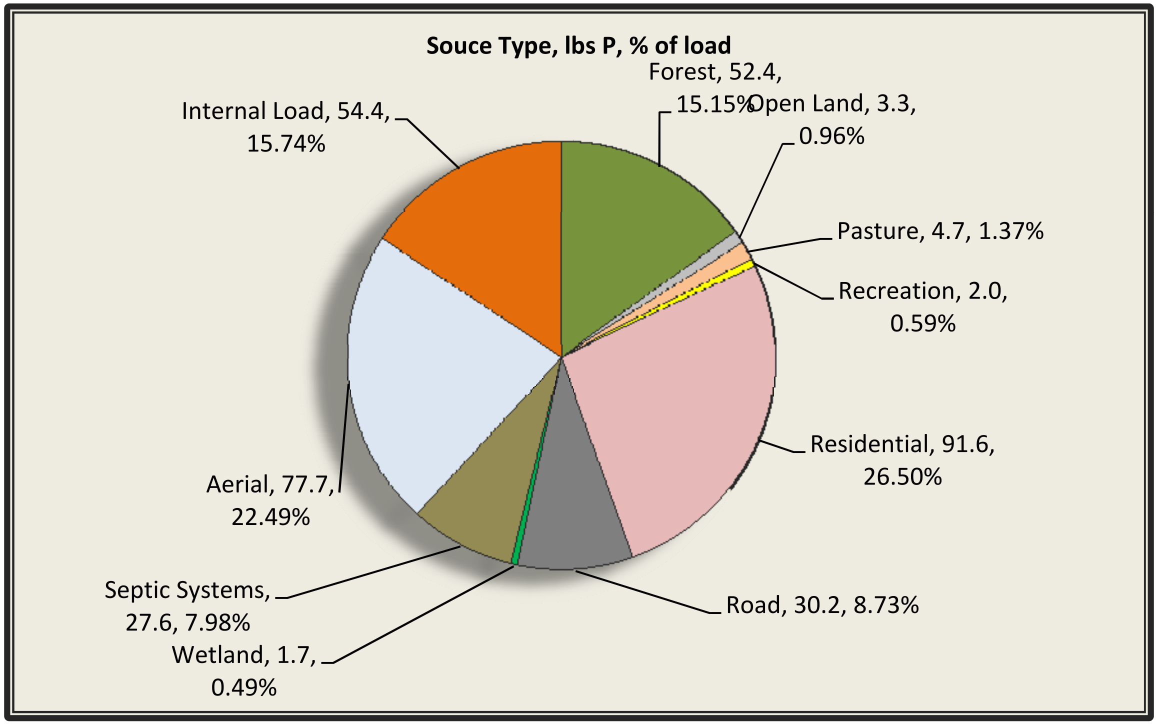
Sources:	lb/yr
Forest	52.4
Open Land	3.3
Pasture	4.7
Recreation	2.0
Residential	91.6
Road	30.2
Special (spray field)	0.0
Wetland	1.7
Septic Systems	27.6
Aerial	77.7
Internal Load	54.4

Nürnberg Model Results	
p-ann	**11.39 ug/L**
p-epi (summer)	**9.59 ug/L**
p-fall	**15.84 ug/L**

Assumptions:

1. External P load (291.8 lb/yr) assumes (1) all residual effects of spray fields have been eliminated and (2) future development conditions based on 2030 buildout scenario.

2. Internal P load (47.6 lb/yr) based on current conditions.



As depicted in Figure 16 below, an annual P reduction of approximately 7.4 lb/yr will be adequate to achieve the water quality goal of summer epilimnion concentrations of 8.5 µg/L. However, based on buildout projections, it will be necessary to either prevent or reduce future loads by an additional 26.4 lb/yr (total of 33.8 lb/yr) in order to maintain the water quality goal in the year 2030.

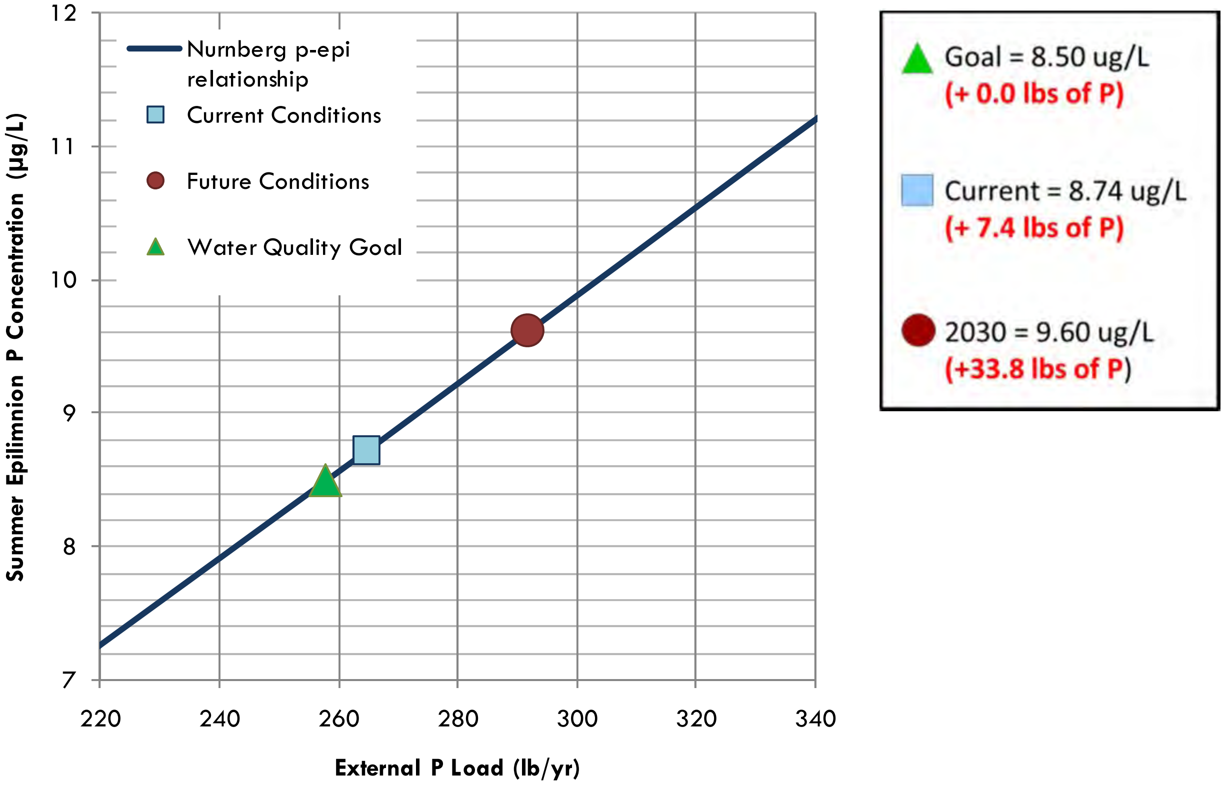
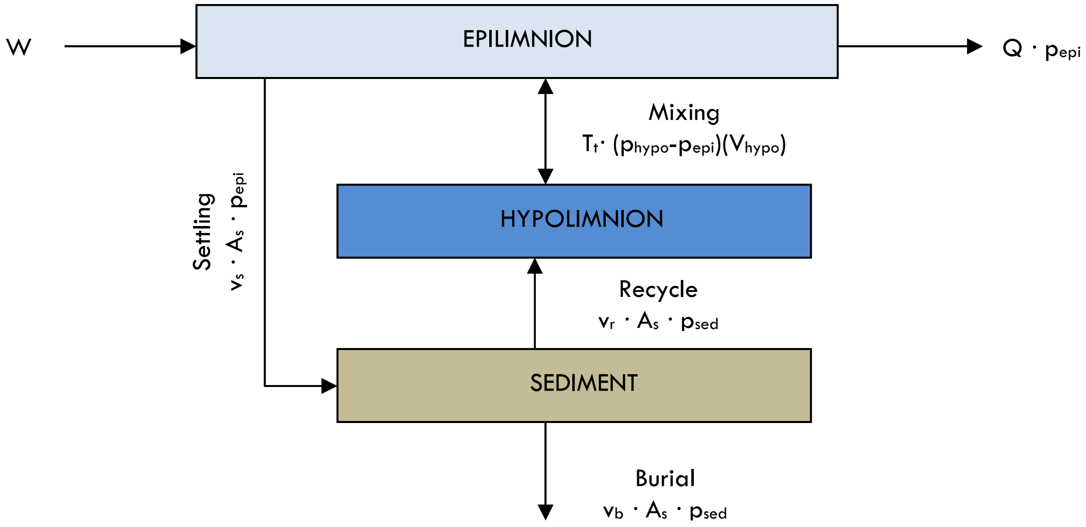


Figure 16. Current and Future conditions compared to water quality goal.

5.5 Additional Modeling: Dynamic Mass Balance Model

Several questions about in-lake dynamics cannot be adequately answered using the steady-state Vollenweider or Nürnberg models. For instance, if external phosphorus loads are reduced, how long will it take for the internal load to respond and establish a new equilibrium? Time-dependant issues such as these can only be addressed by a dynamic, rate-dependant model.

Geosyntec has developed a 3-compartment mass balance model to describe phosphorus dynamics within Mirror Lake. This approach is based on a sediment-water interaction model presented by Chapra (1997). The lake is represented by an epilimnion (surface waters) component, a hypolimnion (deep waters) component, and a sediment component. Phosphorus transfer between these compartments is quantified by various fluxes. In most cases, a flux is estimated as being proportional to the phosphorus concentration of the compartment from which is derives. For instance, if the phosphorus concentration in the sediment is high, then the phosphorus recycling rate (the internal load) will also be high. The three equations used to calculate the phosphorus concentrations within the various compartments are presented below.



$$V_{epi}\frac{dp_{epi}}{dt} = W - (Q \cdot p_{epi}) - (v_s \cdot A_s \cdot p_{epi}) + [T_t \cdot (p_{hypo} - p_{epi})(V_{hypo})]$$

$$V_{hypo}\frac{dp_{hypo}}{dt} = T_{anox}(v_r \cdot A_s \cdot p_{sed}) - [T_t \cdot (p_{hypo} - p_{epi})(V_{hypo})]$$

$$V_{sed}\frac{dp_{sed}}{dt} = (v_s \cdot A_s \cdot p_{epi}) - T_{anox}(v_r \cdot A_s \cdot p_{sed}) - (v_b \cdot A_s \cdot p_{sed})$$

Where:

V_{epi}, V_{hypo}, V_{sed} = volume of epilimnion, hypolimnion, and sediment, respectively;

p_{epi}, p_{hypo}, p_{sed} = phosphorus concentration of epilimnion, hypolimnion, and sediment, respectively;

W = external phosphorus load

Q = hydrologic flowrate

v_s = settling velocity

A_s = area of sediment

T_t = time of turnover, if true, a value of 1, if false, a value of 0

T_{anox} = time period of anoxia, if true, a value of 1, if false, a value of 0

v_r = recycle velocity

v_b = burial velocity

In order to perform the calculation, the derivative portions of the above equations are approximated as a finite difference. The concentrations at time i are calculated based on the concentrations at the previous time, i-1.

$$p_{epi,i} = p_{epi,i-1} + \left[\frac{W - (Q \cdot p_{epi}) - (v_s \cdot A_s \cdot p_{epi}) + [T_t \cdot (p_{hypo} - p_{epi})(V_{hypo})]}{V_{epi}}\right] \cdot \Delta t$$

$$p_{hypo,i} = p_{hypo,i-1} + \left[\frac{T_{anox}(v_r \cdot A_s \cdot p_{sed}) - [T_t \cdot (p_{hypo} - p_{epi})(V_{hypo})]}{V_{hypo}}\right] \cdot \Delta t$$

$$p_{sed,i} = p_{sed,i-1} + \left[\frac{(v_s \cdot A_s \cdot p_{epi}) - T_{anox}(v_r \cdot A_s \cdot p_{sed}) - (v_b \cdot A_s \cdot p_{sed})}{V_{sed}}\right] \cdot \Delta t$$

Parameter estimation methods for each of the terms described above are discussed further in Appendix C. The parameters of the model were calibrated to first allow for steady-state conditions to exist, assuming that the external load (W) was equal to a "forested" condition (156.7 lb/yr, Table 5, Example 3). Between 1870 and 2010, the external load was increased linearly from 156.7 lb/yr to 265.4 lb/yr (Table 5, Example 1) to represent development occurring in the watershed over that time. Also, the maximum amount of additional load from the spray field was applied between 1978 and 2010 (24 lb/yr; i.e. 23.5 lb as in Section 3.5 and 0.5 lb from land use runoff (difference between loading from spray field and forested condition)). Figure 17 below shows the modeled epilimnion and hypolimnion concentrations from 1970 to 2060. The graph shows that there is a response time from the time a load is reduced (i.e. 24 lb/yr from spray field effects are removed) to the time the lake reaches a new equilibrium. In this case, the removal of the spray field requires roughly 10 years (from 2010 to 2020) to achieve its full effect in reducing the lake's P concentration.

The model results were also compared to the 2010 epilimnion and hypolimnion data collected by NHDES. Figure 18 shows the model results compared to the actual measured results. Qualitatively, the epilimnion concentration tracks well along the central tendency of the measured epilimnion values. The spike in hypolimnion concentration due to internal loading is also represented well by the model. Figure 19 shows the model results compared to a longer record of epilimnion data collected by UNH. The dashed line represents the linear trend in the observed epilimnion concentrations.

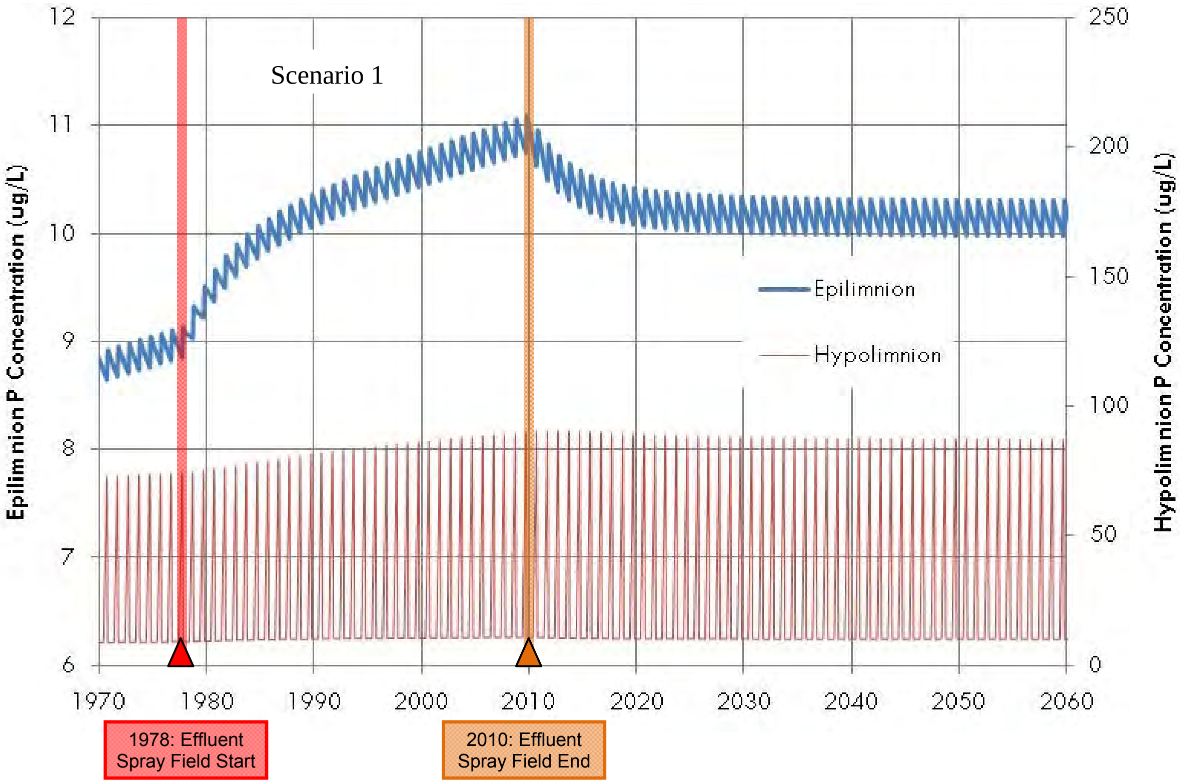


Figure 17. Modeled epilimnetic and hypolimnetic concentrations, 1970 to 2060, assuming spray field loads removed in 2010 and no new development in watershed.

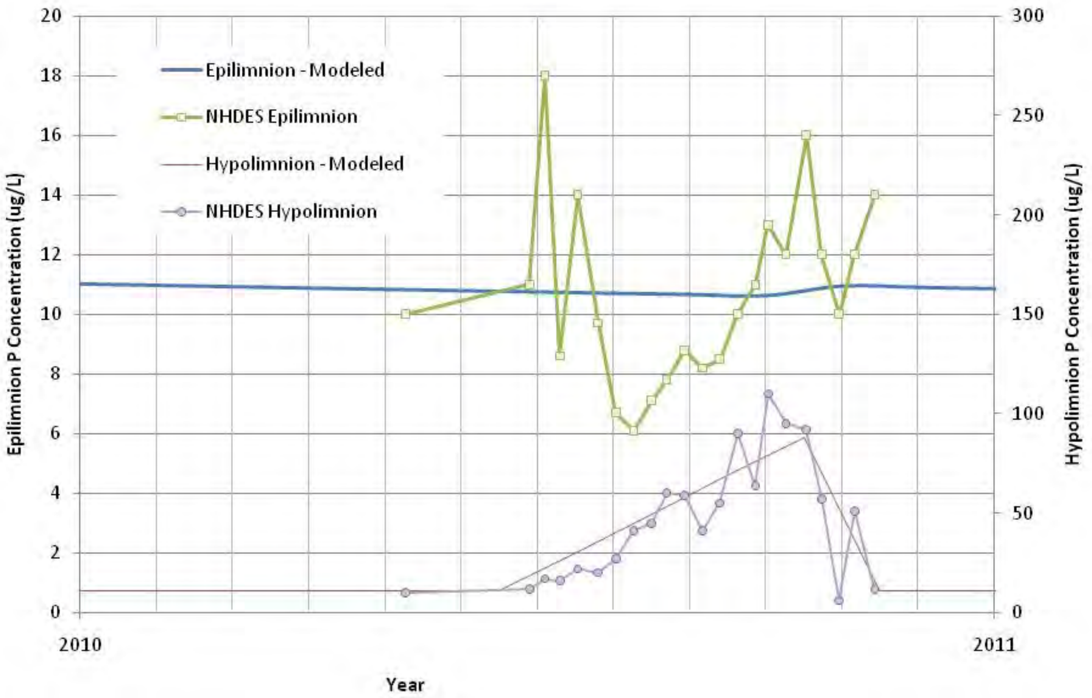


Figure 18. Modeled epilimnetic and hypolimnetic concentrations for 2010, and observed epilimnetic and hypolimnetic concentrations (data collected by NHDES).

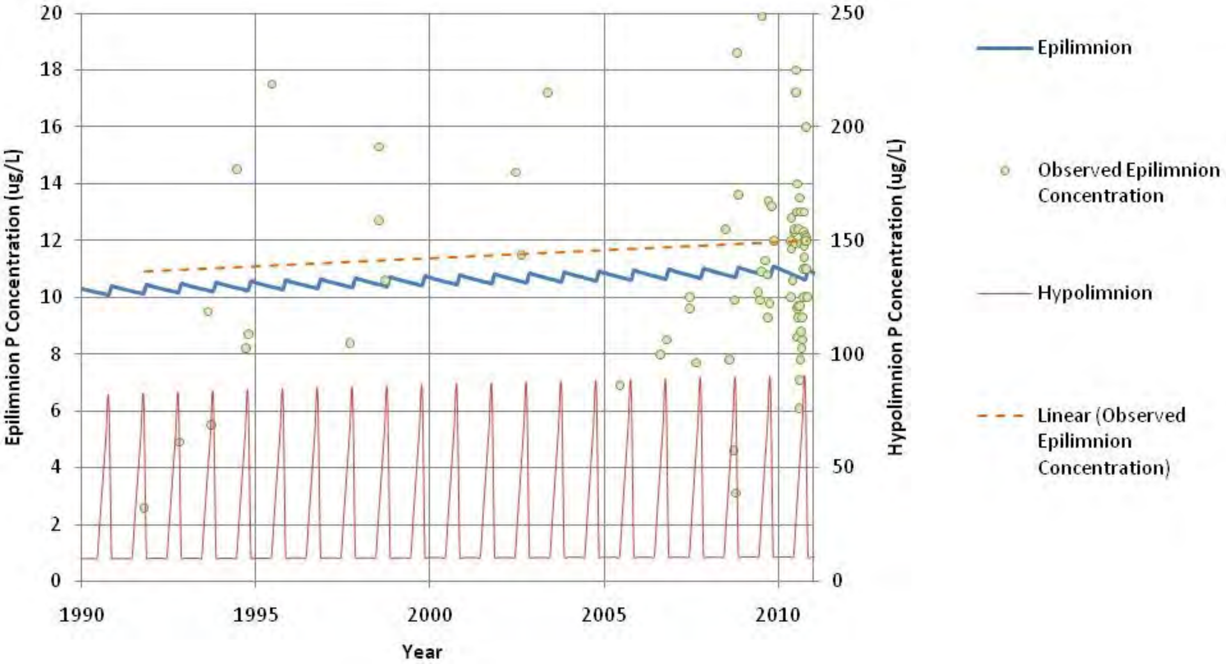


Figure 19. Modeled epilimnetic and hypolimnetic concentrations for 1990-2010, and observed epilimnetic concentrations (data collected by NHDES and UNH).

In terms of the internal load results, the model indicates that under a "forested" condition, the minimum possible internal load for Mirror Lake is 28.6 lb/yr. For comparison, the modeled internal load for 2010 is 50.2 lb/yr, and the observed internal load for 2010 is 54.4 lb/yr. After the loading from the spray fields is removed and the lake has reached a new equilibrium (after approximately 20 years), the total internal load is only expected to be reduced by roughly 1 lb/yr, which is 2.0% of the total internal load, or 4.6% relative to the minimum background internal load of 28.6 lb/yr.

Figure 20 below shows the results of increasing the external load from 265.4 lb/yr in 2010 to 291.8 lb/yr in 2030, representing the future conditions buildout loading (see Table 5, Examples 1 and 7). Under this scenario, the internal load will increase to 53.1 lb/yr, an increase of 5.8% relative to the modeled 2010 internal load.

Finally, the option of sewering or community septic systems is investigated by removing the septic system load. For modeling purposes, the year 2030 was chosen for the date when this load would be removed. The scenario depicted in Figure 21 assumes that an aggressive watershed protection policy has prevented the loading increases due to future buildout. Once again, the time between removal of the load and the time when epilimnion concentrations stabilize is approximately 10-15 years.

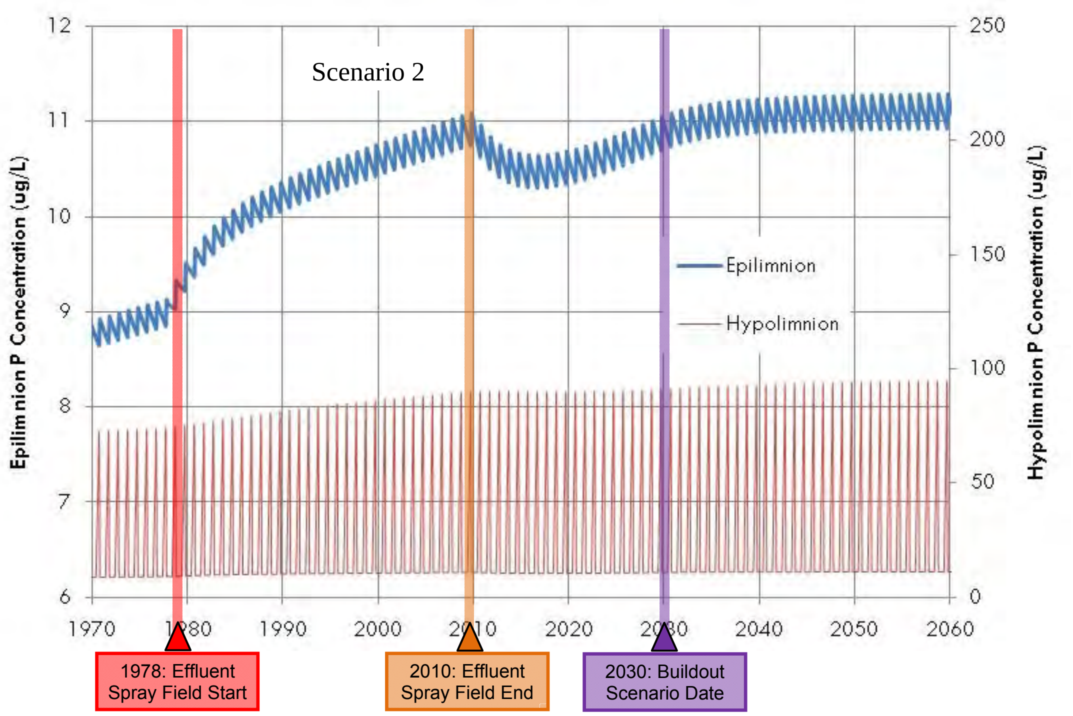


Figure 20. Modeled epilimnetic and hypolimnetic concentrations, 1970 to 2060, assuming spray field loads removed in 2010 and future conditions buildout continues to 2030.

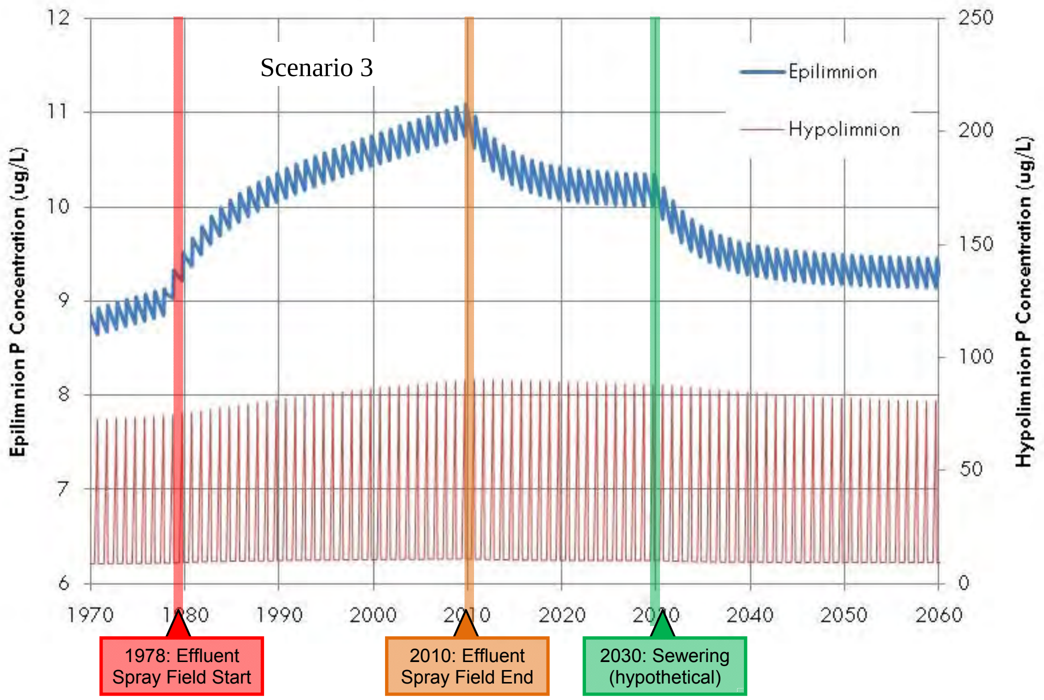


Figure 21. Modeled epilimnetic and hypolimnetic concentrations, 1970 to 2060, assuming spray field loads removed in 2010 and septic system loads removed in 2030.

5.6 Summary of Phosphorus Concentration Modeling Results

- Geosyntec developed two steady state models, the Vollenweider Model and the Nürnberg Model, to predict the relationship between phosphorus loading and in-lake phosphorus concentrations for Mirror Lake.
- The Vollenweider equation predicts an in-lake phosphorus concentration of 13.9 µg/L, significantly higher than the observed 2010 average of 10.4 µg/L. The Vollenweider equation also only predicts one annual concentration that reflects the lake in a fully mixed state (i.e., during spring turnover), and does not predict peak concentrations in late summer and early fall when cyanobacteria blooms are more likely to occur. The Nürnberg Model appeared to provide a more accurate and useful predictive tool for Mirror Lake.
- The Nürnberg model calculates an annual average P concentration (10.5 µg/L), a summer epilimnion P concentration (8.7 µg/L), and a fall P concentration (15.0 µg/L). P concentrations are typically highest in the late summer/fall due to mixing of internal P load that is either bound to sediment or retained in the hypolimnion during other times of the year. The Nürnberg results match well with the 2010 annual and summer observed averages, and somewhat overestimates the observed fall 2010 average.
- According to the Nürnberg Model, every P load increase or decrease of 30.4 lb/yr will result in a corresponding increase or decrease of 1.0 ug/L in the summer epilimnetic P concentration. New development anticipated for the Mirror Lake watershed by 2030 is predicted to yield an in-lake P concentration increase of 0.6 µg/L.
- Geosyntec used the Nürnberg model to analyze a variety of P loading scenarios in order to provide a framework for understanding the range of possible in-lake concentrations, and to aid in the selection of the MLPA's water quality goal. Based on review of these scenarios and discussion with NHDES staff, the MLPA adopted a water quality goal of a summer epilimnion P concentration of 8.5 µg/L. P concentrations below 10 µg/L are generally considered low enough to preclude summer cyanobacteria blooms in most lakes.
- According to the Nürnberg Model, the lake's current P load of 320 lb/yr must be reduced by approximately 7.4 lb/yr to achieve the water quality goal stated above. This equates to a target P load of 312.6 lb/yr, including both external sources and internal loading. However, based on 2030 buildout projections, it will be necessary to either prevent additional loading or reduce future projected loads by 33.8 lb/yr (7.4 lbs/yr plus an additional 26.4 lbs/yr from projected development) in order to maintain the water quality goal.
- In addition to the steady state models discussed above, Geosyntec developed a dynamic, rate-dependent model to investigate how long it takes for Mirror Lake's internal P load to respond to various changes in external P loading. For example, the model was used to investigate the lake's response to elimination of P loading impacts from the WWTF spray field operations in the Mirror Lake watershed. In that scenario, the model predicts that it will take roughly 10 years (from 2010 to 2020) for elimination of the WWTF spray field to achieve its full effect in reducing the in-lake P concentration. The dynamic model was also used to investigate the results of other potential changes to external P loading, such as P-load increases related to future development and P-load reduction due to sewering lakefront properties.

6. ACTION PLAN FOR REDUCING PHOSPHORUS LOADING TO MIRROR LAKE

This section presents a discussion of potential actions that could be taken in the Mirror Lake watershed to reduce phosphorus loading. It discusses potential phosphorus reduction measures that relate to storm water management, septic systems, and watershed land uses. Table 7 (page 74) provides an overview and prioritization of all proposed measures that are presented in this section.

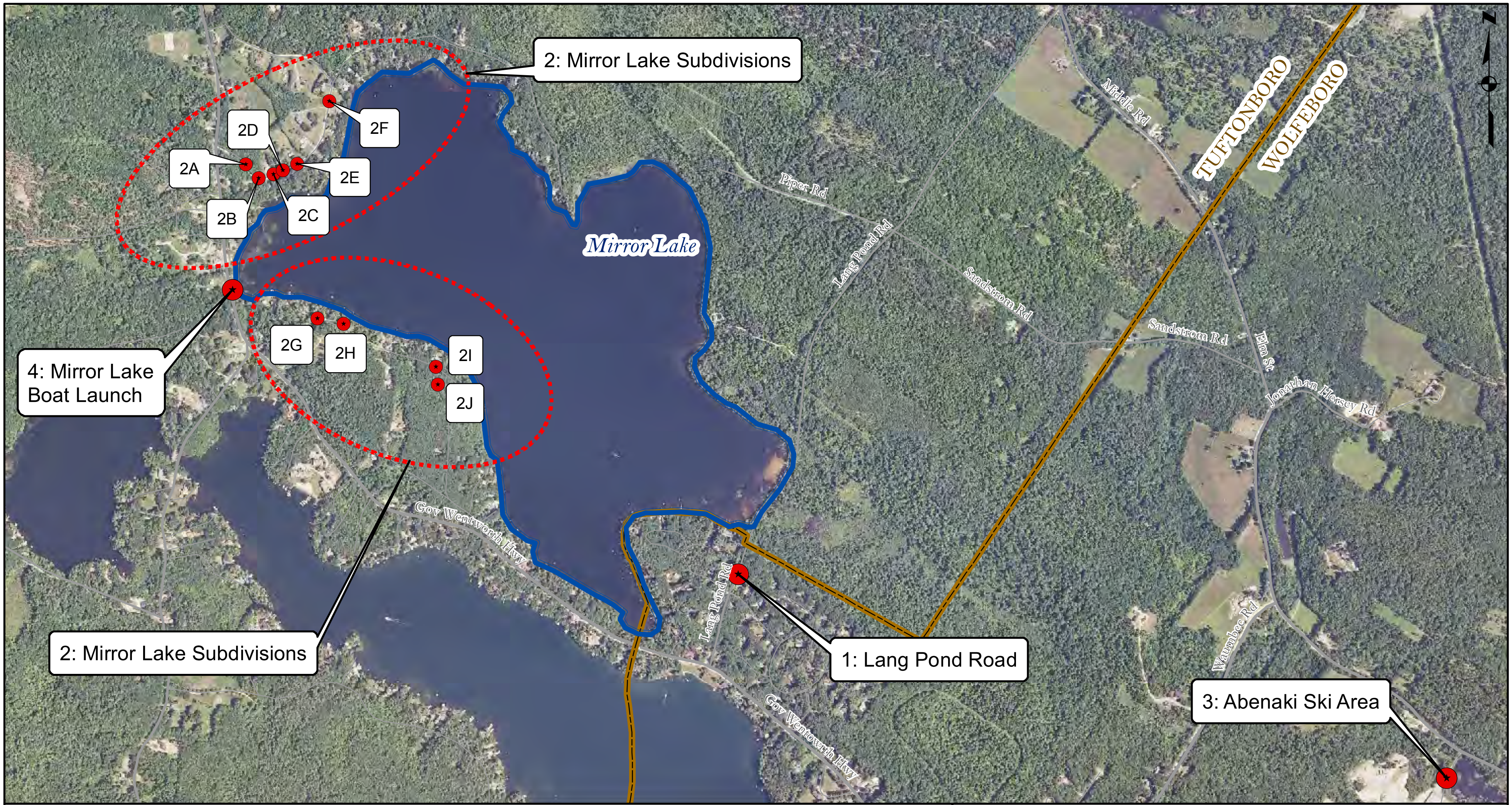
6.1 Storm Water Management

6.1.1 Field Watershed Investigation

Geosyntec conducted field watershed investigations on November 4, 2010 and July 7, 2011. Based on the results of this field investigation, this section provides a discussion of potential phosphorus reduction best management practices (BMPs) that relate to storm water management.

The following pages provide descriptions of the sites identified during the field investigation and recommended improvements. It is important to note that the sites discussed in this section are not intended to be an all-inclusive listing of potential stormwater improvements in Mirror Lake watershed. Rather, these sites are representative examples of potential stormwater improvements and retrofits that could be implemented at numerous sites throughout the watershed.

A map of Mirror Lake and the BMP sites identified by Geosyntec is presented in Figure 22.



1,600 800 0 1,600 3,200
Feet

Legend

- ● Proposed BMP Location
- Mirror Lake
- Town Boundary
- Road

Locations of Proposed BMPs

Mirror Lake Watershed
Tuftonboro/Wolfeboro, New Hampshire

Geosyntec
consultants

Figure
22

Acton, Massachusetts
JUNE 2011

Path: Q:\GISProjects\BW0166-Mirror_Lake\Projects_REPORT_FIGURES\BMP_LOCATIONS.mxd

SITE 1: Lang Pond Road

Site Summary:

Lang Pond Road is an unpaved public road along the southeastern shore of Mirror Lake. Eroded ditches (Photo 1-1) were observed along both sides of a sloped section of Lang Pond Road approximately 1500 feet north of the intersection with Route 109 (*also known as Governor Wentworth Highway and referred to hereafter as Route 109*).

Sediment from the road and ditches is being eroded and transported via runoff down the slope toward Mirror Lake. A portion of this area drains east into the adjacent wetland (Photo 1-2). The wetland drains through a culvert under Lang Pond Road to the lake. The remainder of this area drains west directly toward Mirror Lake (Photo 1-3).

Based on discussions with the Town of Wolfeboro Department of Public Works, the improvements described below assume that an 800-foot section of this road will be paved and associated storm water management infrastructure will be installed. However, pollutant loading reductions could also be achieved if the road remains unpaved, by stabilizing eroding road edge ditches with stone and constructing sediment traps to promote infiltration and energy dissipation. Although the improvements itemized below are located within the Wolfeboro portion of Lang Pond Road, future improvements to the Tuftonboro portion of the road should also be considered, including road edge infiltration practices and/or paving with associated storm water infrastructure.

