AN ABSTRACT OF THE THESIS OF

Patricia E. Tarpey for the degree of Master of Science in Environmental Science and Policy presented on April 16, 2013.

Title: Linking watershed and sub-basin characteristics to in-lake TP concentrations in the Lake Winnipesaukee watershed

As a key natural and economic resource for the state and local communities, degradation of the water quality of Lake Winnipesaukee would have a major impact on the entire NH tourism economy. Efforts to protect the water quality of Lake Winnipesaukee and its surrounding land area have challenged planners and decision makers for several decades.

A primary concern for Lake Winnipesaukee is TP loading from the land into the lake and its impact on lake water quality. One of the difficulties in discerning problems with excessive TP loading for Lake Winnipesaukee is that, due to its size and volume, in-lake effects of TP loading like reduced clarity and algae blooms are slow to appear. The physical structure and shape of Lake Winnipesaukee has been described as more a system of interconnected bays rather than a single cohesive body of water.

Utilizing established TP loading and in-lake response models, the differing characteristics, land-based influences and in-lake response to nutrient inputs were determined for the 10 Lake Winnipesaukee sub-watersheds to evaluate whether Lake Winnipesaukee should remain classified as one assessment unit for water quality reporting purposes to the U.S. EPA. Key findings of the analysis indicate that while approximately 18% of the study sub-watershed area is developed, the TP loading has shown a 2.5 to four-fold increase over pre-development conditions with a corresponding estimated increase in in-lake TP concentrations; the water quality of Paugus Bay is currently positively impacted by Lake Winnipesaukee; and although preliminary findings indicate that the lake should remain classified as one assessment unit, target goals for in-lake TP should be set at the sub-watershed level.

Abstract approved:

Mark Green, Ph.D.

Linking watershed and sub-basin characteristics to in-lake TP concentrations in the Lake Winnipesaukee Watershed, New Hampshire

by
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A THESIS

Submitted to

Plymouth State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented: April 16, 2013
Commencement: June 30, 2013

Master of Science thesis of Patricia E. Tarpey
Presented on April 16, 2013

APPROVED

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I understand that my thesis will become part of the permanent collection of Plymouth State University, Lamson Library. My signature below authorizes release of my thesis to any reader upon request.

Patricia E. Tarpey

ACKNOWLEDGEMENTS

I wish to express deep appreciation to Dr. Mark Green for agreeing to be my advisor toward the end of my degree program. His guidance and support made this degree and document possible. I also want to sincerely thank my committee members Dr. Joseph Boyer, Mr. Jeffrey Schloss and Mr. Andrew Chapman for their valuable input and participation in this project.

In addition I would like to thank my family and especially my husband, Marc Read, for their support, encouragement and patience throughout this process.

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Linking watershed and sub-basin characteristics to in-lake TP concentrations in the Lake Winnipesaukee Watershed, New Hampshire

1. Introduction

1.1 Purpose and Scope

Lake Winnipesaukee is the largest lake in New Hampshire and the third largest in New England. It is a significant asset for state tourism, renowned for its remarkable setting, outstanding water clarity, and economic vitality within New England. The lake and surrounding area offers a wide range of recreational activities, from fishing, boating, and swimming on the lake, to camping, hiking, and skiing in the adjacent mountains. Businesses that support these activities provide a livelihood for many people. Restaurants, motels, marinas, campgrounds and ski resorts are just a few of the many industries that rely on the recreational value of Lake Winnipesaukee.

Impacts to the local economy due to the degradation of water quality could have very detrimental effects. A 2007 study entitled "What's Our Water Worth?" concluded that even a perceived decline in water quality could result in lost retail sales of $25 million, lost income of $8.8 million, and a loss of 396 jobs in the Lakes Region alone (Nordstrom, 2007).

While water resource professionals consider the overall water quality of Lake Winnipesaukee "good" and even "pristine", indicators of water quality in the last 15 years show a downward or negative trend. In the 2004 State of the Lake Report, the Lake Winnipesaukee Watershed Association presented information on the frequency of beach closings due to bacteria (E. coli), the increase in chemical treatments for milfoil, decline in loon populations, and the trend in water quality in various bays of the lake from data gathered from a variety of sources for the period spanning 1980 through 2003 (LWWA, 2004). In 2012 Lake Winnipesaukee was added to the draft list of threatened or impaired waters that require a TMDL (otherwise known as the 303(d) list) for cyanobacteria hepatotoxic (NH DES, 2012).

