Refined Phosphorus TMDL and Restoration Plans for Lake Hopatcong and Lake Musconetcong, Upper Musconetcong River Watershed, Morris and Sussex Counties, New Jersey

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Executive Summary

The Upper Musconetcong River watershed is located in the Upper Delaware watershed (WMA 1). In addition to the river itself, the two major waterbodies located in the Upper Musconetcong River watershed are Lake Hopatcong and, immediately downstream, Lake Musconetcong. Both lakes have been recognized by the New Jersey Department of Environmental Protection (NJDEP) as being impaired for excessive in-lake total phosphorus (TP) concentrations originating from high phosphorus loads. These high TP loads result in a variety of water quality impacts such as algal blooms and nuisance densities of aquatic vegetation, and can eventually contribute to more large-scale impacts such as fish kills.

In response to this impairment, NJDEP conducted phosphorus TMDL analyses on both Lake Hopatcong and Lake Musconetcong. These analyses were completed in 2003. However, it was recognized that some of the data used to quantify the sources of phosphorus for either lake was relatively old (> 20 years). Therefore, it was decided to update the TP budgets for both lakes with the most recent, readily available information, as well as to develop a Restoration Plan for each lake. The updated TP budget would be used to revise the existing TMDL, while the Restoration Plans would be "blueprints" providing detailed recommendations on how to attain each lake's targeted TP load as outlined in the revised TMDL. In addition, the Restoration Plans will also provide guidance in the implementation of in-lake management control strategies that directly focus on the in-lake impairments (i.e., algal blooms, nuisance densities of aquatic vegetation). Such in-lake measures provide management strategies that move beyond the sole goal of reducing the watershed-based TP loads. Princeton Hydro has been contracted by both NJDEP and the Rutgers EcoComplex to revise the phosphorus TMDL for both lakes and develop these Restoration Plans.

A revision and detailed assessment of the TP budget for Lake Hopatcong revealed that septic systems and surface runoff were the largest and second largest sources of TP for the lake, respectively, accounting for slightly over 80% of the annual TP load. Based on the revised TP budget, the existing TP load must be reduced by 41% to achieve the targeted TP loads as outlined in the State's TMDL. The amended reductions in the TP load were proportionally divided among the four municipalities that border Lake Hopatcong. This municipal allocation of the targeted TP load reductions was based on each municipality's relative contribution to the existing TP load. The Township of Jefferson and the Borough of Hopatcong were the largest and second largest sources of watershed-based TP for the lake, respectively, accounting for slightly over 90% of the targeted reductions.

A revision and detailed assessment of the TP budget for Lake Musconetcong revealed that the outflow of Lake Hopatcong (which is the main inflow for Lake Musconetcong) and surface runoff from its immediate watershed were the largest and second largest sources of TP for the lake, respectively, accounting for slightly over 90% of the annual TP load. Based on the revised TP budget, the existing TP load must be

reduced by 37% to achieve the targeted TP loads as outlined in the State's TMDL. It should be noted that of the TP load targeted for reduction at Lake Musconetcong, 77% would be attained by Lake Hopatcong's achievement of its targeted TP load, while the remaining 23% would be attained by reducing the surface runoff TP load originating from the immediate watershed of Lake Musconetcong. For the immediate watershed, the Borough of Hopatcong and the Township of Roxbury were the largest and second largest sources of watershed-based TP for the lake, respectively, accounting for almost 75% of the targeted reductions

The Reckhow model was used to translate the existing and targeted TP loads for each lake to mean, steady-state in-lake TP concentrations. For both lakes, the existing in-lake TP concentration is 0.05 mg/L, while the targeted in-lake concentration is 0.03 mg/L. The predicted in-lake TP concentrations under existing conditions agree moderately well with the observed concentrations.

Existing (measured and predicted) and targeted in-lake TP concentrations were subsequently used to predict how each lake would respond to the various loading scenarios relative to algal growth, specifically as chlorophyll *a* concentrations. Some standard, robust TP – chlorophyll *a* regression models were used to predict the resulting amount of algal biomass under various TP loads, in an effort to provide a means of demonstrating to the layperson how excessive phosphorus loading can impact the water quality of lake from a visual and recreational perspective. Based on these modeling efforts, it was demonstrated that attaining the targeted TP load for both lakes would result in a reduction in the mean and maximum chlorophyll *a* concentrations; such reductions would translate to an improvement in water clarity and quality.

Detailed in-lake monitoring programs were conducted on both lakes during the course of this project. A variety of physical, chemical and biological data were collected at both lakes. This project funded the implementation of three in-lake monitoring events at Lake Musconetcong, as well as a spring fishery survey. The Lake Hopatcong Commission funded the in-lake monitoring program of Lake Hopatcong as an in-kind match. However, the project did fund the collection of some additional and detailed data on the plankton (phytoplankton and zooplankton) and the macrophyte (mat algae and aquatic plants) communities of Lake Hopatcong. All of these ecological data were used to develop a bioremediation strategy for each lake to address the biological impairments currently being experienced.

Utilizing a sub-watershed analysis conducted on the Upper Musconetcong River watershed in the early 1990's, the sub-watersheds were ranked from high to low, based the magnitude of the TP load originating from developed lands. The highest ranked sub-watershed was used to identify "hotspots" that should be considered for the installation of structural BMPs in the Lake Hopatcong and Lake Musconetcong watersheds. The Restoration Plan for each lake provides a list of recommended BMPs that focus primarily on these hotspot locations. However, other factors such as property ownership, accessibility, easements and location of existing utilities will also dictate where structural BMPs can be installed within each municipality.

Some preliminary estimates of the amount of TP removed by each recommended structural BMP are also provided in the Restoration Plans. These estimates are based on UAL model calculations in conjunction with ascribed TP percent removal efficiencies associated with each BMP. It should be emphasized that these are estimates and that direct stormwater sampling of any installed BMP should be conducted to obtain an empirical estimate of the amount of TP removed by any BMP on an annual basis.

In addition to surface runoff, septic systems are also a substantial source of TP, particularly in the Lake Hopatcong watershed. For this source of TP, the Borough of Hopatcong is undergoing a municipal-wide sewering project that will remove a large portion of the TP load originating from septic system. In contrast, a large portion of the Township of Jefferson is in the Highlands Preservation Area, making the potential sewering of large sections of the Township extremely difficult under current regulations. Therefore, the Township of Jefferson will be developing a detailed On-Site Wastewater Treatment System (OWTS) Management Plan for the Lake Shawnee sub-watershed. As part of this project, empirical data will be collected on the TP contributions of near-shore septic systems. The Management Plan will also provide detailed recommendations on reducing the Township's septic contribution to the Lake Hopatcong TP load. However, the Restoration Plan does provide some preliminary recommendations on the management of existing septic systems.

Some bioremediation recommendations were also made for both lakes to directly address the short-term impacts of algal blooms and nuisance densities of aquatic macrophytes. The detailed plankton monitoring conducted at Lake Hopatcong revealed a general absence of large-bodied (> 1 mm) herbivorous (algae-eating) zooplankton. Such conditions are indicative of a large population of zooplankton-eating fishes such as alewife, golden shiners, and young yellow / white perch. Under such conditions, a biomanipulation program that stocks a large number of gamefish that feed on the smaller fish would help the larger-bodied zooplankton to thrive and exert control of the algae. However, no stocking of such fish should be conducted until a detailed fishery survey is conducted at Lake Hopatcong.

In contrast to Lake Hopatcong, a fishery survey was conducted in the spring of 2003 at Lake Musconetcong. The findings of this fishery survey revealed that the fishery community can be considered poor in terms of both recreational use and ecological management through biomanipulation. Gamefish accounted for only a very minor component of the fishery community, with benthic fish and zooplankton-eating fish accounting for the bulk of the community. One of the prevailing factors responsible for the existing fishery community at Lake Musconetcong is the high density of the invasive aquatic plant Eurasian watermilfoil. This plant is the dominant species in the lake and eliminates the complex open water / littoral habitat that many desirable gamefish such as largemouth bass require. Thus, the recommendations for Lake Musconetcong were to

use the systemic herbicide Sonar[R] to eliminate Eurasian watermilfoil, and to control nuisance densities of native vegetation with the mechanical weed harvesters that are currently utilized on Lake Musconetcong.
Shifting from a Eurasian watermilfoil-dominated lake with 100% coverage to a native plant-dominated lake with 30-40% coverage, gamefish habitat will substantially improve and the recommended biomanipulation-stocking program could be initiated in Lake Musconetcong. However, it must be emphasized that no fish should be stocked in Lake Musconetcong for biomanipulation purposes until the Eurasian watermilfoil is eliminated, or at a minimum under control.

Public education and outreach is another important component of both Lake Restoration Plans. As part of this effort, the Lake Hopatcong Commission has begun hosting a twice-yearly TMDL meeting (spring and fall) to provide all municipal, County and State stakeholders with a status report on the TMDL process for the lakes. To date, two stormwater BMP implementation projects have been awarded to the Lake Hopatcong Commission, one from NJDEP and another from USEPA, to install a series of BMPs to reduce the TP load entering Lake Hopatcong. As part of these projects, stormwater monitoring will be conducted to quantify the amount of TP each BMP removes. In turn, the amount of TP removed will be deducted ("credited") from the amount of TP targeted for reduction as part of the TMDL. As previously mentioned, a 604(b) grant was awarded to the Township of Jefferson to initiate the development of a OWTS Management Plan in an effort to reduce the septic system TP contribution to Lake Hopatcong.

In conclusion, the current and future efforts will be documented and tracked by the Lake Hopatcong Commission and the Lake Musconetcong Regional Planning Board to quantify what progress is being made on attaining each lake's targeted TMDL-based TP load. Thus, the Restoration Plan for each lake should be considered a flexible, living document that will be continuously modified to attain the targeted phosphorus loads as described in the revised TMDL but on a site-specific basis.

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Section 1: Introduction

The State of New Jersey recently completed a Total Maximum Daily Load (TMDL) analysis of the Upper Musconetcong River watershed (WMA-1). This watershed is part of the Musconetcong River watershed which, in turn, is part of the Delaware River drainage basin. The TMDL focused on phosphorus, typically the primary nutrient which limits algal and aquatic plant growth. Phosphorus has also been identified by the State, under the 303(d) program, as one of the parameters responsible for the documented impairment of Lake Hopatcong and Lake Musconetcong (NJDEP, 2003a). Thus, the TMDL analysis for the two major waterbodies within the Upper Musconetcong River watershed focuses on phosphorus.

NJDEP proposed a set of phosphorus TMDLs for four eutrophic lakes in the northwest water region of the State in January of 2003. This TMDL was subsequently established in March of 2003 and then approved in September of 2003 (NJDEP, 2003). Two of the four waterbodies were Lake Hopatcong and Lake Musconetcong, both located in Morris and Sussex Counties, New Jersey. While approval was given to the phosphorus TMDLs for Lake Hopatcong and Lake Musconetcong, NJDEP recognized that some of the data used to quantify the existing phosphorus loads entering each lake were based on dated information. For example, the annual phosphorus load contribution originating from on-site wastewater treatment systems (i.e. septic systems) was derived from the original Phase I Diagnostic / Feasibility Study (PAS, 1981).

There are two main objectives associated with this project. First, revise the TP loads for Lake Hopatcong and Lake Musconetcong to provide more up-to-date budget for each lake and its respective TMDL. Second, develop site specific Restoration Plans for each lake that serve as “blueprints” to attain each lake’s targeted TMDL loads. These Restoration Plans will also provide guidance in addressing in-lake impacts that require management beyond controlling the watershed-based TP loads. Such impacts include the management of aquatics vegetation and the use of bioremediation measures such as biomanipulation. Princeton Hydro was hired by both NJDEP and the Rutgers EcoComplex to satisfy these objectives through the fieldwork conducted in 2003 and the development of this Restoration Plan document.

Section 1.1: Brief Description of Lake Hopatcong

Lake Hopatcong and its associated tributaries, Lake Shawnee and its sub-watersheds, form the headwaters of the Upper Musconetcong River watershed. In turn, the outlet of Lake Hopatcong forms the Upper Musconetcong River and enters Lake Musconetcong approximately 1.28 miles from the Lake Hopatcong dam (Figure 1). Therefore, any restoration activities that occur within the sub-watersheds immediately surrounding Lake Hopatcong will benefit Lake Musconetcong and other downstream waterways, in addition to Lake Hopatcong itself. Given these conditions, municipal-based Restoration Plans will be developed for each municipality directly surrounding Lake Hopatcong. However, in order to develop these municipal-based Restoration Plans, some of the data used to create the phosphorus TMDL had to be updated and/or refined.

Section 1.2: Brief Description of Lake Musconetcong

Lake Musconetcong is a 329-acre waterbody located approximately 1.28 miles downstream of the dam of Lake Hopatcong (Figure 1). Similar to Lake Hopatcong, Lake Musconetcong is on the border of Sussex and Morris Counties, surrounded by the Borough of Netcong and Stanhope and the Townships of Roxbury and Byram. In sharp contrast to the complex morphometry of Lake Hopatcong, Lake Musconetcong is a shallow waterbody with a mean depth of 1.5 m (4.8 ft) and a maximum depth of 3.05 m (10.0 ft).

Figure 1

Section 2: Methodology Associated with Refining the Phosphorus TMDL for the Upper Musconetcong River Watershed (Lake Hopatcong)

The cornerstone of the development of the Restoration Plan for Lakes Hopatcong and Musconetcong is the phosphorus TMDL. The New Jersey Department of Environmental Protection (NJDEP) constructed a phosphorus TMDL for each lake using the Unit Areal Loading (UAL) model (NJDEP, 2003) to quantify the sources of phosphorus entering each lake. The UAL model uses empirically-derived loading coefficients for various land types, land uses and existing atmospheric / in-lake conditions to calculate the annual phosphorus loads (Reckhow, 1979; USEPA, 1990). Princeton Hydro relied on the State's TMDL analysis as the foundation for the Restoration Plan, however, this analysis was re-evaluated to ensure all major sources of phosphorus are represented and quantified with a reasonable level of accuracy. The results of this refinement of the phosphorus TMDL for Lake Hopatcong are summarized in Table 1.

Section 2.1: Surface Runoff and Stormwater

As previously described, the UAL model was used to quantify the surface runoff contribution to the lakes' annual phosphorus loads. Land use was determined using NJDEP's existing GIS database of 1995 / 1997 land use coverage. NJDEP subsequently conducted an extensive review of various phosphorus export coefficients and selected specific values for each land use category (NJDEP, 2003). The coefficients were multiplied by their respective land use areas to obtain an estimate of the annual phosphorus load for that particular land use type within each watershed.

Princeton Hydro examined the State's delineated watershed map, which is based on the HUC14 watershed. The State's delineated HUC14 watershed was extremely similar to Princeton Hydro's delineated Upper Musconetcong watershed, which is based on a Digital Elevation Model (DEM). The DEM is a remote sensing-based model that develops an elevation grid at discrete sizes and was used in the 205(J) study to delineate the Upper Musconetcong River watershed (Coastal, 1995). Given the high level of consistency between the State and Princeton Hydro's DEM delineation, the State's map was used for this study. However, as will be described later in this report, the 205(J) delineated sub-watershed map datalayer was used to select prioritized areas for the installation of stormwater Best Management Practices (BMPs) and/or retrofits (see Section 7.1).

Princeton Hydro used the same phosphorus export coefficients identified and selected by NJDEP in calculating the phosphorus loads for the three pieces of land included in the Lake Hopatcong watershed (NJDEP, 2003). The State's calculated phosphorus load from surface runoff for Lake Hopatcong was 2,753 kg per year (NJDEP, 2003). As a result of the refinement analysis described below (Sections 2.2 through 2.6), the refined load from surface runoff is 2,466 kg per year, while 8,097 kg per year is the annual total phosphorus loading for Lake Hopatcong (Table 1).

With the aid of GIS technology, the refined phosphorus loads originating from stormwater were divided along municipal boundaries. This analysis provided a means of quantifying each municipality's contribution to Lake Hopatcong annual phosphorus load (see Section 2.7).

Table 1

Annual Total Phosphorus Loading for Lake Hopatcong

Source	Kg of TP per year	Percent Contribution
Surface Runoff	2,466	31
Sparta Surface Runoff	138	2
Septic Systems	4,223	52
Atmospheric	68	1
Internal Loading	595	7
Outlet of Lake Shawnee	607	7
Total	**8,097**	**100**

Section 2.2: Septic Systems

Many of the homes within the Lake Hopatcong watershed have on-site wastewater disposal (septic systems). The State's 2003 TMDL analysis utilized the septic system phosphorus load that was calculated as part of the lake's original Phase I Diagnostic / Feasibility Study (PAS, 1981), which was funded under the US EPA Clean Lakes (314) program. However, since the data that were used to calculate the septic system contribution to Lake Hopatcong's annual phosphorus load are over 20 years old, one of the tasks ascribed to Princeton Hydro as part of the development of the Restoration Plans was to update the septic system contribution.

The most commonly used and cost effective protocol used to quantify the annual phosphorus contribution from septic systems incorporates information on the number of persons per residence (per capita), soil type and conditions, and distance of leachfield to surface waterway / shoreline (USEPA, 1980). The base formula used to quantify the septic load for each municipality is provided in Equation 1:

$$P_s = EC_s \times \# \text{ of capita} \times (1 - SR)$$

P_s = Annual phosphorus load originating from septic systems (kg / yr)
EC_s = Selected export coefficient to septic tank (kg / capita / yr)
# of capita = Average # of persons per dwelling x # of dwellings
SR = Soil retention coefficient (dimensionless)

The first step in updating the septic system contribution to the lake's annual phosphorus load was to identify how many septic system leachfields exist within a zone of 100 meters (330 ft) along either the lake shoreline or any of the associated tributaries. USEPA studies have identified that on average, septic leachfields within 100 meters of a waterway are a net source of phosphorus (USEPA, 1980). Thus, using GIS methodology, a 100-meter "zone of influence" was identified along all of the tributaries and shoreline of Lake Hopatcong for the four municipalities that possess shoreline property. These municipalities include the Borough of Hopatcong, the Township of Jefferson, the Borough of Mount Arlington and the Township of Roxbury (Figure 2).

Each municipality was then contacted to obtain the most up-to-date information on their local wastewater data. The majority of both the Borough of Mount Arlington and the Township of Roxbury are sewered, so the identification of the few septic system leachfields within each municipality's 100-meter zone of influence was easily completed. In contrast, substantial portions of the Borough of Hopatcong and the Township of Jefferson located within the Lake Hopatcong watershed still utilize septic systems for wastewater treatment. Fortunately for both of these municipalities, digital GIS data were available that assisted in quantifying the number of septic leachfields within the 100 meter septic system zone.

Figure 2

The Borough of Hopatcong digital database was purchased from Civil Solutions and consisted of the lot and block data for the entire Borough, with a database category of Sewered / Non Sewered. Any lots ***not*** identified as sewered were categorized as having an on-site wastewater disposal system (i.e., septic system). The Borough of Hopatcong and the Township of Roxbury were the only municipalities with land in both the Lake Hopatcong and Lake Musconetcong watersheds. However, the Township of Roxbury is almost entirely sewered. Thus, septic system leachfields within the Borough of Hopatcong's zone of influence were separated based on whether they were located in the Lake Hopatcong or Lake Musconetcong watershed.

The Township of Jefferson digital data were purchased from Hatch-McDonald. This database included a data layer that identified areas within the Township that are sewered. These sewered areas were layered over the parcel lot and block digital data to identify those homes known to be sewered. Those homes that were not identified as sewered were designated as possessing on-site wastewater disposal systems.

Once the GIS datalayer of homes identified as using septic systems for on-site wastewater disposal with in both the Borough of Hopatcong and the Township of Jefferson was complete, it was subsequently layered over the 100-meter septic zone of influence along the lake shoreline and associated tributaries. The number of dwellings within each municipality's zone of influence accounts for the second part of the "# of capita" portion of Equation 1.

In order to complete the # of capita calculation, an estimate of the average number of persons living within each dwelling had to be obtained. This was accomplished by examining the 2000 census data for the four municipalities. Using the 2000 census data, the population within each municipality was divided by its respective number of housing units to obtain the average number of persons living within each dwelling. For the Borough of Hopatcong, the average number of persons per dwelling was 2.6, while for the Township of Jefferson this value was 2.5. These municipal-based values account for the first part of the # of capita portion of Equation 1.

While it would be preferable to use the average number of persons per dwelling within the zone of influence instead of each municipality, census data at such a level of detail were not readily available. The municipal data used in the analysis was obtained from the U.S Census Bureau and was not presented in a spatially distributed format. In addition, the municipalities did not have readily available digital lot and block data linked to locally collected census information that could be manipulated through GIS to determine the average number of persons per dwelling within the zone of septic influence. Therefore, the municipal-wide estimates of the average number of people found within each dwelling, within the identified septic zone of influence was used in this model.

A number of empirically-derived phosphorus loading coefficients for wastewater entering the septic tank were reviewed (US EPA, 1980) for the municipal-based septic analysis. A conservative coefficient of 0.74 kg / capita / yr was selected for septic tanks within the Lake Hopatcong watershed.

The soil retention coefficient (SR) is an estimate of how well the septic system's leachfield traps or retains phosphorus, preventing it from entering the lake or tributary via groundwater. The coefficient is a dimensionless value that ranges from 0 to 1.0. If all of the generated phosphorus moving through a septic system enters the lake or tributary, the SR is 0. However, if all of the phosphorus is trapped and treated within the soils and none of it enters a receiving waterway, the SRP is 1.0 (Reckhow, 1980; US EPA, 1980).

Other studies where near shore soils varied from moderate to poor in phosphorus adsorbing capacities had a most likely coefficient of 0.25, while more moderate soils had a coefficient of 0.50 (Reckhow, 1980). Utilizing these ascribed soil retention coefficients as well as a certain degree of professional judgment, it was decided that the soils would be categorized as slight, moderate and severe in terms of the degree of septic limitation. As provided below, the term septic limitation can be used to describe a number of potential soil conditions.

Using data obtained from the Association of New Jersey Environmental Commissions (ANJEC), the soils with the septic zone of influence throughout the Lake Hopatcong watershed were categorized as slight, moderate and severe in terms of septic limitation (NJDEP, 1999). This was accomplished by using septic suitability data originating from the New Jersey Administrative Code N.J.A.C. 7:9A, Appendix D. Based on the code, there are six criteria for septic suitability and three possible "Suitability Classes," including:

1. Fractured rock or excessively coarse substrata
2. Massive rock or hydraulically restrictive substrata
3. Hydraulically restrictive horizon, permeable substratum
4. Excessively coarse horizon
5. Zone of saturation, regional
6. Zone of saturation, perched.

The three suitability classes are simply three Roman Numerals (I, II, III), which are indicative of the severity of the limitation (III being the most severely limited). Based on conservations with NJDEP staff, it was decided to take a very conservative approach toward ascribing a level of limitation to a particular soil type. Thus, if any identified soils were ranked with a Roman Numeral III for <u>any</u> of the six criteria identified above, they were automatically identified as being severe. None of the soils identified in the study site were identified as having a slight degree of septic limitation. Therefore, any soil that was not identified as being severe was identified as being moderate in terms of septic limitation.

Section 2.3: Atmospheric

The atmospheric deposition or dryfall of phosphorus directly onto each lake's surface was obtained from the NJDEP's phosphorus TMDL analysis (NJDEP, 2003). **A** loading coefficient of 0.07 kg TP / ha / yr was used to quantify the atmospheric deposition of phosphorus. This coefficient was derived from a Statewide mean concentration of total phosphorus from the New Jersey Air Deposition Network (Eisenreich and Reinfelder, 2001; Koelliker, et. al., 2004).

Section 2.4: Internal Loading

Internal loads of phosphorus (i.e., liberation of phosphorus from the sediments, macrophyte decomposition and /or groundwater) was obtained from the previous Phase I Diagnostic / Feasibility Studies conducted on each lake (Coastal Environmental Services, 1992; Princeton Aqua Science, 1983).

Section 2.5: Outlet of Lake Shawnee

Lake Shawnee is a 50-acre waterbody located in the Township of Jefferson, in the upper northeastern part of the Upper Musconetcong River watershed. The outflow of Lake Shawnee enters Lake Hopatcong through the Jefferson Canals. The Phase I Diagnostic / Feasibility Study estimated that the outflow from Lake Shawnee accounted for 23% of Lake Hopatcong's annual hydrologic load. In addition, the phosphorus retention (Kirchner and Dillon, 1975) of Lake Shawnee was calculated to be 40.6% (Princeton Aqua Science, 1983).

In order to update the phosphorus load entering Lake Hopatcong from the outlet of Lake Shawnee, both the surface runoff and septic system loads directly entering Lake Shawnee were updated. Similar to the Lake Hopatcong and Lake Musconetcong TMDL, NJDEP's existing GIS database of 1995 / 1997 land use coverage was used to update the surface runoff stormwater loads. In addition, the same methodology that was used to update the Township of Jefferson's septic system TP load (see Section 2.2) was used to update the septic system load directly entering Lake Shawnee.

Based on the updated analysis, the surface runoff TP load directly entering Lake Shawnee from its adjacent sub-watersheds is 389 kg. Of this TP load, 201 kg originates from undeveloped forested land, while the remaining 188 kg originates from developed land (Table 2).

The septic system TP load directly entering Lake Shawnee was calculated to be 633 kg. Thus, the Lake Shawnee septic system TP load was 1.6 times higher than that lake's surface runoff TP load. Combined, the surface runoff and septic system TP loads entering Lake Shawnee total 1,022 kg.

As previously identified, the phosphorus retention of Lake Shawnee is 40.6% (Princeton Aqua Science, 1983). Essentially, this means that Lake Shawnee "functions" as a structural BMP for Lake Hopatcong, retaining 40.6% of the generated phosphorus load. This function was taken into consideration in refining Lake Hopatcong's TMDL. Thus, the remaining 59.4% of the phosphorus flows downstream and into Lake Hopatcong. This means that 607 kg of the Lake Shawnee TP load enters Lake Hopatcong through the Jefferson Canals (Table 2).

Table 2

Breakdown of Annual Total Phosphorus Load Entering Lake Hopatcong from Lake Shawnee

Source of Phosphorus Load	Annual Phosphorus Load in kg
Surface Runoff Load	389
Septic Load	633
Total Gross Load	**1,022**
Phosphorus Retention Coefficient for Lake Shawnee = 0.406	
Surface Runoff Load	231
Septic Load	376
Total Net Load	**607**

Total Gross Load is the Annual TP load entering Lake Shawnee from its immediate drainage area.

Total Net Load is the Annual TP load leaving Lake Shawnee from its outlet and entering Lake Hopatcong. The phosphorus retention coefficient was used to quantify the annual TP load that leaves Lake Shawnee.

Section 2.6: Refined and Updated Annual Phosphorus Load for Lake Hopatcong

The main sources of phosphorus for Lake Hopatcong were categorized into one of five (5) forms and their percent contributions are shown in Table 1. These five sources are drainage from the watershed (surface runoff), septic systems, atmospheric deposition, internal phosphorus regeneration, and the outlet of Lake Shawnee. For the applicability of the TMDL-based Restoration Plan, the TP contribution from the Township of Sparta's surface runoff was separated from the total surface runoff load (Table 1).

Based on the results of this analysis, individual wastewater disposal systems (i.e., septic systems) account for slightly over half of the annual TP load entering Lake Hopatcong. Surface runoff is the second largest source of phosphorus entering Lake Hopatcong, accounting for 30% of the total annual TP load (Table 1). The results of this refinement of the phosphorus TMDL vary from the State's TMDL analysis, where surface runoff and septic system contributions accounted for 55% and 32% of the annual TP load, respectively (NJDEP, 2003). Since the same land use data and phosphorus loading coefficients were used to quantify surface runoff, the difference between these two models was primarily attributed to updating the septic system contribution. As previously described, NJDEP utilized the septic systems load estimates from the original Phase I Study which is over 20 years old. In contrast, this refined analysis utilized updated municipal data as well as more detailed soil information to quantify the annual TP load originating from septic systems.

It is interesting to note that Lake Hopatcong's internal phosphorus load and the outlet of Lake Shawnee each accounted for approximately 7% of the Lake Hopatcong's annual TP load (Table 1). Due to its largely forested conditions, the portion of the Township of Sparta located within the Lake Hopatcong watershed accounts for only 2% of the lake's annual TP load. Finally, atmospheric deposition directly over Lake Hopatcong accounted for only 1% of the annual TP load (Table 1). Based on this refinement of the phosphorus TMDL for Lake Hopatcong, the Restoration Plan should focus on reducing the septic system and surface runoff TP loads.