Proposed Improvement:

- Pave an approximate 800-foot section of Lang Pond Road with standard asphalt.
- In coordination with road paving, install road drainage improvements including 5 catch basins, 4 drop inlets, 1 underdrain sedimentation basin with outlet, and all associated piping and materials (e.g. stone, piping, etc.).

Estimated Cost *(costs provided by Wolfeboro DPW):*

Paving (800 lf of road): $30,000

Storm Drainage Improvements: $52,710 *(see Appendix D2 for itemization)*

Estimated Phosphorus Reduction: 1.1 lb/yr

The photos below show examples of improvements to Lang Pond Road that should be considered if paving does not occur. Photo 1-4 is an example of rock ditch stabilization that could be constructed at Lang Pond Road. Ditch stabilization provides an erosion-resistant conveyance to convey stormwater runoff. The rock surface reduces velocity and causes coarse sediment to settle into voids between rocks. Maintenance includes periodically removing accumulated sediment.

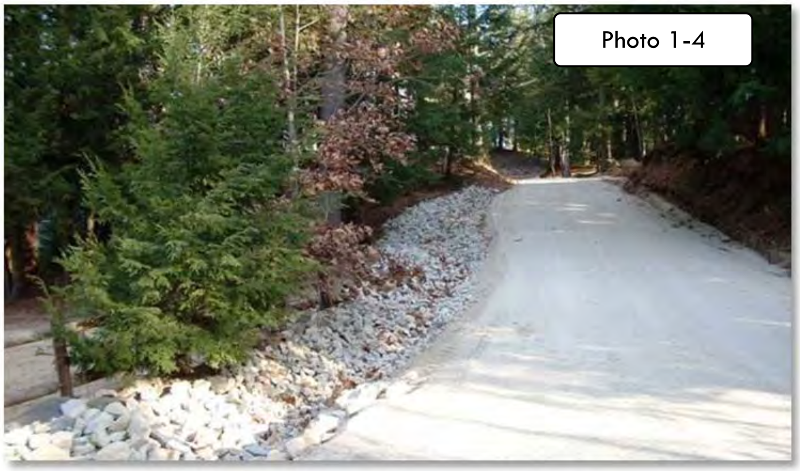


Photo 1-4

Photo 1-5 is an example of a sediment trap with a natural rock spillway that could be constructed at Lang Pond Road. A sediment trap is a small depression that is typically installed at the end of a conveyance (e.g., stable channel, culvert, etc.) that allows sediment-laden stormwater to temporarily pool, allowing sediment to settle out. Cleaner stormwater drains via the natural rock spillway. Depending on site soils, a low flow drain could be installed to completely drain the trap and prevent the trap from becoming a stagnant pool and potential mosquito breeding area.

Photo 1-5

SITE 2: Mirror Lake Subdivisions

Site Summary:

Two residential areas in the Mirror Lake watershed (Photo 2-1) are well suited for Low Impact Development (LID) stormwater retrofits including raingardens, bioretention cells and vegetated swales. These two areas include properties on Mirror Lake Drive and the area comprised of Church Lane, Steeple Lane, Oak Hill Road and Chipmunk Lane. These two areas are characterized by moderate slopes and B and C soils; a well-suited condition for raingarden retrofits. Raingardens installed in C soils may require larger surface areas and stone bases to account for lower infiltration rates associated with C soils. For reference, a NRCS soil survey map identifying soil classes in the Mirror Lake watershed is provided in Figure 24.


Photo 2-1

Proposed Improvements: Sites identified for improvements during site walks conducted with the MLPA and local residents are described below. These sites are representative examples of potential stormwater improvements and retrofits that could be implemented at residential properties throughout the watershed.


Photo 2-2

- **Site 2A:** Install two concrete flow diversions in the existing asphalt road surface of Mirror Lake Drive to divert sheet flow into the adjacent vegetated area. Install a rip rap swale and energy dissipation to divert flows and reduce storm water velocity to discharge in a non-erosive manner into the vegetated area.

  Estimated Cost: $3,200 - $5,200

  Estimated Phosphorus Reduction: 0.05 – 0.07 lb P/yr

- **Site 2B:** Install an approximately 300 square foot bioretention cell (see Image 2-3) to the north of the existing 12-inch diameter corrugated metal pipe located on Mirror Lake Drive, approximately 400 feet east of the intersection with State Route 109 (near 2 Mirror Lake Drive).

  Estimated Cost: $7,200 - $11,700

  Estimated Phosphorus Reduction: 0.35 – 0.43 lb P/yr

Image 2-3

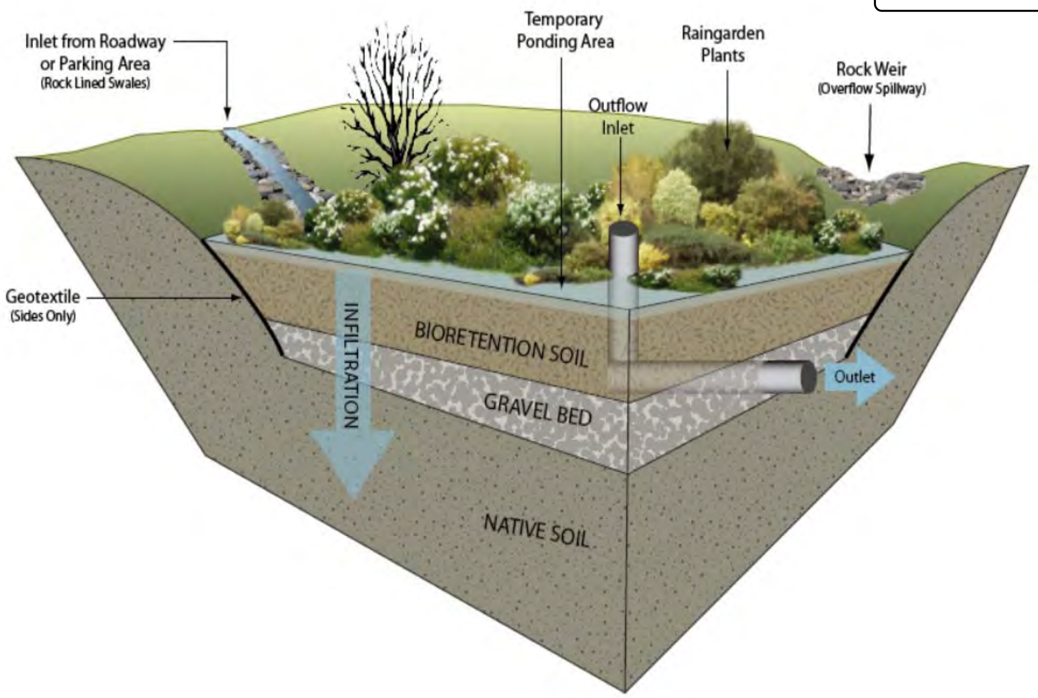


Image 2-3 is a cross section schematic of a bioretention cell. Bioretention cells are shallow landscaped depressions that incorporate plantings and engineered soil with a high porosity and infiltration capacity. Bioretention cells control stormwater runoff volume by providing storage, reducing peak discharge, and removing pollutants through physical, chemical, and biological processes occurring in plants and soil.

- **Site 2C:** Install a bioretention cell (approximately 25 feet long by 5 feet wide) along the south side of 9 Mirror Lake Drive, approximately 5 to 10 feet from the edge of pavement. Install a 10 foot long vegetated swale along Mirror Lake Drive to the south of the site 2B bioretention cell. The vegetated swale would capture drainage from the road and nearby driveway and convey these flows into the bioretention cell. Construction of the bioretention cell and vegetated swale would require that the existing timber retaining wall be removed and the area re-graded to provide proper drainage into the swale and cell.

  Estimated Cost: $3,000 - $5,000

  Estimated Phosphorus Reduction: 0.26 – 0.32 lb P/yr

- **Site 2D:** Install a bioretention cell (approximately 10 feet by 20 feet) at the southwest corner of the intersection of Mirror Lake Drive and the driveway to 11 Mirror Lake Drive.

  Estimated Cost: $4,800 - $7,800

  Estimated Phosphorus Reduction: 0.32 – 0.39 lb P/yr

- **Site 2E:** Install a bioretention cell (approximately 40 feet by 20 feet) to the north of Mirror Lake Drive at the location of the two 12-inch diameter corrugated metal pipes located approximately 1,000 feet east of the intersection with Route 109 (Photo 2-4). The bioretention cell would overflow into the existing culverts during large accumulation, less frequent storms. Currently, a foundation drain at 10 Mirror Lake Drive discharges immediately to the northwest of the corner of the driveway and road. A 4-inch diameter pipe is proposed under the driveway to drain the foundation drain outlet into the bioretention cell.


Photo 2-4

  Estimated Cost: $10,200 - $17,000

  Estimated Phosphorus Reduction: 1.05 – 1.29 lb P/yr

- **Site 2F:** An existing drainage path discharges through a culvert under Mirror Lake Drive in the vicinity of 26 Mirror Lake Drive. The area that drains through this culvert (Photo 2-5) is currently maintained as lawn. Regrading and a planting plan are proposed in the vicinity of the culvert inlet to provide temporary storage as well as water quality treatment during small accumulation, frequent storm events. Area residents report that high volume and velocity runoff downstream of the culvert has resulted in erosion in the channel that drains to Mirror Lake.


Photo 2-5

  Estimated Cost: $7,700 - $12,500

  Estimated Phosphorus Reduction: 0.97 – 1.21 lb P/yr

- **Site 2G and 2H:** There are two corrugated metal culverts at 4 and 14 Church Lane that drain storm flows under Church Lane. Both culverts were filled with sediment on the inlet and did not have energy dissipation at the outlet and erosion was observed immediately downgradient of the culverts' outfalls. Rock inlet protection and rock energy dissipation is recommended for both culverts.

  Estimated Cost: $3,200 - $5,200

  Estimated Phosphorus Reduction: 0.03 – 0.06 lb P/yr

- **Site 2I:** Stormwater runoff from Oak Hill Road drains north across Chipmunk Lane. These flows currently are collected in riprap that has filled with accumulated sediment. Erosion was observed on along the edge of the riprap where flows have bypassed the riprap conveyance. Additional riprap is proposed at this location including removing the existing riprap and reshaping the area to form a shallow parabolic channel that will be lined with rip rap. The area is used for overflow parking from surrounding houses and requires stabilization. The finished riprap surface should be sloped and integrated with the surrounding area to allow for overflow parking.

  Estimated Cost: $2,000 - $3,250

  Estimated Phosphorus Reduction: 0.01 – 0.02 lb P/yr

- **Site 2J:** Stormwater runoff from Oak Hill Road drains north via overland flow toward Chipmunk Lane. A riprap drain out is proposed on the west side of Oak Hill Road (Photo 2-6) to route the stormwater runoff off the pavement and gutter and route these flows into the vegetated area to the west of Oak Hill Road.

  Estimated Construction Cost: $1,600 - $2,600

  Estimated Phosphorus Reduction: 0.01 – 0.02 lb P/yr

Photo 2-6

- **Site 2K - Raingarden Demonstration Program:** Initiate a raingarden program for residents in the Mirror Lake watershed and educate residents about stormwater pollution prevention practices. Raingardens will vary in size depending on drainage area and property owner preference, and may range between 50 to 200 square feet. This would improve water quality and provide pretreatment for stormwater that would otherwise runoff directly into the lake. For the cost and load reduction estimates below, five (5) 100-square foot raingardens were assumed as part of the raingarden demonstration program.

  Estimated Cost: $7,200 - $11,700

  Estimated Phosphorus Reduction: 0.23 – 0.29 lb P/yr

Photo 2-7 is an example of a flowering perennial raingarden along a road edge in a residential yard. Raingardens are shallow landscaped depressions that incorporate plantings and engineered soil. Raingardens control stormwater runoff volume from small drainage areas by providing temporary storage and removing pollutants through physical, chemical, and biological processes occurring in plants and soil. Rain gardens are often appropriate for residential developments, to treat storm water from impervious areas associated with individual lots. The total installed cost of a typical rain garden is approximately $1,500 to $3,500 (contractor installed costs), depending on garden size, soil conditions, type of plantings used, and other site-specific requirements.

Photo 2-8 is an example of a shrub perennial raingarden installed along a road edge. Shrubs require less maintenance than herbaceous plants and have a higher potential for evapotranspiration because of the deeper roots and larger plants.


Photo 2-7


Photo 2-8

SITE 3: Abenaki Ski Area

Site Summary:

There is an unpaved parking area approximately 8,500 square feet in size to the west of the building at the Abenaki Ski Area. The unpaved area drains into a small pond immediately adjacent to the east of the parking area (Photo 3-1). This pond drains north through an unnamed tributary ultimately draining to Mirror Lake. The Abenaki Ski area has potential to be a highly visible sight for educational outreach opportunities.

Proposed Improvement:

- Pave parking spaces with porous pavement and the driveways with standard asphalt (Photo 3-2). This would stabilize the parking area and reduce the potential for sediment and associated pollutants from migrating into the receiving water. A lower-cost alternative would be to pave the area with asphalt.
- Install two bioretention cells (example of bioretention cell is shown in Photo 3-3), each approximately 400 square feet in area in the following locations: (1) adjacent to the proposed paving described above; and (2) one located between the existing paved parking area to the east of the ice rink and the pond.

Estimated Cost:

Porous pavement strip: $54,700 - $66,900

(Asphalt-Only Option): $39,800-$48,600

Bioretention cells: $7,500 – $9,200

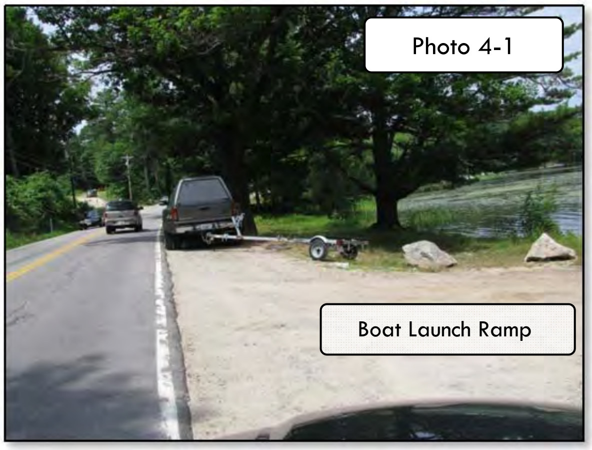
Estimated Phosphorus Reduction:

0.23 – 0.28 lb P/yr

SITE 4: Route 109 / Mirror Lake Boat Launch Subwatershed

Site Summary:

The Mirror Lake boat launch is an unpaved dirt ramp that enters the west end of the lake from Route 109. The boat launch area includes an unpaved area along the road shoulder that is used for vehicle/boat trailer parking (Photo 4-1). A portion of Route 109 near the launch drains through a culvert that discharges towards the boat ramp area (Photo 4-2).



Proposed Improvements:

- Stabilize the boat launch ramp with (1) standard asphalt for the upper 40 feet from Route 109 and (2) cabled, precast-concrete, surfaced planks for the lower portion extending into the lake. Install a linear trench drain (approximately 20 feet long) near the transition between the asphalt and the concrete planks. The trench drain would drain into a bioretention cell (approximately 200 square feet) adjacent to the ramp on town-owned property. Photo 4-3 provides an example of the stabilization that could be completed at this site.
- Install a bioretention cell in the area just downgradient of the culvert outlet, approximately 60 feet long by 3 feet wide (or larger as space allows). Ownership of this area should be confirmed. If privately owned, an easement for the raingarden area should be investigated.
- Other opportunities to reduce the volume and velocity of stormwater discharge from the contributing drainage areas upgradient of Route 109 may also be feasible, pending a more detailed assessment of storm water flow patterns, property ownership and other site-specific constraints.

Estimated Cost:

Cabled concrete boat launch: $12,000
Asphalt paving: $1,800 – $2,200
Trench drain: $1,000
Bioretention cells: $3,700 - $4,500

Estimated Phosphorus Reduction: 0.10 – 0.12 lb/yr

SITE 4: Route 109 / Mirror Lake Boat Launch Subwatershed *(continued)*

Photo 4-3 provides an example of the pavement and linear trench drain that could be installed at the boat launch. This boat ramp was installed in 2010 at Silver Lake in Harrisville, NH.


Photo 4-3

6.1.2 Estimated Storm Water BMP Pollutant Load Reduction

Phosphorus load reductions were estimated for each of the proposed improvements described above in Section 6.1.1. The phosphorus load reductions were estimated using published pollutant reduction rates for BMPs as follows:

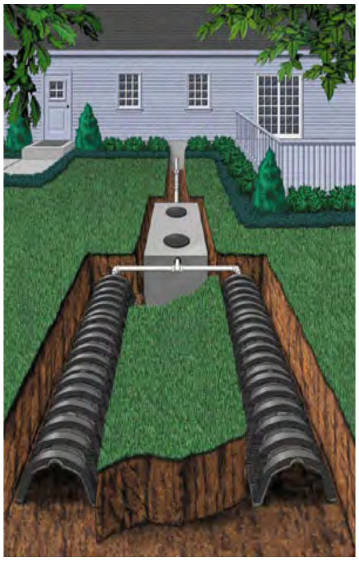
The predicted phosphorus load entering each BMP was estimated based on the land cover in the drainage area contributing flows through the BMP. Each BMP drainage area was delineated based on United States Geological Survey (USGS) topography maps and Geosyntec's field investigations of the watershed and storm drainage structures.

Next, land use categories from existing land use data were assigned to the drainage area. An annual pollutant load was estimated for each catchment using either the Simple Method (described in the New Hampshire Stormwater Manual) or the USEPA STEP-L program. This pre-BMP annual phosphorus load represents the amount of phosphorus expected to enter the lake if the BMP was not in-place.

Next, published BMP phosphorus reduction values were used to estimate the total amount of phosphorus which is expected to be removed (provided that the BMP is properly installed and maintained). Reduction values were obtained from the New Hampshire Stormwater Manual when available. BMP reduction values not provided by the New Hampshire Stormwater Manual were obtained from the Massachusetts Stormwater Handbook. The post-BMP pollutant load represents the pollutant load predicted to enter the Lake if the BMP was installed. Table 7 provides a summary of the phosphorus load reductions estimated for each proposed BMP site. Appendix D1 includes the Simple Method calculations, phosphorus load reduction calculations and costing assumptions used for each site.

The BMPs proposed for Sites 1-4 are estimated to reduce the annual phosphorus load to Mirror Lake by 5.2 lb/year. This load reduction represents about 70% of the targeted phosphorus load reduction (7.4 lb/year) for Mirror Lake as discussed in Section 5.4. However, as previously stated, Sites 1-4 are not intended to be a comprehensive listing of recommended stormwater improvements in the Mirror Lake watershed. Rather, these sites are representative examples of potential stormwater improvements and retrofits that could be implemented at numerous sites throughout the watershed. Significantly greater phosphorus load reductions could be attained from a watershed-wide effort to improve stormwater management through LID practices (e.g. raingardens on residential lots) and improvements to existing storm water drainage features.

6.2 Potential Community Septic Systems Locations



Geosyntec conducted a preliminary review to identify potential areas for community septic systems (Table 6). The review was based on (1) the density of existing homes in close proximity to the Lake and (2) data on soil types and soil drainage classes in the areas surrounding the lake. Five potential service areas for community septic systems serving approximately 86 homes are shown in Figure 23. As shown in Figure 24, many of the soils surrounding the lake have been classified by the USDA-NRCS as hydrologic soil group B. Water flow through these soils is described as “unimpeded”, which tends to make them suitable for siting wastewater treatment facilities.

Geosyntec identified the five areas listed below as potential service areas for community septic systems. Specific locations for the treatment systems were not identified as part of this study, although it is recommended that these systems be sited a minimum of 250 feet from the lake shoreline. For each of the five clusters of homes, the maximum piping distance from a home to a centrally located community septic system would be approximately 0.25 miles.

Table 6: Potential Community Septic Systems

Area	Location	# of Shoreline Homes	Estimated P Reduction (lbs/yr)
1	Mirror Lake Drive: East	11	0.6 – 1.4
2	Mirror Lake Drive: West	22	1.5 – 3.5
3	Oak Hill Road Area	20	1.1 – 2.6
4	Route 109 Area	13	0.6 – 1.4
5	Lang Pond Road Area	20	1.3 – 3.0
See Figure 23 for location of Areas 1-5		**Total:**	**5.1 – 11.9**

The installed cost for a community septic system can vary widely depending on site specific conditions such as soils, slopes, piping distances, etc. In general, the cost of a community system per household will decrease significantly as the number of homes sharing the system increases. For general costing purposes, a cluster mound system servicing 25 homes will cost about $458,000 to install ($18,320 per house). This cost includes $208,000 for design and installation of the system and $250,000 to install piping connections, assuming an average of 100 feet of small diameter pipe per home at $10 per linear foot. Annual maintenance costs for this type of system are estimated at $5,000 ($200 annually per home).

For comparison, a mid-range cost for sewering is approximately $20,000 per home. The high range for sewering projects in the northeast United States is near $30,000 per house. Sewer systems are rarely installed at a cost lower than $15,000 per house.

The potential phosphorus load reductions that may be achieved by installing community septic systems can vary widely depending on factors including: the proximity and condition existing on-site septic systems; the location of the proposed community septic systems (e.g. distance from the lake); soil conditions; and treatment technology of the systems. To maximize phosphorus removal, the infiltration system should be located in medium- to fine-textured soils as far from the lake as possible. When siting options for these systems are less than ideal, treatment technology options that use media surface chemical precipitation or adsorption can be an effective alternative.

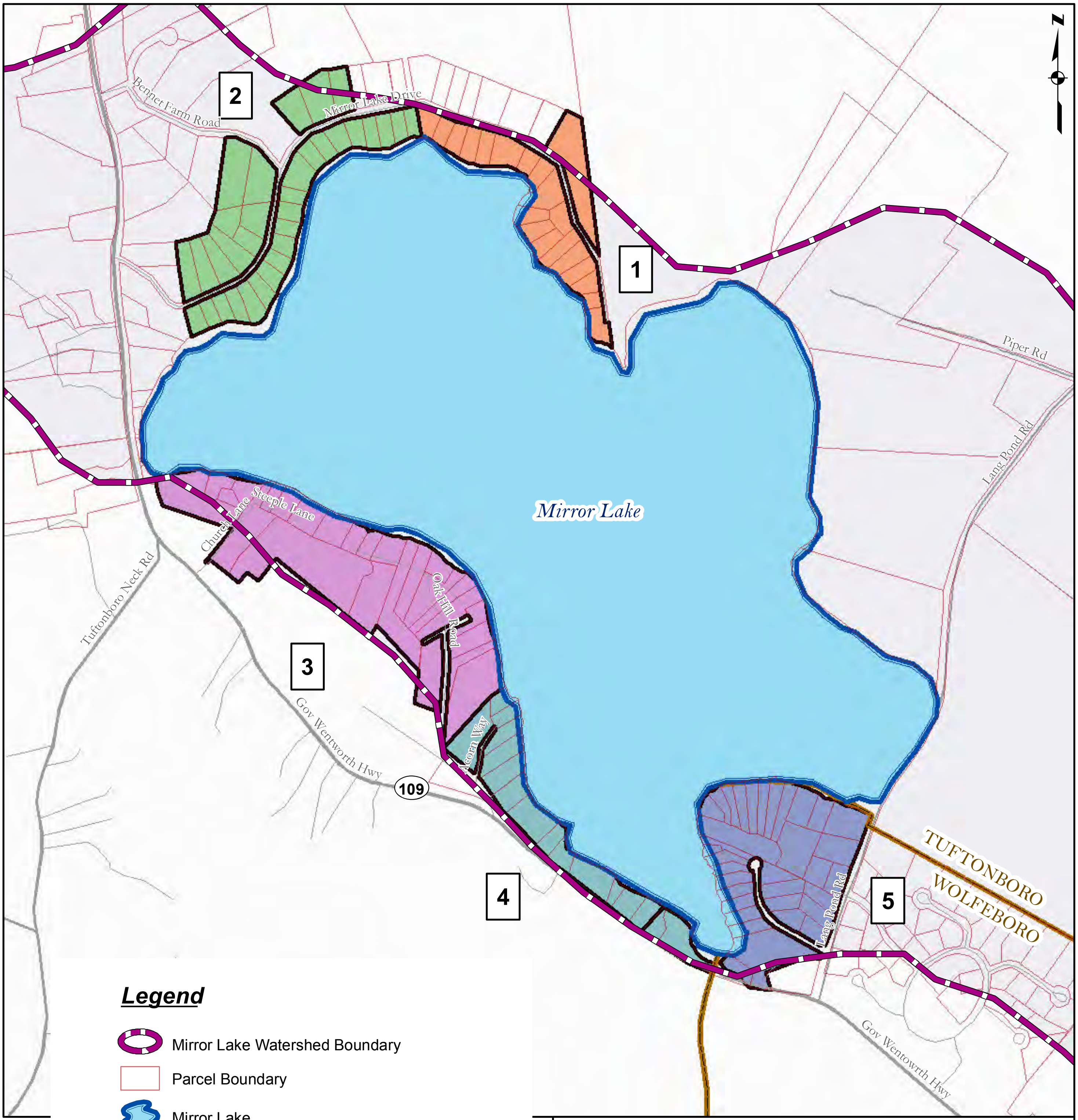
For the 86 homes located within the five potential community septic system locations, a conservative estimated phosphorus load reduction range of 25%-60% (measured as a reduction compared to the existing load from private on-site systems) would result in an estimated phosphorus load reduction of 5.1 to 11.9 lbs P/year. This reduction is within range of the targeted annual phosphorus load reduction of 7.4 lb/yr based on current conditions, as discussed in Section 5.4. The reduction is approximately 15% to 35% of the 33.8 lb/yr reduction that is predicted to be needed by year 2030 based on current conditions and expected future development. Higher load reduction amounts may be possible depending on site-specific conditions and the treatment technology used.

Additional information and case studies on community septic systems can be found at the following links:

- Small Community Wastewater Cluster Systems (Purdue Extension): http://www.extension.purdue.edu/extmedia/ID/ID-265.pdf

- Cluster Wastewater Systems Planning Handbook (NDWRCDP, Lombardo Associates, Inc.), includes various case studies: http://www.ndwrcdp.org/documents/WU-HT-01-45/WUHT0145_web1.pdf

- Case Study, Cedar Lake, MN: www.ellingsoncompanies.com/media/documents/cedar_lake_cluster_system.pdf



Legend

- Mirror Lake Watershed Boundary
- ☐ Parcel Boundary
- Mirror Lake
- Town Boundary
- Road

Potential Community Septic System Regions

- 🟧 1 - Mirror Lake Drive: East
- 🟩 2 - Mirror Lake Drive: West
- 🟪 3 - Oak Hill Road Area
- ▨ 4 - Route 109 Area
- 🟦 5 - Lang Pond Road Area

Potential Community Septic System Regions

Mirror Lake Watershed
Tuftonboro/Wolfeboro, New Hampshire

Geosyntec consultants

Acton, Massachusetts

JUNE 2011

Figure

23

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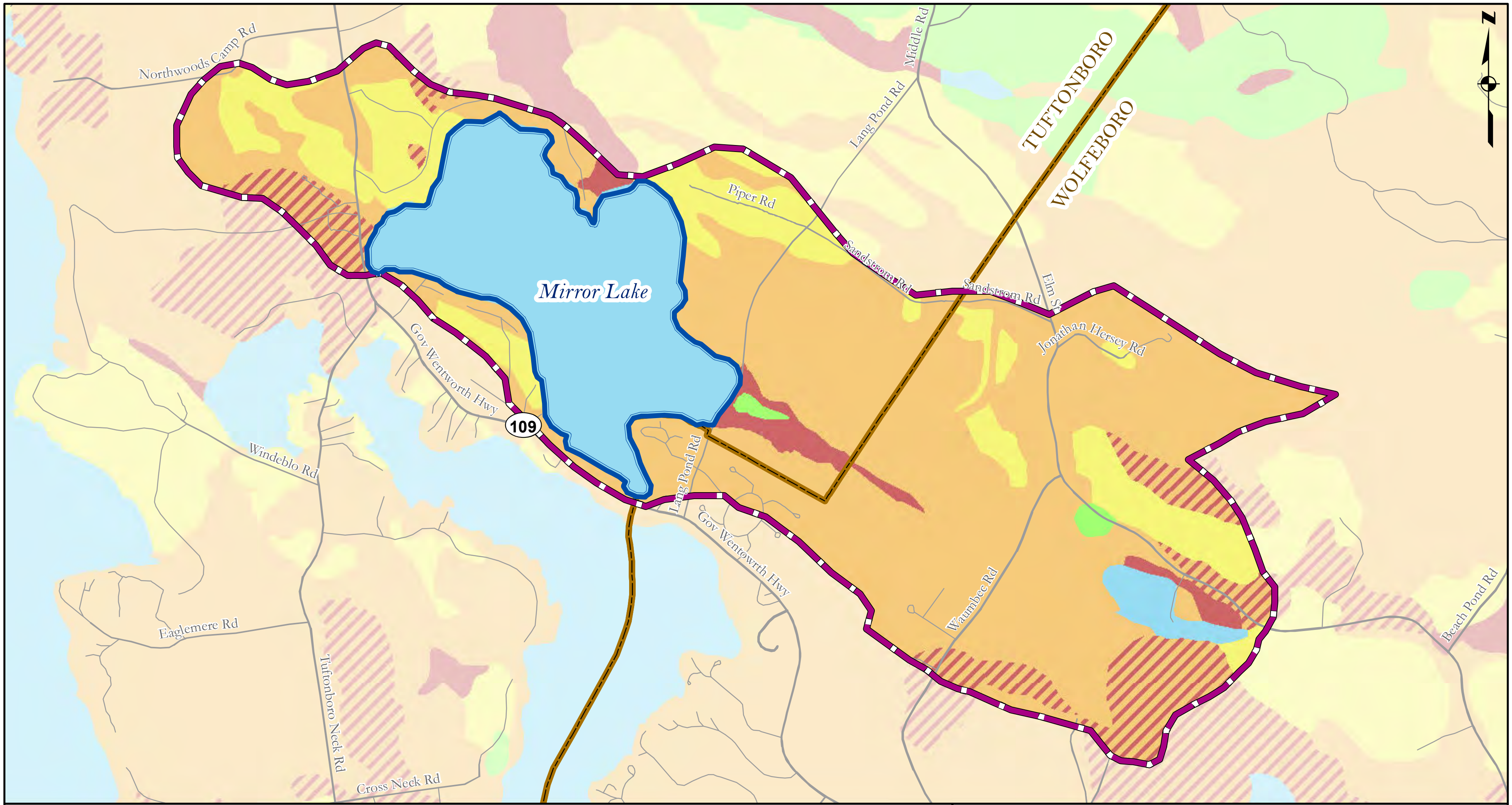

Legend

Hydrologic Soil Group

🟩 A (Well Draining)

🟨 B

🟧 C

▨ C/D

🟥 D (Poorly Draining)

🟦 Open Water

Mirror Lake

Mirror Lake Watershed Boundary

Town Boundary

Road

2,000 1,000 0 2,000 4,000
Feet

NRCS Hydrologic Soil Classification

Mirror Lake Watershed
Tuftonboro/Wolfeboro, New Hampshire

Geosyntec consultants

Acton, Massachusetts

JUNE 2011

Figure

24

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6.3 Land Conservation Measures

As presented in Section 5, future conditions (year 2030) modeling indicates that total phosphorus loading due to potential lake shore development could result in an additional 10.3 pounds of annual phosphorus load to Mirror Lake, including 6.0 pounds due to land use changes and 4.3 pounds due to additional septic system loading. This projected additional phosphorus load from new development represents 30% of the future conditions loading that must be prevented to maintain the water quality goal.

The most notable area for potential near-shore development is along the northeast shoreline in the Lang Pond Road / Piper Road region (Hersey property). Recommended strategies to reduce this future phosphorus load include the following:

- *Land Acquisition/Conservation Easements:* Protection of land either by fee acquisition or conservation easements will not contribute to achieving the water quality goal based on current conditions. However, as presented in Section 5, it could prevent up to 10.3 pounds of additional phosphorus loading under future conditions, which represents 30% of the future conditions loading that must be prevented to maintain the water quality goal.
- *Regulatory and Land Planning Tools:* Regulatory and land planning tools such as zoning bylaws, watershed protection districts and LID Bylaws are recommended and can be effective tools for protecting lakes from adverse impacts due to land development. The Town of Windham, NH recently adopted the Cobbett's Pond Watershed Protection Ordinance, which could serve as an excellent model for a municipal regulatory tool to protect and preserve Mirror Lake. This ordinance can be found at: http://www.cobbettspond.org/images/CobbettsPondOrdinance.pdf. Other model bylaws can be found on the website for the Citizen Planner Training Collaborative, a training and education service provided to planning boards and local officials from the University of Massachusetts and collaborative partners (www.umass.edu/masscptc/examplebylaws.html).

6.4 Summary of Proposed Action Plan to Reduce Phosphorus Loading

- Geosyntec conducted a watershed survey to identify locations where P loading reductions could be achieved through storm water management improvements and other best management practices (BMPs). In general, the stormwater drainage in the watershed appeared to be in good condition and opportunities for storm water management improvements were limited due to the predominantly forested character of the watershed.
- The proposed storm water management BMPs would result in an estimated P load reduction of 5.2 lb/year, which is about 70% of the targeted phosphorus load reduction of 7.4 lb/year for Mirror Lake. These sites are representative examples of potential stormwater improvements and retrofits that could be implemented at numerous sites throughout the watershed. Significantly greater phosphorus load reductions could be attained from a watershed-wide effort to improve stormwater management through Low Impact Development practices (e.g. raingardens and other infiltrating BMPs) and other land management practices such as reduced fertilizer use, use of rain barrels and cisterns, improved septic system management, stabilization of erosion-prone areas, and proper management of domesticated and farm animal waste.

- Geosyntec identified five areas, including a total of 86 homes, as potential service areas for community septic systems. If all five community septic systems were constructed, the estimated annual reduction in P load ranges from 5.1 to 11.0 lb/yr. This range could achieve the targeted annual phosphorus load reduction of 7.4 lb/yr based on current conditions. For general costing purposes, a cluster mound system servicing 25 homes will cost about $458,000 to install ($18,320 per house). Annual maintenance costs are estimated at $5,000 ($200 annually per home).

- Model projections for 2030 indicate that potential lake shore development could result in an additional 10.3 pounds of annual P load to Mirror Lake, including 6.0 pounds due to land use changes and 4.3 pounds from new septic systems. This projected additional P load represents 30% of 34 pounds of annual P loading that must be prevented (based on current conditions) to maintain the water quality goal in 2030 . Recommended strategies to reduce this future phosphorus load include (1) protection of land either by fee acquisition or conservation easements and (2) regulatory and land planning tools such as zoning bylaws, watershed protection districts and Low Impact Development Bylaws.

- Section 5.2 of Appendix B to this report (Mirror Lake Internal Phosphorus Loading and Cyanobacteria Response, NHDES) provides a discussion of in-lake restoration techniques that address internal sediment P loading to lakes. These in-lake techniques include aeration, circulation, biomanipulation, dredging, water exchange, and chemical inactivation processes such as the application of aluminum salts. Based on the current condition of Mirror Lake with regard to P loading and in-lake P concentrations, in-lake management techniques are not recommended at this time. The current water quality of Mirror lake is very good and Geosyntec recommends that priority should be given to maintaining and improving water quality through watershed source controls and non-structural practices such as land conservation, regulatory tools and public education.

- Table 7 provides an overview and prioritization of all proposed measures that are presented in this section.

Table 7: Summary of Proposed Actions to Reduce Phosphorus Loading

BMP TYPE	SITE	COMPONENTS	ESTIMATED COST	TP LOAD REDUCTION (lb/yr)	COST PER LB OF P REDUCED (x $1,000)	PRIORITY
STORMWATER BMPs	1 Lang Pond Road	• Pave/re-surface 800 lf of Lang Pond Road • Install 5 catch basins, 4 drop inlets, 1 underdrain sedimentation basin with outlet, and associated materials (stone, piping, etc.).	$30,000 $52,710	1.10	75.2	HIGH
	2 Mirror Lake Subdivisions	• Install flow diversions • Install four bioretention cells • Construct a wetland in an existing drianage path • Install inlet and outlet protection at two culverts • Install flow diversion and riprap stabilization • Implement residential raingarden program	$73,000 - $90,000	3.32 - 4.06	18.0 - 27.1	HIGH
	3 Abenaki Ski Area	• Pave parking area with combination of standard and porous asphalt • Install bioretention cells to treat parking area runoff	$62,186 - $76,005	0.23 - 0.28	219.5 - 327.8	LOW
	4 Mirror Lake Boat Launch	• Install new cabled concrete boat ramp • Pave upper driveway portion of boat ramp (standard asphalt) • Install trench drain • Install 2 bioretention cells	$22,347 - $27,313	0.10 - 0.12	190.9 - 285.2	HIGH
COMMUNITY SEPTIC SYSTEM	1 Mirror Lake Drive: East	• Community Septic System: Homes served = 11	$201,520	0.6 - 1.4	143.9 - 335.9	MED
	2 Mirror Lake Drive: West	• Community Septic System: Homes served = 22	$403,040	1.5 - 3.5	115.2 - 268.7	MED
	3 Oak Hill Road Area	• Community Septic System: Homes served = 20	$366,400	1.1 - 2.6	140.9 - 333.1	MED
	4 Route 109 Area	• Community Septic System: Homes served = 13	$238,160	0.6 - 1.4	170.1 - 396.9	MED
	5 Lang Pond Road Area	• Community Septic System: Homes served = 20	$366,400	1.3 - 3.0	122.1 - 281.8	MED
CONSERVATION	1 Lang Pond Road / Piper Road Area (Hersey Property)	• Prevention of development along Mirror Lake northeastern shoreline via fee acquisition, conservation easements, etc. (includes cost of potential land purchases)	$250,000 - $1,000,000	9.3 - 11.3	22.1 - 107.5	HIGH
		TOTALS:	**$2,066,000 (low)** **$2,852,000 (high)**	**18 (low)** **29 (high)**	**72 (low)** **158 (high)**	

Note: As discussed in Section 5.4, a P load reduction of 7.4 lb/yr is needed to achieve the MLPA water quality goal (mean summer epilimnion P concentration of 8.5 μ g/L).

