R-WD-20-13

Draft Total Maximum Daily Load for Phosphorus for Locke Lake, Barnstead, NH

STATE OF NEW HAMPSHIRE
DEPARTMENT OF ENVIRONMENTAL SERVICES
29 HAZEN DRIVE
CONCORD, NEW HAMPSHIRE 03301

ROBERT R. SCOTT
COMMISSIONER

Prepared by:
Margaret P. Foss
TMDL Coordinator
Watershed Management Bureau

August 2020

Printed on Recycled Paper

Contents

Executive Summary **1**

1.0 Introduction **1-1**

2.0 Description of Water Body, Standards and Target **2-1**

2.1 Watershed and Waterbody Characteristics 2-1

2.2 Designated Uses 2-9

2.3 Applicable Water Quality Standards 2-10

2.4 Anti-degradation Policy 2-11

2.5 Priority Ranking and Pollutant of Concern 2-11

2.6 Numeric Water Quality Target 2-11

3.0 ENSR-LRM Model of Current Conditions **3-1**

3.1 Hydrologic Inputs and Water Loading 3-1

3.2 Nutrient Inputs 3-2

3.3 Phosphorus Loading Assessment Limitations 3-3

3.4 Lake Response to Current Phosphorus Loads 3-3

4.0 Total Maximum Daily Load **4-6**

4.1 Maximum Annual Load 4-6

4.2 Maximum Daily Load 4-6

4.3 Future Development 4-7

4.4 Critical Conditions 4-7

4.5 Seasonal Variation 4-8

4.6 Reduction Needed 4-8

4.7 TMDL Development Summary 4-9

5.0 TMDL Allocation **5-1**

5.1 Wasteload Allocations (WLAs) and Load Allocations (LAs) 5-1

5.2 Margin of Safety (MOS) 5-1

6.0 Evaluation of Alternative Loading Scenarios **6-1**

6.1 Natural Environmental Background Phosphorus Loading 6-4

6.2 Septic System Load Removal 6-4

6.3 Internal Load Removal 6-4

6.4 Waterfowl Reduction 6-4
6.5 Reduction of Watershed and Waterfowl to Meet In-lake Target of 12 ug/L 6-4

7.0 Implementation Plan 7-1

8.0 Monitoring Plan 8-1

9.0 Reasonable Assurances 9-1

10.0 Public Participation and Substantive Changes 10-1
10.1 Public Participation and Comment 10-1
10.2 Summary of Comments Received and Substantive Changes Made in the Final Report 10-1

11.0 References 11-1

Appendix A: Methodology for Determining Target Criteria

Appendix B: LLRM Methodology Documentation

Appendix C: Land Use Categories, Export Coefficients and Additional Calculations

Appendix D: 2018 VLAP Report

List of Figures

Figure 2-1 Merrimack River HUC 10 Watershed Map 2-2
Figure 2-2 Watershed Drainage Area for Locke Lake 2-4
Figure 2-3 Bathymetry Map of Locke Lake 2-5
Figure 2-4 Plot of Phosphorous Data used for the 2016 Assessment of Locke Lake 2-8
Figure 3-1 Locke Lake Watershed Land Use Map 3-4
Figure 10-1 Public Notice 10-2

List of Tables

Table 2-1 Locke Lake AUID numbers 2-3
Table 2-2 Characteristics of Locke Lake - Barnstead, NH 2-6
Table 2-3 Water Quality Summary Table 2-7
Table 2-4 Designated Uses for New Hampshire Surface Waters (from Env-Wq 1702.17) 2-9
Table 3-1 Locke Lake Water Budget 3-2
Table 3-2. Land Use Categories in Locke Lake Watershed 3-1
Table 3-4 Locke Lake Current Phosphorus Loading Summary 3-3
Table 3-5 Predicted In-lake Total Phosphorus Concentration using Empirical 3-5
Table 3-6 Predicted In-lake Chlorophyll a and Secchi Disk Transparency Predictions based on an Annual Average In-lake Phosphorus Concentration of 26 ug/L 3-5
Table 4-1 Locke Lake Phosphorus Load Allocation 4-8
Table 7-1 Best Management Practices Selection Matrix 7-5

Executive Summary

A Total Maximum Daily Load (TMDL) analysis was conducted for Locke Lake in Barnstead, New Hampshire. Locke Lake is on the 2016 Section 303(d) List of impaired waters for impairment of the Aquatic Life use due to chlorophyll a (chl a), and total phosphorus (TP). Reducing phosphorus concentrations in the lake should improve the associated algal growth in the lake. The TMDL analysis included: 1) the construction of a nutrient budget; 2) development of a target value for phosphorus such that algal growth and bloom formation would meet applicable water quality standards and thresholds; and 3) an estimate of the TP load reduction needed to achieve the target TP concentrations and how those load reductions could be allocated among the various sources of TP. This TMDL is intended to cover the entire lake and the seven beaches on the lake (see table below).

AUID Number	Waterbody Name
NHIMP700060402-02	WEBSTER STREAM - LOCKE LAKE
NHIMP700060402-02-01	LOCKE LAKE - GEORGETOWN BEACH #6
NHIMP700060402-02-02	LOCKE LAKE - NORTH BARNSTEAD ROAD BEACH
NHIMP700060402-02-03	LOCKE LAKE -N SHORE RD BEACH
NHIMP700060402-02-04	LOCKE LAKE - POINT BEACH
NHIMP700060402-02-05	LOCKE LAKE - COLONY BEACH
NHIMP700060402-02-06	LOCKE LAKE - VARNEY BEACH
NHIMP700060402-02-07	LOCKE LAKE - WINCHESTER DRIVE BEACH

Modeling was conducted to predict in-lake TP concentration, as well as chl a concentrations, algal bloom frequency and secchi disk transparency. Existing sources of TP were determined to be from atmospheric deposition, internal loading, septic systems (within 250 feet of the lake), waterfowl and watershed loads. The existing annual load of TP to Locke Lake is estimated to be approximately 537 kg/yr. The in-lake target TP concentration was set at 12 ug/L, which is the predicted TP concentration for mesotrophic lakes that will result in attainment of surface water quality criteria and thresholds for chl a, DO, as well as cyanobacteria. The corresponding TP loading for the target scenario is approximately 250 kg/yr, which represents an approximate 54% (288 kg/yr) reduction from the existing TP load. This reduction may be conservative because the TMDL includes an estimated implicit margin of safety of 20 percent. An implicit 20% Margin of Safety was included to better reflect critical summer conditions when epilimnetic TP concentrations are typically lower than annual mean in-lake concentrations to which the model is calibrated to and to account for model uncertainty. Inclusion of the Margin of Safety results in a target load of 250 kg/yr and an approximate 54% (288 kg/yr) reduction to meet the target of 12 ug/L. A scenario focusing on reductions in watershed loads to achieve the TP target of 12 ug/L is provided although it is recognized that other combinations of source load reductions are possible.

Successful implementation of this TMDL will not be based on meeting the in-lake target TP concentration of 12 ug/l or the reduction target of 54% (288 kg/yr). Rather, compliance will be based on continued lake monitoring and assessment of monitoring results using the methods described for assessing water quality standards attainment in the most recent version of the Consolidated Assessment Listing Methodology (NHDES, 2018) for the response variables (DO, cyanobacteria, and chl a).

Guidance for implementation, monitoring and for obtaining Clean Water Act (Section 319) funding for nonpoint source control is also provided. Monitoring is recommended to document the in-lake response, trends, and compliance with water quality criteria and thresholds following implementation of TP

reduction measures. After significant load reductions have been implemented, monitoring should be conducted to determine if compliance has been achieved or if additional reductions are necessary. This is especially important when the estimated TP load reductions associated with implemented activities approach the load reduction goal since it's possible that, due to the model uncertainties, compliance will be achieved before the TP load reduction goal is met. The process of implementing load reduction activities and monitoring in a step-wise fashion is called phased implementation and is the recommended approach for implementing this TMDL.

1.0 Introduction

The Federal Clean Water Act (CWA) provides regulations for the protection of streams, lakes and estuaries within the United States. Section 303(d) of the CWA requires individual states to identify waters not meeting current state water quality standards due to pollutant discharges and to determine Total Maximum Daily Loads (TMDLs) for these waters. A TMDL sets the maximum amount of a pollutant that a waterbody can receive and still support designated uses. A significant number of New Hampshire lakes are on the 2016 303(d) list due to impairment of designated uses by total phosphorus (TP), chlorophyll *a* (chl *a*), cyanobacteria hepatoxic microcystin (cyanobacteria) blooms, or dissolved oxygen (DO) depletion (NHDES 2016a). Locke Lake was originally included on the 2010 303(d) lists for impairment of the aquatic life uses due to elevated levels of total phosphorus and chlorophyll a (chl *a*). High levels of chl *a* and cyanobacteria blooms are indicative of nutrient enrichment. Phosphorus is the primary limiting nutrient in northern temperate lakes, hence eutrophication due to phosphorus enrichment is the likely cause of high chl a. Nitrogen can also play a role in determining the type of algae present and the degree of eutrophication of a waterbody. However, phosphorus is typically more important in fresh waters and more easily controlled than nitrogen. A TMDL for total phosphorus (TP) as a surrogate for chl *a* has been prepared for Locke Lake, the results of which are presented in this report.

The TMDL is expressed as:

TMDL = Waste Load Allocation (WLA) + Load Allocation (LA) + Margin of Safety (MOS)

The WLA includes the load from permitted discharges, the LA includes nonpoint sources and the MOS ensures that the TMDL will support designated uses given uncertainties in the analysis and variability in water quality data.

Determining the maximum daily nutrient load that a lake can assimilate without exceeding water quality standards is challenging and complex. First, many lakes receive a high proportion of their nutrient loading from non-point sources, which are highly variable and are difficult to quantify. Secondly, lakes demonstrate nutrient loading on a seasonal scale, not a daily basis. Loading during the winter months may have little effect on summer algal densities. Finally, variability in loading may be very high in response to weather patterns, and the forms in which nutrients enter lakes may cause increased variability in response. Therefore, it is usually considered most appropriate to quantify a lake TMDL as an annual load and evaluate the results of that annual load on mid-summer conditions that are most critical to supporting aquatic life and recreational uses. Accordingly, the nutrient loading capacity of lakes is typically determined through water quality modeling, which is usually expressed on an annual basis. Thus, while a single value may be chosen as the TMDL for each nutrient, it represents a range of loads with a probability distribution for associated water quality problems (such as algal blooms). Uncertainty is likely to be quite high, and the resulting TMDL should be viewed as a nutrient-loading goal that helps set the direction and magnitude of management, not as a rigid standard that must be achieved to protect against eutrophication. While daily expression of the TMDL is provided in this report, the annual mean load should be given primacy when developing and evaluating the effectiveness of nutrient loading reduction strategies.

The purpose of the Locke Lake TMDL is to establish a TP loading target that is expected to achieve state water quality criteria and thresholds for TP, chl a. Water quality that meets these objectives is, *a priori*, expected to protect designated uses. This TMDL analysis was prepared according to the United States Environmental Protection Agency's (US EPA) protocol for developing nutrient TMDLs (US EPA, 1999). The main objectives of this TMDL report include the following:

- Describe water body, standards and numeric target value.
- Describe potential sources and estimate the existing TP loading to the lake.
- Estimate the loading capacity.
- Allocate the load among sources.
- Provide alternate allocation scenarios.
- Suggest elements to be included in an implementation plan.
- Suggest elements to be included in a monitoring plan.
- Provide reasonable assurances that the plans will be acted upon.
- Describe public participation in the TMDL process.

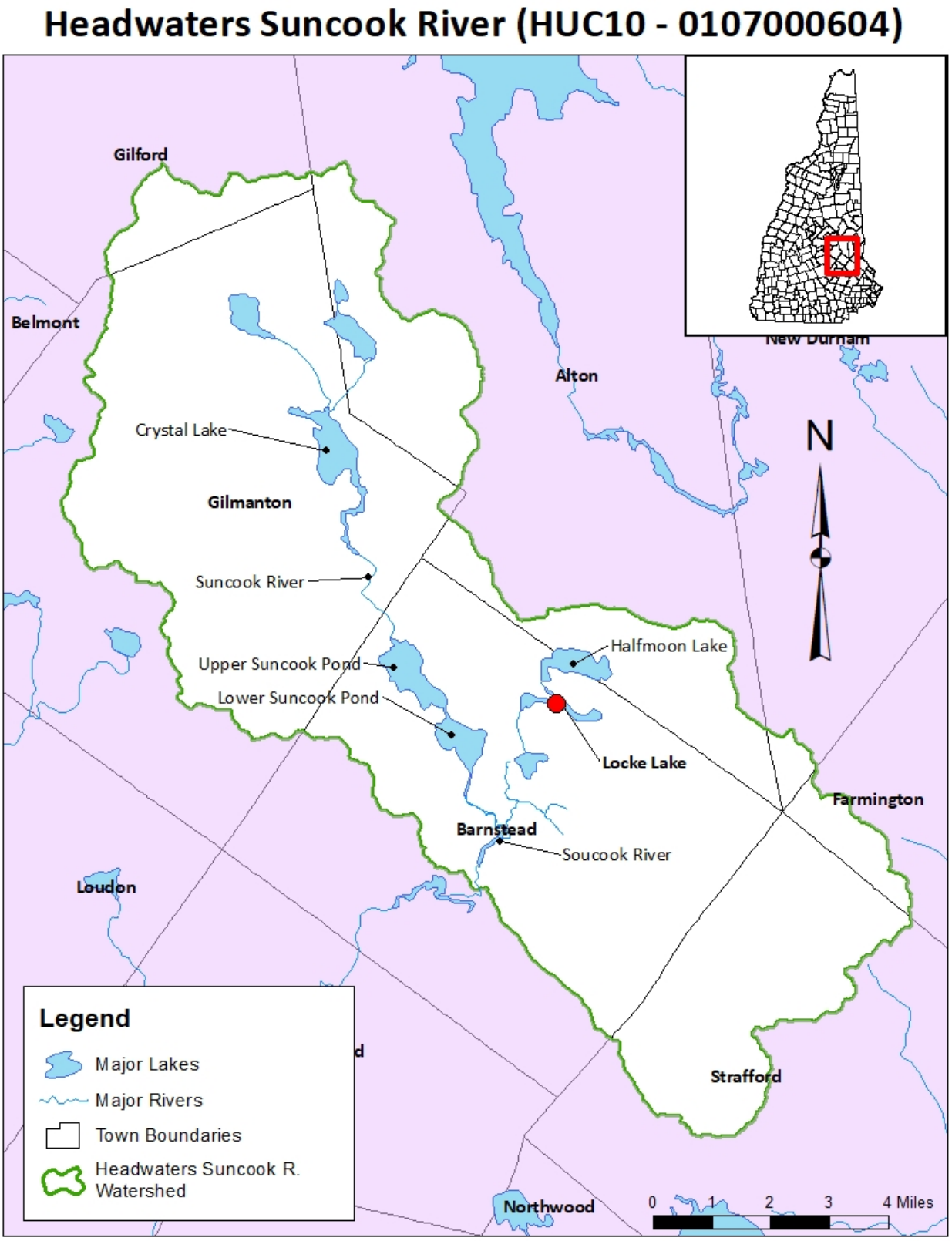
This TMDL for TP will identify the causes of impairment and the pollutant sources and is expected to fulfill the first of the nine requirements for a watershed management plan required to qualify a project for Section 319 restoration funding (see Section 7.0).

2.0 Description of Water Body, Standards and Target

2.1 Watershed and Waterbody Characteristics

Locke Lake is located in Barnstead, New Hampshire, in the Merrimack Watershed (HUC10 number 0107000604 – see Figure 2-1). This watershed covers an area of approximately 100 square miles in the southern section of New Hampshire. There are six towns located at least partially within the watershed, extending north to south from the towns of Gilmanton to Strafford and west to east from the towns of Belmont and Farmington respectively. The primary watercourse in the region is the Suncook River. Much of the Watershed is forests, rolling hills and rural residential areas.

Figure 2-1 Merrimack River HUC 10 Watershed Map



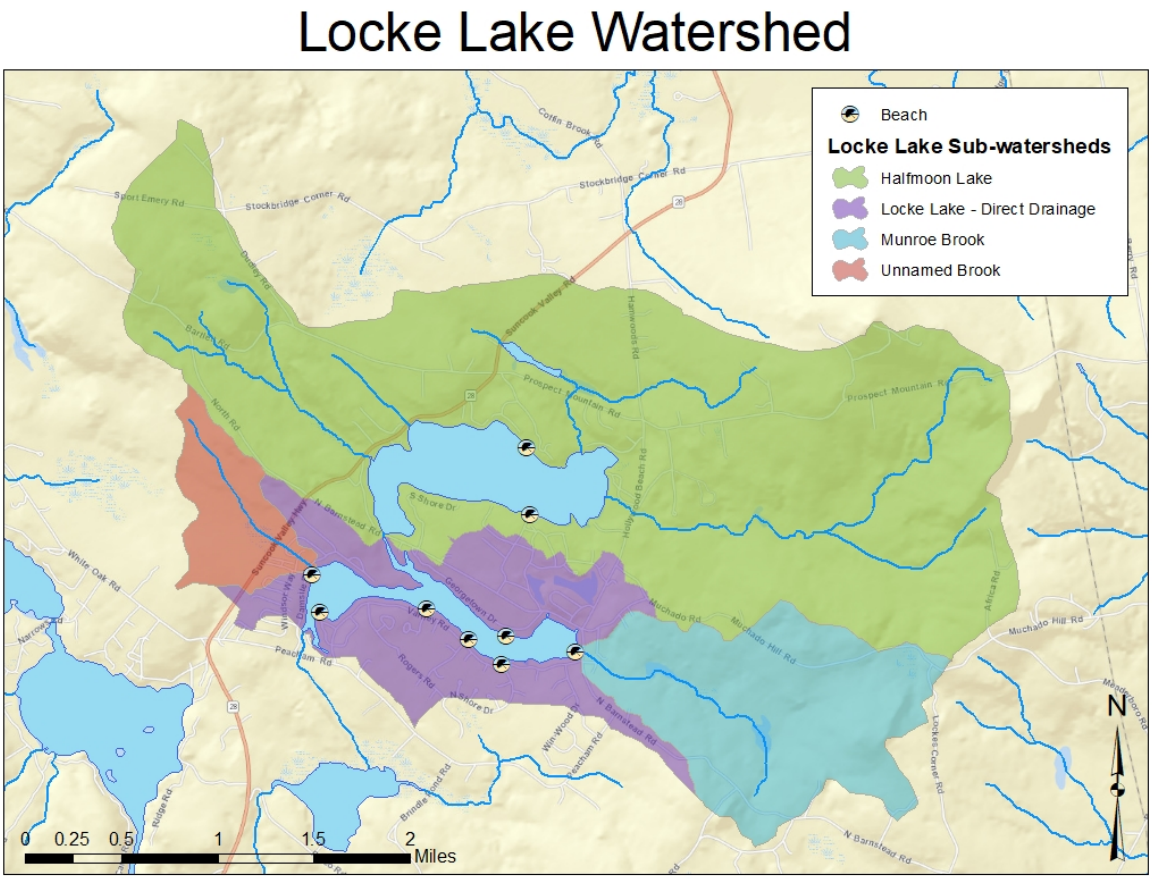
Locke Lake includes two assessment units. The assessment unit identification (AUID) number for the main portion of Locke Lake is NHLAK7000604-02. There are also seven private beaches on Locke Lake. See the table below for the full list of AUIDs:

Table 2-1 Locke Lake AUID numbers

AUID Number	Waterbody Name
NHIMP700060402-02	WEBSTER STREAM - LOCKE LAKE
NHIMP700060402-02-01	LOCKE LAKE - GEORGETOWN BEACH #6
NHIMP700060402-02-02	LOCKE LAKE - NORTH BARNSTEAD ROAD BEACH
NHIMP700060402-02-03	LOCKE LAKE -N SHORE RD BEACH
NHIMP700060402-02-04	LOCKE LAKE - POINT BEACH
NHIMP700060402-02-05	LOCKE LAKE - COLONY BEACH
NHIMP700060402-02-06	LOCKE LAKE - VARNEY BEACH
NHIMP700060402-02-07	LOCKE LAKE - WINCHESTER DRIVE BEACH

This TMDL is intended to cover the entire lake and the seven beaches. The drainage area (i.e., watershed) for Locke Lake is depicted in Figure 2-2. Based on the 2016 NHLCD GIS analysis, excluding the surface area of the pond, the Locke Lake watershed (i.e., the colored areas in Figure 2-2) is approximately 1914 acres in size and is located entirely in the Town of Barnstead. As shown in Figure 2-2, the watershed is depicted as four subwatersheds: the Halfmoon Lake Watershed, the Locke Lake Direct Drainage Watershed, the Munroe Brook Watershed and the Unnamed Brook Watershed area. The Locke Lake Direct Drainage Watershed represents the area that drains more directly to the pond as compared to the surrounding watershed areas. There is one main tributary to the pond, Whiting Brook, which drains into a wetland area that flows into the northwestern side of Locke Lake. The outlet of Locke Lake is located on the eastern end of the lake.

Figure 2-2 Watershed Drainage Area for Locke Lake



Locke Lake has a surface area of approximately 55.54 hectares (ha) (137 acres). The maximum depth of the Pond is 3 meters (m) (9.8 ft) and the mean depth is 0.9 m (3 ft). Based on bathymetry conducted in 2018, the lake volume is approximately 1,201,502 cubic meters (m^3). Based on the 2018 VLAP report, Locke Lake has a flushing rate of approximately 9.9 times per year. Figure 2-3 shows the bathymetry of the Locke Lake based on a bathymetric survey conducted by the New Hampshire Department of Environmental Services (NHDES) in 2018**.** Select characteristics of Locke Lake and its watershed are presented in Table 2-1.

Figure 2-3 Bathymetry Map of Locke Lake

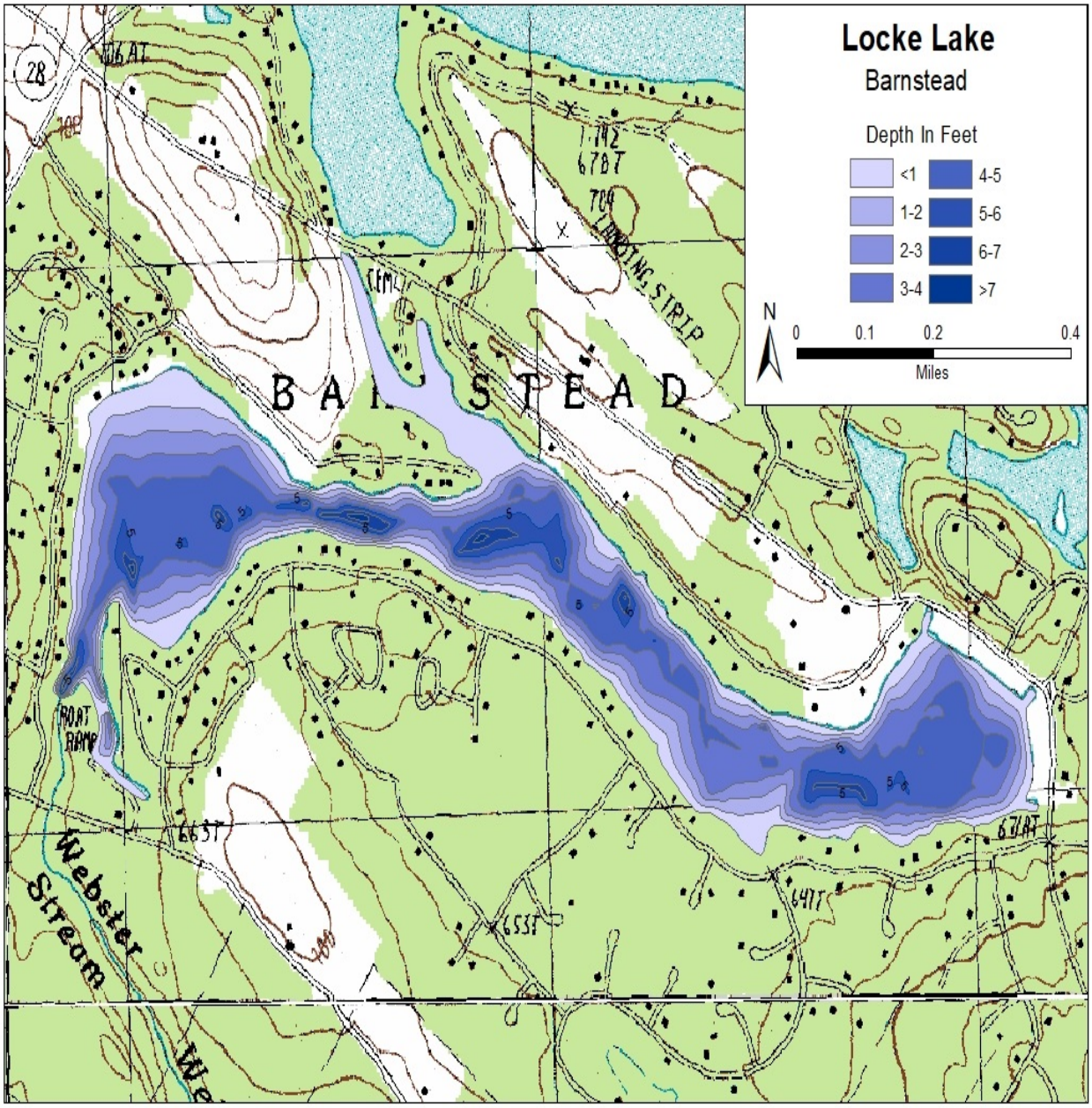


Table 2-2 Characteristics of Locke Lake - Barnstead, NH

Parameter	Value
Assessment Unit Identification	NHLAK70006060402-02
Lake Surface Area (hectares, acres)	55.54 ha, 137 acres
Lake Volume (m^3)	1,201,502
Watershed Area w/o/pond (ha, acres)	774.5 ha, 1,913.9 acres
Mean Depth (m, ft.)	0.9 m, 2.95 ft.
Max Depth (m, ft.)	3 m, 9.84 f.t
Flushing Rate (yr^{-1})	9.9
Upper Layer TP (2009-2019 mean ug/L)*	21.2
Impaired Uses and Causes of Impairment**	*Aquatic Life:* Chlorophyll-a (5-M), Total Phosphorus (5-M) pH (5-M)
Hypolimnetic Anoxia	Yes

*Water quality statistics are calculated from 2009 - 2019 sampling data, 2018 bathymetry data, and the 2018 Volunteer Lake Assessment Report (VLAP).

**Source: 2016 NH 303(d) List of Threatened or Impaired Waters that Require a TMDL (NHDES, 2016a). Category '5'= TMDL Required, Category 'M'= Marginal Impairment, and Category 'P'= Priority Impairment. Impairments shown are for assessment unit

NHDES has periodically conducted water quality sampling in Locke Lake for over four decades. In 2010, NHDES conducted water quality monitoring of Locke Lake in order to update previous lake trophic studies conducted by NHDES. Figure 2-4 shows a plot of the phosphorous data collected from 2002 to 2016. Locke Lake is fortunate to have volunteers who regularly monitor the lake and the inlet tributary as part of the NHDES Volunteer Lake Assessment Program (VLAP). Further, there is a good working relationship between the Barnstead Conservation Commission and the VLAP volunteers.

To develop this lake phosphorous TMDL, NHDES used water quality data collected by VLAP volunteers from the Lake Deep Spot from 2009 to 2018 and additional water quality data collected by NHDES staff in 2019. The mean, median and range of selected water quality parameters from the Deep Spot in the lake during that time span, as well as data collected during the 2010 Lake Trophic Survey and 2019 dissolved oxygen, temperature and phosphorous profile are summarized in Table 2-2. TP concentrations in the epilimnion range from 12.8 to 30.0 ug/L with a median value of 21.2 ug/L. Graphs showing historical TP, chl a and transparency (secchi disk) at the deep spot as well as the DO and temperature profile may be found in the 2018 VLAP report (see Appendix D).

Table 2-3 Water Quality Summary Table

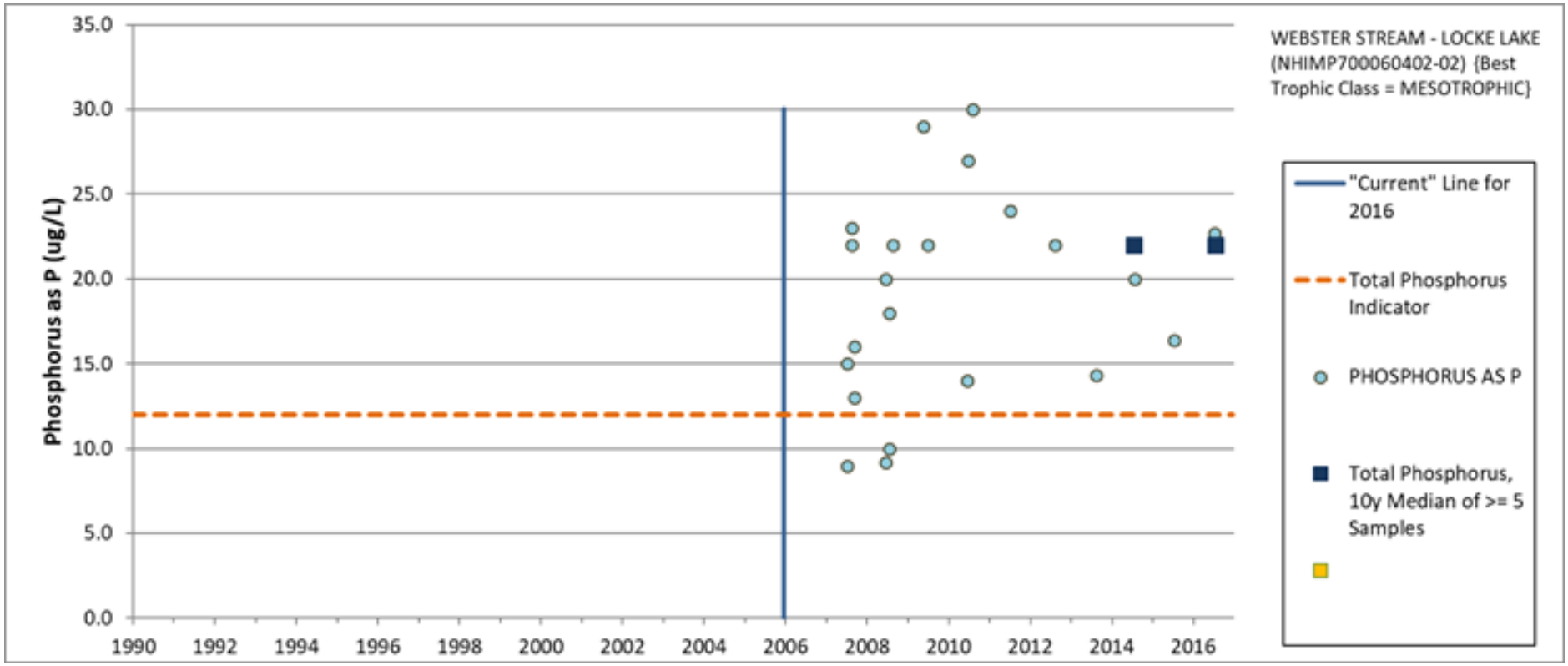
2009-2019 Sampling Data Statistics		
Statistic	**Deep Spot TP (*u*g/L)**	**Deep Spot Chlor a**
n	14	17
Min	12.8	3.2
Mean	21.2	7.5
Max	30.0	12.4
Median	22.0	7.1

2010 Lake Trophic Survey Water Quality (Deep Spot)			
Epi TP (ug/L)	**Hypo TP (ug/L)**	**SDT (m)**	**Chl a* (ug/L)**
n=1	n=1	n=1	n=1
27	na	1.4	

* Chlor a uncorrected for pheophytin

May 2019 Lake Survey Deep Spot Data Profiles				
Depth (M)	**Temp (C)**	**DO (mg/L)**	**DO %Sat**	**TP ug/L**
0.1	14.3	10.47	103.6	13
1.0	14.0	10.51	103.2	
1.5	13.7	10.56	103.2	13.3
1.5 (rep)				14.8

Figure 2-4 Plot of Phosphorous Data used for the 2016 Assessment of Locke Lake



2.2 Designated Uses

Designated uses are uses within a waterbody that must be protected. Surface water classifications establish general designated uses for a waterbody. In New Hampshire, there are two classifications, A and B. Locke Lake is assigned a surface water classification of B. According to RSA 485-A:8, Class B waters "…shall be of the second highest quality and are considered acceptable for fishing, swimming and other recreational purposes and may be used as water supplies after adequate treatment. New Hampshire's surface water quality standards (Env-Wq 1700, NHDES 2017) further define designated uses as shown in the table below.