Some of these indicators of poor water quality can be indirectly linked to levels of phosphorus in the water body. Phosphorus (P), a naturally occurring element and major nutrient required for biological productivity, has been shown to be the limiting nutrient in many freshwater systems (Schindler, 1974) and this is true for Lake Winnipesaukee as well (U.S. EPA, 1974a). Excessive levels of total phosphorus (TP) in freshwater, along with other environmental stressors, may result in increased biological productivity, causing increased phytoplankton (algae) and cyanobacteria cell production in the water column (Dillon and Rigler, 1974a; Schindler, 1974). As the ratio of nitrogen to phosphorus decreases in the waterbody due to increased levels of phosphorus, the ability of cyanobacteria to fix atmospheric nitrogen favors their proliferation over many algal species as was demonstrated in the fertilizer lake experiments conducted by Schindler (1977). The increased biological productivity can cause decreased water clarity, increased chlorophyll-*a* (Chl-*a*) levels, increased turbidity levels, decreased dissolved oxygen (DO) concentrations, potential toxicity to aquatic species and human health, and an undesirable shift in relative abundance of aquatic species (U.S. EPA, 2000a).

In addition, the secondary effects of increased TP may also result in a decrease in property values, economic loss to the communities from a decline in lake-dependent tourism, and an increase in public expenditures to address water quality impairments (Gibbs, J., Halstead, J., Boyle, K., and Huang, J., 2002; Nordstrom, 2007).

TP loading is accelerated through human activities in the watershed. Human and animal waste, residential and agricultural fertilizers and atmospheric deposition are the major sources of anthropogenic P (Carpenter et al., 1998). Phosphorus, found in both organic and inorganic ("orthophosphate") compounds, is bound in soil by adhering to the surface of soil particles. Erosion and sediment transport, including eroding stream banks, roadway runoff, and exposed soil on construction sites are all potential TP sources. High intensity rain events result in polluted stormwater transported from the land and the road network to storm drains and catch basins which discharge directly and indirectly to surface waters.

For these reasons, a primary concern for Lake Winnipesaukee is TP loading from the land into the lake and its impact on lake water quality. One of the difficulties in discerning problems with excessive TP loading for Lake Winnipesaukee is that, due to its size and volume, in-lake effects of TP loading like reduced clarity and algae blooms are slow to appear (J. Schloss, personal communication, October 2009).

It is clear from twenty five years of data collected primarily by the University of New Hampshire Lakes Lay Monitoring Program (UNH LLMP) that TP levels are generally increasing lake-wide (Table 1, Figure 1) (NH Department of Environmental Services, 2009b). These long term trends are likely to continue unless cities and towns in the lake's watershed act to adopt land use best management practices that reduce TP loadings to the lake.