Using the results of the refined phosphorus TMDL, as well as the targeted phosphorus load already established in the State's analysis for Lake Hopatcong (NJDEP, 2003), both the required total reduction and percent reduction were calculated. This calculated reduction establishes a quantified amount of phosphorus that needs to be removed from the lake's annual load in order to comply with the TMDL.

Based on the refined TMDL analysis, the annual phosphorus load currently entering Lake Hopatcong is 8,097 kg (Table 1). With an established targeted TP load of 4,800 kg (NJDEP, 2003), a 41% reduction in the existing phosphorus load is required to attain the targeted load (Table 3). This 41% reduction translates to removing 3,297 kg of TP from the existing annual load. Therefore, one of the primary objectives of the Lake

Hopatcong Restoration Plan is to attain the targeted load by removing this quantified TP load.

As previously identified, over 80% of the annual TP load entering Lake Hopatcong originates from surface runoff and septic systems within the four municipalities that immediately surround the lake (Table 1). Therefore, the majority of the restoration measures for Lake Hopatcong will focus on reducing the phosphorus loads originating from surface runoff and existing septic systems.

Section 2.7: Municipal-Based Phosphorus Loads for Lake Hopatcong

Atmospheric sources of phosphorus (i.e., precipitation, dryfall) are minor and extremely difficult to control. Thus, the control of these sources of phosphorus was not considered for the Restoration Plan. While there are several in-lake techniques designed to control internal phosphorus loading (i.e., alum applications, aeration), this source of phosphorus for Lake Hopatcong is relatively minor and therefore does not warrant a cost effective restoration strategy. It too was not included in the Restoration Plan.

A small portion, approximately 9%, of the Township of Sparta is located within the Lake Hopatcong watershed (Figure 2). Since this land is primarily forested and the Township does not have any lakefront property, it was decided not to include it with the other four municipalities in development of the Restoration Plan. However, the State should consider the possible purchase of this land from the Township or property owner as a proactive measure of protecting the water quality of Lake Hopatcong. This situation may be eligible for a possible trade and credit scenario between the Township of Sparta and the State. However, this is for future consideration and not for the development of the Restoration Plan.

The outlet of Lake Shawnee, entering Lake Hopatcong from the northeastern section of the watershed, contributes approximately the same amount of phosphorus as the lake's internal load. However, since Lake Shawnee is located within the Township of Jefferson, it was included in the Restoration Plan.

Focusing the development of the long-term Restoration Plan on reducing surface runoff and septic system sources of phosphorus will attain the targeted phosphorus load for Lake Hopatcong. This is an achievable objective, since over 80% of the annual phosphorus load entering Lake Hopatcong originates from surface runoff and septic systems. Collectively, the surface runoff and septic system sources of phosphorus will be defined as the "municipal-based" phosphorus load. It is the municipal-based phosphorus loads originating from the four municipalities immediately surrounding Lake Hopatcong (Figure 1) that will be reduced to attain the targeted TMDL phosphorus load.

Table 3 - Refined and Targeted Phosphorus TMDL for Lake Hopatcong

Described Scenario	Associated Value
Annual TP Load (refined TMDL)	8,097 kg
Targeted TP Load (NJDEP, 2003)	4,800 kg
Required Percent Reduction to Attain Targeted TP Load	41 %
Required Reduction in the Existing TP Load	3,297 kg

Table 4 - Municipal-based Phosphorus Loads for Lake Hopatcong

Municipality	kg per yr	Percent Contribution	Required Reductions (kg / yr)
Jefferson Township	4,201	57.6	1,899
Borough of Mt. Arlington	322	4.4	145
Roxbury Township	235	3.2	106
Borough of Hopatcong	2,538	35	1,147
Total	**7,296**	**100**	**3,297**

It was determined that in order for the Restoration Plan to be fair and objective, the targeted phosphorus load reductions will be divided on proportional basis. Specifically, the amount of phosphorus each municipality currently contributes to the lake's existing phosphorus load will be used to quantify its targeted reduction. The results of this strategy are shown in Table 4.

The municipal-based phosphorus loads for the four municipalities surrounding Lake Hopatcong total 7,296 kg per year. The Township of Jefferson accounts for slightly over half of the total municipal-based load. The Borough of Hopatcong was the second largest source of municipal-based phosphorus, accounting for 35% of the total (Table 4). In contrast, the Borough of Mount Arlington and the Township of Roxbury combined account for less than 10% of the total load (Table 4). These results are primarily due to the fact that both Mount Arlington and Roxbury are sewered, while Jefferson and Hopatcong are not. However, it should be noted that the Borough of Hopatcong is currently in the process of being sewered. This will obviously have a substantial impact on the Borough of Hopatcong portion of the Restoration Plan, as well as the relative contributions from the other three municipalities.

Multiplying the percent contribution of each municipality by the required reduction of 3,297 kg produced a required reduction specific to each municipality (Table 4). These municipal-based required reductions will be used to develop a Restoration Plan for each municipality within the Lake Hopatcong watershed.

A previous study determined that there are 42 sub-watersheds within the Upper Musconetcong River watershed (Lake Hopatcong and Lake Musconetcong watersheds combined) (Coastal Environmental Services, Inc., 1995). Using the magnitude of the surface runoff pollutant loads originating from developed land, these sub-watersheds were ranked from highest to lowest. Details on the methodology and results of this analysis are provided in the Restoration Plan portion of this report (Section 6).

Section 3: Methodology Associated with Refining the Phosphorus TMDL for the Upper Musconetcong River Watershed (Lake Musconetcong)

NJDEP calculated the phosphorus TMDL for Lake Musconetcong at the same time it developed the TMDL for Lake Hopatcong. Thus, the methodology that was used for Lake Hopatcong was also used for Lake Musconetcong. In turn, the refinement of the Lake Musconetcong phosphorus TMDL follows the same format and methodology that was used for the refinement of Lake Hopatcong. The results of this refinement of the phosphorus TMDL for Lake Musconetcong are summarized in Table 5.

Table 5

Annual Total Phosphorus Loading for Lake Musconetcong

Source	Kg of TP per year	Percent Contribution
Outflow of Lake Hopatcong	2,348	67
Surface Runoff	824	24
Mount Olive Township Surface Runoff	3	< 1
Township of Byram Surface Runoff	2	< 1
Septic Systems	149	4
Atmospheric	9	< 1
Internal Loading	151	4
Total	**3,486**	**100**

Section 3.1: Outflow of Lake Hopatcong (Upper Musconetcong River)

As documented in the Phase I Diagnostic / Feasibility Study (Coastal Environmental Services, Inc., 1992), the Upper Musconetcong River, which is the outflow of Lake Hopatcong, is the largest source of phosphorus for Lake Musconetcong. Based on the Phase I study, the Upper Musconetcong River accounted for 1,475 kg or 74% of the annual TP load entering Lake Musconetcong. This contributing source of phosphorus was updated for the Restoration Plan for Lake Musconetcong with the aid of two methodologies.

The first methodology used the same approach that was used for the Phase I study; the hydrologic inflow volume was multiplied by the annual mean TP concentration of the river. The only difference between the Phase I analysis and the Restoration Plan analysis was that the Restoration Plan included more recent hydrologic and water quality data.

The volume of hydrologic inflow for the Upper Musconetcong River was based on the annual hydrologic inflows from 1929 through 1974 (USGS #01455500; HUC 02040105) and the annual inflow monitored as part of the Phase I study (Coastal Environmental Services, Inc., 1992). Monitoring of the outflow of Lake Hopatcong was re-established in 2002, and was recently placed on-line with the collection of real time data. However, for the sake of the long-term management of Lake Hopatcong, a long-term annual mean inflow is more appropriate for the model. Such a long-term annual mean takes into account inter-annual variations (i.e., drought and wet years). Based on this long-term database, the annual mean inflow entering Lake Musconetcong is 3.86×10^7 m^3. This estimated annual mean inflow was only 4% lower than the annual inflow measured during the Phase I study.

The next step for this annual hydrologic load "x" concentration model was to obtain a long-term mean TP concentration of the Upper Musconetcong River. The average TP concentration in the main inlet of Lake Musconetcong was quantified based on a variety of data from an inter-annual perspective. Specifically, data sources included:

1. The Phase I Diagnostic / Feasibility Study conducted in 1992-93
2. Data collected by Sussex County from 1990 through 1992
3. The long-term Lake Hopatcong dataset (1990 - 2003), where the outlet TP concentration of Lake Hopatcong was used to quantify the inlet TP concentration of Lake Musconetcong
4. The inlet TP data collected during the 2003 monitoring program of Lake Musconetcong, conducted as part of this Restoration Plan

Combined, the long-term mean TP concentration of the main inlet of Lake Musconetcong was calculated to be 0.05 mg/L. Using a simple water volume x concentration formula, the annual TP load entering Lake Musconetcong from the main inlet was 1,933 kg.

The second methodology used to quantify the annual TP load originating from the main inlet of Lake Musconetcong was the application of the phosphorus retention coefficient. This was the same methodology that was used to quantify the TP load entering Lake Hopatcong.

As previously identified, the updated annual TP load for Lake Hopatcong is 8,097 kg (Table 1). Based on the original Phase I Diagnostic / Feasibility Study of Lake Hopatcong, the phosphorus retention coefficient was 0.717 (PAS, 1983), resulting in 28.3% of the incoming part of the annual phosphorus load leaving the lake. Based on this analysis, the annual TP load entering Lake Musconetcong from the outlet of Lake Hopatcong was 2,348 kg.

The annual Lake Musconetcong main inlet annual phosphorus load, based on the phosphorus retention coefficient method, was 18% higher than the inlet load based on the water volume x TP concentration method. This difference between the two methods was attributed to the fact that the TP concentration data used in the water volume x TP method were almost entirely collected during the growing season; almost no data were collected during the winter months (November through March). The slightly lower estimate provided by the water volume x TP method may be attributed to underestimating the annual TP load. In contrast, the phosphorus retention coefficient method is based on annual loading models. Given these conditions, it was decided to use the more conservative phosphorus retention coefficient method to quantify the annual TP load entering Lake Musconetcong from the main inlet. Therefore, for the refinement of the Lake Musconetcong phosphorus TMDL, the annual phosphorus load entering the lake from the outflow of Lake Hopatcong was determined to be 2,348 kg.

Section 3.2: Surface Runoff and Stormwater

Similar to Lake Hopatcong, the UAL model was used to quantify the surface runoff contribution to the Lake Musconetcong's annual phosphorus loads. Land use was determined using NJDEP's existing GIS database of 1995 / 1997 land use coverage. In turn, phosphorus loading coefficients selected by NJDEP were used to quantify the annual phosphorus loads entering Lake Musconetcong from its immediate drainage area (Figure 3).

Figure 3

There are a total of six municipalities within Lake Musconetcong's immediate drainage area (Figure 3). Of these six municipalities, three have residential lakeshore property. Two of the six municipalities account for relatively minor portions of the drainage area. The Township of Mount Olive accounts for less than 1% of the drainage area, while the Township of Byram accounts for 1.4%. In addition, the land within each of these Townships is dominated by forest / wetlands, resulting in minor surface runoff contributions to Lake Musconetcong. Surface runoff from Mount Olive accounts for only 3 kg per year entering Lake Musconetcong, while Byram accounts for only 2 kg per year (Table 5). Given these minor loads, their contribution to the Lake Musconetcong's annual phosphorus load was separated from the total load originating from surface runoff. Thus, the TMDL-based recommendations that will be made for the Restoration of Lake Musconetcong will focus on surface runoff phosphorus originating from the other four municipalities.

Of the remaining four municipalities, three have lakefront property and include the Borough of Netcong, the Township of Roxbury and the Borough of Stanhope. The fourth municipality, the Borough of Hopatcong, does not have lakefront property at Lake Musconetcong, but does account for a substantial portion of its immediate watershed. Therefore, the Borough of Hopatcong was included in the total phosphorus surface runoff load entering Lake Musconetcong for the sake of the TMDL and its associated Restoration Plan.

The same phosphorus export coefficients that were identified and selected by NJDEP (2003) for the Lake Hopatcong analysis were also used for the phosphorus loading analysis of Lake Musconetcong's surface runoff.

Section 3.3: Septic Systems

Almost all of the developed land within the Lake Musconetcong watershed is sewered. Therefore, the septic system contribution to the lake's annual phosphorus load was identified as negligible in the State's original TMDL analysis (NJDEP, 2003). However, this conclusion was based on data collected as part of the original Phase I study of Lake Musconetcong (Coastal Environmental Services, Inc., 1993). In order to ensure that such conditions are still accurate, Princeton Hydro re-assessed the potential septic system load entering Lake Musconetcong.

Based on the 1995 / 1997 land use coverage database, as well as municipal-based data, there are approximately 114 residential dwellings within the Borough of Hopatcong (Figure 4) that are have on-site wastewater disposal systems (septic systems) that are also within the immediate watershed of Lake Musconetcong. It should be emphasized that these homes are located downstream of Lake Hopatcong and within the established 330-foot (100 meter) septic system zone for a tributary of the Musconetcong River, which in turn enters Lake Musconetcong. Thus, the contribution these septic systems have on the lake's annual phosphorus load was quantified.

The methodology used to refine and quantify the septic system contribution to Lake Hopatcong was also used to quantify the septic system contribution to Lake Musconetcong (for details see Section 2.2).

Figure 4

Section 3.4: Atmospheric

The atmospheric deposition or dryfall of phosphorus directly onto each lake's surface was obtained from NJDEP's phosphorus TMDL analysis (NJDEP, 2003). A loading coefficient of 0.07 kg TP / ha / yr was used to quantify the atmospheric deposition of phosphorus. This coefficient was derived from a Statewide mean concentration of total phosphorus from the New Jersey Air Deposition Network (Eisenreich and Reinfelder, 2001; Koelliker, et. al., 2004).

Section 3.5: Internal Loading

Internal loads of phosphorus (i.e., liberation of phosphorus from the sediments, macrophyte decomposition and /or groundwater) was obtained from the previous Phase I Diagnostic / Feasibility Studies conducted on each lake (Coastal Environmental Services, Inc., 1992; Princeton Aqua Science, 1983).

Section 3.6: Refined and Updated Annual Phosphorus Load for Lake Musconetcong

The main sources of phosphorus for Lake Musconetcong were categorized into one of five (5) forms and their percent contributions are shown in Table 5. These five sources were drainage from the watershed (surface runoff), septic systems, atmospheric deposition, internal phosphorus regeneration, and the outlet of Lake Hopatcong. For the applicability of the TMDL-based Restoration Plan, the TP contributions from the Townships of Mount Olive and Bryam surface runoff was separated from the total surface runoff load (Table 5).

Based on the results of this analysis, the discharge (outflow) of Lake Hopatcong accounted for 67% of the total phosphorus load entering Lake Musconetcong. Surface runoff from Lake Musconetcong's immediate drainage area accounts for an additional 24%. Combined, these two sources account for slightly over 90% of the total annual phosphorus load for Lake Musconetcong (Table 5).

No individual wastewater disposal systems (septic systems) were identified in Lake Musconetcong's immediate drainage area during the development of the Phase I pollutant budgets (Coastal Environmental Services, Inc., 1993). However, as part of refining the phosphorus budget for the Lake Musconetcong TMDL analysis, 114 individual septic systems were identified within its septic zone of influence (for details see Section 3.3). All of the 114 identified septic systems were located within a portion of the Borough of Hopatcong that drains into the Musconetcong River and, in turn, into Lake Musconetcong. These septic systems account for 4% of the lake's existing phosphorus load (Table 5).

The temperature and dissolved oxygen vertical profiles for Lake Musconetcong in 2003 were similar to those measured in 1992 (Coastal Environmental Services, Inc., 1993). Therefore, the internal phosphorus load that was calculated as part of the Phase I pollutant budget analysis was ascribed to the internal phosphorus load for the TMDL analysis. Similar to the septic system load, the internal phosphorus load accounted for approximately 4% of the lake's annual phosphorus load.

Collectively, atmospheric sources of phosphorus, as well as surface runoff from the Townships of Mount Olive and Byram, account for approximately 1% of Lake Musconetcong's annual phosphorus load. Based on this completed refinement of the phosphorus TMDL for Lake Musconetcong, this Restoration Plan should focus on surface runoff from the lake's immediate drainage area. In addition, any assistance or support the stakeholders of the Lake Musconetcong watershed can contribute toward the attainment of Lake Hopatcong's TMDL will benefit Lake Musconetcong in achieving its respective TMDL.

Using the results of the refined phosphorus TMDL, as well as the targeted phosphorus load already established in the State's analysis for Lake Musconetcong (NJDEP, 2003), both the required reduction and percent reduction were calculated. This calculated reduction establishes a quantified amount of phosphorus that must be removed from the lake's annual load in order to comply with the TMDL.

Based on the refined TMDL analysis, the annual phosphorus load currently entering Lake Musconetcong is 3,486 kg (Table 5). With an established targeted TP load of 2,200 kg (NJDEP, 2003), a 37% reduction in the existing phosphorus load is required to attain the targeted load (Table 6). This 37% reduction translates to removing 1,286 kg of TP from the existing annual load.

Section 3.7: Municipal-Based Phosphorus Loads for Lake Musconetcong

As was conducted with Lake Hopatcong, the refined Lake Musconetcong TMDL was used to divide the existing phosphorus loads based on municipal boundaries. This was done because surface runoff from the lake's immediate drainage area was the second largest source of phosphorus. As previously identified, outflow from Lake Hopatcong accounts for the largest source of phosphorus entering Lake Musconetcong. Therefore, efforts to reduce the phosphorus load entering Lake Hopatcong will translate to an improvement in the water quality conditions of Lake Musconetcong. However, as this analysis will show, the stakeholders of the Lake Musconetcong drainage area can not solely depend on restoration actions within the Lake Hopatcong watershed to attain their TMDL.

If Lake Hopatcong is in complete compliance with its TMDL, the total annual phosphorus load would be 4,800 kg. With a phosphorus retention coefficient of 72%, approximately 1,358 kg of phosphorus would leave Lake Hopatcong and enter Lake Musconetcong. Comparing the amount of phosphorus that currently enters Lake Musconetcong from the outflow of Lake Hopatcong (2,348 kg), to that entering Lake Musconetcong under TMDL compliance for Lake Hopatcong (1,358 kg), approximately 990 kg of phosphorus would be removed from Lake Musconetcong's annual TP load as a result of compliance with Lake Hopatcong's TMDL.

The estimated 990 kg of phosphorus removed from the Lake Musconetcong annual TP load as a result of Lake Hopatcong complying with its TMDL would account for 77% of the amount of phosphorus targeted for reduction under Lake Musconetcong's TMDL. The remaining 23%, 296 kg, of the phosphorus required for reduction would need to come from the immediate drainage area of Lake Musconetcong. Thus, these reductions would need to be accomplished by the local municipalities within this immediate drainage area.

Similar to the Lake Hopatcong TMDL, the watershed-based sources of phosphorus for Lake Musconetcong were divided by municipal boundaries. This provided a means of identifying each municipality's existing and targeted annual phosphorus load for the lake. In turn, a site specific set of Restoration recommendations could be provided to each municipality, providing guidance on how each can contribute toward complying with the lake's targeted TMDL phosphorus loads.

As previously stated, there are six municipalities within the immediate drainage area of Lake Musconetcong. Two of these municipalities, the Townships of Mount Olive and Byram, account for minor amounts of undeveloped land and a minor portion of the lake's existing phosphorus load. Combined, these two municipalities account for less than 1% of Lake Musconetcong's annual phosphorus load. Therefore, they were not included in the development of the TMDL-based Restoration Plan. However, potential land acquisitions (i.e., open space land) or possible trade / credit arrangements may be developed to preserve and protect these small sections of land from being developed in the future.

Excluding the Townships of Mount Olive and Byram, there are four municipalities within the immediate watershed for Lake Musconetcong. Three of these four municipalities, the Township of Roxbury and the Boroughs of Netcong and Stanhope, have lakefront property. While the fourth, the Borough of Hopatcong, does not have lakefront property, it does account for the largest portion of land within Lake Musconetcong's immediate watershed. Given its relatively large land-based contribution, the Borough of Hopatcong was included in the municipal-based TMDL analysis.

For the sake of this and Lake Hopatcong's TMDL phosphorus analysis, the municipal-based contribution consisted of sources of phosphorus originating from surface runoff and septic systems. Unlike the Lake Hopatcong watershed, the majority of the communities within Lake Musconetcong's immediate watershed have been sewered. Thus, the septic system contribution to the phosphorus load is minor for Lake Musconetcong. However, a detailed land-based review revealed that approximately 114 septic systems are located within the septic zone of influence (within 330 feet of the lakeshore or associated tributary) for Lake Musconetcong. Specifically, these 114 septic systems are within 330 feet of a tributary that joins a section of the Musconetcong River between Lake Hopatcong and Lake Musconetcong and are located in the section of the Borough of Hopatcong within the immediate watershed of Lake Musconetcong. Thus, the septic system phosphorus load was added to the Borough of Hopatcong's surface runoff phosphorus load to calculate its municipal-based load. Since the other three municipalities are sewered, their municipal-based phosphorus loads originated from primarily surface runoff. The municipal-based phosphorus loads for all four municipalities are shown in Table 7.

As shown in Table 7, municipal-based phosphorus loads account for 973 kg, or 28%, of the existing annual phosphorus load entering Lake Musconetcong. The Borough of Hopatcong is the largest source of municipal-based phosphorus for Lake Musconetcong, accounting for approximately half of the municipal-based load. The second largest source of municipal-based phosphorus for Lake Musconetcong is the Township of Roxbury, which accounts for 24% of the municipal load. The Borough of Netcong and Stanhope each account for approximately 13% of the total municipal-based phosphorus load (Table 7).

Given the relatively small size of the immediate watershed for Lake Musconetcong, as well as the amount of annual phosphorus targeted for reduction, a detailed sub-watershed analysis was not conducted to prioritize the stormwater projects. As detailed in the Restoration Plan (Section 6), many of the selected and prioritized stormwater projects are based on recommendations originally made as part of the Phase I Diagnostic / Feasibility study (Coastal Environmental Services, Inc., 1993). Additional recommendations were based on the known availability of public land for the installation of structural BMPs and retrofits designed to reduce existing phosphorus loads.

Table 6 - Refined and Targeted Phosphorus TMDL for Lake Musconetcong

Described Scenario	Associated Value
Annual TP Load (refined TMDL)	3,486 kg
Targeted TP Load (NJDEP, 2003)	2,200 kg
Required Percent Reduction to Attain Targeted TP Load	37 %
Required Reduction in the Existing TP Load	1,286 kg
Annual TP Load removed from the Required Reduction in the Existing TP Load, if complete compliance with the Lake Hopatcong phosphorus TMDL is achieved.	990 kg
Required Reduction in the Existing TP Load (after Lake Hopatcong's compliance with its phosphorus TMDL)	296 kg

Table 7 - Municipal-based Phosphorus Loads For Lake Musconetcong

Municipality	kg per yr	Percent Contribution	Required Reductions (kg / yr)
Borough of Netcong	131	13	38.5
Township of Roxbury	235	24	71
Borough of Hopatcong	484	50	148
Borough of Stanhope	123	13	38.5
Total	**973**	**100**	**296**

Section 4: Water Quality Models

As identified in the original Scope of Work, a number of water quality / trophic state models were reviewed to determine which model or models can be used to reasonably represent in-lake conditions under various loading scenarios. The selected model(s) will be used to both quantify and predict how both Lake Hopatcong and Lake Musconetcong will respond to changes in their phosphorus loads, as per the implementation of the TMDL Restoration Plan. These models can also be used to predict how future changes within the Upper Musconetcong River watershed may impact water quality (see Section 5.0).

Many shallow waterbodies can accept a higher TP load relative to larger, deep waterbodies due to their higher flushing rates. Given the morphometry and hydrologic / pollutant loads of Lake Musconetcong, a model(s) is needed to reasonably predict in-lake conditions for Lake Musconetcong. Thus, the goal of this sub-task is to:

1. Review the applicability of various water quality / trophic state models for Lake Hopatcong and Lake Musconetcong, using recently collected water quality data.
2. Translate phosphorus loading into biological impacts in order to identify permissible or targeted levels of loading.

The first step in this water quality / trophic model assessment involved re-calculating the phosphorus retention coefficient; that is, the percentage of the annual phosphorus load that is retained in the lake. This value is important in that it largely determines the amount of phosphorus available for algal, and eventually plant, uptake. Waterbodies with a substantial annual hydrologic load flush frequently, typically have lower phosphorus retention, and usually, but not always, support less large and frequent algal blooms than do infrequently flushed waterbodies.

The importance of flushing on phosphorus availability and trophic state stems from its relationship with the areal waterload (q_s). The areal waterload is a function of the lake's surface area and its annual amount of water outflow. The areal waterload was used to calculate the phosphorus retention coefficient using Equation 2 (Kirchner and Dillon, 1975).

Equation 2:

$$R = 0.426e^{(-0.271qs)} + 0.574e^{(-0.00949qs)}$$

Where:

R = Phosphorus Retention

q_s = Areal Waterload = $\dfrac{\text{Annual Outflow from Lake}}{\text{Surface Area of Lake}}$

e = 2.718 (natural log)

Based on the results of the original Phase I study on Lake Musconetcong, its phosphorus retention coefficient was 0.408. This value was based on an annual hydrologic load of 4.75 x 10^7 m^3. Inflow entering Lake Musconetcong from Lake Hopatcong, was obtained from a USGS flow station located immediately downstream of the Lake Hopatcong dam (USGS #01455500; HUC 02040105). For the Phase I study, flow measurements collected through 1992 were used to quantify Lake Musconetcong's main inflow.

For the TMDL Restoration Plan, a larger database was used to quantify the flow entering Lake Musconetcong from Lake Hopatcong. Again, the source of the data was the USGS flow station located immediately downstream of the Lake Hopatcong dam, but this database also included historical data (1929-1974), the data collected during the Phase I Study (1992) and more recent data (2002) to quantify the lake's main inflow. Using this dataset, the long-term mean annual hydrologic load was calculated to be 4.81 x 10^7 m^3. The percent agreement between the Phase I (1993) and TMDL (2003) annual hydrologic load estimates was 99%. Thus, the 1992 data that was used to quantify the hydrologic budget for Lake Musconetcong was similar to long-term hydrologic estimates. Thus, these results should translate to a high level of agreement between the Phase I and the TMDL phosphorus retention coefficients.

As previously identified, the Phase I phosphorus retention coefficient for Lake Musconetcong was 0.408, while the coefficient for the 2003 TMDL study was 0.409. The percent agreement between the two phosphorus retention coefficients was extremely high, being greater than 99%. Thus, the data collected in 1992 during the Phase I study suitably represented long-term hydrologic inputs entering Lake Musconetcong via the main inlet.

In general, waterbodies with phosphorus retention coefficients greater than 0.6 (60%) should be productive and prone to excessive algal blooms. Thus, according to the calculated phosphorus retention coefficient, Lake Musconetcong is not likely to experience excessive algal blooms under typical climatic conditions. For the most part, this assumption is accurate. While planktonic algal blooms are not commonly experienced in Lake Musconetcong, nuisance densities of aquatic plants, particularly the invasive species Eurasian watermilfoil (*Myriophyllum spicatum*), are common. Since these rooted aquatic plants obtain the majority of their nutrient requirements from the sediments, a highly flushed system with a relatively low phosphorus retention coefficient would not limit their growth. However, elevated nutrient concentrations within the water column can stimulate the growth of benthic algae that grow attached to or over the stands of aquatic plants. These algae can detach from the aquatic plants and produce nuisance conditions in the form of surface mats.

A similar approach was used to compare the Lake Hopatcong Phase I (1983) phosphorus retention coefficient to that calculated for the TMDL (2003) study. The phosphorus retention coefficient calculated for Lake Hopatcong under the Phase I study was 0.730, while under the TMDL study the coefficient was 0.717. The agreement between these two coefficients was high (98%).

In contrast to Lake Musconetcong, the Lake Hopatcong phosphorus retention coefficients were greater than the 0.6 threshold, indicating that Lake Hopatcong has the potential to experience excessive algal blooms. This is certainly the case for the River Styx / Crescent Cove section of the lake. High watershed-based phosphorus loading and a relatively low amount of hydrologic exchange between the River Styx / Crescent Cove section and the main basin of the lake result in a high retention of phosphorus. These conditions are responsible for the nuisance algal blooms that plague this part of the lake, particularly during the late summer season.

The next step in this modeling procedure was the selection of a general model that could be used for both lakes to predict in-lake phosphorus concentrations during the growing season (April through September). NJDEP previously reviewed a variety of empirically based water quality models and selected the Reckhow model (1979) to relate annual phosphorus loading to steady-state, in-lake phosphorus concentrations (NJDEP, 2003).