Table 2-4 Designated Uses for New Hampshire Surface Waters (from Env-Wq 1702.17)

Designated Use	NHDES Definition	Applicable Surface Waters
Aquatic Life Integrity	The surface water can support aquatic life, including a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of similar natural habitats of the region.	All surface waters
Fish Consumption	The surface water can support a population of fish free from toxicants and pathogens that could pose a human health risk to consumers.	All surface waters
Shellfish Consumption	The tidal surface water can support a population of shellfish free from toxicants and pathogens that could pose a human health risk to consumers;	All tidal surface waters
Potential Drinking Water Supply	The surface water could be suitable for human intake and meet state and federal drinking water requirements after adequate treatment.	All surface waters
Swimming and Other Recreation in and on the water (i.e., primary and secondary recreation)	The surface water is suitable for swimming, wading, boating of all types, fishing, surfing, and similar activities.	All surface waters
Wildlife	Wildlife, meaning the surface water can provide habitat capable of supporting any life stage or activity of undomesticated fauna on a regular or periodic basis; and	All surface waters

2.3 Applicable Water Quality Standards

The New Hampshire State Water Quality Standards for nutrients in Class B waters (Env-Wq 1703.14) include the following narrative criteria:

> "(b) Class B waters shall contain no phosphorus or nitrogen in such concentrations that would impair any existing or designated uses, unless naturally occurring.
> (c) Existing discharges containing phosphorus or nitrogen, or both, which encourage cultural eutrophication shall be treated to remove the nutrient(s) to ensure attainment and maintenance of water quality standards.
> (d) There shall be no new or increased discharge of phosphorus into lakes or ponds.
> (e) There shall be no new or increased discharge containing phosphorus or nitrogen to tributaries of lakes or ponds that would contribute to cultural eutrophication or growth of weeds or algae in such lakes and ponds."

With the exception of Env-Wq 1703.07(b)(1), applicable water quality standards for DO in Class B waters (Env-Wq 1703.07) include the following:

> "(b) Except as naturally occurs and subject to (c) and (e), below, class B waters shall have a dissolved oxygen content of:
> (1) At least 75% of saturation, as specified in RSA 485-A:8, II, based on a daily average; and
> (2) An instantaneous minimum dissolved oxygen concentration of at least 5 mg/l.
> (c) In areas identified by the New Hampshire fish and game department (NHF&G) as cold water fish spawning areas of species whose early life stages are buried in the gravel on the bed of the surface water, the 7 day mean dissolved oxygen concentration shall be at least 9.5 mg/l and the instantaneous minimum dissolved oxygen concentration shall be at least 8 mg/l for the period from October 1 of one year to May 14 of the next year, provided that the time period shall be extended to June 30 for a specific discharge to a specific waterbody if modeling done in consultation with the NHF&G determines the extended period is necessary to protect spring spawners or late hatches of fall spawners, or both.
> (d) Unless naturally occurring or subject to (a), above, surface waters within the top 25 percent of depth of thermally unstratified lakes, ponds, impoundments, and reservoirs or within the epilimnion shall contain a dissolved oxygen content of at least 75 percent saturation, based on a daily average and an instantaneous minimum dissolved oxygen content of at least 5 mg/l. Unless naturally occurring, the dissolved oxygen content below those depths shall be consistent with that necessary to maintain and protect existing and designated uses."

Based on legislation passed in 2017, NHDES is only authorized (by statute) to establish dissolved oxygen criteria in rule (i.e., regulation) based on concentration (and not saturation)[1]. Since state statute has precedent over regulation, the 75% daily average dissolved oxygen criterion specified in Env-Wq 1703.07 (b)(1), no longer applies. These revisions to New Hampshire water quality standards for dissolved oxygen percent saturation have been submitted to EPA for review, but are not currently in effect for Clean Water Act purposes.

---

[1] RSA **485-A:6 Rulemaking. –**
The commissioner shall adopt rules, under RSA 541-A, after public hearing, relative to:
XIV. Dissolved oxygen concentration water quality standards under RSA 485-A:8, II and II-a.

The NHDES policy for interim nutrient threshold for primary contact recreation (i.e. swimming) in New Hampshire lakes is 15 ug/L chl *a* (NHDES 2008a). NHDES has also developed thresholds for protection of aquatic life for chl a and TP based on trophic level (see Appendix A, Table A-2). Lakes were also listed as impaired for swimming if surface blooms (or "scums") of cyanobacteria were present. For example, a lake was listed as impaired if scums were present only along a downwind shore.

2.4 Anti-degradation Policy

Anti-degradation provisions are designed to preserve and protect the existing beneficial uses of New Hampshire's surface waters and to limit the degradation allowed in receiving waters. Anti-degradation regulations are included in Part Env-Wq 1708 of the New Hampshire Surface Water Quality Regulations. According to Env-Wq 1708.02, anti-degradation applies to the following:

> "(a) Any proposed new or increased activity, including point source and nonpoint source discharges of pollutants, that would lower water quality or adversely affect existing or designated uses;
> (b) Any proposed increase in loadings to a waterbody when the proposal is associated with existing activities;
> (c) Any increase in flow alteration over an existing alteration; and
> (d) Any hydrologic modifications, such as dam construction and water withdrawals."

2.5 Priority Ranking and Pollutant of Concern

Locke Lake (NHLAK700060402-02) is listed on the 2016 303(d) list as having an aquatic life use impairment due to elevated levels of total phosphorus (TP) and chl *a*). The impairments are listed as marginally impaired (category 5-M). It is likely that the impairments observed in Locke Lake are attributable to nutrient enrichment, specifically TP. Control of TP sources to Locke Lake should therefore improve conditions related to TP, chl *a,* and DO such that designated uses are supported. In 2018, NHDES identified Locke Lake as one of the high priority waters for TMDL development and committed (to EPA) to develop a TMDL in 2020.

2.6 Numeric Water Quality Target

As discussed in section 2.3, only narrative criteria for TP exist in New Hampshire's state water quality regulations. Accordingly, to develop a TMDL for this waterbody, it is necessary to derive a numeric TP target value (e.g., in-lake concentration) for determining acceptable nutrient loads. The suggested TP value is described in the following paragraph. The derivation of this target and discussion of alternative approaches in setting targets are presented in Appendix A. It is notable that all three approaches presented result in very similar target concentrations.

As explained in Appendix A, a target of 12 ug/L is typically used for most lakes unless the predicted concentration under natural (pre-development) conditions is greater. In such cases, the natural TP concentration is used as the target. This is consistent with Env-Wq 1703.14(b), which states that Class B waters shall contain no phosphorus in such concentrations that would impair any existing or designated uses, unless naturally occurring. The value of 12 ug/L is derived from an analysis of the observed TP concentrations from a set of impaired and unimpaired lakes in New Hampshire and is further supported by evaluation of the Trophic State Indices (TSI) developed by Carlson (1977) and a probabilistic assessment of the likelihood of blooms (Walker 1984, 2000). The "weight of evidence" suggests that 12 ug/L will support recreational and aquatic life designated uses as reflected in suitable (designated use support) measures of both SDT and chl *a*. In highly colored surface waters such as Locke Lake, the target of 12 ug/L may be

conservative because less light is available for algal (i.e., chl a) growth. That is, highly colored ponds may be able to assimilate higher levels of TP before chl a thresholds to support designated uses are reached (see Appendix A for more information).

3.0 ENSR-LRM Model of Current Conditions

Current TP loading was assessed using the ENSR-LRM methodology, which is a land use export coefficient model developed by the consulting firm AECOM for use in New England and modified for New Hampshire lakes by incorporating New Hampshire land use TP export coefficients when available and adding septic system loading into the model (CT DEP and ENSR 2004). Documentation for ENSR-LRM is provided in Appendix B.

The major direct and indirect nonpoint sources of TP to Locke Lake include:

- Atmospheric deposition (direct precipitation to the lake).
- Surface water base flow (dry weather tributary flows, including any groundwater seepage into streams from groundwater).
- Stormwater runoff (runoff draining to tributaries or directly to the lake).
- Internal recycling (release from sediment by chemical interaction).
- Waterfowl (direct input from resident and migrating birds).
- Direct groundwater seepage including septic system inputs from shorefront residences.

Discharges due to construction activities that may occur in the watershed are not incorporated in the model due to their variability and short-term impacts.

The watershed of Locke Lake was divided into two subwatersheds based on tributary inputs and topography (Figure 2-2). These basins include the Halfmoon Lake Watershed and the Locke Lake Watershed area (which include the two smaller areas identified as the Munroe Brook watershed and the Unnamed Brook watershed). TP loads were estimated for each subwatershed based on runoff and groundwater land use export coefficients. The TP loads were then attenuated as necessary to match the monitoring data. Loads from the watershed as well as direct sources were then used in the model to predict the in-lake concentrations of TP, chl *a*, Secchi Disk Transparency (SDT), and algal bloom probability. The estimated load and in-lake predictions were then compared against measured in-lake concentrations. The attenuation factors for each subwatershed were used as calibration tools to achieve a close agreement between predicted in-lake TP and observed mean/median TP. However, perfect agreement between modeled concentrations and monitoring data were not expected as monitoring data are limited for some locations and are biased towards summer conditions when TP concentrations are expected to be lower than the annual mean predicted by the loading model.

3.1 Hydrologic Inputs and Water Loading

Calculating TP loads to Locke Lake requires estimation of the sources of water to the lake. The three primary sources of water are: 1) atmospheric direct precipitation; 2) runoff, which includes all overland flow to the tributaries and direct drainage to the lake; and 3) baseflow, which includes all precipitation that infiltrates and is then subsequently released to surface water in the tributaries or directly to the lake (i.e., groundwater). Baseflow is roughly analogous to dry weather flows in streams and direct groundwater discharge to the lake. The water budget is broken down into its components in Table 3-1.

- Precipitation - Mean annual precipitation was assumed to be representative of a typical hydrologic period for the watershed. The annual precipitation value was derived from the USGS publication: Open File Report 96-395, "Mean Annual Precipitation and Evaporation - Plate 2", 1996 and confirmed with precipitation data from weather stations in Epping, Durham, and Concord. For the Locke Lake watershed, 1.12 m of annual precipitation was used.

- Runoff - For each land use category, annual runoff was calculated by multiplying mean annual precipitation by basin area and a land use specific runoff fraction. The runoff fraction represents the portion of rainfall converted to overland flow.

- Baseflow - The baseflow calculation was calculated in a manner similar to runoff. However, a baseflow fraction was used in place of a runoff fraction for each land use. The baseflow fraction represents the portion of rainfall converted to baseflow.

Runoff and baseflow fractions from Dunn and Leopold (1978) were assumed to be representative for New Hampshire land uses and are listed in Tables C-1 and C-2 in Appendix C. The hydrologic budget was calibrated to a representative standard water yield for New England (Sopper and Lull, 1970; Higgins and Colonell 1971, verified by assessment of yield from various New England USGS flow gauging stations). Detail on the methodology used for the hydrologic budget estimation and calibration is presented in Appendix B.

Table 3-1 Locke Lake Water Budget

WATER BUDGET	M^3/YR
Atmospheric	693,108
Watershed Runoff	6,041,163
Watershed Baseflow	8,405,730
Total	15,140,001

3.2 Nutrient Inputs

Land Use Export

The Locke Lake watershed boundaries were delineated using NHDES delineations and corrected with USGS topographic maps when necessary. Land uses within the watershed were determined using several sources of information including: (1) Geographic Information System (GIS) data, (2) analysis of aerial photographs and (3) ground-truthing (when appropriate).

The TP load for each subwatershed was calculated using export coefficients for each land use type. The watershed loads for the Halfmoon Lake Watershed and the Locke Lake Watershed areas were adjusted based upon proximity to the lake, soil type, presence of wetlands, and attenuation provided by Best Management Practices (BMPs) for water or nutrient export mitigation. The watershed load (baseflow and runoff) was combined with direct loads (atmospheric, internal load, septic system, and waterfowl) to calculate TP loading. The generated load to the lake was then input into a series of empirical models that

provided predictions of in-lake TP concentrations, chl *a* concentrations, algal bloom frequency and water clarity. Details on model input parameters and major assumptions used to estimate the baseline loading (i.e., existing conditions) for Locke Lake are described below.

- Areal land use estimates were generated from land use and land cover GIS data layers from NH GRANIT. For Locke Lake, data sources are: Land cover data created by GRANIT using Lansat 5 and 7 imagery and other available raster and vector data; the 2001 NH Land Cover Assessment layer © Complex Systems Research Center, University of New Hampshire, and National Wetland Inventory (1971-1992). Land use categories were matched with the ENSR-LRM land use categories and their respective TP export coefficients. Table C-3 in Appendix C lists ENSR-LRM land use categories in which the GRANIT categories were matched. Land cover data and aerial photographs were used to determine certain land use classifications, such as agriculture and forest types. Selected land uses were confirmed on the ground during a watershed survey. Watershed land use is presented spatially in Figure 3-1 and summarized in Table 3-2.

- TP export coefficient ranges were derived from values summarized by Reckhow et al. (1980), Dudley et al. (1997) as cited in ME DEP (2003) and Schloss and Connor (2000). Table C-4 in Appendix C provides ranges for export coefficients, the runoff and baseflow export coefficient for each land use category in Locke Lake and the sources for each export coefficient.

Figure 3-1 Locke Lake Watershed Land Use Map

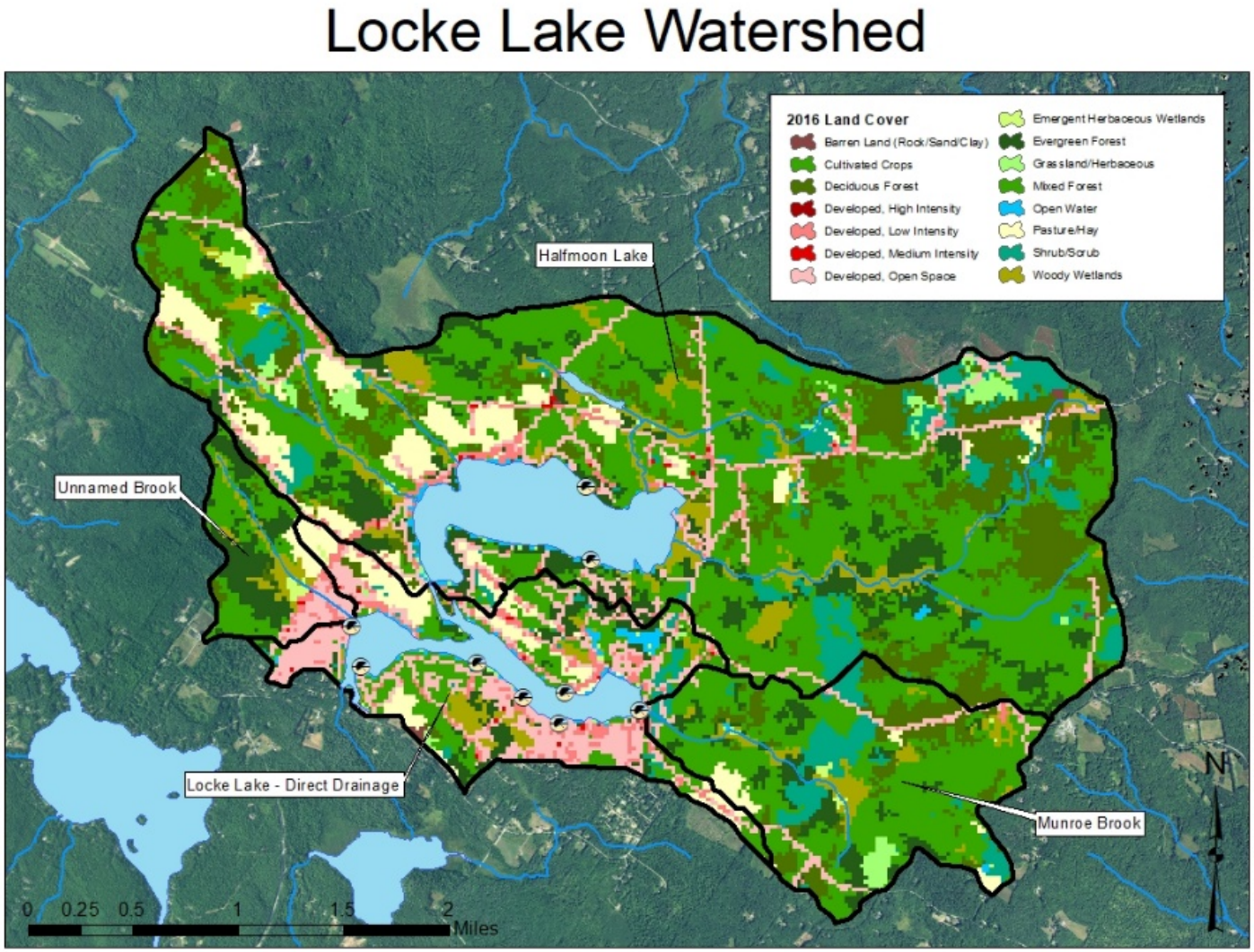


Table 3-2 Land Use Categories in Locke Lake Watershed

	Area (Hectares)	
	Hectares in Halfmoon Watershed	**Hectares in Locke Lake Watershed**
Urban 1 (Low Density Residential)	27.64	38.08
Urban 2 (Mid-Density Residential/Commercial)	2.06	2.51
Urban 3 (Shoreline)	0.00	0.00
Urban 4 (Industrial)	0.00	0.00
Urban 5 (Parks, Recreation Fields, Institutional)	20.79	9.99
Agric 1 (Cover Crop)	0.00	0.00
Agric 2 (Row Crop)	0.09	0.00
Agric 3 (Grazing)	0.00	0.00
Agric 4 (Hayland-Non Manure)	86.67	56.34
Forest 1 (Deciduous)	258.11	54.43
Forest 2 (Non-Deciduous)	150.14	96.76
Forest 3 (Mixed Forest)	637.92	287.37
Forest 4 (Wetland)	103.41	55.62
Open 1 (Wetland/Pond in the watershed, not the lake/pond)	121.60	5.50
Open 2 (Meadow)	91.71	47.07
TOTAL	1600.60	774.56

Atmospheric Deposition

Nutrient inputs from atmospheric deposition were estimated based on a TP export coefficient for direct precipitation. The atmospheric export coefficient of 0.11 kg/ha/yr includes both the mass of TP in rainfall and the mass in dryfall (Schloss, Craycraft, 2013). The sum of these masses is carried by rainfall. The coefficient was then multiplied by the lake area (ha) in order to obtain an annual atmospheric deposition TP load. The contribution of atmospheric deposition to the annual TP load to Locke Lake was estimated to be 6.1 kg/yr or approximately 1.1% of the total load.

Internal Loading

Internal loading does not appear to be a major factor in Locke Lake, which is evident from reviewing the VLAP and NHDES sampling data. In the 2018 VLAP Report, the August 2018 dissolved oxygen data depicts no significant change in dissolved oxygen and temperature from the top to the bottom of the lake at the deep spot sampling location. Similarly, the 2010 VLAP report documents the same lack of significant change in dissolved oxygen and temperature data at the deep spot in July. This indicates that the lake water does not likely stratify in the summer months and therefore has no significant internal loading of phosphorous. The internal loading in the model was therefore set equal to zero.

Septic Systems

TP export loading from residential septic systems was estimated for septic systems within the 250-foot shoreline zone. The minimum distance that new septic systems are allowed to be located adjacent to lakes/ponds in New Hampshire is 125 feet. A shoreline survey using GIS ortho-photographs as well as direct communications with residents and the Town of Barnstead was used to determine the number of year-round and seasonal residences within the 250-foot zone from the shoreline of the pond. It was assumed that if the dwelling was within the 250-foot zone that the septic system was also within the 250 foot zone. The TP load was calculated by multiplying a TP export coefficient (based on literature values for wastewater TP concentrations and expected water use), the number of dwellings, the mean number of people per dwelling, the number of days occupied per year, and an attenuation coefficient (Table C-6). In Locke Lake, the TP loading from shoreline septic systems was estimated to be 122.9 kg/yr, which is approximately 22.9% of the TP load to the lake.

The following assumptions were used to estimate the TP load from septic systems in the watershed.

- 450 residences were estimated to be year-round and 25 residences were estimated to be seasonal.
- Two-and-a-half people were estimated to reside in each dwelling. It was estimated that each resident uses 65 gallons per day for 365 days per year for year-round residents and 90 days for seasonal residents.
- The TP coefficients were calculated based on mean TP concentration in domestic wastewater of 8 mg/L and mean household water uses (Metcalf & Eddy, 1991).
- All septic loads to Locke Lake were attenuated 90% (Dudley and Stephenson, 1973; Brown and Associates, 1980) to account for TP uptake in the soil between the septic systems and the lake. There is no evidence in available watershed reports or evidence from site visits that the majority of the soils underlying the developed area immediately adjacent to Locke Lake has severe limitations for septic systems or has poor filtration characteristics.

Waterfowl

Total phosphorus load from waterfowl was estimated using a TP export coefficient and an estimate of annual mean waterfowl population from VLAP and NHDES observations during sampling events. The mean annual waterfowl population was estimated to be 200 birds per day during non-ice days. The TP export coefficient for the birds, 0.001526 kg/bird/day, was multiplied by 275 non-ice days/year times the mean waterfowl population per day in order to obtain a TP load of 83.93 kg/yr (Table C-7 in Appendix C). This equates to approximately 15.6% of the total TP load.

Phosphorus Loading Assessment Summary

The current TP load to Locke Lake was estimated to be 537.6 kg/yr from all sources. The TP load for each source is presented in Table 3-4.

Phosphorous loading from the surrounding watershed was the largest source at 324.7 kg/yr (approximately 60% of the TP load). The next largest TP source is from the septic systems at 83.9 kg/yr

(approximately 23% of the TP load) followed by the waterfowl load at 83.9 kg/yr (approximately 15.6% of the TP load).

Table 3-3 Locke Lake Current Phosphorus Loading Summary

TP INPUTS	Modeled Current TP Loading (kg/yr)	% of Total Load
Atmospheric	6.1	1.1
Internal Load from Hypolimnion	0.0	0.0
Waterfowl	83.9	15.6
Septic Systems	122.9	22.9
Halfmoon Lake Watershed Load	159.7	29.7
Locke Lake Watershed Load	165.0	30.7
Total	**537.6**	**100**

3.3 Phosphorus Loading Assessment Limitations

While the analysis presented above provides a reasonable accounting of sources of TP loading to Locke Lake, there are several limitations to the analysis:

- Precipitation varies among years and hence hydrologic loading will vary. This may greatly influence TP loads in any given year, given the importance of runoff to loading.
- Spatial analysis has innate limitations related to the resolution and timeliness of the underlying data. In places, local knowledge was used to ensure the land use distribution in the ENSR-LRM model was reasonably accurate, but data layers were not 100% verified on the ground. In addition, land uses were aggregated into classes, which were then assigned export coefficients; variability in export within classes was not evaluated or expressed.
- TP export coefficients as well as runoff/baseflow exports were representative but also had limitations as they were not calculated for the study water body, but rather are regional estimates.
- The TP loading estimates from atmospheric deposition, septic systems, internal loading and waterfowl were limited by the assumptions made in section 3.2.
- In some cases, water quality data for Locke Lake is limited, restricting calibration of the model.

3.4 Lake Response to Current Phosphorus Loads

TP load outputs from the ENSR-LRM Methodology were used to predict in-lake TP concentrations using five empirical models. The models include Kirchner-Dillon (1975), Reckhow (1977), Larsen-Mercier (1976), Jones-Bachmann (1976) and Nurnberg (1998). These empirical models estimate TP from system features, such as depth and detention time of the waterbody. The load generated from the export portion of ENSR-LRM was used in these equations to predict in-lake TP. The mean predicted TP concentration from these models was compared to measured (observed) values. Input factors in the export portion of the model,

such as export coefficients and attenuation, were adjusted to yield an acceptable agreement between measured and average predicted TP. Because these empirical models account for a degree of TP loss to the lake sediments, the in-lake concentrations predicted by the empirical models are lower than those predicted by a straight mass-balance (36 ug/L) where the mass of TP entering the lake is equal to the mass exiting the lake without any retention. Also, the empirical models are based on relationships derived from many other lakes. As such, they may not apply accurately to any one lake, but provide an approximation of predicted in-lake TP concentrations and a reasonable estimate of the direction and magnitude of change that might be expected if loading is altered.

Modeling results are presented in Table 3-5. The predicted TP load using the five empirical models in ENSR-LRM methodology corresponds to predicted mean annual in-lake concentrations ranging from 22 to 28 ug/L with an overall mean annual in-lake TP concentration of 26 ug/L. This is approximately 25% higher than the mean (21.2 ug/L) and 20% higher than the median (22.0 ug/L) summer epilimnetic TP concentrations based on samples collected from 2008 to 2019. Having summer epilimnetic concentrations lower than the predicted mean annual concentration is considered acceptable for the following reasons. Nearly all of the monitoring data are from the summer, a time when epilimnetic concentrations are typically lower than mean annual concentrations. The empirical models, however, all predict mean annual TP concentrations assuming fully mixed conditions. Nurnberg (1996) showed summer epilimnetic concentrations to be 14% lower than annual concentrations using a dataset of 82 dimictic lakes while Nurnberg (1998) indicated a difference of 40% using a dataset of 127 stratified lakes. Therefore, based on the Nurnberg studies, the predicted mean annual TP concentration should be higher than the measured summer epilimnetic concentration.

Once TP estimates were derived, annual mean chl *a* and SDT can be predicted based on another set of empirical equations: Carlson (1977), Dillon and Rigler (1974), Jones and Bachman (1976), Oglesby and Schaffner (1978), Vollenweider (1982), and Jones, Rast and Lee (1979). Bloom frequency was also calculated based on equations developed by Walker (1984, 2000) using a natural log mean chl *a* standard deviation of 0.5. These predictions are presented in Table 3-6.

Table 3-4 Predicted In-lake Total Phosphorus Concentration using Empirical

Empirical Equation	Equation	Predicted TP (*u*g/L)
Mass Balance	TP=L/(Z(F))*1000	36
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	28
Nurnberg 1984	TP=Lext/qs(1-Rpred)+Lint/qr	24
Vollenweider 1975	TP=L(1-Rlm)/(Z(F))*1000	28
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	28
Reckhow General 1977	TP=L/(11.6+1.2(Z(F)))*1000	22
Average of Above 5 Model Values		***26***
Observed Summer Epilimnion Mean		***21.2***
Observed Summer Epilimnion Median		***22.0***

Variable	Description	Units	Equation
L	Phosphorus Load to Lake	g P/m2/yr	
Z	Mean Depth	m	Volume/area
F	Flushing Rate	flushings/yr	Inflow/volume
S	Suspended Fraction	no units	Effluent TP/Influent TP
Qs	Areal Water Load	m/yr	Z(F)
Vs	Settling Velocity	m	Z(S)
Rp	Retention Coefficient (settling rate)	no units	((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs)
Rlm	Retention Coefficient (flushing rate)	no units	1/(1+F^0.5)

Table 3-5 Predicted In-lake Chlorophyll *a* and Secchi Disk Transparency Predictions based on an Annual Average In-lake Phosphorus Concentration of 26 ug/L

Empirical Equation	Equation	Predicted Value
Mean Chlorophyll		***u*g/L**
Carlson 1977	Chl=0.087*(Pred TP)^1.45	9.8
Dillon and Rigler 1974	Chl=10^(1.449*LOG(Pred TP)-1.136)	8.2
Jones and Bachmann 1976	Chl=10^(1.46*LOG(Pred TP)-1.09)	9.4
Oglesby and Schaffner 1978	Chl=0.574*(Pred TP)-2.9	12.0
Modified Vollenweider 1982	Chl=2*0.28*(Pred TP)^0.96	12.8
Average of Model Values		**10.4**
Observed Summer Mean		***7.5***
Peak Chlorophyll		***u*g/L**
Modified Vollenweider (TP) 1982	Chl=2*0.64*(Pred TP)^1.05	39.1
Vollenweider (CHL) 1982	Chl=2.6*(AVERAGE(Pred Chl))^1.06	31.2
Modified Jones, Rast and Lee 1979	Chl=2*1.7*(AVERAGE(Pred Chl))+0.2	35.6
Average of Model Values		**35.3**
Observed Summer Maximum*		***12.4***
Bloom Probability		***% of Summer***

Probability of Chl >15 *u*g/L	See Walker 1984 & 2000	16.4%
Secchi Transparency		***M***
Mean: Oglesby and Schaffner 1978 **Max:** Modified Vollenweider 1982	Chl=10^(1.36-0.764*LOG(Pred TP)) Chl=9.77*Pred TP^-0.28	1.9 3.9
Observed Summer Mean		***1.70***
Observed Summer Maximum		***2.0***

Variable	Description	Units
"Pred TP"	The average TP calculated from the 5 predictive equation models in Table 3-4	*u*g/L
"Pred Chl"	The average of the 3 predictive equations calculating mean chlorophyll	*u*g/L

*The observed summer maximum is based on n=48 and is not necessarily the peak chlorophyll

4.0 Total Maximum Daily Load

4.1 Maximum Annual Load

The annual load capacity is defined by the US EPA in 40 C.F.R. § 130.2(f) as, "The greatest amount of loading that a water can receive without violating water quality standards." The loading capacity is to be protective even during critical conditions, such as summertime conditions for TP loading to nutrient enriched lakes. The ENSR-LRM loading and lake response model was used to calculate the target annual TP load in (kg TP/yr) from the 12 ug/L target in-lake TP concentration discussed in Section 2.6. The TP loads that could practically be reduced were decreased until the target TP in-lake concentration was achieved. Further documentation of the ENSR-LRM model can be found in Appendix B.