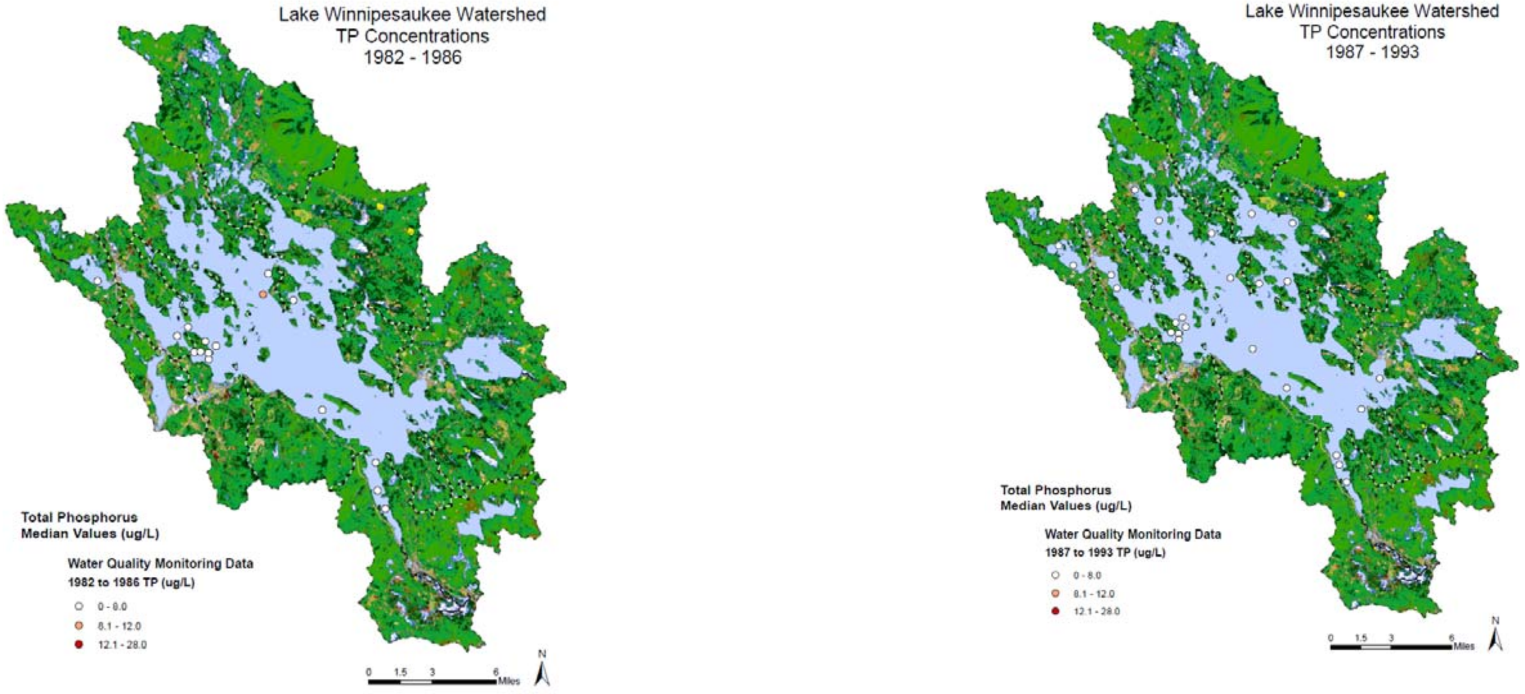
While individual years of data for each bay area are not provided in Table 1, the bay areas of the lake have been shown to exhibit differences in seasonal average water quality, degree of variability and discernible trends (Lakes Region Planning Commission, 1995).

To assist communities and residents in addressing local water quality concerns, the Lakes Region Planning Commission (LRPC) and Lake Winnipesaukee Watershed Association (LWWA) decided to adopt a sub-watershed approach for developing a comprehensive watershed management plan for the Lake Winnipesaukee watershed. Factors including the size of the watershed, the morphology of the lake, and local municipal controls over planning, zoning, and conservation issues and the "good" lake quality have been barriers to developing a single, comprehensive watershed-wide management plan in the past.

Water Quality Summary for Lake Winnipesaukee

	Median TP concentrations											
	1982 - 1986			1987 - 1993			1994 - 1999			2000 - 2006		
Sub-watershed	# Sampling Locations	n	TP (µg/L)	# Sampling Locations	n	TP (µg/L)	# Sampling Locations	n	TP (µg/L)	# Sampling Locations	n	TP (µg/L)
Meredith Bay	1	5	2.3	2	2	6.2	1	1	9.3	3	17	7.2
Center Harbor Bay	2	6	7	4	43	3.5	4	46	7.7	3	4	5.8
Moultonborough Bay Inlet	1	1	1	1	1	8	ND	ND		3	15	13.2
Moultonborough Bay	1	6	3.2	5	38	4	4	141	6.9	3	134	4.5
Wolfeboro Bay	ND	ND		1	1	4	1	52	9.3	1	1	5
Alton Bay	3	8	2.5	3	15	5.3	2	80	6.4	4	139	6.4
The Broads	1	9	5.8	2	151	3.5	5	59	6.5	6	153	5
Saunders Bay	10	47	4.7	18	181	2	2	63	5.8	2	14	6.7
Total	**19**	**82**	**3.2**	**36**	**432**	**4**	**19**	**442**	**6.9**	**25**	**477**	**6.1**