To meet the objectives of the TMDL, the Reckhow model was selected because it has the broadest range of hydrologic, morphological and loading characteristics in its database of north temperate lakes (Equation 3). As outlined in the State's TMDL document, the water quality characteristics of Lake Hopatcong and Lake Musconetcong are within the ranges established for the Reckhow model (NJDEP, 2003). Thus, the Reckhow model was used to model steady state, in-lake TP concentrations in both lakes.

Equation 3: $$[TP] = L / (11.6 + 1.2 * qs)$$

Where:

	[TP]	=	Predicted mean TP concentration (mg/L)
	L	=	areal phosphorus loading ($g/m^2/yr$)
	qs	=	hydraulic retention time (yr)

While results of the Reckhow model are provided in the State's TMDL, these values had to be re-calculated since the annual TP loads for each lake was refined with updated information (i.e. septic system contributions). In addition, the results of these re-calculated in-lake TP concentrations were compared to empirical data collected from each lake to determine how close the predicted modeled data compare to the measured data. The results of the re-calculated Reckhow model analysis, as well as the reference and measured concentrations are provided in Table 8.

Based on the State's TMDL, the mean in-lake TP concentration under reference conditions for both Lake Hopatcong and Lake Musconetcong would be 0.004 mg/L. The reference condition represents a state in which no one is living within the Upper Musconetcong River watershed and none of the land is developed. Thus, the reference TP concentration is the "absolute baseline" concentration for both lakes; it is not possible to reduce the in-lake concentrations below 0.004 mg/L, even in the absence of human impacts.

Using the Reckhow model, the existing mean TP concentration in Lake Hopatcong as per 2003 watershed conditions was calculated to be 0.047 mg/L. Using the 1990-2003 long-term database for Lake Hopatcong, the mean growing season (April to September) TP concentration was 0.043 mg/L (Table 8). Thus, the measured long-term mean agrees reasonably well with the predicted (modeled) concentration. The percent agreement between the measured and predicted concentrations was 91.5%. The slightly elevated predicted TP concentration relative to the measured value probably reflects in-lake concentrations in Lake Hopatcong over the course of an entire year as opposed to the measured data, which focused solely on the growing season from April through September. However, even with this discrepancy, the Reckhow model reasonably predicted in-lake TP concentrations in Lake Hopatcong.

Table 8

Results of the Reckhow Model for Lake Hopatcong and Lake Musconetcong, Under Various TMDL-based Loading Conditions

Water Quality Scenario	Lake Hopatcong	Lake Musconetcong
Reference Condition	0.004	0.004
Existing Conditions – 2003 (as per the Reckhow model)	**0.047 (0.05)**	**0.048 (0.05)**
Targeted Conditions (as per the TMDL)	0.028 (0.03)	0.030 (0.03)
Measured Concentration*	**0.043**	**0.034**

The lowest limit of detection most State-certified laboratories can attain for TP is 0.01 mg/L. Therefore, the level of precision for the expressed TP concentrations were adjusted and provided in parenthesis.

* The measured concentration is the long-term mean concentration for each lake. For Lake Hopatcong, the long-term value is a mean based on surface water TP data collected from 1990 through 2003 at eight sampling stations during the growing season. For Lake Musconetcong, the long-term value is a mean based on data collected during the Phase I study and during the 2003 monitoring season.

The existing water quality database for Lake Musconetcong is considerably smaller than the lake Hopatcong database. The measured mean TP concentration for Lake Musconetcong was based on data collected during the Phase I Diagnostic / Feasibility Study (Coastal Environmental Services, Inc., 1993) as well as part of this project. Thus, based on the available data, the measured mean TP concentration for Lake Musconetcong was 0.034 mg/L, while the predicted Reckhow mean TP concentration was 0.048 mg/L (Table 8).

The measured and predicted (modeled with Reckhow) mean TP concentrations for Lake Musconetcong agreed only moderately well (71%). Similar to Lake Hopatcong, the available water quality database for Lake Musconetcong solely focused on the growing season, so the difference between the measured and predicted TP concentrations may reflect the absence of data collected during the non-growing season times of the year. However, the lower degree of agreement for Lake Musconetcong may also be due to the limited size of the database (essentially two years of data) and the internal processes within shallow lakes that can potentially complicate quantifying the annual phosphorus load (Scheffer, 1998). In any event, the level of agreement between measured and predicted TP concentrations was considered highly acceptable for Lake Hopatcong and acceptable for Lake Musconetcong

The targeted mean in-lake TP concentration for both lakes was re-calculated by using the established threshold annual loads, as per the State's TMDL. The resulting targeted mean TP concentrations represent the upper boundary of acceptable in-lake conditions in terms of the phosphorus TMDL. For Lake Hopatcong the targeted mean TP concentration was **0.030 mg/L**, while for Lake Musconetcong the targeted mean TP concentration was 0.030 mg/L (Table 8).

Based on trophic state criteria developed by USEPA (1980), TP concentrations of 0.03 mg/L represent mesotrophic (moderate productivity) to eutrophic (moderate productivity) conditions. Based on existing (measured and predicted) TP concentrations, both lakes are eutrophic. However, based on the TMDL targeted TP concentrations, Lake Hopatcong would be at the upper end of mesotrophic conditions, while Lake Musconetcong would be at the lower end of eutrophic conditions. Thus, the goal of the TMDL Restoration Plan for both lakes is not necessarily to substantially lower the trophic state of each lake. Instead, the goal is to keep the trophic state of each lake under control and manage each lake as a moderately to slightly highly productive waterbody.

In order to gauge the water quality response to reference, existing and targeted conditions, mean TP concentrations were converted into chlorophyll *a* concentrations. Chlorophyll *a* is a pigment all algae and plants possess and use in the process of photosynthesis. Therefore, measuring chlorophyll *a* in lake water is an effective way of quantifying phytoplankton (free-floating algae) biomass.

It must be emphasized that measurements of open water chlorophyll *a* concentrations do not typically include benthic dwelling algae or rooted aquatic plant biomass. Thus, a complete reliance on phytoplankton biomass as a means of assessing the primary productivity has the potential to substantially underestimate the ecosystem-based level of primary productivity. In spite of this, the particularly strong relationship between TP and chlorophyll *a*, as well as the potential water quality impacts both lakes experience during planktonic algal blooms, do provide a means of translating TMDL-based phosphorus loads into a distinct, measurable and perceived "ecological" endpoint (i.e., algal blooms). Therefore, chlorophyll *a* will be used to confirm the validity of the established targeted phosphorus loads. The ecological and economic impacts associated with benthic algae and aquatic plants will be considered in the biological component of each lake's Restoration Plan.

While chlorophyll *a* is being used as an "ecological endpoint" for the Restoration Plans of Lake Hopatcong and Lake Musconetcong, it is not the recommended final endpoint for the TMDL. The final targeted endpoint for the TMDL will remain total phosphorus (TP) for both lakes. However, utilizing an ecological endpoint such as chlorophyll *a* puts the TMDL and associated Restoration Plans into a perspective that is tangible and easy to understand from a layperson's point of view. Discussing the importance of attaining the targeted in-lake TP concentration and associated annual TP load is easier to convey to all stakeholders if it is directly related to aesthetic and water quality impacts (i.e. algal blooms), conditions that everyone has experienced and agrees is unpleasant and harmful to the environment. Thus, the chlorophyll *a* ecological endpoint is largely an educational tool to rally both short- and long-term support for the implementation of the TMDL-based Restoration Plans

A variety of water quality models were used to predict chlorophyll *a* concentrations based on the various phosphorus loading scenarios (as shown in Table 8) for both lakes. These models included Jones and Bachmann (1976), Vollenweider (1976), Carlson (1977) and Schindler (1978).

Although each model has particular requirements and limitations, all were selected for consideration because each is based on a large empirical lake database. Such models are highly robust and can be used for a wide variety of temperate waterbodies. Thus, the predicted (Reckhow model) and measured TP concentrations for each lake were used to calculate chlorophyll *a* concentrations for both lakes. Model results were then compared to each lake's respective measured chlorophyll *a* concentration.

Of the four water quality models, the Schindler model provided results that were closest to the measured chlorophyll *a* concentrations. As shown in Table 9, the measured and predicted TP concentrations for Lake Hopatcong resulted in chlorophyll *a* concentrations of 13.6 and 15.1 mg/m^3, respectively. Based on the long-term Lake Hopatcong data (1990-2003), the mean chlorophyll *a* concentration over the whole lake is 11.1 mg/m^3. Thus, the Schindler model results had a level of agreement between 74 and 82% with the measured chlorophyll *a* concentration. The level of agreement with the Schindler model was substantially higher than the other models, where predicted (modeled) chlorophyll *a* concentrations varied between 21.8 to 23.0 mg/m^3.

The other models overestimated the amount of algae that would result from the incoming phosphorus loads for Lake Hopatcong. This overestimate of the amount of algal biomass, as chlorophyll *a*, was more than likely the result of not taking into account aquatic plants and/or benthic algae, which directly assimilate a portion of the phosphorus entering Lake Hopatcong. Such organisms utilize phosphorus but are not well represented when measuring open water chlorophyll *a* concentrations.

Using the targeted in-lake TP concentration of 0.028 mg/L as identified in the Lake Hopatcong TMDL (Table 8), the targeted mean chlorophyll *a* concentration through the course of the growing season is predicted to be 8.1 mg/m^3 (Table 9). Relative to the predicted mean chlorophyll *a* concentration, based on the measured TP concentrations (13.6 mg/m^3), this represents a 40% reduction in chlorophyll *a* concentrations in order to comply with the TMDL.

Similar to Lake Hopatcong, the results of the Schindler model were closest to the measured chlorophyll *a* concentrations for Lake Musconetcong. The measured chlorophyll *a* concentration for Lake Musconetcong was 13.8 mg/m^3, while the predicted chlorophyll *a* concentrations using measured and predicted TP concentrations were 10.2 and 15.5 mg/m^3, respectively (Table 9). Thus, the percent agreement between the measured chlorophyll *a* concentration and the two predicted concentrations varied between 74% and 89% for Lake Musconetcong.

The measured chlorophyll *a* concentration for Lake Musconetcong was higher relative to the predicted concentrations calculated with measured TP concentrations and lower relative to the predicted concentrations calculated with predicted TP concentrations (Table 9). These varying concentrations are more than likely due to the shape and shallow depth of Lake Musconetcong. Like the majority of water quality models, the Schindler model is designed to predict planktonic (open water) chlorophyll *a* concentrations. Thus, it does not include nor model benthic algae and/or aquatic plants. However, it was noted during all three 2003 sampling events that some benthic filamentous mat algae were distributed through the water column. It is more than likely that some of the filamentous algae were captured in the samples collected for the analysis of chlorophyll *a*. The examination and identification of the resident phytoplankton confirms this hypothesis (see Section 6.0). Thus, the higher than predicted chlorophyll *a* concentrations, at least with the use of the measured TP concentrations, were attributed to benthic algae detached from the sediments or aquatic plants and floating through the shallow water column. However, in spite of these conditions, the Schindler model still provided a reasonably good means of predicting chlorophyll *a* concentrations in Lake Musconetcong.

Using the targeted in-lake TP concentration of 0.030 mg/L as identified in the Lake Musconetcong TMDL (Table 8), the targeted mean chlorophyll *a* concentration through the course of the growing season is predicted to be 8.8 mg/m^3 (Table 9). Relative to the predicted mean chlorophyll *a* concentration, based on the measured TP concentrations, this represents a 36% reduction in chlorophyll *a* concentrations in order to comply with the TMDL.

Table 9

Measured and Predicted Total Phosphorus and Chlorophyll *a* Concentrations for Lake Hopatcong and Lake Musconetcong

Parameter and Scenario	Lake Hopatcong	Lake Musconetcong
Measured TP	**0.043 mg / L**	**0.034 mg / L**
Predicted TP (under existing conditions)	0.047 mg / L (0.05 mg / L)	0.048 mg / L (0.05 mg / L)
Predicted TP (under targeted conditions)	0.028 mg / L (0.03 mg / L)	0.030 mg / L (0.03 mg / L)
Measured Chlorophyll *a*	**11.1 mg / m^3**	**13.8 mg / m^3**
Predicted Chlorophyll *a* (using measured TP)	13.6 mg / m^3	10.2 mg / m^3
Predicted Chlorophyll *a* (using predicted TP)	15.1 mg / m^3	15.5 mg / m^3
Predicted Chlorophyll *a* (using targeted TP)	8.1 mg / m^3	8.8 mg / m^3

The bold values are empirical data. The remaining data are model results.

The lowest limit of detection most State-certified laboratories can attain for TP is 0.01 mg/L. Therefore, the level of precision for the expressed TP concentrations were adjusted and provided in parenthesis.

Section 5: Build-Out Analysis and its Impact on Water Quality

A build-out analysis allows a municipality to project future development based on existing zoning and land-use regulations. It provides a means of determining the appearance and associated impacts the maximum amount of development allowed under current law will have on the municipality (NJDEP, 2004). Build-out analyses typically involve the use of GIS to collect, layer and synthesize a variety of existing data (i.e., zoning, tax maps, topographic and natural features) to determine the appearance of the municipality in the future. For this study, a build-out analysis was conducted for the Lake Hopatcong and Lake Musconetcong watersheds to determine how build-out conditions are likely to impact water quality.

It should be emphasized that the build-out analysis was only conducted on those sections of each municipality located within the Lake Hopatcong and Lake Musconetcong watersheds. Municipal zoning maps were obtained from each municipality; future or build-out information was used as the basis of this analysis. A methodology was then established to determine complete build-out conditions in both watersheds and translate these conditions to annual phosphorus loading, in-lake TP concentrations and chlorophyll *a* concentrations. The methodology included the following steps:

1. Remove environmentally constrained (undevelopable) land.

- Current zoning maps for each watershed municipality were obtained, digitized and imported into an ArcView GIS format.

- The zoning maps were clipped to the watershed boundaries and overlaid on NJDEP's 1995-97 land use / land cover dataset.

- Based on the land use / land cover data for each municipality, land that is unavailable for development due to environmental constraints (i.e., wetlands, steep slopes, floodplains and Category 1 Waters associated with special water resource protection areas) were so designated and removed from the zoning map.

- Each of these environmentally constrained parcels was placed into the appropriate NJDEP land cover category (i.e., Forest, Water, Wetlands or Barrenland/Transitional area) and assigned a State-established phosphorus loading coefficient (NJDEP, 2003).

2. Remove permanently protected (undevelopable) land.

- Based on the zoning map, master plan and other related information for each municipality, all parcels designated as permanently protected open space or preserved farmland were removed from the zoning map of the watershed.

- Each of these protected parcels was placed into the appropriate NJDEP land cover category (i.e., Forest, Water, Wetlands or Barrenland/Transitional area) and assigned a State-established phosphorus loading coefficient (NJDEP, 2003).

3. Develop future development scenario

- Current zoning for all remaining developable lands was examined.

- Based on zone descriptions found in each municipal land use ordinance, current zone designations were converted to one of six developed land use categories included in the Lake Hopatcong TMDL:

  - High/Medium Density Residential
  - Low Density/Rural Residential
  - Commercial
  - Industrial
  - Urban/Mixed Urban/Other Urban
  - Agriculture

  The assumption was made that each zone would be developed to the maximum extent permitted under current zoning regulations. Conversions of residential zones to land use categories were based on each zone's maximum permitted dwelling units per acre and maximum allowable lot coverage by impervious surface. These were compared to NJDEP's land use / land cover classification system (NJDEP, 2003). Please note that although no agricultural zones exist in the watershed municipalities, agriculture is a permitted use in some districts. However, except in the cases of permanently protected farmland, all of these zones were assumed to be fully built out as residential development only.

- The "converted" zoning maps were then used to produce an updated land use / land cover database of the watershed.

- Each land use category in the updated land use / land cover database was assigned an estimated phosphorus loading coefficient (kg TP/hectare/year), based on the Unit Areal Load (UAL) methodology used in the Lake Hopatcong TMDL as per NJDEP (2003).

- The result is a land use database depicting the watershed under fully developed ("build-out") conditions.

4. Calculate the pollutant load under build-out conditions using the phosphorus loading coefficients identified by NJDEP (2003).

The changes in land use predicted by the build-out methodology described above were used to quantify phosphorus loading under future conditions, using the same methodology and models that were used to refine and update the phosphorus TMDLs. Thus, for Lake Hopatcong the predicted annual phosphorus load under build-out conditions is 8,992 kg per year, which is approximately 12% higher than the existing load (Table 10). When the sewering project is completed for the Borough of Hopatcong, the predicted annual phosphorus load drops to 7,915 kg per year, which is actually 2.2% <u>lower</u> than the existing phosphorus load. Obviously, neither of the build-out conditions is equal to the targeted load of 4,800 kg (Table 10).

Using Reckhow's model, the mean TP concentration in Lake Hopatcong under build-out conditions (with the Borough of Hopatcong sewered) is estimated to be 0.046 mg/L (Table 10). In turn, the mean chlorophyll *a* concentration for Lake Hopatcong would be approximately 15 mg/m^3, with a potential maximum or bloom concentration of 25 mg/m^3 (more details on the maximum chlorophyll *a* concentrations are provided in the subsequent section).

For the municipalities surrounding Lake Musconetcong, the predicted annual phosphorus load under build-out conditions is 3,993 kg, which is 13% higher than the existing load (Table 11). Once the septic systems within the section of the Borough of Hopatcong in the Lake Musconetcong watershed are off-line, the predicted annual phosphorus load under build-out conditions is 3,844 kg. This represents a 9.3% increase relative to the existing load.

Build-out conditions with the Borough of Hopatcong sewered would result in a predicted TP concentration of 0.053 mg/L and a predicted mean chlorophyll *a* concentration of 17.5 mg/m^3 for Lake Musconetcong (Table 11). Relative to existing conditions, this represents an 11% increase in the mean chlorophyll *a* concentration for Lake Musconetcong.

Table 10

Resulting TMDL "Ecological" Endpoints Under Several Phosphorus Loading Conditions for Lake Hopatcong

Parameter	Existing Conditions	Build-out Conditions	Build-out Conditions*	Targeted Conditions
Annual TP Load (kg TP / yr)	8,097	8,992	7,915	4,800
Predicted Reckhow TP Concentration (mg / L)	0.047 (0.05)	0.052 (0.05)	0.046 (0.05)	0.028 (0.03)
Predicted Schindler Chl *a* Concentration (mg / m^3)	15.1	17.2	14.7	8.1
Predicted Maximum Chl *a* Concentration** (mg / m^3)	25.7	29.3	25.0	13.6

Build-out calculations are based on a scenario where all available land is developed (as per municipality guidelines) with no structural BMPs.

* Build-out conditions after the Borough of Hopatcong's sewer project is complete.

** Derived from a regression analysis of lake-specific data (see Appendix A).

The lowest limit of detection most State-certified laboratories can attain for TP is 0.01 mg/L. Therefore, the level of precision for the expressed TP concentrations were adjusted and provided in parenthesis.

Table 11

Resulting TMDL "Ecological" Endpoints Under Several Phosphorus Loading Conditions for Lake Musconetcong

Parameter	Existing Conditions	Build-out Conditions	Build-out Conditions*	Targeted Conditions
Annual TP Load (kg TP / yr)	3,486	3,993	3,844	2,200
Predicted Reckhow TP Concentration (mg / L)	0.048 (0.05)	0.055 (0.06)	0.053 (0.05)	0.030 (0.03)
Predicted Schindler Chl *a* Concentration (mg / m^3)	15.6	18.4	17.5	8.9
Predicted Maximum Chl *a* Concentration** (mg / m^3)	31.0	38.9	36.5	14.4

Build-out calculations are based on a scenario where all available land is developed (as per municipality guidelines) with no structural BMPs.

* Build-out conditions after the Borough of Hopatcong's sewer project is complete.

** Derived from a regression analysis of lake-specific data (see Appendix A).

The lowest limit of detection most State-certified laboratories can attain for TP is 0.01 mg/L. Therefore, the level of precision for the expressed TP concentrations were adjusted and provided in parenthesis.

The results of this build-out analysis indicate that water quality conditions are likely to decline (i.e., increases in the in-lake TP and chlorophyll *a* concentrations) in Lake Hopatcong under fully developed conditions. If a large portion of the Borough of Hopatcong is sewered as planned, future, build-out water quality conditions are likely to be very similar to existing conditions (Table 10). However, it is the targeted conditions of the TMDL, not the existing conditions that should be the long-term planning goal of the Restoration Plan.

In contrast, although sewering the section of the Borough of Hopatcong within the Lake Musconetcong watershed will aid in reducing the annual phosphorus load, build-out conditions are still predicted to result in a further decline in water quality for Lake Musconetcong (Table 11) beyond existing conditions. In either case, it should be emphasized that these build-out analyses did not incorporate any structural or non-structural BMPs. Thus, the long-term goal and responsibility of the Lake Hopatcong Commission, the Lake Musconetcong Regional Planning Board and all of the associated stakeholders is to properly plan and design in minimizing the impacts associated with future development. Such efforts will ensure future compliance with the established phosphorus TMDLs.

Translating TMDL endpoints to perceived water quality problems

As described above, the "ecological" endpoints for both Lake Hopatcong and Lake Musconetcong have been identified as open water chlorophyll *a* concentrations. Using the TMDL established phosphorus target concentrations, the ecological TMDL endpoint is 8.1 mg/m^3 for Lake Hopatcong and 8.8 mg/m^3 for Lake Musconetcong. Relative to their existing mean chlorophyll *a* concentrations of 11.1 mg/m^3 for Lake Hopatcong and 13.8 mg/m^3 for Lake Musconetcong, these endpoints do not appear to result in a major improvement in water quality. The decrease of mean chlorophyll *a* concentrations by only a few units does not initially appear to result in a measurable improvement in water quality. However, it should be recognized that the identified endpoints represent <u>mean</u> values over the course of the growing season (April through September). In order to better assess the water quality benefits in attaining the targeted TMDL phosphorus levels, an analysis of the long-term datasets of both lakes was conducted.

As previously cited, all of the chlorophyll *a* values identified for the TMDL represent mean concentrations over a number of sampling stations. Each year's mean value represents a variety of concentrations, and hence water quality conditions, some of which may attain levels that result in unpleasant water quality conditions for recreational use. Thus, one of the ultimate goals of the phosphorus TMDL is to reduce and minimize the magnitude, duration and frequency of algal blooms in both lakes. To better quantify this, an analysis of each lake's chlorophyll *a* dataset was conducted.

From 1990 to 2004 water samples have been collected and analyzed for chlorophyll *a* at seven to eight sampling stations at Lake Hopatcong from May through September. For each sampling year, the mean growing season chlorophyll *a* value for each sampling station was paired with its respective maximum chlorophyll *a* concentration; slightly over 100 pairings between mean and maximum chlorophyll *a* concentrations were established for Lake Hopatcong. A regression analysis was conducted on this dataset to determine if a relatively simple, linear relationship exists between mean and maximum chlorophyll *a* concentrations. That is, the analysis was conducted to determine if the maximum chlorophyll *a* concentration (i.e., bloom) experienced during a growing season can be predicted based on that season's mean chlorophyll *a* value. Such a relationship would provide a useful way of predicting the magnitude of an algal bloom under the mean chlorophyll *a* concentrations described in the TMDL.

The regression analysis revealed a significant relationship between mean and maximum chlorophyll *a* concentrations in Lake Hopatcong (Appendix A). The p-value was < 0.005 and the r^2 was 0.866. The regression formula developed for this analysis (Appendix A) was used to predict maximum or bloom conditions in Lake Hopatcong under the various TMDL scenarios and the result are provided in Table 10.

Based on USEPA criteria, chlorophyll *a* concentrations between 6.0 and 40 mg/m^3 are considered eutrophic (highly productive). In contrast, a set of criteria based on a large database of lakes throughout the world, defined eutrophic conditions as those with chlorophyll *a* concentrations between 9.0 and 25 mg/m^3 (Nurnberg, 1996). However, an eutrophic lake does not necessarily reflect low water quality conditions. For example, moderately high levels of biological productivity are required in order to sustain and perpetuate a desirable multi-seasonal and multi-storied fishery.

In order to justify the targeted mean chlorophyll *a* concentrations, the predicted maximum (i.e., bloom) conditions shown in Table 10 were compared to a set of criteria based on recreational use (as opposed to levels of productivity). Walmsley and Butty (1979) proposed some typical relationships between chlorophyll *a* concentrations and recreational impacts relative to water quality (Table 12). Based on this relationship between chlorophyll *a* concentrations and perceived water quality conditions, attaining the <u>targeted</u> phosphorus load for Lake Hopatcong will place the seasonal chlorophyll *a* maxima of 13.6 mg/m^3 in a category where algal scums may be present but nuisance conditions will largely be avoided (Table 12).

Under existing conditions and build-out conditions with the sewering of the Borough of Hopatcong complete, the maximum chlorophyll *a* concentration for Lake Hopatcong is between 25 and 26 mg/m^3 (Table 10). Under such scenarios nuisance conditions would be encountered during the growing season. In contrast, under the targeted phosphorus load of 4,800 kg per year, the maximum chlorophyll *a* concentration is expected to be approximately 14 mg/m^3, below the threshold where nuisance conditions are encountered. Therefore, the identified targeted "ecological" endpoint of

8.1 mg/m^3 is appropriate for Lake Hopatcong, since it will shift the maximum chlorophyll *a* concentrations from nuisance conditions to the mere potential presence of algal scums. This is the ecological and recreational value in implementing the phosphorus TMDL for Lake Hopatcong.

A similar statistical analysis and comparison was conducted for Lake Musconetcong; mean and maximum chlorophyll *a* concentrations were paired and a regression analysis was run. Compared to Lake Hopatcong, the Lake Musconetcong database was substantially small in size. However, in spite of the smaller dataset, a significant relationship was found between mean and maximum chlorophyll *a* concentrations in Lake Musconetcong (Appendix A). The p-value was < 0.005 and the r^2 was 0.951. Thus, the Lake Musconetcong regression model was used to predict maximum chlorophyll *a* concentrations with a given mean growing season concentration.

Under existing conditions, the predicted maximum chlorophyll *a* concentration for Lake Musconetcong was 31 mg/m^3. Under build-out conditions and with the Borough of Hopatcong section of its watershed sewered, the predicted maximum chlorophyll *a* concentration for Lake Musconetcong was 36.5 mg/m^3 (Table 11). Both of these values were described as being severe nuisance conditions (Table 12). In addition, based on Princeton Hydro's in-house database of lakes throughout the Mid-Atlantic States, chlorophyll *a* concentrations greater than 30 mg/m^3 are typically perceived by the layperson as being "dirty," "scummy" or not acceptable for recreational use. In contrast, the targeted phosphorus load and average in-lake TP concentration would result in a maximum chlorophyll *a* concentration of 14.4 mg/m^3 (Table 11). While this maximum concentration falls within the category of algal scums potentially evident, nuisance conditions would be avoided. Again, the long-term water quality goal is to avoid the occurrence of nuisance algal blooms that impact the ecological, recreational and economic value of Lake Musconetcong.

Table 12

Impact of Chlorophyll a Concentrations on Perceived Water Quality*

Chlorophyll *a* Concentration	Nuisance Value
0 to 10 mg/m^3	No problems evident
10 to 20 mg/m^3	Algal scums evident
20 to 30 mg/m^3	Nuisance conditions encountered
Greater than 30 mg/m^3	Severe nuisance conditions encountered

* As per Walmsley and Butty (1979).

Section 6: Bioremediation for Lake Hopatcong and Lake Musconetcong

While the TMDL-based Restoration Plan heavily focuses on reducing the phosphorus loads entering both Lake Hopatcong and Lake Musconetcong, it is not the sole strategy recommended for long-term restoration efforts. In particular, ecological bioremediation was incorporated into the Restoration Plan. For the sake of this study, bioremediation involves the management the biological portion of a lake ecosystem to improve upon existing water quality conditions. Such biologically-based management techniques may (reduction of the number of benthic-feeding fishes) or may not (enhanced zooplankton grazing) be associated with controlling or reducing phosphorus loads. However, it should be noted that given its general morphometry and average depth, the emphasis on the use of bioremediation techniques will be larger for Lake Musconetcong relative to Lake Hopatcong. It is well established that interactions among the sediments, littoral zone and the biological community are substantially strong in shallow lakes relative to deeper lakes (Moss, et. al., 1996; Scheffer, 1998).

For the long-term restoration of Lake Hopatcong and Lake Musconetcong, bioremediation includes the management techniques / concepts of biomanipulation and alternative stable states. Biomanipulation is commonly defined as a means of improving the water quality of an aquatic ecosystem by modifying the structure of its food web (Shapiro et al, 1975). Originally, biomanipulation focused exclusively on the pelagic habitat of large, deep lakes. In essence, an increase in piscivorous (game fish) biomass results in a decrease in planktivore (forage fish) biomass, an increase in herbivore (large-bodied zooplankton) biomass and a decrease in phytoplankton biomass. This ultimately produces an increase in water clarity and quality (Brooks and Dodson, 1965; Carpenter and Kitchell, 1996). Figure 5 provides a conceptual interpretation of biomanipulation.