The total maximum annual TP load that is expected to result in an in-lake annual mean TP concentration of 12 ug/L was estimated to be 249.9 kg/yr, which represents an approximate 54% reduction from existing conditions (Table 4-1).

4.2 Maximum Daily Load

Although a daily loading timescale is not meaningful for ecological prediction or long-term watershed management of lakes, this TMDL will present daily pollutant loads of TP in addition to the annual load. US EPA believes that there is some flexibility in how the daily loads may be expressed (US EPA 2006). Several of these options are presented in "Options for Expressing Daily Loads in TMDLs" (US EPA 2007).

The Locke Lake dataset and associated empirical model necessitates a statistical estimation of a maximum daily load because long periods of continuous simulation data and extensive flow and loading data are not available. US EPA (2007) provides such an approach.

The following expression assumes that loading data are log-normal distributed and is based on a long term mean load calculated by the empirical model and an estimation of the variability in loading.

$$MDL = LTA * e^{[z*\sigma - 0.5*\sigma^2]}$$

Where:

MDL = maximum daily limit
LTA = long-term average
Z = z-statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2 + 1)$
CV= coefficient of variation

For the Locke Lake TMDL a coefficient of variation (CV) of 1.1 and a 95% probability level of occurrence (z = 1.64) were used. The CV was calculated as the mean of the CV of loading from 18 subwatersheds draining to Goose Pond and Bow Lake in New Hampshire (Schloss 2008 unpublished data). The long-term average (LTA) load of 0.68 kg/day was calculated by dividing 249.9 kg/yr by 365 days. Based on this equation, the total maximum daily load of TP for Locke Lake is 2.0 kg/day, or approximately 4.4 lbs/day.

4.3 Future Development

Since the human population within a watershed may continue to grow and contribute additional TP to the impaired lakes, TMDLs often include an allocation for growth and associated future TP loading. For example, in Maine, target TP loading from anticipated future development is equivalent to a 1.0 ug/L change in in-lake TP concentration (Dennis et al. 1992). However, the NH water quality regulation Env-Wq 1703.3(a) General Water Quality Criteria states "The presence of pollutants in the surface waters shall not justify further introduction of pollutants from point and/or nonpoint sources." With regard to at least impaired waterbodies, existing loads due to development should be held constant, allowing no additional loading. In order for any future allocation of pollutant load(s) to be granted for an impaired waterbody, the load would need to be reduced elsewhere in the watershed. Given the antidegradation statement above (Section 2.4), this TMDL has been developed assuming no future increase in TP export from these impaired watersheds. However, it should be recognized that the NHDES has no mechanism for regulation/enforcement of TP export from developments of single house lots that do not require a Section 401 Water Quality Certification or fall under the thresholds for alteration of terrain permits (100,000 square feet of disturbance or 50,000 square feet within 250 feet of a lake). Municipalities can, however, regulate such development by revising their land use ordinances/regulations to require no additional loading of TP from new development.

4.4 Critical Conditions

Critical conditions in Locke Lake typically occur during the summertime, when the potential (both occurrence and frequency) for nuisance algal blooms are greatest. The loading capacity for TP was set to achieve desired water quality standards and thresholds during this critical time period and also provide adequate protection for designated uses throughout the year. This was accomplished by using a target concentration based on summer epilimnetic data and applying it as mean annual concentration in the predictive models used to establish the mean annual maximum load. Since summer epilimnetic values are typically about 14 to 40% less than mean annual concentrations (Nurnberg 1996, 1998), an annual load allocation based on summer epilimnetic concentrations will be sufficiently low to protect designated uses impacted by TP in the critical summer period.

4.5 Seasonal Variation

As explained in Section 4.4, the Locke Lake TMDL takes into account seasonal variations because the target annual load is developed to be protective of the most sensitive (i.e., biologically responsive) time of year (summer), when conditions most favor the growth of algae.

4.6 Reduction Needed

Current TP loading and in-lake concentrations are greater than required to support designated uses. The target TP concentration established in Section 2.6 was set to ensure that designated uses were supported. The degree of TP load reduction required to meet designated uses is calculated by subtracting the target load (Section 4.1) from the existing load estimated with ENSR-LRM (Section 3.3). Percent reductions are summarized in Table 4-1. Calculations are detailed in Table C-13 of Appendix C. As shown in Table 4-1, an approximate 54% reduction (287.7 kg/yr) from the total existing load is needed to attain a predicted in-lake target TP concentration of 12 ug/L. Table 4-1 shows one scenario where the reductions come from the two subwatersheds and waterfowl. Other load reduction scenarios are possible. As discussed in Section 7.0, compliance with this TMDL will not be based on meeting the TP target concentration or estimated TP load reduction target. Rather, compliance will be based on continued lake monitoring and assessment of monitoring results using the methods described for assessing water quality standards attainment in the most recent version of the Consolidated Assessment Listing Methodology[2] (CALM) for the response variables DO, cyanobacteria and chl a.

Table 4-1 Locke Lake Phosphorus Load Allocation

Inputs	Current Load (kg/yr)	Target Load to Obtain In-Lake Target Concentration (kg/yr)	Load Reduction to meet In-Lake Target Concentration (kg/yr)	% Reduction by Category
Atmospheric	6.1	6.1	0.0	0%
Internal	0.0	0.0	0.0	0%
Waterfowl	83.9	10.5	73.4	87%
Septic System	122.9	122.9	0.0	0%
Halfmoon Watershed Load	159.7	63.9	95.8	60%
Locke Lake Watershed Load	165.0	46.6	118.4	72%
Total Watershed Loads	**324.6**	**110.4**	**214.2**	**66%**
Modeled Annual Load	**537.6**	**249.9**	**287.7**	**54%**

[2] The CALM describes the process used to assess water quality data and determine if it is meeting standards or if it causing impairment and should be listed on the Section 303(d) list of impaired waters requiring a TMDL. The most recent version of the CALM when this TMDL report was written was the 2016 Section 305(b) and 303(d) Consolidated Assessment and Listing Methodology (NHDES, 2016b).

4.7 TMDL Development Summary

There is currently no numerical water quality standard for TP in the State of New Hampshire. However, the relationship between TP and algal biomass is well documented in scientific literature. This TMDL was therefore developed for TP and is designed to protect Locke Lake and its designated uses that are or may be impacted by excessive chl *a,* cyanobacteria and/or low dissolved oxygen concentrations.

In conclusion, water quality was linked to TP loading by:

- Choosing a target in-lake TP level, based on historic state-wide and in-lake water quality data, best professional judgment, and through consultation with NHDES and US EPA, that is sufficient to attain water quality standards and support designated uses. The target in-lake TP concentration target is 12 ug/L.

- Using the mean of five empirical models that link in-lake TP concentration and load, calibrated to lake-specific conditions, to estimate the load responsible for observed in-lake TP concentrations.

- Determining the overall mean annual in-lake TP concentration from those models, given that the observed in-lake concentrations may represent only a portion of the year or a specific location within the lake.

- Using the predicted mean annual in-lake TP concentration to predict Secchi disk transparency, chl *a* concentration and algal bloom frequency.

- Using the aforementioned empirical models to determine the TP load reduction needed to meet the numeric concentration target.

- Using a GIS-based spreadsheet model to provide a relative estimate of loads from watershed land areas and uses under current and various projected scenarios to assist stakeholders in developing TP reduction strategies.

Documentation of the model approach is presented in Appendix B. This approach is viewed as combining an appropriate level of modeling with the available water quality and watershed data to generate a reasonably reliable estimate of TP loading and concentration under historic, current and potential future conditions. It offers a rational estimate of the direction and magnitude of change necessary to support the designated uses protected by New Hampshire.

5.0 TMDL Allocation

The allocations for the Locke Lake TMDL are expressed as both annual loads and daily loads. However, annual loads better align with the design and implementation of watershed and lake management strategies. The TMDL requires an allocation of the total load of the resource. The allocation includes a waste load allocation (WLA), load allocation (LA), and margin of safety (MOS). The sum of these allocations is equal to the target annual load or TMDL for the resource. Each of these allocations is defined in detail in the following subsections. Seasonal variation is also included in the loading allocations.

The equation for the Locke Lake TMDL analysis is as follows:

$$TMDL = LA + WLA + MOS$$

In the case of Locke Lake, the TMDL is equivalent to the target annual load of 249.6 kg/yr. Allocations of this load are described below.

5.1 Wasteload Allocations (WLAs) and Load Allocations (LAs)

Wasteload allocations (WLAs) identify the portion of the loading capacity that is allocated to point sources and load allocations (LAs) identify the portion of the loading capacity that is allocated to nonpoint sources and natural background. Point sources may include stormwater outfalls and stormwater runoff from present or future construction activities. Nonpoint sources may include diffuse stormwater runoff, surface water base flow (including groundwater in seepage), septic systems, internal recycling, waterfowl, and atmospheric deposition. The real challenge in splitting out point sources from nonpoint sources resides with the available data. In order to accurately develop allocations for these two categories of sources it is typically necessary to have not only a complete accounting of each point source, but also a delineation of the associated drainage area and an estimate of existing pollutant loading. Generating this loading estimate is further compounded by the fact that stormwater discharges are highly variable in frequency, duration, and quality. Because sufficient information at the parcel level is usually not available, it is typically infeasible to draw a distinction between stormwater from existing or future regulated point sources, non-regulated point sources, and nonpoint sources. Much of the watershed load is assumed to be associated with stormwater. The WLA was set equal to the total watershed load of 324.6 kg/yr (see Table 4-1). The remaining 213 kg/yr (537.6-324.6) of the TMDL (which is attributable to atmospheric, septic system, waterfowl and internal loadings) was assigned to the LA. These allocations are also expressed as a percent reduction (see Table 6-1).

5.2 Margin of Safety (MOS)

A MOS in this TMDL accounts for substantial uncertainty in inputs to the model. The MOS can be either explicit or implicit. If an explicit MOS is used, a portion of the total target load is allocated to the MOS. If the MOS is implicit, a specific value is not assigned to the MOS. Use of an implicit MOS may be appropriate when assumptions used to develop the TMDL are believed to be so conservative that they sufficiently account for the MOS.

As discussed in section 2.6, an in-lake target concentration of 12 ug/L of TP was used to determine this TMDL. Setting the TMDL based on an in-lake target concentration of 12 ug/L includes an implicit MOS because the target of 12 g/L is primarily based on summer epilimnetic concentrations. This TMDL, however, is based on empirical models that predict mean annual TP lake concentrations assuming fully

mixed conditions. Studies on other lakes indicate that mean annual concentrations can be 14% to 40% higher than summer epilimnetic concentrations (Nurnberg 1996, 1998). A value of approximately 15 ug/L could have been used in the models to predict the TMDL. However, in order to include an MOS, 12 ug/L was used. By setting the target equal to 12 ug/L in the models used to determine the TMDL, an implicit MOS of approximately 20% is provided.

See Appendix A for further discussion of the MOS for each of the three approaches used to set the target and Appendix B for detailed descriptions of the model sensitivities, limitations and the methodology for proper calibration and validation of the model.

6.0 Evaluation of Alternative Loading Scenarios

The ENSR-LRM model was used to evaluate a number of alternative loading scenarios and the probable lake response to these loadings. These scenarios included:

- Current Loading (Baseline).
- Natural Environmental Background Loading (Predevelopment).
- Removal of Septic Load.
- Removal of Load from Waterfowl.
- Reduction of Watershed, Waterfowl and septic Loads to Meet In-lake Target of 12 ug/L.

The current loading scenario (baseline model run) is discussed above in Section 3.0. Each scenario described below represents a reduction from the current loading scenario. The discussion of each scenario includes only the portions of the current loading scenario that were altered for the specific simulation. A comparison of the results of each of the alternative scenarios is presented in Tables 6-1 and 6-2.

Table 6-1 Comparison of Phosphorous Loading Scenarios for Locke Lake

Inputs	Baseline Load (kg/yr)	No Septic Loads (kg/yr)	No Birds (kg/yr)	Predevelopment Load (kg/yr)	Target Model Run
Atmospheric	6.1	6.1	6.1	6.1	6.1
Internal	0.0	0.0	0.0	0.0	0.0
Waterfowl	83.9	83.3	0.0	0.0	10.5
Septic System	122.9	0.0	122.9	0.0	122.9
Halfmoon Watershed Load	159.7	159.7	159.7	114.2	63.9
Locke Lake Watershed Load	165.0	165.0	165.0	108.6	46.6
Modeled Annual Total Load kg/yr	537.6	414.0	453.6	228.8	249.9
Total Overall Load Reduction kg/yr	0.0	123.5	83.9	308.7	287.6
Total Percent Overall Reduction	0%	23%	16%	57%	54%
Total Watershed Load kg/yr	324.7	324.7	324.7	222.8	110.5
Total Watershed Reduction kg/yr	0	0.0	0.0	101.9	214.2
Percent Watershed Load Reduction %	0%	0%	0%	31%	66%

Table 6-2. Lake Water Quality Response to Different Loading Scenarios for Locke Lake

Parameters	Baseline/Current Load	Predevelopment / Natural Environmental Background	Baseline/Current Load without Septic Load	Baseline/Current Load without Waterfowl	Target Model Run with some loads reduced to achieve in-lake TP of 12 ug/L
TP Load (kg/yr)	537.6	228.8	414.7	453.6	249.9
Mean Annual TP (*u*g/L)	26	12.2	20.1	21.9	12
Mean Secchi Disk Transparency (m)	1.9	3.4	2.3	2.2	3.4
Mean Chlorophyll *a* (*u*g/L)	10.4	3.9	7.5	8.4	3.8
Peak Chlorophyll *a* (*u*g/L)	35.3	14	25.9	28.7	13.7
Probability of Summer Bloom (Chl *a* > 15 *u*g/L) %	16.4%	0.2%	5.1%	7.8%	0.1%

6.1 Natural Environmental Background Phosphorus Loading

Natural environmental background levels of TP in the lake were evaluated using the ENSR-LRM model. Natural background was defined as background TP loading from non-anthropogenic sources or the predevelopment scenario. Hence, land uses in the watershed were set to its assumed "natural" state of forests and wetlands. Loading was then calculated using the ENSR-LRM model as described above. This estimate is useful as it sets a realistic lower bound of TP loading and in-lake concentrations possible for Locke Lake. Loadings and target concentrations below these levels are very unlikely to be achieved.

To estimate background loading the septic loads were removed, waterfowl loads were kept the same and all developed lands were converted to mixed forest lands. Wetland areas were not changed because it was assumed no wetland had been lost due to development. The TP load under this scenario is 228.8 kg/yr. The calculated background loading of TP to Locke Lake would result in a mean in-lake TP concentration of 12.2 ug/L, a mean Secchi Disk transparency of 3.9 m, a mean chlorophyll a concentration of 3.9 ug/L and a bloom probability of chl *a* > 15 ug/L of 0.2%. Estimated TP loading to the lake under this scenario is approximately 57% lower than current loads to the lake.

6.2 Septic System Load Removal

This scenario involved removal of the septic loads only. It is a reasonable approximation of what would occur if the lake were sewered or all existing septic systems exported TP at a negligible concentration. Under this scenario, the total loading is 414.7 kg/yr, which is approximately 23% lower than the current loading and would likely not support designated uses based on the predicted values in Table 6-2. Removal of all septic sources would likely be costly and not substantially impact the lake. However, this analysis did not account for actively failing septic systems. Such systems may have localized impacts on TP and should be addressed as they are discovered.

6.3 Internal Load Removal

The sampling data from Locke Lake indicates that the lake water stays mixed throughout the summer and the lake does not form a hypolimnion. Internal loading in the model is calculated from the area of the hypolimnion, so in the case of Locke Lake, a scenario to remove the internal loading was not run.

6.4 Waterfowl Reduction

This scenario examined the impact on TP loading if all of the birds were removed from the pond. Under this scenario, internal loading is removed as a source of TP. Removal of all bird loadings results in a total load of approximately 453.6 kg/yr, which is approximately 15% lower than the current loading and would likely not support designated uses based on the predicted values in Table 6-2.

6.5 Reduction of Watershed and Waterfowl to Meet In-lake Target of 12 ug/L

As discussed in sections 2.6 and 6.1, and as shown in Tables 4-1 and 6-1, this TMDL is based on a target in-lake TP concentration of 12 ug/L for Locke Lake. To achieve this load, current loads must be reduced by approximately 54 % (Tables 4-1 and 6-1). A target model run was set up to simulate reductions in the watershed and waterfowl loads. Table 4-1 shows that in order to achieve an in-lake TP concentration of 12 ug/L, a reduction of approximately 66% in the surrounding watershed area would meet an in-lake TP concentration of 12 ug/L. This reduction in overall watershed loading is technologically achievable as it is within the maximum estimated achievable watershed reductions of approximately 60-70% (Center for Watershed Protection, 2000).

While the individual source load reduction scenarios presented above provide a reasonable accounting of their individual impacts on the total contributions to the lake, a combination of implementation measures are typically needed to reduce loads.

7.0 Implementation Plan

Successful implementation of this TMDL will not be based on meeting the in-lake target TP concentration of 12 ug/l or the reduction target of 54% (387.7 kg/yr reduction) to achieve the target load of 249.9 kg/yr (see Table 4-1). Rather, compliance will be based on continued lake monitoring and assessment of monitoring results using the methods described for assessing water quality standards attainment in the most recent version of the Consolidated Assessment Listing Methodology[3] (CALM) for the response variables DO, cyanobacteria and chl a.

To track progress towards the load reduction goal, it is recommended that estimates of TP reductions associated with each load reduction activity be quantified. After significant load reductions have been implemented, monitoring should be conducted to determine if compliance has been achieved or if additional reductions are necessary. This is especially important when the estimated TP load reductions associated with implemented activities approach the load reduction goal since it's possible that, due to the model uncertainties, compliance will be achieved before the TP load reduction goal is met. The process of implementing load reduction activities and monitoring in a step-wise fashion is called phased implementation and is the recommended approach for implementing this TMDL.

The discussion below provides general recommendations for possible future load reduction activities (commonly called best management practices or BMPs). The recommendations are intended to provide options of potential watershed and lake management strategies that can improve water quality to achieve compliance. Although a comprehensive diagnostic/feasibility study and detailed implementation plan is beyond the scope of this report, the following discussion should help to narrow the range of management options in accordance with assumed loading issues and desired loading reductions.

A possible scenario to achieve the overall 54% reduction is provided in Table 4-1. As shown, this scenario assumes a watershed load reduction of approximately 66% (214.2 kg/yr reduction) and a waterfowl load reduction of 87% (73.4 kg/yr reduction) under this scenario. As discussed in Section 6.5 and Section 6.6, other combinations of source reductions are possible which may become evident as monitoring continues and the implementation plan is refined.

With regards to watershed load reductions, Table 4-1 indicates that approximately 66% (214.2 kg/yr) of the current watershed TP load should be reduced. This reduction in subwatershed and overall watershed loading should be technologically achievable as it is within the maximum estimated achievable reduction of approximately 60-70% (Center for Watershed Protection 2000). It is assumed that watershed reductions would be obtained mainly from the runoff portion of the load and, as stated earlier, it is anticipated that implementation would be phased in over a period of several years, with monitoring and adjustment as necessary.

As discussed in section 4.3, this TMDL has been developed assuming no future increase in TP export from the Locke Lake watershed. Since NHDES has no mechanism for regulation/enforcement of TP export from developments of single house lots that do not require a Section 401 Water Quality Certification or fall

---

[3] The CALM describes the process used to assess water quality data and determine if it is meeting standards or if it causing impairment and should be listed on the Section 303(d) list of impaired waters requiring a TMDL. The most recent version of the CALM when this TMDL report was written was the 2016 Section 305(b) and 303(d) Consolidated Assessment and Listing Methodology (NHDES, 2016b).

under the thresholds for alteration of terrain permits (100,000 square feet of disturbance or 50,000 square feet within 250 feet of a lake) it is recommended that municipalities within the Locke Lake watershed regulate such development by revising their land use ordinances/regulations to require no additional loading of TP from new development.

Any areas of natural wetlands in the Locke Lake watershed should also be preserved as they naturally serve to slow runoff water thereby encouraging infiltration of water and removal of TP through settling, soil adsorption and plant uptake. These functions should be maintained. Maintaining buffers of vegetation (shrubs and trees) between lawns areas and the pond, especially in the direct drainage area closest to the pond, can also increase infiltration of runoff to the pond.

With regards to reducing existing watershed loads, there are a number of watershed BMPs that may be appropriate for implementation in the Locke Lake watershed (Table 7-1). In general, these BMPs fall into three main functional groups: 1) Recharge/Infiltration Practices, 2) Low Impact Development Practices, and 3) Extended Detention Practices. Table 7-1 lists the practices, the pollutants typically removed and the degree of effectiveness for each type of BMP. Specific information on the BMPs is well summarized by the Center for Watershed Protection (2000).

Waterfowl on the lakes contribute to nutrient loading. The scenario presented in Table 6-1 assumes a large reduction (87 percent) in the number of waterfowl (i.e., from an average of 200 to 25 birds per day during the ice-out period). This reduction in waterfowl is estimated to result in a TP load reduction of approximately 73.4 kg/yr (83.9 kg/yr minus 73.4 kg/yr = 10.5 kg/yr target) which represents 4% of the total target load reduction. Efforts to reduce the number of waterfowl can have a significant impact on the total load reduction target. Elimination of waterfowl feeding, discouraging waterfowl with the use of decoys (such as trumpeter swan and coyote) and the regrowth of a vegetated buffer around the immediate shoreline can help reduce the resident waterfowl population and associated TP loadings. Since bird feces are also a source of bacteria, bird deterrence activities have an added benefit of reducing bacteria loading into the lake.

On July 1, 2010, New Hampshire passed a law that banned phosphates in household cleaners (RSA 485-A55 and 56). In addition, on June 4, 2013, New Hampshire passed a new fertilizer law (RSA:431) which limits the nutrient content (total phosphorous and soluble and total nitrogen) and application rates of residential turf fertilizer[4]. The fertilizer law became effective on January 1, 2014. Encouraging minimal use of fertilizers is recommended. Both of these statutes should help to reduce the impact of TP loading in Locke Lake. The elimination of phosphates from household cleaning products, the use of fertilizers with low levels of TP along with efforts to remove exotic weeds (milfoil and fanwort) may partly explain the apparent decreasing trend in TP. Other factors, such as weather, can also significantly affect in-lake TP concentrations.

[4] The law only applies to fertilizer applied to residential turf. It does not apply to agricultural land, golf courses, parks, athletic fields and sod farms. According to 431:4-b Phosphorus Content of Fertilizer. –
I. No fertilizer sold at retail that is intended for use on turf shall exceed a content level of 0.67% available phosphate unless specifically labeled for establishing new lawns, for repairing a lawn, for seeding, or for use when a soil test indicates a phosphorus deficiency.

To estimate the load reduction due to application of fertilizers containing essentially no TP (i.e., no more than 0.67%), Appendix F Attachment 2 of EPA's 2016 Draft MS4 permit provides the following equation.

$$\textbf{Credit}_{\text{no P fertilizer}} = (\textbf{Area}_{\text{turf grass no TP}}) \times (\textbf{PLER}_{\text{PC-HSG}}) \times (0.33)$$

Where:
Credit (no TP fertilizer) = Amount of TP load reduction credit for not applying fertilizers containing TP (lbs/year)

Area = All applicable turf grass area within (acres)

PLE PC – HSG Land Use = Phosphorous Load Export Rate for pervious cover and HSG (lbs/hectare/yr)

0.33 = 33% TP Load reduction factor for not applying fertilizers containing phosphorous.

If the following is assumed for Locke Lake:

- HSG-C is the predominant soil type;
- the total area of the Urban 1 (Low Density Residential), Urban 2 (Medium Density) and Urban 5 (Parks, Recreation Fields and Institution) in the Locke Lake watershed (including the Halfmoon and Locke Lake subwatesheds) are 65.72, 4.57 and 30.78 hectares (Ha) respectively;
- 89%, 89%, and 92% of the area in the Urban 1, Urban 2 and Urban 5 land uses respectively are pervious;
- 35% of the pervious area is considered fertilized turf; and
- a PLE of 0.24 kg/Ha/yr (from Table 2-1 in Appendix F, Attachment 2 of the MS4 permit);

The estimated load reduction in the Locke Lake watershed due to use of fertilizer without TP is approximately 15.7 kg/yr. This represents less than 1% (0.94%) of the total watershed target load reduction. This estimate is based on assumptions regarding soil grouping and turf area where no TP fertilizer is applied which should be better quantified and confirmed. Nevertheless, it does provide a rough idea of the magnitude of reductions MS4 communities may be able to claim for using no TP fertilizer.

Increasing the frequency of street sweeping is another non-structural BMP that can be used to reduce TP loadings. Example calculations are provided in Appendix F of the 2017 NH MS4 permit.

Structural BMPs such as detention, bioretention and infiltration practices can improve the quality of storm water originating from the roads and developments in the Locke Lake watershed. These BMPs help to reduce channel erosion and reduce TP concentrations by plant uptake, settling and contact with the soil prior to entry to the lake. Information on how to design many structural BMPs is available in the NH Stormwater Manual, Volume 2.

This type of stormwater detention can be further enhanced by the construction of vegetated rain gardens (a form of bioretention) to capture and treat stormwater runoff to further reduce sediment and nutrient loading. In particular, the area of erosion at the public beach at the north end of the lake may be a good candidate for rain garden installation to divert and infiltrate the runoff across the sandy beach. Once again, Appendix F of the MS4 permit includes methods to calculate TP load reductions for these BMPs. Additional

information for homeowners and municipalities can be found on the NHDES Stormwater Management for Homeowners webpage.

Retrofitting developed land with low impact designs is a highly desirable option, especially near the lake. Numerous homes are very close to the lake and provide limited vegetated buffer. Educational programs can help raise the awareness of homeowners on how they can alter drainage on their property to reduce nutrients entering the lake. Another option to engage the community is through technical assistance programs, such as BMP training for municipal officials and septic system inspection programs. Guidelines for evaluating TP export to lakes are found in "Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development" (Dennis et al., 1992). Recent guidance for low-impact living on the shoreline, "Landscaping at the Water's Edge: An Ecological Approach," has been developed by UNH Cooperative Extension (2007). In addition, good housekeeping measures such as strict adherence with pet waste ordinances are highly recommended.

With regards to possible funding, Section 319 of the Clean Water Act was established to assist states in nonpoint source control efforts. Under Section 319, grant money can be used for technical assistance, financial assistance, education training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects.

US EPA has identified a minimum of nine elements that must be included in a Section 319 management plan for achieving improvements in water quality. A summary of the nine elements is provided below. The full description can be found in US EPA (2005).

1) Identification of causes of impairment and pollutant sources.

2) An estimate of the load reductions expected from management measures.

3) A description of the nonpoint source measures needed to achieve load reductions.

4) An estimate of the technical and financial assistance needed and the cost.

5) An information and education component.

6) A schedule for implementation.

7) Description of milestones to determine if goals are being met.

8) Criteria to determine progress in reducing loads.

9) Monitoring to evaluate effectiveness of implementation efforts over time.

This TMDL was written to meet the criteria of the first element. Application materials and instructions for 319 funding can be obtained through:

Nonpoint Source Coordinator
New Hampshire Department of Environmental Services
29 Hazen Drive
P.O. Box 95
Concord, NH 03302
Watershed Assistance Section Grants/Loans

Proactive planning can prevent the further degradation of lake water quality. The TMDL process is intended to give a direction and goal for planning and watershed management. As the lake improves, the implementation strategy should be re-evaluated and adjusted as necessary using current monitoring data and modeling, until compliance is ultimately achieved (i.e., the phased implementation approach).

Table 7-1 Best Management Practices Selection Matrix

Key
- Adverse Impact
- Moderate Mitigation
- Good Mitigation
- Minimal Mitigation
- Moderately Suited
- Well Suited
- Not Applicable

Management Practice	Ability to Mitigate															Applicability							Notes
	Runoff Volume (↓)	Peak Flow Rates (↓)	Bankfull Flow (↓)	Baseflow (↓)	Mod. Sed. Transport	Channel Morph. Changes [1]	In-Stream Temp. (↓)	Sediment conc. (↓)	Nutrient conc. (↓)	Metal Conc. (↓)	Hydrocarbon Conc. (↓)	Bacteria/Pathogens (↓)	Organic carbon Conc. (↓)	MTBE Conc. (↓)	Pesticide conc. (↓)	Deicer conc. (↓)	New Development	Retrofit	Urban	Sub-Urban	Residential Sub-Division	Commercial	Industrial	
Recharge / Infiltration Practices[2]																								
Infiltration Swale	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	Permeable site soils required. Pre-treatment recommended.
Infiltration Trench/Galley	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Permeable site soils required. Pre-treatment recommended.
Retention/Infiltration Basin	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	Permeable site soils required. Pre-treatment recommended.
Low Impact Development Practices																								
Bioretention	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Disconnecting Impervious Area	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Minimal Mitigation	Well Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Flow Path Practices	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Includes increasing roughness, sheet flow, flow path length, and flattenting slopes.
Green Roof	Good Mitigation	Good Mitigation	Good Mitigation	Minimal Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Well Suited	Moderately Suited	Well Suited	Well Suited	Moderately Suited	Well Suited	Well Suited	
Minimize Disturbance Area	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Minimize Site Imperviousness	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Includes imiting use of sidewalks, and reducing road/driveway length/width.
Porous Pavement	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Preserve Infiltratable Soils	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Preserve Natural Depression Areas	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Rain Barrels/Cisterns	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Rain Garden	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Good Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Soil Amendment	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Well Suited	Well Suited	Moderately Suited	Well Suited	Well Suited	Moderately Suited	Moderately Suited	Used as a component of LID site design.
Vegetated Filter Strip	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Well Suited	Well Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Vegetation Preservation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Extended Detention Practices																								
Created Wetland/Biofilter Detention	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Moderate Mitigation	Adverse Impact	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Extended Detention Pond	Minimal Mitigation	Good Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Moderate Mitigation	Adverse Impact	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Minimal Mitigation	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Wet Detention	Minimal Mitigation	Good Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Moderate Mitigation	Adverse Impact	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Good Mitigation	Adverse Impact	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Minimal Mitigation	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Other Best Management Practices																								
Deep Sump Catch Basins	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Moderate Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Pre-treatment prior to infiltration BMPs
Sand/Organic Filter	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Minimal Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Swale	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Moderate Mitigation	Moderate Mitigation	Good Mitigation	Moderate Mitigation	Moderate Mitigation	Minimal Mitigation	Moderate Mitigation	Minimal Mitigation	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	Dry swale with some infiltration.
Water Quality Inlet	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Moderate Mitigation	Minimal Mitigation	Minimal Mitigation	Moderate Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Minimal Mitigation	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Includes proprietary hydrodynamic devices. Pre-treatment prior to exfiltration BMPs.