7. SUMMARY OF TECHNICAL AND FINANCIAL SUPPORT

7.1 Technical Support

Most of the phosphorus loading reduction measures described in Section 6 will require a moderate to high level of technical support. The required types of technical support include site topographic surveys, preparation of existing conditions base plans, and preparation of definitive site drawings by an engineer that would be used for permitting, contractor bidding and construction. Stormwater improvement sites requiring low level of technical support would generally be appropriate for design-build construction using field manuals. A listing of the stormwater improvement sites according to estimated level of required technical support is as follows:

Moderate	**High**
Site 1: Lang Pond Road	Site 3: Abenaki Ski Area
Site 2: Mirror Lake Subdivisions, Church Lane, Oak Hill Road	Site 4: Mirror Lake Boat Launch

In addition to the technical support described above, construction of some of the projects described in Section 6 may require a Minimum Impact Wetlands Application to the NHDES Wetlands Bureau. Wetlands were not delineated as part of this project. As such, technical support from a New Hampshire certified wetland scientist would be required on sites where wetlands are present for wetland delineation and permitting support.

Improvements related to on-site wastewater management and the proposed community septic systems discussed in Section 6.2 will require a high degree of technical support from a wastewater engineering firm. Such support is expected to include a feasibility study with detailed investigations and recommendations on siting options and costing for the proposed community systems. Detailed engineering plans for the systems would then be required.

Other types of technical support that may be required for the recommended measures discussed in this report include graphic design and printing support for public outreach and educational materials, septic system inspection services, and legal assistance for land conservation acquisitions and development of regulatory language for future municipal bylaws.

7.2 Financial Support

Site improvements and management recommendations described in Section 6 will require funding to install and complete. Likely sources of funding include, but are not limited to, MLPA dues and Section 319 grant funds. Alternative funding may be in the form of donated labor from the Towns of Tuftonboro/Wolfeboro, MLPA volunteers and local contractors. Brief descriptions of potential grant funding sources are provided below:

Section 319 Watershed Assistance and Restoration Grants:

NHDES Watershed Assistance and Restoration Grants are funded through the U.S. Environmental Protection Agency under Section 319 of the Clean Water Act. Two thirds of the annual funds are available for restoration projects that address impaired waters and implement watershed based plans designed to achieve water quality standards. A project eligible for funds must plan or implement measures that prevent, control, or abate non-point source pollution. These projects should: (1) restore or maintain the chemical, physical, and biological integrity of New Hampshire's waters; (2) be directed at encouraging, requiring, or achieving implementation of BMPs to address water quality impacts from land-use; (3) be feasible, practical and cost effective; and (4) provide an informational, educational, and/or technical transfer component. The project must include an appropriate method for verifying project success with respect to the project performance targets, with an emphasis on demonstrated environmental improvement.

Nonprofit organizations registered with the New Hampshire Secretary of State and governmental subdivisions including municipalities, regional planning commissions, non-profit organizations, county conservation districts, state agencies, watershed associations, and water suppliers are eligible to receive these grants. More information on this grant program can be found at: www.des.state.nh.us/wmb/was/grants.htm.

Agricultural Nutrient Management (ANM) Grant Program

The ANM grant program assists agricultural land and livestock owners with efforts to protect surface waters and public water supplies through better management of agricultural nutrients. Applicants may apply for up to $2,500, with no match required. Examples of past grant projects include: fencing livestock out of surface waters, controlled wetland crossings, structures for manure/compost storage, roofs for manure/compost storage, barn roof gutters/downspouts, pasture pumps or other watering systems as alternatives to surface waters, and vegetated buffers/divergence berms. More information on this grant program can be found at: http://des.nh.gov/organization/divisions/water/wmb/was/documents/ag_fact_sheet.pdf

Conservation License Plate Grant Program

Conservation Grants are funded through purchase of the New Hampshire Conservation License Plate ("Moose Plate"). Applicants apply in two groups, grants under $5,000 and grants over $5,000. The Conservation Grant Program's six focus areas include:

- Preserve, protect and conserve water quality and water quantity;
- Planning or implementation of BMPs for agriculture, forestry or storm water management;
- Restore, enhance or conserve wildlife habitat;
- Reduce, prevent and/or mange soil erosion and/or flooding;
- Conservation planning that accomplishes a conservation protection outcome; and
- Permanent land protection through conservation easement or fee purchase.

Eligible grant applicants include:

- County Conservation Grants: County Conservation Districts and County Cooperative Extension Natural Resource Programs; and

- Municipal and Nongovernmental Entity Conservation Grants: municipal conservation agencies engaged in conservation programs; public and private schools, K through 12; scout groups; other nonprofit entities engaged in conservation programs.

Information on the grant program can be found at www.nh.gov/scc/grants/index.htm, and the application form is at www.nh.gov/scc/grants/index.htm.

8. PUBLIC INFORMATION AND EDUCATION

The MLPA, with consultation and input from Geosyntec, conducted the following activities related to public information and education as specified under Task 31 of the MLPA's Scope of Services for the Section 319 grant:

Capital Campaign:

Solicitations: Solicitation mailings were sent to select individuals and businesses in the Mirror Lake watershed and in the Tuftonboro and Wolfeboro communities. Solicitations also involved one-on-one meetings with selected individuals and businesses.

Bocce Tournament: More than 65 people participated the MLPA Bocce Tournament Fund Raiser on August 7, 2010. There were 32 competitors, the majority of whom reside in Wolfeboro and Tuftonboro. Services and food were donated by MLPA members. There was a silent auction of donations obtained from individuals and businesses. Over $1,600 was raised. A presentation was made concerning the Section 319 grant and MLPA's efforts to address lake quality issues and a press release of the event was published in *The Granite State News*.

Capacity Building/Awareness Events:

Bake Sale: A bake sale was held outside the Mirror Lake Community Church, with permission from the church council, for the purpose of (1) raising funds for the MLPA; (2) providing educational materials to the members of the church as well as to interested pedestrians and motorists; and (3) educating and involving children of MLPA members regarding their role in preserving and protecting the lake. MLPA participants prepared the baked goods, made signs, and sold food and lemonade to attendees. MLPA members provided baked items while a team of children and adult supervisors conducted the sale. All proceeds ($232) were donated to the MLPA.

Information Centers: On August 14, 2010 volunteers visited the New Hampshire Department of Education, met with a representative from the Media Department and reviewed the materials available for educational purposes. They reviewed sample brochures and discussed which ones would be most appropriate for watershed education and how to order copies. On August 26, 2010, a volunteer met with the Wolfeboro Chamber of Commerce to see what materials they distribute to the public regarding care of watersheds and lakes (limited to information about geese). The volunteer also requested permission to place DES materials on their shelves, which was granted. On August 28, a volunteer met with Andrea LaMoreaux at the New Hampshire Lakes Association to review materials and discuss services in conjunction with the Mirror Lake project. $25 was paid for 50 booklets (*Help Protect New Hampshire's Lakes: A guide to wise lake and watershed stewardship*). Educational material was distributed by volunteers who manned the Mirror Lake boat launch, at community events held in Wolfeboro at Cate Park, at local craft fairs and at all of MLPA's events. Literature for distribution included such items as: *DES Environmental Fact Sheet; Why Watersheds are Important to Protect; Fireworks and New Hampshire's Lakes; Help Protect New Hampshire's Lakes-A guide to wise lake and watershed stewardship; and A Laker's Dozen-13 Ways you Can Help the Lake.* Printing costs were donated by an MLPA member, and MLPA banner was purchased for MLPA.

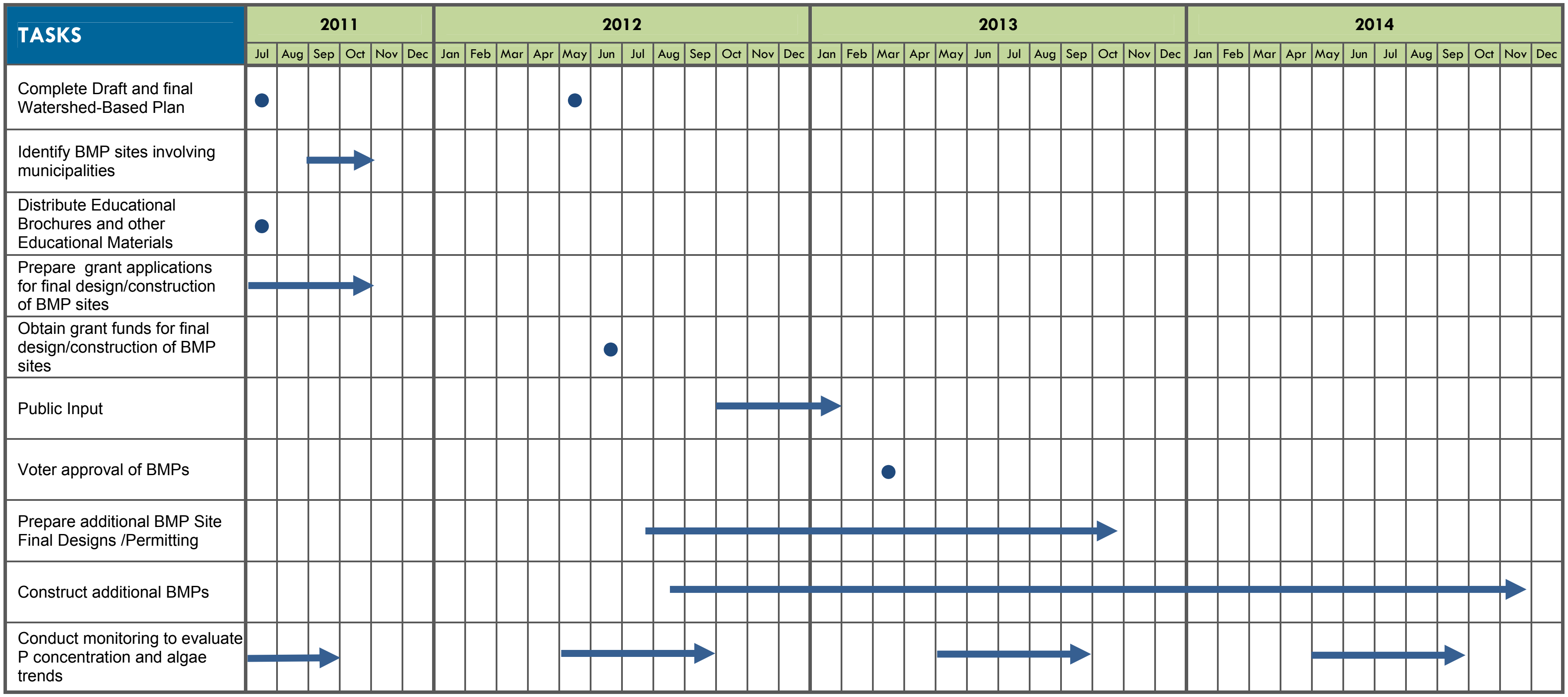
Yard Sale: On August 28, 2010, residents of Mirror Lake participated in a community yard sale with the proceeds of $210 donated to MLPA. The Mirror Lake Estates Association provided an open area convenient for sellers and buyers (Lot 12) which was used for the sale in addition to space provided by nearby private property owners. A fee of $15 per table was charged for participation. The sale was advertised in local papers and literature was distributed.

Field Guide to the Aquatic Plants of Mirror Lake: Geosyntec developed a *Field Guide to the Aquatic Plants of Mirror Lake* (Appendix E) based on the results of a July 2010 aquatic vegetation survey conducted as part of this project. It is recommended that this field guide be distributed to all lakefront property owners to aid in ongoing volunteer monitoring to prevent the introduction of invasive species to Mirror Lake.

9. SCHEDULE AND INTERIM MILESTONES

The improvements recommended for Mirror Lake and its watershed are ranked in order of priority as described in Section 6 of this report. A proposed schedule and associated interim milestones for these improvements are provided below.

Figure 25. Mirror Lake Watershed Restoration Plan - Implementation Schedule and Interim Milestones



10. EVALUATION CRITERIA AND MONITORING

As discussed in Section 5.4, this watershed restoration plan recommends targeting an in-lake summer epilimnetic phosphorus (TP) concentration for Mirror Lake of 8.5 µg/L. To achieve this TP concentration, the Nürnberg equation in Section 5.4 predicts that the annual phosphorus load to the lake must be reduced by an estimated 7.4 lb/year. Section 6 of this report describes management measures that may be implemented to achieve this targeted phosphorus load reduction. Geosyntec recommends the following monitoring and evaluation criteria to determine the effectiveness of these proposed measures in reducing in-lake phosphorus concentrations and improving the water quality of Mirror Lake.

- **Phosphorus Monitoring:** The MLPA should continue monitoring in-lake phosphorus concentrations through the NHVLAP or the UNHLLMP. In-lake phosphorus measurements will provide the most direct means of evaluating the effects of measures which have been implemented specifically to reduce phosphorus loading. As discussed in Section 5.2, the in-lake phosphorus concentrations predicted by the Nürnberg equation vary seasonally and are dependent on either stratification or mixing of the lake. As such, the monitoring program should extend from the onset of stratification through the late fall. Additionally, monitoring of phosphorus levels from a profile (samples from the epilimnion, metalimnion and hypolimnion) at the deep spot monitoring location will provide useful data on the response of internal loading to implementation of the measures recommended in Section 6.

- **Algae Monitoring:** In recent years, an increase in the observation of nuisance blue-green blooms has been one of the most notable and visible symptoms of the possible nutrient enrichment and declining water quality of Mirror Lake. Continued monitoring of the abundance and composition of the lake's algal community will provide a useful metric for understanding water quality trends in response to implementation of the measures recommended in Section 6.

- **Aquatic Plant Monitoring:** As documented in Geosyntec's 2010 aquatic vegetation survey and the "*Field Guide to the Aquatic Plants of Mirror Lake*" developed as part of this WMP project, Mirror Lake currently has an assemblage of beneficial native aquatic plants. However, invasive, non-native species such as Variable Milfoil (*Myriophyllum heterophyllum*) are present in nearby water bodies such as Lake Winnipesaukee. Invasive species have the potential to grow in dense monoculture stands that displace native plants and can accelerate eutrophication by contributing nutrients and organic biomass to the lake at a more rapid pace than native plant communities. As such, ongoing volunteer monitoring is highly recommended to increase the likelihood that any future introductions of non-native species will be quickly identified. The likelihood of success in controlling invasive species is typically much higher when an infestation is caught and aggressively treated in its early stages.

- **Public Outreach, Education and Land Use Activities:** In addition to the monitoring efforts described above, the effectiveness of recommended measures related to public outreach and land use activities can be evaluated with several simple metrics, including:

    - Quantify the number of public education brochures that are distributed to watershed residents;

    - Quantify other watershed improvements initiated by homeowners as a result of outreach and education efforts, such as installation of residential raingardens and other LID practices.

- **Watershed Boundary Refinement**: Existing data does not allow for a precise determination of the hydrologic relationship between Mirror Lake and Nineteen Mile Brook to the north. To more accurately delineate the Mirror Lake watershed, a groundwater flow investigation is recommended to study the hydrologic link between Mirror Lake and Nineteen Mile Brook via the wetlands north of Hersey Cove. This investigation will provide important information on the possibility of additional hydrologic and nutrient fluxes to Mirror Lake.

APPENDIX A:

Septic System Inventory

SEPTIC SYSTEM INVENTORY

Parcel Map-Block-Lot Number, Assessor's Parcel ID	Town	Street Address Number	Street Name	Type of Treatment System	Size of Tank (Gallons)	Volume of Treatment System (GPD or gal)	Date Treatment system installed	Septic Plan and Permit on record Town Hall	Number bedrooms served	Number People Served	Distance of drain field from Mirror Lake shoreline	Months/ year Occupied	Was data obtained from public records?	Was data obtained from door-to-door questionnaire and/or Property Owner?	What other parcels/homes share the system ?	Comments, notes, etc. Include information on seasonal use of the home (weekends, summer only, etc.)
64-2-2	Tuftonboro	88	Lang Pond Road	Septic & Leach	1250	450	2003	Y	2	?	100	?	Y	N	0	Hse. Built 2001, Plan for 3 bdrms.
64-2-5	Tuftonboro	78	Lang Pond Road	Septic Tank	500	300	1999	N	2	2	150	1	N	Y	0	Septic installed in 1999 upon purchase of property.
64-2-1	Tuftonboro	77	Lang Pond Road	Septic Tank	750	300	2004	N	2	<4	150	<6	Y	Y	0	Hse. Built 1960 - info from memory - 2004 new septic
63-1-22	Tuftonboro			Vacant		0		?					Y			
63-1-23	Tuftonboro	9	Governor John Wentworth Highway	Septic Tank with Leach field	1000	300	1975	N	2	?	100	<1	N	Y	0	
63-1-24	Tuftonboro	11	Governor John Wentworth Highway			300		N	2				Y			Hse. Built 1962
63-1-26	Tuftonboro	15	Governor John Wentworth Highway	Septic Tank	1000	300	2004	N	2	2	80	12	N	Y	0	
63-1-27	Tuftonboro	17	Governor John Wentworth Highway	Septic Tank	750	150	1969	N	1	1	75'	12	Y	Y	0	Hse. Built 1948 - Info from Septic Plan
63-1-28	Tuftonboro	19-23	Governor John Wentworth Highway	Septic Tanks	5 tanks - sizes unknown	1950	1970's	N	13	14>	75	3	Y	Y	5	Hse. Built 1968 - Pow Wow Lodges 5 Cottages, 4 unit motel
63-1-29	Tuftonboro	25	Governor John Wentworth Highway	Septic & Holding	500	1050	1961	N	7	<7	75	12	N	Y	0	7 Bedrooms - 3 are seasonal. Installed early 60's
63-1-30	Tuftonboro	27	Governor John Wentworth Highway	Setpic	500	300	1965	N	2	2	150	6	Y	Y	0	Hse. Built 1965, Tank cleaned 2009, info DJ Plumbing
63-1-31	Tuftonboro	31	Governor John Wentworth Highway	Septic Tank & Leach field	1600	450	1996	?	3	<6	300'	3	Y	Y	0	Hse. Built 1996 - info from Septic Plan - Distance to lake approx.
63-1-32	Tuftonboro	1	Oak Hill Road	Septic Tank	500	450	1950	N	3	2	60	4	Y	Y	0	Hse. Built 1940
63-1-	Tuftonboro		NOT VALID	NOT VALID		0		?					Y			
63-1-33	Tuftonboro	3	Oak Hill Road	Septic & Leach	1000	300	1985	Y	2	?	100	?	Y	N	0	Hse. Built 1900
64-1-4	Tuftonboro	1	Acorn Way	Septic & Leach	1000	450	2005	Y	3	5	200	3.5	N	Y	0	Weekends year round
64-1-3	Tuftonboro	3	Acorn Way	Septic & Leach	750	450	2007	N	3	<4	60	1	N	Y	0	Weekends in Summer only
64-1-2	Tuftonboro	5	Acorn Way	Septic	1000	300	1950	N	2	2	300	<6	Y	Y	0	Hse. Built 1950 - Septic Approved 2000, owner, memory and records
64-1-1	Tuftonboro	7	Acorn Way	Septic & Leach	500	300	1991	N	2	<4	60	3	Y	Y	0	Hse. Built 1955 - Info from DJ Septic & Memory
63-1-34	Tuftonboro	?	?	Vacant		0		?					Y			
52-1-1	Tuftonboro	7	Oak Hill	Septic & Leach	1250	450	1996	Y	3		100	?	Y	N	0	Hse. Built 1990
52-1-2	Tuftonboro	9	Oak Hill	Vacant		0		?					Y			
52-1-4	Tuftonboro	12	Chipmunk Lane	Holding Tank	500	300	1950	N	2	2	100	<4	Y	Y	0	Hse. Built 1950 - info from memory.
52-1-5	Tuftonboro	10	Chipmunk Lane	Septic Tank & Leach field	500	250	1972	N	1	2	65	1	Y	Y	0	Hse. Built 1960 - info from owner.
52-1-7	Tuftonboro	8	Chipmunk Lane	Septic Tank	500	450	1965	N	3	2 to 6	175	2.5	Y	Y	0	Hse. Built 1960 - info from memory
52-1-8	Tuftonboro	6	Chipmunk Lane	Septic/Holding Tank w/leach field	750	490	1990	N	2	4 to 5	125		N	Y	0	Septic inspected in July 2010 - good working order per document.
52-1-3	Tuftonboro	6	Oak Hill	Septic Tank	1500	450	1987	?	3	1	1000	12	Y	Y	0	Hse. Built 1990 - Info from owner/records
52-1-9	Tuftonboro	4	Chipmunk Lane	Septic & Leach	1250	450	2010	Y	3	?	100	?	Y	N	0	Hse. Built 1950
52-1-10	Tuftonboro	2	Chipmunk Lane	Septic	2500	450	2004	Y	3	2	150	6	N	Y	0	Full six months occupancy
52-1-11	Tuftonboro	17	Oak Hill	Septic Tank & Leach	1000	450	2010	N	3	<4	70'	6	Y	Y	0	Buillt 1960 - Septic Tank 1990, Leach - 2010
52-1-12	Tuftonboro	19	Oak Hill	Septic Tank	500	450	1950	N	3	1	110	4	Y	Y	0	Hse. Built 1955
52-1-14	Tuftonboro	30	Church Lane	Septic Tank	1250	600	1992	Y	4	8	100	6	N	Y	0	Septic Plan
52-1-37	Tuftonboro	5	Samm Road			450		?	3				Y			Hse. Built 2006
52-1-15	Tuftonboro	28	Church Lane	Septic Tank - Septitech 400	2000	300	2004	Y	2	2	90	6	N	Y	0	System consists of 2 - 1k gallon tanks & plans call for 4 bdrms - 8 people
52-1-16	Tuftonboro	26	Church Lane	Septic & Leach	1365	300	2007	Y	2		150	?	Y	N	0	Hse. Built 2006
52-1-17	Tuftonboro	24	Church Lane	?	?	300	?	N	2	0		0	Y	N	0	Hse. Built 1950
52-1-18	Tuftonboro	6	Steeple Lane	Septic	1000	300	2000	Y	2	?	100	?	N	Y	0	
52-1-35	Tuftonboro	11	Church Lane	Septic & Leach	?	450	1998	Y	3	?	?	?	Y	N	0	Hse. Built 1990

SEPTIC SYSTEM INVENTORY

Parcel Map-Block-Lot Number, Assessor's Parcel ID	Town	Street Address Number	Street Name	Type of Treatment System	Size of Tank (Gallons)	Volume of Treatment System (GPD or gal)	Date Treatment system installed	Septic Plan and Permit on record Town Hall	Number bedrooms served	Number People Served	Distance of drain field from Mirror Lake shoreline	Months/ year Occupied	Was data obtained from public records?	Was data obtained from door-to-door questionnaire and/or Property Owner?	What other parcels/homes share the system ?	Comments, notes, etc. Include information on seasonal use of the home (weekends, summer only, etc.)
52-1-19	Tuftonboro	4	Steeple Lane	Septic & Leach	1000	450	2004	Y	3	3	115	<6	Y	Y	0	Hse. Built 1938, 1996 Tank installed, 2004 2nd process tank & leach field. Septitech
52-1-20	Tuftonboro	2	Steeple Lane	Septic	1000	300	2005	Y	2	4	120		N	Y	0	
52-1-13	Tuftonboro	85	Governor John Wentworth Highway			600		N	4				Y			Hse. Built 1960 was 9-13 Church Lane
52-1-21	Tuftonboro	14	Church Lane	Septic & Leach	2100	450	1996	N	3	2	175	4	Y	Y	0	Hse. Built 1990 - Info from owner/Septic Plan
52-1-25	Tuftonboro			Vacant		0		?					Y			
52-1-22	Tuftonboro	12	Church Lane	Septeci & Leach	1000	450	1970's	N	3	<12	160	<6	Y	Y	0	Hse. Built 1960 - info from memory.
52-1-23	Tuftonboro	8	Church Lane	Septic		300	1973	N	2	4			N	Y	0	2 houses on one lot - 2 separate systems
52-1-23	Tuftonboro	10	Church Lane	Septic		600	2001	N	4	2			N	Y	0	
52-1-28	Tuftonboro	93	Governor John Wentworth Highway	Vacant		0		?					Y			
52-1-32	Tuftonboro	101	Governor John Wentworth Highway	Septic & Leach	1000	750	2006	Y	5	?	75	12	Y	N	1	Hse. Built 2002 shares septic with 103 GWH
52-1-36	Tuftonboro	103	Governor John Wentworth Highway	Septic & Leach	Same as 101 GWH	Same as 101 GWH	Same	Y	3	?	Same as 101 GWH	12	Y	Y	Shared with 101 GWH	Hse. Built 2007 - Survey retuned N/A for people servd
52-1-33	Tuftonboro	105	Governor John Wentworth Highway	Eviro-septic leaching	1250	450	2006	Y	3	2	85	12	N	Y	0	Adderess changed per homeowner notes & Parcel ID
52-1-34	Tuftonboro	109	Governor John Wentworth Highway	Septic & Leach	1000	450	1983	Y	3	?	100	?	Y	N	0	Hse. Built 1970
52-3-70	Tuftonboro	3	Mirror Lake Drive			450		N	3				Y			Hse. Built 1978
52-3-71	Tuftonboro	111	Governor John Wentworth Highway			450		?	3				Y			Hse. Built 1900
52-3-69	Tuftonboro	5	Mirror Lake Drive	Septic Tank	1000	450	1973	N	3	2	140	12	N	Y	0	
52-3-78	Tuftonboro	7	Mirror Lake Drive	**Vacant**		0		N					Y			
52-3-68	Tuftonboro	9	Mirror Lake Drive	Septic Tank	500	300	1960	N	2	2	125	12	N	Y	0	
52-3-67	Tuftonboro	11	Mirror Lake Drive	Septic Tank	500	450	1973	N	3	4	125	1	N	Y	0	One month per year - July
52-3-66	Tuftonboro	13	Mirror Lake Drive	Septic Tank	1500	450	1992	N	3	1	100	12	N	Y	0	1956 Orig system, 1992 1500 gallon tank, 1998 new drain field
52-3-65	Tuftonboro	15	Mirror Lake Drive	Septic Tank w/pump up	1365	450	2004	Y	3	<7	180	6	Y	Y	0	Hse. Built 1960 - Septic 2004
52-3-79	Tuftonboro	17	Mirror Lake Drive	Septic & Leach	1250	450	2006	Y	3	?	150	?	Y	N	0	Hse. Built 2007
52-3-64	Tuftonboro	19	Mirror Lake Drive	Septic Tank and Pump	500	450	1950	N	3	2	80	7	Y	Y	0	Hse. Built 1965, New leach field added and regularily pumped and serviced by Lakes Region Septic.
52-3-63	Tuftonboro	21	Mirror Lake Drive	Septic & Leach	1000	450	2004	Y	3	4	75	<6	Y	Y	0	Hse. Built 1980, Septic updated 2004 - Septic Plan shows 75' - People 4-10?
52-3-62	Tuftonboro	23	Mirror Lake Drive	Septic Tank		450	1967	N	3	2	100					
52-3-61	Tuftonboro	25	Mirror Lake Drive	Septic Tank w/leach field	1000	450	1985	N	3	2	175	12	Y	Y	0	Hse. Built 1968, updated 1985 Leach 20'x35' Blueprints Lakes Reegion Survey Service
52-3-	Tuftonboro		Mirror Lake Drive	NOT VALID		0		?					Y			
52-3-59	Tuftonboro	29	Mirror Lake Drive			450		N	3				Y			Hse. Built 1979
52-3-58	Tuftonboro	31	Mirror Lake Drive	Septic Tank w/leach field	1000	750	1988	N	5	4	93	6	Y	Y	0	Hse. Built 1940 - info from memory - people served was ? - selected 4
52-3-57	Tuftonboro	33	Mirror Lake Drive	**Vacant**		0		?								Vacant lot.
52-3-56	Tuftonboro	35	Mirror Lake Drive	Septic Tank	1000	300	1994	Y	2	2	130	12	N	Y	0	
52-3-55	Tuftonboro	37	Mirror Lake Drive	Septic Tank	750	300	1988	N	2	>3	150	<2	N	Y	0	Original system 1958, tank replaced lat 80's
52-3-54	Tuftonboro	39	Mirror Lake Drive	Septic Tank	1000	450	1985	Y	3	2	80	6	N	Y	0	Data from Septic Plan
52-3-53	Tuftonboro	41	Mirror Lake Drive	Septic Tank w/leach field	?	300	1960	N	2	1	70	3	Y	Y	0	Hse. Built 1960 - No cleaning products with phosphorus have ever been knowingly used.
52-3-52	Tuftonboro	43	Mirror Lake Drive	Vacant		0		?					Y			
52-3-80	Tuftonboro	45	Mirror Lake Drive	Septic Tank w/pump up	1000	300	1975	N AFO	2	3	300	6	N	Y	0	1975 State Approved Septic Design
52-3-51	Tuftonboro	47	Mirror Lake Drive	**Vacant**		0		?					Y			Same ownership as 45 Mirror Lake
52-3-50	Tuftonboro	49	Mirror Lake Drive	Septic Tank	1000	450	1988	N	2	2	120	12	N	Y	0	

SEPTIC SYSTEM INVENTORY

Parcel Map-Block-Lot Number, Assessor's Parcel ID	Town	Street Address Number	Street Name	Type of Treatment System	Size of Tank (Gallons)	Volume of Treatment System (GPD or gal)	Date Treatment system installed	Septic Plan and Permit on record Town Hall	Number bedrooms served	Number People Served	Distance of drain field from Mirror Lake shoreline	Months/ year Occupied	Was data obtained from public records?	Was data obtained from door-to-door questionnaire and/or Property Owner?	What other parcels/homes share the system ?	Comments, notes, etc. Include information on seasonal use of the home (weekends, summer only, etc.)
52-3-49	Tuftonboro	51	Mirror Lake Drive	Just a Plan	?	300	?	N AFO	2	?	?	?	Y	?	0	Hse. Built 1960
52-3-48	Tuftonboro	53	Mirror Lake Drive	Septic Tank & Leach field	750	300	1997	N	2	2	75	1	N	Y	0	Hse. Built 1960 # of Bdrms 1 (4wks) 2 (2wks)/yr - People 2 (4wks) 5 (2wks)
52-3-47	Tuftonboro	55	Mirror Lake Drive	Septic	1000	300	?	N	2	1	?	12	Y	Y	0	Hse. Built 1960 - Info recent Home Inspection
52-3-46	Tuftonboro	57	Mirror Lake Drive	Septic	?	450	?	Y	3	3	100	?	N	Y	0	
52-3-45	Tuftonboro	61	Mirror Lake Drive	Septic	2100	450	2004	Y	3	2	100	?	N	Y	0	
52-3-44	Tuftonboro	63	Mirror Lake Drive	Septic & Leach	1250	450	2001	Y	3	?	100	?	Y	N	0	Hse. Built 1990
52-3-82	Tuftonboro	68	Mirror Lake Drive	Vacant		0		?					Y			
52-3-43	Tuftonboro	67	Mirror Lake Drive	Septic/Holding Tank w/leach field	1000	150	1981	Y	1	1	200	12	Y	Y	0	Hse. Built 1960, Inspected 1981 3 bdrm plan.
52-3-83	Tuftonboro		Mirror Lake Drive	Vacant		0		?					Y			MLEA Common Lot
52-3-42	Tuftonboro	69	Mirror Lake Drive	Razed 3/10 by TFD		0		N								This home had been vacant for 20 years per owner.
52-3-41	Tuftonboro	71	Mirror Lake Drive	Septic	1000	600	1988	N	4	<4	250	1	N	Y	0	People served: Max 4 in the past 27 years. Last 10 years the house has been mostly empty
52-3-40	Tuftonboro	73	Mirror Lake Drive	Septic	1000	450	1990	N	3	4	80	4	Y	Y	0	Hse. Built 1960, 2 - 6 people/wk for approx 4 months (June to Sept)
52-3-39	Tuftonboro	75	Mirror Lake Drive	Septic Tank	750	450	?	N	3	1	250	12	Y	Y	0	Hse. Built 1970, regularly serviced
52-3-38	Tuftonboro	77	Mirror Lake Drive	Holding Tank	1000	450	1980	N	3	9	75	4	Y	Y	0	Hse. Built 1980 - Info from memory
52-3-37	Tuftonboro	79	Mirror Lake Drive	?	?	?	1987	N AFO	3	?	75	?	Y	N	0	Hse. Built 1990, Septic Plan only, no record of what's installed
52-3-36	Tuftonboro	81	Mirror Lake Drive	Drywell	1000	300	1950's	N	2	2	50	<2	N	Y	0	
52-3-35	Tuftonboro	83-85	Mirror Lake Drive	Septic Tank & Leach	1000	300	1971	N	2	2	85	12	N	Y	0	Full septic system with 360 Sq-Ft. Leech Field.
52-3-75	Tuftonboro		Mirror Lake Drive	Vacant		0		?					Y			
52-3-15	Tuftonboro	6	Mirror Lake Drive	Septic Tank	1000	600	1967	?	4	2	400	12	Y	Y	0	Hse. Built 1967 - Info from Memory and Assessors
52-3-16	Tuftonboro	8	Mirror Lake Drive	Septic Tank	1000	450	1974	?	3	2	250	12	Y	Y	0	Hse. Built 1973
52-3-17	Tuftonboro	10	Mirror Lake Drive	Septic	1000	450	1971	?	3	2	600	12	Y	Y	0	Hse. Built 1971
52-3-18	Tuftonboro	14	Mirror Lake Drive			450		?	3				Y			Hse. Built 1970
52-3-77	Tuftonboro	22	Mirror Lake Drive	DOES NOT EXIST		0		?					Y			
52-3- 19	Tuftonboro	22	Mirror Lake Drive	DOES NOT EXIST		0		?					Y			
52-3-21	Tuftonboro	26	Mirror Lake Drive	Septic	1000	450	1970	?	3	2	275	12	N	Y	0	
52-3-	Tuftonboro					0		?								
52-2-8	Tuftonboro	106	Governor John Wentworth Highway			600		?	4				Y			Hse. Built 1840
52-3-22	Tuftonboro	32	Mirror Lake Drive	Vacant		0		?					Y			
52-3-23	Tuftonboro	34	Mirror Lake Drive	Septic	?	450	2006	N	3	3	400	12	Y	Y	0	Hse. Built 2006
52-3-73	Tuftonboro	36	Mirror Lake Drive	Septic	1250	450	2002	?	3	2	400	12	N	Y	0	Data from Septic plan
52-3-24	Tuftonboro	38	Mirror Lake Drive	Vacant		0		?					Y			
52-3-25	Tuftonboro	40	Mirror Lake Drive			150		?	1				Y			Hse. Built 2005
52-3-26	Tuftonboro	42	Mirror Lake Drive	Vacant		0		?					Y			
52-3-27	Tuftonboro	46	Mirror Lake Drive	Vacant		0		?					Y			
52-3-28	Tuftonboro	48	Mirror Lake Drive	Vacant		0		?					Y			
52-3-29	Tuftonboro	50	Mirror Lake Drive	Septic Tank		450		?	3	1	350	12	N	Y	0	Distiance is visual approximation.
52-3-31	Tuftonboro	52	Mirror Lake Drive	Vacant		0		?					Y			
52-3-31	Tuftonboro	54	Mirror Lake Drive	Vacant		0		?					Y			