The potential application of biomanipulation has expanded to include a variety of lakes and habitats, such as shallow eutrophic lakes and benthic habitats (Dodds, 2002). For shallow lakes, bioremediation can also be approached through the concept of alternative stable states (Scheffer, 1998). Essentially, relatively shallow lakes or sections of lakes (i.e., bays or coves), which allow enough sunlight to reach the sediment to stimulate rooted aquatic plant growth throughout the majority of the bottom, can typically exist in one of two states. The first state is a vegetation-dominated, clear water condition, while the second is a non-vegetated, turbid condition prone to algal blooms (Moss, et al., 1997).

Figure 5

When nutrient concentrations are low, the stable state tends to be the vegetated, clear water condition. In contrast, when nutrient concentrations are high, the stable state tends to be turbid, algae dominated conditions. Moderate nutrient concentrations can easily favor either of the stable states (Moss, et al., 1997). With the choice between the clear water and turbid stable states, the clear water state is preferred in most cases (Cooke, et al., 1993). In spite of the potential for rooted aquatic plants, especially exotic species, to attain nuisance densities, the vegetated, clear water state is preferred since it has a higher biological diversity and recreational value (Moss, et al., 1997). In addition, it tends to be more cost effective and less of an ecological impact to manage a lake for nuisance rooted aquatic plants relative to nuisance algal blooms (Cooke, et al., 1993; Princeton Hydro, unpublished data). A conceptual diagram of the alternative stable states model is provided in Figure 6.

The goal of this section of the Restoration Plan is to use the ecological field data that were collected from Lakes Hopatcong and Musconetcong to evaluate the applicability of biomanipulation and alternative stable states. Given each lakes' morphometry, size and mean depth, both biomanipulation and alternative stable states will be considered for Lake Hopatcong, while alternative stable states will be the primary method of bioremediation considered for Lake Musconetcong.

Section 6.1 Bioremediation in Lake Hopatcong

Lake Hopatcong has a relatively complex morphometry. It has a main central basin that has a mean depth of 8.2 meters (27 ft), with a number of coves, bays and canals surrounding the main basin (Figure 7). The coves, bays and canals vary widely in general morphometry. For example, Byram Cove has a maximum depth of approximately 8 meters (26.4 ft), while the Jefferson Canals are relatively shallow with mean depths of 1 to 2 meters (3.3 to 6.6 ft). Excluding the central basin (Figure 7), the remaining, "shallow" section of Lake Hopatcong has a mean depth of 3.7 meters (12.3 ft).

Such a complex morphometry results in some sections of the lake experiencing nuisance densities of rooted aquatic plants, while others have the potential to experience algal blooms. Additionally, other sections may experience both nuisance conditions. Thus, biomanipulation and alternative stable state restoration techniques were both considered for application in Lake Hopatcong.

Figure 6

Figure 7

In order to assess the potential application of biomanipulation in Lake Hopatcong a detailed biological data had to be collected. These data included phytoplankton, zooplankton and the fishery community of the lake. While a considerable amount of data were collected on the phytoplankton and zooplankton, both as part of the standard annual water quality monitoring program and particularly during the 2003 monitoring year, fishery data have not been recently collected. Some anecdotal information on the resident fishery community of Lake Hopatcong was used make some generalized recommendations on the design and implementation of a biomanipulation program. However, it should be emphasized that detailed, site-specific data on the lake's existing fishery community need to be collected prior to implementing form of biomanipulation.

As part of the Lake Hopatcong Commission's standard, long-term monitoring program, qualitative phytoplankton and zooplankton samples are collected at the mid-lake sampling station (Station #2) during each monitoring event. These samples are typically collected with plankton nets, towed from the anoxic / oxic (no oxygen zone / oxygenated zone) interface to the surface. The phytoplankton are collected with a 53-um mesh net, while the zooplankton are collected with a 163-um mesh net. These qualitative vertical net tows were collected at Station #2 through the 2003 monitoring year, and continue to be collected. However, quantitative samples were collected at all eleven Lake Hopatcong sampling stations in 2003 as part of development of this Restoration Plan.

Quantitative phytoplankton and zooplankton samples were collected at all eleven monitoring stations on 26 June 2003. The phytoplankton samples were collected approximately 0.5 meters below the surface at each sampling station with a Van Dorn sampling device. The sample was preserved with Lugol's solution and stored in an iced cooler (Lind, 1985; Wetzel and Likens, 1991) for transport to Princeton Hydro's biological laboratory. In addition to identifying the dominant organisms to genus or species, the abundance (cells per mL) and biomass (ug per L) of the phytoplankton were also calculated as per Wetzel and Likens (1991). A number of manuals were used in the identification of the phytoplankton and included Smith (1950), Needham and Needham (1962), Prescott (1964), and Wehr and Sheath (2003).

Zooplankton are known to vertically migrate through the water column. They tend to concentrate in the deeper waters during the day and come to the surface at night (Hutchinson, 1967; Moss, 1980) as a means to avoid being preyed upon by zooplanktivorous fishes which are visual feeders (Dodds, 2002). Thus, in order to obtain a more complete assessment of the zooplankton community throughout Lake Hopatcong, sub-surface and deep water samples were collected for these organisms with a Schindler plankton trap (Wetzel and Likens, 1991) at all but two of the eleven sampling stations. The exceptions were Stations #10 (Northern Woodport Bay) and #11 (Jefferson Canals). These sampling stations were only 1 –2 meters deep, providing a negligible amount of deep water refuge habitat for zooplankton. Therefore, a mid-depth sample was collected for the analysis of zooplankton at Stations #10 and #11, instead of the standard surface and deep samples collected at the other stations.

The sub-surface zooplankton samples were collected approximately 0.5 meters below the water's surface. If the bottom waters at a particular sampling stations were anoxic (dissolved oxygen concentrations less than 1 mg/L), the deep water zooplankton sample was collected approximately 0.5 meters above the anoxic zone. If the sampling station was oxygenated to the bottom, the deep sample was collected approximately 0.5 meters above the sediments.

Similar to the phytoplankton, the zooplankton samples were preserved with Lugol's solution and stored in an iced cooler (Lind, 1985; Wetzel and Likens, 1991) for transport to Princeton Hydro's biological laboratory. The zooplankton were identified down to the most practical taxon, either genus or species. In addition, abundance and biomass will be calculated as per Wetzel and Liken (1991) and Thorp and Covich (1991). The taxonomic manuals used to identify the zooplankton included Needham and Needham (1964), Pennack (1978).

As previously cited, this detailed survey of the plankton of Lake Hopatcong was conducted on 26 June 2003. The goal of scheduling the plankton survey sampling event in early summer was to sample during the lake's clear water phase, which is when zooplankton densities typically attain their seasonal maxima in many temperate lakes (Mills and Forney, 1983; Scheffer, 1998).

After a temperate lake ices out in early spring, snowmelt transports nutrients to the lake where it can stimulate a spring algal bloom. In temperate lakes, as water temperatures increase through the spring and into the early summer, herbivorous zooplankton numbers also increase. With a seasonal increase in food availability in the form of the spring algal bloom, a late spring/early summer "bloom" of zooplankton commonly occurs. Thus, subsequent to the spring algal bloom, herbivorous zooplankton increase and "graze down" the spring algae. This grazing commonly results in the clear water phase, where the zooplankton eat a substantial proportion of the lake's total algal community, resulting in an increase in water clarity. For most temperate lakes, this clear water phase typically occurs in late spring or early summer (May or June).

Since the spring of 2003 was relatively cool and wet, it was decided to conduct the quantitative plankton sampling event on 26 June 2003, still within the seasonal period of the clear water phase. The subsequent sections of the report review the plankton data for Lake Hopatcong within the context of the implementation of a clear water phase.

Section 6.2 Phytoplankton in Lake Hopatcong

Table 13 summarizes the results of analyzing the phytoplankton samples collected throughout Lake Hopatcong during the 26 June 2003 sampling event. The raw data are provided in Appendix B. Algal abundance varied from 1,520 cells per mL at Station #7 to 12,991 cells per mL at Station #6 (Table 13). Algal biomass varied from 855 ug/L at Station #7 to 50,368 ug/L at Station #6.

The majority of the phytoplankton identified during the 26 June 2003 sampling event were genera that are easily grazed on by large herbivorous zooplankton such as *Daphnia*. These genera included green algae, cryptomonds and some diatoms. In terms of abundance, diatoms followed by green algae were typically the dominant algal groups. In terms of biomass, diatoms were by far the dominant algal group throughout the lake. Such conditions are very common for large temperate lakes in the early summer season.

During the 26 June 2003 sampling event only two genera of blue-green (also known as cyanobacteria) algae were identified in Lake Hopatcong. The colonial blue-green *Gloeocapsa* was identified at Station #3 and was one of the dominant groups in terms of biomass, while the filamentous blue-green *Pseudanabaena* was the dominant alga in terms of abundance at Station #4. Blue-green algae tend to be the algal group responsible for the majority of problems associated with recreational lakes and potable water supplies. Some of the more common problems associated with blue-green algae include aesthetically displeasing surface scums, taste and odor problems and the potential generation of cyanotoxins.

Another issue of concern associated with blue-green algae is that many forms of these algae are not easily grazed upon by zooplankton. These conditions are primarily the result of many blue-green algae being composed of large filaments, bundles of filaments or globular colonies, sometimes encased in mucilage, making them highly difficult to ingest. Cyanotoxins may also impact the feeding rates and efficiency of zooplankton. Given such conditions, most blue-green algae are not considered to be highly "grazable" forms of algae.

Although two genera of blue-green algae were identified in Lake Hopatcong at the time of the 26 June 2003 plankton survey, these genera do not tend to produce major water quality problems. Thus, given the dominance of highly "grazable" genera of algae throughout Lake Hopatcong, as well as the low frequency of blue-green algae, biomanipulation appears to be a viable long-term restoration technique. However, it should be emphasized that nuisance, non-grazable blue-green algae to tend to attain detectable concentrations during the second half of the growing season. In particular, scum forming genera such as *Anabaena*, *Aphanizomenon* and *Microcystis* have been identified in the open waters of Lake Hopatcong (Station #2) during the height of the summer season. Deep water blue-green algae such as *Oscillatoria* and a benthic dwelling forms such as *Lyngbya* have also been identified in Lake Hopatcong. In order to obtain a more seasonal view of Lake Hopatcong's phytoplankton community, the 2003 phytoplankton data that were collected and examined as part of long-term monitoring program, are summarized in Table 14.

As part of the Lake Hopatcong long-term monitoring program, vertical net tows for plankton are collected during each of the five monitoring events at the mid-lake sampling station (Station #2). These samples are examined on a qualitative basis and the 2003 data are provided in Table 14. The seasonal succession of phytoplankton in Lake Hopatcong in 2003 was typical of moderately productive, temperate waterbodies. In May and June the phytoplankton community was dominated by green algae, chrysophytes, and particularly diatoms. By the mid-summer season, the green algae were the dominant algal group and by the late summer season the blue-green algae were the dominant group. As water temperatures declined in early fall, the blue-green algae were replaced as the dominant group by the diatoms and the chrysophytes (Table 14).

Genera of blue-green algae, notorious for producing nuisance surface scums during hot, dry, windless days, were identified in the July through September 2003 samples. These included *Anabaena*, *Coelosphaerium* and *Microcystis*. In addition, the deep-dwelling blue-green alga *Oscillatoria* was identified in the July through September samples. The vertical net tows more than likely collected this alga in the deeper waters of the lake. While *Oscillatoria* does not form the metallic green surface scums as the other identified genera, it has been known to bloom in the deeper waters and be transported to the surface waters during storm events. Once at the surface *Oscillatoria* begins to decompose, producing unpleasant colors, surface scums and odors similar to rotten fish.

Based on the samples collected and analyzed in 2003, two conclusions can be made on the phytoplankton community of Lake Hopatcong. First, the community is relatively diverse and many of the identified algae are easily grazed by herbivorous zooplankton. This is particularly the case for first half of the growing season. Second, the presence of a number of nuisance blue-green algae in Lake Hopatcong, especially during the mid- to late summer season, indicates that the lake certainly has the potential to produce large-scale algal blooms / surface scums. Even a slight to moderate increase in the phosphorus load could push Lake Hopatcong into a state of experiencing large and frequent, lake-wide blue-green algae blooms. Such blooms are already experienced in the River Styx / Crescent Cove section of the lake through the later half of the growing season.

As will be outlined in detail in the Restoration Plan (see Section 6.0), efforts to reduce the existing phosphorus load and maintain the targeted phosphorus load, as per the TMDL, will aid in maximizing the effectiveness of any bioremediation techniques that are implemented in Lake Hopatcong. The key to maximizing this effectiveness is to minimize the frequency, duration and magnitude of blue-green algae blooms throughout Lake Hopatcong.

Table 13

Summary of Phytoplankton Data Collected at Lake Hopatcong During the 26 June 2003 Plankton Survey

Sampling Station	Abundance (cells per mL)	Biomass (ug per L)
Station 1	3,858	1,957
Station 2	7,274	27,389
Station 3	3,001	2,703
Station 4	12,219	16,664
Station 5	5,926	8,682
Station 6	12,991	50,368
Station 7	1,520	855
Station 8	10,697	24,931
Station 9	6,479	25,738
Station 10	5,417	8,368
Station 11	3,889	11,162

Table 14

Summary of Qualitative Phytoplankton Data Collected at Lake Hopatcong During 2003 Monitoring Program

Sampling Date	Dominant Phytoplankton
22 May 2003	Diatoms, green algae, chrysophytes
26 June 2003	Diatoms
31 July 2003	Green algae, diatoms, blue-green algae
27 August 2003	Blue-green algae
16 September 2003	Chrysophytes, diatoms blue-green algae

Section 6.3 Zooplankton in Lake Hopatcong

Table 15 summarizes the results of the zooplankton samples collected throughout Lake Hopatcong during the 26 June 2003 sampling event. As previously mentioned zooplankton, particularly large-bodied forms such as *Daphnia*, vertically migrate through the water column, primarily as an adaptive measure to avoid being eaten by visually-based feeders such as zooplanktivorous fishes (i.e. alewife, golden shiners, young perch). Thus, with the exception of the shallow sampling sites of Stations #10 and #11, surface and deep (approximately 0.5 meters above the sediments) zooplankton samples were collected with a Schindler plankton trap. Mid-depth samples were collected at Stations #10 and #11 (Table 15).

A comparison between surface and bottom zooplankton abundance at Stations #1 through #9 revealed that only three of the sampling stations had deep zooplankton abundance values higher than their respective surface values. In addition, the difference between the surface and deep abundance values was not substantial (Table 15). Similar results were observed for the biomass values, where four of the nine stations had deep values higher than their respective surface values (Table 15). These data indicate that a large portion of the existing zooplankton community of Lake Hopatcong was not vertically migrating through the water column. Typically, deep water abundance and biomass zooplankton values are substantially higher than their respective surface water values, particularly with large-bodied zooplankton.

The weak degree of vertical zooplankton migration in Lake Hopatcong on 26 June 2003 was primarily due to the low number of large-bodied zooplankton. It is the large-bodied, herbivorous (algae-eating) genera that exhibit the strongest patterns of vertical migration. Three such herbivorous zooplankton were identified in Lake Hopatcong. The most common of these three herbivorous zooplankton was the moderately sized cladoceran *Ceriodaphnia*. The other two genera were somewhat rare and included the cladoceran *Daphnia* and the copepod *Diaptomus*.

In spite of the presence of three herbivorous zooplankton in Lake Hopatcong, their abundance relative to the total number of zooplankton, as well as their total lengths, were indicative of a zooplankton community under stress. Specifically, this stress is more than likely grazing pressure from zooplanktivorous fish. The ecological indicators that lead to this conclusion include the low percentage of large herbivorous zooplankton (specifically *Daphnia*) and the percentage of herbivores relative to total zooplankton abundance and biomass. These indicators are discussed below in detail.

Table 15
Summary of Zooplankton Data Collected at Lake Hopatcong During the 26 June 2003 Plankton Survey

Sampling Station	Sub-surface		Deep	
	Abundance	**Biomass**	**Abundance**	**Biomass**
Station 1	387	293	348	306
Station 2	690	269	633	664
Station 3	1,107	650	1,157	713
Station 4	425	291	201	117
Station 5	340	315	378	230
Station 6	179	120	376	221
Station 7	260	333	675	147
Station 8	647	342	626	337
Station 9	1,417	869	709	395
Station 10*	338	179	Not sampled	Not sampled
Station 11*	98	33	Not sampled	Not sampled

* the zooplankton samples collected at Stations #10 and #11 were mid-depth samples.

Under conditions with a low degree of predation by zooplanktivorous fishes, large-bodied zooplankton will thrive. For example, under such conditions species of *Daphnia* should be abundant, particularly during the late spring and early summer season, and their total length should be greater than 1 mm (USEPA, 1998). Of the twenty Lake Hopatcong zooplankton samples collected during the 26 June 2003 sampling event, only one had a species of *Daphnia*. This was the surface sample collected at Station #7 (Inlet from Lake Shawnee). The abundance of *Daphnia* at this sample was only 19 *Daphnia* per liter and their mean length was only 0.75 mm. In addition, since *Daphnia* were only identified at the station immediately adjacent to the inlet from Lake Shawnee, it is possible that these organisms were transported from Lake Shawnee to Lake Hopatcong. These data indicate that the zooplankton community of Lake Hopatcong is probably under predatory stress by zooplanktivorous fishes such as alewife, golden shiners and/or young perch.

The herbivorous copepod *Diaptomus* was identified in Lake Hopatcong but was not as rare *Daphnia*. Of the 20 samples collected during the 26 June 2003 sampling event, *Diaptomus* was only found in eight. In contrast, *Ceriodaphnia* was found in 18 of the 20 samples. While *Ceriodaphnia* does feed on algae, it is only a moderate grazer and does not remove a large amount of algae from the water column as does *Daphnia* and *Diaptomus*.

Additional evidence of heavy zooplanktivory (feeding on zooplankton) is provided by examining the percent of herbivorous zooplankton relative to total zooplankton. The number of *Ceriodaphnia*, *Daphnia* and *Diaptomus* for each sample was summed and divided by its respective number of total zooplankton for both abundance and biomass. For the abundance of the surface water samples the percent of herbivores varied from 0 to 36%, with Stations #3 and #9 having the highest percent values. For the abundance of the deep water samples the percent of herbivores varied from 0 to 44%, with Station #2 having the highest percent value. The deep water of Station #3 had the second highest, with 39%. It is interesting to note that the highest percent of herbivores was found in the bottom waters of Station #2, the deepest sampling station. Such results are common for temperate lakes; large herbivorous zooplankton find refuge from zooplanktivorous fishes, residing in the deep, dark waters of the bottom.

In terms of biomass, the percent of herbivorous zooplankton in the surface waters of Lake Hopatcong varied from 0 to 43%. An exception to this was the surface waters of Station #7, where the percent of herbivorous zooplankton accounted for 75% of the total biomass. This high contribution of herbivorous zooplankton to total biomass in the surface waters of Station #7 was due to *Ceriodaphnia* and *Daphnia*. In sharp contrast, no herbivores were found in the deep waters of Station #7. Again, the presence of *Daphnia* and the high percentage of herbivores in the surfaces waters of Station #7 were attributed to its close proximity to the outlet of Lake Shawnee. It is more than likely that the *Daphnia* identified at Station #7 were washed in from Lake Shawnee, however, more detailed sampling of both Lake Hopatcong and Lake Shawnee is required to confirm this statement.

In summary, while herbivorous zooplankton were present in Lake Hopatcong, the majority of these herbivorous were the moderately sized cladoceran *Ceriodaphnia*. The herbivorous copepod *Diaptomus* was uncommon. The large-bodied cladoceran *Daphnia* was only found at one sampling station and was more than likely washed into the lake from Lake Shawnee. The relatively low abundance and biomass of herbivorous zooplankton and the relatively low total length of those found in the lake, indicate that the zooplankton community is probably under stress through grazing pressure exerted by zooplanktivorous fish such as alewife, shiners and young perch.

Section 6.4 Management of Aquatic Plants (Alternative Stable States)

As shown in Figure 7, Lake Hopatcong can be separated into two major ecosystems, with the first being the main central basin that functions as a deep, dimictic (turns over twice a year), temperate lake. The second ecosystem is the diverse, polymictic (turns over a number of times through the year) nearshore habitat that harbors a diverse community of aquatic macrophytes (plants and mat algae).

The community of aquatic plants and algae distributed throughout the shallow, nearshore sections of the lake serve to filter particulates and their adsorbed pollutants (i.e. phosphorus) from stormwater as it enters the lake. This positive feedback mechanism contributes toward increasing the water clarity of the open water section of the lake by filtering out particulates and limiting the amount of phosphorus that reaches the open waters. Other benefits associated with aquatic macrophytes includes the creation of habitat for fish, aquatic invertebrates and other organisms, refuge for young fish from piscivorous fishes, buffering the shoreline from wind and wave erosion, and providing dissolved oxygen through photosynthesis.

While aquatic macrophytes to provide a variety of ecological benefits, excessive densities can produce nuisance conditions that impact recreational activities such as fishing, boating, sailing and swimming. Some more ecologically-based impacts include reducing the diversity of the fishery community and serving as a source of nutrients and the uptake of dissolved oxygen through decomposition. In addition, the dominance of the aquatic macrophyte community by exotic (non-native) species can exacerbate negative impacts on fish and wildlife, as well as reduce overall community diversity by out-competing more favorable, native species. Therefore, the long-term restoration / management goal regarding aquatic macrophytes in Lake Hopatcong is to eliminate the exotic species but control the native species. Aquatic macrophytes are desirable for their associated benefits but excessive densities are to be avoided or at least minimized.

The TMDL for Lake Hopatcong focuses on phosphorus, the primary limiting nutrient for both algae and aquatic plants. The short-term response of an increase in phosphorus loading is an increase in algal growth and the production of unpleasant blooms. Since submerged aquatic plants and many forms of benthic algae obtain the bulk of their required phosphorus from the sediments, the nutrient load entering the lake via watershed sources does not have a short-term impact on the macrophyte community. However, from a long-term perspective, a portion of the phosphorus entering the lake is retained and settles to the bottom, making it available to rooted aquatic plants and benthic algae through the sediments. Thus, watershed-based sources of phosphorus contribute to both algal blooms and nuisance densities of aquatic vegetation.

In addition to phosphorus, other non-point source pollutants entering Lake Hopatcong that negatively impact water quality and recreational use by increasing the growth of aquatic macrophytes. For example, stormwater transports total suspended solids (TSS) to Lake Hopatcong via surface runoff. As TSS accumulates in the bays, coves and canals of the lake, the resulting in-filling reduces mean water depth. This allows more sunlight to intercept the sediments, which is more conducive submerged aquatic plant growth. Fortunately, the majority of the BMPs recommended for reducing the phosphorus loads will also reduce the TSS loads. Thus, from a long-term perspective reducing the phosphorus and TSS loads entering Lake Hopatcong will contribute toward limiting aquatic plant growth.

Currently, the Lake Hopatcong Commission, the State-appointed group comprised of local, County and State representative and whose purpose is to the steward of the lake and its watershed, operates and maintains a mechanical weed harvesting program at Lake Hopatcong. From May through October the operations staff utilizes a fleet of three single-stage mechanical weed harvesters to cut, collect and remove plant biomass from Lake Hopatcong (see Appendix C for photographs of the harvesters in operation). While a few private homeowners obtain permits to have licensed applicators chemically treat immediately in front of their homes to control nuisance densities of aquatic plants, mechanical weed harvesting is the primary method of providing relief from excessive plant growth in Lake Hopatcong.

To determine if mechanical weed harvesting is the most ecologically friendly and cost effective approach toward controlling nuisance plant densities in Lake Hopatcong, detailed observational data were collected on the lake's resident plant community. As part of Lake Hopatcong's long-term water quality monitoring program, observation data of the resident aquatic plant community were collected at each sampling station, during each sampling event. A copy of the 2003 long-term water quality monitoring report for Lake Hopatcong is provided in Appendix D. This report includes a map of Lake Hopatcong, displaying the eleven standard sampling stations are that monitored during the long-term program.

Beyond the standard monitoring program, an additional sampling event was conducted on 25 August 2003. This additional aquatic plant sampling event was conducted to survey areas of the lake that are not normally monitored as part the long-term monitoring program. The results of the aquatic plant surveys conducted during both the long-term monitoring events and the additional event were placed into an Access database (Appendix C). The sections of the lake that were monitored, beyond the standard long-term monitoring program are shown in Figure 8. For convenience, the results of the aquatic plant Access database are summarized below; more detailed ecological data on some of the more common macrophytes identified in Lake Hopatcong are provided in Appendix C.

Figure 8

During the 22 May 2003 sampling event, Eurasian watermilfoil (*Myriophyllum spicatum*) was the dominant species in all eight sampling stations that were shallow enough to harbor a submerged aquatic plant community. Other milfoil species (*M. sibiricum*), tapegrass (*Vallisneria americana*), common waterweed (*Elodea candensis*), Curley-leaved pondweed (*Potamogeton crispus*) and a number of floating-leaved species (i.e., lilies and watershield) were also identified in Lake Hopatcong during the late May sampling event. Mats of the benthic blue-green alga *Lyngbya* were also identified in the northern end of the lake in Woodport Bay (Station #10; see map in Appendix D).

By 26 June 2003, Eurasian watermilfoil was the dominant species in only three of the eight shallow sampling stations. Several species of water lily were the dominant plants in the Jefferson Canals (Station #11), while the benthic alga *Lyngbya* was the dominant macrophyte in Woodport Bay and Henderson Cove (Station #6). Coontail (*Ceratophyllum demersum*) was the dominant species off Liffy Island and several additional species pondweed (*Potamogeton perfoliatus* and *P. amplifolius*) were identified.

By 31 July 2004 Eurasian watermilfoil was the dominant species in only one of the eight shallow sampling stations. In contrast, the benthic alga *Lyngbya* was the dominant macrophyte in four of the eight stations. Tapegrass was the dominant plant in the Canals of Jefferson (Station #11); a variety of other species were identified at this station, including bladderwort (*Utricularia sp*.), northern milfoil, large-leaved pondweed (*Potamogeton amplifolius*) and variable-leaf pondweed (*Potamogeton gramineus*). The sampling stations in the northern end of the lake, including the northwestern shallow stations in Jefferson Township, all had a brown and turbid appearance. In contrast, the main basin, mid-lake and southern stations had a green color.

Station #3 had a gray-green color, which was attributed to a moderate algal bloom. In general, an algal bloom is typically perceived as a problem by the layperson when chlorophyll *a* concentrations are equal to or greater than 30.0 mg/m^3. On 31 July 2004, the chlorophyll *a* concentration at Station #3 was 49.5 mg/m^3, while the other sampling stations had concentrations between 3.7 and 12.3 mg/m^3 (for convenience, a copy of the 2003 long-term monitoring report is provided in Appendix D). Such results are typical for Station #3.

Very few weeds were identified in the River Styx / Crescent Cove (Station #3) section of the lake. Given the mean depth of 1-3 meters in the River Styx / Crescent Cove section, this part of the lake typically has high densities of submerged aquatic plants through the entire growing season. However, in 2003 the operations staff of the LHC harvested the River Styx / Crescent Cove section early in the growing season instead of later. The removal of the submerged vegetation, coupled with the early summer algal blooms that regularly plague this part of the lake, prevented the re-establishment of the submerged vegetation. Since algal blooms are a regular occurrence in Station #3, the operations staff utilized the concept of alternative stable states to manage the aquatic macrophytes in this part of the lake. A minimal amount of submerged vegetation was found at Station #3 for the rest of the 2003 growing season. Thus, this section of the lake only had to be monitored and harvesting efforts could focus on other sections in more need of such management activities. As the LHC continues to collect long-term monitoring and harvesting data, similar modifications / approaches to the weed harvesting program will be utilized to increase its efficiency.

As previously mentioned, in addition to the five standard long-term monitoring events, an additional monitoring event was conducted on 25 August 2003 to survey areas of the lake that are not normally monitored. This additional survey specifically focused on the resident aquatic plant communities. These surveyed areas are shown in Figure 8 and the results of the survey can be found in the 2003 water quality monitoring report (Appendix D). However, for convenience, the survey is briefly reviewed.