[1] *Impacts include channel enlargement/incision/embededness, changes in pool/riffle structure, and reduced channel sinousity.*

[2] *Recharge and infiltration measures require permeable soils and pre-treatment is recommended. See specific BMP descriptions for more information.*

8.0 Monitoring Plan

NHDES conducted water quality monitoring of Locke Lake in the summers of 2010 for a Lake Trophic Study. The deepest site in the center of the lake is the primary sampling location in Locke Lake (Figure 2-3). Water quality samples collected during the summer are tested for epilimnetic and hypolimnetic TP. In addition, a composite sample of the water column to the depth of the thermocline is tested for chl *a*. A DO profile from top to bottom is conducted and a Secchi disk transparency measurement is taken.

Volunteer Monitors have collected additional samples on Locke Lake since 2002. Samples collected by volunteers are analyzed for alkalinity, chlorophyll a, chloride, specific conductance, E coli, total phosphorous, transparency, turbidity and pH. It is recommended that VLAP sampling be continued to document the in-lake response, trends, and compliance with water quality criteria and thresholds following implementation of TP reduction measures. Assessment of the data should be in accordance with the most recent NHDES Consolidated Assessment and Listing Methodology (NHDES, 2016b). As discussed in the previous section, successful implementation of this TMDL will be based on compliance with water quality criteria for TP and thresholds for planktonic chl *a* and cyanobacteria. To help prioritize implementation of TP reduction measures in the subwatersheds, it may be instructive for stakeholders to collect dry and wet weather TP samples (along with estimates of flow) in tributaries draining to the Lake (such as the Whiting Brook on the northwest side of the lake). Estimates of the TP loads can then be calculated using the concentration and flow data[5]. Tributaries impacted by humans (i.e., not natural) with the highest TP load would be the target of initial efforts to reduce TP.

Given the population density around both Halfmoon Lake and Locke Lake, septic systems are a significant source of TP loading in the watershed. A survey of septic systems would help confirm model input, including the assumption that there are no failed septic systems. Finally, bird counts should be regularly recorded to better quantify their impact and provide a baseline to measure mitigation measures.

Prior to implementation of any new monitoring activities associated with this TMDL, it is recommended that NHDES be consulted to help ensure that the monitoring plan will achieve its objectives. Monitoring assistance from NHDES is contingent on the availability of sufficient staff and funding.

[5] Concentration multiplied by flow multiplied by an appropriate conversion factor yields a load.

9.0 Reasonable Assurances

The TMDL provides reasonable assurances that nonpoint source reductions will occur by providing information on the cooperative efforts of the NHDES and watershed stakeholders to initiate the process of addressing nonpoint source pollution in the watershed. The successful reduction in nonpoint TP loading, however, depends on the willingness and motivation of stakeholders to get involved and the availability of federal, state and local funds.

Section 5.1 describes how wasteload allocations (WLAs) from regulated point sources and non-regulated load allocations (LAs) for nonpoint sources were determined. Given the difficulty in accurately separating these sources, it's possible the WLA may include some loads from nonpoint sources. The state fully acknowledges that it will take a concerted effort to reduce phosphorus loading to the maximum extent practicable from as many sources as possible in order to fully support designated uses in this waterbody. In some cases, phosphorus reductions from individual sources can and should be greater than the prescribed reductions in this TMDL, in order to make up for areas of the watershed where greater reductions are not attainable.

Reasonable assurance that non-regulated point source and nonpoint source load reductions will occur include the following:

- RSA 485-A:12, which requires persons responsible for sources of pollution that lower the quality of waters below the minimum requirements of the classification to abate such pollution, will be enforced.

- To the extent resources are available; NHDES will work with watershed stakeholders to identify specific phosphorus sources within the watershed. Technical assistance is available to mitigate phosphorus export from existing nonpoint sources. Requests for 319 funding to implement specific BMPs within the watershed typically receive high priority. The NHDES Stormwater Manual provides information on site design techniques to minimize the impact of development on water quality as well as BMPs for erosion and sediment control and treatment of post-construction stormwater pollutants. Also of use to municipalities is the Innovative Land Use Planning Techniques Handbook, which provides model municipal ordinances including one on post-construction stormwater management. Both documents are accessible on the NHDES website NHDES staff also provides assistance by working with Lake Associations to identify LID projects that would qualify for 319 funding.

- Per RSA 483-A:7 Lakes Management and Protection Plans, the lakes coordinator and the Office of Energy and Planning, in cooperation with regional planning agencies, and appropriate council on resources and development agencies, shall provide technical assistance and information in support of lake management and local shoreland planning efforts consistent with the guidelines established under RSA 483-A:7, and compatible with the criteria established under RSA 483-A:5**.**

- For lakes included in the NHDES Volunteer Lake Assessment Program, NHDES staff typically meets with participants on an annual basis during field sampling visits and annual workshops at which time discussions can be held regarding TP reduction opportunities and how to secure 319 grants where eligible.

10.0 Public Participation and Substantive Changes

10.1 Public Participation and Comment

US EPA regulations (40 CFR 130.7 (c) (ii)) require that calculations to establish TMDLs be subject to public review. The following is a description of the public review process for this TMDL.

On August 26, 2020, a public notice (see Figure 10-1 below) announcing the availability of the draft TMDL for public review and comment and the Draft TMDL Report were posted on the NHDES TDML website and sent to stakeholders.

The following stakeholders were notified directly by email or mail:

- Town of Barnstead, NH.
- Town of Barnstead Conservation Commission.
- Locke Lake Association.

Written public comments were accepted from August 26, 2020 through September 23, 2020.

10.2 Summary of Comments Received and Substantive Changes Made in the Final Report

This section will be completed after the public comment period is completed for this draft report.

Figure 10-1 Public Notice

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

Date: August 26, 2020

Subject: **PUBLIC NOTICE – Draft Locke Lake Phosphorus TMDL Report Available for Public Comment**

PUBLIC COMMENTS ACCEPTED UNTIL 4 PM ON SEPTEMBER 23, 2020

Dear Interested Party or Stakeholder:

The Draft Total Maximum Daily Load (TMDL) report to address water quality issues associated with phosphorus in Locke Lake in Barnstead, New Hampshire is now available for public review and comment on the New Hampshire Department of Environmental Services (NHDES) TMDL publications website.

A copy of the report is also available for review at the Barnstead Town Hall.

Locke Lake is on the NH 2016 list of impaired waters [i.e. the section 303(d) list] because of elevated levels of chlorophyll a (a measure of plant growth such as algae) and total phosphorous. Phosphorus is the nutrient responsible for algal growth in most freshwater lakes, ponds and rivers. The TMDL report identifies an in-lake target phosphorus value that, when met, should result in attainment of New Hampshire surface water quality standards. The report also includes a phosphorus budget, identification of phosphorus sources, recommended phosphorus reductions for each source to meet the target value as well as potential watershed remediation activities to reduce phosphorus inputs to the waterbodies.

Comments will be accepted until 4 pm on September 23, 2020. Only written comments will be accepted. All comments must include the name of the TMDL, the date and contact information (your name, address, phone, e-mail, and organization.)

Comments can be mailed to:

TMDL Program
NHDES Watershed Management Bureau
29 Hazen Drive, P.O. Box 95
Concord, NH 03301
Attention Margaret P. Foss, TMDL Coordinator

or sent by email to TMDL@des.nh.gov. A public comment form can be found at the NHDES TMDL website. Use of the form is optional.

If you have any questions about the report, please contact Margaret Foss, NHDES TMDL Coordinator at margaret.foss@des.nh.gov

11.0 References

Brown and Associates. (1980). An assessment of the impact of septic leach fields, home lawn fertilization and agricultural activities on groundwater quality. Prepared for NJ Pinelands Commission. K.W. Brown and Associates, College Station, TX.

Carlson, R. (1977). A Trophic State Index for Lakes. *Limnology and Oceanogr*aphy, 22, pp. 261-369.

Center for Watershed Protection. (2000). National Pollutant Removal Performance Database, 2nd ed. CWP, Ellicot City, MD.

Connecticut Department of Environmental Protection and ENSR. (2004). A Total Maximum Daily Load Analysis for Kenosia Lake in Danbury, Connecticut. Available at http://www.ct.gov/dep/lib/dep/water/tmdl/tmdl_final/kenosialaketmdl.pdf [Accessed March 20, 2007].

Craycraft, R. and Schloss, J. (2005). Baboosic Lake Water Quality Monitoring: 2005, Center for Freshwater Biology, University of New Hampshire.

Dennis, J., Noel, J., Miller, D., Elliot, C., Dennis, M.E. and Kuhns, C. (1992). Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development. Maine Department of Environmental Protection, Augusta, Maine.

Dillon, P.J. and Rigler, F.H. (1974). The Phosphorus-Chlorophyll Relationship in Lakes. *Limnol0gy and Oceanography* 19, pp. 767-773.

Dudley, J.G. and Stephenson, D.A. (1973). Nutrient Enrichment of Ground Water from Septic Tank Disposal Systems. Upper Great Lakes Regional Commission.

Dudley, R.W., Olson, S.A. and Handley, M. (1997). A preliminary study of runoff of selected contaminants from rural Maine highways. U.S. Geological Survey, Water-Resources Investigations Report 97-4041 (DOT, DEP, WRI), 18 pages.

Dunn, T. and Leopold, L.B. (1978). Water in Environmental Planning. W.H. Freeman and Company, San Francisco, CA.

Economic and Labor Market Information Bureau. (2007). New Hampshire Employment Security. Available at: http://www.nh.gov/nhes/elmi/communpro.htm [Accessed 11 November 2007].

ENSR. (2007). New Hampshire Lakes Total Maximum Daily Load (TMDL) Project Data Collection from Outside Sources. Prepared for US EPA Region 1.

Higgins, G.R. and Colonell, J.M. (1970). Hydrologic Factors in the Determination of Watershed Yields. Publication #20. WRRC, UMASS, Amherst, MA.

Jones, J. and Bachmann, R. (1976). Prediction of Phosphorus and Chlorophyll Levels in Lakes. JWPCF 48, pp. 2176-2184.

Jones, R.A., Rast, W. and Lee, G.F. (1979). Relationship between summer mean and summer maximum chlorophyll *a* concentrations in lakes. Env. Sci. & Technol. 13, pp. 869-870.

Kirchner, W. and Dillon, P. (1975). An Empirical Method of Estimating the Retention of Phosphorus in Lakes. Water Resourc. Res. 11, pp. 182-183.

Larsen, D. and Mercier, H. (1976). Phosphorus Retention Capacity of Lakes. J. Fish. Res. Bd. Can. 33, pp. 1742-1750.

Maine Department of Environmental Protection. (2003). Three-cornered Pond PCAP-TMDL. Maine DEP LW 2002-0562.

Metcalf & Eddy, Inc. (1991). 3rd ed. Wastewater Engineering Treatment, Disposal and Reuse. Tchobanoglous, G. and Burton, F.L. McGraw-Hill, Inc.: New York.

Mitchell, D.F, Wagner, K.J., Monagle, W.J. and Beluzo, G.A. (1989). A Littoral Interstitial Porewater (LIP) Sampler and Its Use in Studying Groundwater Quality Entering a Lake. *Lake and Reservoir Management*, 5(1), pp. 121-128.

New Hampshire Department of Environmental Services. (2018). *Locke Lake Trophic Report*.

New Hampshire Department of Environmental Services. (2005). *Analysis of NH DES Data to Determine Preliminary Total Phosphorus Criteria for Freshwaters*. [Interoffice memorandum from Phil Trowbridge to Greg Comstock]. August 5, 2005.

New Hampshire Department of Environmental Services. (2006). NH Volunteer Lake Monitoring Program Reports. Available at: http://www.des.state.nh.us/wmb/vlap/2006/index.html.New Hampshire Department of Environmental Services. (2020). GIS data: Bathymetry, Water Use, EMD Stations, and Watersheds.

New Hampshire Department of Environmental Services. (2008). *2008 Section 305(b) and 303(d) Surface Water Quality Report. Consolidated Assessment and Listing Methodology and Comprehensive Monitoring Strategy*. Document NHDES-R-WD-02-11. September, 2008.

New Hampshire Department of Environmental Services. (2008). 2008 303(d) Surface Water Quality List.

New Hampshire Department of Environmental Services. (2010). 2010 303(d) Surface Water Quality List.

New Hampshire Department of Environmental Services. (2012). 2012 303(d) Surface Water Quality List.

Des.nh.gov, (2014). *2014 303(d) Surface Water Quality List*. [online] New Hampshire Department of Environmental Services. Available at: http://www.des.nh.gov/organization/divisions/water/wmb/swqa/2014/index.htm.

Des.nh.gov, (2016). *2016 303(d) Surface Water Quality List*. [online] New Hampshire Department of Environmental Services. Available at: http://www.des.nh.gov/organization/divisions/water/wmb/swqa/2016/index.htm.

New Hampshire Department of Environmental Service. (2016). *2016 Section 305(b) and 303(d) Consolidated Assessment and Listing Methodology*. R-WD-17-08. [pdf]

Available at: https://www.des.nh.gov/organization/divisions/water/wmb/swqa/2016/index.htm.

New Hampshire Department of Environmental Services. (2017). *New Hampshire Code of Administrative Rules, Chapter Env-Wq 1700 Surface Water Quality Standards*. [pdf] https://www.des.nh.gov/organization/commissioner/legal/rulemaking/documents/env-wq1700rwa-adptpst.pdf.

New Hampshire Fish and Game. (2007). *New Hampshire Freshwater Fishing Guide. An Angler's Guide to the Granite State's Best Freshwater Lakes, Ponds, Rivers and Streams.* New Hampshire Fish and Game Public Affairs Division. Concord, NH. Available at: http://www.wildlife.state.nh.us/Fishing/fishing_forecast/Locations_Southeast.htm [Accessed November 11, 2007].

New Hampshire GRANIT. (2007). Complex Systems Research Center. Available at: http://www.granit.unh.edu/ [Accessed March 11, 2007].

Nurnberg, G.K. (1984). The prediction of internal phosphorous load in lakes with anoxic hypolimnia. *Limnology and Oceanography*, 29(1), pp. 111-124.

Nurnberg, G.K. (1996). Trophic State of Clear and Colored, Soft and Hardwater lakes with Special Consideration of Nutrients, Anoxia, Phytoplankton and Fish. *Journal of Lake and Reservoir Management,* 12(4), pp. 432-447.

Nurnberg, G.K. (1998). Prediction of annual and seasonal phosphorus concentrations in stratified and unstratified polymictic lakes. *Limnology and Oceanography*, 43(7), pp. 1544-1552.

Oglesby, R.T. and Schaffner, W.R. (1978). Phosphorus Loadings to Lakes and some of their responses. Part 2. Regression Models of Summer Phytoplankton Standing Crops, Winter Total P, and Transparency of New York Lakes with Phosphorus Loadings. *Limnology and Oceanogr*aphy, 23, pp. 135-145.

Reckhow, K. (1977). *Phosphorus Models for Lake Management*. PhD. Harvard University.

Reckhow, K.H., Beaulac, M.N. and Simpson, J.T. (1980). Modeling phosphorus loading and lake response under uncertainty: a manual and compilation of export coefficients. EPA 440/5-80-011, US-EPA, Washington, D.C.

Schloss, J.A. and Connor, J. (2000). Development of Statewide Nutrient Loading Coefficients through Geographic Information System Aided Analysis. University of New Hampshire, Water Resources Research Center, project summary.

Schloss, J.A. (2008). Unpublished LLMP data for Goose Pond and Bow Lake.

Schloss, J. A. and Craycraft, R.C. (2013). *Final Report: Newfound Lake Water Quality Modeling: September 2013*. Durham: UNH Center for Freshwater Biology, UNH Cooperative Extension and UNH Center for Freshwater Biology, University of New Hampshire. CFB Report # 2013-09-DES-02.

Sopper, W.E. and Lull, H.W. (1970). Streamflow Characteristics of the Northeastern United States. Bulletin 766. Penn State Agricultural Experiment Station, University Park, PA.

United States Environmental Protection Agency. (1998). *National Strategy for the Development of Regional Nutrient Criteria.* [Fact Sheet] Office of Water. Washington, D.C. Document EPA 822-F-98-002.

United States Environmental Protection Agency. (1999). *Protocol for Developing Nutrient TMDL's*. EPA-841-B-99-077, EPA, Washington, DC. Available at: http://www.epa.gov/owow/tmdl/nutrient/pdf/nutrient.pdf.

United States Environmental Protection Agency. (2000). *Nutrient Criteria Technical Guidance Manual. Lakes and Reservoirs*. Office of Water. Washington, D.C. Document EPA 822-B-00-004.

United States Environmental Protection Agency. (2000). *Ambient Water Quality Criteria Recommendations. Rivers and Streams in Ecoregion XIV.* Office of Water. Washington, D.C. Document EPA 822-B-00-022.

United States Environmental Protection Agency. (2000). *Ambient Water Quality Criteria Recommendations. Rivers and Streams in Ecoregion VII.* Office of Water. Washington, D.C. Document EPA 822-B-00-018.

United States Environmental Protection Agency. (2005). Handbook for Developing Watershed Plans to Restore and Protect Our Waters. Document EPA 841-B-05-005.

U.S. Environmental Protection Agency. (2006). Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications, for NPDES Permits.

U.S. Environmental Protection Agency. (2007). Options for Expressing Daily Loads in TMDLs. Draft 6/22/08. U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds.

Epa.gov, (2017). *New Hampshire Small MS4 General Permit*. U.S. Environmental Protection Agency. Available at: https://www3.epa.gov/region1/npdes/stormwater/MS4_NH.html.

University of New Hampshire Cooperative Extension. (2007). Landscaping at the Waters Edge: An Ecological Approach.

Vollenweider, R.A. (1975). Input-output models with special references to the phosphorus loading concept in limnology. *Schweiz. Z. Hydrol*, 37, pp. 53-62.

Vollenweider, R. (1982). Eutrophication of Waters: Monitoring, Assessment and Control. OECD, Paris.

Walker. W.W. (1984). Statistical bases for mean chlorophyll *a* criteria. Pages 57-62 in Lake and Reservoir Management – Practical Applications. Proceedings of the 4th annual NALMS symposium. USEPA, Washington, DC

Walker. W.W. (2000). Quantifying uncertainty in phosphorus TMDLs for lakes. Prepared for NEIWPCC and US EPA Region I. Concord, MA.

Wetzel, R. G. (2001). Limnology: Lake and River Ecosystems. Academic Press: Boston

Appendix A Methodology for Determining Target Criteria

1.0 Derivation of Total Phosphorus (TP) Target Values

As part of its contract with the US EPA, Region 1, AECOM is assisting NHDES in developing Total Maximum Daily Loads (TMDLs) for 30 nutrient-impaired waterbodies in New Hampshire, under *Task 1, Development of Lake Phosphorus TMDLs*. To develop TMDLs for these waterbodies it is necessary to derive numeric total phosphorus (TP) target values (e.g., in-lake concentrations) for determining acceptable watershed nutrient loads. The background, approach and TP target values are provided below.

1.1 Regulatory Background

As part of the national Nutrient Strategy originally set forth by the "Clean Water Action Plan" (US EPA, 1998), US EPA has directed the states to promulgate nutrient criteria or alternative means to address and reduce the effects of elevated nutrients (eutrophication) in lakes and ponds, reservoirs, rivers and streams, and wetlands. Where available, these nutrient criteria can be useful in developing TMDLs as well as in demonstrating potential compliance due to the implementation strategy selected to reduce impairment.

At this time, New Hampshire has not established a numeric water quality standard (or nutrient criterion) for TP to protect the designated water uses. Rather, New Hampshire has established a series of use-specific assessment criteria that are used to identify and list waters for impairment of designated uses under the unified Clean Water Act (CWA) Section 305(b) and Section 303(d) Consolidated Assessment and Listing Methodology (CALM) (NHDES, 2016). Thus, while the 30 lakes considered by this investigation are considered likely to be impacted by excessive nutrients, the specific listed impairments are for the phytoplankton primary photopigment chlorophyll *a* (chl *a*) and the presence of cyanobacteria (indicator for primary contact recreation) and/or dissolved oxygen (DO) (indicator for aquatic life support) (NHDES, 2006, 2008b).

1.1.1 New Hampshire Water Use Assessment Criteria

The following assessment criteria have been established for evaluation compliance with water use support and for reporting and identifying waterbodies for listing on the unified CWA Section 305(b)/303(d) list in New Hampshire:

1.1.1.1 Chlorophyll *a*

Assessment for the trophic indicator photopigment chl *a* is evaluated through comparison of samples generally collected during the summer index period (defined as May 24 – September 15) to the freshwater chl *a* interim criterion of 15 ppb (0.015 mg/L) (NH DES, 2008a). If the criterion is exceeded then the waterbody is considered non-supporting for the primary contact recreation water use.

1.1.1.2 Dissolved Oxygen

Applicable water quality standards for DO include the following:

Env-Wq 1703.07 (b): Except as naturally occurs, or in waters identified in RSA 485-A:8, III, or subject to (c) below, class B waters shall have a DO content of at least 75% of saturation, based on a daily mean, and an instantaneous minimum DO concentration of at least 5 mg/L.

Env-Wq 1703.07 (d): Unless naturally occurring or subject to (a) above, surface waters within the top 25 percent of depth of thermally unstratified lakes, ponds, impoundments and reservoirs or within the epilimnion shall contain a DO content of at least 75 percent saturation, based on a daily mean and an instantaneous minimum DO content of at least 5 mg/L. Unless naturally occurring, the DO content below those depths shall be consistent with that necessary to maintain and protect existing and designated uses.

1.1.1.3 Cyanobacteria

A lake is listed as not supporting primary contact recreation if cyanobacteria scums are present. Reduction of TP loading will reduce the likelihood of scum formation.

1.1.2 Linkage of Assessment Criteria to TP TMDLs

The chl *a,* cyanobacteria and DO assessment criteria described above provide NHDES with a consistent and efficient means to identify and list impaired waters for purposes of 305(b)/303(d). However, these parameters are not amenable to development of a TMDL for correction of these impairments for several reasons including:

- these are merely secondary indicators of eutrophication but not the primary cause (i.e., excessive nutrients);
- measurement of these parameters is complicated by physical (e.g., light availability) and temporal considerations (e.g., pre-dawn measurements);
- it is not feasible to establish watershed load allocations for chl *a* or DO;
- there are limited control technologies or best management practices (BMPs) for these parameters; and/or
- it is much more technically and economically feasible to address the primary cause (i.e., excessive nutrients) as a means to reduce or eliminate impairments.

While AECOM uses the term “excessive nutrients” as the primary cause, it is generally understood, and for purposes of this TMDL development assumed that, TP is the limiting nutrient for plant growth in these waters. Therefore, it is necessary to derive numeric TP target values that are both protective of the water uses and correlate to lake conditions under which the chl *a,* the presence of cyanobacteria scums and DO assessment criteria are met. TP is used as a surrogate for impairments related to chl *a*, cyanobacteria scums and DO.

1.2 Proposed TP TMDL Target Values

According to the 40 CFR Part 130.2, the TMDL for a waterbody is equal to the sum of the individual loads from point sources (i.e., wasteload allocations or WLAs), and load allocations (LAs) from nonpoint sources (including natural background conditions). Section 303(d) of the CWA also states that the TMDL must be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety (MOS) which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality. In equation form, a TMDL may be expressed as follows:

$$\mathbf{TMDL = WLA + LA + MOS}$$

Where:

WLA =Waste Load Allocation (i.e., loadings from point sources);
LA = Load Allocation (i.e., loadings from nonpoint sources including natural background); and
MOS = Margin of Safety.

TMDLs can be expressed in terms of either mass per time, toxicity or other appropriate measure [40 CFR, Part 130.2 (i)). However, in light of legal action, the US EPA has issued guidance that TMDLs should be expressed on a daily timescale to meet the wording of the legislation that created the program. Yet for lakes, daily nutrient loading limits are of little use in management, as lakes integrate loading over a much longer time period to manifest observed conditions. Expression of nutrient loads on seasonal to annual time scales is appropriate, although daily loads will be reported to meet program guidelines.

The MOS can be either explicit or implicit. If an explicit MOS is used, a portion of the total target load is allocated to the MOS. If the MOS is implicit, a specific value is not assigned to the MOS. Use of an implicit MOS may be appropriate when assumptions used to develop the TMDL are believed to be so conservative that they sufficiently account for the MOS.

1.3 Potential approaches to Derivation of TP target values.

While the need for development of nutrient criteria for lakes is well-documented, there is no clear consensus among the States or federal agencies regarding the best means to accomplish this goal, due to the complexity in defining precisely what concentrations will be protective of waterbodies' water quality as well as their designated uses. Some of the more common approaches include:

- Use of NHDES water quality recommendations;
- Use of nutrient levels for commonly accepted trophic levels; and
- Use of probabilistic equations to establish targets to reduce risk of adverse conditions.

1.3.1 Target based on population of New Hampshire lakes

In the *Lake and Reservoir Technical Guidance Manual* (US EPA, 2000a), the US EPA provided a statistical approach for determining nutrient criteria that was subsequently used to develop a set of ecoregion-specific ambient water quality recommendations that were issued in 2000-2001 (US EPA, 2000b; US EPA 2000c).

The US EPA approach consists of selecting a pre-determined percentile from the distribution of measured variables from either (1) known reference lakes, (i.e., the highest quality or least impacted lakes) or (2) general population of lakes including both impaired and non-impaired lakes. The US EPA defined reference lakes as those representative of the least impacted conditions or what was considered to be the most attainable conditions for lakes within a state or ecoregion.

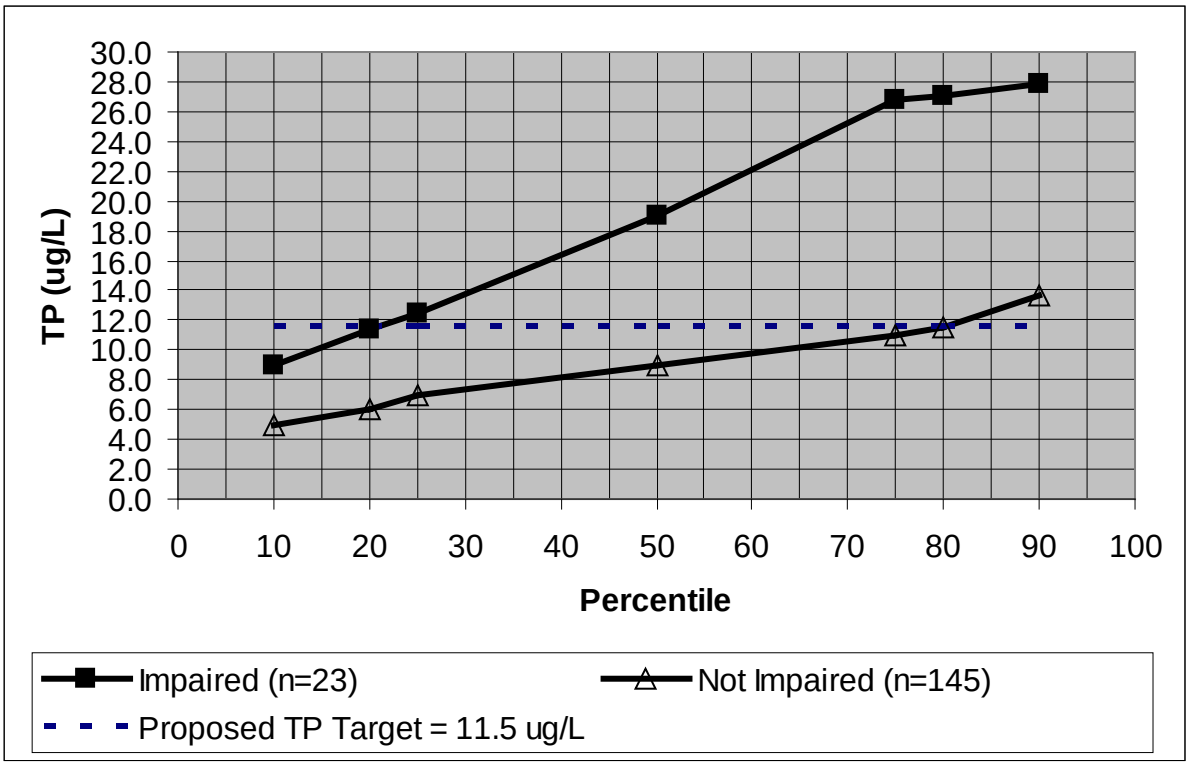
NHDES used a similar statistical approach when developing preliminary TP criteria for freshwaters in New Hampshire (NHDES, 2005). The NHDES evaluation identified statistically significant relationships between chl *a* and TP for lakes. Statistical relationships were based on: 1) the median of TP samples taken at one-third the water depth in unstratified lakes and at the mid-epilimnion depth in stratified lakes; and 2) the

median of composite chl *a* samples of the water column to the mid-metalimnion depth in stratified lakes and to the two-thirds water depth in unstratified lakes during the summer months (June through September). A total of 168 lakes were included in the analysis of which 23 were impaired for chl *a* (i.e., lakes with chl *a* greater than or equal to 15 g/L). Of the 23 impaired lakes, approximately 14 were stratified (60%) and 9 were unstratified (40%).

Figure A-2 shows the cumulative frequency plots for the impaired and non-impaired lakes. Based on Figure A-2, an initial TP target of 11.5 ug/L was selected. As shown, 20% of the impaired lakes and 80% of the non-impaired lakes have TP concentrations $\leq$ 11.5 ug/L which means that 20% of the non-impaired lakes have TP concentrations $\geq$ 11.5 ug/L). After rounding, a target of 12 ug/L strikes a reasonable balance between the percent of lakes that are impaired at concentrations below this level and the percent of lakes that are not impaired at concentrations above this concentration. A value of 12 ug/L is very similar to TP targets set by other methods discussed below.

Setting the TMDL based on an in-lake target concentration of 12 ug/L includes an implicit MOS for the following reasons. As discussed above, the target of 12 ug/L is primarily based on summer epilimnetic concentrations. However, the LLRM model uses empirical models that predict mean annual TP lake concentrations assuming fully mixed conditions. Studies on other lakes indicate that mean annual concentrations can be 14% to 40% higher than summer epilimnetic concentrations (Nurnberg 1996, 1998). A value of 15 ug/L could have been used in the models to predict the TMDL. However, in order to include an MOS, 12 ug/L can be used. By setting the target equal to 12 ug/L in the models used to determine the TMDL, an implicit MOS of approximately 20% is provided.

Figure A-2: Cumulative Frequency Distribution of TP Concentrations in Impaired and Unimpaired New Hampshire Lakes.