Parcel Map-Block-Lot Number, Assessor's Parcel ID	Town	Street Address Number	Street Name	Type of Treatment System	Size of Tank (Gallons)	Volume of Treatment System (GPD or gal)	Date Treatment system installed	Septic Plan and Permit on record Town Hall	Number bedrooms served	Number People Served	Distance of drain field from Mirror Lake shoreline	Months/ year Occupied	Was data obtained from public records?	Was data obtained from door-to-door questionnaire and/or Property Owner?	What other parcels/homes share the system ?	Comments, notes, etc. Include information on seasonal use of the home (weekends, summer only, etc.)
52-3-32	Tuftonboro		Mirror Lake Drive	Vacant		0		?					Y			
52-2-11	Tuftonboro		Governor John Wentworth Highway	Vacant		0		?					Y			
52-2-16	Tuftonboro	98	Governor John Wentworth Highway	Septic	1000	450	?	?	3	1	?	12	Y	Y	0	Hse. Built 1800
52-2-10	Tuftonboro	100	Governor John Wentworth Highway			300		?	2				Y			Hse. Built 1700
52-3-34	Tuftonboro		Mirror Lake Drive	Vacant		0		?					Y			
52-3-33	Tuftonboro		Mirror Lake Drive	Vacant		0		?					Y			
64-2-4	Tuftonboro		Piper Road	Vacant		0		?					Y			
52-3-91	Tuftonboro		Piper Road	Vacant		0		?					Y			
64-2-6	Tuftonboro		Piper Road	Vacant		0		?					Y			
126-19-0	Wolfeboro	50	Lang Pond Road	Septic	1500	1500 gallon	1986		4	4	300 feet		no	no	none	Not seasonal
126-18-0	Wolfeboro	29	Museum Shores Rd	Septic	1000	1000 gallon	1984		2	1	75 feet		no	from owner	None	Year Round
126-17-0	Wolfeboro	27	Museum Shores Rd	Septic	300	300 gallon	1965		1	2	80 feet		No	from owner	None	Seasonal
126-16-0	Wolfeboro	33	Museum Shores Rd	Septic	500	500 gallons	1965/1970		3	2	150 feet		no	from owner	none	Seasonal
126-15-0	Wolfeboro	37	Museum Shores Rd	Septic	1000	1000 gallon	1985		3	2	125 feet		no	from owner	none	Seasonal
126-14-0	Wolfeboro	39	Museum Shores Rd	Septic	1000	1000 gallon	1995		3	2	150 feet		No	from owner	None	Seasonal
126-13-0	Wolfeboro	43	Museum Shores Rd	Septic	1000	1000 gallon	1981		3	2			yes	no	None	Year Round - Approval #95402 - shown as Lot #4 - confirm at Town Hall
126-12-0	Wolfeboro	47	Museum Shores Rd	Septic		600 GPD	2002		4	2	260 feet		yes	DES permit	None	Seasonal
125-4-0	Wolfeboro	49	Museum Shores Rd	Septic	1000	1000 gallon	1981		3	2	150 feet		no	from owner	None	Year Round
125-3-0	Wolfeboro	51	Museum Shores Rd	Septic	1000	1000 gallon	1980		4	2	140 feet		No	from owner	None	Seasonal
125-2-0	Wolfeboro	53	Museum Shores Rd	Septic		450 GPD	2006		3	2	Unknown		yes	DES permit	None	Year Round
126-11-0	Wolfeboro	55	Museum Shores Rd	Holding Tank	500	500 gallons	1965		1	2	60		no	from owner	none	Seasonal
126-23-0	Wolfeboro	21	Museum Shores Rd	Septic	300	300 gallons	1967		3	2	350		no	no	none	Seasonal
126-10-0	Wolfeboro	None	LAND ONLY													
126-24-0	Wolfeboro	35	McCarthy Anna Rd	Septic	750	750 gallon	1986		3	Unknown	Unknown		yes	DES permit	None	Year Round - Approval #122468 (old records on file at DES)
126-9-0	Wolfeboro	34	McCarthy Anna Rd	Septic	1000	1000 gallon	???		3	2	80 feet		no	DJ Septic	None	Seasonal
125-1-0	Wolfeboro	36	McCarthy Anna Rd	Septic	500	500 gallons	1999		2	3	65 + or -		no	Judy Hampe	None	Seasonal
126-8-0	Wolfeboro	32	McCarthy Anna Rd	Septic		600 GPD	2009		4	?	Unknown		yes	DES permit	None	Year Round - approval #738
126-7-0	Wolfeboro	30	McCarthy Anna Rd													
126-6-0	Wolfeboro	None	LAND ONLY													
126-5-0	Wolfeboro	24	McCarthy Anna Rd	Septic	1000	1000 gallon	1970		3	2	120 feet		no	from owner	None	Seasonal
126-4-0	Wolfeboro	20	McCarthy Anna Rd													
126-3-0	Wolfeboro	18	McCarthy Anna Rd	Septic	1000	1000 gallon	1985		3	2	180 feet		no	Septic Plan	None	Year Round
126-25-0	Wolfeboro	23	McCarthy Anna Rd	Septic	1000	1000 gallon	1986		3	1	300 feet		no	no	none	House for sale, year round
126-26-0	Wolfeboro	None	LAND ONLY													
126-27-0	Wolfeboro	11	McCarthy Anna Rd	Septic	750	300 GPD/750 tank	1986		2	Unknown	abt 200 feet		yes	DES permit	None	Unknown if Seasonal or Year Round - Approval #130539
126-20-0	Wolfeboro	40	Lang Pond Road													
126-2-0	Wolfeboro	765	North Main Street LAND ONLY													
126-1-0	Wolfeboro	767	North Main Street													

SEPTIC SYSTEM INVENTORY

Parcel Map-Block-Lot Number, Assessor's Parcel ID	Town	Street Address Number	Street Name	Type of Treatment System	Size of Tank (Gallons)	Volume of Treatment System (GPD or gal)	Date Treatment system installed	Septic Plan and Permit on record Town Hall	Number bedrooms served	Number People Served	Distance of drain field from Mirror Lake shoreline	Months/ year Occupied	Was data obtained from public records?	Was data obtained from door-to-door questionnaire and/or Property Owner?	What other parcels/homes share the system ?	Comments, notes, etc. Include information on seasonal use of the home (weekends, summer only, etc.)
142-59-0	Wolfeboro		LAND ONLY													
142-58-0	Wolfeboro	755	North Main Street													
126-46-0	Wolfeboro	43	Lang Pond Road													
142-33-0	Wolfeboro		LAND ONLY													
144-6-0	Wolfeboro	390	Pine Hill Road	Septic		360 GPD	1969		N/a	Unknown	N/A		yes	DES permit	None	Approval #8866 on 11/18/1969
144-8-0	Wolfeboro		Parking Lot LAND ONLY													
144-7-0	Wolfeboro		Pine Hill Road LAND ONLY													
144-10-0	Wolfeboro	460	Pine Hill Road													
159-22-0	Wolfeboro		Waumbeck Rd LAND ONLY													Plan #129302 on file - never built
143-3-0	Wolfeboro		Waumbeck Rd LAND ONLY													
143-2-0	Wolfeboro	213	Waumbeck Road													
144-2-0	Wolfeboro		Waumbeck Road LAND ONLY													
127-6-0	Wolfeboro		Off Waumbeck Rd LAND ONLY													
143-12-0	Wolfeboro	3	Autumn Lane	Septic		450 GPD	2003		3	Unknown	unknown		yes	DES permit	None	Approval #CA2003052910
143-12-3	Wolfeboro	2	Autumn Lane	Septic		450 GPD	2004		3	Unknown	Unknown		yes	DES permit	None	Approval #CA2003056857

APPENDIX B:

Mirror Lake Internal Phosphorus Loading and Cyanobacteria Response (NHDES)

Mirror Lake
Tuftonboro, New Hampshire

Internal Phosphorus Loading and Cyanobacteria Response

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

2011

DES-R-WD-11-19

Mirror Lake
Internal Phosphorus Loading and Cyanobacteria Response

Final Report
2011

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1.0 INTRODUCTION AND PURPOSE

1.1 Introduction

Mirror Lake is located in the Lakes Region of New Hampshire. The 378 acre lake, located primarily in Tuftonboro, has a relatively small 1,792 acre watershed (Appendix A) within Tuftonboro (population 2,148; U.S. Census 2000) and neighboring Wolfeboro (population 6,083; U.S. Census 2000). With an average depth of 4 meters, Mirror Lake consists of a single basin with a maximum depth of 13.1 meters. The Mirror Lake Protective Association has been monitoring lake water quality through the University of New Hampshire's Center of Freshwater Biology Lakes Lay Monitoring Program since 1991.

The presence of cyanobacteria surface scums is documented by DES Beach Program personnel during the swimming season (June through August) or when there are lakeshore owner complaints. In Mirror Lake, cyanobacteria surface scums often occur in late summer and early fall, although cyanobacteria cell migration occurs through the water column throughout July to mid-October. DES biologists documented cyanobacteria blooms or surface scums on September 16, 2008 and September 2, 2010.

Mirror Lake, used mostly by lake residents and transient boaters and fisherman, was designated in the 2008 Federal Section 303(d) list as a waterbody impaired for "primary contact recreation"--a result of reoccurring cyanobacteria surface scums. Mirror Lake was not listed on the 303(d) list for the "aquatic life use" (ALU) impairment in 2010, since the 10 year median Total Phosphorus (TP) was 8.0 ug/L and chlorophyll-a (Chl-a) value was 2.7 ug/L and therefore well within or better than the criteria for mesotrophic lakes (data sources included UNH and DES). Median epilimnetic TP and Chl-a (6 meter composite) values collected by DES from May 24 through September 15, 2010 were 9.25 ug/L and 4.55 ug/L, respectively, also within the ALU criteria mesotrophic range. See Appendix B for a summary of the State's Consolidated Assessment Listing Methodology and Section 303(d)/ 305(b) reporting.

The impaired waterbody designation resulted in a DES funded EPA Section 319 NPS restoration grant to develop a watershed management plan (WMP). The Mirror Lake Watershed Management Plan, anticipated for release this year, will assist with watershed planning and outline potential best management practices to reduce phosphorus (P) loading to Mirror Lake. The WMP goals will likely include reducing cyanobacteria cell production, increasing lake clarity and increasing recreational use days. The decrease in cyanobacteria cell production and cyanotoxicity can only be achieved through phosphorus load reductions to the lake from watershed and internal P loading. Outlining a strategy to manage or control cyanobacteria cell production is an extremely difficult task. An actual in-lake phosphorus threshold concentration that limits cyanobacteria cell production has not been determined through limnological research. However, it is well documented that increased P and nitrogen (N) loading results in subsequent increases to in-lake phosphorus concentration and primary productivity. Furthermore, freshwater systems having molar ratios of total N to total P that are less than 15 become nitrogen limited and are more likely to experience cyanobacteria dominance (Smith 1983, 1990).

Phosphorus loading reductions through watershed management and hypolimnetic phosphorus inactivation were successful at Kezar Lake in North Sutton, New Hampshire

(Connor and Martin 1989). This lake restoration project effectively demonstrated that substantial chlorophyll reductions, increased lake clarity, and elimination of cyanobacteria dominance to a natural succession of phytoplankton species can occur following watershed phosphorus loading reductions and properly researched and implemented in-lake restorative efforts. Although Mirror Lake is not currently impaired for Chl-a, P load reductions both from the watershed and internally from the lake would likely lower the Chl-a concentration through a reduction of phytoplankton and cyanobacteria cell production.

Although cyanobacteria blooms are often documented in late summer and fall as the cells rise to the surface, cell densities have periodically been documented by DES biologists at monitored lake depths since 1992 (New Hampshire Department of Environmental Services, 1994). Cyanobacteria cell densities and other data show that lake temperature and hypolimnetic anoxia increase with summer progression, leading to internal phosphorus loading. Because of the simultaneous release and uptake within the sediments, documentation of internal P load rates can only be estimated through mass balance equations. Limnological studies have shown phosphorus entrainment through stratified lakes, phosphorus mixing in weakly stratified lakes and total phosphorus mixing during fall turnover. It is likely that the high hypolimnetic phosphorus load does impact Mirror Lake's water quality. Estimating the internal P load and cyanobacteria response will provide a better understanding of the impacts of internal P loading on Mirror Lake for inclusion in the Mirror Lake Watershed Management Plan.

Several in-lake Water Quality Models (Vollenweider 1976; Chapra 1975; Dillon and Rigler 1974; Kirchner and Dillon 1975; Larsen and Mercier 1976; Jones and Bachmann 1976) may be utilized in the WMP to predict the influence of watershed phosphorus loading on lake quality. These models predict in-lake phosphorus concentration based on phosphorus loads from the watershed following spring overturn, during fully-mixed conditions. These models place little emphasis on internal phosphorus loads, which can have a substantial impact on water quality, causing increased primary productivity and cyanobacteria blooms. As a result, several Nürnberg Models (1998) that account for internal P loads will also be evaluated. Only through continued research will limnologists fully understand the role of internal P loading and how it influences cyanobacteria and subsequent scum formation.

1.2 Purpose

The purpose of this Mirror Lake study was to:

1) Monitor the fully-mixed, spring and fall in-lake phosphorus conditions

2) Measure in-lake temperature, dissolved oxygen (DO), specific conductance, turbidity, pH and chlorophyll-a after the spring turnover through summer and fall until the fall turnover

3) Measure internal P loading after the spring turnover through summer and fall until the fall turnover

4) Measure internal P loading prior to cyanobacteria dominance of the phytoplankton (as measured by relative abundance)

The above information was then applied to in-lake phosphorus models to determine the internal P load impact on in-lake P concentrations and determine the P load reductions necessary to prevent increased algal and cyanobacteria cell production. These elements will be addressed in the Mirror Lake Watershed Management Plan.

2.0 METHODOLOGY

Weekly in-lake data was collected for the following lake quality parameters:

1) Temperature, dissolved oxygen (DO), specific conductance, turbidity, pH and chlorophyll-a. The deep spot depth profile was measured for the above listed parameters using a Hydrolab DataSonde 5 at intervals ranging from 0.1 to 0.5 meters. Each recorded measurement was a five-measurement average.

2) Chlorophyll-a, composite sample. Surface to mid-metalimnion or slightly deeper if Chl-a was evident below the mid-metalimnion based on data collected during the depth profile.

3) Plankton haul (80 micron net) sample to determine plankton relative abundances. Two samples were collected; one corresponding with the Chl-a sample depth (0-6 meters) and one with lake bottom depth (0-12 meters).

4) Discrete Total Phosphorus (P) samples taken at 3 meters, to represent epilimnetic and metalimnetic P concentrations, and at 11 meters, to represent hypolimnetic P concentration.

5) Secchi disk depth to measure lake clarity.

Additional nutrient sample collection included a P profile in April and October, 2010 and a P and dissolved ortho-phosphorus (DOP) profile in August, 2010.

Additional phytoplankton sample collection included meter interval discriminate plankton hauls in August, 2010.

3.0 STUDY DATA

In-lake data was collected beginning during the spring turnover in early April, 2010 and weekly from late May until the fall turnover in mid-October, 2010. The following sections discuss data collected for temperature and dissolved oxygen profiles, phosphorus, turbidity and chlorophyll-a profiles, secchi depth and relative plankton abundance.

3.1 Temperature/ Dissolved Oxygen

Temperature/DO or Temperature/LDO profiles were collected April 8 and weekly from May 27 through October 13. Figure 3-1, demonstrates that the lake was thermally destratified when water temperatures measured were between 6ºC and 12ºC. Oxygen concentrations were greater than 10 mg/l, or 90 percent saturation, throughout the April profile. Thermal stratification of the lake was documented by May 27 as seen in Figure 3-2. Hypolimnetic dissolved oxygen concentration gradually decreased throughout the month of June from approximately 15 percent to 9 percent in the bottom half meter.

Starting July 1 and continuing through August 19, a low hypolimnetic dissolved oxygen concentration area (less than 3 percent saturation) expanded. By early July, low dissolved oxygen concentrations were measured in the bottom 0.8 meters. Low dissolved oxygen concentrations were measured in late August within the bottom 4.8 (8.8-13.5 meter depth) to 5.8 (6.7-12.5 meter depth) meters with the occasional exception of a dissolved oxygen increase or spike due to increased algal productivity around 7.5 meters. See Figures 3-3 through 3-6 for dissolved oxygen percent saturation profiles. Starting in mid-September, temperature stratification began to weaken, with thermal conditions present by October 13; this is shown in Figures 3-7 and 3-8.

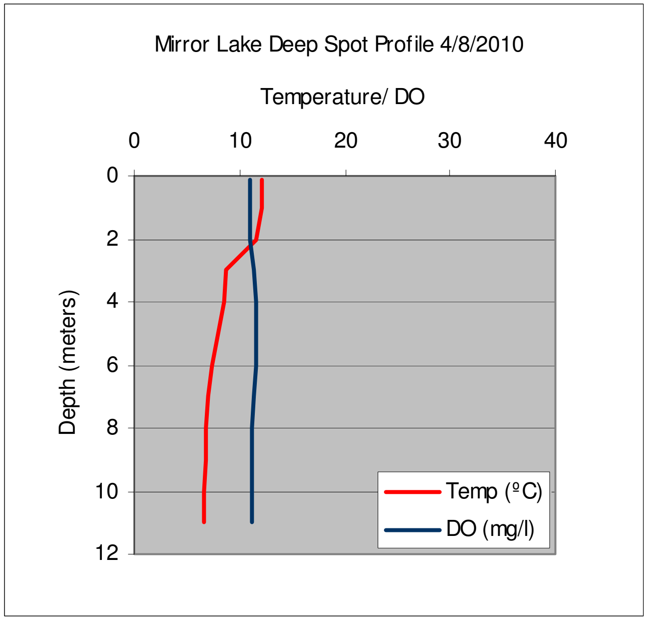

Figure 3-1: Temp/ DO profile, April 8

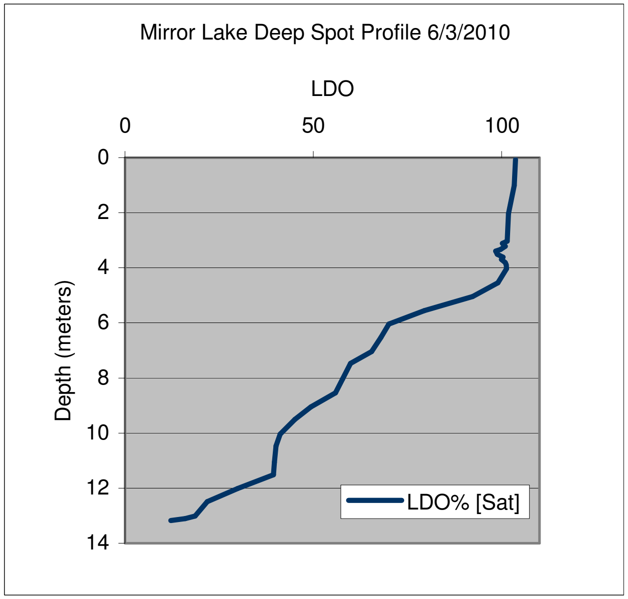

Figure 3-3: LDO profile, June 3

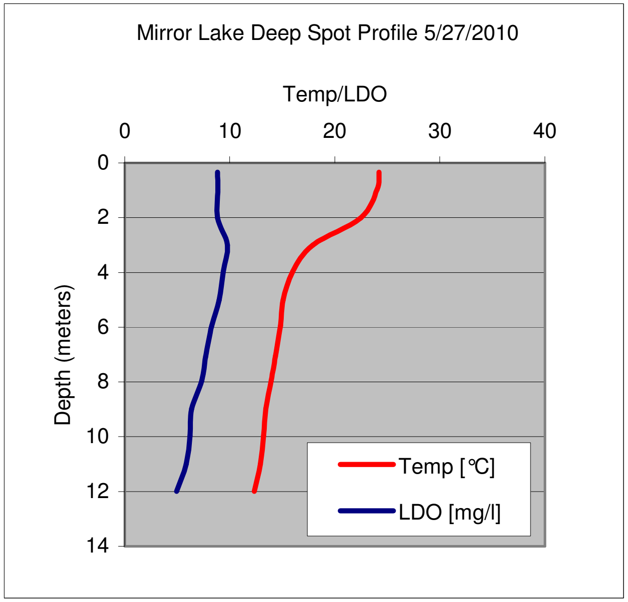

Figure 3-2: Temp/ LDO profile, May 27

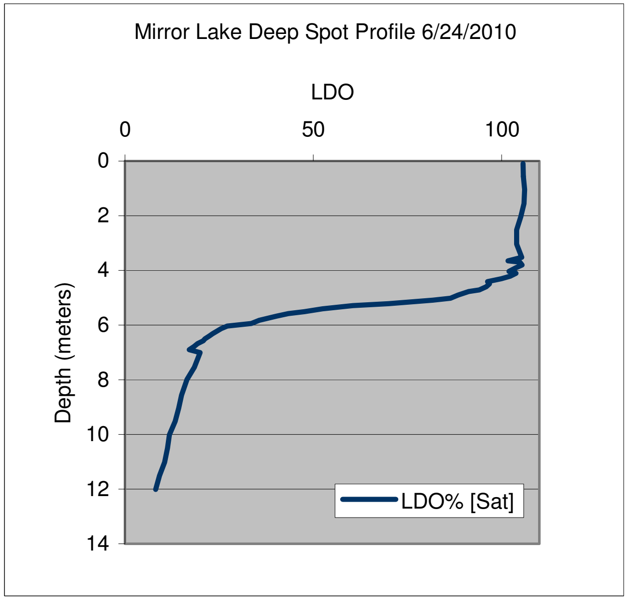

Figure 3-4: LDO profile, June 24

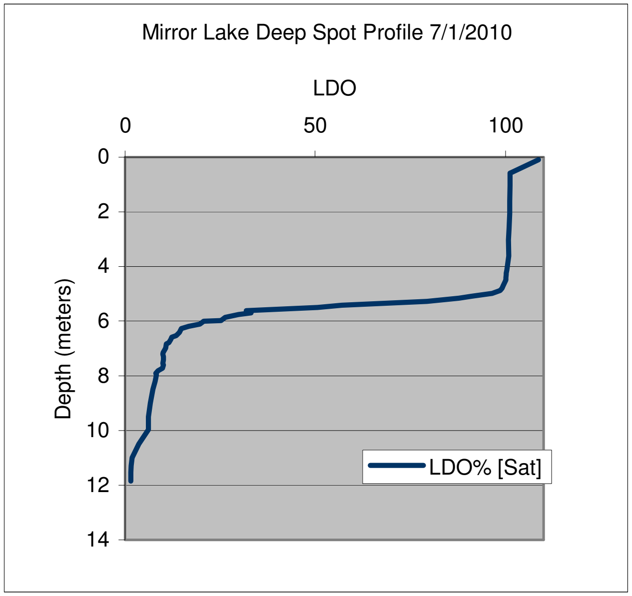

Figure 3-5: LDO profile, July 1

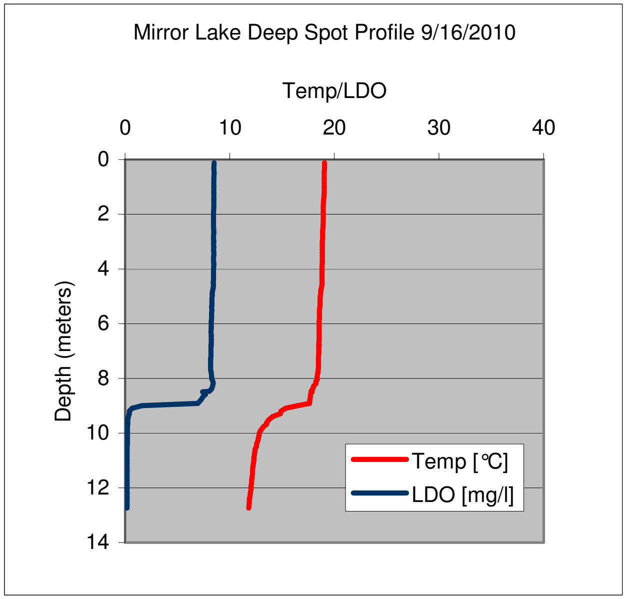

Figure 3-7: Temp/ LDO profile, September 16

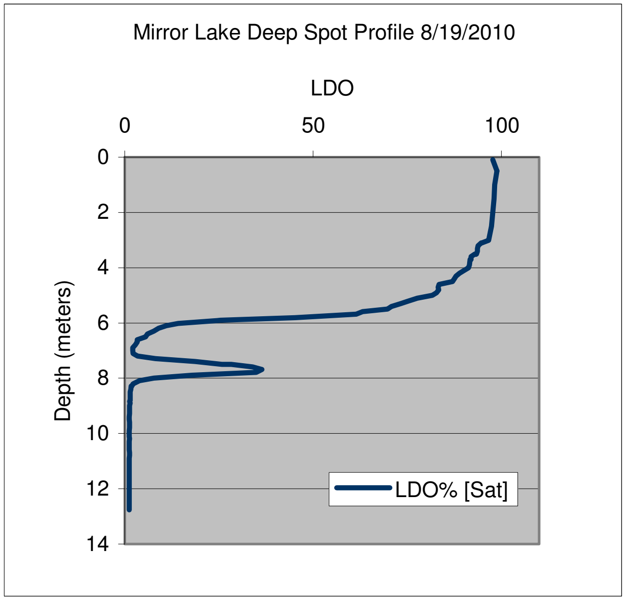

Figure 3-6: LDO profile, August 19

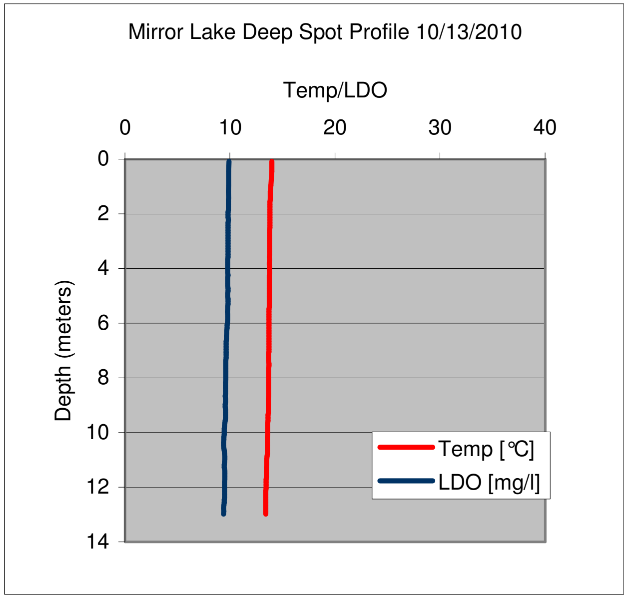

Figure 3-8: Temp/ LDO profile, October 13

3.2 Phosphorus

Total Phosphorus samples were collected on the dates and depths provided in Table 3-1.

Table 3-1: P Sample Dates and Depths

Date	Depth (meters)
April 8, 2010	1, 3, 7, 10
May 27, 2010	0.1, 2, 4, 6, 8, 10, 12, 13
September 16, 2010	0.5, 2, 4, 6, 8, 10, 12
October 13, 2010	1, 3, 7, 10
Weekly, June 3- October 13, 2010	3 (epilimnion) and 11 (hypolimnion)

The total lake volume, based on DES Lake Survey historical bathymetry, was estimated at approximately 6,185,000 cubic meters. In 2010, Mirror Lake bathymetry was reassessed. GPS was used to map 0.5 meter contours (Appendix C) for lake depths and to determine volumetric data for each half meter interval. The revised volume for Mirror Lake was 5,590,719 cubic meters.

Two methodologies, comparing whole water in-situ summer P increases were used to estimate internal P loading. These included measuring: 1) weekly in-situ summer P increases using P concentration data from the epilimnion and hypolimnion only and 2) in-situ summer P increases using P concentration profile data comparing maximum summer whole water column P mass in early September with that at the beginning of the summer period in late June, prior to summer internal P loading.

Internal P loading, weekly in-situ summer P increase comparison

Internal P loads can easily be calculated for anoxic lakes where anoxia is fully contained in the hypolimnion. Assuming uniform hypolimnetic P concentrations, simply multiply the hypolimnetic P concentration by the hypolimnetic lake volume. However, in Mirror Lake, anoxic conditions are present in the metalimnion from mid-August through September as the lake thermocline deepens during periods of warm summer temperatures. As a result, the hypolimnetic P mass does not remain in the hypolimnion and is instead transported physically as a result of thermocline deepening and biologically by algae and cyanobacteria at the hypolimnion-metalimnion interface and within the metalimnion.

To estimate the P load representative of internal P loading in Mirror Lake, P loads for the hypolimnion and the epilimnion/metalimnion must be calculated. Since metalimnetic P samples were not collected weekly, epilimnetic P samples were used to represent both metalimnetic and epilimnetic P. P mass values were extrapolated for each of the lake layers (hypolimnion and reduced volume epilimnion/metalimnion) by multiplying the P concentration by the associated depth volume; either the 0-9 meter depth volume directly over the 9 meter depth plane (Volume B), representing the epilimnion and metalimnion, or 9-13.5 meter depth volume (Volume C) to represent the hypolimnion. To simplify the internal P load estimate, it was assumed that: 1) the epilimnetic/ metalimnetic volume that receives internal P loads is directly above where internal P loads are generated, 2) the anoxic hypolimnion is below 9 meters as derived from profile data and 3) that the internal P load transported to the epilimnion/metalimnion was evenly distributed throughout that volume. See Figure 3-9 for the Mirror Lake volume distribution used to calculate internal loading. Volume A is the remaining volume in the epilimnion and hypolimnion that is assumed to receive no internal P loads prior to destratification.

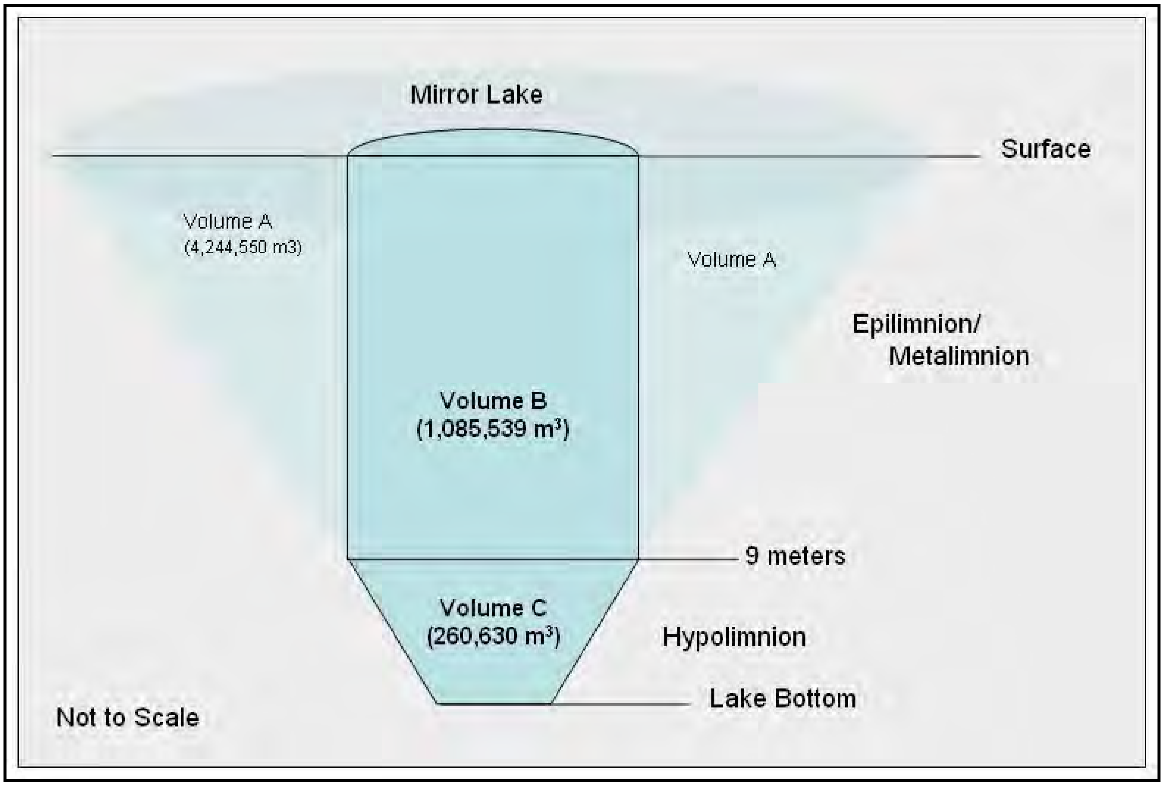

Figure 3-9: Mirror Lake Volume Distribution

To determine the P load representative of hypolimnetic internal P loading, a baseline P mass value prior to initiation of internal P loading in the hypolimnion was established. From May 27 through June 24, the hypolimnetic P mass ranged from 3.1 to 5.7 kg (Table 3-2). On June 24, the baseline hypolimnetic P mass equaled 5.2 kg. Any increase in hypolimnetic P mass after June 24 was considered a result of internal P loads. Internal P loading was due to a decrease in hypolimnetic oxygen below 2 percent and corresponding increase in hypolimnetic P concentration from 20 ug/l to 27 ug/l from June 24 to July 1.

To determine the P load representative of internal P loading in the epilimnion/metalimnion, a baseline P mass value for the epilimnion/metalimnion was established. On July 1, the baseline epilimnetic/metalimnetic P mass equaled 6.6 kg. Any increase in epilimnetic/metalimnetic P mass after July 8 was assumed to be due to internal P loads transported from the hypolimnion. This was supported by a P concentration increase in the deep spot epilimnion after July 8.

As the summer and anoxic conditions progressed, the P loads resulting from internal loading increased. On September 1, at the approximate height of internal P loading, a maximum internal P load of 30.9 kg existed in Mirror Lake. (See Appendices D and E.)

There are several shortcomings to this modeling approach. There is a lack of metalimnetic P data throughout the sampling season, site specific lake P data other than the deep spot and fluid dynamics modeling that would have yielded a better understanding of internal P load distribution throughout the lake system. In addition, variability in the predicted P mass and resulting load is dependent on the start and end dates selected for the model input based up P concentration trends. To reduce this variability, a trend line based upon the weekly data shown in Appendix E can be drawn representing the daily P mass increase in both the hypolimnion (6/24 – 9/1) and epilimnion/metalimnion (7/8 – 8/12 or 8/13 – 9/1); this also represents the internal P loads (Figure 3-10). If the slope of each trend line is multiplied by the number of internal P load days, [70 for the hypolimnion and 36 (7/8 – 8/12 time period) or 20 (8/13 – 9/1 time period) for the epilimnion/metalimnion] and summed, this variability is reduced. The resulting internal P load calculation is therefore reduced to 24.69 kg (Table 3-2).

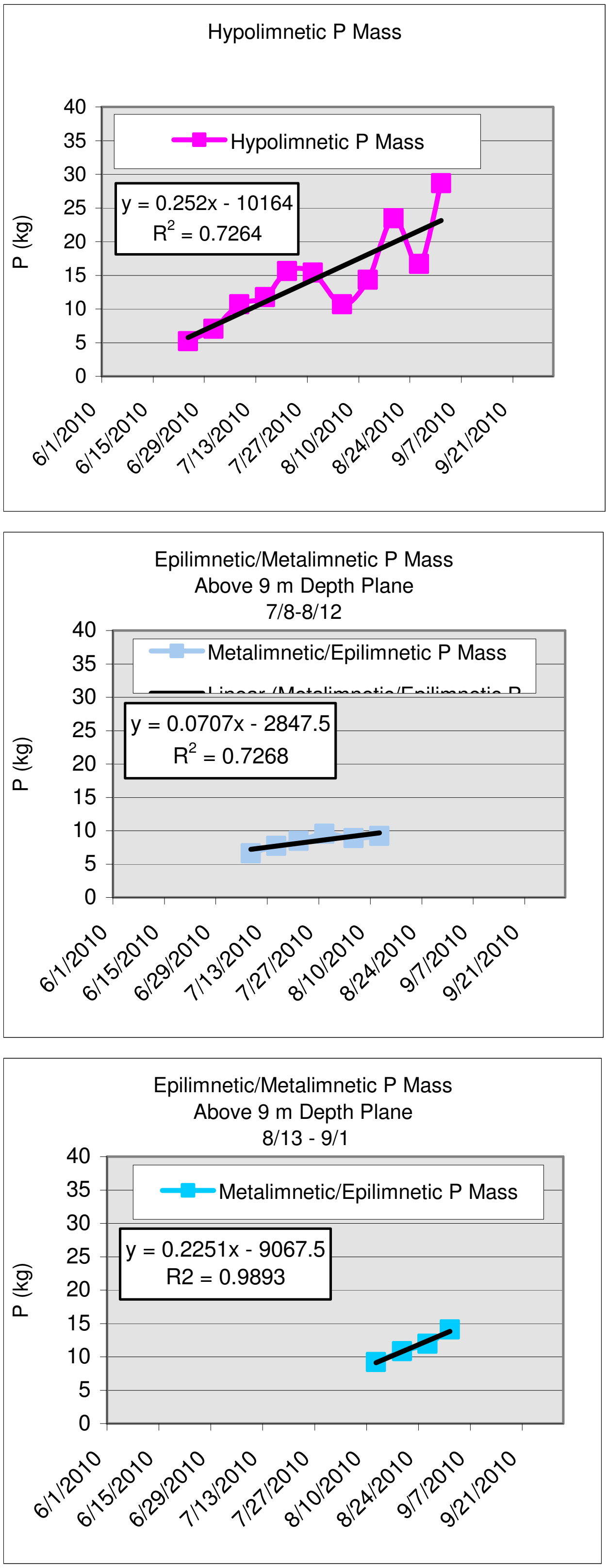

Figure 3-10: Hypolimnetic P Mass and Epilimnetic/Metalimnetic P Mass Trend Lines

Table 3-2: Weekly Internal P Load, Hypo. and Epi./Meta. Trend Line

	Trend Line Slope	Internal P Load Period	Internal P load Days	Internal P Load (kg)
Hypo.	0.2520	6/24-9/1	70	17.64
Meta./Epi.	0.0707	7/8-8/12	36	2.55
Meta./Epi.	0.2251	8/13-9/1	20	4.50
Total Internal P Load				**24.69**

Internal P loading, late spring versus late summer in-situ comparison

A second methodology, late spring versus late summer in-situ comparison, was used to estimate P loads resulting from internal loading (Nürnberg 1987). To estimate internal P loads, maximum whole water column P mass during maximum anoxia in September was compared to whole water P mass in late May prior to internal P loading. For Mirror Lake, P profiles were collected on April 8 during spring, fully-mixed lake conditions; May 27, prior to internal loading; September 16, at the height of internal P loading and therefore the approximate maximum summer whole water P mass; and October 13, during fall, fully-mixed lake conditions. Whole water P mass estimates were determined by multiplying concentrations by volumes. Volumes were first calculated as they were in Figure 3-9, with the exception that the water column volume directly above the 9 meter depth plane was further divided based upon P sample collection on that date (Figure 3-11). The resulting whole water P mass difference from May to September resulting from internal P loading was 6.2 kg (Table 3-3). However, a whole water P mass difference of 6.2 kg likely underestimates the internal P load as it only captures the internal P load that is transported from the hypolimnion vertically throughout the lake, ignoring any lateral transport from the hypolimnion.