A total of 12 areas of Lake Hopatcong were surveyed during the 25 August 2003 monitoring event. Eurasian watermilfoil and tapegrass were each the dominant plant in four of the monitored areas. The mat algal *Lyngbya*, southern naiad (*Najas guadalupensis*) and large-leaf pondweed were each the dominant plant in one of the twelve monitored areas. As described in detail in the 2003 report, areas that were recently mechanically harvested exhibited substantially lower amount of submerged macrophyte biomass. One of the surveyed areas, near Floating Island (M-9), is known to be chemically-treated with a State-certified aquatic herbicide. In spite of the chemical control, large-leaved pondweed and mats of *Lyngbya* were still observed at this site.

While Eurasian watermilfoil was identified in Lake Hopatcong during the 28 August 2003 sampling event, it was not the dominant species at any of the long-term monitoring stations. Instead, tapegrass (*Vallisneria americana*), a highly favorable species for recreational fishing and native wildlife, was the dominant species at two of the long-term stations, while the mat alga *Lyngbya* was the dominant macrophyte in three of the stations. Coontail was the dominant species in the River Styx / Crescent Cove (Station #3) area, while Large-leaved pondweed was the dominant species in Great Cove (Station #8).

From late August to 16 September 2003, overall plant densities declined in Lake Hopatcong. Such seasonal declines are very common in temperate lakes from late summer, into fall. Other than tapegrass off Liffy Island (Station #1) and *Lyngbya* in Henderson Cove (Station #6), macrophyte densities over the sediments were general low. The onset of fall, in conjunction with the mechanical weed harvesting program, contributed toward the relatively low densities of submerged macrophytes in September 2003. However, another important factor contributed toward the distribution and densities of macrophytes in Lake Hopatcong through the 2003 growing season.

The spring of 2003 was relatively cool and wet, with a relatively high frequency of storm events. Such conditions, as were experienced in 2003, appear to favor algal growth as long as the frequency and magnitude of storms is not large enough to substantially increase the flushing rate of the lake. Under such conditions increased turbidity due to algal biomass and/or inorganic particulates, reduce the amount of light that reaches the sediment, which in turn stimulate submerged macrophyte growth. Thus, more algae and an increase in turbidity in the spring will result in lower macrophyte growth. Such relationships will be used in a continuing effort to improve upon the existing mechanical weed harvesting program of Lake Hopatcong.

Section 6.5 Assessment of Bioremediation in Lake Hopatcong

The phytoplankton assemblage of Lake Hopatcong is composed of a variety of algal groups, many of which include genera that are easily grazed by herbivorous zooplankton. Three herbivorous zooplankton were identified in the lake, however, two were rare that the third was not abundant. In addition, all identified herbivorous zooplankton were less than 1.0 mm in total length, indicating that they are stressed via predation pressure by zooplanktivorous fishes (US EPA, 1998). These data indicate that the zooplankton community is under a considerable amount of stress through a heavy degree of predation by zooplanktivorous fishes such as alewife, golden shiners, and young white / yellow perch.

Based on the data collected to date, biomanipulation has the potential to produce improvements in water quality if implemented in Lake Hopatcong. Specifically, the diverse phytoplankton community and the “stressed” herbivorous zooplankton community, indicate that stocking the lake with more large, gamefish and/or removing a large fraction of the zooplanktivorous fish population, would result in an improvement in water quality. However, without detailed information on the existing densities and structure of the fishery of Lake Hopatcong, it is extremely difficult to provide specific plan. Therefore, the first step for the long-term management of Lake Hopatcong from a bioremediation perspective will be to conduct a detailed fishery survey of the lake.

The near shore, shallow water habitat areas of Lake Hopatcong (Figure 7) harbor a variety of aquatic plants and benthic algae. In 2003 a total of sixteen species of macrophytes were identified in Lake Hopatcong. Some of these species, such as Eurasian watermilfoil and Curley-leaved pondweed, are well known exotic species that have a negative impact on native species. Others, such as tapegrass and a number of the other pondweed species, are native species and serve as valuable sources of food and refuge for fish, invertebrates and wildlife. However, once any of these species attain high enough densities and reach the water’s surface, are a nuisance in terms of recreational use, which also impacts the economic value of the lake and its associated natural resources. Therefore, the long-term management strategy is to control but not eliminate the diverse community of submerged macrophytes distributed throughout the shallow water habitats of Lake Hopatcong.

Section 6.6 Bioremediation in Lake Musconetcong

Unlike the complex morphometry of Lake Hopatcong, Lake Musconetcong is a shallow waterbody with a mean depth of 1.5 meters (4.8 ft) and a maximum depth of 3.0 meters (10.0 ft). While it has a number of small coves, there are not substantial differences in the water depths between the coves and the main part of the lake (Figure 3). Thus, while Lake Hopatcong exhibited traits of a dimictic and polymictic ecosystem, the entire basin of Lake Musconetcong functions as a polymictic waterbody.

As with any shallow waterbody, the biological component of the ecosystem will have a greater impact on water quality relative to a deep waterbody. This is primarily a function of their water volume to sediment surface area ratio. For large, deep lakes the volume to surface area ratio is large, while for shallow lakes the ratio is relatively small. This results in more of the overlaying water interaction with the sediments in shallow lakes. In turn, biological processes such as the growth and death of aquatic macrophytes and the feeding of benthic fishes such as carp, have a larger impact on the whole lake water quality. This is in contrast to larger, deeper lakes where such impacts tend to be limited to the littoral zone (i.e. shallow bays and coves).

Since the biology of the Lake Musconetcong has a substantial impact on its water quality and recreational use, the Restoration Plan for Lake Musconetcong will focus more attention on biological management (see Section 7.0). In addition, as shown in Section 3.0, the majority of the phosphorus entering Lake Musconetcong originates from Lake Hopatcong. Therefore, Lake Hopatcong complying with its TMDL will have a substantially positive impact on the water quality of Lake Musconetcong.

In order to assess the potential application of biomanipulation in Lake Musconetcong a variety of biological data had to be collected. However, unlike Lake Hopatcong, Lake Musconetcong does not have a long-term monitoring program. Therefore, more quantitative data were collected at Lake Musconetcong and included phytoplankton, zooplankton, aquatic macrophytes and the lake's resident fishery community.

Lake Musconetcong was sampled three times during the 2003 growing season. These sampling events were 29 April, 3 July and 27 August 2003. At each of the five sampling stations (Figure 9), *in-situ* measurements of dissolved oxygen, temperature, pH and conductivity were collected. Water quality was measured with a Secchi disk. Mid-depth discrete water samples were also collected at each sampling station for total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), and chlorophyll a. Additional quantitative samples were collected for phytoplankton, zooplankton and aquatic macrophytes at each station, during each sampling event. Besides the standard monitoring, a fishery survey of Lake Musconetcong was conducted on 29-30 May and 6 June 2003. The sampling program was designed to collect a sufficient amount of ecological data to represent and assess water quality conditions in Lake Musconetcong through the course of a growing season.

Figure 9

Section 6.7 Phytoplankton in Lake Musconetcong

Table 16 summarizes the Lake Musconetcong phytoplankton data; the raw data are provided in Appendix E. Algal abundance in Lake Musconetcong varied from a low of 776 cells per mL on 27 April to a high of 11,441 cell per mL on 3 July 2003. Algal biomass varied from a low 1,271 ug / L on 27 April to a high of 24,514 ug / L on 3 July 2003 (Appendix E). The green algae were typically the most diverse algal group in Lake Musconetcong with many of the identified genera being filamentous forms that begin growing over the sediments of aquatic plants. As these filamentous accumulate gas bubbles they detach and float through the water column, sometimes forming visible algal mats.

During the 27 April 2003 sampling event, two genera of diatoms, *Asterionella* and *Melosira*, and the filamentous green alga *Desmidium* were the dominant algae in Lake Musconetcong. By 3 July 2003, the green algae were the dominant algae and include a number of small-celled (*Gloeocystis*, *Scenedesmus* and *Sphaeriocystis*) and filamentous (*Ulothrix*, *Spondylosium* and *Oedogonium*) genera. Several genera of diatoms were also common, particularly at Stations 1 and 2 (Table 16).

By 27 August 2003, the dominant algal group shifted from green algae and diatoms to blue-green algae. Particularly, the filamentous blue-green alga *Anabaena* was dominant. *Anabaena* is well known to produce a variety of nuisance problems including surface scums, unpleasant odors, and produce cyanotoxins. Blue-green algae proliferate during the dry hot summer season and tend to do particularly well in the presence of elevated TP concentrations (> 0.03 mg/L).

Based on collected data, a substantial proportion of the phytoplankton community in Lake Musconetcong is susceptible to grazing by herbivorous zooplankton. Specially, many of the diatoms and green algae identified in Lake Musconetcong could be controlled through grazing. In contrast, the filamentous green algae and the blue-green algae identified in the July and August samples, respectively, are not very susceptible to zooplankton grazing.

While the filamentous green algae may be controlled by other herbivores such as tadpoles, the phosphorus load of Lake Musconetcong needs to be lowered in order to minimize the impact these forms of algae have on the lake's water quality. TP concentrations varied from < 0.02 to 0.12 mg/L during the 2003 sampling program. Thus, there were times when in-lake TP concentrations were above the targeted TMDL-based TP concentration of 0.030 mg/L identified for Lake Musconetcong.

Table 16

Summary of Quantitative Phytoplankton Data Collected at Lake Musconetcong During 2003 Monitoring Program

Sampling Date	Dominant Phytoplankton
29 April 2003	Station 1: Diatoms (*Asterionella* and *Melosira*) Station 2: Diatoms (*Asterionella*) Station 3: Green algae (*Desmidium*) Station 4: Green algae (*Desmidium*) Station 5: Diatoms (*Asterionella*)
3 July 2003	Station 1: Green algae (*Scenedesmus* and *Sphaeriocystis*) and Diatoms (*Asterionella* and *Melosira*) Station 2: Green algae (*Ulothrix*) and several diatoms Station 3: Green algae (*Oedogonium*) Station 4: Green algae (*Spondylosium* and *Oedogonium*) Station 5: Green algae (*Gloeocystis*)
27 August 2003	Station 1: Blue-green algae (*Anabaena* and *Coelosphaerium*) Station 2: A variety of green algae and the blue-green algae (*Anabaena*) Station 3: Green algae (*Sphaeriocystis*) and several diatoms Station 4: Blue-green algae (*Anabaena*) Station 5: Blue-green algae (*Anbabaena*) and a variety of green algae

Section 6.8 Zooplankton in Lake Musconetcong

Tables 17 and 18 summarize the zooplankton abundance and biomass values, respectively, for Lake Musconetcong. The detailed information is provided in Appendix E. Given the relatively shallow water depth of Lake Musconetcong, only mid-depth samples were collected at each sampling station with a Schindler plankton trap.

On 29 April 2003, zooplankton abundance varied from 169 to 564 animals per liter, while biomass varied from 95.7 to 418.5 ug per liter (Tables 17 and 18, respectively). No herbivorous zooplankton were identified in Stations 1 through 3 during the 29 April sampling event. Some *Daphnia* were identified in Station 4 and both *Daphnia* and *Ceriodaphnia* were identified in Station 5 during the 29 April sampling event. However, the abundance of these herbivorous zooplankton was low; the percent of herbivores to total zooplankton abundance at Stations 4 and 5 were both 9%.

On 3 July 2003, zooplankton abundance varied from 95 to 556 animals per liter, while biomass varied from 67.3 to 566.1 ug per liter (Tables 17 and 18, respectively). No herbivorous zooplankton were identified in Stations 1 and 5. *Ceriodaphnia* was identified at Station 3, while both *Ceriodaphnia* and *Diaptomus* were identified at Stations 2 and 4. The percent of herbivorous zooplankton to total abundance among Stations 2 through 4 varied from 18 to 36%.

On 27 August 2003, zooplankton abundance varied from 191 to 500 animals per liter, while biomass varied from 151.8 to 321.5 ug per liter (Tables 17 and 18, respectively). No herbivorous zooplankton were identified in Stations 3 and 5. *Ceriodaphnia* was identified at Stations 2 and 4, while both *Ceriodaphnia* and *Diaphnia* were identified at Station 1. The percent of herbivorous zooplankton to total abundance varied from 4 to 20%.

As identified earlier in this report, in the absence of grazing pressure by fish the total length of *Daphnia* should be greater than 1 mm (USEPA, 1998). The total length of the *Daphnia* observed in Lake Musconetcong varied between 0.95 and 1.2 mm. Based on these total length measurements, as well as the moderate percentage of herbivorous zooplankton, grazing on the zooplankton by fish is not as strong as more than likely occurs in Lake Hopatcong. This indicates that only a moderate amount of effort may be required to modify or re-structure the fishery community of Lake Musconetcong to maximize the benefits of biomanipulation.

Table 17

Summary of Zooplankton Abundance Data Collected at Lake Musconetcong during the 2003 Monitoring Program

Sampling Station	29 April 2003 (animals per L)	3 July 2003 (animals per L)	27 August 2003 (animals per L)
Station #1	322	95	191
Station #2	564	556	500
Station #3	169	431	431
Station #4	512	412	422
Station #5	463	404	363

Table 18

Summary of Zooplankton Biomass Data Collected at Lake Musconetcong during the 2003 Monitoring Program

Sampling Station	29 April 2003 (ug / L)	3 July 2003 (ug / L)	27 August 2003 (ug / L)
Station #1	233.9	67.3	192.4
Station #2	329.3	566.1	318.0
Station #3	95.7	243.1	321.5
Station #4	418.5	190.3	151.8
Station #5	415.4	263.1	223.9

Section 6.9 Fishery Community of Lake Musconetcong

Unlike Lake Hopatcong, the bio-assessment of Lake Musconetcong included a fishery survey. To obtain a complete assessment of the fish community of Lake Musconetcong, a variety of survey methods were used through the course of the survey. These methods included electroshocking, shoreline seining, and the deployment and retrieval of trap nets and gill nets. Two trap nets and three gill nets were deployed on 29 May 2003 and retrieved on 30 May 2003. Shoreline seining and electroshocking was conducted on 3 June 2003. The electroshocking survey was conducted with a Coffelt VVP Electroshocking Unit, equipped with probes powered by a 5 HP Honda generator, mounted on a 16 ft Boston Whaler.

A total of 473 fish were collected during the 2003 fishery survey at Lake Musconetcong, which included a total of fifteen species (Table 19). More details on the fishery survey are provided in Appendix F.

No fish were retrieved from the two trap nets. In contrast, 43, 58 and 63 fish were retrieved from the first, second and third gill nets, respectively, for a total of 164 fish. The dominant species collected from two of the three gill nets was the bluegill sunfish, while white perch was the dominant species in the remaining gill net.

Of the thirteen fish collected through the shoreline seining, nine were banned killifish, three were bluegills and one was a largemouth bass. Electroshocking accounted for approximately 63% of the total number of collected fish. Of the six transects of electroshocking conducted in Lake Musconetcong, bluegill were the dominant species in five of them.

In terms of abundance, bluegills were the dominant species, accounting for approximately 63% of the total catch (Table 19). Young bluegills were particularly common. For example, bluegill within the size category 0 to 3” accounted for 70% of the bluegills catch and 45% of the total catch. Thus, young bluegills were, by far, the most abundance species and size class in Lake Musconetcong.

Yellow bullhead was the second most common species, accounting for slightly over 10% of the total catch. Yellow perch, golden shiner and white perch each accounted for another 4 to 6% of the total catch. Combined, the five most abundant species accounted for a total of 88% of the total catch during the Lake Musconetcong fishery survey.

Table 19

Using the size and abundance data shown in Table 19 and species-based, weight – length regression coefficients derived from the scientific literature (www.fishbase.org), fish biomass was calculated for the results of the Lake Musconetcong fishery survey. Based on these calculations, yellow bullhead and common carp accounted for the largest and second largest amount of fish biomass during the survey (Figure 10). Combined, these two benthic fish accounted for 42% of the total fish biomass. White perch and bluegill combined accounted for another 22% of the total fish biomass. In contrast, two desirable piscivorous fish species, chain pickerel and largemouth bass, accounted for only 6 and 1.2% of the total fish biomass, respectively.

Based on the results of the spring 2003 fishery survey of Lake Musconetcong, the lake is dominated by young bluegills and the two benthic species yellow bullhead and common carp. Large piscivorous fish, such as chain pickerel and largemouth bass were relatively uncommon. In terms of abundance, chain pickerel and largemouth bass accounted for 2.7 and 1.7% of the total catch, respectively (Table 19).

For a shallow, submerged macrophyte-dominated ecosystem, the fishery community of Lake Musconetcong can be described as poor in terms of both recreational use and ecological management through biomanipulation. Small, young-of-the-year bluegills were the dominant fish in terms of abundance. Zooplankton accounts for a substantial proportion of the diet of these young fish. In addition, the presence of large-bodied benthic feeding fish tends to hamper restoration measures by potentially transferring phosphorus from the sediments into the water column. However, water clarity in Lake Musconetcong was typically to the bottom during the 2003 monitoring program and aquatic macrophyte abundance and biomass was high (see Section 6.9), so the impacts of the benthivorous fishes were not of primary concern relative to the young bluegill. Other zooplanktivorous fish, such as golden shiners, were also identified in moderate numbers during the fishery survey.

Largemouth bass accounted for only 1.7% of the total catch during the survey with a total length distribution of six fish in the 3-6" size range, one fish in the 6-9" size range and one fish in the 12-15" size range (Table 19). No young-of-the-year (< 3") or large (> 15") largemouth bass were captured during the survey. The high number of young bluegills and absence of young largemouth bass indicates that the bluegills are out-competing the largemouth bass for spawning habitat and/or food resources for young fish. In addition, the absence of larger sized largemouth bass is more than likely the result of the excessive densities of submerged vegetation hampering the ability of the bass to successfully obtain food.

Figure 10

The general body shape of the chain pickerel is better adapted to maneuvering in high plant density environments. Thus, chain pickerel accounted for a larger portion of the total survey catch relative to largemouth bass and the total length of the pickerel were generally larger than the bass (Table 19). As outlined in the Restoration Plan, one of the long-term objectives for the management of Lake Musconetcong will be to improve upon the existing largemouth bass fishery for both recreational and water quality (i.e. biomanipulation) reasons.

In spite of the high abundance of zooplanktivorous fishes was a moderate amount of herbivorous zooplankton in Lake Musconetcong. The continued presence of these large-bodied herbivorous zooplankton was more than likely attributed to the high densities of submerged aquatic vegetation, which serve as refuge and cover from zooplanktivorous fishes. In spite of this, an added degree of algal control could be achieved by a more pro-active strategy toward managing both the fishery and aquatic macrophyte community of Lake Musconetcong (for details see Restoration Plan). As will be discussed, such a pro-active strategy would also contribute toward improving upon the existing recreational value of Lake Musconetcong.

To summarize the fishery survey, the fishery community of Lake Musconetcong was dominated by young bluegills in terms of abundance and benthic fishes in terms of biomass. In spite of the presence of a large number of zooplankton-eating fish, a moderate number of herbivorous zooplankton was present. However, the abundance of herbivorous zooplankton would be higher if the number of zooplanktivorous fish was reduced. Given the existing morphometry and habitat of Lake Musconetcong, the number of largemouth bass was sub-optimal. This was primarily attributed to intense competition between adult largemouth bass and bluegills for spawning space and between young-of-the-year bass and bluegills for food. As will be described in the subsequent section, high densities of aquatic plants, particularly the exotic species Eurasian watermilfoil, also contributed toward negatively impacting the population of largemouth bass in Lake Musconetcong.

Section 6.10 Management of Aquatic Plants (Alternative Stable States)

Unlike Lake Hopatcong, a long-term monitoring program does not exist for Lake Musconetcong. Therefore, as part of its bio-assessment, quantitative samples were collected for the identification and measurement of the aquatic macrophytes at each sampling station during each sampling event. A quadrant of a calibrated surface area was laid over the sediments at each sampling station and the above sediment biomass was harvested with a rake. The material was placed into a labeled plastic bag and then placed in an iced cooler. The samples were taken to Princeton Hydro's biological laboratory where the material was separated by species. The wet weight for each species within each sample was measured and recorded. The raw data are provided in Appendix G.

During the 29 April 2003 sampling event six species of aquatic plants were identified Lake Musconetcong (Table 20). Eurasian watermilfoil was identified at four of the five sampling stations and was the dominant plant, in terms of biomass, at two of these stations. Curley-leaved pondweed was identified at three of the five stations and was the dominant species at two of the five stations. Both of these species are exotic species that negatively impact the fishery and wildlife value of native ecosystems. Coontail, a native species, was the dominant plant species at the remaining sampling station (Station #5). Broad-leaved pondweed, thin-leaved pondweed (*Potamogeton pectinatus*) and southern naiad were also identified on 29 April 2003.

By the time of the fishery survey was conducted in 2003, late May to early June, Eurasian watermilfoil completely infested Lake Musconetcong. The mechanical weed harvesting program, implemented by volunteers associated with the Lake Musconetcong Regional Planning Board, was initiated in mid-June. While the weed harvesting program provided relief from the milfoil, this plant was still one of the dominant species through the later part of the growing season (see below).

During the 3 July 2003 sampling event five species of aquatic plants were identified Lake Musconetcong, as well as measurable amounts of filamentous mat algae. While five species were identified on 3 July 2003, Eurasian watermilfoil and mat algae were the only macrophytes identified at four of the five stations (Table 20). The other species, which included Broad-leaved pondweed, thin-leaved pondweed, coontail and southern naiad, were only identified at Station #3 (Table 20). As described in Section 6.7, a variety of filamentous green algae were responsible for these observed algal mats.

During the 27 August 2003 sampling event five species of aquatic plants were identified Lake Musconetcong, as well as some filamentous mat algae. However, from early July to late August the amount of mat algae decline in Lake Musconetcong. Eurasian watermilfoil was the dominant species at Stations #4 and #5, while coontail was the dominant species at Stations #1 through #3 (Table 20). Broad-leaved pondweed, thin-leaved pondweed and common waterweed (*Elodea canadensis*) were also identified in the lake during the late August sampling event.

Table 20

In order to demonstrate the benefits associated with Lake Musconetcong's mechanical weed harvesting program, the total above sediment plant biomass data were graphed and displayed in Figure 11. During the late April sampling event, macrophyte biomass varied from slightly over 1,000 grams / m^2 to slightly less than 8,400 grams / m^2. While quantitative macrophyte data were not collected during the fishery survey, extremely high densities of submerged aquatic plants and associated mat algae almost entirely covered the sediments of Lake Musconetcong at that time. The community of aquatic plants was almost entirely composed of Eurasian watermilfoil.

Sometime between early June and early July, the Lake Musconetcong mechanical weed harvesting program was initiated at resulted in a substantial reduction in the amount of submerged aquatic macrophytes. With the exception of Station #3 (Mid-lake), above sediment plant biomass on 3 July was less than 100 grams / m^2 (Figure 11). In contrast, over 8,400 grams / m^2 of above sediment plant biomass was measured at Station #3. Based on these data, it is more than likely that the mid-lake portion of the lake was not yet harvested by 3 July 2003. In addition, 66% of the harvested biomass at Station #3 on 3 July 2003 was Eurasian watermilfoil.

While Eurasian watermilfoil was the dominant species at two of the five sampling stations on 27 August 2003, the degree of its dominance relative to pre-harvesting conditions was lower. Thus, harvesting a large portion of the Eurasian watermilfoil biomass early in the year, reduced the competitive edge this invasive species has on the lake. Other native species, such as coontail, had an opportunity to grow later in the summer. Coontail was the dominant species at Stations #1 through #3 on 27 August 2003. Total above the sediment plant biomass remained low in late August, varying between 240 and 380 grams / m^2 (Figure 11). The operation of the mechanical weed harvesting program through the later part of summer kept aquatic plant biomass under control.

High densities of any submerged aquatic plant can negatively impact the recreational and water quality value of a waterbody, however, exotics such as Eurasian watermilfoil and Curley-leaved pondweed particularly nuisance species due to their aggressive growth patterns and rates, as well as low fishery and wildlife value relative to other plant species such as tapegrass.

Curley-leaved pondweed can attain densities that negatively impact the recreational use of a lake, however, this species tends to bloom in the spring and dies off naturally by the early summer. This is most likely the case for Lake Musconetcong. While Curley-leaved pondweed was one of the most abundant species during the late April sampling event, by early July it was not longer identified in the lake. Since densities of Curley-leaved pondweed are on the decline by the height of the recreational season (Memorial Day weekend), no management control strategies are recommended for this species at this time.

In contrast to Curley-leaved pondweed, Eurasian watermilfoil tends to attain its maximum densities during the summer season, when recreational use of the lake is at its maximum. In addition, the ecosystem-based impacts of this exotic species were documented in 2003. Immediately prior to the initiation of the mechanical weed harvesting program, Lake Musconetcong was completely inundated with the plant. This infestation of Eurasian watermilfoil negatively impacted the rest of the aquatic plant community as well as the fishery community of the lake. Therefore, a more pro-active, in-lake strategy needs to be supplemented to the existing weed harvesting program.

Figure 11

Section 7: Restoration Plan for Lake Hopatcong

Using the findings of the updated phosphorus TMDL, the primary objective of the Restoration Plan for Lake Hopatcong is to reduce the existing annual phosphorus load of 8,097 kg (17,813 lbs) to a targeted load of 4,800 kg (10,560 lbs). This annual reduction will result in the following positive impacts:

1. Reduce the annual mean, in-lake TP concentration from 0.05 mg/L to 0.03 mg/L,

2. Reduce the growing season mean chlorophyll *a* concentrations from 15 mg/m^3 to 8 mg/m^3, and

3. Reduce the growing season maximum chlorophyll *a* concentrations from 26 mg/m^3 to 14 mg/m^3.

The net result of achieving these goals will be a reduction in the magnitude, duration and frequency of algal blooms in Lake Hopatcong. In turn, keeping algal blooms under control will favor clear water conditions and the growth of submerged aquatic plants in the shallower portions of the lake. While excessive plant densities are not a desirable condition, they are preferred over nuisance algal blooms.

The high densities of aquatic plants in Lake Hopatcong can be controlled through a number of in-lake restoration techniques, with an emphasis placed on the current mechanical weed harvesting program. Finally, to supplement the long-term control of algal blooms and foster clear water conditions, the development of a biomanipulation program should be conducted to increase the number of herbivorous zooplankton. However, additional data need to be collected on the fishery community of Lake Hopatcong in order to attain this last goal.

Section 7.1 Municipal-based Phosphorus Loads (Stormwater Loads)

The cornerstone of the Lake Hopatcong TMDL is the reduction of the existing phosphorus load to the targeted level, which will result in improvements in water quality primarily through minimizing the duration, magnitude and frequency of algal blooms. As described in detail in Section 2.0, the responsibility of reducing the existing phosphorus load to the targeted level was proportionally distributed among the municipalities; each municipality's required reduction was based on its relative contribution to the lake's annual phosphorus load. While Section 2.0 described the methodology used to determine each municipality's required reduction, this section of the Restoration Plan provides guidance for implementing measures to attained the targeted phosphorus loads. For convenience, these restoration measures were allocated on a municipal basis, similar to the required phosphorus reductions.

Prior to the development of the TMDL, a Regional NPS Pollution Control Management Plan (Coastal Environmental Services, Inc., 1995) was developed for the Upper Musconetcong River Watershed (Lake Hopatcong and Lake Musconetcong watershed combined). This study divided the watershed into 42 sub-watersheds, which were ranked from highest to lowest developed loads for five (5) NPS pollutants. Developed loads, known in the NPS report as manageable loads, are pollutant loads produced on land that is used for some type of human activity (i.e., residential, commercial, transportation, agricultural).

The twenty sub-watersheds with the highest manageable phosphorus loads were selected as phosphorus "hot spots" within the Lake Hopatcong watershed (Figure 12). In turn, the identification of locations for the installation of structural BMPs focused on these phosphorus hot spots in order to comply with the TMDL.

Using each municipality's identified required reduction in its respective annual phosphorus load originating from stormwater, a series of structural BMPs were identified for consideration. The goal of this analysis was to provide each municipality with a series of <u>suggested</u> structural BMPs to be installed within the phosphorus load hot spots as shown in Figure 12. Existing watershed constraints and conditions were used to guide the selection of the BMPs. Issues that were considered included the existence of an extensive and complex stormwater infrastructure, the fact that most of the hot spot areas are in residential / commercial areas with significant space limitations associated with the installation of structural BMPs and other natural topographic features such as steep slopes and shallow depth to bedrock.