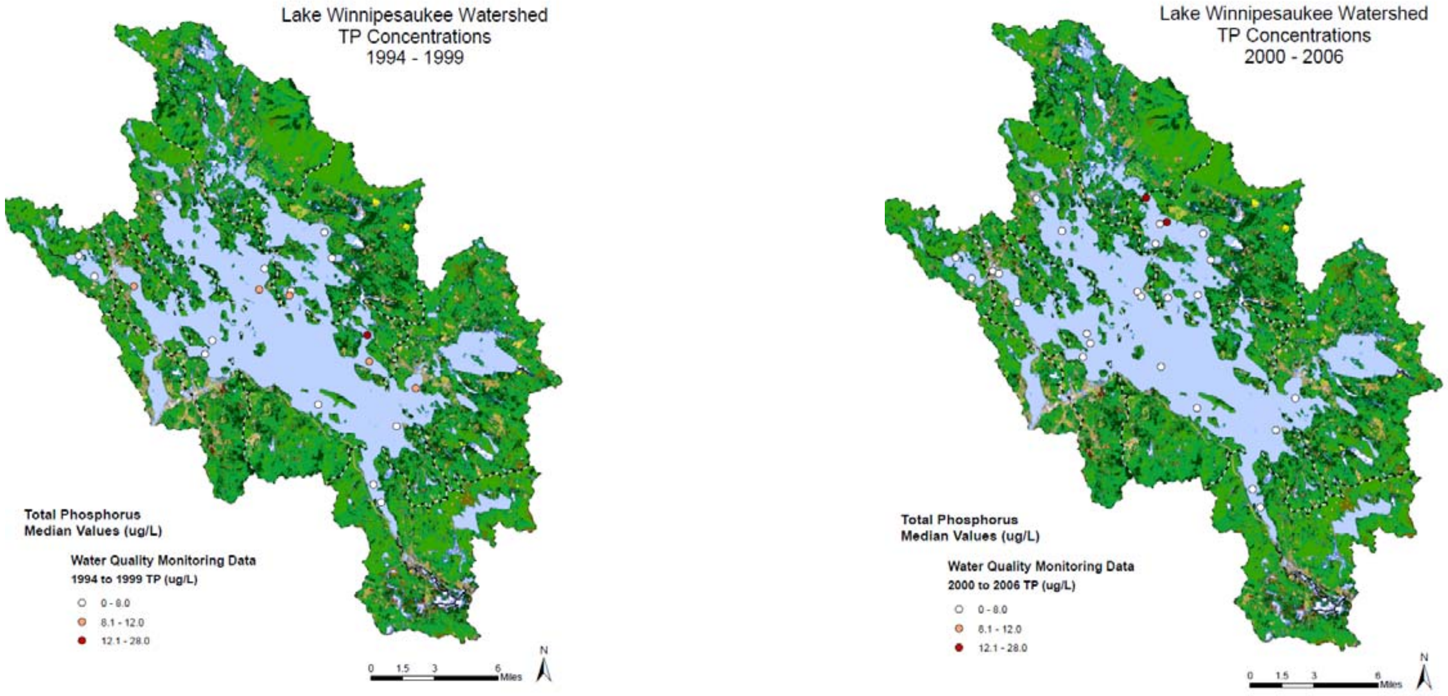
Table 1. Summary of TP data for Lake Winnipesaukee by sub-watershed from 1982 through 2006.
Data was obtained
from the NH DES Environmental Monitoring Database.
n = number of samples
ND = no data available



a.

b.

Figure 1. Map (a) of the median TP concentrations for sampling locations in Lake Winnipesaukee for the period 1982-1986, and (b) for the period 1987-1993.



c.

d.

Figure 1 (continued). Map (c) displays the median TP concentrations for sampling locations in Lake Winnipesaukee for the period 1994-1999, and (d) for the period 2000-2006.