To account for the P load transported laterally, it was assumed that the majority of the lateral transport would occur in the metalimnion, where the P could be assimilated by algae. The epilimnion/metalimnion interface on September 16 was approximately 3.5 meters. The model showed that if laterally-mixed conditions occurred within each lake layer as depicted in Figure 3-12 from approximately 3.5 meters to the bottom, that 15.6 kg of the 82.4 kg total lake P mass resulted from internal P loading when compared to the May 27 whole water P mass estimate (66.8 kg P) as shown in Table 3-4.

As with the previous models, there are shortcomings to this modeling approach, including a lack of P data within other parts of the lake to verify the extent of lateral P transport or increased fluid dynamics modeling. Having additional P data and fluid dynamics modeling would have yielded a better understanding of the distribution of internal P loads throughout the lake system.

The internal P load models provided outputs that suggest the internal summer P load for Mirror Lake in 2010 fell between 6.2 kg and 24.69 kg. Recognizing there will be output variability with any model, the weekly in-situ summer P increase comparison (24.69 kg P) was considered to yield the most robust model output since this methodology accounted for more detailed, weekly P load assessments. As a result, this value will be applied to Section 4.0 of this report.

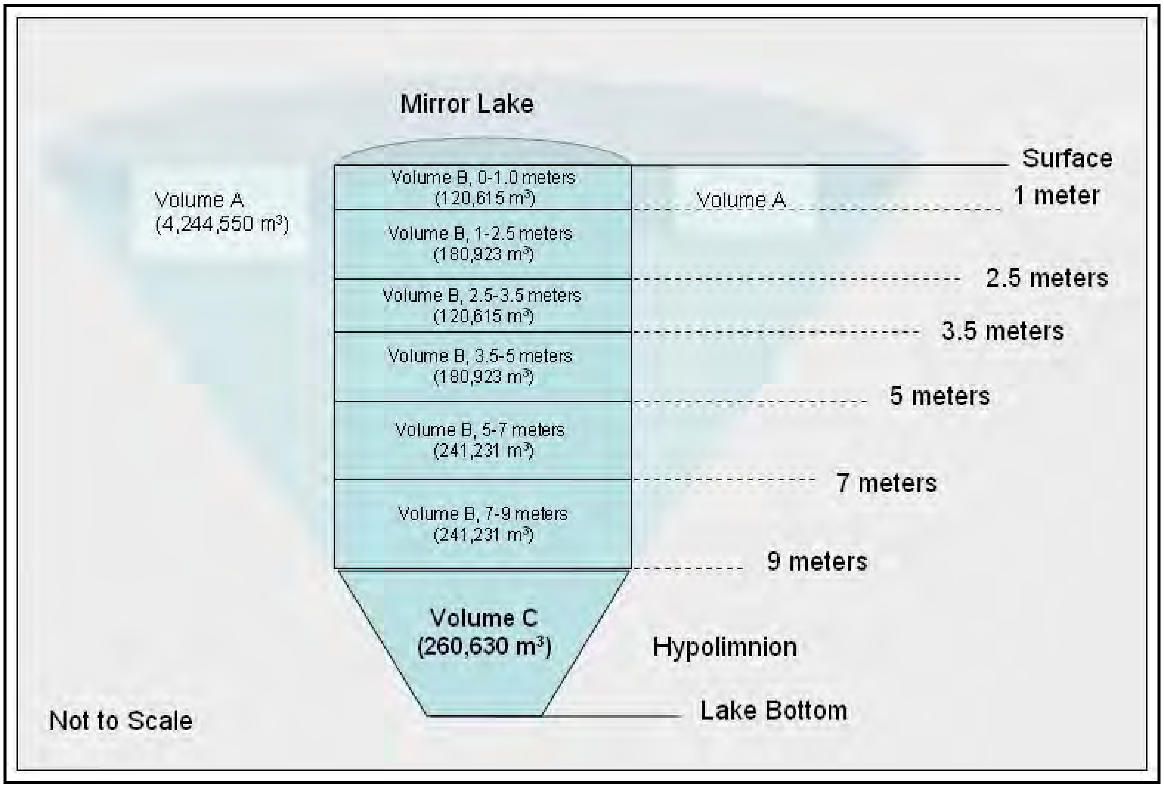

Figure 3-11: Mirror Lake Volume Distribution, September 16: Vertical P Transport

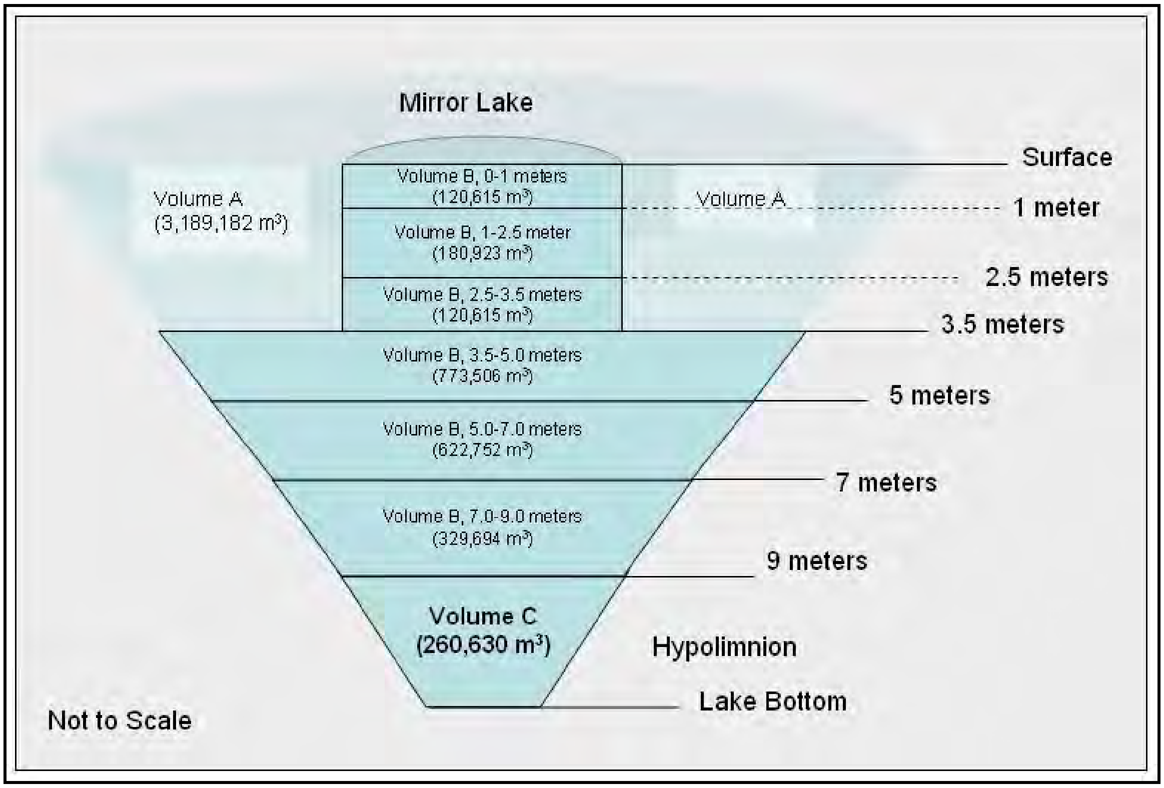

Figure 3-12: Mirror Lake Volume Distribution, September 16: Vertical and Horizontal P Transport

Table 3-3: Mirror Lake Phosphorus Whole Water Profiles with Vertical P Transport

<table>
<tr><td colspan="7">4/8/2010</td></tr>
<tr><td>Depth (m)</td><td colspan="2">TP (ug/l)</td><td colspan="2">Volume (l)</td><td>Mass (kg)</td><td>Volume-Weighted Avg. P (ug/l)</td></tr>
<tr><td>1.00</td><td colspan="2">12.0</td><td colspan="2">2341204229</td><td>28.1</td><td rowspan="4"></td></tr>
<tr><td>3.00</td><td colspan="2">10.0</td><td colspan="2">2036438871</td><td>20.4</td></tr>
<tr><td>7.00</td><td colspan="2">9.7</td><td colspan="2">887796578</td><td>8.6</td></tr>
<tr><td>10.00</td><td colspan="2">9.8</td><td colspan="2">325280846</td><td>3.2</td></tr>
<tr><td colspan="3">Total</td><td colspan="2">5590720523</td><td>60.3</td><td>0.0108</td></tr>
<tr><td colspan="7">5/27/2010</td></tr>
<tr><td>Depth (m)</td><td colspan="2">TP (ug/l)</td><td colspan="2">Volume (l)</td><td>Mass (kg)</td><td>Volume-Weighted Avg. P (ug/l)</td></tr>
<tr><td>0.100</td><td colspan="2">11.0</td><td colspan="2">1256165093</td><td>13.8</td><td rowspan="8"></td></tr>
<tr><td>2.000</td><td colspan="2">12.0</td><td colspan="2">2001673183</td><td>24.0</td></tr>
<tr><td>4.000</td><td colspan="2">11.0</td><td colspan="2">1119804824</td><td>12.3</td></tr>
<tr><td>6.000</td><td colspan="2">15.0</td><td colspan="2">622752132</td><td>9.3</td></tr>
<tr><td>8.000</td><td colspan="2">12.0</td><td colspan="2">329694994</td><td>4.0</td></tr>
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<tr><td>12.000</td><td colspan="2">14.0</td><td colspan="2">68278829</td><td>1.0</td></tr>
<tr><td>13.000</td><td colspan="2">18.0</td><td colspan="2">7570768</td><td>0.1</td></tr>
<tr><td colspan="3">Total</td><td colspan="2">5590720523</td><td>66.8</td><td>0.0119</td></tr>
<tr><td colspan="7">9/16/2010</td></tr>
<tr><td>Depth (m)</td><td>TP (ug/l) (Vol A)</td><td>TP (ug/l) (Vol B/C)</td><td>Volume A (l)</td><td>Volume B/C (l)</td><td>Mass (kg)</td><td>Volume-Weighted Avg. P (ug/l)</td></tr>
<tr><td>0.5</td><td>9.6</td><td>11.0</td><td>1135549548</td><td>120615545</td><td>12.2</td><td rowspan="9"></td></tr>
<tr><td>2.0</td><td>9.6</td><td>11.0</td><td>1389422858</td><td>180923317</td><td>15.3</td></tr>
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<tr><td>10.0</td><td>N/A</td><td>32.0</td><td>N/A</td><td>148422219</td><td>4.7</td></tr>
<tr><td>11.0</td><td>N/A</td><td>92.0</td><td>N/A</td><td>66339157</td><td>6.1</td></tr>
<tr><td>12.0</td><td>N/A</td><td>140.0</td><td>N/A</td><td>45868920</td><td>6.4</td></tr>
<tr><td colspan="3">Total</td><td colspan="2">5590720523</td><td>72.9</td><td>0.0130</td></tr>
<tr><td colspan="7">10/13/2010</td></tr>
<tr><td>Depth</td><td colspan="2">TP (mg/l)</td><td colspan="2">Volume (l)</td><td>Mass (kg)</td><td>Volume-Weighted Avg. P (ug/l)</td></tr>
<tr><td>1.000</td><td colspan="2">14.0</td><td colspan="2">2341204229</td><td>32.8</td><td></td></tr>
<tr><td>3.000</td><td colspan="2">14.0</td><td colspan="2">2036438871</td><td>28.5</td><td></td></tr>
<tr><td>7.000</td><td colspan="2">12.0</td><td colspan="2">887796578</td><td>10.7</td><td></td></tr>
<tr><td>10.000</td><td colspan="2">12.0</td><td colspan="2">279411926</td><td>3.4</td><td></td></tr>
<tr><td>11.000</td><td colspan="2">12.0</td><td colspan="2">45868920</td><td>0.6</td><td></td></tr>
<tr><td colspan="3">Total</td><td colspan="2">5590720523</td><td>75.8</td><td>0.0136</td></tr>
<tr><td colspan="5">P Load increase from April 8 to May 27, 2010</td><td>6.5</td><td rowspan="3"></td></tr>
<tr><td colspan="5">P Load increase from May 27 to September 16, 2010 (Internal P Load)</td><td>6.2</td></tr>
<tr><td colspan="5">P Load increase from September 16 to October 13, 2010</td><td>2.9</td></tr>
</table>

Table 3-4: Mirror Lake Phosphorus Whole Water Profiles with Vertical and Horizontal P Transport

4/8/2010						
Depth (m)	TP (ug/l)		Volume (l)		Mass (kg)	Volume-Weighted Avg. P (ug/l)
1.00	12.0		2341204229		28.1	
3.00	10.0		2036438871		20.4	
7.00	9.7		887796578		8.6	
10.00	9.8		325280846		3.2	
Total			**5590720523**		**60.3**	0.0108
5/27/2010						
Depth (m)	TP (ug/l)		Volume (l)		Mass (kg)	Volume-Weighted Avg. P (ug/l)
0.100	11.0		1256165093		13.8	
2.000	12.0		2001673183		24.0	
4.000	11.0		1119804824		12.3	
6.000	15.0		622752132		9.3	
8.000	12.0		329694994		4.0	
10.000	12.0		184780700		2.2	
12.000	14.0		68278829		1.0	
13.000	18.0		7570768		0.1	
Total			**5590720523**		**66.8**	0.0119
9/16/2010						
Depth (m)	TP (ug/l) (Vol A)	TP (ug/l) (Vol B/C)	Volume A (l)	Volume B/C (l)	Mass (kg)	Volume-Weighted Avg. P (ug/l)
0.5	9.6	11.0	1135549548	120615545	12.2	
2.0	9.6	11.0	1389422858	180923317	15.3	
3.0	9.6	16.0	657009920	120615545	8.2	
4.0	N/A	24.0	N/A	773506366	18.6	
6.0	N/A	12.0	N/A	622752132	7.5	
8.0	N/A	10.0	N/A	329694994	3.3	
10.0	N/A	32.0	N/A	148422219	4.7	
11.0	N/A	92.0	N/A	66339157	6.1	
12.0	N/A	140.0	N/A	45868920	6.4	
Total			**5590720523**		**82.4**	0.0147
P Load increase from April 8 to May 27, 2010					**6.5**	
P Load increase from May 27 to September 16, 2010 (Internal P Load)					**15.6**	

3.3 Chlorophyll-a

Chlorophyll-a concentration is a measure of a green photosynthetic pigment present in phytoplankton and cyanobacteria cells. Measuring Chl-a, provides biologists with an indication of lake productivity through phytoplanktonic cellular concentration in the water column at any given time. Chl-a composite samples are typically collected as whole water samples from the water column where light-dependent algal productivity typically occurs (surface to the metalimnion). In addition to collecting Chl-a composite samples, for this study, Chl-a measurements were recorded from the surface to approximately 12 meters using a Hydrolab DS5 and Turner fluorescent chlorophyll-a sensor to develop Chl-a profiles. The collection of chlorophyll-a data identified potential cyanobacteria layers migrating from the hypolimnion to the metalimnion and epilimnion.

Maximum or peak Chl-a values varied throughout the 2010 summer season. Chl-a concentrations were less than 10 ug/l from late May to mid-June, 10 - 75 ug/l from mid-June to mid-August and less than 15 ug/l from mid-August to mid-October. Algal and/or cyanobacteria densities, as measured by chlorophyll-a concentration, were greatest within the metalimnion on most sampling events. Several sampling events revealed increased secondary Chl-a concentrations from mid-July through early September measured at the uppermost hypolimnetic section. The following profiles, Figures 3-13 through 3-32, show the progression of the Chl-a concentrations from May through October.