In 2009, NHDES refined its analysis to include TP and chlorophyll a thresholds based on trophic criteria and the EPA reference approach (NHDES, 2009[6]). EPA guidance recommends using the distributions of water quality parameters in reference lakes (i.e., lakes with minimal human disturbance) and all lakes to identify targets for water quality criteria. The 75th percentile of concentrations in the reference lakes provides one estimate of the criteria. The 25th percentile in all lakes is another estimate. The two values bound the range of potential criteria concentrations for a parameter. Using the reference approach, the summer epilimnetic TP and chlorophyll a target concentrations are the following:

	Oligotrophic	Mesotrophic	Eutrophic
TP (ug/L)	< 8	≤ 12	≤ 28
Chlorophyll a (ug/L)	< 3.3	≤ 5	≤ 11

The above concentrations are currently being used to assess lakes and agree fairly well with literature values from other trophic studies presented in the section 1.3.2. Since Locke Lake is a mesotrophic lake (NHDES, 1997), a TP target of 12 ug/L would apply.

[6] See NHDES report: Assessment of Chlorophyll-a and Phosphorus in New Hampshire Lakes for Nutrient Criteria Development.

The TP target of 12 ug/L for mesotrophic lakes may be somewhat conservative (i.e., low) for colored lakes since color can attenuate light in the water column and suppress algal growth and its impacts on designated uses. The average color in the epilimnion of all mesotrophic lakes in New Hampshire is 35.8 cpu (n=412). The average color in the epilimnion of Locke Lake is 45.3 cpu (n=3), slightly higher than the average of all mesotrophic lakes in New Hampshire. Elevated color could potentially reduce the ability for organisms to photosynthesize so the slightly elevated average color suggests that use of an in-lake TP target greater than 12 ug/L for Locke Lake may still result in compliance with nutrient related response parameters such as chlorophyll-a, cyanobacteria and dissolved oxygen.

1.3.2 Trophic State Classification of Waterbodies

Trophic state is an alternative means of setting a TP target concentration. One of the more powerful paradigms in limnology is the concept and classification of lakes as to their so-called trophic state. A trophic state classification is typically based on a generally recognized set or range of chemical concentrations and physical and biological responses. Lakes are generally classified as oligotrophic, mesotrophic, or eutrophic; the three states representing a gradient between least affected to most impacted waterbodies. Classification is based on the proximity of a lake's chemistry and biology to the list of characteristic for a specific trophic type. Classification may be based on both quantitative (e.g., chemical concentrations, turbidity) and/or qualitative factors (e.g., presence of pollution-tolerant species, aesthetic appearance).

While this system is widely accepted, there is no consensus regarding the absolute nutrient or trophic parameter value that defines a waterbody trophic state, although some guidelines have been suggested (US EPA, 1999). Indeed, it should be remembered that classification of lakes into the categories produces an arbitrary difference among lakes that may show very little differences in nutrient concentration. Despite its limitations, the trophic state concept is easily understood and widely used by limnologists, lake associations, state agencies, etc., to classify lakes and manage lakes. Further, it can be used as an indirect means of linking impairment of designated uses with critical nutrient levels or threshold values (i.e., the transition from one trophic state to another is likely associated with effects on designated uses).

To provide a means of quantifying the decision-making about trophic classification, waterbodies may be classified according to the Carlson Trophic State Index (TSI), a widely used indicator of trophic state (Carlson 1977). Carlson's TSI is an algal biomass-based index that relates the relationship between trophic parameters to levels of lake productivity. The TSI method provides three equations relating log-transformed concentrations of TP, chl *a*, and SDT to algal biomass, resulting in three separate TSI scores (e.g., TSI(TP), TSI(chl *a*), TSI(SDT)). The three equations are scaled such that the same TSI value should be obtained for a lake regardless of what parameter is used. Comparison of the results of the TSI system to more traditional trophic state classification identified TSI scores that are associated with the transition from one trophic state to another (Carlson, 1977).

For purposes of comparison, we initially used a system assuming thresholds or criteria for the transition from an oligotrophic to a mesotrophic state (estimated as a TSI value of 35) and for transition from a mesotrophic state to a eutrophic state (estimated as a TSI value of 50). The selected TSI thresholds are based on general lake attributes and are not specific to the New England ecoregions. However, Table A-2 represents a first approximation of the range of trophic indicators assigned to a trophic state.

Table A-2. Trophic Status Classification based on water quality variables

Variables	Oligotrophic (TSI < 30)	Mesotrophic (30 ≤ TSI < 50)	Eutrophic (TSI > 50)
TP (g/L)	<10	10-24	>24
Chl *a* ((l 4	<1.5	1.5-7.2	>7.2
SDT (m)	>6	2-6	<2

It can be seen that the NH criterion for chl a (15 ug/L) will generally not be exceeded by a lake having a mesotrophic status (chl a of 1.5 – 7.2 ug/L). In most cases, mesotrophic conditions are also supportive of all aquatic life conditions. It can also be seen that the proposed New Hampshire criterion of 12 ug/L TP discussed in Section 1.3.1 will place the lake in the mesotrophic category. However, the ranges of concentrations considered by this approach are relatively large and alternative numeric criteria could be used equally as well. Accordingly, development or refinement based on ecoregion-specific information regarding trophic response and/or protection of designated uses was used to refine these ranges.

Based on our inspection of the water quality and biotic responses of the 30 New Hampshire lakes of this study, it appears that these lakes are more responsive to inputs of TP than the general class of national lakes that Carlson considered in devising his classes. For example, AECOM considers it likely that allowing > 20 ug/L TP for an in-lake surface concentration will result in eutrophic lake conditions in these lakes and uses that contention as justification to narrow the range of appropriate mean concentrations to 10-20 ug/L. The midpoint of this range is approximately 15 ug/L. An annual mean concentration of 15 ug/L TP is also coincidentally the threshold value for mesotrophic lakes used by the New Hampshire Lay Lakes Monitoring Program (LLMP) (Craycraft and Schloss, 2005).

The trophic status classification is assumed to be based on mean annual TP. However, most water quality samples are taken during summer conditions. Total algal growth is typically predicted from spring turnover TP values, which tend to be higher by approximately 20% on mean (Nurnberg, 1996, 1998). Therefore, using a TP target of 20% lower than 15 the trophic status classification is assumed to be based on chl *a*. An implicit MOS of 20% would result in a target concentration for Locke Lake of 13 ug/L.

As mentioned in the previous section, in 2009 NHDES developed interim TP and chl a criteria based on lake trophic level for the protection of aquatic life (NHDES, 2009) which were first used to develop the 2010 303(d) list (NHDES, 2010b). The study evaluated median chl a and TP concentrations for 233 lakes and developed interim criterion using the reference concentration approach (EPA, 2000d). Reference lakes were defined as lakes with average specific conductance values less than 50 uS/cm. As shown in the table below, the criteria vary by trophic class where the trophic class is based on NHDES trophic evaluations. Where multiple trophic evaluations have been conducted, the best (i.e. cleanest) trophic class is used to determine the appropriate criterion. The “best” trophic class for Locke Lake is mesotrophic. In accordance with the Consolidated Listing and Assessment Methodology (NHDES, 2016), the medians are based on summer data (i.e., samples taken from May 24th to September 15th).

	Median TP (ug/L)	Median Chl (ug/L)
Oligotrophic	< 8.0	< 3.3
Mesotrophic	<=12.0	<= 5.0
Eutrophic	<= 28	<= 11

To be fully protective, the target used in the TMDL should be most stringent TP needed to protect all designated uses. As mentioned, the criteria shown in the table above are for the protection of the aquatic life use. As discussed in the previous section, the median TP for the protection of primary contact recreational uses (i.e., swimming) should be no greater than 12 ug/L. Consequently, if the lake is eutrophic or mesotrophic, the target TP was set equal to 12 ug/L in order to be protective of both uses. However, if a lake is oligotrophic, the target TP was set equal to 8 ug/L since this is more stringent than the 12 ug/L threshold for the protection of primary contact recreation. Since Locke Lake is mesotrophic, the target TP according to the lake trophic level is 12 ug/L. However, as discussed in section 1.4 below, the only exception to this rule is if the predicted TP concentration under "natural" conditions (i.e., no anthropogenic sources) exceeded the TP target discussed above. When this situation occurs, the target is set equal to the natural TP concentration.

1.3.3. Probabilistic Approach to Setting TP Target Goal

Target TP goals can also be determined using a probabilistic approach that aims at reducing the level and frequency of deleterious algal blooms (as indicated by chl *a* levels). The concept is to set a TP criterion that achieves a desired probability (i.e., risk) level of incurring an algal bloom in a lake system. Based on the level of acceptable risk or how often a system can experience an exceedance of an adverse condition (in this case defined as a chl *a* level of 15 ug/L), the TP criterion is selected.

Water quality modeling performed by Walker (1984, 2000) provides a means to calculate the TP level associated with any set level of exceedance of any set target level. For these TMDLs, the goal is to minimize the potential risk of exceedance of 15 ug/L chl *a* (summer algal bloom), but not place the criterion so low that it could not realistically be achieved due to TP contributions from natural background conditions. The corresponding TP concentration are used as the basis for developing target TMDLs, although not as the final target TP target value, since it incorporates no MOS factor and does not account for uncertainty in the TP loading and concentration estimates.

A target TP concentration of 12 ug/L typically corresponds to a potential risk of exceedance of 15 ug/L chl *a* in the summer of 0.1%, which is considered low enough to support designated uses in the lake.

For this method, the MOS is implicit due to conservative assumptions because the Walker bloom probability model is based on summer water quality data. However, the TP concentrations predicted by the ENSR-LRM model are annual mean concentrations which are typically higher than summer values. Applying the bloom probability model to annual mean concentrations rather than lower summer concentrations will result in an overestimate of the probability of blooms occurring in the summer.

1.4 Summary of Derivation of TP Target Goal

As part of its US EPA/NHDES contract for developing TMDLs for 30 nutrient-impaired New Hampshire waterbodies, AECOM developed an approach and rationale for deriving numeric TP target values for determining acceptable watershed nutrient loads. These TP target values are protective of the water uses and correlate to lake conditions under which the existing New Hampshire chl *a*, cyanobacteria, and DO assessment criteria are met.

To derive these criteria, AECOM considered the following options: (1) examination of the distribution of TP concentrations in impaired and unimpaired lakes in New Hampshire; (2) use of nutrient levels for commonly-accepted trophic levels; and (3) use of probabilistic equations to establish targets to reduce risk of adverse conditions. All three approaches yield a similar target value. Because the first option uses data from New Hampshire lakes, it is viewed as the primary target setting method. The other two methods confirm the result of the first method, a target of 12 ug/L is appropriate. This target would lead to the desired low probability of algal blooms and a mean chl *a* level that supports all expected lake uses in mesotrophic lakes such as Locke Lake. Based on the data that went for these analyses, there is an MOS of approximately 20%.

For watersheds that do not have permitted discharges such as MS4 systems (i.e., WLA = 0), the LA term simplifies to the amount of watershed TP load needed to produce a modeled in-lake concentration of 12 ug/L. Urban watersheds will need to account for the influence of stormwater when determining acceptable loads.

Based on the above discussion, a target value of 12 ug/L TP will be used to establish target TP loading for the New Hampshire Lake Phosphorus TMDLs, with the following exceptions:

- If modeling indicates that TP loadings under "natural" conditions will result in TP concentrations greater than 12 ug/L, then the TMDL target will be set equal to the modeled TP concentration corresponding to the all-natural loading scenario for that lake. There is no need, nor is it usually feasible, to reduce loadings below those occurring under natural conditions. Furthermore, state surface water quality standards allow exceedances of criteria (i.e., targets) if they are due to naturally occurring conditions. For example, Env-Wq 1703.14 (b) states the following:

"Class B waters shall contain no TP or nitrogen in such concentrations that would impair any existing or designated uses, unless naturally occurring."

- If observed monitoring data indicates actual chl *a* violations are occurring in the lake at TP concentrations less than 12 ug/L, then the target shall be set equal to either 1) the median concentration of the sampling data with a 20% reduction to incorporate an MOS (or another percent reduction determined appropriate for that particular lake) or 2) to the modeled concentration corresponding to background (i.e. natural) conditions.

As discussed in section 1.3.2, the lowest (i.e., most stringent) criterion needed to protect the aquatic life and primary contact recreational uses was used as the target unless the predicted natural TP concentration was higher.

Appendix B ENSR-LRM Methodology Documentation

APPENDIX B:
LLRM – Lake Loading Response Model Users Guide
(also called SHEDMOD or ENSR-LRM)

Model Overview

The Lake Loading Response Model, or LLRM, originated as a teaching tool in a college course on watershed management, where it was called SHEDMOD. This model has also been historically called ENSR-LRM. The intent was to provide a spreadsheet program that students could use to evaluate potential consequences of watershed management for a target lake, with the goal of achieving desirable levels of phosphorus (TP), nitrogen (N), chlorophyll a (Chl) and Secchi disk transparency (SDT). For the New Hampshire Lake TMDLs only TP, Chl and SDT were simulated. As all cells in the spreadsheet are visible, the effect of actions could be traced throughout the calculations and an understanding of the processes and relationships could be developed.

LLRM remains spreadsheet based, but has been enhanced over the years for use in watershed management projects aimed at improving lake conditions. It is still a highly transparent model, but various functions have been added and some variables have been refined as new literature has been published and experience has been gained. It is adaptable to specific circumstances as data and expertise permit, but requires far less of each than more complex models such as SWAT or BASINS. This manual provides a basis for proper use of LLRM.

Model Platform

LLRM runs within Microsoft Excel. It consists of three numerically focused worksheets within a spreadsheet:

1. Reference Variables – Provides values for hydrologic, export and concentration variables that must be entered for the model to function. Those shown are applicable to the northeastern USA, and some would need to be changed to apply to other regions.
2. Calculations – Uses input data to generate estimates of water, N and TP loads to the lake. All cells shaded in blue must have entries if the corresponding input or process applies to the watershed and lake. If site-specific values are unavailable, one typically uses the median value from the Reference Variables sheet.
3. Predictions – Uses the lake area and inputs calculated in the Calculations sheet to predict the long-term, steady state concentration of N, TP and Chl in the lake, plus the corresponding SDT. This sheet applies five empirical models and provides the average final results from them.

Watershed Schematic

Generation of a schematic representation of the watershed is essential to the model. It is not a visible part of the model, but is embodied in the routing of water and nutrients performed by the model and it is a critical step. For the example provided here, the lake and watershed shown in Figure 1 is modeled. It consists of a land area of 496.5 hectares (ha) and a lake with an area of 40 ha. There are two defined areas of direct drainage (F and G), from which water reaches the lake by overland sheetflow, piped or ditched stormwater drainage, or groundwater seepage (there are no tributaries in these two drainage basins). There is also a tributary (Trib 1) that is interrupted by a small pond, such that the corresponding watershed might best be represented as two parts, upstream and downstream of that pond, which will provide some detention and nutrient removal functions. There is another tributary (Trib 2) that consists of two streams that combine to form one that then enters the lake, the classic "Y' drainage pattern. With differing land uses associated with each of the upper parts of the Y and available data for each near the confluence, this

part of the watershed is best subdivided into three drainage areas. As shown in Figure 2, the watershed of Figure 1 is represented as the lake with two direct drainage units, a tributary with an upper and lower drainage unit, and a tributary with two upper and one lower drainage units. The ordering is important on several levels, most notably as whatever nutrient loading attenuation occurs in the two lower tributary basins will apply to loads generated in the corresponding upper basins. Loads are generated and may be managed in any of the drainage basins, but how they affect the lake will be determined by how those loads are processed on the way to the lake. LLRM is designed to provide flexibility when testing management scenarios, based on watershed configuration and the representation of associated processes.

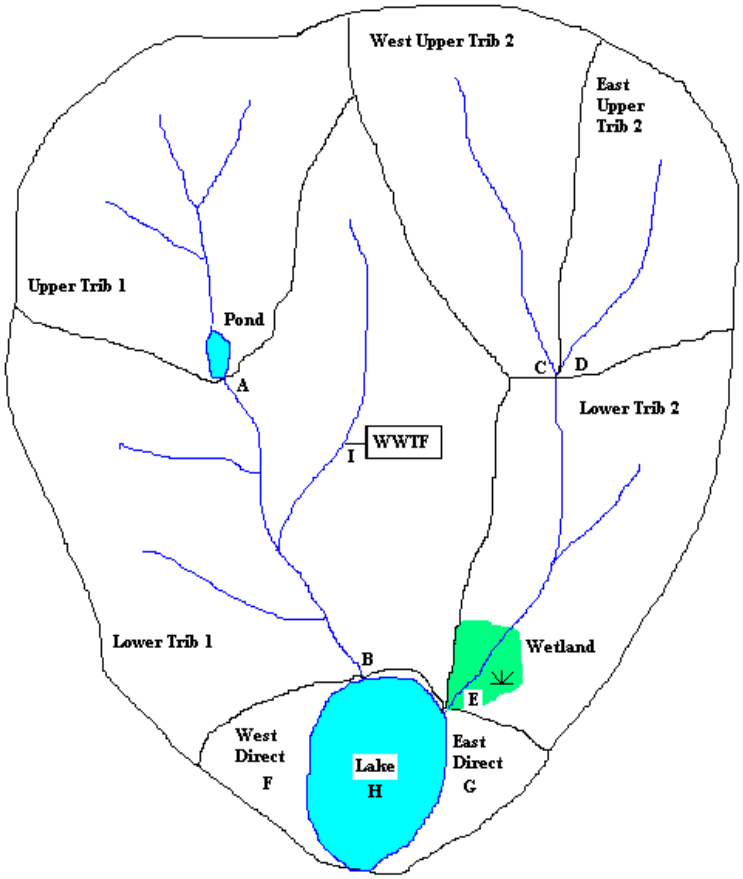


Figure 1. Watershed Map for Example System

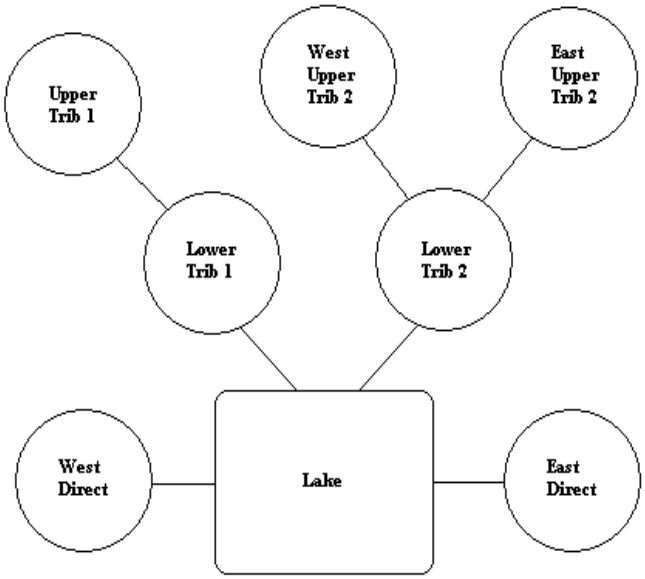


Figure 2. Watershed Schematic for Example System

Model Elements

There are three main types of inputs necessary to run LLRM:

1. Hydrology inputs – These factors govern how much water lands on the watershed and what portion is converted to runoff or baseflow. The determination of how much precipitation becomes runoff vs. baseflow vs. deep groundwater not involved in the hydrology of the target system vs. loss to evapotranspiration is very important, and requires some knowledge of the system. All precipitation must be accounted for, but all precipitation will not end up in the lake. In the northeast, runoff and baseflow may typically account for one to two thirds of precipitation, the remainder lost to evapotranspiration or deep groundwater that may feed surface waters elsewhere, but not in the system being modeled. As impervious surface increases as a percent of total watershed area, more precipitation will be directed to runoff and less to baseflow. There are two routines in the model to allow "reality checks" on resultant flow derivations, one using a standard areal water yield based on decades of data for the region or calculated from nearby stream gauge data, and the other applying actual measures of flow to check derived estimates.
2. Nutrient yields – Export coefficients for N and TP determine how much of each is generated by each designated land use in the watershed. These export values apply to all like land use designations; one cannot assign a higher export coefficient to a land use in one basin than to the same land use in another basin. Differences are addressed through attenuation. This is a model constraint, and is imposed partly for simplicity and partly to prevent varied export assignment without justification. Where differing export really does exist for the same land uses in different basins of the watershed, attenuation can be applied to adjust what actually reaches the lake. Nutrient export coefficients abound in the literature, and ranges, means and medians are supplied in the Reference Variables sheet. These are best applied with some local knowledge of export coefficients, which can be calculated from land area, flow and nutrient concentration data. However, values calculated from actual data will include attenuation on the way to the point of measurement. As attenuation is treated separately in this model, one must determine the pre-attenuation export coefficients for entry to initiate the model. The model provides a calculation of the export coefficient for the "delivered" load that allows more direct comparison with any exports directly calculated from data later in the process.
3. Other nutrient inputs – five other sources of N and TP are recognized in the model:
    a. Atmospheric deposition – both wet and dry deposition occurs and have been well documented in the literature. The area of deposition should be the entire lake area. Choice of an export coefficient can be adjusted if real data for precipitation and nutrient concentrations is available.
    b. Internal loading – loads can be generated within the lake from direct release from the sediment (dissolved TP, ammonium N), resuspension of sediment (particulate TP or N) with possible dissociation from particles, or from macrophytes ("leakage" or scenescence). All of these modes have been studied and can be estimated with a range, but site specific data for surface vs. hypolimnetic concentrations, pre-stratification whole water column vs. late summer hypolimnetic concentrations, changes over time during dry periods (limited inflow), or direct sediment measures can be very helpful when selecting export coefficients.
    c. Waterfowl and other wildlife – Inputs from various bird species and other water dependent wildlife (e.g., beavers, muskrats, mink or otter) have been evaluated in the literature. Site specific data on how many animals use the lake for how long is necessary to generate a reliable estimate.
    d. Point sources – LLRM allows for up to three point sources, specific input points for discharges with known quantity and quality. The annual volume, average concentration, and basin where the input occurs must be specified.
    e. On-site wastewater disposal (septic) systems – Septic system inputs in non-direct drainage basins is accounted for in baseflow export coefficients, but a separate process is provided for direct drainage areas where dense housing may contribute disproportionately. The number of houses in

two zones (closer and farther away, represented here as <100 ft and 100-300 ft from the lake) can be specified, with occupancy set at either seasonal (90 days) or year round (365 days). For the NH lake nutrient TMDLs, one zone of 125 feet from the lake was used. The number of people per household, water use per person per day, and N and TP concentrations and attenuation factors must be specified. Alternatively, these inputs can be accounted for in the baseflow export coefficient for direct drainage areas if appropriate data are available, but this module allows estimation from what is often perceived as a potentially large source of nutrients.

LLRM then uses the input information to make calculations that can be examined in each corresponding cell, yielding wet and dry weather inputs from each defined basin, a combined total for the watershed, a summary of other direct inputs, and total loads of TP and N to the lake, with an overall average concentration for each as an input level. Several constraining factors are input to govern processes, such as attenuation, and places to compare actual data to derived estimates are provided. Ultimately, the lake area and loading values are transferred to the Prediction sheet where, with the addition of an outflow TP concentration and lake volume, estimation of average in-lake TP, N, Chl and SDT is performed. The model is best illustrated through an example, which is represented by the watershed in Figures 1 and 2. Associated tables are directly cut and pasted from the example model runs.

Hydrology

Water is processed separately from TP and N in LLRM. While loading of water and nutrients are certainly linked in real situations, the model addresses them separately, then recombines water and nutrient loads later in the calculations. This allows processes that affect water and nutrient loads differently (e.g., many BMPs) to be handled effectively in the model.

Water Yield

Where a cell is shaded, an entry must be made if the corresponding portion of the model is to work. For the example watershed, the standard yield from years of data for a nearby river, to which the example lake eventually drains, is 1.6 cubic feet per square mile (cfsm) as shown below. That is, one can expect that in the long term, each square mile of watershed will generate 1.6 cubic feet per second (cfs). This provides a valuable check on flow values derived from water export from various land uses later in the model.

COEFFICIENTS	
STD. WATER YIELD (CFSM)	1.6
PRECIPITATION (METERS)	1.21

Precipitation

The precipitation landing on the lake and watershed, based on years of data collected at a nearby airport, is 1.21 m (4 ft, or 48 inches) per year, as shown above. Certainly there will be drier and wetter years, but this model addresses the steady state condition of the lake over the longer term.

Runoff and Baseflow Coefficients

Partitioning coefficients for water for each land use type have been selected from literature values and experience working in this area. Studies in several of the drainage basins to the example lake and for nearby tributaries outside this example system support the applied values with real data. It is expected that the sum of export coefficients for runoff and baseflow will be <1.0; some portion of the precipitation will be lost to deep groundwater or evapotranspiration.

	RUNOFF EXPORT COEFF.			BASEFLOW EXPORT COEFF.		
	Precip	P Export	N Export	Precip	P Export	N Export
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
LAND USE	(Fraction)	(kg/ha/yr)	(kg/ha/yr)	(Fraction)	(kg/ha/yr)	(kg/ha/yr)
Urban 1 (Residential)	0.30	0.65	5.50	0.15	0.010	5.00
Urban 2 (Roads)	0.40	0.75	5.50	0.10	0.010	5.00
Urban 3 (Mixed Urban/Commercial)	0.60	0.80	5.50	0.05	0.010	5.00
Urban 4 (Industrial)	0.50	0.70	5.50	0.05	0.010	5.00
Urban 5 (Parks, Recreation Fields, Institutional)	0.10	0.80	5.50	0.05	0.010	5.00
Agric 1 (Cover Crop)	0.15	0.80	6.08	0.30	0.010	2.50
Agric 2 (Row Crop)	0.30	1.00	9.00	0.30	0.010	2.50
Agric 3 (Grazing)	0.30	0.40	5.19	0.30	0.010	5.00
Agric 4 (Feedlot)	0.45	224.00	2923.20	0.30	0.010	25.00
Forest 1 (Upland)	0.10	0.20	2.86	0.40	0.005	1.00
Forest 2 (Wetland)	0.05	0.10	2.86	0.40	0.005	1.00
Open 1 (Wetland/Lake)	0.05	0.10	2.46	0.40	0.005	0.50
Open 2 (Meadow)	0.05	0.10	2.46	0.30	0.005	0.50
Open 3 (Excavation)	0.40	0.80	5.19	0.20	0.005	0.50
Other 1	0.10	0.20	2.46	0.40	0.050	0.50
Other 2	0.35	1.10	5.50	0.25	0.050	5.00
Other 3	0.60	2.20	9.00	0.05	0.050	20.00

Setting export coefficients for the division of precipitation between baseflow, runoff and other components (deep groundwater, evapotranspiration) that do not figure into this model is probably the hardest part of model set-up. Site specific data are very helpful, but a working knowledge of area hydrology and texts on the subject is often sufficient. This is an area where sensitivity testing is strongly urged, as some uncertainly around these values is to be expected. There is more often dry weather data available for tributary streams than wet weather data, and some empirical derivation of baseflow coefficients is recommended. Still, values are being assigned per land use category, and most basins will have mixed land use, so clear empirical validation is elusive. As noted, sensitivity testing by varying these coefficients is advised to determine the effect on the model of the uncertainty associated with this difficult component of the model.

Nutrient Yields for Land Uses

Phosphorus and Nitrogen in Runoff

The values applied in the table above are not necessarily the medians from the Reference Variables sheet, since there are data to support different values being used here. There may be variation across basins that is not captured in the table below, as the same values are applied to each land use in each basin; that is a model constraint. Values for “Other” land uses are inconsequential in this case, as all land uses are accounted for in this example watershed without creating any special land use categories. Yet if a land use was known to have strong variation among basins within the watershed, the use of an “Other” land use class for the strongly differing land use in one or another basin could incorporate this variability.

Phosphorus and Nitrogen in Baseflow

Baseflow coefficients are handled the same way as for runoff coefficients above. While much of the water is likely to be delivered with baseflow, a smaller portion of the TP and N loads will be delivered during dry weather, as the associated water first passes through soil. In particular, TP is removed effectively by many soils, and transformation of nitrogen among common forms is to be expected.

The table above is commonly adjusted to calibrate the model, but it is important to justify all changes. Initial use of the median TP export value for a land use may be based on a lack of data or familiarity with the system, and when the results strongly over- or under-predict actual in-lake concentrations, it may be necessary to adjust the export value for one or more land use categories to achieve acceptable agreement. However, this should not be done without a clear understanding of why the value is probably higher or lower than represented by the median; the model should not be blindly calibrated, and field examination of conditions that affect export values is strongly recommended.

Other Nutrient Inputs

Atmospheric Deposition

Both wet and dry deposition nutrient inputs are covered by the chosen values, and are often simple literature value selections. Where empirical data for wet or dry fall are available, coefficients should be adjusted accordingly. Regional data are often available and can be used as a reality check on chosen values. Choices of atmospheric export coefficients are often based on dominant land use in the contributory area (see Reference Variables sheet), but as the airshed for a lake is usually much larger than the watershed, it is not appropriate to use land use from the watershed as the sole criterion for selecting atmospheric export coefficients. Fortunately, except where the lake is large and the watershed is small, atmospheric inputs tend not to have much influence on the final concentrations of TP or N in the lake, so this is not a portion of the model on which extreme investigation is usually necessary.

For the example system, a 40 ha lake is assumed to receive 0.2 kg TP/ha/yr and 6.5 kg N/ha/yr, the median values from the Reference Variables sheet. The model then calculates the loads in kg/yr to the lake and uses them later in the summary.

AREAL SOURCES										
	Affected Lake Area (ha)	P Export Coefficient (kg/ha/yr)	N Export Coefficient (kg/ha/yr)	P Load (from coeff) (kg/yr)	N Load (from coeff) (kg/yr)	Period of Release (days)	P Rate of Release (mg/m2/day)	N Rate of Release (mg/m2/day)	P Load (from rate) (kg/yr)	N Load (from rate) (kg/yr)
Direct Atmospheric Deposition	40	0.20	6.50	8	260					
Internal Loading	20	2.00	5.00	40	100	100	2.00	5.00	40	100

Internal Loading

Internal release of TP or N is generally described as a release rate per square meter per day. It can be a function of direct dissolution release, sediment resuspension with some dissociation of available nutrients, or release from rooted plants. The release rate is entered as shown in the table above, along with the affected portion of the lake, in this case half of the 40 ha area, or 20 ha. The period of release must also be specified, usually corresponding to the period of deepwater anoxia or the plant growing season. The model then calculates a release rate as kg/ha/yr and a total annual load as shown in the table above.

For the New Hampshire lake nutrient TMDLs, the release rate from internal loading was calculated using water quality data (pre-stratification vs. late summer hypolimnetic TP concentrations or late summer hypolimnetic vs. late summer epilimnetic TP concentrations) and dividing by the anoxic area of the lake.

Waterfowl or Other Wildlife

Waterfowl or other wildlife inputs are calculated as a direct product of the number of animal-years on the lake (e.g., 100 geese spending half a year = 50 bird-years) and a chosen input rate in kg/animal/yr, as shown in the table below. Input rates are from the literature as shown in the Reference Variables sheet, while animal-years must be estimated for the lake.