The watershed planning process involves conducting a watershed and in-lake analysis for each sub-watershed in the Lake Winnipesaukee watershed to ultimately result in a comprehensive watershed-wide management plan. This process will assist communities in understanding how land use and future development impacts their local water quality, and is a necessary task for successful lake water quality management planning (Reckhow, 1981).

The overall goal of the Lake Winnipesaukee Watershed management plan is the long term water quality protection of the lake through the reduction and/or mitigation of nutrient inputs, specifically phosphorus.

With financial assistance received from the New Hampshire Department of Environmental Services through the Clean Water Act Section 319 funds from the U.S. Environmental Protection Agency, the sub-watershed management planning process was begun in five of the 10 HUC-12 sub-watersheds; Lake Waukewan, Meredith Bay, Saunders Bay, Paugus Bay, and Center Harbor Bay (Figure 2). Paugus Bay, a separate assessment unit for water quality reporting purposes, is of particular interest to the City of Laconia due to its role as the primary drinking water source for the city. Located downstream of Lake Winnipesaukee, its water quality is potentially affected by activities and landscape change throughout the Lake Winnipesaukee watershed.

A requirement of management plans funded through the Watershed Assistance Grant program is the establishment of local water quality goals for in-lake TP levels per assessment unit that either meet or exceed the TP threshold established by the State.

In 2010 NH DES set numeric nutrient thresholds for TP and Chl-*a* for the aquatic life designated use, which is the most restrictive of the designated uses (Table 2). The method used by the NH DES for the establishment of these thresholds can be found in the report "Assessment of Chlorophyll-*a* and Phosphorus in New Hampshire Lakes for Nutrient Criteria Development" and is discussed further in section 2 of this paper (NH Department of Environmental Services, 2009a).

Table 2. NH State Nutrient total phosphorus (TP) and chlorophyll-*a* (Chl-*a*) Thresholds for Aquatic Life Designated Use

Trophic State	**TP (µg L^{-1})**	**Chl-*a* (µg L^{-1})**
Oligotrophic	< 8.0	< 3.3
Mesotrophic	<= 12.0	<= 5.0
Eutrophic	<= 28	<= 11

Lake Winnipesaukee, currently legislatively classified as a Class B waterbody and biologically categorized as oligotrophic (low productivity), is subject to the Chl-*a* and TP thresholds of 3.3 µg L^{-1} and 8 µg L^{-1}, respectively to determine if the lake has a nutrient impairment not supportive of the aquatic life designated use. Paugus Bay and Lake Waukewan, which are separate assessment units from Lake Winnipesaukee, are also subject to the Chl-*a* and TP thresholds of 3.3 µg L^{-1} and 8 µg L^{-1} respectively.

One of the challenges in understanding Lake Winnipesaukee's water quality is that the lake's physical structure and shape is more a system of interconnected basins rather than a single cohesive body of water. Each embayment has differing characteristics and land-based influences and in-lake responses to nutrient inputs (Lakes Region Planning Commission, 1995).

Working with the five sub-watersheds selected for development of the first management plans (Figure 2), this study seeks to analyze these different sub-watersheds by determining:

1. the watershed morphometric and hydrologic characteristics of each sub-basin, and
2. the estimated phosphorus loading associated with each sub-watershed and the associated sub-basin in-lake TP response to the loading.

Secondly, the study will use the information determined from the watershed and in-lake analyses to attempt to answer the question whether Lake Winnipesaukee should remain classified as one assessment unit or should each sub-basin be assessed individually?

Therefore, the primary focus of this thesis is to determine the sub-watershed and sub-basin characteristics of Lake Winnipesaukee and to link those characteristics to the in-lake TP concentrations observed. This information will help identify the relative contributions of the different sub-basins to the overall nutrient load to the lake, the potential sensitivity of a sub-basin to land use change, and help communities target and prioritize nutrient reduction and management activities.