Given the existing watershed / land use constraints, the selection of recommended BMPs for Lake Hopatcong focused on small size, retrofit BMPs (i.e., vegetative filters, bioretention, retrofitting of existing extended detention basins), rather than larger regional BMPs such as wet ponds or regional wetlands. Additionally, the BMPs considered for the restoration of Lake Hopatcong focused exclusively on those structures identified by NJDEP in the State's *Stormwater Best Management Practices Manual* (NJDEP, 2004). This provided a way of ascribing phosphorus removal efficiencies that are accepted by the State to each recommended BMP. The structural BMPs listed in the State's BMP manual were reviewed and summarized in a series of fact sheets provided in Appendix H.

Figure 12

Each fact sheet covers a particular structural BMP and includes a description of the BMP, the advantages and disadvantages associated with its installation, mean of calculating estimated costs, required maintenance activities and State-accepted pollutant removal efficiencies (Appendix H). While various manufactured devices / retrofits were included in the fact sheet database, none of these structures have State-approved phosphorus removal efficiencies at this time. However, such structures should not be avoided and should be considered under particular site-specific circumstances. For example, manufactured treatment devices / retrofits may enhance or increase the pollutant removal efficiencies of State-approved BMPs if they are installed as pre-treatment structures.

Cost estimates for the proposed BMPs are based on information provided by USEPA (2002) and by estimating the volume of runoff generated by size specific drainage areas, under specific assumptions about land use conditions (NJDEP, 2004). These cost data were used to calculate the cost associated with the design and installation of BMPs for each sub-watershed within each municipality (Appendix I). The State-approved phosphorus removal efficiencies (Appendix H) were then used to determine how much phosphorus would be removed by each installed BMP.

Based on the required reductions, as per the phosphorus TMDL, the installation of stormwater BMPs within three of the four municipalities would result in complete compliance with each respective municipality's targeted load. The exception to this was the Township of Jefferson, where approximately 66% of the annual phosphorus load originates from septic system leachate. Implementing stormwater restoration measures within the Township of Jefferson will certainly result in a partial reduction of its existing phosphorus load and produce water quality benefits. However, the phosphorus load originating from septic systems must be addressed if the Township's required phosphorus reduction is to be attained.

A substantial portion of the Borough of Hopatcong's required phosphorus reduction will be attained through its existing sewering project. However, some stormwater restoration measures are still required for complete compliance with its targeted load. Of particular concern are the sub-watersheds that surround the River Styx / Crescent Cove section of the lake (Figure 12).

One critical component that was not included in the Restoration Plan is information regarding very local, site specific, and land ownership conditions. Such information should be collected by the Lake Hopatcong Commission, municipalities and other stakeholders (i.e., private land owners, Counties, State). This Restoration Plan was developed to be reviewed, considered, modified and updated on a regular basis by the Commission and associated stakeholders in an effort to comply with the targeted loads established by the TMDL. It must be emphasized that the recommended stormwater restoration measures (Appendix H and I) are intended to serve as a guide in considering restoration actions for specific areas within the watershed. Thus, what was actually implemented may be significantly different than what is originally proposed in the TMDL Restoration Plan. However, the key will be to document these projects and ascribe phosphorus "reduction credits" to them. This documentation of the progress of the TMDL will be the responsibility of the Lake Hopatcong Commission (for details see Section 7.6).

Finally, a detailed outline of how the estimated amounts of TP removed with each recommended BMP were calculated is provided in Appendix L. Essentially, a localized application of the UAL model was used in conjunction with BMP-specific percent TP removal rates to estimate how much TP each installed BMP would remove on an annual basis. It should be emphasized that these are preliminary estimates and that stormwater monitoring should be conducted with any installed BMP to empirically quantify it capacity to remove TP on an annual basis.

TOWNSHIP OF JEFFERSON

The Township of Jefferson encompasses a total of 27,546 acres in Morris County, of which approximately 33% (9,103 acres) falls within the Lake Hopatcong watershed. Of this acreage, 906 acres drains directly to Lake Shawnee. Just over 13% (1,221 acres) of Jefferson's total watershed acreage is developed as residential housing, with 973 acres of high and medium density housing and 248 acres of rural and low density housing. Commercial businesses and light manufacturing operations also play a small but significant role in the local landscape, covering a total of approximately 132 acres (almost 2% of the watershed acreage). However, Jefferson still remains largely forested over approximately 5,287 acres (58% of the watershed acreage), a feature which greatly enhances the overall character and natural setting of the Township. The Township also includes over 1,155 acres of streams and lakes and nearly 902 acres of wetlands. Other land uses include commercial, industrial and other urban uses (including transportation, communications and utilities facilities, recreational land and athletic fields, for a total of approximately 304 acres), brush and shrubland (approximately 64 acres), and altered, disturbed and transitional lands (just under 38 acres).

To achieve the total phosphorus (TP) reduction required by the state's TMDL for Lake Hopatcong, a pollutant loading analysis was conducted for the Lake Hopatcong watershed (Section 2.0). Based on the results of this analysis, a target annual phosphorus reduction goal was developed for each municipality. For the Township of Jefferson, the total required phosphorus reduction is 1,899 kg. This total is divided between the following two drainage areas in the Township:

1. The land area draining directly to Lake Hopatcong (1,614 kg of phosphorus, of which 1,272 kg will be addressed through the an eventual extension of sewer service to areas currently served by on-site septic systems). The remaining 342 kg is associated with stormwater runoff and will be reduced through the implementation of stormwater best management practices (BMPs).

2. The land area draining to Lake Shawnee (285 kg of phosphorus, of which 171 kg will be addressed through an eventual extension of sewer service to areas currently served by on-site septic systems). The remaining 114 kg is associated with stormwater runoff and will be reduced through the implementation of stormwater BMPs.

To attain the Township's targeted phosphorus load a combination of stormwater restoration measures and sewering will be required. This section of the Restoration Plan focuses on the stormwater restoration measures, while Section 7.2 focuses on on-site wastewater and what restoration measures can be accomplished prior to the initiation of sewering within the municipality.

As shown in Figure 13, several priority areas in both the Lake Hopatcong and Lake Shawnee watersheds, within the Township of Jefferson, have been targeted for BMP installations and retrofitting of the current stormwater infrastructure (i.e. detention basins). These areas were selected because they contribute the largest amounts of stormwater-related phosphorus (Coastal Environmental Services, Inc., 1995). The following is a description of the selected priority areas, BMPs and predicted phosphorus removal levels for the Township of Jefferson.

Figure 13

Priority Area J-A. This area is located north of Nolans Point Road to Brady Park, north of Brady Bridge and out to Espanong Road. This area falls within Sub-watersheds 11, 12, 13, 14, 15, 16 and 17. To achieve the allocated 139 kg total phosphorus/year reduction in these sub-watersheds, recommended BMPs include:

PRIORITY AREA J-A		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	11	3
Sub-surface sand filter		3
Infiltration basin		4
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Bioretention system	12	2
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Bioretention system	13	2
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Retrofit existing detention basins	14	3
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Pervious paving system		4
Pervious paving system		4
Pervious paving system		4
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1

PRIORITY AREA J-A		
Sub-surface sand filter	15	2
Infiltration basin		3
Retrofit existing detention basins	16	3
Retrofit existing detention basins		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Bioretention system		2

Bioretention system		2
Pervious paving system	16	2
Pervious paving system		2
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Retrofit existing detention basins	17	2
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Pervious paving system		4
Pervious paving system		4
Pervious paving system		4
Bioretention system		2
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1

Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
TOTAL		**139**

Priority Area J-B. This area is located along the northeast shoreline of Lake Hopatcong from Sierra Road to south of Woodport (including land from the shoreline to Route 15). This area falls within Sub-watersheds 3, 4, 7 and 8. To achieve the allocated 106 kg total phosphorus/year reduction in these sub-watersheds, recommended BMPs include:

PRIORITY AREA J-B		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Wet Pond	3	10
Retrofit existing detention basins		4
Retrofit existing detention basins		3
Retrofit existing detention basins		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Retrofit existing detention basins	4	4
Retrofit existing detention basins		3
Sub-surface sand filter	4	3
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Pervious paving system		2
Bioretention systems		2
Sub-surface sand filter	7	3
Sub-surface sand filter		3
Sub-surface perimeter sand filter		1

PRIORITY AREA J-B		
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Retrofit existing detention basins	8	3
Retrofit existing detention basins		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Pervious paving system		4
Bioretention system		2
TOTAL		**106**

Priority Area J-C. This area falls mainly within sub-watersheds 1 and 5, which drain into Lake Shawnee. This area is located north of where Weldon Road joins Route 15, along West Shawnee Trail up to where Weldon Road is parallel with the shoreline road West Lakeview Trail. To achieve the allocated 57 kg total phosphorus/year reduction in sub-watersheds 1 and 5, recommended BMPs include:

PRIORITY AREA J-C		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Constructed wetlands	1	7
Wet pond		7
Retrofit existing detention basins		2
Sub-surface sand filter		2
Wet pond	5	9
Retrofit existing detention basins		3
Sub-surface sand filter		6
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
TOTAL		**57**

Priority Area J-D. This area is located along East Shawnee Trail (Lake Shawnee drainage). This area falls within the Lake Shawnee Sub-watersheds 2, 9 and 10 (and partially within Sub-watershed 6, which contributes only a minimal phosphorus load and thus is omitted here). To achieve the allocated 58 kg total phosphorus/year reduction in these sub-watersheds, recommended BMPs include:

PRIORITY AREA J-D		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Constructed wetlands	2	7
Wet pond		7
Retrofit existing detention basins		2
Sub-surface sand filter		4
Sub-surface sand filter		2
Constructed wetlands	9	9
Retrofit existing detention basins		2
Sub-surface sand filter		6
Sub-surface sand filter		3
Sub-surface sand filter		3
Infiltration basin		3
Infiltration basin		3
Sub-surface sand filter	10	3
Infiltration basin		4
TOTAL		**58**

BOROUGH OF MT. ARLINGTON

The Borough of Mt. Arlington covers 1,811 acres in Morris County, of which 65% (1,178 acres) falls within the Lake Hopatcong watershed. Approximately 34% (403 acres) of the Borough's watershed acreage is developed as residential housing, with 352 acres of high and medium density housing and nearly 51 acres of rural and low-density housing. Commercial businesses account for approximately 29 acres (2.5%) of the borough's watershed land area. Approximately 255 acres (22%) of the borough's watershed portion is forested, while wetlands account for approximately 13 acres (1%) and brush and shrubland cover almost 12 acres (just under 1%). Other land uses in the watershed portion of Mt. Arlington include other urban uses (including transportation, communications and utilities facilities, recreational land and athletic fields, for a total of about 26 acres) and altered, disturbed and transitional lands (under 6 acres).

To achieve the total phosphorus (TP) reduction required by the state's TMDL for Lake Hopatcong, a pollutant loading analysis was conducted for the Lake Hopatcong watershed. Based on the results of this analysis, a target annual phosphorus reduction goal was developed for each municipality. For the Borough of Mt. Arlington, the total required phosphorus reduction is 146 kg, which represents the amount of phosphorus associated with stormwater runoff. The required pollutant reduction will be achieved through implementation of stormwater best management practices (BMPs).

To maximize the Borough's pollutant removal efficiency and meet the target phosphorus reduction, several priority areas have been targeted for BMP installation and/or retrofit of the current stormwater infrastructure. These areas were selected because they contribute the largest amounts of stormwater-related phosphorus (Figure 14). The following is a description of the selected priority areas, BMPs and predicted phosphorus removal levels for the Borough of Mt. Arlington.

Figure 14

Priority Area M-A. This area is located along the southern side of Bertrand Island Road. However, to facilitate BMP implementation, it may be more efficient to address stormwater concerns for the entire island. This area falls within sub-watershed 26. To achieve the allocated 7 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

PRIORITY AREA M-A		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Bioretention system	26	2
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
TOTAL		**7**

Priority Area M-B. This area is located along Windermere Road, south of where it connects with Edgemere Avenue (between Arlington and Rooney). This area falls within sub-watershed 27. To achieve the allocated 19 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

PRIORITY AREA M-B		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	27	9
Infiltration basin		4
Retrofit existing detention basin		3
Pervious paving system		2
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
TOTAL		**19**

Priority Area M-C. This area includes outfall structures and streambanks of an unnamed tributary that runs parallel to Glen Avenue (just off Windermere Road). This area falls within sub-watershed 28. To achieve the allocated 21 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

PRIORITY AREA M-C		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	28	9
Infiltration basin		5
Retrofit existing detention basin		3
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
TOTAL		**21**

Several other sub-watersheds fall partially within the Borough of Mount Arlington:

Sub-watershed 29. To achieve Mount Arlington's allocated 37 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

SUB-WATERSHED 29		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	29	5
Sub-surface sand filter		3
Retrofit existing detention basin		3
Retrofit existing detention basin		3
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
TOTAL		**37**

Sub-watershed 31. To achieve Mount Arlington's allocated 33 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

SUB-WATERSHED 31		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	31	5
Sub-surface sand filter		3
Retrofit existing detention basin		3
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Bioretention system		2
TOTAL		**33**

Sub-watershed just north and east of Bertrand Island. To achieve Mount Arlington's portion of the allocated 16 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

SUB-WATERSHED NORTH AND EAST OF BERTRAND ISLAND		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	n/a	3
Retrofit existing detention basin		3
Infiltration basin		4
Bioretention system		2
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
Sub-surface perimeter sand filter		1
TOTAL		**16**

Sub-watersheds surrounding Van Every Cove and the southern section of Great Cove. To achieve Mount Arlington's portion of the allocated 17 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

SUB-WATERSHEDS SURROUNDING VAN EVERY COVE AND THE SOUTHERN SECTION OF GREAT COVE		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Infiltration basin	n/a	4
Infiltration basin		4
Sub-surface sand filter		3
Sub-surface sand filter		3
Retrofit existing detention basins		3
TOTAL		**17**

TOWNSHIP OF ROXBURY

The Township of Roxbury encompasses a total of 14,016 acres in Morris County, of which approximately 13% (1,765 acres) falls within the Lake Hopatcong watershed. A little more than 25% (443 acres) of the Township's watershed acreage is developed as residential housing, with 409 acres of high and medium density housing and nearly 34 acres of rural and low-density housing. Commercial businesses and light manufacturing operations account for approximately 81 acres (nearly 5%) of the township's watershed land area. Nearly 32 acres (1.8%) of the watershed portion of the Township is used for extractive mining. Approximately 681.5 acres (almost 39%) of the watershed portion of the Township is forested, while wetlands account for approximately 77.5 acres (4.5%) and brush and shrubland cover almost 51.5 acres (almost 3%). Other land uses in the watershed portion of Roxbury include other urban uses (including transportation, communications and utilities facilities, recreational land and athletic fields, for a total of approximately 146 acres) and altered, disturbed and transitional lands (just under 3 acres). Agricultural lands (cropland and pastureland) comprise only about 0.9 acres (0.05% of the watershed land area) in Roxbury.

To achieve the total phosphorus (TP) reduction required by the state's TMDL for Lake Hopatcong, a pollutant loading analysis was conducted for the Lake Hopatcong watershed. Based on the results of this analysis, a target annual phosphorus reduction goal was developed for each municipality. For the Township of Roxbury, the total required phosphorus reduction is 106 kg, which represents the amount of phosphorus associated with stormwater runoff. The required pollutant reduction will be achieved through implementation of stormwater best management practices (BMPs).

To maximize the Township's pollutant removal efficiency and meet the target phosphorus reduction, several priority areas have been targeted for BMP installation and/or retrofit of the current stormwater infrastructure. These areas were selected because they contribute the largest amounts of stormwater-related phosphorus (Figure 15). The following is a description of the selected priority areas, BMPs and predicted phosphorus removal levels for the Township of Roxbury.

Figure 15

Priority Area R-A. This area is located along Mt. Arlington Boulevard (from near the Mt. Arlington border southwest to below Reed Road). This segment of the road crosses Sub-watersheds 29, 30, 31 and 32. To achieve the allocated 73 kg total phosphorus/year reduction in these sub-watersheds, recommended BMPs include:

PRIORITY AREA R-A		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	29	3
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Sub-surface sand filter	30	3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
Infiltration basin	31	4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Sub-surface sand filter		3
Bioretention system		2
Infiltration basin	32	4
Pervious paving system		2
TOTAL		**73**

Priority Area R-B. This area includes Hopatcong State Park, which falls within sub-watersheds 24 and 25. To achieve the total allocated 33 kg total phosphorus/year reduction in these sub-watersheds, recommended BMPs include:

PRIORITY AREA R-B		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	24	11
Infiltration basin		4
Infiltration basin		4
Infiltration basin		4
Bioretention system		2
Pervious paving system		2
Pervious paving system		2
Sub-surface sand filter	25	4
TOTAL		**33**

Priority Area R-C. This area is located along Sunset Lane and falls within sub-watershed 30. To achieve the allocated 14 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include:

PRIORITY AREA R-C		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	30	3
Sub-surface sand filter		3
Infiltration basin		4
Infiltration basin		4
TOTAL		**14**

Priority Area R-D. This area is located along King Road and falls within sub-watershed 29. To achieve the allocated 19 kg total phosphorus/year reduction in this sub-watershed, recommended BMPs include those noted under "Priority Area R-A" above.

BOROUGH OF HOPATCONG

The Borough of Hopatcong encompasses a total of 7,898 acres in Sussex County, of which approximately 59% (4,695 acres) falls within the Lake Hopatcong watershed. Just over 36% (1,707 acres) of the Borough's watershed acreage is developed as residential housing, with 1,573 acres of high and medium density housing and 134 acres of rural and low density housing. Commercial businesses and light manufacturing operations also play a small but significant role in the local landscape, covering a total of approximately 100 acres (a little over 2% of the watershed acreage). Extractive mining is also a small but noteworthy land use in the watershed portion of the Borough, covering approximately 79 acres or almost 2% of the watershed acreage in the municipality. However, Hopatcong still remains largely forested over approximately 1,629 acres (35% of the watershed acreage), a feature which greatly enhances the overall character and natural setting of the Borough. Other land uses in the watershed portion of the Borough include other urban uses (including transportation, communications and utilities facilities, recreational land and athletic fields, for a total of approximately 99 acres), brush and shrubland (approximately 69 acres), and altered, disturbed and transitional lands (just under 30 acres).

To achieve the total phosphorus (TP) reduction required by the state's TMDL for Lake Hopatcong, a pollutant loading analysis was conducted for the Lake Hopatcong watershed. Based on the results of this analysis, a target annual phosphorus reduction goal was developed for each municipality. For the Borough of Hopatcong, the largest municipality in the watershed, the total required phosphorus reduction is 1,147 kg. However, the majority of this amount (1,077 kg) will be addressed through the extension of sewer service to areas currently served by on-site septic systems. This sewering project is currently underway. The remaining 70 kg is associated with stormwater runoff and will be reduced through implementation of stormwater best management practices (BMPs).

To maximize the Borough's pollutant removal efficiency and meet the target phosphorus reduction, several priority areas have been targeted for BMP installation and/or retrofit of the current stormwater infrastructure. These areas were selected because they contribute the largest amounts of stormwater-related phosphorus (Figure 16). The following is a description of the selected priority areas, BMPs and predicted phosphorus removal levels for the Borough of Hopatcong.

Figure 16

Priority Area H-A. This area is located near Route 607 and the Roxbury Township border, bounded by Stone Avenue, Lakeside Boulevard and Randolph Avenue. It falls mainly within sub-watersheds 22 and 23. To achieve the allocated 21 kg total phosphorus/year reduction in these sub-watersheds, recommended BMPs include:

PRIORITY AREA H-A		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	22	6
Infiltration basin		4
Bioretention system		2
Sub-surface sand filter	23	7
Bioretention system		2
TOTAL		**21**

Priority Area H-B. This area falls within sub-watersheds 20 and 21 and includes the immediate drainage discharging into the southern end of Crescent Cove. The area is bounded by Mountain Road and River Styx Road, Jefferson Trail and Lehigh Way, Brooklyn Mountain Road and Squire Road, and River Styx Road. Emphasis should be placed in the area where Crescent Road, Lakeside Boulevard and Bell Avenue intersect because of the high pollutant loading associated with this area. To achieve the allocated 29 kg total phosphorus/year reduction in sub-watersheds 20 and 21, recommended BMPs include:

PRIORITY AREA H-B		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	20	7
Bioretention system		2
Infiltration basin		4
Sub-surface sand filter	21	6
Infiltration basin		4
Bioretention system		2
Pervious paving system		4
TOTAL		**29**

Priority Area H-C. This area falls mainly within sub-watersheds 18 and 19 and includes the immediate drainage area discharging to the southern end of Byram Cove. The area is bounded by Maxim Drive, Squaw Trail and Brooklyn Mountain Road, and Rollins Trail. Emphasis should be placed on the drainage area of the small unnamed tributary (from Rocky Trail to where Maxim Drive circles the cove toward the west) because of the high pollutant loading associated with this area. To achieve the allocated 26 kg total phosphorus/year reduction in sub-watersheds 18 and 19, recommended BMPs include:

PRIORITY AREA H-C		
BMP Description	**Sub-watershed #**	**Predicted TP Removal Level (kg/year)**
Sub-surface sand filter	18	10
Sub-surface sand filter		6
Infiltration basin		4
Sub-surface sand filter	19	6
TOTAL		**26**

Section 7.2 Municipal-based Phosphorus Loads (Septic Systems)

In addition to surface runoff generated from stormwater, leachate from septic systems is another significant source of phosphorus for Lake Hopatcong. As described in Section 2.2, a well-established USEPA model was used to quantify the existing phosphorus loads originating from septic systems. Using this model, the septic-based phosphorus load was estimated at 4,233 kg per year for Lake Hopatcong. This represents 52% of the total annual phosphorus load to the lake (8,097 kg per year).

Almost all of the homes within the Borough of Mount Arlington and the Township of Roxbury are sewered so their contributions to the annual phosphorus load originating from septic systems are minimal. In contrast, the homes within the Township of Jefferson and the Borough of Hopatcong use on-site septic systems and account for the majority of the septic-based phosphorus load entering Lake Hopatcong. In fact, the refined phosphorus TMDL estimated that septic system leachate accounts for slightly over half of the annual phosphorus load entering Lake Hopatcong (Table 1).

The Township of Jefferson accounts for approximately 66% of the annual phosphorus load originating from septic system leachate. This estimate for the Township of Jefferson includes the net phosphorus load entering Lake Hopatcong from homes within the sub-watersheds immediately surrounding Lake Shawnee. The Borough of Hopatcong accounts for another 34% of the annual phosphorus originating from septic system leachate, while the Borough of Mount Arlington and the Township of Roxbury combined account for only 0.1% of the total input from septic systems.

As previously mentioned, once the sewering project within the Borough of Hopatcong is complete, the Township of Jefferson will be the sole major source of phosphorus originating from septic system leachate. Both the Township of Jefferson and the Lake Shawnee Community Association recognize that sewering of the Township will be required to ensure the long-term protection and preservation of Lake Hopatcong as a valuable recreation, ecological and economic resource for the State. Thus, the Township and Commission will continue to seek funds and program to sewer the lake communities of the Township of Jefferson.

Since sewer service for the Township of Jefferson is not expected to occur in the immediate future, the Township intends to address the existing septic system phosphorus load through alternative measures. Specifically, a septic maintenance plan is recommended as a low-cost way to address the septic system phosphorus load, using two complementary approaches: a local ordinance and a public education program.

The first element of the proposed septic maintenance plan involves the adoption of a septic maintenance ordinance by the Township of Jefferson. Regular maintenance, including routine inspections and pumpouts, is critical to the efficient long-term operation of subsurface septic systems. Without proper maintenance, septic systems may fail due to a buildup of materials ("sludge") in the tank. This causes wastewater to flow out of the tank and into the leach field too quickly, before a sufficient amount of solids have settled out. The increased concentration of solids entering the leach field can reduce soil permeability and cause the field to also fail, allowing significant concentrations of phosphorus and other nutrients to leach out into the surrounding soil (USEPA, 2001). From there, they may enter the groundwater and form a contaminated plume that can flow into local waterbodies downstream from the system. The shorter the distance between the septic system and the waterbody (e.g., lakeshore residences and those within the 330-ft (100 m) "septic zone of influence"), the higher the potential for contamination.

Although septic system failure is often accompanied by surface ponding and foul odors, phosphorus leaching may also occur without signs that are obvious to the homeowner. To ensure proper functioning, USEPA guidance recommends that septic systems should be inspected annually and pumped out every two to five years (USEPA, 2001). It is recommended that the Township of Jefferson adopt an ordinance requiring homeowners to pump their systems out once every three years. An example of such an ordinance is provided on the website of the Association of NJ Environmental Commissions (www.anjec.org). Typically, this type of ordinance establishes a program (often coordinated by the local Board of Health) wherein residents are required to obtain a license for their onsite systems (generally accompanied by a minimal license fee, ranging from approximately $5.00 to $15.00 (ANJEC, 2002). Licenses may be issued when systems are constructed or altered and when the property is sold or transferred, and may be renewed annually or during each pumpout.

As a condition of issuing or renewing a septic license, homeowners would be required to provide:

a) Proof that the septic tank has been pumped by a licensed septic sludge removal operator at least once every three years, and

b) An annual septic system inspection report (the Township may wish to develop a standard form) completed by an inspector approved by the Township (e.g., a staff member of the Board of Health, a licensed septic installer; an NJDEP-registered inspector, an NJDEP-registered waste hauler, a licensed professional engineer, health officer or sanitarian). The report should indicate that the system has been maintained, is not in need of pumping, and is functioning in conformance with all applicable requirements of the ordinance (ANJEC, 2002).

Alternatively, the Township may choose to have the Board of Health or other municipal entity perform the inspections, but this may prove to be excessively expensive and burdensome for staff. In the event of noncompliance, the ordinance could also specify penalties and fines and allow the Township to perform repairs on faulty systems and charge the costs to the homeowner.

In addition to the licensing system, the septic maintenance ordinance could provide for the distribution of educational materials to residents through mailings by the

Township. A broad array of educational materials and related information—much of it easily accessible online—is available from various public agencies and other organizations. (A list of sources is provided by USEPA (2001).) Educational materials should focus on the three main components of septic system maintenance:

1. Source reduction. Homeowners should be encouraged to decrease or eliminate the use of phosphorus-containing products (e.g., soaps, detergents, dishwashing liquids, etc.), which add to the phosphorus load in the septic system. The Township may also choose to prohibit the use of such products within the septic ordinance.

2. Water conservation. A septic system's ability to adequately renovate wastewater can be compromised if saturated soil conditions persist in the leach field. Saturated conditions can occur due to environmental factors (e.g., poorly drained soils or high water table), but can also be the result of hydraulic overloading (when the volume of effluent exceeds the leach field's capacity to dissipate it). By decreasing their water consumption, homeowners can reduce the amount of water entering the septic system and reduce the chances that the leach field will become overloaded with effluent. Water-saving strategies include installation and use of: water-saving toilets, toilet tank inserts, low-flow showerheads, on/off showerhead valves, front-loading washers and those with adjustable cycle settings and washwater recycle features, faucet aerators, hot water pipe insulation and other mechanisms. Residents should also be encouraged to adopt conservative water use habits such as not leaving the water running while soaping dishes or brushing teeth, watering lawns in the evening or early morning, checking all faucets for leaks, etc.

3. System maintenance. The benefits of proper septic system maintenance have been described above. All residents should be provided with an informational brochure or booklet describing the importance of maintaining their septic system and the requirements of the septic maintenance ordinance. In particular, residents should be advised that the cost and inconvenience of replacing a failing system far exceeds the expense of regular inspections and pumpouts. The Township should also consider sponsoring a septic system maintenance workshop for homeowners.

Although the recommended septic maintenance program is designed to reduce phosphorus loading from faulty or failing septic systems, even the adoption of a municipal ordinance cannot guarantee that every system will be inspected and maintained properly, or that all failing systems will be repaired promptly. In addition, even properly functioning systems can contribute some phosphorus to the groundwater and ultimately to Lake Hopatcong (depending on the age and condition of the system and the soil type). For this reason, the most effective means of reducing septic-based phosphorus loads to the lake is to completely eliminate the use of onsite septic systems by extending sewer service to the entire Township of Jefferson. Recognizing that this will be an expensive undertaking, it is recommended that the Township work with the Lake Hopatcong Commission to seek funding in the form of grants or low- or no-interest loans to implement the proposed sewering project. Funding sources may include USEPA, the United States Department of Agriculture (USDA) Water and Environmental Programs, the NJ Department of Community Affairs Smart Growth Planning Grants program, the National Small Flows Clearinghouse and others.