NON-AREAL SOURCES										
	Number of Source Units	Volume (cu.m/yr)	P Load/Unit (kg/unit/yr)	N Load/Unit (kg/unit/yr)	P Conc. (ppm)	N Conc. (ppm)	P Load (kg/yr)	N Load (kg/yr)		
Waterfowl	50		0.20	0.95			10	47.5		
Point Sources										
PS-1		45000			3.00	12.00	135	540		
PS-2		0			3.00	12.00	0	0		
PS-3		0			3.00	12.00	0	0		
Basin in which Point Source occurs (0=NO 1=YES)										
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10
PS-1	0	0	0	1	0	0	0	0	0	0
PS-2	0	0	0	0	0	0	0	0	0	0
PS-3	0	0	0	0	0	0	0	0	0	0

Point Source Discharges

LLRM allows for three point source discharges. While some storm water discharges are legally considered point sources, the point sources in LLRM are intended to be daily discharge sources, such as wastewater treatment facility or cooling water discharges. The annual volume of the discharge must be entered as well as the average concentration for TP and TN, as shown in the table above. The model then calculates the input of TP and TN. It is also essential to note which basin receives the discharge, denoted by a 1 in the appropriate column. As shown in the table above, the example system has a discharge in Basin 4, and no discharges in any other basin (denoted by 0).

On-Site Wastewater Disposal Systems

While the input from septic systems in the direct drainage areas around the lake can be addressed through the baseflow export coefficient, separation of that influence is desirable where it may be large enough to warrant management consideration. In such cases, the existing systems are divided into those within 100 feet of the lake and those between 100 and 300 feet of the lake, each zone receiving potentially different attenuation factors. For the New Hampshire lake TMDLs, a single 125-foot zone was used. A further subdivision between dwelling occupied all year vs. those used only seasonally is made. The number of people per dwelling and the water use per person per day are specified, along with the expected concentrations of TP and TN in septic system effluent, as shown in the table below. The model then calculates the input of water, TP and TN from each septic system grouping. If data are insufficient to subdivide systems along distance or use gradients, a single line of this module can be used with average values entered.

DIRECT SEPTIC SYSTEM LOAD												
Septic System Grouping (by occupancy or location)	Days of Occupancy/Yr	Distance from Lake (ft)	Number of Dwellings	Number of People per Dwelling	Water per Person per Day (cu.m)	P Conc. (ppm)	N Conc. (ppm)	P Attenuation Factor	N Attenuation Factor	Water Load (cu.m/yr)	P Load (kg/yr)	N Load (kg/yr)
Group 1 Septic Systems	365	<100	25	2.5	0.25	8	20	0.2	0.9	5703	9.1	102.7
Group 2 Septic Systems	365	100 - 300	75	2.5	0.25	8	20	0.1	0.8	17109	13.7	273.8
Group 3 Septic Systems	90	<100	50	2.5	0.25	8	20	0.2	0.9	2813	4.5	50.6
Group 4 Septic Systems	90	100 - 300	100	2.5	0.25	8	20	0.1	0.8	5625	4.5	90.0
Total Septic System Loading										31250	31.8	517.0

Subwatershed Functions

The next set of calculations addresses inputs from each defined basin within the system. Basins can be left as labeled, 1, 2, 3, etc., or the blank line between Basin # and Area (Ha) can be used to enter an identifying name. In this case, basins have been identified as the East Direct drainage, the West Direct drainage, Upper Tributary #1, Lower Tributary #1, East Upper Tributary #2, West

Upper Tributary #2, and Lower Tributary #2, matching the watershed and schematic maps in Figures 1 and 2.

Land Uses

The area of each defined basin associated with each defined land use category is entered, creating the table below. The model is set up to address up to 10 basins; in this case there are only seven defined basins, so the other three columns are left blank and do not figure in to the calculations. The total area per land use and per basin is summed along the right and bottom of the table. Three "Other" land use lines are provided, in the event that the standard land uses provided are inadequate to address all land uses identified in a watershed. It is also possible to split a standard land use category using one of the "Other" lines, where there is variation in export coefficients within a land use that can be documented and warrants separation.

Land use data is often readily available in GIS formats. It is always advisable to ground truth land use designation, especially in rapidly developing watersheds. The date on the land use maps used as sources should be as recent as possible.

BASIN AREAS											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	TOTAL
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
LAND USE	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)	AREA (HA)
Urban 1 (Residential)	12.0	8.5	8.4	47.4	6.7	4.5	18.1				105.5
Urban 2 (Roads)	3.7	5.5	0.0	5.9	0.8	0.6	2.3				18.8
Urban 3 (Mixed Urban/Commercial)	3.6	5.8	0.0	5.9	0.8	0.6	2.3				19.0
Urban 4 (Industrial)	0.0	0.0	0.0	23.5	0.0	0.0	0.0				23.5
Urban 5 (Parks, Recreation Fields, Institutional)	0.0	3.2	0.0	0.0	0.0	0.0	0.0				3.2
Agric 1 (Cover Crop)	0.0	0.0	0.0	0.8	12.3	0.0	0.0				13.1
Agric 2 (Row Crop)	0.0	0.0	0.0	0.0	16.2	0.0	0.0				16.2
Agric 3 (Grazing)	0.0	0.0	0.0	0.0	4.0	0.0	0.0				4.0
Agric 4 (Feedlot)	0.0	0.0	0.0	0.0	0.5	0.0	0.0				0.5
Forest 1 (Upland)	7.7	17.5	50.3	90.3	9.2	32.0	33.6				240.6
Forest 2 (Wetland)	0.0	0.2	0.0	14.5	0.0	0.0	1.9				16.6
Open 1 (Wetland/Lake)	2.5	0.6	2.0	0.1	0.0	0.1	14.2				19.4
Open 2 (Meadow)	2.0	1.3	0.0	10.2	0.1	0.0	0.2				13.8
Open 3 (Excavation)	0.1	0.1	0.0	2.3	0.0	0.0	0.0				2.5
Other 1											0.0
Other 2											0.0
Other 3											0.0
TOTAL	31.6	42.6	60.7	200.9	50.6	37.7	72.4	0	0		496.5

Load Generation

At this point, the model will perform a number of calculations before any further input is needed. These are represented by a series of tables with no shaded cells, and include calculation of water, TP and TN loads from runoff and baseflow as shown below. These loads are intermediate products, not subject to attenuation or routing, and have little utility as individual values. They are the precursors of the actual loads delivered to the lake, which require some additional input information.

WATER LOAD GENERATION: RUNOFF											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	TOTAL
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
LAND USE	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)
Urban 1 (Residential)	43560	30855	30492	172056	24182	16277	65563	0	0	0	382985
Urban 2 (Roads)	18005	26457	0	28676	4030	2713	10927	0	0	0	90808
Urban 3 (Mixed Urban/Commercial)	26136	42108	0	43014	6045	4069	16391	0	0	0	137763
Urban 4 (Industrial)	0	0	0	142175	0	0	0	0	0	0	142175
Urban 5 (Parks, Recreation Fields, Institutional)	0	3872	0	0	0	0	0	0	0	0	3872
Agric 1 (Cover Crop)	0	0	0	1387	22325	0	0	0	0	0	23712
Agric 2 (Row Crop)	0	0	0	0	58806	0	0	0	0	0	58806
Agric 3 (Grazing)	0	0	0	0	14520	0	0	0	0	0	14520
Agric 4 (Feedlot)	0	0	0	0	2723	0	0	0	0	0	2723
Forest 1 (Upland)	9325	21175	60863	109263	11126	38720	40600	0	0	0	291073
Forest 2 (Wetland)	0	150	0	8746	0	0	1153	0	0	0	10049
Open 1 (Wetland/Lake)	1494	334	1210	56	0	37	8591	0	0	0	11722
Open 2 (Meadow)	1210	768	0	6199	38	0	122	0	0	0	8336
Open 3 (Excavation)	593	454	0	10991	0	0	0	0	0	0	12038
Other 1	0	0	0	0	0	0	0	0	0	0	0
Other 2	0	0	0	0	0	0	0	0	0	0	0
Other 3	0	0	0	0	0	0	0	0	0	0	0
TOTAL (CU.M/YR)	100323	126173	92565	522564	143794	61816	143347	0	0	0	1190582
TOTAL (CFS)	0.11	0.14	0.10	0.59	0.16	0.07	0.16	0.00	0.00	0.00	1.33

WATER LOAD GENERATION: BASEFLOW											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	TOTAL
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)
Urban 1 (Residential)	21780	15428	15246	86028	12091	8139	32781	0	0	0	191492
Urban 2 (Roads)	4501	6614	0	7169	1008	678	2732	0	0	0	22702
Urban 3 (Mixed Urban/Commercial)	2178	3509	0	3585	504	339	1366	0	0	0	11480
Urban 4 (Industrial)	0	0	0	14218	0	0	0	0	0	0	14218
Urban 5 (Parks, Recreation Fields, Institutional)	0	1936	0	0	0	0	0	0	0	0	1936
Agric 1 (Cover Crop)	0	0	0	2775	44649	0	0	0	0	0	47424
Agric 2 (Row Crop)	0	0	0	0	58806	0	0	0	0	0	58806
Agric 3 (Grazing)	0	0	0	0	14520	0	0	0	0	0	14520
Agric 4 (Feedlot)	0	0	0	0	1815	0	0	0	0	0	1815
Forest 1 (Upland)	37301	84700	243452	437052	44504	154880	162402	0	0	0	1164291
Forest 2 (Wetland)	0	1203	0	69969	0	0	9220	0	0	0	80393
Open 1 (Wetland/Lake)	11953	2672	9680	450	0	294	68728	0	0	0	93777
Open 2 (Meadow)	7260	4605	0	37192	226	0	732	0	0	0	50016
Open 3 (Excavation)	297	227	0	5496	0	0	0	0	0	0	6019
Other 1	0	0	0	0	0	0	0	0	0	0	0
Other 2	0	0	0	0	0	0	0	0	0	0	0
Other 3	0	0	0	0	0	0	0	0	0	0	0
Point Source #1	0	0	0	45000	0	0	0	0	0	0	45000
Point Source #2	0	0	0	0	0	0	0	0	0	0	0
Point Source #3	0	0	0	0	0	0	0	0	0	0	0
TOTAL (CU.M/YR)	85270	120894	268378	708932	178122	164330	277961	0	0	0	1803888
TOTAL (CFS)	0.10	0.14	0.30	0.79	0.20	0.18	0.31	0.00	0.00	0.000	2.02

LOAD GENERATION: RUNOFF P											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	TOTAL
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
LAND USE	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)
Urban 1 (Residential)	7.8	5.5	5.5	30.8	4.3	2.9	11.7	0.0	0.0	0.0	68.6
Urban 2 (Roads)	2.8	4.1	0.0	4.4	0.6	0.4	1.7	0.0	0.0	0.0	14.1
Urban 3 (Mixed Urban/Commercial)	2.9	4.6	0.0	4.7	0.7	0.4	1.8	0.0	0.0	0.0	15.2
Urban 4 (Industrial)	0.0	0.0	0.0	16.5	0.0	0.0	0.0	0.0	0.0	0.0	16.5
Urban 5 (Parks, Recreation Fields, Institutional)	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6
Agric 1 (Cover Crop)	0.0	0.0	0.0	0.6	9.8	0.0	0.0	0.0	0.0	0.0	10.5
Agric 2 (Row Crop)	0.0	0.0	0.0	0.0	16.2	0.0	0.0	0.0	0.0	0.0	16.2
Agric 3 (Grazing)	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	1.6
Agric 4 (Feedlot)	0.0	0.0	0.0	0.0	112.0	0.0	0.0	0.0	0.0	0.0	112.0
Forest 1 (Upland)	1.5	3.5	10.1	18.1	1.8	6.4	6.7	0.0	0.0	0.0	48.1
Forest 2 (Wetland)	0.0	0.0	0.0	1.4	0.0	0.0	0.2	0.0	0.0	0.0	1.7
Open 1 (Wetland/Lake)	0.2	0.1	0.2	0.0	0.0	0.0	1.4	0.0	0.0	0.0	1.9
Open 2 (Meadow)	0.2	0.1	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
Open 3 (Excavation)	0.1	0.1	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Other 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	15.6	20.6	15.7	79.4	147.1	10.2	23.6	0.0	0.0	0.0	312.2

LOAD GENERATION: RUNOFF N											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	TOTAL
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
LAND USE	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)
Urban 1 (Residential)	66.0	46.8	46.2	260.7	36.6	24.7	99.3	0.0	0.0	0.0	580.3
Urban 2 (Roads)	20.5	30.1	0.0	32.6	4.6	3.1	12.4	0.0	0.0	0.0	103.2
Urban 3 (Mixed Urban/Commercial)	19.8	31.9	0.0	32.6	4.6	3.1	12.4	0.0	0.0	0.0	104.4
Urban 4 (Industrial)	0.0	0.0	0.0	129.3	0.0	0.0	0.0	0.0	0.0	0.0	129.3
Urban 5 (Parks, Recreation Fields, Institutional)	0.0	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.6
Agric 1 (Cover Crop)	0.0	0.0	0.0	4.6	74.8	0.0	0.0	0.0	0.0	0.0	79.4
Agric 2 (Row Crop)	0.0	0.0	0.0	0.0	145.8	0.0	0.0	0.0	0.0	0.0	145.8
Agric 3 (Grazing)	0.0	0.0	0.0	0.0	20.8	0.0	0.0	0.0	0.0	0.0	20.8
Agric 4 (Feedlot)	0.0	0.0	0.0	0.0	1461.6	0.0	0.0	0.0	0.0	0.0	1461.6
Forest 1 (Upland)	22.0	50.1	143.9	258.3	26.3	91.5	96.0	0.0	0.0	0.0	688.0
Forest 2 (Wetland)	0.0	0.7	0.0	41.3	0.0	0.0	5.4	0.0	0.0	0.0	47.5
Open 1 (Wetland/Lake)	6.1	1.4	4.9	0.2	0.0	0.1	34.9	0.0	0.0	0.0	47.7
Open 2 (Meadow)	4.9	3.1	0.0	25.2	0.2	0.0	0.5	0.0	0.0	0.0	33.9
Open 3 (Excavation)	0.6	0.5	0.0	11.8	0.0	0.0	0.0	0.0	0.0	0.0	12.9
Other 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	139.9	182.0	195.0	796.6	1775.2	122.5	261.0	0.0	0.0	0.0	3472.2

LOAD GENERATION: BASEFLOW P											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	TOTAL
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
LAND USE	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)
Urban 1 (Residential)	0.12	0.09	0.08	0.47	0.07	0.04	0.18	0.00	0.00	0.00	1.06
Urban 2 (Roads)	0.04	0.05	0.00	0.06	0.01	0.01	0.02	0.00	0.00	0.00	0.19
Urban 3 (Mixed Urban/Commercial)	0.04	0.06	0.00	0.06	0.01	0.01	0.02	0.00	0.00	0.00	0.19
Urban 4 (Industrial)	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.24
Urban 5 (Parks, Recreation Fields, Institutional)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Agric 1 (Cover Crop)	0.00	0.00	0.00	0.01	0.12	0.00	0.00	0.00	0.00	0.00	0.13
Agric 2 (Row Crop)	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.16
Agric 3 (Grazing)	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.04
Agric 4 (Feedlot)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Forest 1 (Upland)	0.04	0.09	0.25	0.45	0.05	0.16	0.17	0.00	0.00	0.00	1.20
Forest 2 (Wetland)	0.00	0.00	0.00	0.07	0.00	0.00	0.01	0.00	0.00	0.00	0.08
Open 1 (Wetland/Lake)	0.01	0.00	0.01	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.10
Open 2 (Meadow)	0.01	0.01	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Open 3 (Excavation)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Other 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Point Source #1	0.00	0.00	0.00	135.00	0.00	0.00	0.00	0.00	0.00	0.00	135.00
Point Source #2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Point Source #3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	0.25	0.33	0.35	136.42	0.46	0.22	0.48	0.00	0.00	0.00	138.50

LOAD GENERATION: BASEFLOW N											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	TOTAL
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
LAND USE	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)
Urban 1 (Residential)	60.00	42.50	42.00	236.99	33.31	22.42	90.31	0.00	0.00	0.00	527.53
Urban 2 (Roads)	18.60	27.33	0.00	29.62	4.16	2.80	11.29	0.00	0.00	0.00	93.81
Urban 3 (Mixed Urban/Commercial)	18.00	29.00	0.00	29.62	4.16	2.80	11.29	0.00	0.00	0.00	94.88
Urban 4 (Industrial)	0.00	0.00	0.00	117.50	0.00	0.00	0.00	0.00	0.00	0.00	117.50
Urban 5 (Parks, Recreation Fields, Institutional)	0.00	16.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.00
Agric 1 (Cover Crop)	0.00	0.00	0.00	1.91	30.75	0.00	0.00	0.00	0.00	0.00	32.66
Agric 2 (Row Crop)	0.00	0.00	0.00	0.00	40.50	0.00	0.00	0.00	0.00	0.00	40.50
Agric 3 (Grazing)	0.00	0.00	0.00	0.00	20.00	0.00	0.00	0.00	0.00	0.00	20.00
Agric 4 (Feedlot)	0.00	0.00	0.00	0.00	12.50	0.00	0.00	0.00	0.00	0.00	12.50
Forest 1 (Upland)	7.71	17.50	50.30	90.30	9.20	32.00	33.55	0.00	0.00	0.00	240.56
Forest 2 (Wetland)	0.00	0.25	0.00	14.46	0.00	0.00	1.91	0.00	0.00	0.00	16.61
Open 1 (Wetland/Lake)	1.23	0.28	1.00	0.05	0.00	0.03	7.10	0.00	0.00	0.00	9.69
Open 2 (Meadow)	1.00	0.63	0.00	5.12	0.03	0.00	0.10	0.00	0.00	0.00	6.89
Open 3 (Excavation)	0.06	0.05	0.00	1.14	0.00	0.00	0.00	0.00	0.00	0.00	1.24
Other 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Point Source #1	0.00	0.00	0.00	540.00	0.00	0.00	0.00	0.00	0.00	0.00	540.00
Point Source #2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Point Source #3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	106.60	133.54	93.30	1066.71	154.61	60.06	155.54	0.00	0.00	0.00	1770.36

Load Routing Pattern

The model must be told how to route all inputs of water, TP and TN before they reach the lake. Since attenuation in an upstream basin can affect inputs in an upstream basin that passes through the downstream basin, the model must be directed as to where to apply attenuation factors and additive effects. In the table below, each basin listed on the lines labeled on the left that passes

through another basin labeled by column is denoted with a 1 in the column of the basin through which it passes. Otherwise, a 0 appears in each shaded cell. All basins pass through themselves, so the first line has a 1 in each cell. Basins 1 and 2 go direct to the lake, and so all other cells on the corresponding lines have 0 entries. Basin 3 passes through Basin 4 (see Figure 2), and so the line for Basin 3 has a 1 in the column for Basin 4. Likewise, Basins 5 and 6 pass through Basin 7, so the corresponding lines have a 1 entered in the column for Basin 7.

ROUTING PATTERN										
	(Basin in left hand column passes through basin in column below if indicated by a 1)									
1=YES 0=NO XXX=BLANK	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2			
	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)
INDIVIDUAL BASIN	1	1	1	1	1	1	1	1	1	1
BASIN 1 OUTPUT	XXX	0	0	0	0	0	0	0	0	0
BASIN 2 OUTPUT	0	XXX	0	0	0	0	0	0	0	0
BASIN 3 OUTPUT	0	0	XXX	1	0	0	0	0	0	0
BASIN 4 OUTPUT	0	0	0	XXX	0	0	0	0	0	0
BASIN 5 OUTPUT	0	0	0	0	XXX	0	1	0	0	0
BASIN 6 OUTPUT	0	0	0	0	0	XXX	1	0	0	0
BASIN 7 OUTPUT	0	0	0	0	0	0	XXX	0	0	0
BASIN 8 OUTPUT	0	0	0	0	0	0	0	XXX	0	0
BASIN 9 OUTPUT	0	0	0	0	0	0	0	0	XXX	0
BASIN 10 OUTPUT	0	0	0	0	0	0	0	0	0	XXX
CUMULATIVE DRAINAGE AREAS										
	(Total land area associated with routed water and nutrients)									
1=YES 0=NO XXX=BLANK	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2			
	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)
INDIVIDUAL BASIN	31.6	42.6	60.7	200.9	50.6	37.7	72.4	0.0	0.0	0.0
BASIN 1 OUTPUT	XXX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 2 OUTPUT	0.0	XXX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 3 OUTPUT	0.0	0.0	XXX	60.7	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 4 OUTPUT	0.0	0.0	0.0	XXX	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 5 OUTPUT	0.0	0.0	0.0	0.0	XXX	0.0	50.6	0.0	0.0	0.0
BASIN 6 OUTPUT	0.0	0.0	0.0	0.0	0.0	XXX	37.7	0.0	0.0	0.0
BASIN 7 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0	0.0
BASIN 8 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
BASIN 9 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0
BASIN 10 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX
TOTALS	31.6	42.6	60.7	261.6	50.6	37.7	160.7	0.0	0.0	0.0

The model then combines the appropriate watershed areas as shown above, generating larger sub-watersheds that are used later to calculate overall export coefficients, comparative water yields and related checks for model accuracy.

Load Routing and Attenuation

With the loads calculated previously for each basin under wet and dry conditions and the routing of those loads specified, the model can then combine those loads and apply attenuation values chosen to reflect expected losses of water, TP or TN while the generated loads are on their way to the lake.

Water

Water is attenuated mostly by evapotranspiration losses. Some depression storage is expected, seepage into the ground is possible, and wetlands can remove considerable water on the way to the lake. In general, a 5% loss is to be expected in nearly all cases, and greater losses are plausible with lower gradient or wetland dominated landscapes. In the example system, only the lower portion of Tributary 2 is expected to have more than a 5% loss, with a 15% loss linked to the wetland associated with this drainage area and tributary (see Figure 1).

WATER ROUTING AND ATTENUATION										
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2			
SOURCE	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)	(CU.M/YR)
INDIVIDUAL BASIN	185594	247067	362153	1231497	321916	226145	421308	0	0	0
BASIN 1 OUTPUT	XXX	0	0	0	0	0	0	0	0	0
BASIN 2 OUTPUT	0	XXX	0	0	0	0	0	0	0	0
BASIN 3 OUTPUT	0	0	XXX	344045	0	0	0	0	0	0
BASIN 4 OUTPUT	0	0	0	XXX	0	0	0	0	0	0
BASIN 5 OUTPUT	0	0	0	0	XXX	0	305820	0	0	0
BASIN 6 OUTPUT	0	0	0	0	0	XXX	214838	0	0	0
BASIN 7 OUTPUT	0	0	0	0	0	0	XXX	0	0	0
BASIN 8 OUTPUT	0	0	0	0	0	0	0	XXX	0	0
BASIN 9 OUTPUT	0	0	0	0	0	0	0	0	XXX	0
BASIN 10 OUTPUT	0	0	0	0	0	0	0	0	0	XXX
CUMULATIVE TOTAL	185594	247067	362153	1575542	321916	226145	941966	0	0	0
BASIN ATTENUATION	0.95	0.95	0.95	0.95	0.95	0.95	0.85	1.00	1.00	1.00
OUTPUT VOLUME	176314	234714	344045	1496765	305820	214838	800671	0.0	0.0	0.0
Reality Check from Flow Data				1500000.0			800000.0			
Calculated Flow/Measured Flow	#DIV/0!	#DIV/0!	#DIV/0!	0.998	#DIV/0!	#DIV/0!	1.001	#DIV/0!	#DIV/0!	#DIV/0!
Reality Check from Areal Yield X Basin Area	174638.7	235450.8	335258.2	1444750.2	279386.8	208035.3	887509.1	0.0	0.0	0.0
Calculated Flow/Flow from Areal Yield	1.010	0.997	1.026	1.036	1.095	1.033	0.902	#DIV/0!	#DIV/0!	#DIV/0!

The resulting output volume for each basin is calculated in the table below, and two reality check opportunities are provided. First any actual data can be added for direct comparison; average flows are available for only two points, the inlets of the two tributaries, but these are useful. In many cases no flow data may be available. The model therefore generates an estimate of the expected average flow as a function of all contributing upstream watershed area and the water yield provided near the top of the Calculations sheet (covered previously). While this flow estimate is approximate, it should not vary from the modeled flow by more than about 20% unless there are unusual circumstances.

In the example, the ratio of the calculated flow from the complete model generation and routing to the estimated yield from the contributing drainage area ranges from 0.902 to 1.095, suggesting fairly close agreement. As some ratios are lower than 1 and others are higher than 1, no model-wide adjustment is likely to bring the values into closer agreement. Slight changes in attenuation for each basin could be applied, but are not necessary when the values agree this closely.

Phosphorus

The same approach applied to attenuation of water is applied to the phosphorus load, as shown in the table below. Here attenuation can range from 0 to 1.0, with the value shown representing the portion of the load that reaches the terminus of the basin. With natural or human enhanced removal processes, it is unusual for all of the load to pass through a basin, but it is also unusual for more than 60 to 70% of it to be removed. What value to pick depends on professional judgment regarding the nature of removal processes in each basin. Infiltration, filtration, detention and uptake will lower the attenuation value entered below, and knowledge of the literature on Best Management Practices is needed to make reliable judgments on attenuation values.

LOAD ROUTING AND ATTENUATION: PHOSPHORUS										
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2			
	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)
BASIN 1 INDIVIDUAL	15.8	20.9	16.3	215.8	147.6	10.4	24.1	0.0	0.0	0.0
BASIN 1 OUTPUT	XXX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 2 OUTPUT	0.0	XXX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 3 OUTPUT	0.0	0.0	XXX	12.2	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 4 OUTPUT	0.0	0.0	0.0	XXX	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 5 OUTPUT	0.0	0.0	0.0	0.0	XXX	0.0	118.1	0.0	0.0	0.0
BASIN 6 OUTPUT	0.0	0.0	0.0	0.0	0.0	XXX	7.8	0.0	0.0	0.0
BASIN 7 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0	0.0
BASIN 8 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
BASIN 9 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0
BASIN 10 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX
CUMULATIVE TOTAL	15.8	20.9	16.3	228.0	147.6	10.4	149.9	0.0	0.0	0.0
BASIN ATTENUATION	0.90	0.90	0.75	0.85	0.80	0.75	0.70	1.00	1.00	1.00
OUTPUT LOAD	14.2	18.8	12.2	193.8	118.1	7.8	104.9	0.0	0.0	0.0

In the example system, the direct drainage basins were assigned values of 0.90, representing a small amount of removal mainly by infiltration processes. Upper Tributary #1 has a small pond and was accorded a value of 0.75 (25% removal); a larger pond might have suggested a value closer to 0.5. Lower Tributary #1 has an assigned value of 0.85 based on channel processes that favor uptake and adsorption. West and East Upper Tributary #2 have value based on drainage basin features as evaluated in the field, while the wetland associated with Lower Tributary #2 garners it the lowest load pass-through at 0.7. A more extensive wetland with greater sheet flow might have earned a value near 0.5. Resulting output loads are then calculated.

Nitrogen

The same process used with water and TP attenuation applies to TN, but attenuation of TN is rarely identical to that for TP. Nitrogen moves more readily through soil, and while transformations occur in the stream, losses due to denitrification require slower flows and low oxygen levels not commonly encountered in steeper, rockier channels. However, losses from uptake and possibly denitrification are possible in wetland areas, such as that associated with Lower Tributary #2. Accordingly, attenuation values are assigned as shown in the table below, with generally lower losses for TN than for TP. As with TP attenuation, choosing appropriate values does require some professional judgment.

LOAD ROUTING AND ATTENUATION: NITROGEN										
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2			
	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)	(KG/YR)
BASIN 1 INDIVIDUAL	246.5	315.6	290.1	1863.3	1929.8	182.6	416.6	0.0	0.0	0.0
BASIN 1 OUTPUT	XXX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 2 OUTPUT	0.0	XXX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 3 OUTPUT	0.0	0.0	XXX	232.1	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 4 OUTPUT	0.0	0.0	0.0	XXX	0.0	0.0	0.0	0.0	0.0	0.0
BASIN 5 OUTPUT	0.0	0.0	0.0	0.0	XXX	0.0	1543.8	0.0	0.0	0.0
BASIN 6 OUTPUT	0.0	0.0	0.0	0.0	0.0	XXX	146.0	0.0	0.0	0.0
BASIN 7 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0	0.0
BASIN 8 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0	0.0
BASIN 9 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX	0.0
BASIN 10 OUTPUT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	XXX
CUMULATIVE TOTAL	246.5	315.6	290.1	2095.4	1929.8	182.6	2106.4	0.0	0.0	0.0
BASIN ATTENUATION	0.95	0.95	0.80	0.90	0.80	0.80	0.75	1.00	1.00	1.00
OUTPUT LOAD	234.2	299.8	232.1	1885.8	1543.8	146.0	1579.8	0.0	0.0	0.0

Load and Concentration Summary

Water

Water loads were handled to the extent necessary in the previous loading calculations, and are used in this section only to allow calculation of expected TP and TN concentrations, facilitating reality checks with actual data.

Phosphorus

Using the calculated load of TP for each basin and the corresponding water volume, an average expected concentration can be derived, as shown in the table below. Where sampling provides actual data, values can be compared to determine how well the model represents known reality. Sufficient sampling is needed to make the reality check values reliable; it is not appropriate to assume that either the data or the model is necessarily accurate when the values disagree. However, with enough data to adequately characterize the concentrations observed in the stream, the model can be adjusted to produce a better match. Estimated and actual concentrations are used to generate a ratio for easy comparison.

The TP loads previously calculated represent the load passing through each basin, but do not represent what reaches the lake, as not all basins are terminal input sources. The model must be told which basins actually drain directly to the lake, and for which the exiting load is part of the total load to the lake.

LOAD AND CONCENTRATION SUMMARY: PHOSPHORUS											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
OUTPUT (CU.M/YR)	176314	234714	344045	1496765	305820	214838	800671	0	0	0	
OUTPUT (KG/YR)	14.2	18.8	12.2	193.8	118.1	7.8	104.9	0.0	0.0	0.0	
OUTPUT (MG/L)	0.081	0.080	0.035	0.129	0.386	0.036	0.131	#DIV/0!	#DIV/0!	#DIV/0!	
REALITY CHECK CONC. (FROM DATA)	0.078	0.076	0.040	0.150	0.325	0.035	0.125				
CALCULATED CONC./MEASURED CONC.	1.035	1.056	0.886	0.863	1.188	1.038	1.049	#DIV/0!	#DIV/0!	#DIV/0!	
BASIN EXPORT COEFFICIENT	0.45	0.44	0.20	0.74	2.33	0.21	0.65	#DIV/0!	#DIV/0!	#DIV/0!	
TERMINAL DISCHARGE?	1	1	0	1	0	0	1	1	1	1	
(1=YES 2=NO)											
LOAD TO RESOURCE											TOTAL
WATER (CU.M/YR)	176314	234714	0	1496765	0	0	800671	0	0	0	2708464
PHOSPHORUS (KG/YR)	14.2	18.8	0.0	193.8	0.0	0.0	104.9	0.0	0.0	0.0	331.8
PHOSPHORUS (MG/L)	0.081	0.080	0.000	0.129	0.000	0.000	0.131	#DIV/0!	#DIV/0!	#DIV/0!	0.123

For the example system, the ratio of the calculated concentration to average actual values derived from substantial sampling (typically on the order of 10 or more samples representing the range of dry to wet conditions) ranges from 0.886 to 1.188, or from 11% low to 19% high, within a generally acceptable range of ±20%. This is not a strict threshold, especially with lower TP concentrations where detection limits and intervals of expression for methods can produce higher percent deviation with very small absolute differences. Yet in general, <20% difference between observed and expected watershed basin output values is considered reasonable for a model at this level of sophistication.