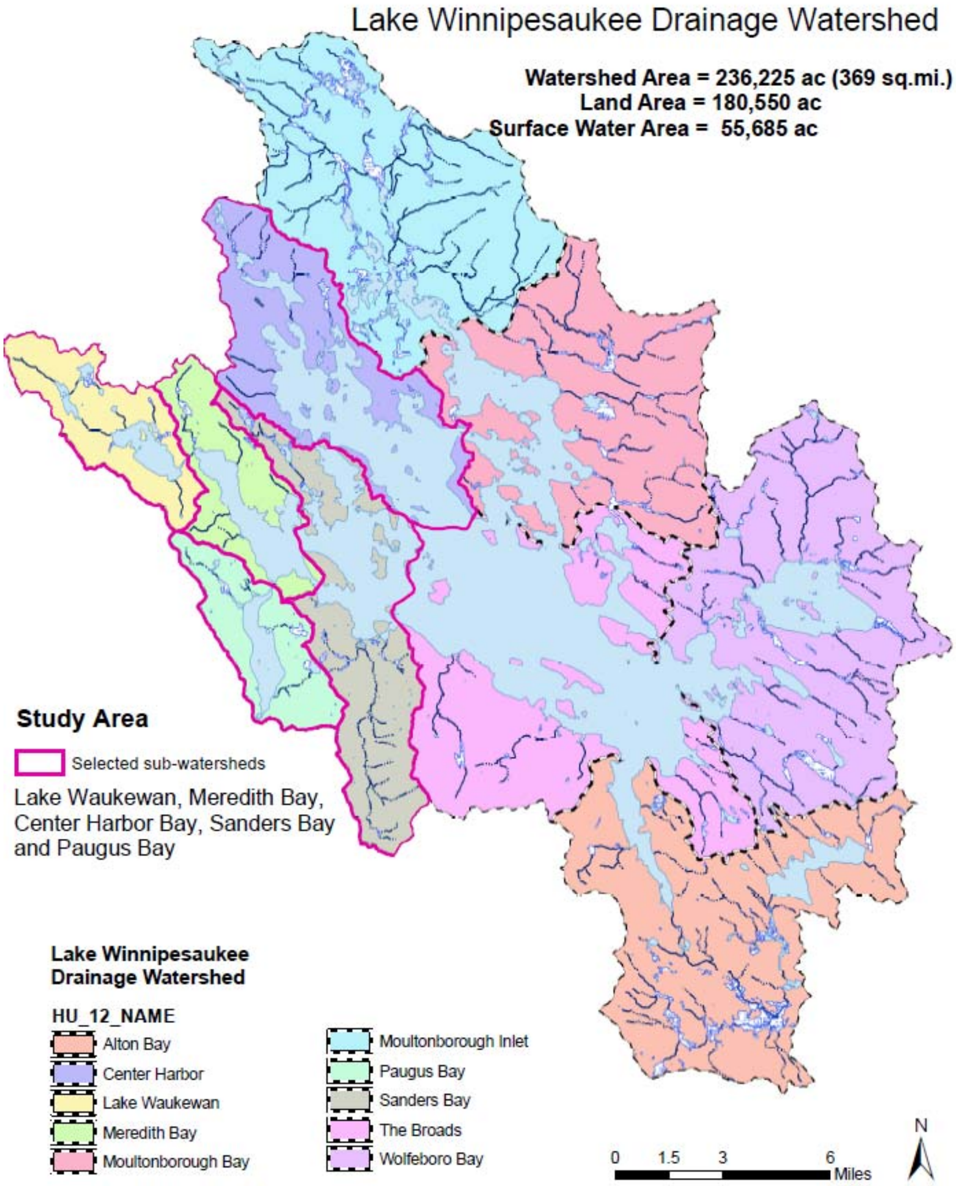


Figure 2. Map depicting the Lake Winnipesaukee drainage watershed and the initial study area of the five sub-watersheds.

1.2 Background on water quality protection efforts

Efforts to protect the water quality of Lake Winnipesaukee and its surrounding land area began in the 1960’s with a study financed by the City of Laconia and undertaken under the supervision of the Water Supply and Pollution Control Commission, the U.S. EPA, the Winnipesaukee River Basin Study Commission, and representatives from several communities. The study focused on water quality problems primarily associated with pollution from wastewater discharges and led to the creation of the Winnipesaukee River Basin Program, resulting in construction of a public sewage disposal pipeline system and facilities serving portions of the Winnipesaukee River Basin communities of Center Harbor, Meredith, Laconia, Gilford, Belmont, Sanbornton, Tilton, Northfield, and Franklin (NH DES, 2007).