Monitoring

The model described in Section 2.2 that was used to quantify existing phosphorus loads originating from septic systems is well established and has been accepted by both USEPA and NJDEP for TMDL development. However, municipalities in the Upper Musconetcong watershed may choose to refine these estimates through on-the-ground water quality monitoring. By analyzing the amount of phosphorus present in septic system effluent, a municipality can more accurately measure how much phosphorus can be attributed to septic sources and target remediation efforts to failing systems. This can be an extremely valuable effort for several reasons. First, while even properly operating septic systems can contribute some nutrients to surface waterbodies (depending on the soil percolation rate) (Green, 2001), failing systems can contribute substantial nutrient loads. Second, research suggests that many homeowners do not perform regular inspection and maintenance of their septic systems and/or have little knowledge of where to obtain guidance on septic issues (Green, 2001; Cornell College of Human Ecology, n.d.).

As a result, while a significant number of homes may have faulty septic systems, municipalities may have little (if any) information about whether those systems are functioning properly, and little control over septic system management after initial approval of the system's installation. Because even a well-designed system can fail without proper maintenance, this means that the phosphorus loads attributed to septic sources may be significantly higher than the modeled estimates. Faulty septic systems located within the "zones of influence" near Lake Hopatcong and Lake Musconetcong may therefore be having a serious, but unquantified, impact on water quality.

If a municipality chooses to refine the modeled septic-based phosphorus loading calculations provided in this report, several methodologies exist that can be used to more accurately measure phosphorus loading from septic systems.

Septic leachate detector

A portable fluorescence-conductivity meter (a.k.a. septic leachate detector or "Septic Snooper") can be used to detect the existence of septic plumes resulting from the faulty operation of onsite wastewater disposal systems (Princeton Aqua Science, 1983).

This instrument can locate potential near-shore "hot spots" of excess nutrients, bacteria and other substances by detecting elevated electrical conductivity of lake water and fluorescent substances. Household wastes and sewage contain substances that increase conductivity, such as chlorides in waste products, or that fluoresce, such as urine breakdown products and detergents. However, these hot spots may also originate from other sources (e.g., road salt, pet and livestock wastes). The septic leachate detector cannot determine the source of a hot spot, but it can be used to prioritize sites for further water quality monitoring.

Infrared aerial analysis

Potentially failing septic systems can also be identified by means of an infrared aerial survey of the lake. Using false-color infrared imagery, the leach fields of failing systems can be detected by their more intense red hue (Princeton Aqua Science, 1983). This data can then be correlated with the results of the septic leachate detector test, as well as soil permeability / septic suitability data, to focus on unsewered areas where there is a high likelihood of septic failure. Water quality monitoring should then be conducted in these areas and compared to results from sewered areas of the lakeshore to determine the phosphorus contribution of the septic systems. This calculation can then be compared to the modeled phosphorus load estimate calculated for this study.

Groundwater sampling

Septic effluent can be sampled directly downstream of individual septic systems. Typically, piezometers are installed in a pattern that can be used to delineate the size of the phosphorus plume emanating from a septic system (Meehan, 2003). These instruments are designed to be driven into the soil in order to penetrate below the surface of the water table. Groundwater samples can then be drawn up through the piezometer and analyzed for phosphorus and other nutrients or pollutants (Welskel and Howes, 1992). Similarly, soil core samplers or augers can be used to collect soil samples for phosphorus analysis, although this method is likely to be less reflective of migrating phosphorus (Green, 2001).

Although this is the most direct method of sampling septic effluent, it may also be the most costly, based on the number of septic systems to be evaluated. This method also requires permission to access private property, which may add extra time to the planning process.

Dye Testing

To determine whether an individual septic system is malfunctioning, a fluorescent dye can be flushed down a toilet or other drain. If wastewater is seeping out of the septic tank or coming to surface of the leach field (which indicates the need for a pump-out or other maintenance or repair), the dye should appear on the surface of the ground. This type of test can be useful for identifying faulty systems, but it requires full homeowner cooperation and access to the inside of individual homes.

These suggested sampling techniques provide a means of obtaining more site-specific data on the existing septic systems, beyond the watershed approach of modeling the annual septic-based phosphorus load.

Section 7.3 Consideration of a Biomanipulation Program

The primary goal of the Restoration Plan is to comply with the refined phosphorus TMDL for Lake Hopatcong. Specifically, the existing annual phosphorus load must be reduced to a targeted annual load, to avoid or at least minimize the duration, magnitude and frequency of algal blooms in Lake Hopatcong. By lowering the amount of phosphorus entering Lake Hopatcong, algal growth will be reduced.

In spite of the strong relationship between phosphorus and freshwater algal growth, other factors contribute toward controlling the amount of algae that is generated. These include light, the availability of carbon, other inorganic nutrients, local climatic conditions, parasites and other algal diseases. Another factor that has received a considerable amount of attention over the last twenty years is herbivorous zooplankton.

Freshwater zooplankton are composed primarily of four groups of organisms: protozoa, rotifers, and two groups of crustacea, the copepods and cladocerans. A number of the large-sized copepods and cladocerans are highly herbivorous, feeding primarily on algae. These large-bodied zooplankton exert a positive impact on the overall water quality of a lake or reservoir by keeping algal densities low through grazing. Such conditions are most obvious during the late spring / early summer season in temperate waterbodies. Typically, snow melt and spring storms transport phosphorus and other nutrients to receiving waterbodies. As seasonal water temperatures increase, spring algal blooms are the result. It is common for these spring blooms to give the water a green or brownish color. It is also common for these blooms to appear and quickly disappear, producing a "clear water" phase during the late spring / early summer seasons. Such an immediate "clearing" of a lake or reservoir is associated with an increase in the population of herbivorous zooplankton.

Under such conditions, the grazing of phytoplankton by large-bodied zooplankton can be a natural means of controlling excessive algal growth. For large, deep waterbodies, this is usually accomplished by modifying the fishery community. Such a management strategy is called biomanipulation (Figure 5). Essentially, the number of zooplankton-eating fish is reduced by stocking larger gamefish. In turn, a reduction in the number of zooplankton-eating fish allows the large-bodied, herbivorous zooplankton to increase in abundance, which results in a reduction in the amount of algae.

As described in Section 6.2, a large portion of the existing phytoplankton community in Lake Hopatcong is composed of genera that are easily grazed by large-bodied, herbivorous zooplankton. Such an algal community should foster the development of a large population of herbivorous zooplankton, particularly during the late spring / early summer seasons. However, this was not the case for Lake Hopatcong; large-bodied herbivores were rare and only one moderate herbivore, *Ceriodaphnia*, was identified in moderate numbers (Section 6.3). In addition, the total lengths of the herbivorous zooplankton in Lake Hopatcong were consistently less than 1 mm. Collectively, these data indicate that the relatively low abundance of large-bodied herbivorous zooplankton may be due to a high number of zooplankton-eating fish such as alewife, golden shiners and young yellow / white perch.

If biomanipulation is considered for Lake Hopatcong, the goal would be to reduce the number of zooplankton-eating fish and allow herbivorous zooplankton to thrive and in turn naturally control excessive algal growth through grazing. However, two points must be emphasized with regard to this restoration technique:

1. The primary focus for Lake Hopatcong should be to reduce its existing phosphorus load to the targeted level, as identified in the TMDL. Biomanipulation tends to be more effective after excessive phosphorus loads are under control. Typically, biomanipulation is used to supplement a watershed-based nutrient control program. Thus, biomanipulation enhances the effectiveness of phosphorus control, particularly during the late spring / early summer season.

2. No biomanipulation measures should be implemented until a detailed, holistic assessment of the fishery community of Lake Hopatcong is completed. The Division of Fish and Wildlife and the Knee Deep Club, a pro-active, local fishing organization, have both stocked and selectively collected data on the gamefish of Lake Hopatcong. However, a large-scale, holistic fishery survey of the lake should be conducted in order to design a biomanipulation program specifically suited for Lake Hopatcong.

Depending on the amount of data collected, a reasonably holistic fishery survey for Lake Hopatcong is estimated to cost between $50,000.00 and $100,000.00. The high cost of such a survey is attributed to both the size of the lake and its complex morphometry, which produces a variety of littoral and pelagic habitats (Figure 7) for fish. A detailed fishery survey would required the collection of data from all of the major coves, bay and canals (Figure 2) in order to make a complete assessment of the fishery community.

Since fish populations are generally non-randomly distributed and clumped in response to environmental variables and habitat (USEPA, 1998), a variety of sampling methods are strongly recommended for surveying Lake Hopatcong. These include electroshocking, the use of deep-water, pelagic Otter trawls, the deployment and retrieval of gill nets and trap nets, and some selective shoreline seining.

Only after a detailed fishery survey is complete can recommendations be made on how to proceed with a biomanipulation program for Lake Hopatcong. However, based on in-house project experience and the existing scientific literature, some general points of consideration can be presented regarding potential recommendations, depending on existing conditions.

If the dominant zooplankton-eating fish are landlocked alewife (*Alosa pseudoharengus*), which specialize in feeding on zooplankton, the establishment of an aggressive, two-tiered fishery may be required. In the past, alewife has been stocked in large lakes to serve as prey for larger gamefish. However, the high feeding efficiency of alewife can result in a complete decimation of large-bodied, herbivorous zooplankton. Under such conditions, even with nutrient loading under control, algal growth can be unchecked, leading to unpleasant blooms. In order to reduce the population of alewife, as well as similar species such as gizzard shad (*Dorosoma cepedianum*) and golden shiners (*Notemigonus crysoleucas*), two gamefish species have been used in other large, deep northern New Jersey lakes. These species include hybrid striped bass and brown trout.

Hybrid striped bass are a hybrid of striped bass (*Morone saxatilis*) and white bass (*Morone chrysops*). They are large, open water piscivores, which prey mainly upon smaller, zooplanktivorous fish species (e.g., gizzard shad, golden shiner). Due to their large size, they are able to feed on prey that are not easily consumed by other piscivorous fish (e.g., largemouth bass) due to their size. Hybrid striped bass tend to grow quickly and are relatively long-lived (five- to seven-year lifespan), making them effective predators over a number of years.

Brown trout (*Salmo trutta*) are native to Europe and western Asia and were originally stocked in U.S. waters in the late 1880s. They are now common throughout the United States and Canada. Like all trout, brown trout are a cold water species and have higher requirements in terms of water quality. However, relative to other trout species they are fairly robust. The optimal temperature for brown trout is between 20 and 26^{o}C, while for other trout species temperatures should be less than 20^{o}C (USEPA, 1993). Like all trout, dissolved oxygen concentration should be equal to or greater than 5 mg/L for optimal conditions.

Given the depth and morphometry of Lake Hopatcong, "holdover"' brown trout habitat persists in the mid-depths of the lake through the summer season. While the size of this holdover habitat varies depending on climatic conditions, it is sufficient to allow brown trout to survive in Lake Hopatcong through the summer season. Anecdotal fishery information collected by the Knee Deep Club provides evidence of such holdover brown trout.

If alewife or similar species are the dominant nuisance species responsible for the low abundance of herbivorous zooplankton in Lake Hopatcong, a two-tiered game fishery, with hybrid striped bass in the surface waters and brown trout in the mid-depth holdover waters, would exert a substantial level of predation on zooplanktivorous fishes. Such an approach has been used in Culver Lake, New Jersey. The establishment of a two-tiered fishery, subsequently coupled with direct stocking of herbivorous zooplankton, resulted in a recovery of herbivorous zooplankton in Culver Lake. A similar biomanipulation program may be applicable in Lake Hopatcong, if the zooplanktivorous species of concern are alewife or a similar species.

It is possible that the primary zooplankton-eating species of concern are young-of-the-year yellow perch (*Perca flavescens*) and/or white perch (*Morone americana*). These young fish are known to heavily graze on zooplankton, which can result in a decline in water quality in the form of algal blooms (Cooke, et al., 1993). If this is the case in Lake Hopatcong, a biomanipulation program should consider walleye (*Stizostedion vitreum*) for the control of the high densities of perch. While walleye are currently stocked in Lake Hopatcong, the existing population may not be abundant enough to keep young perch numbers under control, assuming that that young perch are the species of concern.

Finally, if excessive densities of various species of panfish, such as bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*), appear to impact near-shore densities of zooplankton, a combination of public panfish fishing derbies, coupled with possibly stocking the littoral area with largemouth bass (*Micropterus salmoides*), may be required. Again, the development and design of a biomanipulation program for Lake Hopatcong will be highly dependent on the results of a detailed fishery survey.

In conclusion, given the relatively low abundance of large-bodied, herbivorous zooplankton in Lake Hopatcong, the potential implementation of a biomanipulation program should be serious considered. However, the primary restoration / management focus should still remain on controlling the watershed-based phosphorus loads. Biomanipulation should be considered as a supplemental management measure for Lake Hopatcong. In addition, the implementation of a biomanipulation program should be not undertaken until a detailed and holistic fishery survey is completed on the lake.

Obviously, stocking the lake for recreational purposes should continue in order to perpetuate the high recreational value associated with fishing at Lake Hopatcong. However, if biomanipulation is seriously considered for the lake, some site-specific fishery data need to be collected and reviewed to develop the most effective biomanipulation program.

Section 7.4 Aquatic Plant Management

Sixteen species of aquatic macrophytes were identified in Lake Hopatcong during the 2003 monitoring program, with two of the most abundant plants being the exotic species Eurasian watermilfoil and the native species tapegrass. The benthic macro-alga *Lyngbya* was also fairly abundant, particularly in the shallow to moderately deep sections of the northern end of the lake.

Different species tend to bloom in different times of year at different areas of the lake. Species composition, distribution and the amount of macrophyte biomass also vary, based on local climatic conditions. For example, based on aquatic plant harvesting data collected by the Lake Hopatcong Commission over the last 3-4 years, more aquatic macrophyte biomass is available for mechanical weed harvesting during a dry and hot growing season than during a wet and cool growing season.

Given the complexity and diversity associated with the macrophyte community of Lake Hopatcong, mechanical weed harvesting is the most effective means of controlling excessive growth of submerged vegetation. It must be emphasized that the high degree of effectiveness is a result of the community-wide benefits associated with mechanical weed harvesting. In contrast, other aquatic macrophyte management techniques tend to control only one part or portion of the whole macrophyte community. For example, tapegrass, which is already one of the most common species in Lake Hopatcong, is relatively tolerant of the aquatic herbicides that are available for use in New Jersey. Therefore, a large-scale chemical treatment program in Lake Hopatcong could result in excessive densities of tapegrass.

Periodic drawdowns may provide some additional control of rooted aquatic plants. However, the effectiveness of this technique is strongly dependent on having an extremely cold winter with very little snow. Also, some plant species actually thrive under frequent drawdowns due to reduced competition. While drawdown is certainly a viable management technique that should be more critically reviewed and considered for Lake Hopatcong, it will not completely eliminate nuisance densities of rooted aquatic plants.

The primary reason for conducting mechanical weed harvesting is to reduce aquatic plant densities and enhance the recreational value and use of Lake Hopatcong. However, another benefit of mechanical weed harvesting is that it also removes plant biomass and associated phosphorus from the lake. Thus, mechanical weed harvesting can actually function as a restoration measure that contributes toward attaining the targeted phosphorus levels established in the TMDL.

In order to determine how much phosphorus is removed from Lake Hopatcong as a result of mechanical weed harvesting, the Lake Hopatcong Commission will conduct some additional sampling in 2005 or 2006. Specifically, samples of aquatic plants throughout the lake will be collected, dried and digested to determine the amount of phosphorus in their tissues. In conjunction with the data collected as part of the weed harvesting program, the amount of phosphorus removed from the lake through this in-lake activity will be quantified and compared to the targeted phosphorus loads established under the TMDL.

Finally, mechanical weed harvesting can also benefit the lake's fishery by providing ecotones or transitional boundaries between stands of submerged aquatic vegetation and open water. Many species of fish, particularly largemouth bass, are better adapted to living and feeding in ecotone habitats. Thus, opening up a weed-infested cove with mechanical weed harvesting can enhance its recreational value. Additionally, such ecotone habitat may also enhance the effectiveness of biomanipulation by allowing piscivorous fish easier access to prey. Given the recreational and ecological benefits, as well as the phosphorus-reducing potential, of mechanical weed harvesting, this in-lake restoration technique will continue to be implemented in Lake Hopatcong.

Section 7.5 Public Awareness

As part of this project, Princeton Hydro provided technical assistance for public awareness and targeted education efforts to the stakeholders within the Musconetcong River watershed. A set of four topics were identified for the TMDL Public Awareness program, which included the management and value of clear water ecosystems, plant diversity, the control and management of exotic / invasive plant species, and measures of consideration for municipal stormwater management programs. A fifth topic was identified for the public awareness program, which was what the lake user can do to contribute toward reducing the lake's existing phosphorus load.

An set of educational handouts / brochures was developed to explain in layperson's terms how the five Public Awareness topics impact the water quality of Lake Hopatcong. The complete set of this educational literature is provided in Appendix J. The Lake Hopatcong Commission, the Lake Musconetcong Regional Planning Board, all seven municipalities within the Upper Musconetcong River watershed and the two Counties will be provided with digital copies of these handouts for distribution. The goal is to educate the stakeholders within the Upper Musconetcong River watershed on both general lake ecology and management, as well as what can be done on a local level to reduce the existing phosphorus and other NPS pollutants loads entering Lake Hopatcong and Lake Musconetcong.

As part of this Public Awareness program, a number of public presentations / workshops have been or will be conducted. In 2004, Princeton Hydro attended two public events, provided ecological workshops on aquatic ecology and distributed some of the handouts and brochures. The first public presentation was on 13 June 2004 at Netcong Day / Save the Lake Day and the second was on 19 September 2004 at the Stanhope Day event.

Princeton Hydro also gave a brief presentation on the findings of the phosphorus TMDL at a stormwater meeting hosted by the Lake Hopatcong Commission on 14 January 2004. Attendees at the meeting included representatives from the four municipalities within the Lake Hopatcong watershed, the two Counties and NJDEP. In addition, in 2005 Princeton Hydro will give another set of presentations on the Public Awareness topics, with an emphasis placed on aquatic plants and invasive species.

Both the Lake Hopatcong Commission and the Lake Musconetcong Regional Planning Board should continue to serve as stewards of Lake Hopatcong and Lake Musconetcong, respectively. In this role, each organization should strive to educate and inform their respective watershed stakeholders on what can be accomplished from both an individual and community-based perspective to protect and preserve these valuable aquatic resources. Distributing educational material, hosting public meetings and workshops and giving presentations to various organizations are some of the methods that should be used on a frequent basis to generate long-term support for attaining the goals of each lake's TMDL.

Section 7.6 Future Implementation and Documentation of the Lake Hopatcong TMDL

This document refined and updated the phosphorus TMDL that was originally developed by NJDEP in early 2004. In turn, the refined phosphorus TMDL was used to provide specific restoration measures that focus on reducing the existing phosphorus loads to targeted levels and on a municipal basis. In-lake management techniques, such as biomanipulation and the management of the aquatic macrophyte community, were also considered as part of the Lake Hopatcong phosphorus TMDL. With the TMDL and Restoration Plan complete, the next phase of this long-term process is to focus on implementing the resulting recommendations.

The Lake Hopatcong Commission is a State-appointed organization that serves as the steward of Lake Hopatcong. As such, the Commission will be the primary organization responsible for complying with the Lake Hopatcong phosphorus TMDL. Specifically, this will include working with all stakeholders (local groups, municipalities, Counties, State, etc.) to implement the various restoration measures outlined in the TMDL, with a particular emphasis on watershed-based management activities. Another responsibility of the Commission will include documenting the status of the various restoration projects and tracking the annual phosphorus load as efforts are made to attain the targeted loads. Other responsibilities include seeking funding for the implementation of the various restoration measures and continually educating and updating the stakeholders on the progress made with the TMDL.

To ensure that a cooperative and communicative relationship is well established between the Lake Hopatcong Commission and the other stakeholders regarding the status of the phosphorus TMDL, all interested and participating parties will meet twice a year to discuss the long-term progress made on the TMDL. These meetings will be held in January / February and July / August of each year and hosted by the Commission. At those meetings, the Commission will made a formal presentation on the status of the TMDL. Each stakeholder will then report on projects / efforts that have been conducted to date toward the TMDL. A summary of the progress made (i.e., efforts in support of reducing the existing phosphorus loads) will be distributed to all stakeholders approximately one week after each meeting.

This arrangement, where the Lake Hopatcong Commission will be the primary organization tracking TMDL progress, will be the most efficient means of attaining the goals set forth in the TMDL. The municipalities and Counties will be extremely busy with regard to developing, complying and/or reviewing the Municipal Stormwater Management Plans (N.J.A.C. 7:14A). However, many of the efforts associated with these plans will contribute toward complying with the targeted TMDL phosphorus load and must be documented to receive credit, which will be the Commission's role. Concurrently, much of the work that will be accomplished by the Commission toward compliance with the TMDL can be utilized by the municipalities in addressing many of the requirements outlined in their municipal plans. Thus, another goal of the semi-annual meetings concerning the TMDL will be an exchange of information among the various stakeholders who have an interest in the preservation and protection of Lake Hopatcong.

Section 8: Restoration Plan for Lake Musconetcong

Since 67% of the annual phosphorus load entering Lake Musconetcong originates from Lake Hopatcong, the most effective watershed-based strategy for Lake Musconetcong, in terms of reducing its phosphorus load, is to support efforts that reduce Lake Hopatcong's annual phosphorus load. However, as outlined in its TMDL (Section 3.0), the annual phosphorus load originating from the immediate drainage basin for Lake Musconetcong also needs to be reduced by 296 kg in order to achieve its targeted phosphorus load.

Based on the findings of the updated phosphorus TMDL, one of the two main objectives of the Restoration Plan for Lake Musconetcong is to reduce its existing annual phosphorus load of 3,486 kg (7,669 lbs) to a targeted load of 2,200 kg (4,840 lbs). This annual reduction will result in the following positive impacts:

1. Reduce the annual mean, in-lake TP concentration from 0.048 mg/L to 0.030 mg/L,

2. Reduce the growing season mean chlorophyll *a* concentrations from 16 mg/m^3 to 9 mg/m^3, and

3. Reduce the growing season maximum chlorophyll *a* concentrations from 31 mg/m^3 to 14 mg/m^3.

The net result of achieving these goals will be a reduction in the magnitude, duration and frequency of algal blooms in Lake Musconetcong. In turn, keeping algal blooms under control will allow Lake Musconetcong to remain in its existing clear water state, which favors the growth of submerged aquatic plants. This leads to the second main objective of the Lake Musconetcong Restoration Plan, which is to avoid or at least minimize nuisance densities of submerged aquatic vegetation. The specific goal of this objective is to eliminate the exotic, invasive species Eurasian watermilfoil from Lake Musconetcong, while managing the native aquatic vegetation so it does not attain nuisance densities. As described below, a variety of in-lake restoration techniques are being proposed to address the nuisance plant densities in Lake Musconetcong, which include the use of a systematic herbicide, the continued use of the mechanical weed harvesting program, and the dredging of the lake.

Section 8.1 Municipal-based Phosphorus Loads (Septic Systems)

Unlike the Lake Hopatcong watershed, the majority of the communities within the immediate watershed of Lake Musconetcong are sewered. The exception to this is the Borough of Hopatcong. While this Borough does not have lakefront property, it does account for half of the 296 kg of phosphorus targeted for reduction under the Lake Musconetcong TMDL (Table 7).

The Borough of Hopatcong is currently in the process of sewering a significant portion of its homes, including 114 homes located within the immediate watershed of Lake Musconetcong. Sewering these homes will result in removing 149 kg of phosphorus from Lake Musconetcong's annual phosphorus load. Since the Borough of Hopatcong's required reduction for Lake Musconetcong's annual phosphorus load is 148 kg of phosphorus per year, sewering the 114 homes will address their contributing load. Thus, once the sewering project is complete, the remaining 147 kg of phosphorus targeted for reduction will be addressed through stormwater BMP projects conducted in the Borough of Netcong, the Township of Roxbury and the Borough of Stanhope.

Section 8.2 Municipal-based Phosphorus Loads (Stormwater Loads)

As described in Section 3.7, given the relatively small size of the immediate watershed for Lake Musconetcong, as well as the amount of annual phosphorus targeted for reduction, a detailed sub-watershed analysis was not conducted to prioritize the stormwater projects. Many of the selected and prioritized stormwater projects were already identified as part of the Phase I Diagnostic / Feasibility study (Coastal Environmental Services, Inc., 1993). Additional recommendations were based on the known availability of public land for the installation of structural BMPs and retrofits designed to reduce existing phosphorus loads.

As previously stated, after the sewering project is complete for the Borough of Hopatcong, the required reduction of the stormwater phosphorus load originating from Borough of Netcong, the Township of Roxbury and the Borough of Stanhope totals 147 kg. The methodology used to select BMPs and determine the amount of phosphorus they will remove and the associated costs of implementing these BMPs for the immediate watershed of Lake Musconetcong was similar to that described in Section 7.1 and Appendices H and I.

The remaining 147 kg of phosphorus targeted for reduction within the immediate watershed of Lake Musconetcong was proportionally divided as identified in Table 7 in Section 3.7, where the required reductions for each of the three municipalities are 38 kg for the Borough of Netcong, 38 kg for the Borough of Stanhope and 71 kg for the Township of Roxbury. The proposed BMPs, their estimated phosphorus reductions and associated costs for each municipality are provided in Appendix K. Described below are "hot spot" areas that the Lake Musconetcong Regional Planning Board should focus on for future stormwater implementation projects. It should be emphasized that given the dominance of residential land within the immediate watershed of Lake Musconetcong, phosphorus removal and cost estimates focused primarily on single-family residential land with 40% impervious cover.

Finally, as was provided for Lake Hopatcong in Section 7.1, a detailed outline of how the estimated amounts of TP removed with each recommended BMP were calculated is provided in Appendix L. Essentially, a localized application of the UAL model was used in conjunction with BMP-specific percent TP removal rates to estimate how much TP each installed BMP would remove on an annual basis. It should be emphasized that these are preliminary estimates and that stormwater monitoring should be conducted with any installed BMP to empirically quantify it capacity to remove TP on an annual basis.

Borough of Netcong

Two hot spots or areas of interest for the installation of various structural BMPs in the Borough of Netcong include the Musconetcong State Park and Arbolino Park. Beyond these two public parks, additional BMP installations should focus on the residential roadways within the Borough. For convenience, some BMP projects are proposed and outlined for the hot spot areas of each municipality. It is recommended that these sites be prioritized over other areas for stormwater BMP implementation projects, due to their accessibility and public ownership.

Musconetcong State Park. This park is located in the Borough of Netcong, near the lake's spillway. A drainage swale adjacent to the park is known to discharge stormwater runoff and associated pollutants to the lake at a point close to the park's boat launch (Coastal Environmental Services, Inc., 1993). Because this swale receives runoff from some of the more intensively developed areas of the watershed, this runoff tends to have high sediment and petroleum hydrocarbon loads. In order to reduce the phosphorus load (a large portion of which is adsorbed onto soil particles) entering the lake via runoff from this swale, it is recommended that the existing swale be upgraded to function as a vegetative filter. In addition, a pocket wetland is recommended for installation near the lake's shore, coupled with the installation of a series of sand filters.

Based on conversations with the Lake Musconetcong Regional Planning Board (LMRPB) some type of restoration / BMP project is scheduled to be conducted by the State at the Musconetcong State Park sometime in the near future. Therefore, this site is not a high priority for implementation by the LMRPB.

Arbolino Park. This park is also located in the Borough of Netcong. Runoff from a drainage swale adjacent to the park has been found to contain high nitrate concentrations and sediment loads (Coastal Environmental Services, Inc., 1993). In order to reduce the phosphorus load (again, a portion of which is adsorbed onto soil particles) entering the lake via runoff from this swale, it is recommended that the existing swale be converted to a type of BMP that provides stormwater treatment. In addition, a series of infiltration basins and sand filters throughout the drainage basin would also contribute toward reducing the phosphorus load entering the lake through the park.

Recent sites visits to Arbolino Park indicate that the existing swale and associated banks are relatively stable and highly vegetated. Thus, any further augmentation of the swale does not seem necessary. However, a series of structural BMPs, strategically installed immediately upstream of the swale, would contribute toward a substantial reduction in the TP and TSS loads that Lake Musconetcong from this sub-watershed. Two such site-specific projects are described.

The first proposed site is along Allen Street, directly across from Arbolino Park. There is an open ditch within a parking lot at this site, where three stormwater pipes converge prior to discharge to the Arbolino Park swale. Either at or immediately upstream of this location a large, underground structural BMP could be installed, such as a sand filter or Aqua-Filter. More than likely, easements will to be obtained for access to the site.

The second proposed site is located immediately upstream of Allen Street, along Railroad Avenue, just below of Netcong Heights. Similar to the Allen Street site, there may be the potential to install a large structural BMP underground, preferably under a municipal or County road, retrofitted into the existing stormwater infrastructure.