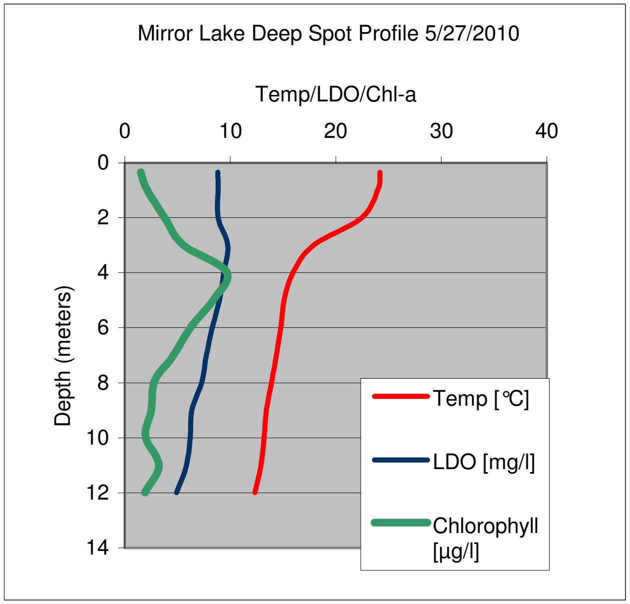

Figure 3-13: Temp/LDO/ Chl-a profile, May 27

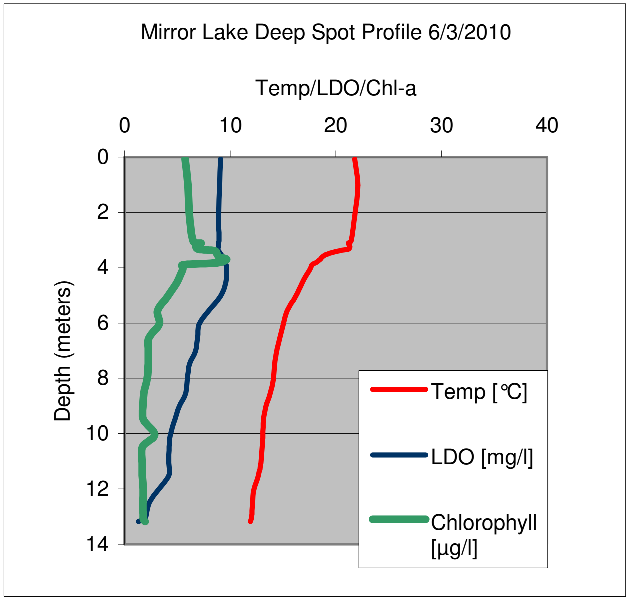

Figure 3-14: Temp/LDO/ Chl-a profile, June 3

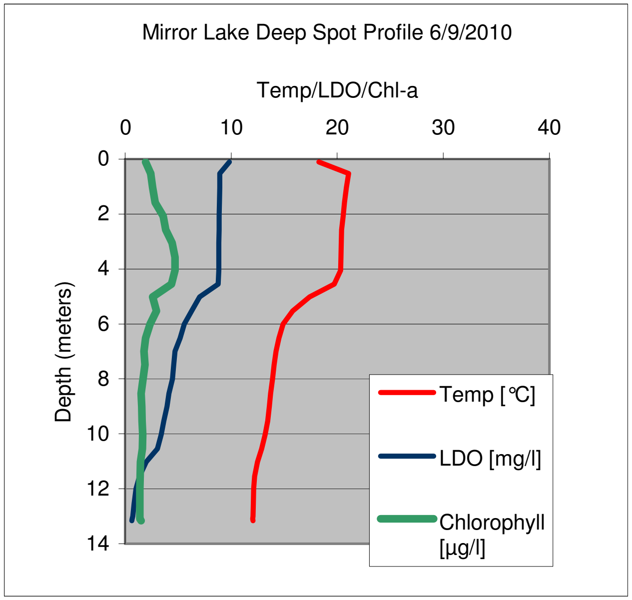

Figure 3-15: Temp/LDO/ Chl-a profile, June 9

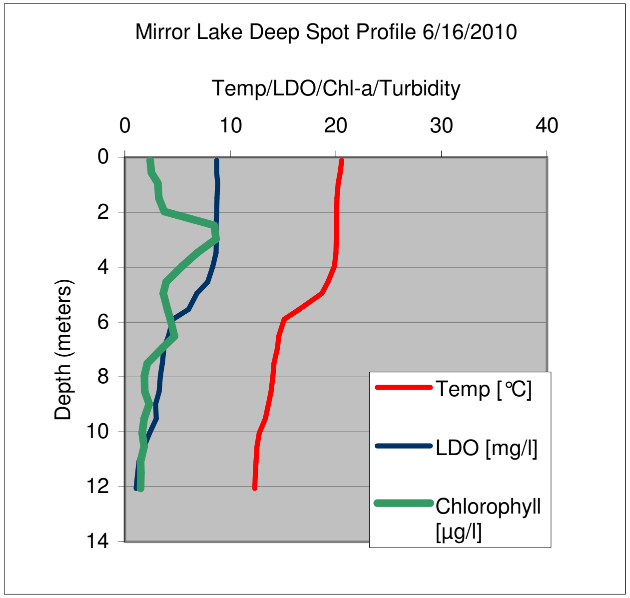

Figure 3-16: Temp/LDO/ Chl-a profile, June 16

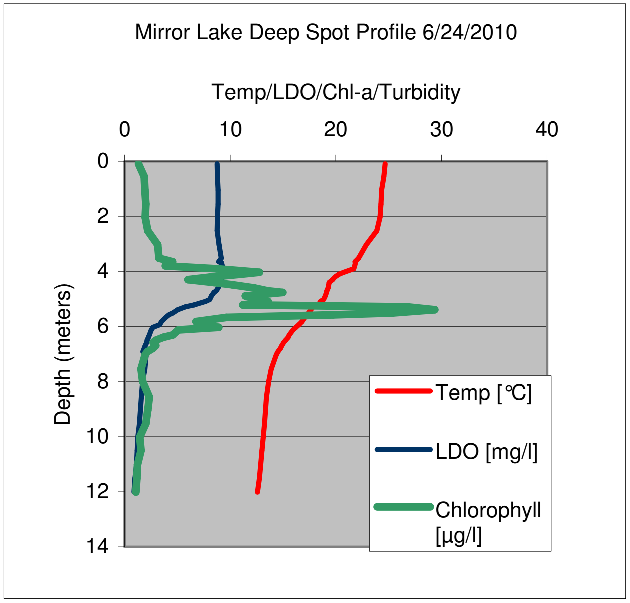

Figure 3-17: Temp/LDO/ Chl-a profile, June 24

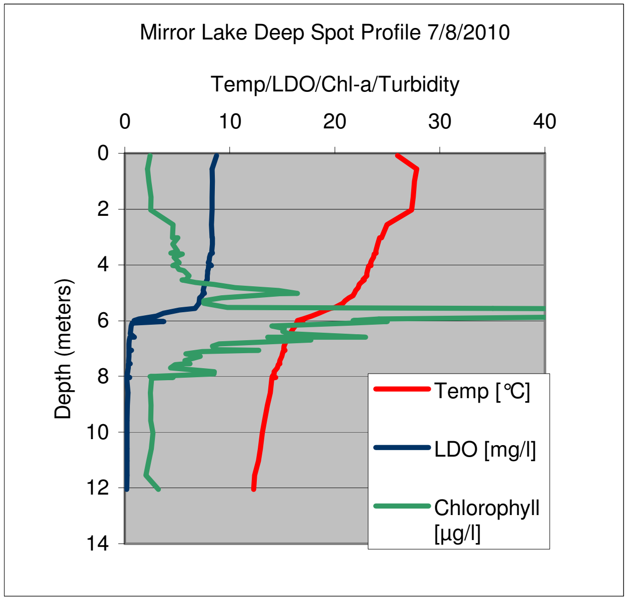

Figure 3-19: Temp/LDO/ Chl-a profile, July 8

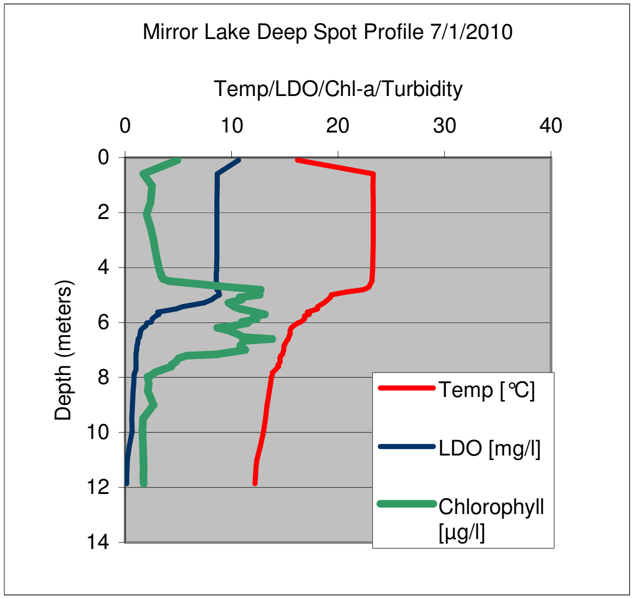

Figure 3-18: Temp/LDO/ Chl-a profile, July 1

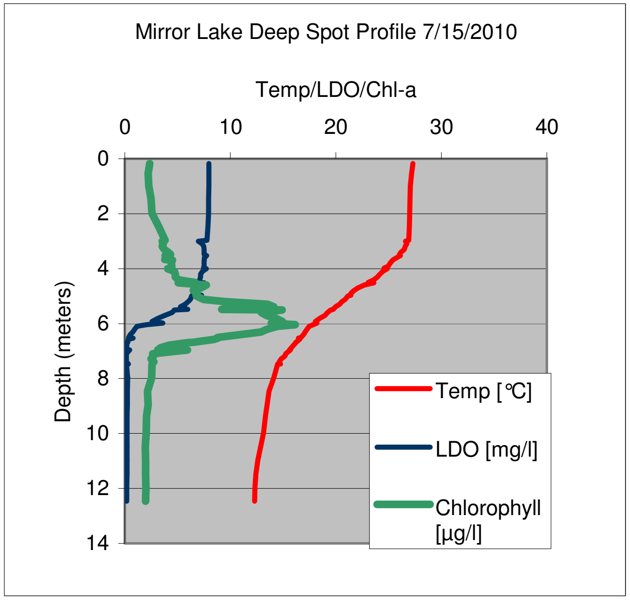

Figure 3-20: Temp/LDO/ Chl-a profile, July 15

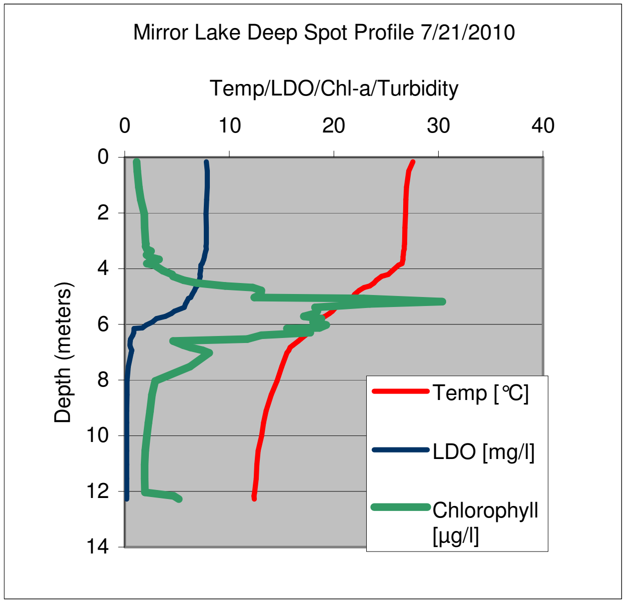

Figure 3-21: Temp/LDO/ Chl-a profile, July 21

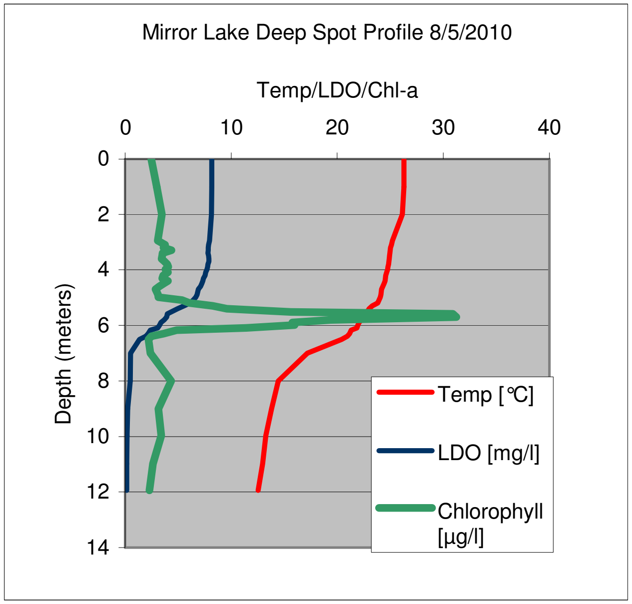

Figure 3-23: Temp/LDO/ Chl-a profile, August 5

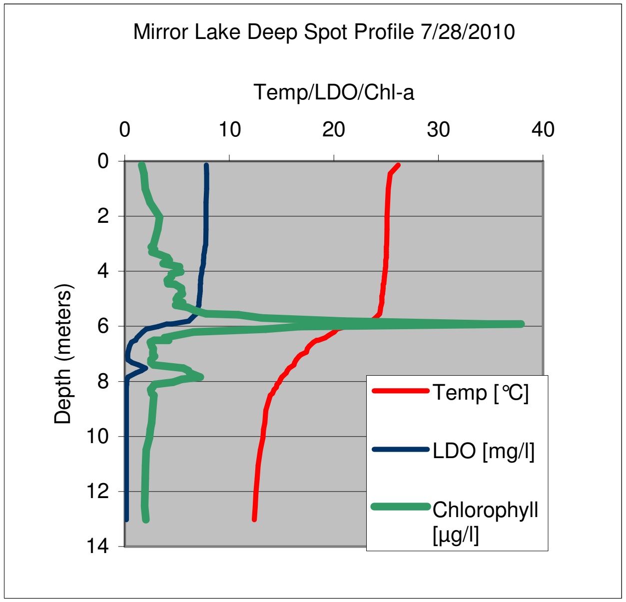

Figure 3-22: Temp/LDO/ Chl-a profile, July 28

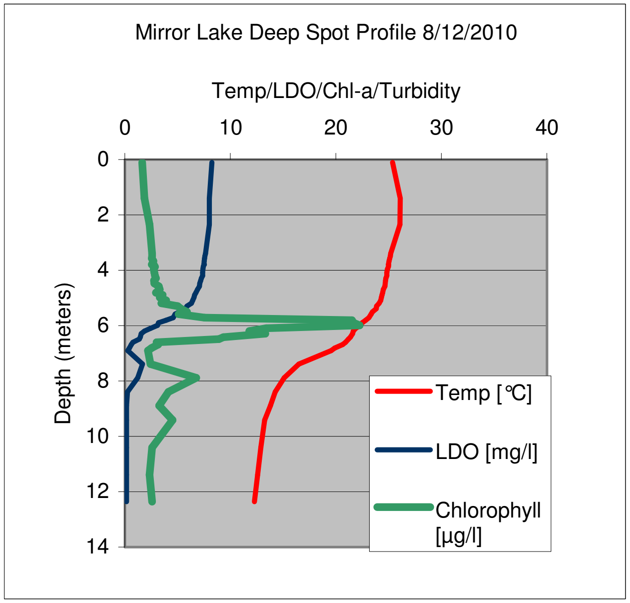

Figure 3-24: Temp/LDO/ Chl-a profile, August 12

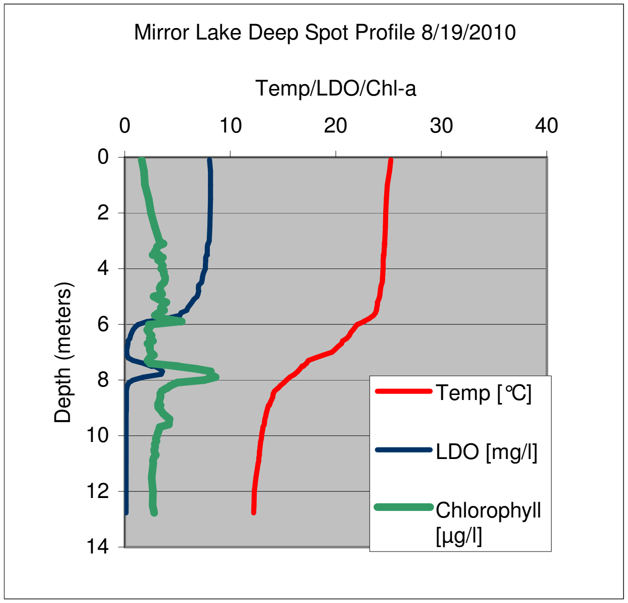

Figure 3-25: Temp/LDO/ Chl-a profile, August 19

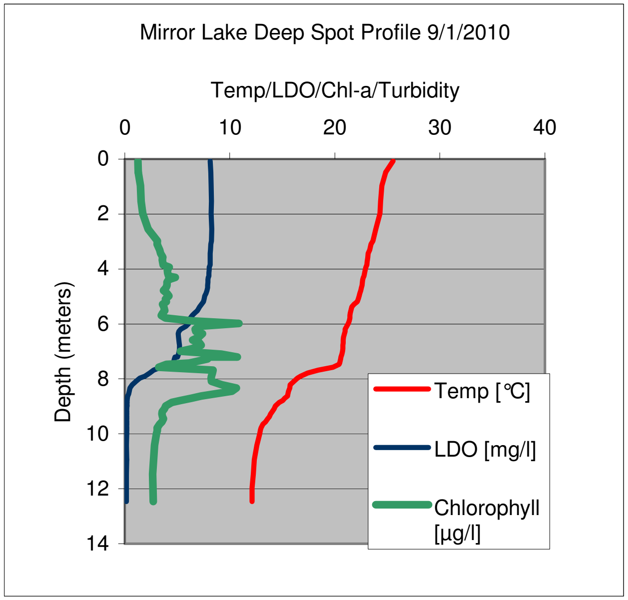

Figure 3-27: Temp/LDO/ Chl-a profile, September 1

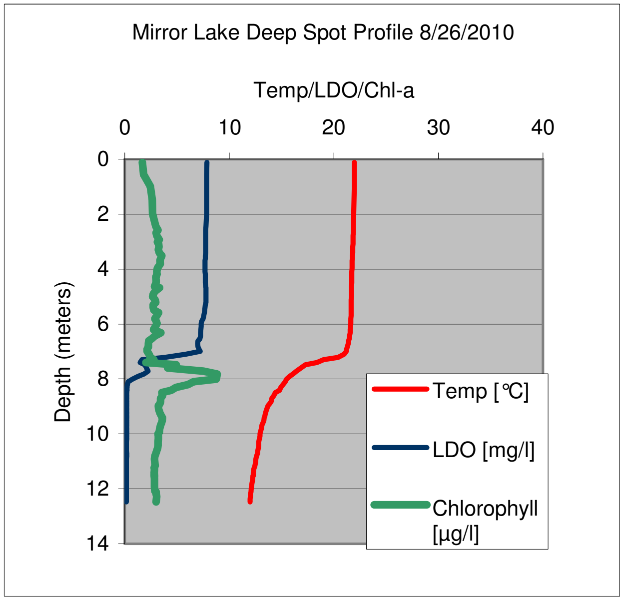

Figure 3-26: Temp/LDO/ Chl-a profile, August 26

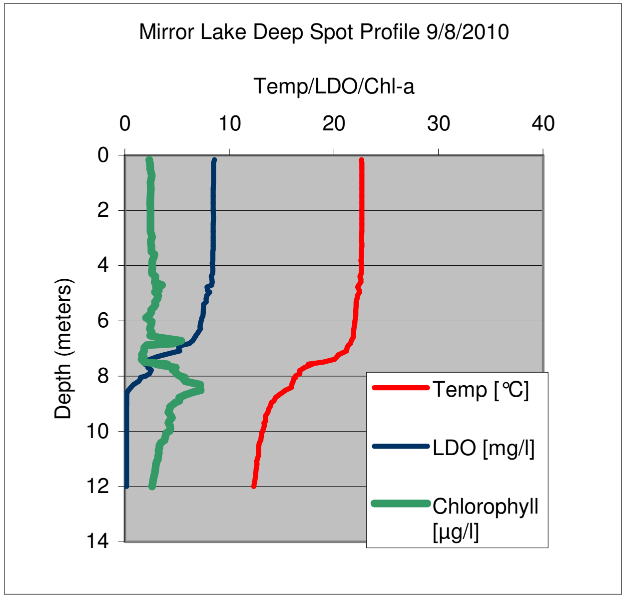

Figure 3-28: Temp/LDO/ Chl-a profile, September 8

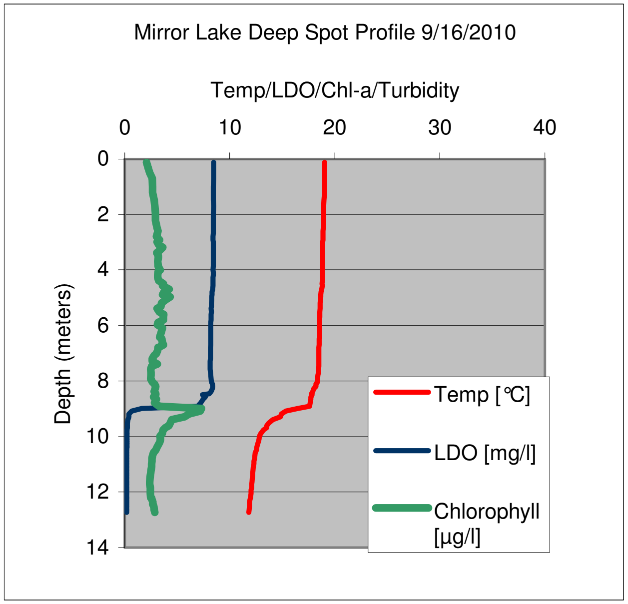

Figure 3-29: Temp/LDO/ Chl-a profile, September 16

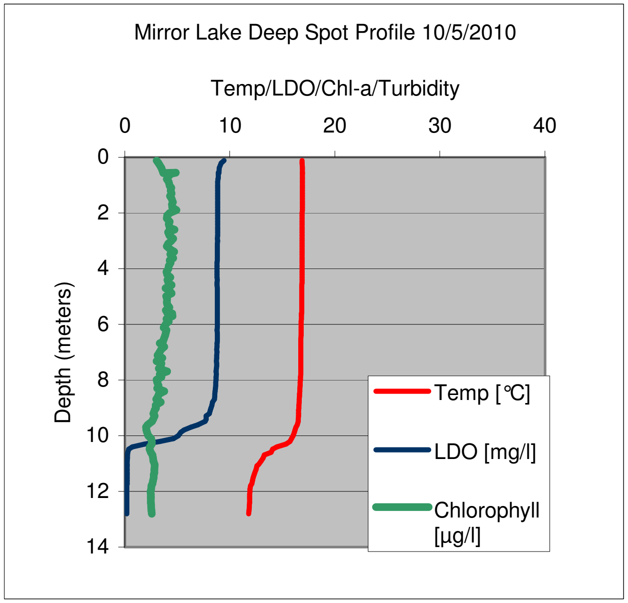

Figure 3-31: Temp/LDO/ Chl-a profile, October 5

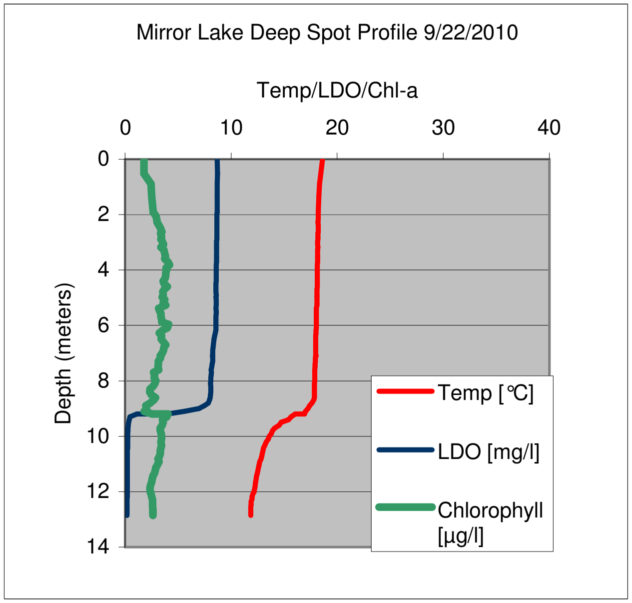

Figure 3-30: Temp/LDO/ Chl-a profile, September 22

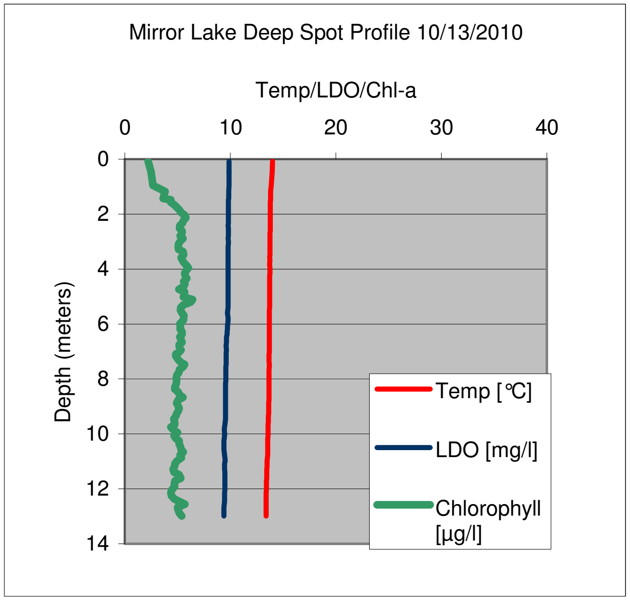

Figure 3-32: Temp/LDO/ Chl-a profile, October 13

3.4 Secchi Depth

Secchi depth measurements were recorded on a weekly basis from May through October (Figure 3-33). During the early summer months, end of May through early July, the secchi depth averaged 3.74 meters. Within two weeks of the onset of hypolimnetic internal loading, secchi depth increased, averaging 5.08 meters. This is most likely a result of a shift in algal productivity deeper in the water column, as seen in Figures 3-20 through 3-23. Secchi depth decreased slightly in early August to 4.43 meters, and decreased again to 3.70 meters in late August. The decrease in late August may be a result of significant rainfall in the previous 24 hours (1.63 inches, Manchester, NOAA), causing the transport of suspended solids into the lake, decreasing clarity. Secchi depth slightly increased to a mean depth of 4.69 meters during the month of September and again decreased to a mean depth of 4.00 meters in early October as the lake became fully-mixed during the fall turnover.

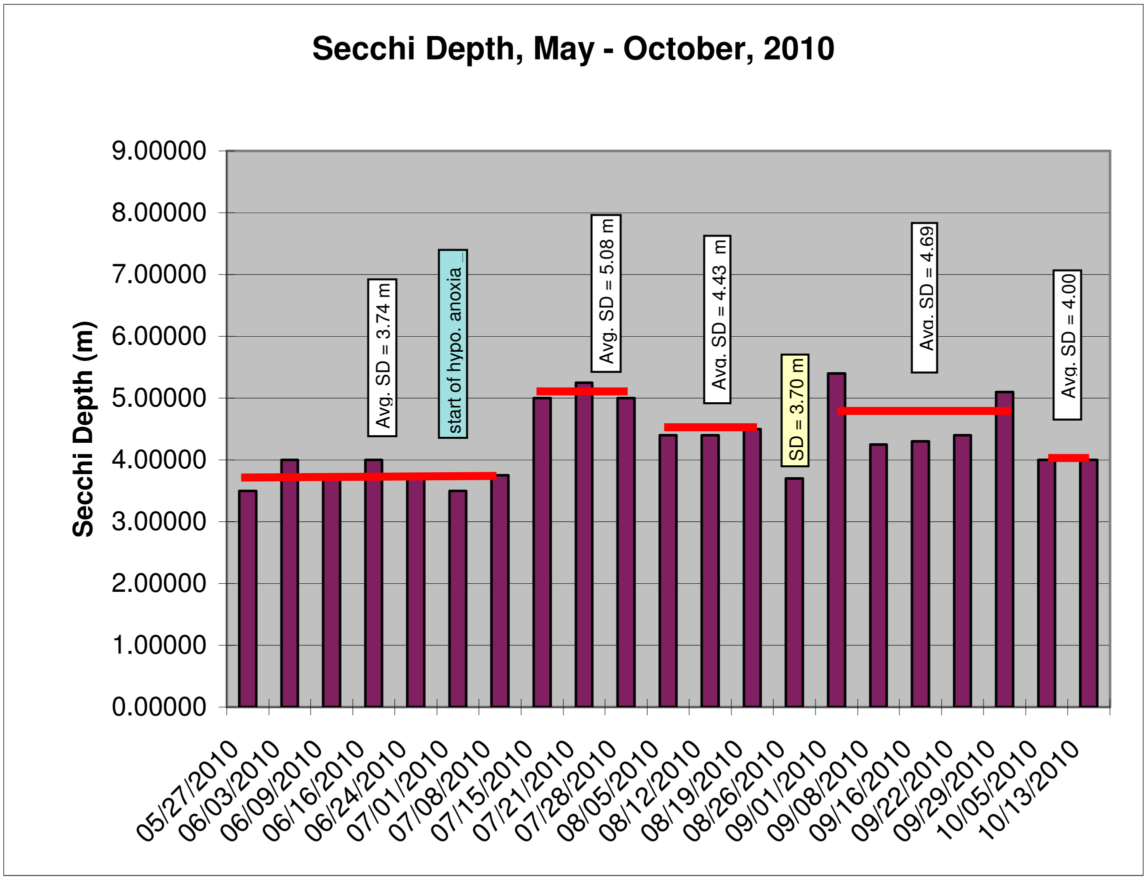

Figure 3-33: Mirror Lake Secchi Depth

3.5 Plankton

Three 80 micron plankton net samples were collected on a weekly basis from late May through early October; one mid-metalimnion vertical haul, one six meter vertical haul, and one full water column (0-13 +/- meter) vertical haul. Two taxonomic algal groups, [Chrysophyta (Golden-Brown) and Bacillariophyta (Diatoms)] and cyanobacteria dominated the Mirror Lake plankton community (full water column) at different times during the season. Golden-Brown, Diatom and cyanobacteria groupls often had relative abundances greater than 50 percent for extended periods of time during 2010. A third phytoplankton group, Pyrrophyta (Dinoflagellates) was present during most of the season but never attained whole water column relative abundance levels greater than 50 percent (Figure 3-34). However, Pyrrophyta did have relative abundances greater than 50 percent in the upper 6 meters during August (Figure 3-35).

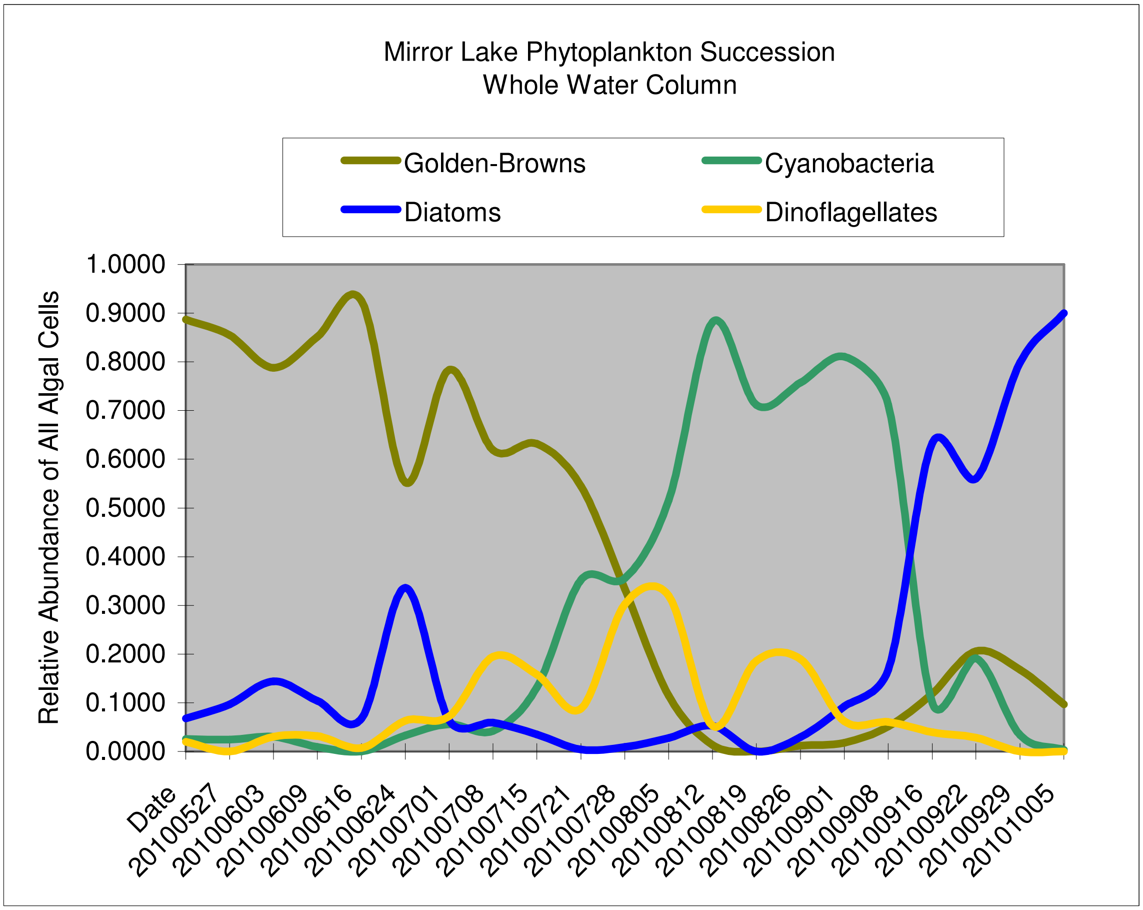

Figure 3-34: Mirror Lake Phytoplankton Succession, Whole Water Column

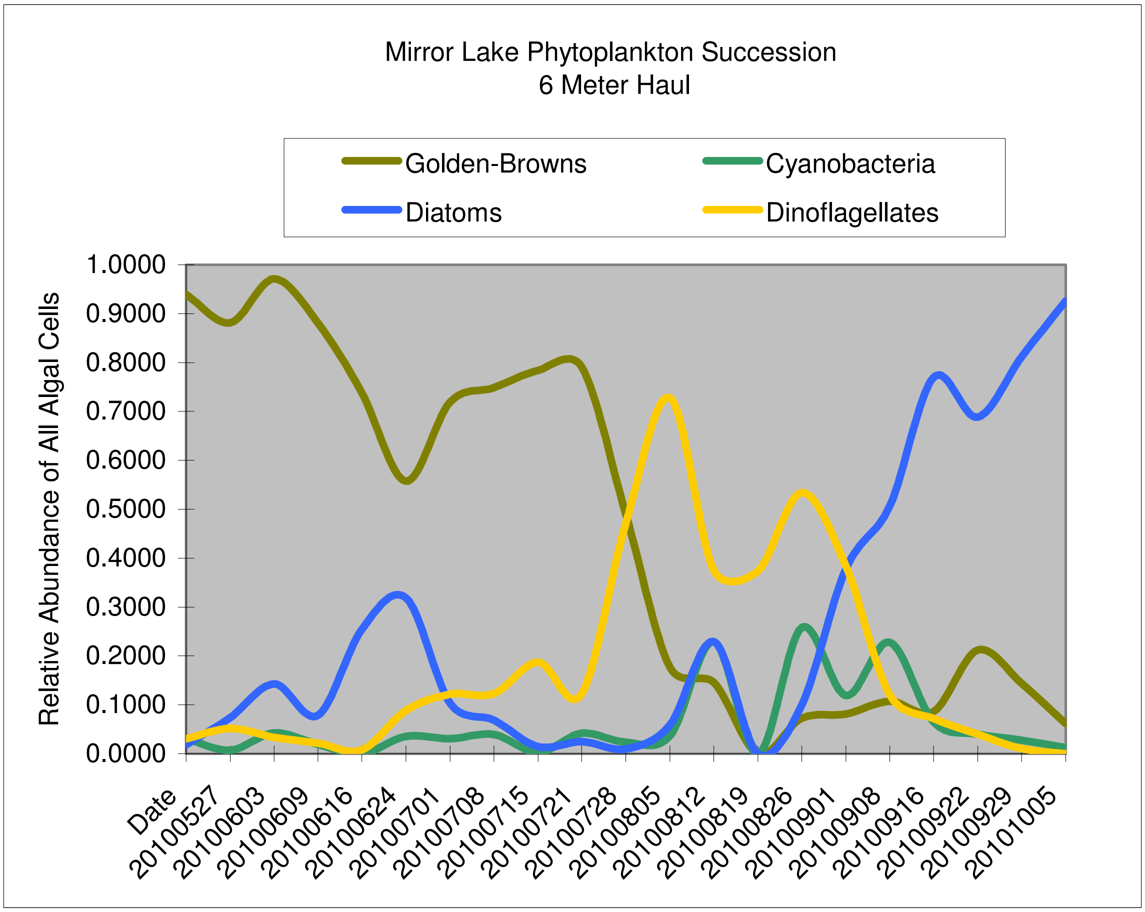

Figure 3-35: Mirror Lake Phytoplankton Succession, 6 Meter Haul

Asterionella, Rhizosolenia and *Tabellaria* were the most dominant Diatoms during 2010, with *Asterionella's* relative abundance peaking both in early July and early October (Figure 3-36). *Synura*, *Dinobryon* and *Chrysosphaerella* were the most dominant Golden-Browns with relative abundances greater than 30 percent from May through late-July (Figure 3-37). *Oscillatoria* and *Coeleosphaerium* were the most dominant cyanobacteria (Figure 3-38). *Oscillatoria* maintained a relative abundance greater than 30 percent from late July through mid-September. *Ceratium* was the only Dinoflagellate with relative abundances greater than 20 percent (Figure 3-39).

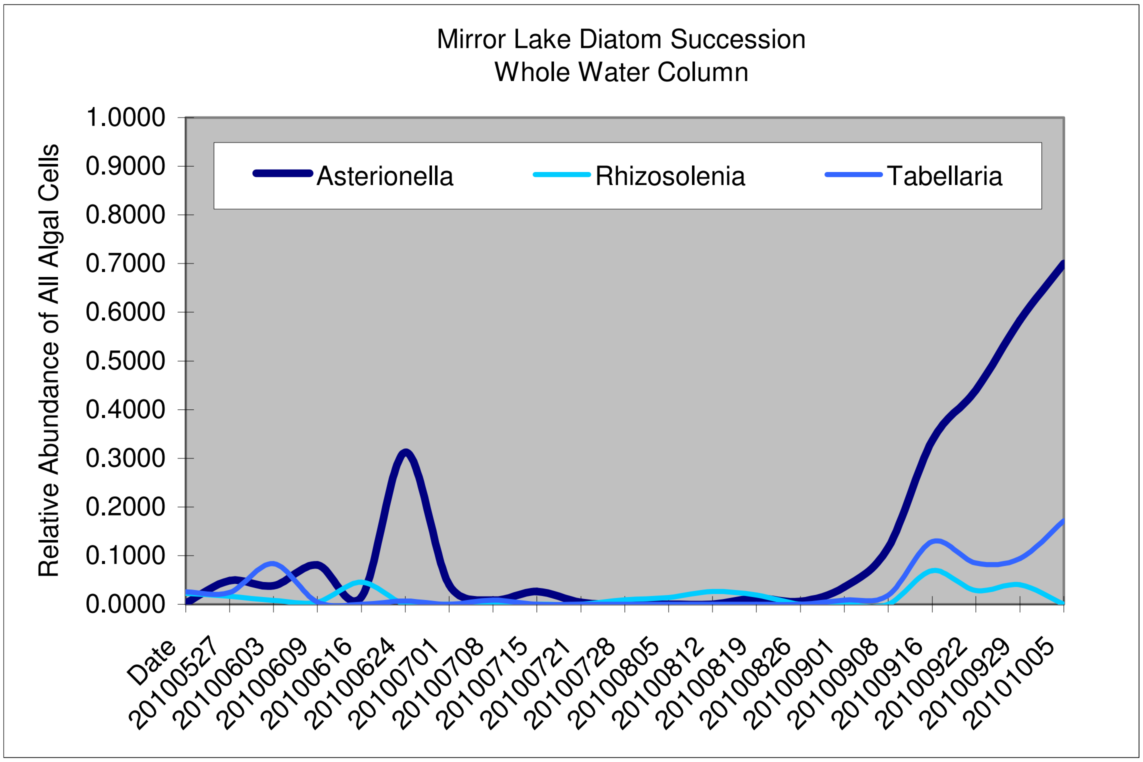

Figure 3-36: Mirror Lake Diatom Succession, Whole Water Column

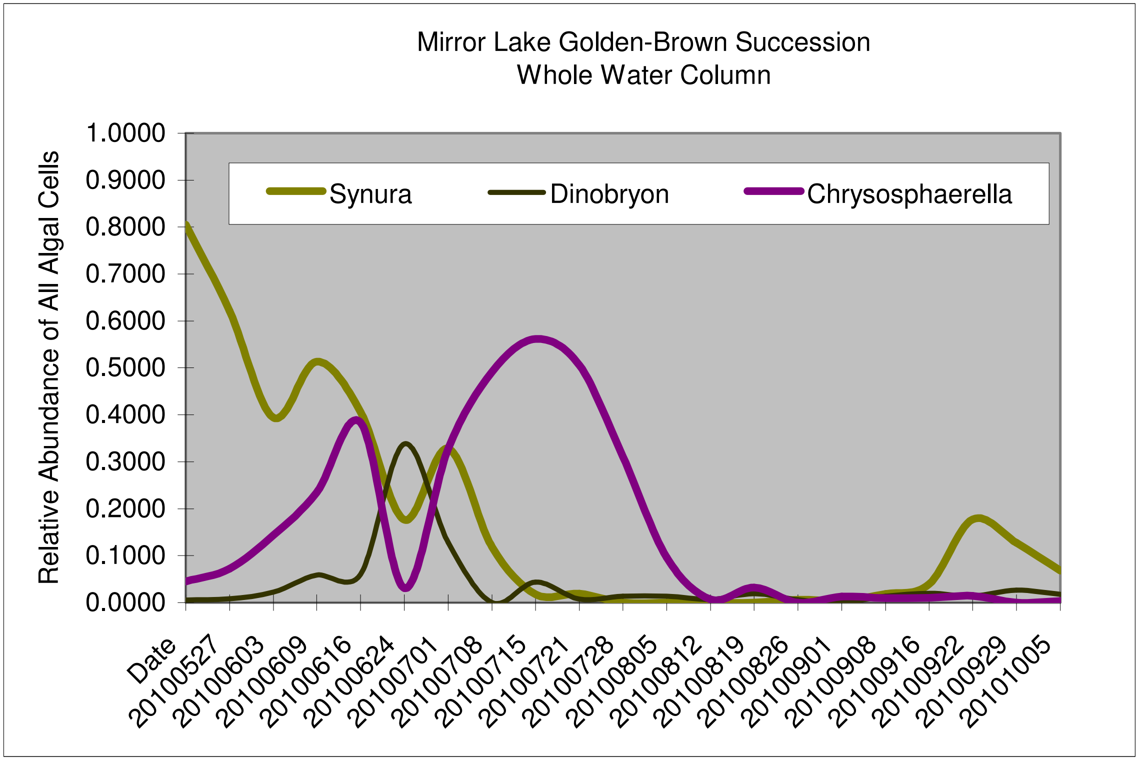

Figure 3-37: Mirror Lake Golden-Brown Succession, Whole Water Column

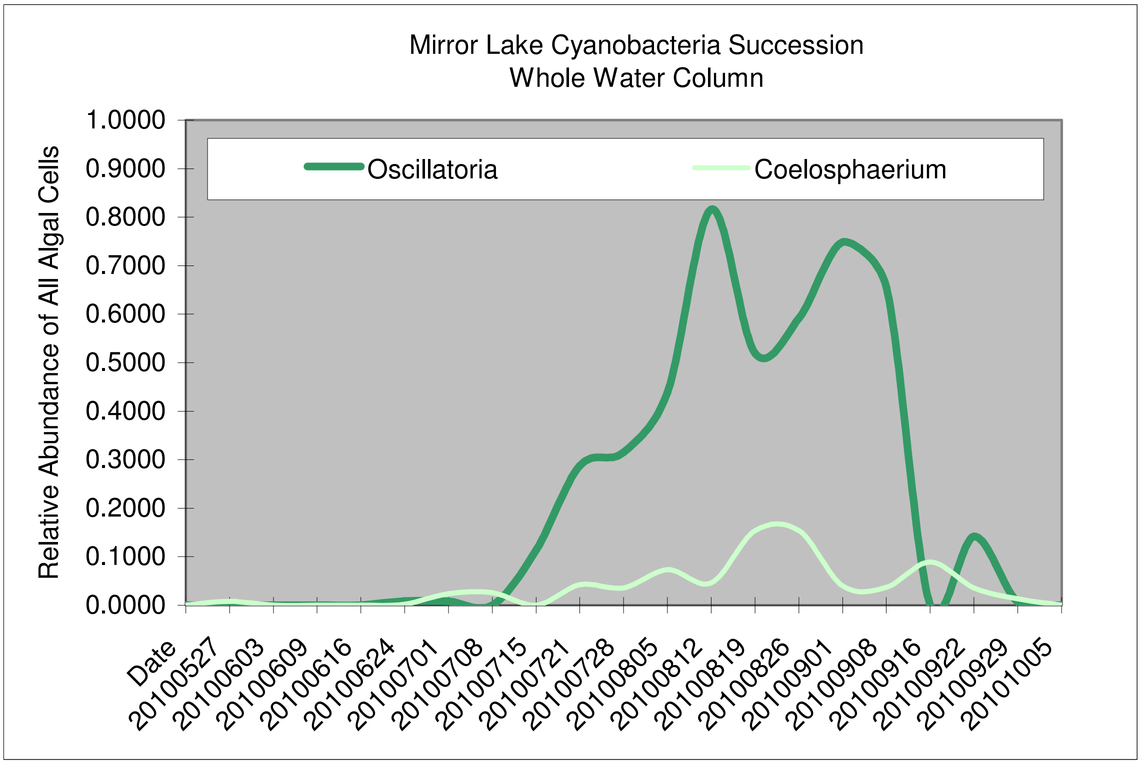

Figure 3-38: Mirror Lake Cyanobacteria Succession, Whole Water Column

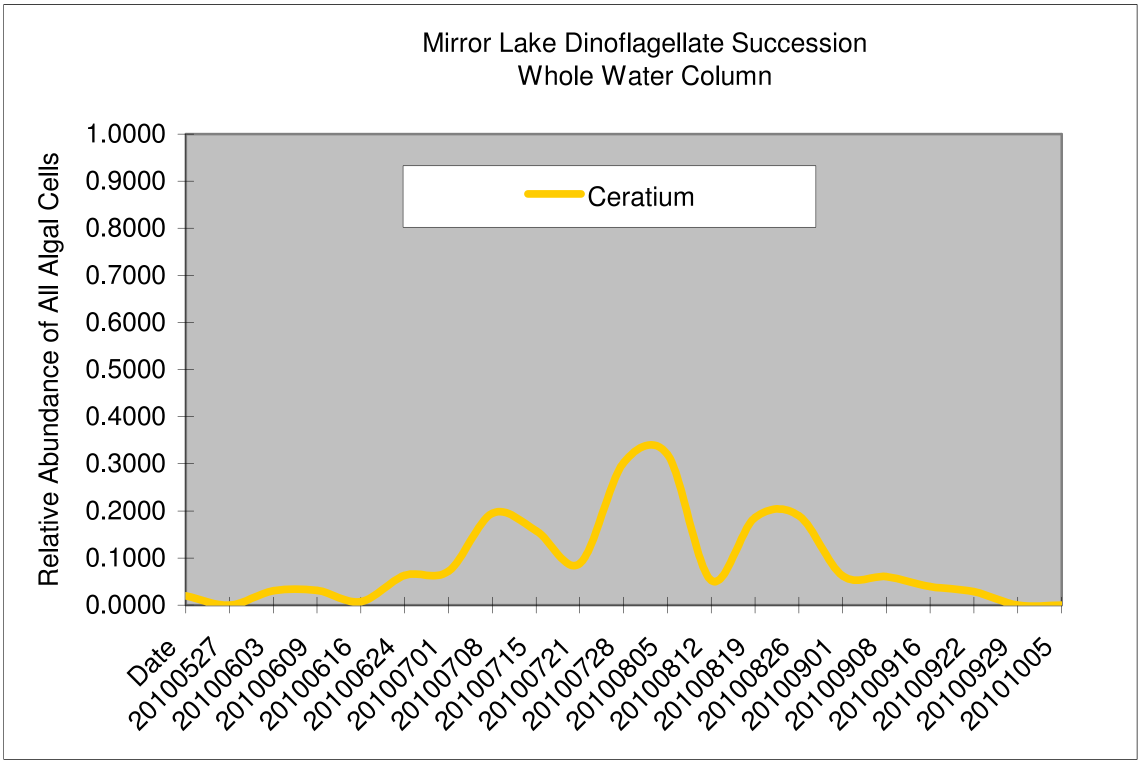

Figure 3-39: Mirror Lake Dinoflagellate Succession, Whole Water Column

Phytoplankton dominance was evaluated at the deep spot on August 26 for each one meter interval. Cyanobacteria was most abundant from 0-3 meters (*Coelospharium*), a mix of algal groups dominated from 3-6 meters (*Ceratium*, *Tabellaria*, and *Synura*), and cyanobacteria dominated from 6-12 meters (*Coelospharium*, *Oscillatoria*, *Anabaena*) (Table 3-5). *Oscillatoria* was the densest (29.61 %) phytoplanktonic species on August 26 (Table 3-6).

Table 3-5: Incremental Phytoplankton Relative Abundance and Density, August 26

Depth	Dominant Genus	Relative Abundance (%)	Density (cells/ml)
0-1 meter	*Coelospharium*	32.1	7.28
1-2 meter	*Coelospharium*	32.5	3.15
2-3 meter	*Coelospharium*	33.8	3.49
3-4 meter	*Ceratium, Tabellaria*	24.8 24.8	2.23
4-5 meter	*Synura*	39.8	0.80
5-6 meter	*Ceratium*	33.6	1.40
6-7 meter	*Coelospharium*	28.9	1.41
7-8 meter	*Oscillatoria*	94.7	51.89
8-9 meter	*Anabaena*	86.4	15.00
9-10 meter	*Oscillatoria*	54.8	2.80
10-11 meter	*Oscillatoria*	94.8	2.24
11-12 meter	*Oscillatoria*	64.4	2.18

Table 3-6: Whole Water Column Phytoplankton Density, August 26

Algal Family	Algal Genus	Whole Water Column Phytoplankton Relative Abundance (%)
Green	*Arthrodesmus*	0.13%
Green	*Closterium*	0.20%
Green	*Xanthidium*	0.07%
Green	*Scenedesmus*	0.07%
Green	*Sphaerocystis*	0.27%
Green	*Staurastrum*	0.67%
Cyanobacteria	*Coelospharium*	17.30%
Cyanobacteria	*Microcystis*	2.26%
Cyanobacteria	*Anabaena*	7.12%
Cyanobacteria	*Oscillatoria*	29.61%
Golden-Brown	*Chrysosphaerella*	6.25%
Golden-Brown	*Dinobryon*	0.60%
Golden-Brown	*Mallomonas*	0.73%
Golden-Brown	*Synura*	3.06%
Golden-Brown	*Uroglenopsis*	0.13%
Dinoflagellate	*Ceratium*	13.97%
Dinoflagellate	*Gymnodinium*	0.07%
Dinoflagellate	*Peridinium*	0.07%
Diatom	*Cyclotella*	0.00%
Diatom	*Melosira*	2.33%
Diatom	*Rhizosolenia*	2.46%
Diatom	*Asterionella*	0.27%
Diatom	*Fragillaria*	1.26%
Diatom	*Surirella*	0.07%
Diatom	*Synedra*	0.13%
Diatom	*Tabellaria*	10.91%

4.0 STUDY FINDINGS

Spring, non-stratified in-lake phosphorus concentration

Sample results from April 8, 2010 revealed that 10.8 ug/l P could be considered the spring, non-stratified in-lake phosphorus concentration for Mirror Lake (Table 4-1).

Table 4-1: Mirror Lake P Concentration, April

4/8/2010			
Depth (m)	TP (ug/l)	Volume (l)	Mass (kg)
1.00	12.0	2341204229	28.1
3.00	10.0	2036438871	20.4
7.00	9.7	887796578	8.6
10.00	9.8	325280846	3.2
Total		**5590720523**	**60.3**
Average	60.3 kg P / 5590720523 liters = **10.8 ug/l P**		

Early fall, maximum in-lake phosphorus concentration

Sample results from September 16 revealed that 13 to 14.7 ug/l reflects the summer maximum in-lake phosphorus concentration range for Mirror Lake (Tables 4-2 and 4-3) in 2010.

Table 4-2: Mirror Lake P Concentration, September with Vertical Mixing

9/16/2010					
Depth (m)	TP (ug/l) (Vol A)	TP (ug/l) (Vol B/C)	Volume A (l)	Volume B/C (l)	Mass (kg)
0.5	9.6	11.0	1135549548	120615545	12.2
2.0	9.6	11.0	1389422858	180923317	15.3
3.0	9.6	16.0	657009920	120615545	8.2
4.0	9.6	24.0	592583049	180923317	10.0
6.0	9.6	12.0	381521042	241231090	6.6
8.0	9.6	10.0	88463904	241231090	3.3
10.0	N/A	32.0	N/A	148422219	4.7
11.0	N/A	92.0	N/A	66339157	6.1
12.0	N/A	140.0	N/A	45868920	6.4
Total				**5590720523**	**72.9**
Average	72.9 kg P / 5590720523 liters = **13.0 ug/l P**				

Table 4-3: Mirror Lake P Concentration, September with Vertical and Horizontal Mixing

9/16/2010					
Depth (m)	TP (ug/l) (Vol A)	TP (ug/l) (Vol B/C)	Volume A (l)	Volume B/C (l)	Mass (kg)
0.5	9.6	11.0	1135549548	120615545	12.2
2.0	9.6	11.0	1389422858	180923317	15.3
3.0	9.6	16.0	657009920	120615545	8.2
4.0	N/A	24.0	N/A	773506366	18.6
6.0	N/A	12.0	N/A	622752132	7.5
8.0	N/A	10.0	N/A	329694994	3.3
10.0	N/A	32.0	N/A	148422219	4.7
11.0	N/A	92.0	N/A	66339157	6.1
12.0	N/A	140.0	N/A	45868920	6.4
Total			**5590720523**		**82.4**
Average	82.4 kg P / 5590720523 liters = **14.7 ug/l P**				

Fall, non-stratified in-lake phosphorus concentration

Sample results from October, 13 showed that 13.6 ug/l P reflects the fall, non-stratified in-lake phosphorus concentration for Mirror Lake (Table 4-4) in 2010.

Table 4-4: Mirror Lake P Concentration, October

10/13/2010			
Depth	TP (ug/l)	Volume (l)	Mass (kg)
1.000	14.0	2341204229	32.8
3.000	14.0	2036438871	28.5
7.000	12.0	887796578	10.7
10.000	12.0	279411926	3.4
11.000	12.0	45868920	0.6
Total		**5590720523**	**75.8**
Average	75.8 kg P / 6184999523 liters = **13.6 ug/l P**		

Internal phosphorus loading estimates for the summer season

An estimate of the internal P load was calculated using two methodologies (section 3.2), weekly in-situ summer P increase comparison and spring and summer in-situ P comparison.

The internal P load estimates ranged from 6.2 kg to 24.69 kg P. The most accurate estimate of the lake's internal P load was 24.69 kg, as this was based upon weekly sampling data.

The relationship between internal phosphorus loading and dominance of cyanobacteria

Internal P loading began in early July. By early August, cyanobacteria, including *Oscillatoria*, *Coelosphaerium* and *Anabaena*, were the dominant planktonic organisms in the water column after anoxia was well established. Once anoxia set in, internal phosphorus loads became available to cyanobacteria which have the ability to regulate buoyancy. This ability to regulate buoyancy gives the cyanobacteria a large advantage in seeking light and nutrient regimes for optimal growth (Sandgren 1988). During August, depths greater than 6 meters provided this optimum growth regime. By late August cyanobacteria continued to have the greatest relative abundance in the whole water column, including a presence in the upper 6 meters which continued through the first week of September (Figure 3-35). After September 8, most of the cyanobacteria retreated below 6 meters, with a tremendous decrease in the relative abundance of *Oscillatoria* after mid-September. This occurred approximately two weeks after the highest levels of cumulative internal P loading in early September (Figures 3-12 and Table 4-1).

Predicted internal loading impact and in-lake phosphorus concentration loading models

Several in-lake P load models were evaluated to determine which model best predicted in-lake P concentration. The initial model screening assumed that there was a watershed P load of 120.4 kg (Robert Hartzel, personal communication, 2010) and no internal P loading. Based on four deep spot samples collected on April 8 (1.0, 3.0, 7.0 and 10.0 meters) the volume-weighted, spring, in-lake P concentration is approximately 10.8 ug/l. Several models (Vollenweider 1976; Chapra 1975; Larsen and Mercier 1976; and Jones and Bachmann 1976) over-predicted and several models (Dillon and Rigler 1974; Reckhow 1977; Nürnberg 1998) under-predicted the in-lake P concentration. The Nürnberg model (1998, Eq. 2) predicted an in-lake P concentration of 8.6 ug/l, the closest predicted value (Table 4-5) to the April 8 volume-weighted in-lake P concentration (Table 4-2). The downside of predictive P loading models is that they do not incorporate internal P loading.