Figure 3. The Winnipesaukee River Basin Program Service Area (http://des.nh.gov/organization/divisions/water/wrbb/documents/service_area.pdf)

In the mid 1970's as part of an area-wide wastewater management study, a water quality management plan for the 21 communities within the lakes region, titled "208A Water Quality Report", was the first attempt to develop a comprehensive watershed management plan for the lakes region. The project, funded by the U.S. Environmental Protection Agency (U.S. EPA), was undertaken by the Lakes Region Planning Commission (LRPC) and included an intensive water quality sampling and analysis of four lakes and their major tributaries, including Lake Winnipesaukee. Objectives of the sampling program were to provide a limnological evaluation of the lakes, baseline tributary water quality and discharge data, data for tributary nutrient loadings, and data for a lake nutrient and biological model (Normandeau Associates, 1977). The overall purpose of the project was to develop a water quality management plan for 21 communities that would serve as a guide to the protection of the Lakes Region's valuable water resources.

Water quality data from the study showed that the TP concentrations in Lake Winnipesaukee were on average below 20 μg L^{-1}, with the exception of Moultonborough Bay, which had mean values ranging from 25 -30 μg L^{-1}. Numerous parameters were evaluated, resulting in Moultonborough Bay being classified as mesotrophic, and the remainder of Lake Winnipesaukee classified as oligotrophic (Normandeau Associates, 1977). The results of the study provided the input data needed for the development of a nutrient and hydrologic model of the Lake

Winnipesaukee watershed and for Moultonborough Bay (Resource Planning Associates Inc., 1977c).

One of the conclusions drawn from the modeling project was the major improvement in water quality expected from the implementation of the Winnipesaukee River Basin Sewer Program. The modeling estimated that TP concentrations over the entire lake would be expected to decline from 11 $\mu g\ L^{-1}$ to 8 $\mu g\ L^{-1}$ through the elimination of the three wastewater treatment plants discharging to Lake Winnipesaukee at the time. The study also concluded that sewering Moultonborough Bay would have little or no impact on water quality in the bay, as the largest source of nutrient loading comes from the watershed, not from shorefront septic systems (Resource Planning Associates Inc., 1977c).

In 1995 a study, titled "Water Quality Trend Analysis of Lake Winnipesaukee", was published that analyzed the water quality data of Lake Winnipesaukee to determine if a correlation could be made between water quality trends, land use and local regulations. The water sampling design considered the basin structure of the lake and investigated water quality trends at six lake sub-basins. Although the data generated from the study is limited, it was noted that some of the water quality differences observed were the result of differences in residence time, the ratio of drainage area to water area of the bays, steepness of terrain and runoff (Lakes Region Planning Commission, 1995).

Since that time there have been various local and independent efforts to evaluate water quality, determine land use change and impacts, and assess the concerns and issues of the public. In 2006, North Country Resource Conservation and Development Area Council, Inc. brought together representatives from the communities of Meredith, Laconia and Gilford for the purposes of forming a sub-watershed advisory group to address concerns regarding water quality protection of the lake and its watershed across jurisdictional boundaries. These three communities were chosen as the pilot group to begin the sub-watershed approach for several reasons, including the facts that each community employs professional planning staff and each community recently conducted a local study on watershed planning or water resource protection.

Following that initial effort, in 2008, the LRPC, along with its project partners, received a Watershed Assistance Grant under Section 319 of the Clean Water Act from the U.S. EPA to develop a Watershed Management Plan for the Meredith, Paugus, and Saunders Bays sub-watersheds; the fundamental goal being: "to halt or minimize further water quality degradation attributable to nutrient inputs, primarily phosphorus in order to maintain our high quality water" (http://winnipesaukeegateway.org/management-plans/plan-1-meredith-paugus-and-saunders-bay/introduction/). Subsequent Section 319 Clean Water Act funding allowed land use and in-lake analyses to be completed for the Center Harbor Bay sub-watershed as well.