That some values are higher than expected and others lower suggests that now model-wide adjustment will improve agreement (such as an export coefficient change), but attenuation values for individual basins could be adjusted if there is justification.

For the example system, Basins 1, 2, 4 and 7 contribute directly to the lake, and are so denoted by a 1 in their respective columns on the line for terminal discharge. These loads will be summed to derive a watershed load of TP to the lake.

Nitrogen

The model process followed for TN is identical to that applied to TP loads from basins. For TN in the example system, comparison of expected vs. observed values yields a range of ratios from 0.929 to 1.188, representing 7% low to 19% high. Only one out of seven values is lower than 1, so perhaps some adjustment of the TN export coefficients is in order, but most individual basin values are within 8% of each other, so without clear justification, the judgment exercised in the original choices for export coefficients and attenuation is not generally overridden. The same basins denoted as terminal discharges for TP are so noted for TN, allowing calculation of the total watershed load of TN to the lake.

LOAD AND CONCENTRATION SUMMARY: NITROGEN											
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10	
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2				
OUTPUT (CU.M/YR)	176314	234714	344045	1496765	305820	214838	800671	0	0	0	
OUTPUT (KG/YR)	234.2	299.8	232.1	1885.8	1543.8	146.0	1579.8	0.0	0.0	0.0	
OUTPUT MG/L	1.328	1.277	0.675	1.260	5.048	0.680	1.973	#DIV/0!	#DIV/0!	#DIV/0!	
REALITY CHECK CONC. (FROM DATA)	1.430	1.240	0.650	1.180	4.250	0.650	1.830				
CALCULATED CONC./MEASURED CONC.	0.929	1.030	1.038	1.068	1.188	1.046	1.078	#DIV/0!	#DIV/0!	#DIV/0!	
BASIN EXPORT COEFFICIENT	7.41	7.03	3.82	7.21	30.52	3.88	9.83	#DIV/0!	#DIV/0!	#DIV/0!	
TERMINAL DISCHARGE?	1	1	0	1	0	0	1	1	1	1	
(1=YES 2=NO)											
LOAD TO RESOURCE											TOTAL
WATER (CU.M/YR)	176314	234714	0	1496765	0	0	800671	0	0	0	2708464
NITROGEN (KG/YR)	234.2	299.8	0.0	1885.8	0.0	0.0	1579.8	0.0	0.0	0.0	3999.7
NITROGEN (MG/L)	1.328	1.277	0.000	1.260	0.000	0.000	1.973	#DIV/0!	#DIV/0!	#DIV/0!	1.477

Grand Totals

The final portion of the Calculation sheet is a summary of all loads to the lake and a grand total load with associated concentrations for TP and TN, as shown below. The breakdown of sources is provided for later consideration in both overall target setting and in consideration of BMPs. For the example system, the watershed load is clearly dominant, and would need to be addressed if substantial reductions in loading were considered necessary. The loads of water, TP and TN are then transferred automatically to the Prediction sheet to facilitate estimation of in-lake concentrations of TP, TN and Chl and a value for SDT. The derived overall input concentration for TP is also transferred; the in-lake predictive models for TN do not require that overall input concentration, but the comparison of TP and TN input levels can be insightful when considering what types of algae are likely to dominate the lake phytoplankton.

LOAD SUMMARY			
DIRECT LOADS TO LAKE	P (KG/YR)	N (KG/YR)	WATER (CU.M/YR)
ATMOSPHERIC	8.0	260.0	484000
INTERNAL	40.0	100.0	0
WATERFOWL	10.0	47.5	0
SEPTIC SYSTEM	31.8	517.0	31250
WATERSHED LOAD	331.7	3998.4	2707372
TOTAL LOAD TO LAKE	421.5	4922.9	3222622
(Watershed + direct loads)			
TOTAL INPUT CONC. (MG/L)	0.131	1.528	

Water Quality Predictions

Prediction of TP, TN, Chl and SDT is based on empirical equations from the literature, nearly all pertaining to North American systems. Only a few additional pieces of information are needed to run the model; most of the needed input data are automatically transferred from the Calculations

sheet. As shown below, only the concentration of TP leaving the lake and the lake volume must be entered on the Prediction sheet. If the outflow TP level is not known, the in-lake surface concentration is normally used. If the volume is not specifically known, an average depth can be multiplied by the lake area to derive an input volume, which will then recalculate the average depth one cell below. The nature of the TN prediction models does not require any TN concentration input.

IN-LAKE MODELS FOR PREDICTING CONCENTRATIONS: Current Conditions					
THE TERMS					
	PHOSPHORUS				
SYMBOL	PARAMETER	UNITS	DERIVATION	VALUE	
TP	Lake Total Phosphorus Conc.	ppb	From in-lake models	To Be Predicted	
KG	Phosphorus Load to Lake	kg/yr	From export model	422	
L	Phosphorus Load to Lake	g P/m2/yr	KG*1000/A	1.054	
TPin	Influent (Inflow) Total Phosphorus	ppb	From export model	131	
TPout	Effluent (Outlet) Total Phosphorus	ppb	From data, if available	75	Enter Value (TP out)
I	Inflow	m3/yr	From export model	3222622	
A	Lake Area	m2	From data	400000	
V	Lake Volume	m3	From data	1625300	Enter Value (V)
Z	Mean Depth	m	Volume/area	4.063	
F	Flushing Rate	flushings/yr	Inflow/volume	1.983	
S	Suspended Fraction	no units	Effluent TP/Influent TP	0.573	
Qs	Areal Water Load	m/yr	Z(F)	8.057	
Vs	Settling Velocity	m	Z(S)	2.330	
Rp	Retention Coefficient (settling rate)	no units	((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs)	0.491	
Rlm	Retention Coefficient (flushing rate)	no units	1/(1+F^0.5)	0.415	
	NITROGEN				
SYMBOL	PARAMETER	UNITS	DERIVATION	VALUE	
TN	Lake Total Nitrogen Conc.	ppb	From in-lake models	To Be Predicted	
KG	Nitrogen Load to Lake	kg/yr	From export model	4923	
L1	Nitrogen Load to Lake	g N/m2/yr	KG*1000/A	12.31	
L2	Nitrogen Load to Lake	mg N/m2/yr	KG*1000000/A	12307	
C1	Coefficient of Attenuation, from F	fraction/yr	2.7183^(0.5541(ln(F))-0.367)	1.01	
C2	Coefficient of Attenuation, from L	fraction/yr	2.7183^(0.71(ln(L2))-6.426)	1.30	
C3	Coefficient of Attenuation, from L/Z	fraction/yr	2.7183^(0.594(ln(L2/Z))-4.144)	1.85	

Phosphorus Concentration

TP concentration is predicted from the equations shown below. The mass balance calculation is simply the TP load divided by the water load, and assumes no losses to settling within the lake. Virtually all lakes have settling losses, but the other equations derive that settling coefficient in different ways, providing a range of possible TP concentration values. Where there is knowledge of the components of the settling calculations, a model might be selected as most representative or models might be eliminated as inapplicable, but otherwise the average of the five empirical models (excluding the mass balance calculation) is accepted as the predicted TP value for the lake.

THE MODELS				
	PHOSPHORUS	PRED.	PERMIS.	CRITICAL
		CONC.	CONC.	CONC.
NAME	FORMULA	(ppb)	(ppb)	(ppb)
Mass Balance	TP=L/(Z(F))*1000	131		
(Maximum Conc.)				
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	67	18	36
(K-D)				
Vollenweider 1975	TP=L/(Z(S+F))*1000	101	27	55
(V)				
Larsen-Mercier 1976	TP=L(1-Rlm)/(Z(F))*1000	76	21	41
(L-M)				
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	83	22	45
(J-B)				
Reckhow General (1977)	TP=L/(11.6+1.2(Z(F)))*1000	50	13	27
(Rg)				
Average of Model Values		75	20	41
(without mass balance)				
Measured Value		75		
(mean, median, other)				
From Vollenweider 1968				
Permissible Load (g/m2/yr)	Lp=10^(0.501503(log(Z(F)))-1.0018)	0.28		
Critical Load (g/m2/yr)	Lc=2(Cp)	0.57		

The predicted in-lake TP concentration can be compared to actual data (an average value is entered in the shaded cell as a reality check) and to calculation of the permissible and critical concentrations as derived from Vollenweider's 1968 work. For the example lake, the predicted TP level of 75 ug/L is an exact match for the measured value of 75 ug/L, but both are well above the critical concentration.

The permissible concentration is the value above which algal blooms are to be expected on a potentially unacceptable frequency, while the critical concentration is the level above which unacceptable algal growths are to be expected, barring extreme flushing, toxic events or light limitation from suspended sediment.

Use of the range of values derived from these empirical equations provides some sense for the uncertainty in the analysis. Changing input loads, lake volume, or other key variables allows for sensitivity analysis.

Nitrogen Concentration

Prediction of TN is based on three separate empirical equations from the same work, each calculating settling losses differently. A mass balance equation is applied as well, as with the prediction of TP. An actual mean value is normally entered in the shaded cell as a reality check. For the example system, the actual mean TN value is within the range of predicted values, but is about 5.6% lower than the average of predicted values. One might consider adjusting export coefficients or attenuation rates in the Calculations sheet, to bring these values closer together, but the discrepancy is relatively minor.

	NITROGEN	
Mass Balance	TN=L/(Z(F))*1000	1528
(Maximum Conc.)		
Bachmann 1980	TN=L/(Z(C1+F))*1000	1011
Bachmann 1980	TN=L/(Z(C2+F))*1000	923
Bachmann 1980	TN=L/(Z(C3+F))*1000	789
Average of Model Values		908
(without mass balance)		
Measured Value		860
(mean, median, other)		

Chlorophyll Concentration, Water Clarity and Bloom Probability

Once an average in-lake TP concentration has been established, the Predictions sheet derives corresponding Chl and SDT values, as shown below. Five different equations are used to derive a predicted Chl value, and an average is derived. Peak Chl is estimated with three equations, with an average generated. Average and maximum expected SDT are estimated as well. Bloom frequency is based on the relationship of mean Chl to other threshold levels from other studies, and the portion of time that Chl is expected to exceed 10, 15, 20, 30 and 40 ug/L is derived.

A set of shaded cells are provided for entry of known measured values for comparison. For the example lake, the average and peak Chl levels predicted from the model are slightly higher than actual measured values, while the average and maximum SDT from the model are slightly lower than observed values, consistent with the Chl results. Agreement is generally high, however, with differences between 10 and 20%. There were not enough data to construct a dependable actual distribution of Chl over the range of thresholds provided for the example lake.

There are other factors besides nutrients that can strongly affect the standing crop of algae and resulting Chl levels, including low light from suspended sediment, grazing by zooplankton, presence of heterotrophic algae, and flushing effects from high flows. Consequently, close agreement between predicted and actual Chl will be harder to achieve than for predicted and actual TP. Knowledge of those other potentially important influences can help determine if model calibration is off, or if closer agreement is not rationally achievable.

PREDICTED CHL AND WATER CLARITY			
MODEL	Value	Mean	Measured
Mean Chlorophyll (ug/L)			
Carlson 1977	45.9		
Dillon and Rigler 1974	38.4		
Jones and Bachmann 1976	44.7		
Oglesby and Schaffner 1978	40.4		
Modified Vollenweider 1982	35.5	41.0	37.5
Peak Chlorophyll (ug/L)			
Modified Vollenweider (TP) 1982	119.7		
Vollenweider (CHL) 1982	133.1		
Modified Jones, Rast and Lee 1979	139.5	130.8	118.1
Secchi Transparency (M)			
Oglesby and Schaffner 1978 **(Avg)**	0.8		1.0
Modified Vollenweider 1982 **(Max)**	2.9		3.1
Bloom Probability			
Probability of Chl >10 ug/L **(% of time)**	99.5%		
Probability of Chl >15 ug/L **(% of time)**	96.1%		
Probability of Chl >20 ug/L **(% of time)**	88.2%		
Probability of Chl >30 ug/L **(% of time)**	64.6%		
Probability of Chl >40 ug/L **(% of time)**	42.0%		

Evaluating Initial Results

LLRM is not meant to be a "black box" model. One can look at any cell and discern which steps are most important to final results in any give case. Several quality control processes are recommended in each application.

Checking Values

Many numerical entries must be made to run LLRM. Be sure to double check the values entered. Simple entry errors can cause major discrepancies between predictions and reality. Where an export coefficient is large, most notably with Agric4, feedlot area, it is essential that the land use actually associated with that activity be accurately assessed and entered.

Following Loads

For any individually identified load that represents a substantial portion of the total load (certainly >25%, perhaps as small a portion as 10%), it is appropriate to follow that load from generation through delivery to the lake, observing the losses and transformations along the way. Sometimes the path will be very short, and sometimes there may be multiple points where attenuation is applied. Consider dry vs. wet weather inputs and determine if the ratio is reasonable in light of actual data or field observations. Are calculated concentrations at points of measurement consistent with the actual measurements? Are watershed processes being adequately represented? One limitation of the model involves application of attenuation for all loads within a defined basin; loads may enter at the distal or proximal ends of the basin, and attenuation may not apply equally to all sources. Where loading and attenuation are not being properly represented, consider subdividing the basin to work with drainages of the most meaningful sizes.

Reality Checks

LLRM can be run with minimal actual water quality data, but to gain confidence in the predictions it is necessary to compare results with sufficient amounts of actual data for key points in the modeled system. Ideally, water quality will be tested at all identified nodes, including the output points for all basins, any point source discharges, any direct discharge pipes to the lake, and in the lake itself. Wet

and dry weather sampling should be conducted. Flow values are highly desirable, but without a longer term record, considerable uncertainty will remain; variability in flow is often extreme, necessitating large data sets to get representative statistical representation. Where there are multiple measurement points, compare not just how close predicted values are to observed values, but the pattern. Are observed values consistently over- or underpredicted? A rough threshold of ±20% is recommended as a starting point, with a mix of values in the + or – categories.

Sensitivity Testing

The sensitivity of LLRM can be evaluated by altering individual features and observing the effect on results. For any variable for which the value is rather uncertain, enter the maximum value conceivable, and record model results. Then repeat the process with the minimum plausible value, and compare to ascertain how much variation can be induced by error in that variable. Which variables seem to have the greatest impact on results? Those variables should receive the most attention in reality checking, ground truthing, and future monitoring, and would also be the most likely candidates for adjustment in model calibration, unless the initially entered values are very certain.

For example, the runoff coefficients for TP from the various land uses were set below the median literature values, based on knowledge of loads for some drainage areas from actual data for flow and concentration. However, it is possible that the actual load generated from various land uses is higher than initially assumed, and it is the attenuation that should be adjusted to achieve a predicted in-lake concentration that matches actual data. If the median TP export for runoff is entered into the Calculations sheet, substituting the unshaded values for the shaded values in the table below, the resulting in-lake TP prediction is 89 ug/L, much higher than the 75 ug/L from real data.

	Original P Export Coefficient	New P Export Coefficient
LAND USE	(kg/ha/yr)	(kg/ha/yr)
Urban 1 (Residential)	0.65	1.10
Urban 2 (Roads)	0.75	1.10
Urban 3 (Mixed Urban/Commercial)	0.80	1.10
Urban 4 (Industrial)	0.70	1.10
Urban 5 (Parks, Recreation Fields, Institutional)	0.80	1.10
Agric 1 (Cover Crop)	0.80	0.80
Agric 2 (Row Crop)	1.00	2.20
Agric 3 (Grazing)	0.40	0.80
Agric 4 (Feedlot)	224.00	224.00
Forest 1 (Upland)	0.20	0.20
Forest 2 (Wetland)	0.10	0.20
Open 1 (Wetland/Lake)	0.10	0.20
Open 2 (Meadow)	0.10	0.20
Open 3 (Excavation)	0.80	0.80
Other 1	0.20	0.20
Other 2	1.10	1.10
Other 3	2.20	2.20

To get a closer match for the known in-lake value, attenuation would have to be adjusted (reduction in the portion of the generated load that reaches the lake) by about 0.1 units (10%), as shown below. This would result in a predicted in-lake TP concentration of 77 ug/L, not far above the measured 75 ug/L. It is apparent

that choice of export coefficients is fairly important, but that error in those choices can be compensated by adjustments in attenuation that are not too extreme to be believed. Yet those choices will affect the results of management scenario testing, and should be made carefully. The intent is to properly represent watershed processes, both loading and attenuation, not just the product of the two.

	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7
	E. Direct	W. Direct	Upper T1	Lower T1	W. Upper T2	E. Upper T2	Lower T2
ORIGINAL BASIN ATTENUATION	0.90	0.90	0.75	0.85	0.80	0.75	0.70
NEW BASIN ATTENUATION	0.80	0.80	0.65	0.75	0.70	0.65	0.60

Aside from changes in all export coefficients, one might consider the impact of changing a single value. As that value applies to all areas given for the corresponding land use, its impact will be proportional to the magnitude of that area relative to other land uses. A change in forested land use exports may be very influential if most of the watershed is forested. A much larger change would be necessary to cause similar impact for a land use that represents a small portion of the watershed.

Model Calibration

Actual adjustment of LLRM to get predicted results in reasonable agreement with actual data can be achieved by altering any of the input data. The key to proper calibration is to change values that have some uncertainty, and to change them in a way that makes sense in light of knowledge of the target watershed and lake. One would not change entered land use areas believed to be correct just to get the predictions to match actual data. Rather, one would adjust the export coefficients for land uses within the plausible range (see Reference Variables sheet), and in accordance with values that could be derived for selected drainage areas (within the target system or nearby) from actual data. Or one could adjust attenuation, determining that a detention area, wetland, or other landscape feature had somewhat greater or lesser attenuation capacity that initially estimated. Justification for all changes should be provided; model adjustment should be transparent and amenable to scrutiny.

For the example system, it may be appropriate to adjust either TN export coefficients or attenuation to get the average of the three empirical equation results for TN (see Predictions sheet) to match the observed average more closely. In the example, a predicted TN concentration of 908 ug/L was derived, while the average of quite a few in-lake samples was 860 ug/L. With a difference of <6%, this is not a major issue, but since all but one of the individual basin predictions for TN concentration were also overpredictions, adjustment can be justified.

If all the TN export coefficients in the Calculations sheet are reduced by 10%, an entirely plausible situation, the new TN prediction for the lake becomes 861 ug/L, a very close match for the observed 860 ug/L. Export coefficients were not changed selectively by land use; all were simply adjusted down a small amount, well within the range of possible variation in this system. Alternatively, if the TN attenuation coefficient for each basin is reduced in the Calculations sheet by 0.05 (representing 5% more loss of TN on the way to the lake), the new predicted in-lake TN concentration becomes 842 ug/L, not far below the observed 860 ug/L. Attenuation in each basin was adjusted the same way, showing no bias. Either of these adjustments (export coefficients or attenuation values) would be reasonable within the constraints of the model and knowledge of the system.

The only way to change the export coefficient for land use in a single basin is to split off that land use into one of the “Other” categories and have it appear in only the basins where a different export coefficient is justified. This is hardly ever done, and justification should involve supporting data. Likewise, if one basin had a particularly large load and a feature that might affect that load, one might justify changing the

attenuation for just that one basin, but justification should be strong to interject this level of individual basin bias.

Model Verification

Proper verification of models involves calibration with one set of data, followed by running the model with different input data leading to different results, with data to verify that those results are appropriate. Where data exist for conditions in a different time period that led to different in-lake conditions, such verification is possible with LLRM, but such opportunities tend to be rare. If the lake level was raised by dam modification, and in-lake data are available for before and after the pool rise, a simple change in the lake volume (entered in the Predictions sheet) can simulate this and allow verification. If in-lake data exist from a time before there was much development in the watershed, this could also allow verification by changing the land use and comparing results to historic TP and TN levels in the lake. However, small changes in watershed land use are not likely to yield sufficiently large changes in in-lake conditions to be detectable with this model. Additionally, as LLRM is a steady state model, testing conditions in one year with wetter conditions against another year with drier conditions, with no change in land use, is really not a valid approach.

Model verification is a function of data availability for at least two periods of multiple years in duration with different conditions that can be represented by the model. Where available, use of these data to verify model performance is strongly advised. If predictions under the second set of conditions do not reasonably match the available data, adjustments in export coefficients, attenuation, or other features of the model may be needed. Understanding why conditions are not being properly represented is an important aspect of modeling, even when it is not possible to bring the model into complete agreement with available data.

Scenario Testing

LLRM is meant to be useful for evaluating possible consequences of land use conversions, changes in discharges, various management options, and related alterations of the watershed or lake. The primary purpose of this model is to allow the user to project possible consequences of actions and aid management and policy decision processes. Testing a conceived scenario involves changing appropriate input data and observing the results. Common scenario testing includes determining the likely “original” or “pre-settlement” condition of the lake, termed “Background Condition” here, and forecasting the benefit from possible Best Management Practices (BMPs).

Background Conditions

Simulation of Background Conditions is most often accomplished by changing all developed land uses to forest, wetland or water, whichever is most appropriate based on old land use maps or other sources of knowledge about watershed features prior to development of roads, towns, industry, and related human features. Default export coefficients for undeveloped land use types are virtually the same, so the distinction is not critical if records are sparse.

For the example system, all developed land uses were converted to forested upland, although it is entirely possible that some wetlands were filled for development before regulations to protect wetlands were promulgated, and some may even have been filled more recently. The resulting land use table, shown below, replaces that in the original model representing current conditions. The watershed area is the same, although in some cases diversions may change this aspect as well. Many lakes have been created by human action, such that setting all land uses to an undeveloped state

would correspond to not having a lake present, but the assumption applied here is that the user is interested in the condition of the lake as it currently exists, but in the absence of human influences.

BASIN AREAS

LAND USE	BASIN 1 E. Direct AREA (HA)	BASIN 2 W. Direct AREA (HA)	BASIN 3 Upper T1 AREA (HA)	BASIN 4 Lower T1 AREA (HA)	BASIN 5 W. Upper T2 AREA (HA)	BASIN 6 E. Upper T2 AREA (HA)	BASIN 7 Lower T2 AREA (HA)	BASIN 8 AREA (HA)	BASIN 9 AREA (HA)	BASIN 10 AREA (HA)	TOTAL AREA (HA)
Urban 1 (Residential)											0.0
Urban 2 (Roads)											0.0
Urban 3 (Mixed Urban/Commercial)											0.0
Urban 4 (Industrial)											0.0
Urban 5 (Parks, Recreation Fields, Institutional)											0.0
Agric 1 (Cover Crop)											0.0
Agric 2 (Row Crop)											0.0
Agric 3 (Grazing)											0.0
Agric 4 (Feedlot)											0.0
Forest 1 (Upland)	27.1	40.6	60.7	176.0	50.5	37.6	56.2				448.7
Forest 2 (Wetland)	0.0	0.2	0.0	14.5	0.0	0.0	1.9				16.6
Open 1 (Wetland/Lake)	2.5	0.6	0.0	0.1	0.0	0.1	14.2				17.5
Open 2 (Meadow)	2.0	1.3	0.0	10.2	0.1	0.0	0.2				13.8
Open 3 (Excavation)											0.0
Other 1											0.0
Other 2											0.0
Other 3											0.0
TOTAL	31.6	42.7	60.7	200.8	50.6	37.7	72.5	0	0		496.6

Also altered in this example, but not shown explicitly here, are the internal load (reduced to typical background levels of 0.5 mg TP/m2/d and 2.0 mg TN/m2/d), point source (removed), septic system inputs (removed), and attenuation of TP and TN (values in cells lowered by10%, representing lesser transport to the lake through the natural landscape).

Resulting in-lake conditions, as indicated in the column of the table below labeled “Background Conditions,” include a TP concentration of 16 ug/L and a TN level of 366 ug/L. Average Chl is predicted at 5.7 ug/L, leading to a mean SDT of 2.7 m. Bloom frequency is expected to be 8.6% for Chl >10 ug/L and 1.5% for Chl >15 ug/L, with values >20 ug/L very rare. While the example lake appears to have never had extremely high water clarity, it was probably much more attractive and useable than it is now, based on comparison with current conditions in the table. If this lake was in an ecoregion with a target TP level of <16 ug/L, it is expected that meeting that limit would be very difficult, given apparent natural influences.

SUMMARY TABLE FOR SCENARIO TESTING	Existing Conditions		Background Conditions	Complete Build-out	WWTF Enhanced	Feasible BMPs
	Calibrated Model Value	Actual Data	Model Value	Model Value	Model Value	Model Value
Phosphorus (ppb)	75	75	16	83	49	24
Nitrogen (ppb)	861	860	366	965	745	540
Mean Chlorophyll (ug/L)	40.7	37.5	5.7	46.7	23.3	9.3
Peak Chlorophyll (ug/L)	130.0	118.1	20.1	148.5	76.1	31.6
Mean Secchi (m)	0.8	1.0	2.7	0.8	1.2	2.0
Peak Secchi (m)	2.9	3.1	4.5	2.8	3.3	4.0
Bloom Probability						
Probability of Chl >10 ug/L	99.5%		8.6%	99.8%	92.6%	34.4%
Probability of Chl >15 ug/L	96.0%		1.5%	97.8%	73.6%	11.3%
Probability of Chl >20 ug/L	87.9%		0.3%	92.6%	52.3%	3.7%
Probability of Chl >30 ug/L	64.1%		0.0%	73.8%	22.5%	0.5%
Probability of Chl >40 ug/L	41.5%		0.0%	52.5%	9.2%	0.1%

Changes in Land Use

Another common scenario to be tested involves changes in land use. How much worse might conditions become if all buildable land became developed? For the example system, with current zoning and protection of some undeveloped areas, a substantial fraction of currently forested areas could still become low density residential housing. Adjusting the land uses in the corresponding input table to reflect a conversion of forest to low density urban development, as shown below, and adding 28 septic systems to that portion of the loading analysis (not shown here) an increase in TP, TN and Chl is derived, and a decrease in SDT are observed (see summary table above). TP rises to 83 ug/L and TN to 965 ug/L, but the change in Chl and SDT are not large, as the lake would already be hypereutrophic.

BASIN AREAS

LAND USE	BASIN 1 E. Direct AREA (HA)	BASIN 2 W. Direct AREA (HA)	BASIN 3 Upper T1 AREA (HA)	BASIN 4 Lower T1 AREA (HA)	BASIN 5 W. Upper T2 AREA (HA)	BASIN 6 E. Upper T2 AREA (HA)	BASIN 7 Lower T2 AREA (HA)	BASIN 8 AREA (HA)	BASIN 9 AREA (HA)	BASIN 10 AREA (HA)	TOTAL AREA (HA)
Urban 1 (Residential)	16.0	18.5	23.4	87.4	6.7	12.5	38.6				203.1
Orginal Urban 1	12.0	8.5	8.4	47.4	6.7	4.5	18.1				
Urban 2 (Roads)	3.7	5.5	0.0	5.9	0.8	0.6	2.3				18.8
Urban 3 (Mixed Urban/Commercial)	3.6	5.8	0.0	5.9	0.8	0.6	2.3				19.0
Urban 4 (Industrial)	0.0	0.0	0.0	23.5	0.0	0.0	0.0				23.5
Urban 5 (Parks, Recreation Fields, Institutional)	0.0	3.2	0.0	0.0	0.0	0.0	0.0				3.2
Agric 1 (Cover Crop)	0.0	0.0	0.0	0.8	12.3	0.0	0.0				13.1
Agric 2 (Row Crop)	0.0	0.0	0.0	0.0	16.2	0.0	0.0				16.2
Agric 3 (Grazing)	0.0	0.0	0.0	0.0	4.0	0.0	0.0				4.0
Agric 4 (Feedlot)	0.0	0.0	0.0	0.0	0.5	0.0	0.0				0.5
Forest 1 (Upland)	3.7	7.5	35.3	50.3	9.2	24.0	13.0				143.0
Original Forest 1	7.7	17.5	50.3	90.3	9.2	32.0	33.6				240.6
Forest 2 (Wetland)	0.0	0.2	0.0	14.5	0.0	0.0	1.9				16.6
Open 1 (Wetland/Lake)	2.5	0.6	2.0	0.1	0.0	0.1	14.2				19.5
Open 2 (Meadow)	2.0	1.3	0.0	10.2	0.1	0.0	0.2				13.8
Open 3 (Excavation)	0.1	0.1	0.0	2.3	0.0	0.0	0.0				2.5
Other 1											0.0
Other 2											0.0
Other 3											0.0
TOTAL	31.6	42.7	60.7	200.9	50.6	37.8	72.5				496.8

Changes in Wastewater Management

Managing wastewater is often a need in lake communities. In LLRM, wastewater treatment facilities (WWTF) are represented as point sources, with flow and concentration provided. On-site wastewater disposal (septic) systems are part of the baseflow of drainage areas with tributaries, and can be represented that way for direct drainage areas as well, but the option exists to account separately for septic systems in the direct drainage area. Changes to point sources or septic systems can be made in LLRM to simulate possible management actions.

In the example system, there is one small WWTF that discharges into Lower Tributary #1 and 250 residential units that contribute to septic system inputs in the two defined direct drainage areas (see Figure 1). If the units now served by septic systems were tied into the WWTF via a pumping station, the flow through the WWTF would increase from 45,000 cu.m/yr under current conditions to 71,953 cu.m/yr, the amount of wastewater calculated to be generated by those 250 residential units. If WWTF effluent limits for TP and TN were established at 0.1 and 3.0 mg/L, respectively, the concentration in the discharge would be reduced from 3.0 and 12.0 mg/L (current values from monitoring) to the new effluent limits. The result would be a higher flow from the WWTF with lower TP and TN levels, and an elimination of septic system inputs in the model, both simple changes to make, as shown in the table below.