The Nürnberg model was modified, accounting for internal P loading, to predict spring, in-lake P concentrations (Nürnberg 1998, Eq. 4) or fall, in-lake P concentrations (Nürnberg 1998, Eq. 5) (Table 4-6). When an internal P load of 24.69 kg (section 3.2) is applied, Equation 4 and Equation 5 predict an in-lake concentration of 10.4 ug/l (12 months of internal P load settling) and 14.9 ug/l (0 months of internal P load settling), respectively. Assuming that internal P loads settle for approximately 10 months, (July or the onset of internal loading through April) Equation 4 can be further modified, yielding an in-lake P concentration of 11.1 ug/l. This is a 0.3 ug/l difference from the volume-weighted, in-lake P concentration value derived from the April 8 data (Table 4-1). If the internal P loads were assumed to settle for 3 months (July-Sept), Equation 4 could be modified, yielding an in-lake P concentration of 13.8 ug/l. This relates well with the volume-weighted, in-lake P concentration values derived from the October 13 data (13.6 ug/l) but underestimated the September 16 data (14.7 ug/l) (Tables 4-2 through 4-4). However, the Nürnberg model output (Nürnberg 1998, Eq. 5) predicts a value of 14.9 ug/l if no settling of internal P loads occurs. Additional P data for a more detailed profile and within other parts of the lake to verify the extent of lateral P transport or increased fluid dynamics modeling may have yielded a more accurate volume-weighted in-lake P estimate

Table 4-5: In-lake P Concentration Model Predictions with No Internal P Loading

Parameter	Symbol	Units	Equation	Value (Study Period)
Watershed area	Aw	m^2	measured	5,905,405
Lake area	Al	m^2	measured	1,346,595
Lake volume	V	m^3	measured	5,590,720
Lake discharge	Q	m^3	Q=Wi-(1-lake evap)	3,998,132
Hydraulic residence time	T	yr	T=V/Q	1.40
Flushing rate	F	yr^{-1}	Flushing Rate = 1/T	0.72
Mean depth	Z	m	measured	4.1
Watershed annual loading, phosphorus, WS	Wext	kg	modeled	**120.4**
Internal P load, in-situ fall increase, partial net estimate, Nurnberg and LaZerte, 2001	Wint, partial net	kg	modeled	**0.0**
Total annual loading, phosphorus	L	kg	calculated sum	**120.4**
Areal water load or surface overflow rate	qs	m/yr	Z(F) or Z/T	2.94
Annual precip., USDA, NOAA, 1971-2001	Wp	m/yr	chart	1.1026
Annual evapotranspiration percent, Randall 1996	We	m/yr	chart	0.4750
Annual runoff percent, Randall	Wr	m/yr	chart	0.5250
Pan Evaporation	pan evap	m/yr	Table	32.0000
Water inflow	Wi	m^3	Wi=qs*A	4,585,112
P Retention coefficient, Nurnberg, no P Lint	Rpred	N/A	Rpred=15/(18+qs)	0.7164
Total external areal P loading	Lp or Lext	$g/m^2/yr$	Lext=P*1000/Al	0.0894
Total internal areal P loading	Lint	$g/m^2/yr$	Lint=P*1000/Al	0.0000
Vollenweider 1976, in-lake P concentration, spring	V (1976)	mg/L or g/m^3	$P = \frac{Lp}{qs}\left[\frac{1}{1+\sqrt{\frac{z}{qs}}}\right]$	0.0139
Chapra 1975, in-lake P concentration, spring	C (1975)	mg/L or g/m^3	P=Lp(1-r)/(Z*F)	0.0147
Dillon and Rigler 1974, in-lake P concentration, spring	D-R (1974)		P=Lp*(1-Rp)/qs	0.0076
Kirchner and Dillon 1975, in-lake P concentration, spring	K-D (1975)		P=Lp*(1-Rp)/qs	0.0076
Larsen and Mercier 1976, in-lake P concentration, spring	L-M (1976)		P=Lp(1-Rlm)/qs	0.0139
Jones and Bachman 1976, in-lake P concentration, spring	J-B (1976)		P=0.84(Lp)/(Z(0.65+F))	0.0134
Reckhow 1977, in-lake P concentration, spring	Rg (1977)		P=Lp/(11.6+1.2(Z(F)))	0.0059
Nürnberg 1998, in-lake P concetration, spring, No internal P load	N(1998, Eq. 2)	mg/L or g/m3	P=((Lext/qs(1-Rpred))	0.0086

Table 4-6: Nürnberg, In-lake P Concentration Predictions

Parameter	Symbol	Units	Equation	Value (Study Period)
Watershed area	Aw	m^2	measured	5,905,405
Lake area	Al	m^2	measured	1,346,595
Lake volume	V	m^3	measured	5,590,720
Lake discharge	Q	m^3	Q=Wi-Lpevap	3,998,132
Hydraulic residence time	T	yr	T=V/Q	1.40
Flushing rate	F	yr^{-1}	Flushing Rate = 1/T	0.72
Mean depth	Z	m	measured	4.1
Watershed annual loading, phosphorus, WS	Wext	kg	modeled	**120.4**
Internal P load, in-situ fall increase, partial net estimate, Nurnberg and LaZerte, 2001	Wint, partial net	kg	modeled	**24.69**
Total annual loading, phosphorus	L	kg	calculated sum	**145.1**
Areal water load or surface overflow rate	qs	m/yr	Z(F) or Z/T	2.94
Annual precip., USDA, NOAA, 1971-2001	Wp	m/yr	chart	1.1026
Annual evapotranspiration percent, Randall	We	m/yr	chart	0.4750
Annual runoff percent, Randall	Wr	m/yr	chart	0.5250
Pan Evaporation	pan evap	m/yr	Table	32.0000
Lake Evaporation	lake evap	m^3	Wi=qs*A	4,585,112
P Retention coefficient, Kirchner and Dillon 1975	Rp	N/A	Rpred=15/(18+qs)	0.7164
Total external areal P loading	Lp or Lext	$g/m^2/yr$	Lext=P*1000/Al	0.0894
Total internal areal P loading	Lp	$g/m^2/yr$	Lint=P*1000/Al	0.0183
Nürnberg 1998, in-lake P concetration, fall Internal P load settling for 12 months	N (1998), Eq. 4	mg/L or g/m^3	P=(Lext+Lint)/qs(1-Rpred)	0.0104
Nürnberg 1998, in-lake P concentration, spring Internal P load settling for 10 months	N(Eq. 4 modified internal load settling time)		P=(Lext/qs(1-Rpred) + Lint/qs*(1-(10/12)*Rpred))	0.0111
Nürnberg 1998, in-lake P concetration, fall Internal P load settling for 3 months	N(Eq. 4 modified internal load settling time)		P=(Lext/qs(1-Rpred) + Lint/qs*(1-(3/12)*Rpred))	0.0137
Nürnberg 1998, in-lake P concentration, fall Internal P load settling for 2 months	N(Eq. 4 modified internal load settling time)		P=(Lext/qs(1-Rpred) + Lint/qs*(1-(2/12)*Rpred))	0.0141
Nürnberg 1998, in-lake P concentration, fall Internal P load settling for 1 month	N(Eq. 4 modified internal load settling time)		P=(Lext/qs(1-Rpred) + Lint/qs*(1-(1/12)*Rpred))	0.0145
Nürnberg 1998, in-lake P concetration, fall, Internal P load settling for 0 months	N (1998), Eq. 5		P=(Lext/qs(1-Rpred) + Lint/qs)	0.0149

5.0 CONCLUSIONS AND RECOMMENDATIONS

Mirror Lake in Tuftonboro, New Hampshire, was designated in the 2008 Federal Section 303(d) list as a waterbody impaired for primary contact recreation; a result of recurring cyanobacteria surface scums.

The watershed plan currently being developed by Geosyntec Consultants will account for internal P loading estimates according to this report and prioritize watershed and in-lake treatment measures using this information.

Minimizing excessive cyanobacteria cell production and resultant cyanobacteria scums will likely require summer and fall, fully-mixed in-lake P concentrations to not exceed 12 ug/l and maybe less. The Nürnberg (1998, Eq. 4) model estimates the annual permissible load to achieve an in-lake goal of 12 ug/l P is approximately 105.09 kg P, which includes internal P loading (24.69 kg) but does not factor-in any internal P load settling. Watershed modeling estimates by Geosyntec Consultants indicate watershed P loads of 120.4 kg P. Watershed P loads and internal P loads combined account for an estimated 145.1 kg. Assuming the internal P load remained and did not settle during the period of internal loading, a load reduction of 40.0 kg P resulting in an 80.4 kg annual P load from the watershed would be needed to achieve a fall, in-lake, 12 ug/l P concentration goal. Phytoplankton response is related to P load reductions or P increases from both the watershed and in-lake sources. All P load reductions will result in water quality improvements, including increased clarity and reduced incidences and magnitudes of cyanobacteria blooms and scums. Phosphorus reductions typically coincide with improvements in lake water quality.

If the Mirror Lake watershed was modeled to show a completely forested condition or “best-case” scenario, the watershed P load would be approximately 75 kg, yielding a spring, in-lake condition of 5.4 ug/l P, assuming no internal P loading. There is the potential to remove more than 40 kg P annually and achieve the “best-case” scenario if lake restorative techniques could eliminate internal P loading. To achieve a summer epilimnetic P concentration of 8.0 ug/l, the nutrient criteria for oligotrophic lake’s aquatic life use designation, 9 kg P would need to be removed, assuming no internal P load occurrence. To achieve a summer epilimnetic concentration of 8.0 ug/l, 44 kg P would need to be removed, assuming a 24.69 kg internal P load reoccurs annually and settles no less than 10 months.

5.1 Watershed Management

Everyone lives in a watershed. What you do in your watershed can affect the entire watershed and can impact the health of the waterbodies that we recreate on and depend upon. The health of our waterbodies largely depends on the quality of our stormwater. Stormwater is water from rain or melting snow that does not soak into the ground. In a forest, meadow, or other natural landscape, stormwater soaks into the ground and naturally filters through the soil. When forests and meadows are developed, they are replaced with neighborhoods, shopping centers, and other areas that introduce impervious surfaces such as rooftops, roads, parking lots, and even lawns. Impervious surfaces prevent rain or melting snow from soaking into the ground and create excess stormwater runoff and stormwater pollution (McCarthy 2011).

It is essential that best management practices or low impact design techniques be utilized by everyone. These best management practices include: minimizing areas of driveways and paths, maintaining as much natural buffer as possible with minimization of maintained lawns, creating “rain gardens” or other infiltration techniques for roof runoff, and directing driveway drainage either away from the lake or to areas where infiltration is possible. Increasing lake and tributary setbacks for septic systems and implementing stormwater BMPs or low impact design retrofits for developed land in the watershed will be a significant benefit in the long-term maintenance of watershed health and lake quality. Equally important is the maintenance of forest cover throughout the watershed. Section 3.0 describes that by late-July, internal P loads of only 13 kg resulted in an increase in cyanobacteria below 6 meters; by mid-August, internal loads of approximately 20 kg P resulted in increased cyanobacteria in the upper water column. Even small P load reductions, totaling less than 20 kg P, will likely result in significant water quality improvements if no increased P loading occurs from other watershed sources to the lake.

5.2 In-lake Restoration: Hypolimnetic Phosphorus Inactivation

In-lake restorative techniques have been researched for many years. Case studies evaluate the restorative and management techniques for lakes (Cooke et al. 2005). Even though all lakes and watersheds are physically, chemically and biologically different, one or a combination of watershed management and lake restorative techniques may provide short or long-time remedial actions that improve lake quality. There are several in-lake restorative actions that have proven to reduce internal sediment P loading to some lakes. Although there are no inexpensive means to achieve sediment P reductions, there are techniques that are more cost-effective than others. Both limnologists and engineers have evaluated a series of lake restorative techniques (Cooke et al. 1977; 1986; 2005). Each hypolimnetic phosphorus inactivation technique was evaluated by comparing case studies throughout the world. These restorative techniques were examined and rated by the pros and cons, history of lake quality improvements and the methodology’s cost effectiveness. These in-lake techniques include aeration, circulation, biomanipulation, dredging, water exchange and a series of chemical inactivation processes. One proven technique considered for use in cases of sediment phosphorus loading is phosphorus inactivation with aluminum salts. New Hampshire was the first state to use an innovative delivery system that injected a mixture of aluminum salts into the lake hypolimnion. A discussion of aluminum salts injection and New Hampshire’s research on hypolimnetic injection are presented below.

Phosphorus precipitation and sediment P inactivation through aluminum salts injection are lake restoration techniques that reduce phosphorus in the water column or at a specific thermal stratification level through P stripping and in the sediment through chemical bonding. Sediment phosphorus inactivation results in longer-term lake quality improvement when compared to water column precipitation. Sediment inactivation is particularly useful in accelerating lake improvement in those lakes that have a significant internal phosphorus load. (Cooke et al. 1977; 2005; Larsen et al. 1979). It is important to stress that all watershed P sources should be reduced or eliminated prior to the use of this technique. Increased watershed P inputs would counteract any in-lake restorative techniques, minimize lake quality improvements and would increase the cost/benefit ratios of any in-lake project. The key to success for an in-lake phosphorus reduction project is the simultaneous reduction of watershed phosphorus loading to the lake.

Aluminum salts injection benefits include in-lake phosphorus reduction, decrease or elimination of internal sediment P loading, increased transparency, decreased chlorophyll, reductions in algal and cyanobacteria abundance and cell dominance shifts from cyanobacteria to other more beneficial algal populations.

Potential P inactivation drawbacks correspond to chemical reactions in the water from added compounds. Lakes with low buffering capacity (low ANC) are particularly vulnerable to complications following additions of aluminum sulfate. Small doses of aluminum sulfate can exhaust the buffering capacity to a point that causes lake pH to fall below 6.0. Once this occurs, aluminum may be released from the aluminum phosphate compound which could potentially cause aluminum toxicity in the lake. Knowing the lake chemistry before aluminum salts are used as inactivates is extremely important to the project's success. Research methods to ameliorate aluminum toxicity involve adding salts like sodium aluminate to buffer acidity. Increased aquatic plant growth due to increased light transmission may be considered a drawback by some lake users. As lake clarity increases, sunlight penetration extends to greater depths. This allows increased aquatic plant production throughout the littoral zone. A hypolimnetic treatment is desired over whole lake treatments because the dense aluminum floc in the upper waters can disrupt and reduce important invertebrate populations.

Hypolimnetic aluminum salts treatment research efforts were initiated at Kezar Lake, located in North Sutton, New Hampshire. Lyon Brook, the main tributary to Kezar Lake, received an extraordinary phosphorus load from the discharge of treated sewage effluent from the now defunct New London Sewage Treatment Facility (Connor and Smith 1983). The project plan was first to eliminate or reduce the watershed input of P to the Kezar Lake watershed; this included the piping of sewage to the Sunapee Wastewater Facility, watershed protection ordinances, low impact development techniques and wetlands manipulation. Once these watershed protection techniques were established in the New London, Lyon Brook watershed, in-lake restorative techniques that included aluminum sulfate and sodium aluminate were used as sediment phosphorus inactivants to improve lake quality (Connor and Smith 1986). The treatment occurred during June of 1984. A ten-year monitoring program provided an extensive lake database to evaluate the short-and-long-term effectiveness of sediment phosphorus inactivation as a lake restoration technique (Connor and Martin 1989; Connor and Smagula 2000). Within a year of the treatment a reduction in the hypolimnetic oxygen depletion resulted in hypolimnetic oxygen maintenance, a decrease in algal and cyanobacteria abundance (measured by chlorophyll-a concentration and microscopic cell counts), an increase in lake clarity from 0.5 M to over 3.0 M, a shift from cyanobacteria dominance to algal species typical to New Hampshire lakes and ponds, and an increase in trophic status from eutrophic to mesotrophic. No negative impacts to lake organisms or lake chemistry were detected in the post-treatment monitoring program (Connor and Smagula 2000). Within five years the variability of lake trophic conditions stabilized. More than twenty-five years later, the lake is still showing signs of good water quality as seen through DES Volunteer Lake Assessment Program sampling results.

If aluminum salts treatment for Mirror Lake were necessary, it would likely cost more than $100,000 (30 acre in-lake treatment at $3500/acre). Some treatments are met with limited success, especially if watershed BMPs have not been implemented, resulting in temporary improvements as elevated phosphorus loading continues and settles in the lake, uncapped by the previous aluminum salt treatment and therefore potentially available for algal uptake. Occasionally, an increase in algal or cyanobacteria blooms may occur after treatment. In-lake treatments would only be considered following implementation of the Mirror Lake Watershed Management Plan BMPs as outlined in the plan and as needed to achieve watershed phosphorus source reductions to pre-development or low-level impact conditions. Possible scenarios where phosphorus inactivation treatments may not yield the desired water quality improvement should be considered. Most importantly, in-lake restoration using hypolimnetic phosphorus inactivation cannot be considered without a source of funding.

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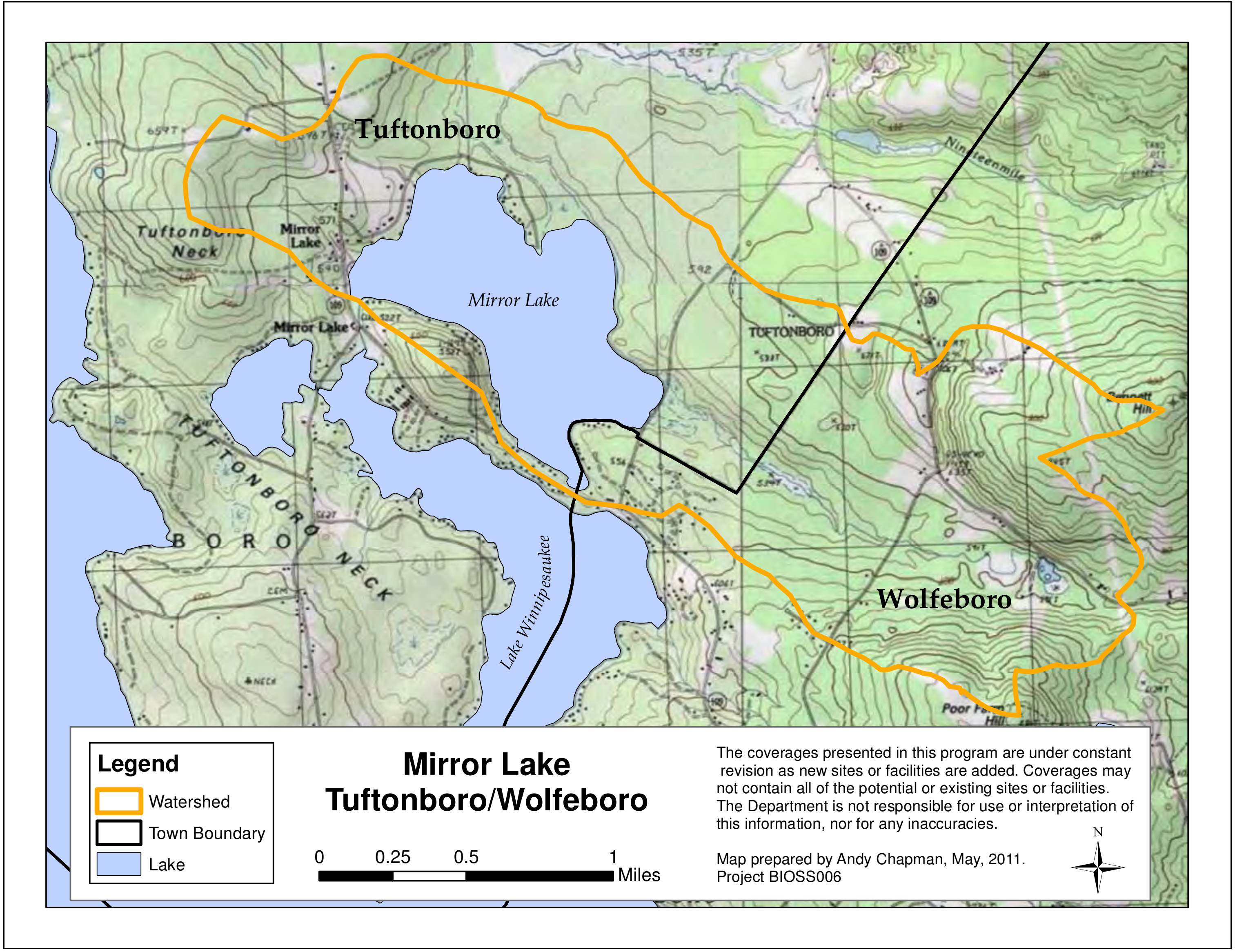
APPENDICES

Appendix A: Mirror Lake Watershed



The coverages presented in this program are under constant revision as new sites or facilities are added. Coverages may not contain all of the potential or existing sites or facilities. The Department is not responsible for use or interpretation of this information, nor for any inaccuracies.

Map prepared by Andy Chapman, May, 2011.
Project BIOSS006

Appendix B: New Hampshire Consolidated Listing Methodology Summary

New Hampshire is required to report on a two year cycle the water quality status of the state's surface waters in accordance with Section 305(b) and 303(d) of the Federal Water Pollution Control Act as last reauthorized by the Water Quality Act of 1987 [PL92-500, commonly called the Clean Water Act (CWA)], and New Hampshire Statutes Chapter 485-A:4.XIV (New Hampshire 2008 SECTION 305(b) and 303(d), Surface Water Quality Report and RSA 485-A:4.XIV Report to the Governor and General Court).

The "305(b) Report" describes the quality of the state's surface waters and an analysis of the extent to which all such waters provide for the protection and propagation of a balanced population of shellfish, fish and wildlife, and allow recreational activities in and on the water. Section 303(d) requires submittal of a list of waters (i.e., the 303(d) List) that are:

- impaired or threatened by a pollutant or pollutant(s),
- not expected to meet water quality standards within a reasonable time even after application of best available technology standards for point sources or best management practices for nonpoint sources and,
- require development and implementation of a comprehensive water quality study (i.e., called a Total Maximum Daily Load or TMDL study) that is designed to meet water quality standards.

Nutrient criteria developed by NHDES and the Nutrient Criteria Committee (Trowbridge 2009) are used to assess both the primary contact recreation (PCR) and the aquatic life uses (ALU) in New Hampshire lakes.

For PCR assessments, the nutrient response variables chlorophyll-a (Chl-a) and cyanobacteria scums are secondary indicators for PCR assessments. They can cause a "not support" assessment but, by themselves, cannot result in a "full support" designation (the primary indicator *E. coli* is needed for a "full support" assessment). The logic is that elevated Chl-a levels or the presence of cyanobacteria scums interfere with the aesthetic enjoyment of swimming and, in the case of cyanobacteria, pose a potential public health issue for recreational uses. If Chl-a or cyanobacteria cause a "not support" assessment, the causal variable total phosphorus (TP) is also assessed as not supporting PCR.

For aquatic life use assessments, the combination of the causal variable total phosphorus (TP) and the response variable Chl-a is one of three core indicators (pH and DO are the other two) that are required to make a "full support" assessment. Chl-a dictates the assessment if both Chl-a and TP data are available and the assessments differ. The results are combined according to the following decision matrix:

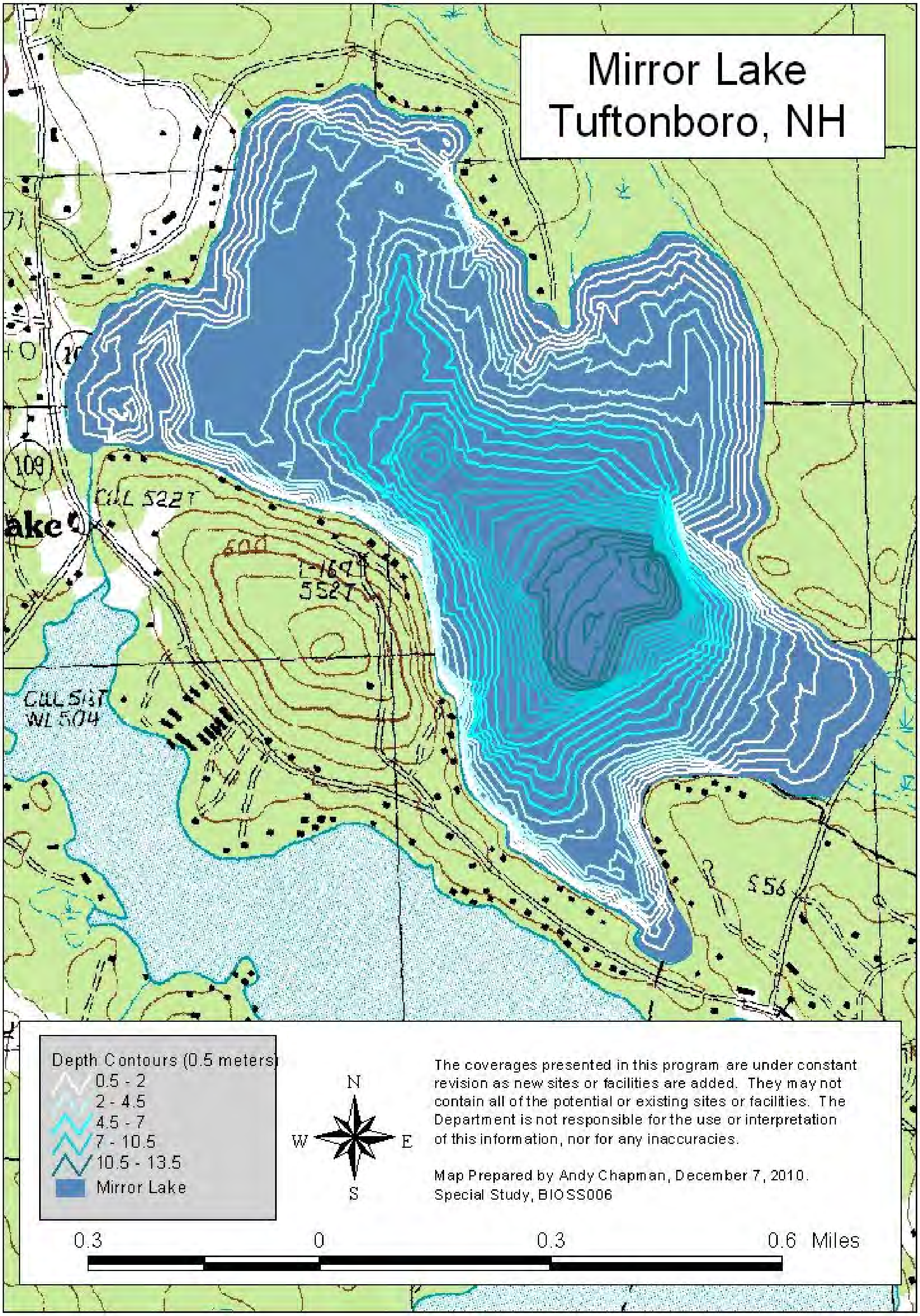
	TP threshold exceeded	TP threshold not exceeded	Insufficient information for TP
Chl-a threshold exceeded	Impaired	Impaired	Impaired
Chl-a threshold not exceeded	Fully supporting	Fully supporting	Fully supporting
Insufficient information for Chl-a	Impaired	Fully supporting	Insufficient information

The ALU nutrient criteria vary by lake trophic class. Trophic classes are determined by primary production or plant biomass with increasing biomass from oligotrophic to eutrophic lakes. The logic is that each trophic class has a given phytoplankton biomass (Chl-a) representing a balanced, integrated and adaptive community for that trophic class, and exceedences of the Chl-a criterion suggest the phytoplankton community is out of balance (i.e., not fully supported). The ALU nutrient criteria by trophic class are depicted in the table below:

Aquatic Life Use Nutrient Criteria by Trophic Class

	TP (ug/L)	Chl (ug/L)
oligotrophic	< 8.0	< 3.3
mesotrophic	8.0 – 12.0	3.3 – 5.0
eutrophic	> 12 - 28	> 5 - 11

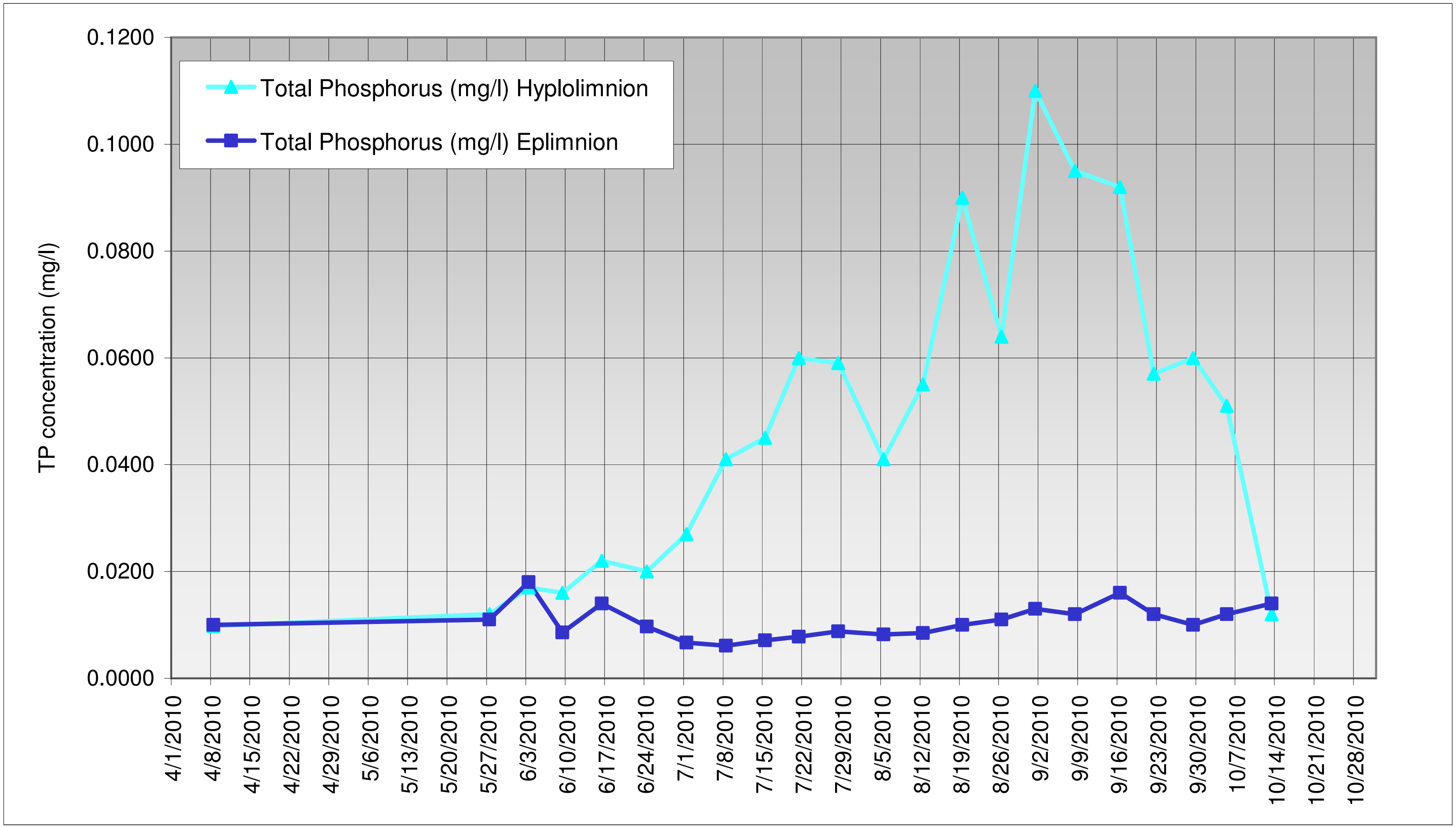
Appendix C: Mirror Lake Bathymetry



The coverages presented in this program are under constant revision as new sites or facilities are added. They may not contain all of the potential or existing sites or facilities. The Department is not responsible for the use or interpretation of this information, nor for any inaccuracies.

Map Prepared by Andy Chapman, December 7, 2010.
Special Study, BIOSS006

Appendix D: Epilimnetic and Hypolimnetic Phosphorus Concentrations April-October



Epilimnion sample depth = 3 meters, * 4 M sample collected May 27.
Hypolimnion sample depth = 11 meters, * 10 M sample collected April 8, 2010, and May 27.

Appendix E: Comparison of Phosphorus Mass and Concentration in the Upper (Epi/Meta) and Lower (Hypo) Layers of Mirror Lake

Date	Phosphorus (mg/l) 3 meters [over hypo, 9-14 meters]	Epi./Meta. Phosphorus [1] (kg) [over hypo 9-14 meters]	Phosphorus (mg/l) [not over hypo, 9-14 meters]	Epi./Meta. Phosphorus [1] (kg) [not over hypo 9-14 meters]	Phosphorus (mg/l) 11 meters	Hypo. Phosphorus [1] (kg)	Total Phosphorus Load (kg)	Volume weighted lake P concentration (mg/l)	Internal P load (kg) post 7/1/10 remaining in Hypo.	Internal P load (kg) post 8/19/10 transported to Meta./Epi.	Weekly Total Internal P load (kg) in lake
4/8/2010	0.0100	10.9	0.0100	42.4455	0.0098	2.6	55.86	0.0100			
5/27/2010	0.0110	11.9	0.0110	46.6901	0.0120	3.1	61.76	0.0110			
6/3/2010	0.0180	19.5	0.0180	76.4019	0.0170	4.4	100.37	0.0180			
6/9/2010	0.0086	9.3	0.0086	36.5031	0.0160	4.2	50.01	0.0089			
6/16/2010	0.0140	15.2	0.0140	59.4237	0.0220	5.7	80.36	0.0144			
6/24/2010	0.0097	10.5	0.0097	41.1721	0.0200	5.2	56.91	0.0102			
7/1/2010	0.0067	7.3	0.0067	28.4385	0.0270	7.0	42.75	0.0076	1.8		1.8
7/8/2010	0.0061	6.6	0.0061	25.8918	0.0410	10.7	43.20	0.0077	5.5		5.5
7/15/2010	0.0071	7.7	0.0071	30.1363	0.0450	11.7	49.57	0.0089	6.5	1.1	7.6
7/21/2010	0.0078	8.5	0.0078	33.1075	0.0600	15.6	57.21	0.0102	10.4	1.8	12.3
7/28/2010	0.0088	9.6	0.0088	37.3520	0.0590	15.4	62.28	0.0111	10.2	2.9	13.1
8/5/2010	0.0082	8.9	0.0082	34.8053	0.0410	10.7	54.39	0.0097	5.5	2.3	7.8
8/12/2010	0.0085	9.2	0.0085	36.0787	0.0550	14.3	59.64	0.0107	9.1	2.6	11.7
8/19/2010	0.0100	10.9	0.0096	40.6497	0.0900	23.5	74.96	0.0134	18.2	4.2	22.5
8/26/2010	0.0110	11.9	0.0096	40.6497	0.0640	16.7	69.27	0.0124	11.5	5.3	16.8
9/1/2010	0.0130	14.1	0.0096	40.6497	0.1100	28.7	83.43	0.0149	23.5	7.5	30.9
9/8/2010	0.0120	13.0	0.0096	40.6497	0.0950	24.8	78.44	0.0140	19.5	6.4	26.0
9/16/2010	0.0160	17.4	0.0096	40.6497	0.0920	24.0	82.00	0.0147	18.8	10.7	29.5
9/22/2010	0.0120	13.0	0.0096	40.6497	0.0570	14.9	68.53	0.0123	9.6	6.4	16.0
9/29/2010	0.0100	10.9	0.0096	40.6497	0.0600	15.6	67.14	0.0120	10.4	4.2	14.7
10/5/2010	0.0120	13.0	0.0096	40.6497	0.0510	13.3	66.97	0.0120	8.1	6.4	14.5
10/13/2010	0.0140	15.2	0.0096	40.6497	0.0120	3.1	58.97	0.0105	destratified	destratified	0

[1] Calculated based upon 2010 bathymetry data. Epilimnion/Metalimnion volume directly over 9 meter depth plane = 1,085,539,904 liters. Epilimnion/Metalinion volume not directly over 9 meter depth = 4,244,550,322 liters. Hypolimnion depth = 260,630,296 liters.

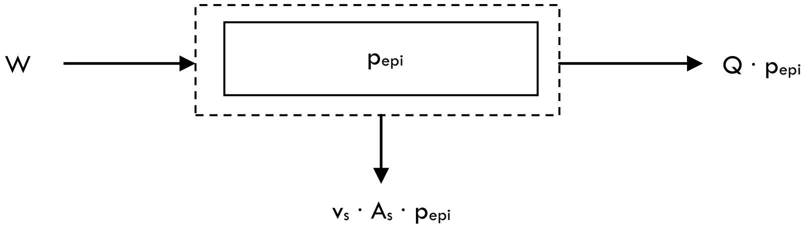
[2] Epilimnion sample depth is 3 meters, except for May 27, 2010, 4 meter sample depth. Hypolimnion sample depth is 11 meters, except for April 8, 2010, and May 27, 2010, 10 meter sample depth.