Netcong Heights. This section of Netcong Borough is located at the southeastern end of Lake Musconetcong. This area has been identified as a priority because of the significant sediment and particulate pollutant loads originating from nearby Route 46. In order to reduce the phosphorus load entering the lake via runoff from this area, the installation of a "pocket" wetland is recommended, along with a set of sand filters and/or infiltration basins.

While there is some space for the possible installation of type of larger structural BMP, it is understood that the State Department of Transportation (DOT) is working on a stormwater infrastructure project that will direct a large portion of the runoff that normally entering Lake Musconetcong from Route 46 away from the lake. Therefore, it is recommended that the LMRPB contract the State DOT to find out what type of stormwater technology is being utilized for the Route 46 project. If a portion of the runoff still enters Lake Musconetcong some additional stormwater project may be required.

Borough of Stanhope

For the Borough of Stanhope, the hot spot of prioritized activity includes several drainage areas along Musconetcong Avenue.

Musconetcong Avenue. This road is located in the Borough of Stanhope and runs along Lake Musconetcong's southwestern shoreline. A priority area has been identified where Musconetcong Avenue meets the base of Maple Terrace. A small drainageway, which is responsible for an influx of sediment and particulate pollutants to the lake, is located at this site (Coastal Environmental Services, Inc., 1993). In order to reduce the phosphorus load entering the lake via runoff from this drainageway, replacement of the existing drainageway with bioretention and vegetative filters is recommended.

In addition, there is the potential to install a larger, underground structure, such as a sand filter or Aqua-Filter, somewhere along Maple Terrace, prior to the runoff being intercepted along Musconetcong Avenue.

Some type of large, underground BMP structure may also be installed along Walton Road, which runs parallel to the lake. Some additional restoration efforts, which may include a combination of wetland augmentation (i.e. micro-pool habitat) and structural BMP installations, should be considered for where Coursen Street and Port Morris Road merge. It should be noted this is a critical site of access for the mechanical weed harvesting equipment.

Township of Roxbury

Targeted areas for the Township of Roxbury include the drainage areas surrounding Route 46 and Port Morris Park.

Route 46. This State road runs through the Borough of Netcong and the Township of Roxbury. A series of perimeter sand filters, coupled with vegetative filters and bioretention system to remove the particulates prior to entering the sand filters, could substantially reduce the phosphorus loads generated from Route 46.

As previously mentioned, the State DOT maybe diverting a large portion of the runoff generated along Route 46 away from Lake Musconetcong. Therefore, a stormwater BMP project may not be needed at this site, at least under the State's project is complete.

Port Morris Park. A substantial portion of the runoff with the Township of Roxbury's section of the Lake Musconetcong watershed enters the lake through Port Morris Park and adjacent shoreline areas. Compared to other sections of the immediate watershed, the Port Morris Park and upland areas are not as heavily developed for residential use. Thus, the majority of the BMP installations for this section of the immediate watershed focus on larger BMPs that rely on vegetation for stormwater treatment (i.e., vegetative filter strips and pocket wetlands).

Section 8.3 Aquatic Plant Management

In sharp contrast to the Lake Hopatcong Restoration Plan, the highest priority objective of the Lake Musconetcong Restoration Plan is not reducing its annual phosphorus load. As previously identified, 67% of the annual phosphorus load entering Lake Musconetcong originates from the outflow of Lake Hopatcong. Therefore, efforts to reduce the annual phosphorus load entering Lake Hopatcong will provide a direct benefit to Lake Musconetcong, as well as the entire Musconetcong River watershed. The highest priority objective for the Lake Musconetcong Restoration Plan is to eliminate the invasive species Eurasian watermilfoil (*Myriophyllum spicatum*) and control the growth of the native aquatic plant species.

As previously described, the dominant nuisance water quality condition experienced in Lake Musconetcong is excessive densities of rooted aquatic plants. In particular, the invasive species Eurasian watermilfoil was the dominant nuisance plant in Lake Musconetcong (see Section 6.10). As an invasive species, Eurasian watermilfoil easily attains nuisance densities, while at the same time having little or no wildlife / fishery value. The extremely "stunted" largemouth bass fishery provided evidence as to the negative impact Eurasian watermilfoil has had on Lake Musconetcong's fishery.

Currently, mechanical weed harvesting is used to manage the excessive densities of submerged vegetation in Lake Musconetcong. As the 2003 ecological database revealed, Eurasian watermilfoil was by far the dominant plant species in Lake Musconetcong prior to the initiation of the weed harvesting program in mid-June of 2003. The mechanical weed harvesting substantially reduced the amount of aquatic macrophyte biomass in the lake and also reduced the relative dominance of Eurasian watermilfoil. While Eurasian watermilfoil was still one of the most common species during the August sampling event, coontail was gaining dominance in Lake Musconetcong at this time. Thus, mechanical weed harvesting provides relief from excessive densities of submerged aquatic plants; however, it does not have the potential to completely eliminate the invasive species Eurasian watermilfoil.

Given the "stranglehold" Eurasian watermilfoil has on Lake Musconetcong, it is recommended that a systemic herbicide be used to eliminate this invasive plant. Subsequent to this, mechanical weed harvesting would be used to keep native plant densities under control. As explained in detail below, the long-term aquatic plant control strategy for Lake Musconetcong is to eliminate the invasive species and control the natives.

In contrast to contact herbicides, a systemic herbicide affects the targeted plant internally instead of externally. That is, uptake of the chemical disrupts biochemical functions, thereby killing the plant. One systemic herbicide approved for use in New Jersey is Sonar[R], with the active ingredient fluridone.

Sonar^R is assimilated through the roots and into the plant tissue early in the growing season. There it begins to disrupt the production of chlorophyll pigments, which are used in photosynthesis. This effectively "starves" the plant and it dies. In contrast, contact herbicides "burn" the plant tissue from the outside.

Sonar^R has several advantages over contact herbicides. First, contact herbicides typically require multiple applications (between two and four) through the course of one growing season to obtain an acceptable level of control. In contrast, if properly timed and executed, one systemic treatment can result in an entire year of control. In some cases (particularly in the case of milfoil), two or three years of control may be realized with Sonar^R. Thus, while Sonar^R is an expensive product, the reduced level of required treatments still makes it cost effective relative to contact herbicides.

While contact herbicides need to be applied to lakes when there is a sufficient amount of plant biomass to react to the chemical, Sonar^R is best applied in the spring, when seasonal growth rates are high. This treatment strategy effectively eliminates the possibility of fish kills that are the result of a depletion of DO from the bacterial decomposition of plant biomass. Other advantages Sonar^R has over contact herbicides include its extremely low toxicity on non-target organisms, its ability to control certain nuisance species with varying concentrations, and its ability to break down quickly in the open waters of a lake (i.e., it does not accumulate in the sediments or aquatic organisms).

One disadvantage of Sonar^R is that it is a slow-acting herbicide, which requires a minimum of 30 days to manifest some observable degree of plant control. Since Sonar^R is slow acting, targeted control concentrations must be sustained over the course of at least a month. This means outflow from the lake must be eliminated, or at least minimized, for at least 30 days after Sonar^R is added to the lake. In some cases, a partial drawdown may be required early in the spring to ensure that the targeted level of fluridone is sustained over the 30-day period. Such conditions have the potential to impact recreational use later in the growing season if sufficient precipitation is not received to restore the lake to its natural water level.

In the case of Lake Musconetcong, a partial drawdown is not recommended for the application of Sonar^R. Instead, an alterative approach is recommended, where the Sonar^R treatment program would be divided into a series of sub-treatments over the course of the treatment period. Water samples would be periodically collected and analyzed for fluridone to maintain the targeted concentrations over the course of 30 days. In addition, a time-released, granular version of Sonar^R could be used instead of the liquid product to maintain a more consistent in-lake concentration under various weather conditions. This approach would require an additional level of planning and monitoring, but such efforts would maximize the desired level of Eurasian watermilfoil control.

Another disadvantage of Sonar^R is its impact on terrestrial vegetation such as grass and shrubs. While there are no recreational contact restrictions associated with Sonar^R, there is an irrigation restriction since fluridone can kill terrestrial plants.

Therefore, any local residents using lakewater to irrigate their lawns or gardens run the risk of killing their vegetation. In order to avoid this a very pro-active public awareness campaign would have to be implemented by the Lake Musconetcong Regional Planning Board prior to any implementation of a Sonar^R treatment program.

In spite of the disadvantages associated with Sonar^R, it has the potential to eliminate or at least substantially reduce Eurasian watermilfoil. The targeted concentrations for the control of Eurasian watermilfoil with Sonar^R is low, ranging between 5 and 10 ppb of the active ingredient fluridone. This targeted concentration is low enough to avoid impacting many native species of plants. In fact, some desirable native species, such as tapegrass, cannot be controlled with Sonar^R. Thus, designing the proposed Sonar^R treatment program to control Eurasian watermilfoil would not substantially impact the desirable native plant species. In turn, mechanical weed harvesting would be used to control excessive densities of the native species.

Given a surface area of 329 acres and an annual flushing rate of approximately 24 times per day, the following recommendations are made for a Eurasian watermilfoil eradiation / control program for Lake Musconetcong:

1. The goal of the Sonar^R treatment program is to maintain a fluridone concentration between 5 and 10 ppb for approximately 60 days. Therefore, if the treatment program is initiated in early May, it should be completed by early July.

2. With a flushing rate of approximately twice a month, a combination of liquid and solid product should be used for the treatment. The liquid product should be used to establish an initial concentration of 10 ppb.

3. Approximately 21 days after the initial application, the fluridone concentration should be maintained at 5 ppb, while approximately 45 days after the initial application the fluridone concentration should be maintained at 3-5 ppb. The solid, slow-release product is recommended for these maintenance treatments.

4. Four sampling stations should be established throughout Lake Musconetcong for FasTEST analysis. Water samples will be collected five times over the 60-day treatment period for FasTEST analyses, which measure the amount of fluridone in the water. This analysis program will provide a proactive means of determining when to conduct the second and third sub-treatments to ensure that the fluridone remains within the targeted concentrations through the 60-day treatment period.

5. An aquatic macrophytes monitoring program should also be implemented before, during and immediately subsequent to the Sonar^R treatment program. The exact scope of the program will depend on the level of detail thought necessary to appropriately document the effectiveness of the treatment program. However, at a minimum, a monitoring program similar to the one conducted as part of the lake's TMDL Restoration Plan (see Section 6.10) should be implemented. The

program should include at least one monitoring event prior to the initiation of the treatment program, two to three events during the treatment program and at least two more after the treatment program is complete.

Based on the details provided above, the estimated cost to implement the proposed Sonar^R treatment program to eradiate Eurasian watermilfoil in Lake Musconetcong is between \$42,000.00 and \$45,000.00, depending on the scope of the associated aquatic macrophytes monitoring program.

Under optimal climatic conditions, an appropriately conducted Sonar^R treatment program could completely eradiate the Eurasian watermilfoil in Lake Musconetcong. Since the targeted concentrations of fluridone are high enough to control only Eurasian watermilfoil, the goal of this restoration measure is to shift the submerged, rooted plant dominance in Lake Musconetcong to native plant species. Excessive densities of native plant species would then be managed through the implementation of the mechanical weed harvesting program overseen by the Lake Musconetcong Regional Planning Board.

Depending on climatic conditions during the implementation of the Sonar^R treatment program, between one to three years of substantial Eurasian watermilfoil control is predicted for Lake Musconetcong. If the watermilfoil recovers and re-establishes in Lake Musconetcong, it may take another one to two years for the invasive species to attain pre-treatment densities. Thus, the implementation of one Sonar^R treatment program is expected to have an effective duration of two to five years in Lake Musconetcong. However, additional measures can be implemented to maximize the duration of effectiveness of the Sonar^R treatment program (see below).

Lake Hopatcong is immediately upstream of Lake Musconetcong and is documented to contain Eurasian watermilfoil, although not at the extreme dominance and densities experienced in Lake Musconetcong. Thus, "floaters" from Lake Hopatcong have the potential to make their way downstream and into Lake Musconetcong. In addition, since Lake Musconetcong is a popular public waterbody for recreational use, boats and trailers and put into the lake on a daily basis during the growing season. These boats and trailers may be another source of Eurasian watermilfoil fragments to re-infest Lake Musconetcong. Given these complicating issues, to minimize the re-establishment of Eurasian watermilfoil in Lake Musconetcong:

1. As part of the yearly mechanical weed harvesting program, the harvester operators should be trained to recognize and properly identify Eurasian watermilfoil. The earlier Eurasian watermilfoil is detected in the lake, the easier it is to remove and manage. It is more cost-effective to remove floating fragments and/or isolated patches of the plant, rather than wait for it to develop into an ecosystem-wide problem. Such a proactive strategy would also extend the duration of effectiveness of the Sonar^R treatment program for an undetermined period of time.

2. Aggressive public awareness programs should be targeted residents and visitors of both Lake Hopatcong and Lake Musconetcong on the identification of Eurasian watermilfoil and the importance of removing all plant material from a boat or trailer before placing it into a waterbody (for more details see Section 8.5).

3. If larger, isolated patches of Eurasian watermilfoil are detected in some select locations of Lake Musconetcong (for example, in a cove or bay) a localized treatment of Sonar^{R} could be conducted with the solid product. Depending upon the site-specific conditions, such a treatment approach may be feasible and would certainly be substantially lower in cost than a whole-lake application.

In conclusion, the most cost-effective, long-term and ecologically beneficial approach toward addressing the excessive aquatic plant densities in Lake Musconetcong is to eliminate the dominance of the invasive, exotic species Eurasian watermilfoil in the lake by conducting a whole-lake Sonar^{R} treatment program. This systemic herbicide treatment program should be conducted at a low enough concentration to control the watermilfoil but not impact the desirable native aquatic vegetation. Subsequent to the Sonar^{R} treatment program, the local communities should utilize their existing mechanical weed harvesting equipment and program to keep the native aquatic vegetation under control, enough to support a vial and healthy shallow lake ecosystem, while at the same time removing enough plant biomass to maximize the recreational use of the lake.

Coupled with this proposed aquatic plant management program should be a proactive Public Awareness campaign that educates residents and visitors of both Lake Musconetcong and Lake Hopatcong on how to properly identify and address the presence of Eurasian watermilfoil. Such a campaign should focus specifically on in-lake monitoring for plant fragments and isolated patches, as well as providing information on identification and removal of plant fragments from boats and trailers.

Section 8.4 Consideration of a Biomanipulation Program

As described in Section 6.8, a moderate number of moderately-sized herbivorous zooplankton were identified in Lake Musconetcong during the 2003 monitoring program. Based on the collected data, the number and mean total length of the herbivorous portion of the lake's zooplankton community could be increased through some biomanipulation management effects. Specifically, an increase in both the abundance and size of the algae-eating zooplankton would increase the level of algal control experienced in Lake Musconetcong through grazing. Such efforts would aid in minimizing the duration, frequency and magnitude of algal blooms.

Prior to any biomanipulation measures being implemented, the first restoration objective is to eliminate the invasive species Eurasian watermilfoil and manage the abundance of native vegetation such as tapegrass and coontail. Therefore, it is strongly recommended that the recommendations made below for the biomanipulation component of the Lake Musconetcong Restoration Plan be delayed until the aquatic plant management portion of the plan is implemented.

Given its general morphometry, Lake Musconetcong has the potential to provide habitat for a large and healthy largemouth bass / chain pickerel fishery. Such a large community of gamefish would exert a high degree of predation pressure on zooplanktivorous (fish that eat zooplankton) fish such as alewives, golden shiners and young white / yellow perch. Such a re-structuring of the fishery community would result an increase in the number of large-bodied, herbivorous zooplankton. In turn, this would exert a strong degree of control on the algae, reducing the number and frequency of nuisance algal blooms. However, as previously cited, the aquatic plant densities are currently too high in Lake Musconetcong for such an optimal fishery community.

It is well documented that for largemouth bass, the optimal surface area coverage of submerged aquatic plants is between 30 and 40% (Wiley et al., 1987). Areal coverages greater than 40%, such as those experienced in Lake Musconetcong, typically result in a sub-optimal population of largemouth bass. In contrast, many sunfish such as bluegill thrive in waterbodies with aquatic plant surface areal coverages greater than 40%. Sunfish are more fecund, more aggressive than bass in establishing spawning beds and maneuver more easily in high plant densities. In addition, young sunfish are better competitors for food than young largemouth bass under these conditions. Thus, under existing conditions within Lake Musconetcong, bluegill successfully out-compete largemouth bass.

In order to maximize the beneficial impacts associated with biomanipulation, the existing fishery community should be shifted to favor the largemouth bass. To accomplish this, the following measures should be implemented in the following order:

1. Eliminate, or at least significantly reduce, the Eurasian watermilfoil in Lake Musconetcong, as detailed in Section 8.4.

2. Prior to, during and after the Eurasian watermilfoil control program, panfish fishing derbies should be promoted to aid in educating the public about the need to reduce the existing population of bluegill in Lake Musconetcong.

3. Once the Eurasian watermilfoil is under control, design and implement a fishery stocking program for Lake Musconetcong that will contribute toward increasing the dominance of largemouth bass.

4. Prior to implementing the stocking program, a supplemental fishery survey should be conducted to re-assess the lake's fishery community after the Eurasian watermilfoil is eliminated. The results of this assessment should be used to determine if any modifications to the proposed stocking plan (see below) are required.

After the Eurasian watermilfoil is eliminated or substantially reduced in Lake Musconetcong, the fishery community will be re-structured to facilitate a higher degree of algal control through biomanipulation. In addition, this re-structuring should also enhance the recreational value of Lake Musconetcong. The goal is to shift the dominance of the fishery community away from bluegill and toward largemouth bass.

The proposed biomanipulation stocking program focuses on stocking two size classes of largemouth bass in Lake Musconetcong. Specifically, 4-6" largemouth bass at a stocking rate of 25 fish per acre, and 8-10" largemouth bass at a stocking rate of 10 fish per acre is recommended for Lake Musconetcong under post-Eurasian watermilfoil eradication conditions. Additionally, fathead minnows should be added as a forage fish. Unlike sunfish, fathead minnows do not compete with young bass for food and adult bass for spawning habitat. In addition, fathead minnows tend to reside in near-shore areas, providing open water refuge for herbivorous zooplankton. Thus, fathead minnows should be stocked in Lake Musconetcong at a rate of 500 fish per acre.

The proposed fishery stocking plan, as outline above, is estimated to cost between $63,000.00 and $65,000.00. This cost includes the purchase, transport and stocking of the fish from a New Jersey fish hatchery, filing the required stocking permit and a limited amount of monitoring. Such a stocking plan could be implemented over two to three years instead of one in order to make it more feasible on a cost and logistic basis.

The annual maintenance / monitoring costs associated with the implementation of this proposed biomanipulation stocking program will depend on the degree to lake responses to the initial stocking program and the amount of monitoring that is conducted. Supplemental stocking is estimated to cost between $0.00 and $6,500.00 per year, again depending on how the lake responses to the initial stocking event. More than likely, at least between two to four years of some degree of supplemental stocking will be required to stabilize the fishery community.

The implementation of a monitoring program that focuses on the biomanipulation program of Lake Musconetcong is estimated to cost approximately $5,000.00 per year, which would include a two day fishery survey in the spring and some identification / enumeration work on the phytoplankton and zooplankton communities. Assistance from NJ Fish and Wildlife and/or the collection of data by local volunteers (i.e. creel surveys) would aid in reducing this annual monitoring cost

It should be emphasized that the goal of this proposed stocking plan is to increase the dominance of largemouth bass in Lake Musconetcong, at the expense of the bluegill.

However, it must be recognized that the proposed stocking plan should not be considered until the Eurasian milfoil is either eradicated or substantially reduced in Lake Musconetcong.

Finally, while bioremediation efforts such as biomanipulation are designed to improve in-lake water quality conditions, these management measures do not address the phosphorus loads entering the lakes. As has been cited in the Restoration Plan, bioremediation efforts are a “top down” approach to lake management, instead of the convention “bottom up” approach, which focuses on controlling the nutrient loads (Carpenter, et. al., 1996). Thus, the bioremediation measures focus solely on the symptom of the problem (algal blooms) and not the cause (excessive phosphorus loading). Give this distinction, it should be emphasized that recommended bioremediation measures are not part of the regulated portion of the Restoration Plan; that is, bioremediation is not being used to reduce the existing phosphorus loads to the targeted phosphorus loads, as identified in this refined TMDL.

Section 8.5 Public Awareness and Future Implementation of the Lake Musconetcong TMDL

The scope and objectives of the Public Awareness component of the Lake Musconetcong Restoration Plan are the same as those outlined for Lake Hopatcong (Section 7.5). Thus, the same handouts that will be available to the Lake Hopatcong Commission will also be made available to the Lake Musconetcong Regional Planning Board (LMRPB) for general distribution (Appendix J).

The development of future public awareness literature for Lake Musconetcong should focus on the identification, control and proactive management of the invasive species Eurasian watermilfoil. This is in sharp contrast to Lake Hopatcong, where the primary message that needs to be conveyed is the importance of watershed-based phosphorus control measures. As described in Section 7.5, providing both residents and visitors with information about recognizing Eurasian watermilfoil will be critical in maintaining a favorable lake ecosystem once the existing watermilfoil has been eradicated.

As previously mentioned, a number of public presentations / workshops have been or will be conducted as part of the Public Awareness program. In 2004, Princeton Hydro attended two public events, provided workshops on aquatic ecology and distributed some of the handouts and brochures. Both of these events were within the immediate watershed of Lake Musconetcong. The first public presentation was on 13 June 2004 at Netcong Day / Save the Lake Day and the second was on 19 September 2004 at the Stanhope Day event.

As the steward of Lake Musconetcong, the LMRPB will be the primary organization responsible for complying with the Lake Musconetcong phosphorus TMDL. This will include working with all stakeholders to implement various watershed-based management projects to comply with the TMDL, as well as working on a long-term effort to eliminate Eurasian watermilfoil and manage the densities of native vegetation.

Unlike the Lake Hopatcong Commission, the LMRPB is not a State-appointed agency. Instead, it is a volunteer-based group concerned with the lake and its valuable resources. Therefore, the LMRPB relies on funds and grants from the local municipalities, the Counties, the State and at times Federal sources. Thus, the implementation of the recommendations outlined in the Lake Musconetcong plan may be delayed, until funds from the appropriate sources are procured. However, as it has in the past, the LMRPB will continue to seek sources of funding to implement projects that both comply with the recommendations of the TMDL, as well as enhance and protect the water quality, ecological and recreational resources associated with Lake Musconetcong.

Section 9: Conclusions for Lake Hopatcong

Based on the findings of the refined phosphorus TMDL for Lake Hopatcong, the existing annual total phosphorus load of 8,097 kg (17,813 lbs) must be reduced to the targeted load of 4,800 kg (10,560 lbs). The targeted load is based on attaining an acceptable level of algae in the water column. The difference between the existing and targeted loads is the required reduction in phosphorus that the Restoration Plan must address in order to comply with the TMDL.

The installation of structural BMPs, coupled with the sewering of houses which currently use on-site wastewater disposal systems (septic systems) in the Borough of Hopatcong and the implementation of a septic maintenance plan in the Township of Jefferson, are the primary restoration measures recommended for Lake Hopatcong. Again, the goal is to reduce the watershed-based phosphorus load to the targeted levels.

While the emphasis of the Restoration Plan is placed on watershed control measures, some in-lake management techniques were also considered for future actions. For example, based on the phyto- and zooplankton data, Lake Hopatcong has the potential to be better managed in terms of excessive algal growth through biomanipulation. Circumstantial information indicates that the zooplankton-eating fish community should be reduced and the most efficient and effective means to do this is to stock larger gamefish. However, prior to implementing any such management action, detailed ecosystem-based data are required on the existing fishery community of Lake Hopatcong. In addition, a biomanipulation program would supplement, but not replace, the watershed-based strategy of reducing the existing phosphorus loads entering the lake.

Mechanical weed harvesting is an effective means of controlling nuisance densities of submerged aquatic plants in Lake Hopatcong. In addition, harvesting activities enhance the ecological, recreational and economic value of this important natural resource. Future work will be conducted to quantify the amount of phosphorus that is removed from the lake through mechanical weed harvesting activities.

The Lake Hopatcong Commission will be the primary organization responsible for documenting and tracking the status of the Lake Hopatcong phosphorus TMDL. Two meetings will be hosted each year by the Commission, where all participating stakeholders will provide an update on their contributions toward the TMDL. These meetings will also provide a forum for the exchange of information among the stakeholders. Finally, the Commission will also be the lead agency in educating stakeholders about what can be done on both individual and community-based levels to reduce the existing annual phosphorus loads entering Lake Hopatcong.

Section 10: Conclusions for Lake Musconetcong

Based on the findings of the refined phosphorus TMDL for Lake Musconetcong, the existing annual total phosphorus load of 3,486 kg (7,669 lbs) must be reduced to the targeted load of 2,200 kg (4,840 lbs). The targeted load is based on attaining an acceptable level of algae in the water column. The difference between the existing and targeted loads is the required reduction in phosphorus that the Restoration Plan must address in order to comply with the TMDL.

Since 67% of Lake Musconetcong's annual phosphorus load originates from the outflow of Lake Hopatcong, a substantial portion of the targeted TMDL will be achieved through the watershed-based control measures proposed for implementation within the Lake Hopatcong watershed. In addition to this, the municipalities within the immediate watershed of Lake Musconetcong are required to reduce their existing annual phosphorus load by 296 kg (651 lbs).

The reduction of the phosphorus load entering Lake Musconetcong is an important component of its long-term Restoration Plan. However, the primary restoration objective should be the elimination of the Eurasian watermilfoil that plagues the lake and the establishment and maintenance of a shallow lake ecosystem dominated by native aquatic vegetation. The implementation of a whole-lake Sonar^R treatment program to eliminate the Eurasian watermilfoil and the subsequent management of the native vegetation with mechanical weed harvesting is the proposed macrophytes strategy for Lake Musconetcong. These in-lake measures should be coupled with an aggressive Public Awareness program to minimize and delay for as long as possible the re-introduction of Eurasian watermilfoil back into Lake Musconetcong.

In addition to the use of the systematic herbicide Sonar^R and the mechanical weed harvesting program, dredging should also be considered in the long-term management of

Lake Musconetcong. A selective dredging project conducted in the mid-1990's of the lake revealed that areas that have been dredged tend to support lower densities of native vegetation, such as tapegrass, in contrast to Eurasian watermilfoil. Therefore, the removal of the accumulated sediment in Lake Musconetcong should be a high priority in-lake restoration measure for the long-term management of the lake.

Although some moderately-sized herbivorous zooplankton were identified in Lake Musconetcong, large-bodied herbivorous zooplankton were rare. To increase the level of algal control through zooplankton grazing, a biomanipulation program should be implemented at Lake Musconetcong. Such a program would also be designed to improve the lake's existing largemouth bass fishery. However, prior to the implementation of any biomanipulation program, the Eurasian watermilfoil should be eliminated or at least substantially reduced. The goal of the biomanipulation program will be to shift at least some of the dominance of the fishery community from the bluegill in favor of largemouth bass. Such a change within the ecosystem would allow larger-bodied zooplankton, such as *Daphnia*, to thrive and thus serve as a natural means of controlling excessive algal growth.

The Lake Musconetcong Regional Planning Board (LMRPB) is the volunteer-based, interagency organization that functions as the steward of Lake Musconetcong. This includes managing and operating the mechanical weed harvesting program and overseeing the implementation of various watershed-based and public awareness programs. The LMRPB will continue to work with the municipalities, the Counties, the State, the Lake Hopatcong Commission and local residents to preserve and protect Lake Musconetcong, as well as oversee the implementation of the TMDL-based Restoration Plan.

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Appendix A
Results of Regression Data on the Long-term Chlorophyll *a* Databases for Lake Hopatcong and Lake Musconetcong

Appendix B
Phytoplankton and Zooplankton Data
for Lake Hopatcong

Appendix C
Mechanical Weed Harvesting and Aquatic Macrophyte Database for Lake Hopatcong

Appendix D
Lake Hopatcong Water Quality Monitoring
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Appendix E
Phytoplankton and Zooplankton Data
for Lake Musconetcong

Appendix F
Results of the Fishery Survey
for Lake Musconetcong

Appendix G
Water Quality and Aquatic Macrophyte Database
for Lake Musconetcong

Appendix H
Structural Best Management Practices (BMPs) Fact Sheets

Appendix I
Recommended BMPs and their associated costs for the municipalities within the Lake Hopatcong watershed

Appendix J
Public Awareness Literature for
Lake Hopatcong and Lake Musconetcong

Appendix K
Recommended BMPs and their associated costs for the municipalities within the Lake Musconetcong watershed

Appendix L
Formal response to comments on the TMDL made by the Rutgers EcoComplex and the New Jersey Department of Environmental Protection
(April 2005)