NON-AREAL SOURCES												
	Number of Source Units	Volume (cu.m/yr)	P Load/Unit (kg/unit/yr)	N Load/Unit (kg/unit/yr)	P Conc. (ppm)	N Conc. (ppm)	P Load (kg/yr)	N Load (kg/yr)				
Waterfowl	50		0.20	0.95			10	47.5				
Point Sources												
PS-1		71953			0.10	3.00	7.2	215.9				
PS-2		0			3.00	12.00	0	0				
PS-3		0			3.00	12.00	0	0				
Basin in which Point Source occurs (0=NO 1=YES)												
	BASIN 1	BASIN 2	BASIN 3	BASIN 4	BASIN 5	BASIN 6	BASIN 7	BASIN 8	BASIN 9	BASIN 10		
PS-1	0	0	0	1	0	0	0	0	0	0		
PS-2	0	0	0	0	0	0	0	0	0	0		
PS-3	0	0	0	0	0	0	0	0	0	0		
DIRECT SEPTIC SYSTEM LOAD												
Septic System Grouping (by occupancy or location)	Days of Occupancy/Yr	Distance from Lake (ft)	Number of Dwellings	Number of People per Dwelling	Water per Person per Day (cu.m)	P Conc. (ppm)	N Conc. (ppm)	P Attenuation Factor	N Attenuation Factor	Water Load (cu.m/yr)	P Load (kg/yr)	N Load (kg/yr)
Group 1 Septic Systems	365	<100	0	2.5	0.25	8	20	0.2	0.9	0	0.0	0.0
Group 2 Septic Systems	365	100 - 300	0	2.5	0.25	8	20	0.1	0.8	0	0.0	0.0
Group 3 Septic Systems	90	<100	0	2.5	0.25	8	20	0.2	0.9	0	0.0	0.0
Group 4 Septic Systems	90	100 - 300	0	2.5	0.25	8	20	0.1	0.8	0	0.0	0.0
Total Septic System Loading										0	0.0	0.0

The result, shown in the summary table for scenario testing above, is an in-lake TP concentration of 49 ug/L and a new TN level of 745 ug/L. These are both substantial reductions from the current levels, but continued elevated Chl (mean = 23.3 ug/L, peak = 76.1 ug/L) and a high probability of algal blooms is expected. Water clarity improves slightly (from 0.8 to 1.2 m on average), but at the cost of the sewerage and treatment, this is unlikely to produce a success story.

Best Management Practices

The application of BMPs is generally regarded as the backbone of non-point source pollution management in watershed programs. Considerable effort has been devoted to assessing the percent removal for various pollutants that can be attained and sustained by various BMPs. BMPs tend to fall into one of two categories: source controls and pollutant trapping. Source controls limit the generation of TP and TN and include actions like bans on lawn fertilizers containing TP or requirements for post-development infiltration to equal pre-development conditions, and would be most likely addressed in LLRM by a change in export coefficient. Pollutant trapping limits the delivery of generated loads to the lake and includes such methods as detention, infiltration, and buffer strips, and is most often addressed in LLRM by changes in attenuation values.

There are limits on what individual BMPs can accomplish. While some site specific knowledge and sizing considerations help modify general guidelines, the following table provides a sense for the level of removal achievable with common BMPs.

Range and Median for Expected Removal (%) for Key Pollutants by Selected Management Methods, Compiled from Literature Sources for Actual Projects and Best Professional Judgment Upon Data Review.

	TSS	Total P	Soluble P	Total N	Soluble N	Metals
Street sweeping	5-20	5-20	<5	5-20	<5	5-20
Catch basin cleaning	5-10	<10	<1	<10	<1	5-10
Buffer strips	40-95 (50)	20-90 (30)	10-80 (20)	20-60 (30)	0-20 (5)	20-60 (30)
Conventional catch basins (Some sump capacity)	1-20 (5)	0-10 (2)	0-1 (0)	0-10 (2)	0-1 (0)	1-20 (5)
Modified catch basins (deep sumps and hoods)	25 (25)	0-20 (5)	0-1 (0)	0-20 (5)	0-1 (0)	20 (20)
Advanced catch basins (sediment/floatables traps)	25-90 (50)	0-19 (10)	0-21 (0)	0-20 (10)	0-6 (0)	10-30 (20)
Porous Pavement	40-80 (60)	28-85 (52)	0-25 (10)	40-95 (62)	-10-5 (0)	40-90 (60)
Vegetated swale	60-90 (70)	0-63 (30)	5-71 (35)	0-40 (25)	-25-31 (0)	50-90 (70)
Infiltration trench/chamber	75-90 (80)	40-70 (60)	20-60 (50)	40-80 (60)	0-40 (10)	50-90 (80)
Infiltration basin	75-80 (80)	40-100 (65)	25-100 (55)	35-80 (51)	0-82 (15)	50-90 (80)
Sand filtration system	80-85 (80)	38-85 (62)	35-90 (60)	22-73 (52)	-20-45 (13)	50-70 (60)
Organic filtration system	80-90 (80)	21-95 (58)	-17-40 (22)	19-55 (35)	-87-0 (-50)	60-90 (70)
Dry detention basin	14-87 (70)	23-99 (65)	5-76 (40)	29-65 (46)	-20-10 (0)	0-66 (36)
Wet detention basin	32-99 (70)	13-56 (27)	-20-5 (-5)	10-60 (31)	0-52 (10)	13-96 (63)
Constructed wetland	14-98 (70)	12-91 (49)	8-90 (63)	6-85 (34)	0-97 (43)	0-82 (54)
Pond/Wetland Combination	20-96 (76)	0-97 (55)	0-65 (30)	23-60 (39)	1-95 (49)	6-90 (58)
Chemical treatment	30-90 (70)	24-92 (63)	1-80 (42)	0-83 (38)	9-70 (34)	30-90 (65)

While BMPs in series can improve removal, the result is rarely multiplicative; that is, application of two BMPs expected to remove 50% of TP are unlikely to result in 0.5 X 0.5 = 0.25 of the load remaining

(75% removal) unless each BMP operates on a different fraction of TP (particulates vs. soluble, for example). This is where judgment and experience become critical to the modeling process. In general, BMPs rarely remove more than 2/3 of the load of P or N, and on average can be expected to remove around 50% of the P and 40% of the N unless very carefully designed, built and maintained. The luxury of space is not often affordable, forcing creativity or greater expense to achieve higher removal rates.

In the example system, setting attenuation for all basins to 0.5 for P and 0.6 for N is viewed as a practical level of BMP application for a first cut at what BMPs might be able to do for the lake. Careful consideration of which BMPs will be applied where in which basins is in order in the final analysis, but to set a reasonable approximation of what can be achieved, these are supportable attenuation values. Note that values are not set at 0.5 or 0.6 of the value in place in the calibrated model, but rather a low end of 0.5 or 0.6. If, as with Basin 7 (Lower Tributary #2) in the example system, the attenuation values for P and N under current conditions are 0.70 and 0.75, the practical BMP values of 0.5 and 0.6, respectively, represent less of a decline through BMPs than for the direct drainage areas, which have current condition attenuation values of 0.9 for P and 0.95 for N.

In addition to setting P attenuation at 0.5 for P in all basins and 0.6 for N in all basins in the example system, the WWTF has been routed to a regional WWTF out of the watershed, and the all areas within 300 ft of the lake have been sewered, with that waste also going to the regional WWTF. Consequently, the WWTF and direct drainage septic system inputs have been eliminated. Finally, internal loading has been reduced to 0.5 mg P/m/day and 2.0 mg N/m^2/day, achievable with nutrient inactivation and lowered inputs over time.

The results, as indicated in the summary table for scenario testing above, include an in-lake P concentration of 24 ug/L and an N level of 540 ug/L. The predicted mean Chl is 9.3 ug/L, with a peak of 31.6 ug/L. SDT would be expected to average 2.0 m and have a maximum of 4.0 m. While much improved over current conditions, these are marginal values for supporting the range of lake uses, particularly contact recreation and potable water supply. As a first cut assessment of what BMPs might do for the system, it suggests that more extreme measures will be needed, or that in-lake maintenance should be planned as well, since algal blooms would still be expected. Further scenario testing with the model, combined with cost estimation for potential BMPs, may shed light on the cost effectiveness of rehabilitating the example lake.

Appendix C Land Use Categories, Export Coefficients and Additional Calculations

Table C-1. Runoff and baseflow fraction ranges

	Low	Med	High
Baseflow fraction	0.10	0.40	0.95
Runoff fraction	0.01	0.20	0.40

Table C-2. Runoff and baseflow factions used in the model for Locke Lake.

Landuse Category	**Runoff Fraction**	**Baseflow Fraction**
Urban 1 (Low Density Residential)	0.30	0.25
Urban 2 (Mid-Density Residential/Commercial)	0.50	0.15
Urban 3 (Roads)	0.60	0.05
Urban 4 (Industrial)	0.50	0.05
Urban 5 (Parks, Recreation Fields, Institutional)	0.30	0.30
Agric 1 (Cover Crop)	0.15	0.30
Agric 2 (Row Crop)	0.30	0.30
Agric 3 (Grazing)	0.30	0.30
Agric 4 (Hayland-Non Manure)	0.30	0.30
Forest 1 (Deciduous)	0.20	0.40
Forest 2 (Non-Deciduous)	0.20	0.40
Forest 3 (Mixed Forest)	0.20	0.40
Forest 4 (Wetland)	0.05	0.40
Open 1 (Wetland / Pond)	0.05	0.40
Open 2 (Meadow)	0.30	0.30
Open 3 (Cleared/Disturbed Land)	0.80	0.05

Table C-3 Land use categories from NH GRANIT land cover data used in Locke Lake LLRM

ENSR-LRM LAND USE	Land Use Description	Land Cover Code[2]	Land Cover Description	NWI Code[3]
Urban 1 (Residential)	Residential	100		not wetland area
	Farmstead			
Urban 2 (Mixed Urban/Commercial)	Mixed Urban/ Commercial	100		not wetland area
Urban 3 (Roads)	Transportation/Roads	140		
	Railroads			
	Auxiliary Transportation			
Urban 4 (Industrial)	Industrial			
Urban 5 (Parks, Recreation Fields, Institutional)	Playing Fields/Recreation	170		
	Power lines, Nonagriculture Fields	700		
Agric 1 (Cover Crop)	Agriculture			
Agric 2 (Row Crop)	Agriculture	211	Row Crops	
Agric 3 (Grazing)	Agriculture		Hay/rotation/permanent pasture	
Agric 4 (Hayland-no manure)	Agriculture	212	Hay/rotation/permanent pasture	
Agric 5 (Orchard)	Agriculture	221	Fruit Orchard	
Forest 1 (Deciduous)	Forested	412	Beech/oak	
	Forested	414	Paper birch/aspen	
	Forested	419	Other hardwoods	
Forest 2 (Non-Deciduous)	Forested	421	White/red pine	
	Forested	422	Spruce/fir	
	Forested	423	Hemlock	
	Forested	424	Pitch pine	
Forest 3 (Mixed)	Forested	430	Mixed forest	
Forest 4 (Wetland)	Forested			PF___
		610	Forested wetlands	
Open 1 (Wetland / Lake)	Water	500	Non-forested wetlands	
	Open wetland	620	Open water	
				PSS_, L1_, PEM__
Open 2 (Meadow)				
Open 3 (Cleared/Disturbed Land)	Gravel pits, quarries			
		790	Cleared/other open	
		710	Disturbed	

[2] Land cover data created by GRANIT using Lansat 5 and 7 imagery and other available raster and vector data.

[3] National Wetlands Inventory (NWI) data is used to improve the accuracy of wetland areas that are either not delineated in the land use and land cover data or poorly represented by raster cells. Priority ranking is given to the Land Use data set for all non-wetland areas, NWI data for wetland areas, and Land cover for forest type areas.

Table C-4 Land use export coefficients (kg/ha/yr) used in Locke Lake TMDL

ENSR-LRM Land Use	Runoff P export coefficient range	Runoff P export coefficient used*	Source	Baseflow P export coefficient range	Baseflow P export coefficient used*	Source
Urban 1 (Low Density Residential)	0.11-8.42	0.79	Reckhow et al. 1980, Schloss et al. 2000-Table 5	0.001-0.05	0.01	ENSR Unpublished Data; Mitchell et al. 1989
Urban 2 (Mid-Density Residential/Commercial)	0.11-8.42	0.9	Reckhow et al. 1980	0.001-0.05	0.01	"
Urban 3 (Roads)	0.60-10	0.3	Dudley et al. 1997	0.001-0.05	0.01	"
Urban 4 (Industry)	0.11-8.42	0.9	Reckhow et al. 1980	0.001-0.05	0.01	"
Urban 5 (Park/Institutional/Recreation/Cemetery)	0.19-6.23	0.6	Reckhow et al. 1980	0.001-0.05	0.01	"
Agric 1 (Cover Crop)	0.10-2.90	0.8	Reckhow et al. 1980	0.001-0.05	0.01	"
Agric 2 (Row Crop)	0.26-18.26	0.37	Reckhow et al. 1980	0.001-0.05	0.01	"
Agric 3 (Grazing)	0.14-4.90	1.5	Reckhow et al. 1980	0.001-0.05	0.01	"
Agric 4 (Hayland-No Manure)	0.35	0.37	Dennis and Sage 1981	0.001-0.05	0.01	"
Forest 1 (Deciduous)	0.034-0.973	0.03	Schloss et al. 2000-Table 4	0.001-0.010	0.004	"
Forest 2 (Non-Deciduous)	0.01-0.138	0.03	Schloss et al. 2000-Table 4	0.001-0.010	0.004	"
Forest 3 (Mixed)	0.01-0.138	0.03	Schloss et al. 2000-Table 4	0.001-0.010	0.004	"
Forest 4 (Wetland)	0.003-0.439	0.2	Reckhow et al. 1980	0.001-0.010	0.004	"
Open 1 (Wetland / Pond)	0.009-0.25	0.01	Reckhow et al. 1980	0.001-0.010	0.004	"
Open 2 (Meadow)	0.02-0.83	0.2	Reckhow et al. 1980	0.001-0.010	0.004	"
Open 3 (Bare Open)	0.25-1.75	0.8	Reckhow et al. 1980	0.001-0.010	0.01	"

*Value is not a median

Table C-6. Septic system calculations in Locke Lake model.

Category	# of Dwellings with Septic Systems	People/ Dwelling	TP Atten Factor	Mean TP Conc (mg/L)	P Load (kg/pers/yr)	P Load (kg/yr)	Water (gal/day)	# of Days	Water Load (m^3/yr)
Year Round Residential	450	2.5	0.15	8	0.72	121.2	65	365	101035.0
Seasonal Residential	25	2.5	0.15	8	0.18	1.7	65	90	1384.0
Total Septic System Loading						122.9			102419.0

Table C-7. Waterfowl loading calculations in Locke Lake model.

Bird Type	# of Birds	P Load (kg/bird/day)	Non-Ice Days (days)	P Load (kg/yr)	Coefficient Source	Bird Count Source
Geese, Ducks	200	0.001526	275	83.93	Scherer et al. 1995	Local knowledge and observations

Appendix D 2018 VLAP Report for Locke Lake

Volunteer Lake Assessment Program Individual Lake Reports

LOCKE LAKE, BARNSTEAD, NH

MORPHOMETRIC DATA

Watershed Area (Ac.):	2,039	**Max. Depth (m):**	3	**Flushing Rate (yr^{1})**	9.9
Surface Area (Ac.):	253	**Mean Depth (m):**	0.9	**P Retention Coef:**	0.59
Shore Length (m):	8,138	**Volume (m^3):**	1,012,016	**Elevation (ft):**	639

TROPHIC CLASSIFICATION

Year	Trophic class
2010	MESOTROPHIC

KNOWN EXOTIC SPECIES

Variable Milfoil

The Waterbody Report Card tables are generated from the DRAFT 2018 305(b) report on the status of N.H. waters, and are based on data collected from 2008-2017. Detailed waterbody assessment and report card information can be found at www.des.nh.gov/organization/divisions/water/wmb/swqa/index.htm

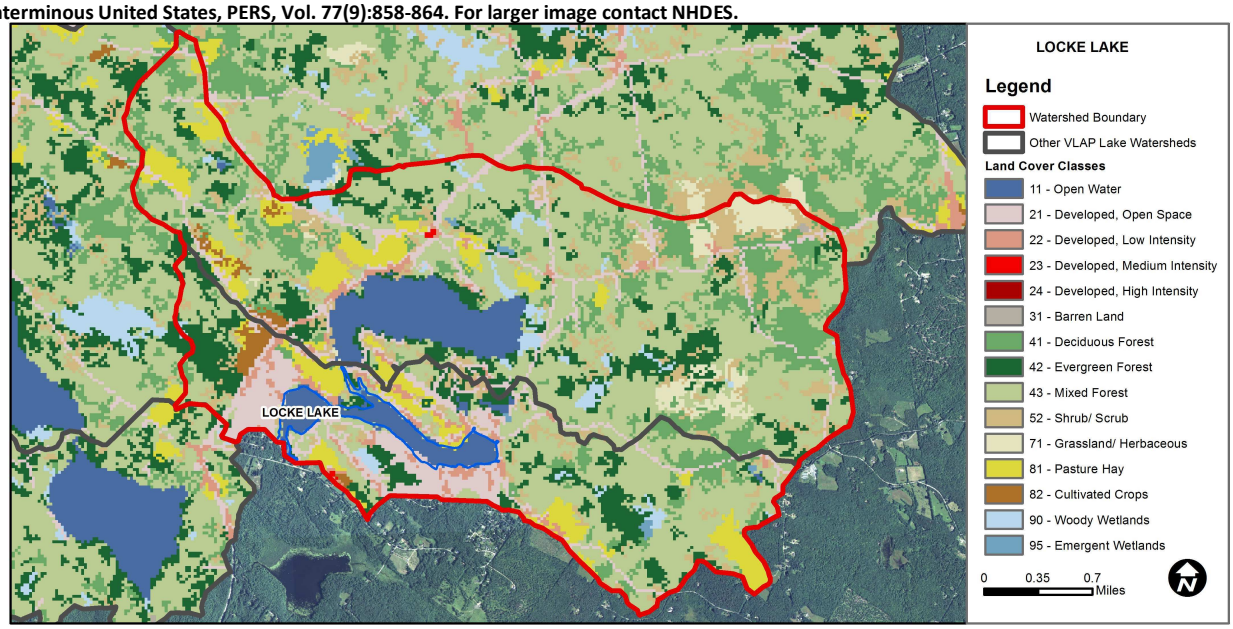
Designated Use	Parameter	Category	Comments
Aquatic Life	Phosphorus (Total)	Slightly Bad	Data exceed water quality standards or thresholds for a given parameter by a small margin.
	pH	Slightly Bad	Data periodically exceed water quality standards or thresholds for a given parameter by a small margin.
	Oxygen, Dissolved	Encouraging	Limited data for this parameter predicts water quality standards or thresholds are being met; however more data are necessary to fully assess the parameter.
	Dissolved oxygen satura	Encouraging	Limited data for this parameter predicts water quality standards or thresholds are being met; however more data are necessary to fully assess the parameter.
	Chlorophyll-a	Slightly Bad	Data exceed water quality standards or thresholds for a given parameter by a small margin.
Primary Contact Recreation	Escherichia coli	No Data	No data for this parameter.
	Cyanobacteria hepatoto	Slightly Bad	Cyanobacteria bloom(s).
	Chlorophyll-a	Encouraging	Limited data for this parameter predicts water quality standards or thresholds are being met; however more data are necessary to fully assess the parameter.

BEACH PRIMARY CONTACT ASSESSMENT STATUS

LOCKE LAKE - POINT BEACH	Escherichia coli	Good	Sampling data commonly meet water quality standards or thresholds for this parameter.
LOCKE LAKE - GEORGETOWN BEACH #6	Escherichia coli	Good	Sampling data commonly meet water quality standards or thresholds for this parameter.
LOCKE LAKE - NORTH BARNSTEAD ROAD BEACH	Escherichia coli	Cautionary	Limited data for this parameter predicts exceedance of water quality standards or thresholds; however more data are necessary to fully assess the parameter.
LOCKE LAKE - COLONY BEACH	Escherichia coli	Bad	Data periodically exceed water quality standards or thresholds for this parameter by a large margin.
LOCKE LAKE - WINCHESTER DRIVE BEACH	Escherichia coli	Very Good	All sampling data meet water quality standards or thresholds for this parameter.
LOCKE LAKE - VARNEY BEACH	Escherichia coli	Very Good	All sampling data meet water quality standards or thresholds for this parameter.
LOCKE LAKE -N SHORE RD BEACH	Escherichia coli	Very Good	All sampling data meet water quality standards or thresholds for this parameter.

WATERSHED LAND USE SUMMARY

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PERS, Vol. 77(9):858-864. For larger image contact NHDES.



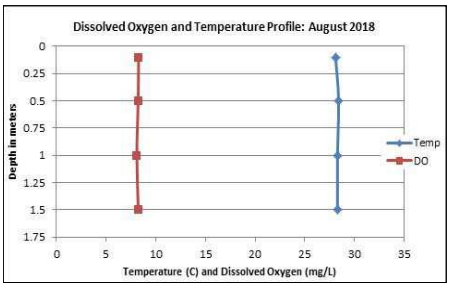
Land Cover Category	% Cover	Land Cover Category	% Cover	Land Cover Category	% Cover
Open Water	7.34	Barren Land	0.03	Grassland/Herbaceous	2.31
Developed-Open Space	9.43	Deciduous Forest	11.87	Pasture Hay	6.93
Developed-Low Intensity	2.16	Evergreen Forest	11.7	Cultivated Crops	0.96
Developed-Medium Intensity	0.06	Mixed Forest	37.54	Woody Wetlands	1.82
Developed-High Intensity	0	Shrub-Scrub	7.54	Emergent Wetlands	0.3

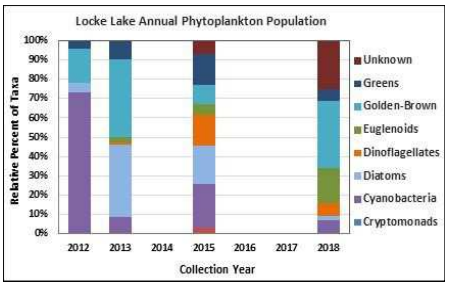
Volunteer Lake Assessment Program Individual Lake Reports
Locke Lake, Barnstead
2018 Data Summary

Recommended Actions: Great job on increasing the monitoring frequency in 2018! Most of the sampling focused on tributaries entering the lake and indicates a higher pollutant load coming from the Colony Inlet sub-watershed, particularly between Colony South Inflow and Colony Inlet. Focus on ways to reduce stormwater runoff from residential properties along the road and the Windsor Drive residential area. Educate residents on removing pet waste from yards and the roadside to help reduce bacteria levels in the system. DES' "NH Homeowner's Guide to Stormwater Management" is a great resource. Start a Pet Waste Outreach Campaign to encourage all colony residents to properly dispose of pet waste. For more information visit www.des.nh.gov/organization/divisions/water/wmb/coastal/scoop_the_poop.htm Keep up the great work!

Observations (*Refer to Table 1 and Historical Deep Spot Data Graphics*)

- **Chlorophyll-a:** Chlorophyll level was slightly elevated in August and was greater than the state median and the threshold for mesotrophic lakes. Historical trend analysis indicates relatively stable chlorophyll levels since monitoring began.
- **Conductivity/Chloride:** Epilimnetic (deep spot), Colony Beach #1, Inlet, Munroe Inlet, Outlet, Point Beach, Rt. 28 RE Culvert, and Varney Rd. Beach conductivity and/or chloride levels were slightly greater than the state medians, yet not above a level of concern. However, historical trend analysis indicates significantly increasing (worsening) epilimnetic conductivity levels since monitoring began. 125 Dam Site Rd., Colony Inlet, Colony at Windsor, Colony South Inflow, Fire Pond Emerson Dr., and Rt. 28 Fire Pond Outlet conductivity and chloride levels were elevated, and chloride levels at the Fire Pond Emerson Dr. station approached the state chronic chloride standard due to impacts from Rt. 28.
- **Color:** Apparent color was measured in the epilimnion and indicates the lake water is moderately tea colored, or brown.
- **E. coli:** Colony Beach #1, Point Beach and Varney Rd. Beach E. coli levels were les than the state standard of 88 cts/100 mL for beaches. 125 Dam Site Rd., Fire Pond Emerson Dr., Inlet, Munroe Inlet, Rt. 28 Fire Pond Outlet, and Rt. 28 RE Culvert E. coli levels were much less than the state standard of 406 cts/100 mL for surface waters. Colony South Inflow and Colony at Windsor E. coli levels were higher, particularly in August following the significant storm event, but remained less than the state standard. Colony Inlet E. coli levels exceeded the state standard in June.
- **Total Phosphorus:** Epilimnetic, Inlet, Munore Inlet, Point Beach, and Varney Rd. Beach phosphorus levels were within a low to moderate range for those stations. Epilimnetic phosphorus levels were slightly greater than the state median and threshold for mesotrophic lakes and historical trend analysis indicates relatively stable epilimnetic phosphorus levels since monitoring began. 125 Dam Site Rd. phosphorus levels were slightly elevated in July during low flow conditions. Fire Pond Emerson Dr. and Rt. 28 RE Culvert phosphorus levels were within a slightly elevated range and remained relative stable from June to August. Rt. 28 Fire Pond Outlet phosphorus levels were elevated in June and increased in July. Outlet phosphorus levels were slightly elevated in June and July due to above average flushing rate as a result of board removal from the dam. Colony South Inflow, Colony at Windsor and Colony Inlet experienced elevated phosphorus levels, particularly at Colony Inlet which is the furthest downstream.
- **Transparency:** Transparency was good and the Secchi disk was visible on the lake bottom.
- **Turbidity:** Epilimnetic, Colony Beach #1, Inlet, Munroe Inlet, Point Beach, and Varney Rd. Beach turbidity levels were within a low to moderate range. All other stations experienced elevated turbidity levels on at least one sampling event. Field data noted low flows in June and July, and lab data notes moderately colored water with sediment during the July sampling event.
- **pH:** Epilimnetic, 125 Dam Site Rd., Colony Beach #1, Fire Pond Emerson Dr., Inlet, Outlet, Point Beach, and Varney Rd. Beach pH levels were within the desirable range 6.5-8.0 units. Historical trend analysis indicates relatively stable epilimnetic pH levels since monitoring began. Colony Inlet and Munroe Inlet pH levels were slightly less than desirable. Colony South Inflow, Colony at Windsor, Rt. 28 Fire Pond Outlet, and Rt. 28 RE Culvert pH levels were slightly acidic and less than desirable.





NH Water Quality Standards: Numeric criteria for specific parameters. Results exceeding criteria are considered a water quality violation.
Chloride: > 230 mg/L (chronic)
E. coli: > 88 cts/100 mL – public beach
E. coli: > 406 cts/100 mL – surface waters
Turbidity: > 10 NTU above natural level
pH: between 6.5-8.0 (unless naturally occurring)

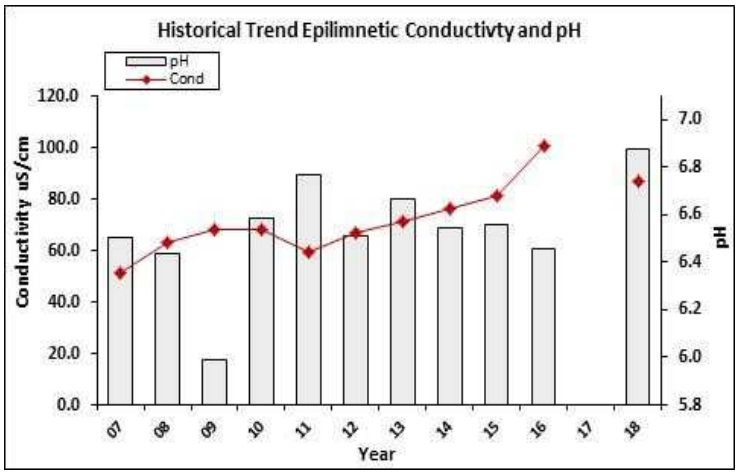
Table 1. 2018 Average Water Quality Data for LOCKE LAKE - BARNSTEAD

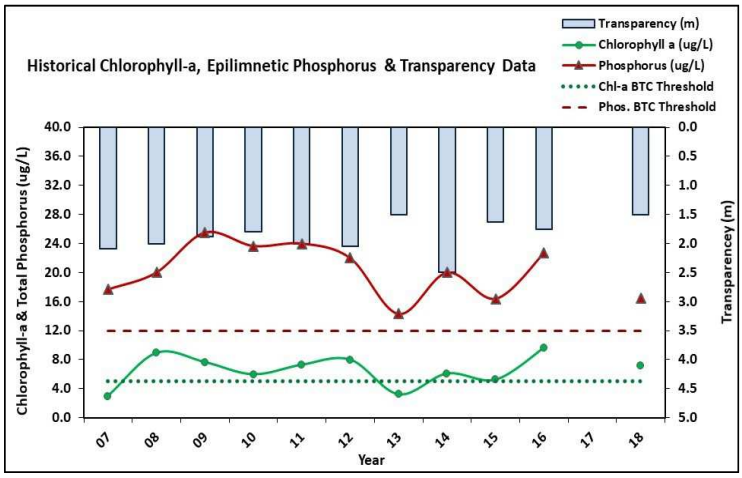
Station Name	Alk. mg/l	Chlor-a ug/l	Chloride mg/l	Color pcu	Cond. us/cm	E. coli mpn/100ml	Total P ug/l	Trans. m NVS	Turb. ntu	pH
Epilimnion	5.3	7.12		80	87.1		16	1.50	1.32	6.88
125 Dam Site Rd.			76		325.0	135	23		2.43	6.94
Colony Beach #1					99.0	57	33		1.52	6.83
Colony Inlet			51		211.3	364	85		5.24	6.42
Colony at Windsor			53		211.8	187	64		4.26	5.93
Colony South Inflow			47		185.4	183	50		1.50	5.28
Fire Pond Emerson Dr.			161		525.7	27	34		9.43	6.75
Inlet			18		80.3	41	10		0.88	6.55
Munroe Inlet			11		59.8	30	23		0.84	6.36
Outlet					100.1		32		2.24	6.46
Point Beach					90.9	51	19		0.86	6.78
Rt. 28 Fire Pond Outlet			58		203.0	63	70		3.17	5.22
Rt. 28 RE Culvert			17		79.1	69	30		1.94	4.98
Varney Road Beach					91.8	5	17		0.87	6.63

NH Median Values: Median values for specific parameters generated from historic lake monitoring data.
Alkalinity: 4.5 mg/L
Chlorophyll-a: 4.39 mg/m^3
Conductivity: 42.3 uS/cm
Chloride: 5 mg/L
Total Phosphorus: 11 ug/L
Transparency: 3.3 m
pH: 6.6

Historical Water Quality Trend Analysis

Parameter	Trend	Explanation	Parameter	Trend	Explanation
Conductivity	Worsening	Data significantly increasing.	Chlorophyll-a	Stable	Trend not significant; data moderately variable.
pH (epilimnion)	Stable	Trend not significant; data moderately variable.	Transparency	Stable	Trend not significant; data moderately variable.
			Phosphorus (epilimnion)	Stable	Trend not significant; data show low variability.





This report was generated by the NHDES Volunteer Lake Assessment Program (VLAP). For more information contact VLAP at (603) 271-2658 or sara.steiner@des.nh.gov