APPENDIX C:

Mirror Lake Dynamic Model Parameter Estimation

APPENDIX C: Dynamic Mass Balance Model Parameter Estimation

In order to perform the calculations in the dynamic mass balance model, the velocity terms (settling velocity, burial velocity, and recycle velocity) must be estimated. The velocities are estimated by assuming a steady state condition. To estimate settling velocity, the current steady state condition of the summer epilimnion (with no internal load) is used.



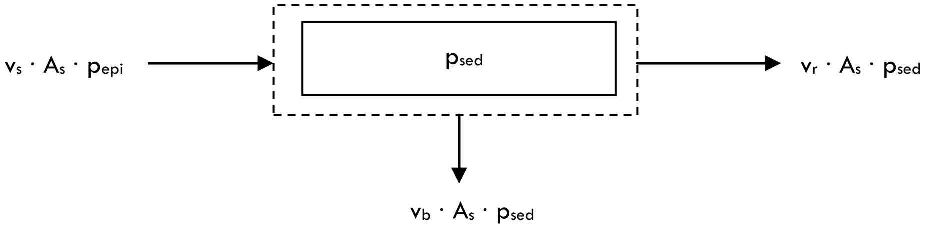
$$V_{epi}\frac{dp_{epi}}{dt} = 0 = W - \left(Q \cdot p_{epi}\right) - \left(v_s \cdot A_s \cdot p_{epi}\right)$$

$$v_s = \frac{W - \left(Q \cdot p_{epi}\right)}{A_s \cdot p_{epi}}$$

$$v_s = \frac{120\ \frac{kg}{yr} - \left(3{,}950{,}380 \frac{m^3}{yr} \cdot 8.7\ \frac{\mu g}{L} \cdot \frac{1kg}{10^9 \mu g} \cdot \frac{10^3 L}{m^3}\right)}{119{,}980\, m^2 \cdot\ 8.7\ \frac{\mu g}{L} \cdot \frac{1kg}{10^9 \mu g} \cdot \frac{10^3 L}{m^3}}$$

$$v_s = 82 \frac{m}{yr}$$

Next, the burial velocity v_b is estimated similarly by using the steady state condition of the sediment compartment, assuming that the mass settled (S) minus the mass recycled (R) is equal to the mass buried.



$$S - R = \left(v_b \cdot A_s \cdot p_{sed}\right)$$

In order to solve for v_b, the concentration of phosphorus in the sediment must first be known. Deep sediments were not sampled as part of this project, therefore, p_{sed} will be estimated based on information provided in a study by Nurnberg, where sediment phosphorus concentration is related to the sediment release rate. Assuming 4 months of anoxic conditions and a total internal load of 21.6 kg,

$$RR = \frac{21.6\,kg}{(119{,}980 m^2)(4 * 30.5\,days)} = 1.47\,\frac{mg}{m^2 \cdot day}$$

Based on this release rate, a sediment phosphorus content of approximately 90 µg/g wet weight is predicted by the relationship presented by Nurnberg. Assuming a dry density of sediment (ρ_{dry}) of 2.55x10^6 gm/m^3, a porosity (σ) of 0.875 (Chapra, 1997), the sediment wet density is:

$$\rho_{wet} = (1 - \sigma) \cdot \rho_{dry} + \sigma \cdot \rho_{water} = (0.125)(2.55 \times 10^6) + (0.875)(1 \times 10^6) = 1.194\,\frac{gm}{cm^3}$$

and the estimated sediment phosphorus concentration is

$$p_{sed} = 90\,\frac{\mu g}{gm} \cdot 1.194\,\frac{gm}{cm^3} = 107.5\,\frac{\mu g}{cm^3}$$

At this point, settling velocity can be computed as follows:

$$v_b = \frac{S - R}{(A_s \cdot p_{sed})} = \frac{85.6\frac{kg}{yr} - 21.6\frac{kg}{yr}}{(119{,}980\,m^2 \cdot 0.1075\,\frac{kg}{m^3})} = 4.96 \times 10^{-3}\,\frac{m}{yr}$$

Given the internal load of 21.6 kg/yr, the estimated recycle velocity is:

$$v_r = \frac{R}{(A_s \cdot p_{sed})} = \frac{21.6\frac{kg}{yr}}{(119{,}980\,m^2 \cdot 0.1075\,\frac{kg}{m^3})(1/3)} = 5.03 \times 10^{-3}\,\frac{m}{yr}$$

APPENDIX D:

D1: BMP Cost Estimation

D2: Preliminary Cost Estimate, Lang Pond Road Drainage Upgrade (Wolfeboro DPW)

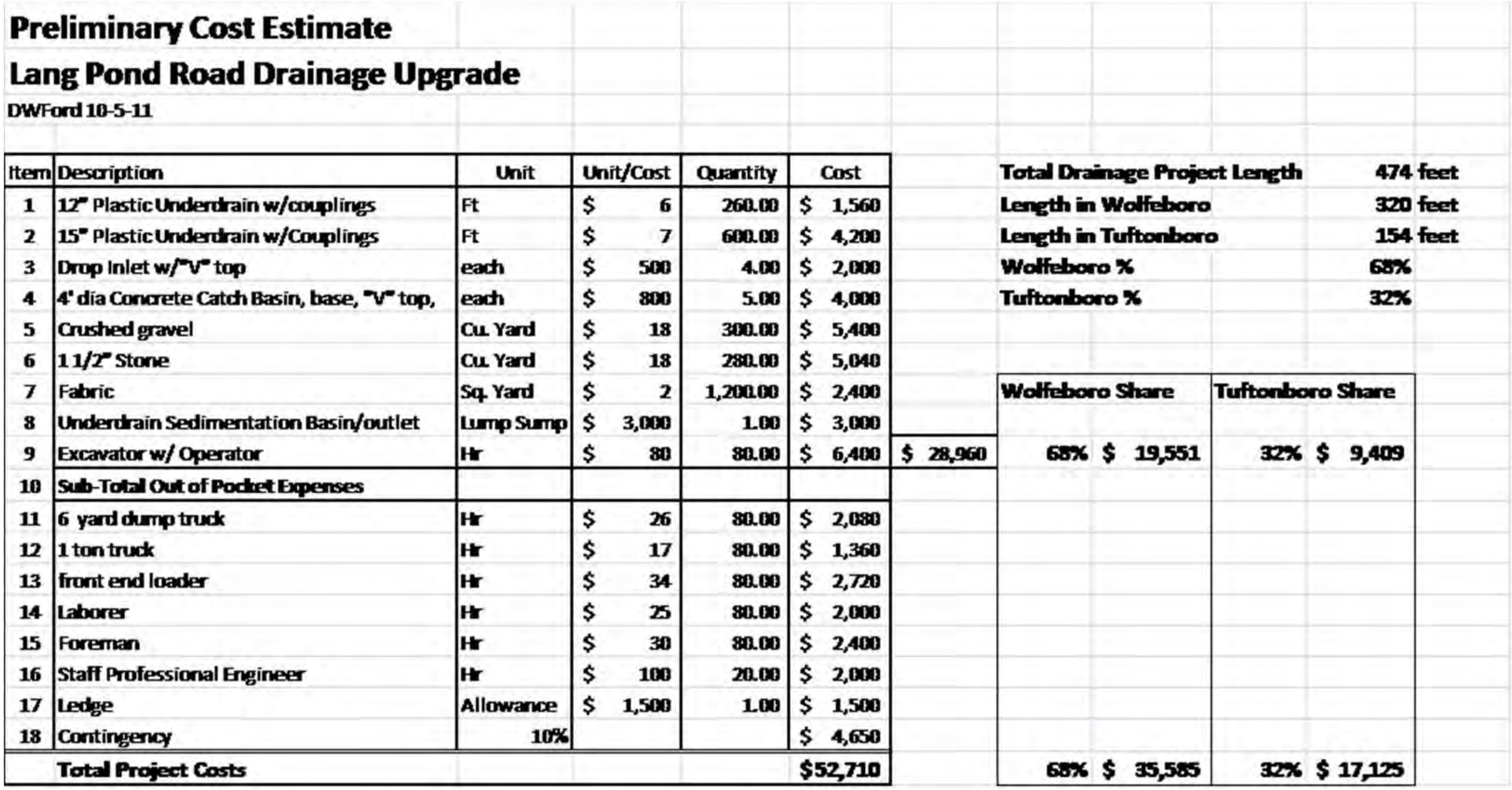
APPENDIX D1: BMP COST ESTIMATES

SITE	BMP / STORMWATER IMPROVEMENT	COMPONENT	QUANTITY	UNIT PRICE	COMPONENT COST	TOTAL COST	TP LOAD (lb/yr)	PERCENT REDUCTION	TP LOAD REDUCTION (lb/yr)
1	Lang Pond Road	Pave 800 lf of Lang Pond Rd.; Install 5 catch basins, 4 drop inlets, 1 underdrain sedimentation basin with outlet, and associated materials (stone, piping, etc.).	*Quantities and costs from Wolfeboro DPW, see Appendix D2*			$52,710			1.1[4]
						Low - High			
2	Mirror Lake Subdivisions					$73,301 - $89,590			3.32 - 4.06
a		flow diversions	2 ea	$2,000 ea	$4,000	$3,200 - $5,200	0.6	10%	0.05 - 0.07
b		300 sq ft biocell	300 sf	$30 sf	$9,000	$7,200 - $11,700	0.6	65%	0.35 - 0.43
c		125 sq ft biocell	125 sf	$30 sf	$3,750	$3,000 - $4,875	0.45	65%	0.26 - 0.32
d		200 sq ft biocell	200 sf	$30 sf	$6,000	$4,800 - $7,800	0.54	65%	0.32 - 0.39
e		800 sq ft biocell	800 sf	$16 sf	$12,800	$10,240 - $16,640	1.8	65%	1.05 - 1.29
f		constructed wetland	800 sf	$12 sf	$9,600	$7,680 - $12,480	2.4	45%	0.97 - 1.19
g		culvert improvements	1 ea	$2,000 ea	$2,000	$1,600 - $2,600	0.3	10%	0.03 - 0.03
h		culvert improvements	1 ea	$2,000 ea	$2,000	$1,600 - $2,600	0.3	10%	0.03 - 0.03
i		flow diversion	1	$2,500 ea	$2,500	$2,000 - $3,250	0.15	10%	0.01 - 0.02
j		flow stabilization	1 ea	$2,000 ea	$2,000	$1,600 - $2,600	0.15	10%	0.01 - 0.02
k		Rain Garden Installation	500 sf	$18 sf	$9,000	$7,200 - $11,700	0.4	65%	0.23 - 0.29
3	Abenaki Ski Area					$64,994 - $79,437	0.28	92%	0.23 - 0.28
		Standard Asphalt	4250 sf	$4 sf	$17,000				
		Porous Asphalt	4250 sf	$7 sf	$29,750				
		Bioretention	800 sf	$11 sf	$8,800				
4	Mirror Lake Boat Launch					$22,347 - $27,313	0.14	76%	0.10 - 0.12
		Cabled Concrete Boat Launch	-	-	$12,000				
		Standard Asphalt	480 sf	$4 sf	$1,920				
		Trench Drain	20 lf	$50 lf	$1,000				
		Bioretention Cells	380 sf	$11 sf	$4,180				

Notes:

1. Unit costs from Charles River Watershed Association, R.S. Means and based on past Geosyntec projects and contractor estimates.
2. Costs for Sites 2, 3 and 4 include additional 30% to reflect mobilization, erosion and sediment controls, contingency, etc.
3. BMP TP loading calculated using the Simple Method (Site 2) and the Spreadsheet Tool for Estimating Pollutant Loads provided by USEPA (Sites 1, 3 and 4)
4. TP Load reduction represents the phosphorus load due to erosion (soil loss) of the currently unpaved road surface and road side ditches (load reduced by paving/stabilization).

Appendix D2: Lang Pond Road (Site 1) Estimated Construction Costs from Town of Wolfeboro



Preliminary Cost Estimate

Lang Pond Road Drainage Upgrade

DWFord 10-5-11

Item	Description	Unit	Unit/Cost	Quantity	Cost	
1	12" Plastic Underdrain w/couplings	Ft	$ 6	260.00	$ 1,560	
2	15" Plastic Underdrain w/Couplings	Ft	$ 7	600.00	$ 4,200	
3	Drop Inlet w/"V" top	each	$ 500	4.00	$ 2,000	
4	4' dia Concrete Catch Basin, base, "V" top,	each	$ 800	5.00	$ 4,000	
5	Crushed gravel	Cu. Yard	$ 18	300.00	$ 5,400	
6	1 1/2" Stone	Cu. Yard	$ 18	280.00	$ 5,040	
7	Fabric	Sq. Yard	$ 2	1,200.00	$ 2,400	
8	Underdrain Sedimentation Basin/outlet	Lump Sump	$ 3,000	1.00	$ 3,000	
9	Excavator w/ Operator	Hr	$ 80	80.00	$ 6,400	$ 28,960
10	Sub-Total Out of Pocket Expenses					
11	6 yard dump truck	Hr	$ 26	80.00	$ 2,080	
12	1 ton truck	Hr	$ 17	80.00	$ 1,360	
13	front end loader	Hr	$ 34	80.00	$ 2,720	
14	Laborer	Hr	$ 25	80.00	$ 2,000	
15	Foreman	Hr	$ 30	80.00	$ 2,400	
16	Staff Professional Engineer	Hr	$ 100	20.00	$ 2,000	
17	Ledge	Allowance	$ 1,500	1.00	$ 1,500	
18	Contingency	10%			$ 4,650	
	Total Project Costs				$52,710	

Total Drainage Project Length	474	feet
Length in Wolfeboro	320	feet
Length in Tuftonboro	154	feet
Wolfeboro %	68%	
Tuftonboro %	32%	

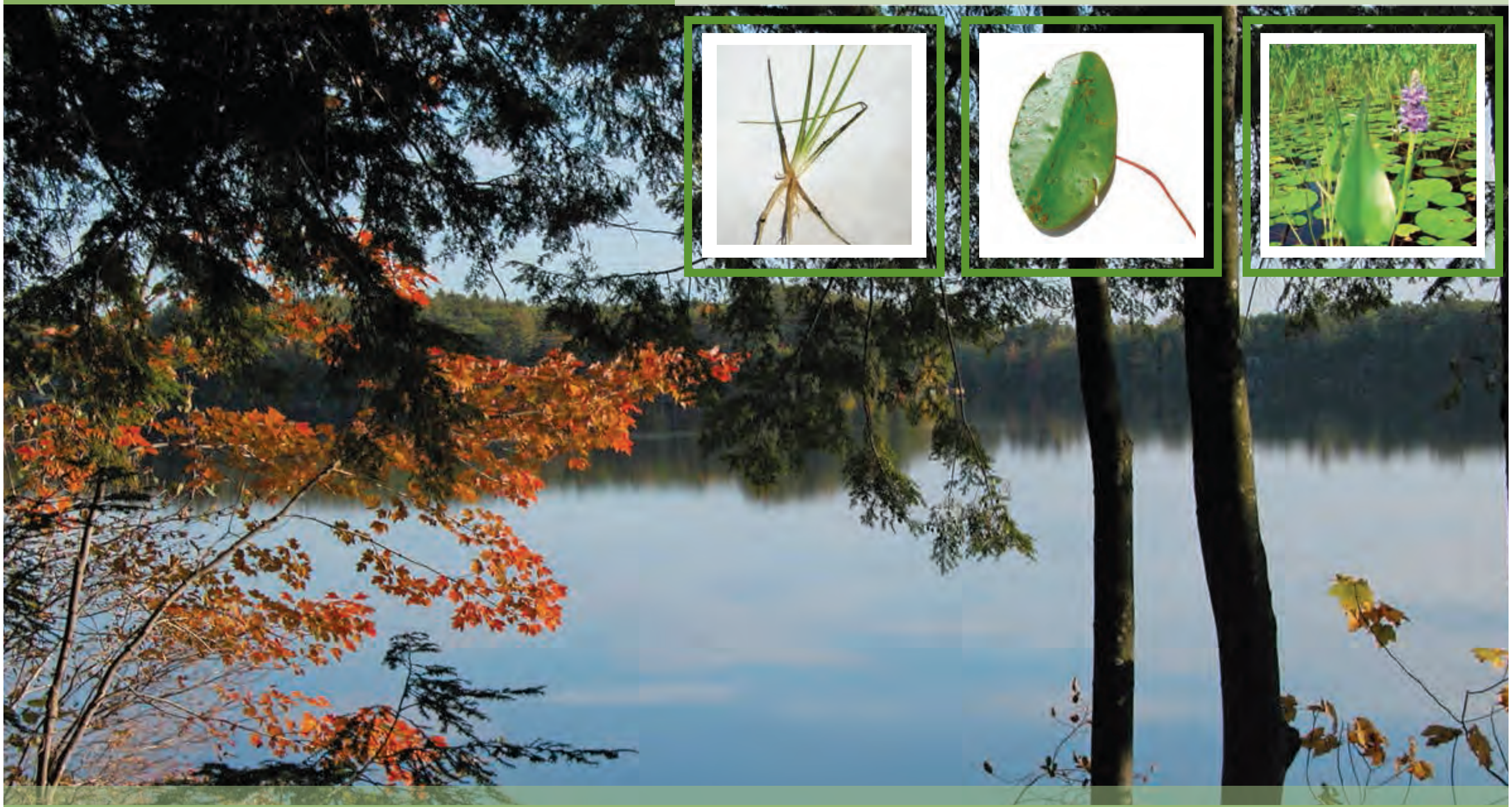
Wolfeboro Share		Tuftonboro Share	
68%	$ 19,551	32%	$ 9,409
68%	$ 35,585	32%	$ 17,125

APPENDIX E

Field Guide to the Aquatic Plants of Mirror Lake

Field Guide

to the aquatic plants of mirror lake



Prepared by:

Geosyntec
consultants

289 Great Rd., Acton, MA 01720
(978) 263-9588

Prepared for:
Mirror Lake Protective Association

July 2011

This Field Guide to the Aquatic Plants of Mirror Lake has been developed to assist in efforts to conduct regular aquatic vegetation monitoring at Mirror Lake.

New Hampshire lakes and ponds host a great variety of aquatic plants. If you find a plant in Mirror Lake which is not included in this field guide, there are a number of more comprehensive field guides that can be used as a reference for species identification. Some recommended references include the following:

- Aquatic Plants & Algae of New Hampshire's Lakes and Ponds. New Hampshire Department of Environmental Services. (Available online at: www.des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-05-30.pdf)

- G.E. Crow and C.B. Hellquist. 2000. Aquatic and Wetland Plants of Northeastern North America. The University of Wisconsin Press.

- Fassett, N.C. 1940. A Manual of Aquatic Plants. The University of Wisconsin Press.

This field guide is based on the results of an aquatic vegetation survey of Mirror Lake conducted by Geosyntec Consultants in July 2010. Emergent wetland plants were recorded only if they were rooted in standing water within the perimeter of Mirror Lake. The species identified during the survey are listed in the table on the following page.

Funding for this Field Guide was provided by a grant from the New Hampshire Department of Environmental Services with funding from the US Environmental Protection Agency under Section 319 of the Clean Water Act.

Scientific Name	Common Name	Page
SUBMERSED SPECIES		
Chara vulgaris	**Musk Grass**	**4**
Elatine minima	**Waterwort**	**4**
Eleocharis robbinsii	**Spike Rush**	**5**
Elodea nuttallii	**Waterweed**	**5**
Isoetes sp.	**Quillwort**	**6**
Najas flexilis	**Bushy Pondweed**	**6**
Potamogeton amplifolius	**Big-leaf Pondweed**	**7**
Potamogeton bicupulatus	**Snailseed Pondweed**	**7**
Potamogeton epihydrus	**Ribbonleaf Pondweed**	**8**
Utricularia purpurea	**Purple Bladderwort**	**8**
Vallisneria americana	**Wild Celery**	**9**
FLOATING LEAF SPECIES		
Brasenia schreberi	**Watershield**	**10**
Nuphar variegatum	**Yellow Water Lily**	**10**
Nymphaea odorata	**White Water Lily**	**11**
Nyphoides cordata	**Little Floatingheart**	**11**
Potamogeton natans	**Floating-leaf Pondweed**	**12**
EMERGENT SPECIES		
Decodon verticillatus	**Water Willow**	**13**
Eriocaulon septangulare	**Pipewort**	**13**
Elodea nuttallii	**Waterweed**	**14**
Pontederia cordata	**Pickerelweed**	**14**
Scirpus validus	**Soft-Stem Bulrush**	**15**
Sparganium sp.	**Burr-Reed**	**15**
Typha latifolia	**Cattail**	**16**

Musk Grass (Chara vulgaris)

Musk grasses have a distinct musky odor and are brittle when crushed between two fingers. Similar-looking vascular plants such as Bushy Pondweeds (Najas spp.) and Coontail (Ceratophyllum demersum) do not produce an odor when crushed.

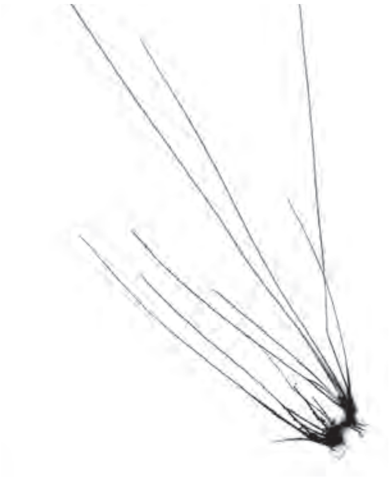
Illustration from: G.E. Crow and C.B. Hellquist. 1982. Aquatic Vascular Plants of New England. New Hampshire Agricultural Experiment Station.

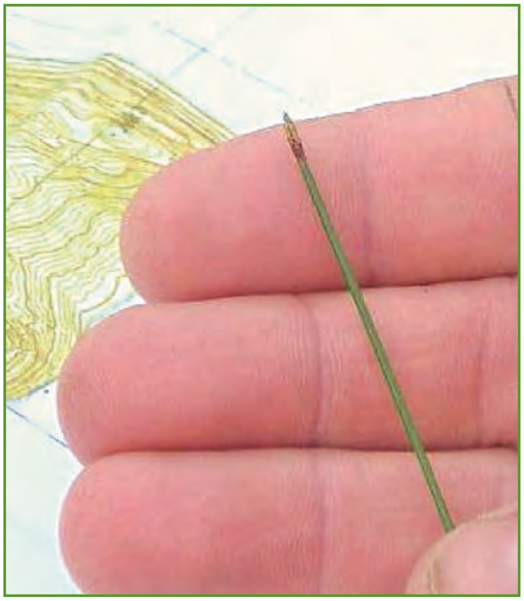
Small Waterwort (Elatine minima)

This tiny plant is typically found growing in shallow water. Its leaves are rounded at the tip and up to 4 mm long.

Robbins' Spike Rush (Eleocharis robbinsii)

The soft green stems of this plant often grow clumped together with oval shaped spikelets forming at the tips.





Waterweed (Elodea canadensis)

This Elodea species has leaves with blunt tips that whorl around the stem (3 or 4 leaves per whorl). This plant can be confused with the Najas species, which have opposite leaves rather than whorled leaves.

Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station.

Quillwort (Isoetes sp.)

The leaves of this plant become narrower from the base toward the sharply pointed tip. This plant looks similar to Pipewort, but does not have cross lines on its roots.

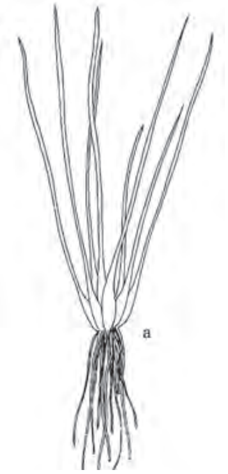


Illustration from: G.E. Crow and C.B. Hellquist. 2000. *Aquatic and Wetland Plants of Northeastern North America.* The University of Wisconsin Press.

Bushy Pondweed (Najas flexilis)

Bushy Pondweed can be distinguished from other Najas species by the pointed tips of its oppositely arranged leaves.

Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station.

Big-leaf Pondweed (Potamogeton amplifolius)

This common pondweed species is distinguished by its large, curved submersed leaves which are typically 3-7 cm wide.

Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station.

Snailseed Pondweed (Potamogeton bicupulatus)

This pondweed has submersed and floating leaves that are spirally arranged. The floating leaves, although not always present, have 3-7 veins.

Illustration from: Britton & Brown's Illustrated Flora of the Northern United States and Canada, 2nd ed.

Ribbonleaf Pondweed (Potamogeton epihydrus)

The floating leaves of this pondweed, when present, range from 34”-3 3/16” long and up to 1 3/8” wide. The submerged leaves look wilted and have a lightly colored stripe down the center.

Illustration from: USDA-NRCS PLANTS Database / USDA NRCS. *Wetland flora: Field office illustrated guide to plant species.*

Purple Bladderwort (Utricularia purpurea)

The branches of this bladderwort form clusters with bladders located at the tips. When in bloom, the flowers are purple.

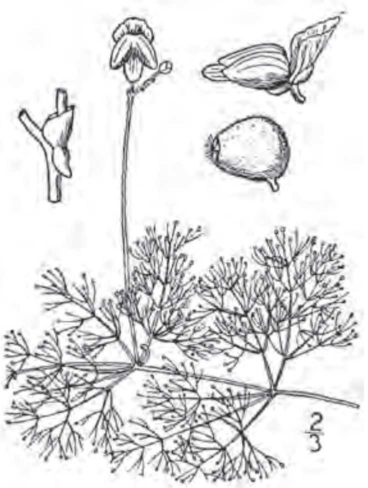


Illustration from: USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. *Illustrated flora of the northern states and Canada*. Vol. 3: 226.

Water Celery (Vallisneria americana)

Wild celery has ribbon-like leaves with bluntly rounded tips. A distinct light green stripe runs down the center of the leaves, which is most visible when the leaf is held up to light.

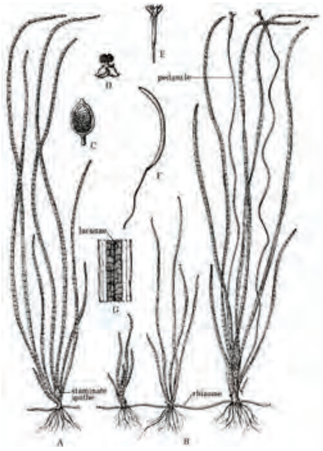


Illustration from: G.E. Crow and C.B. Hellquist. 1982. Aquatic Vascular Plants of New England. New Hampshire Agricultural Experiment Station.

Watershield (Brasenia schreberi)

There is a jelly-like substance on the underside of this plant's oval-shaped leaves and also on the plant's stem. The leaves are 2"-3" long and there may be dull colored red flowers present.

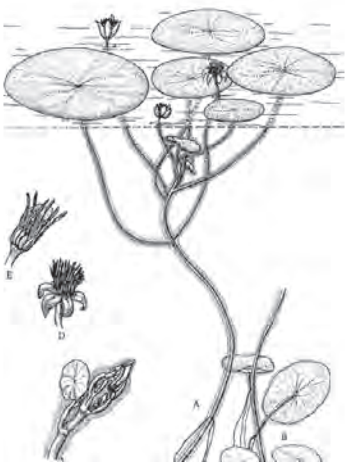
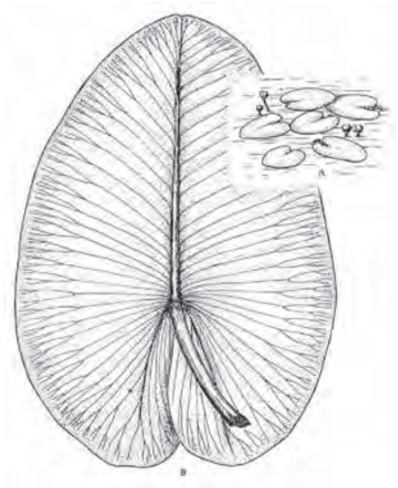


Illustration from: G.E. Crow and C.B. Hellquist. 2000. *Aquatic and Wetland Plants of Northeastern North America*. The University of Wisconsin Press.

Yellow Water Lily (Nuphar spp.)

Yellow water lilies have yellow flowers and large floating leaves with rounded lobes that frequently overlap.



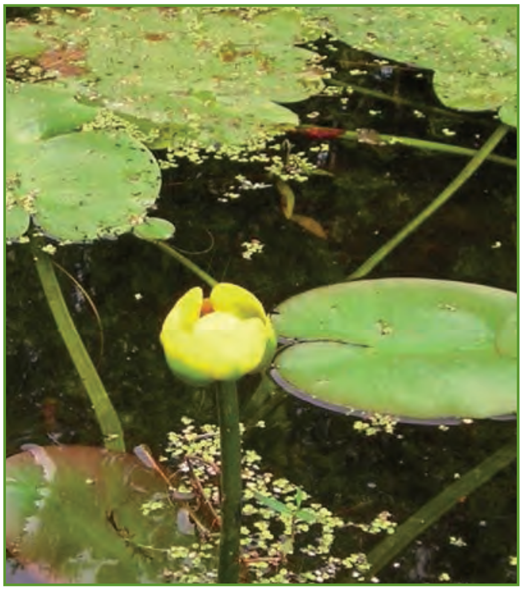
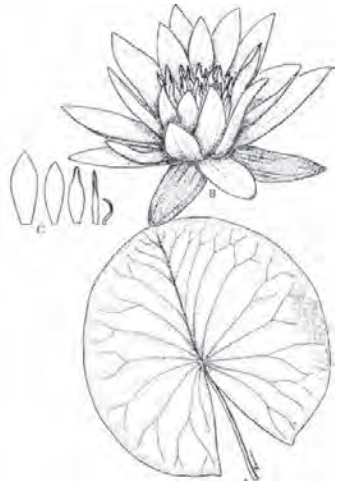


Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England*. New Hampshire Agricultural Experiment Station.

White Water Lily (Nymphaea odorata)

White water lilies have white flowers and floating leaves with pointed lobes that rarely overlap.



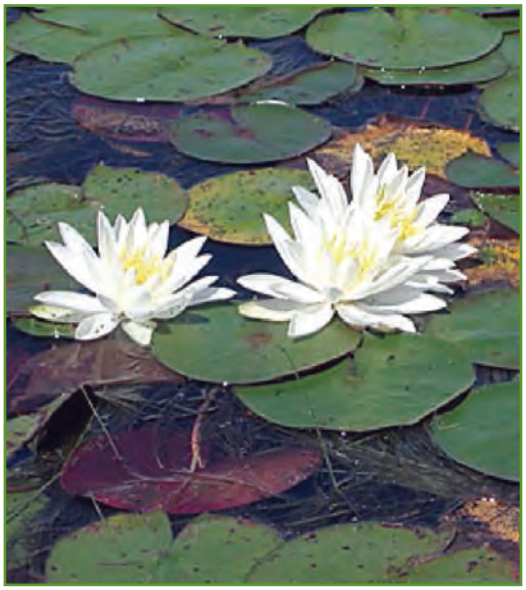


Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station

Little Floating Heart (Nyphoides cordata)

This plant has heart-shaped leaves roughly the size of a silver dollar and small white flowers. Its roots can be found bunched on the stem just below the surface of the water.

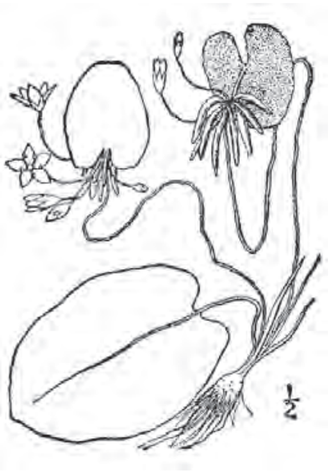


Illustration from: USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. *Illustrated flora of the northern states and Canada.* Vol. 3: 18.

Floating Leaf Pondweed (Potamogeton natans)

Submersed leaves are narrow (1-2 mm wide, 10-20 cm long), often disintegrating with age, tapering to an obtuse tip. Floating leaves are oval shaped and 3-10 cm long.

Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England*. New Hampshire Agricultural Experiment Station.

Water Willow (Decodon verticillatus)

This emergent shrub can grow up to 6 feet tall and has purple flowers when in bloom.

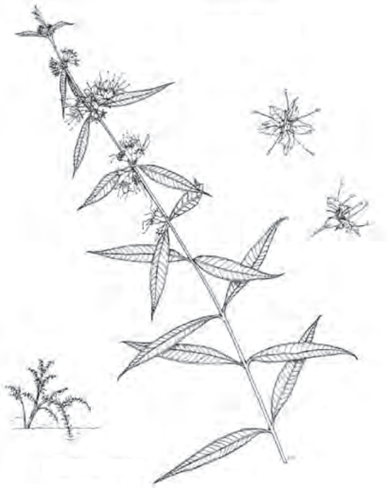


Illustration from: IFAS, Center for Aquatic Plants, University of Florida, Gainsville, 1996

Pipewort (Eriocaulon septangulare)

The most prominent feature of this plant is its white roots that have cross lines on them. At the end of the Pipewort's stalk there often is a button-like white flower that emerges.

Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station.

Waterweed (Elodea nuttallii)

This Elodea species has leaves with pointed tips that whorl around the stem (3 or 4 leaves per whorl). This plant can be confused with Elodea canadensis, which has leaves with blunt tips, and with Najas species that have opposite leaves rather than whorled leaves.

Illustration from: Crow, G.E. and Hellquist, C.B. 1982. Aquatic Vascular Plants of New England. New Hampshire Agricultural Experiment Station.

Pickerelweed (Pontederia cordata)

This perennial emergent plant can grow up to 4' tall. The leaves are waxy and can vary in size and shape. The violet flowers grow at the end of a vertical spike

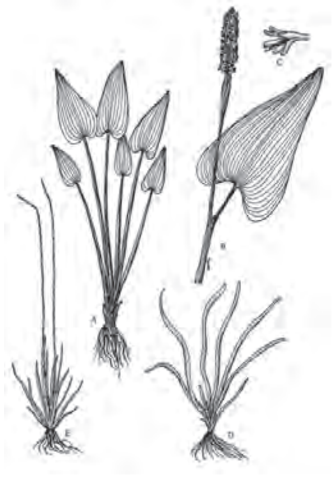
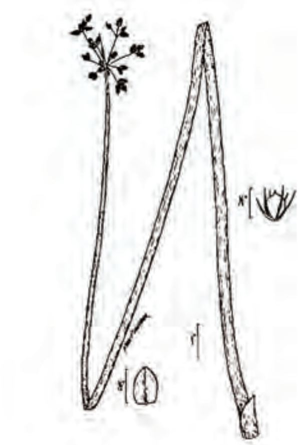


Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station.

Soft-Stem Bulrush (Scirpus validus)

This Elodea species has leaves with pointed tips that whorl around the stem (3 or 4 leaves per whorl). This plant can be confused with Elodea canadensis, which has leaves with blunt tips, and with Najas species that have opposite leaves rather than whorled leaves.



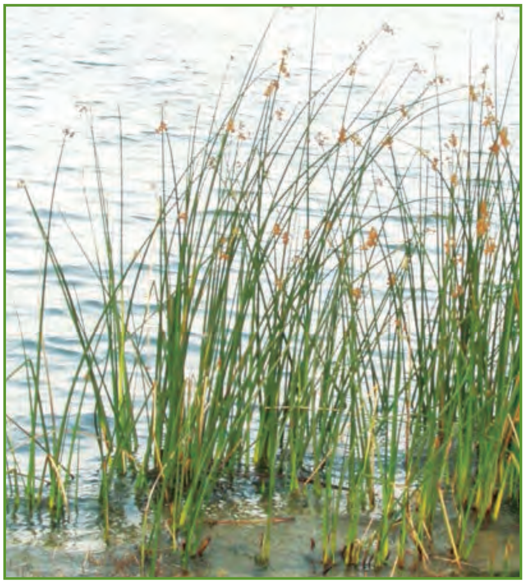


Illustration from: USDA, NRCS. 2011. The PLANTS Database (http://plants.usda.gov, 29 June 2011). National Plant Data Team, Greensboro, NC 27401-4901 USA.

Bur-reed (Sparganium sp.)

Bur-reed is an emergent wetland plant that typically grows up to two feet tall. Its bright green, strap-like leaf blades grow up to 1 inch wide. Its spherical flower heads are green in early season, becoming brown and bur-like later.

Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station.

Cattail (Typha latifolia)

Cattails are easily identified by their tall, sword-shaped leaves and fruiting spikes. Broad-leaved Cattail is distinguished from Narrow-leaved Cattail by its broader leaves and fruiting spikes that don't have a separation between the male and female sections.

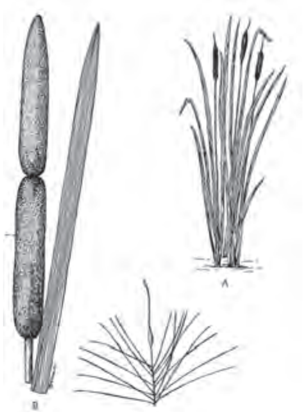


Illustration from: Crow, G.E. and Hellquist, C.B. 1982. *Aquatic Vascular Plants of New England.* New Hampshire Agricultural Experiment Station.

Mirror Lake