2.0 Rationale and Significance

2.1 Review of the factors influencing lake productivity

The size and shape of a lake basin affect nearly all physical, chemical, and biological parameters of a lake. However, mean depth is regarded as the best single morphometric index of conditions, exhibiting an inverse relationship to productivity in many large lakes (Wetzel, 2001). Other physical characteristics influencing lake productivity include geology, topography and land use, watershed area to lake area ratio, hydraulic residence time, and flushing rate. Productivity in freshwater ecosystems is related to the nutrient load, particularly TP as demonstrated by Schindler in the early 1970's (Schindler, 1974).

Efforts to estimate in-lake response to nutrient loading resulted in a large body of scientific research in the late 1960's and 70's focused on the development of empirical models to predict trophic state of a waterbody based on in-lake TP concentration (Chapra, 1979; Dillon and Rigler, 1974b; Reckhow, 1979; Vollenweider, 1975, 1976; Yeasted and Morel, 1978). The research looked at various characteristics or parameters to determine the dominant factor(s) influencing lake productivity. The models developed were based on simple mass balance equations and therefore assumed a steady state environment. However TP is subject to chemical and biological transformations and transfer to and from the sediments; therefore a loss term was added to the models to account for the non-conservative nature of phosphorus (Yeasted and Morel, 1978).

The theoretical models developed for phosphorus budgets are based on the following premise: $V\,(dp/\underline{dt}) = W - Qp - S$,

where V (dp/dt) represents the net in-lake TP concentration after subtracting out the TP that is removed through flushing (Qp) and sedimentation (S) from the mass of P input (W) (Chapra, 1982).

The basic equation has been modified to include different estimators of the terms and to better represent some classes of lakes (Peters, 1986). The model developed by Vollenweider (1975) investigated the relationship between nutrient loading and mean depth and was later amended by him to account for the importance of water residence time as well as include a loss factor for sedimentation; $P=Lp/(Z^*(S+F))$, where P represents the predicted in-lake TP concentration, Lp is the areal phosphorus loading, Z is the mean depth, S is the suspended fraction of P, and F is the flushing rate (Vollenweider, 1975).

Dillon (1975) modified Vollenweider's original model to include flushing rate as a key parameter, as well as adding a phosphorus retention coefficient. Dillon (1975) looked at the TP budget for Cameron Lake, Ontario and determined that despite a high TP loading rate, the lake was not eutrophic because a high flushing rate counteracted the effect of the high loading.

In general, the longer water is retained in a lake (slow flushing time), the greater the amount of TP trapped by the sediments (Resource Planning Associates Inc., 1977b).

Flushing rate has an inverse relationship to volume; the greater the volume, the longer the water residence time (T_w), and by inverse the lower the flushing rate. Assimilative capacity is more difficult to quantify in shallow lakes where there are many different types of sediment-water interactions occurring which produce feedback loops and non-linear responses (Havens and Schelske, 2001).

Chapra (1979) states that the simple mass-balance models developed by Vollenweider (1975), and Dillon and Rigler (1974b), are not directly applicable to river-run lakes, embayments, and the near shore zone since the mechanisms underlying long-term TP dynamics – sedimentation and transport – are not explicitly accounted for in the empirical equations. In his study of Lake Erie, Chapra (1979) investigated modifying the phosphorus loading models to apply to embayments, where turbulence or diffusive transport is of considerable importance.

Chapra (1982) chose to focus on settling velocity rather than the phosphorus retention coefficient to model the effect of resuspension of bottom sediments and determined that resuspension is important for lakes less than 10 meters deep because such systems would be more susceptible to wind-induced sediment resuspension. He modeled this effect by making the apparent settling velocity a function of lake depth, however he acknowledged the model had limited applicability and required further testing and calibration with a larger data set (Chapra, 1982).

Brett and Benjamin (2008) conducted a statistical reassessment of lake data from the published literature to determine which lake characteristics are most strongly associated with lake phosphorus concentration and retention. Five hypotheses were tested related to the empirical form of the term σ, the rate coefficient representing net loss of phosphorus due to sedimentation of P-containing particles in the lake; 1) the rate coefficient is the same for all lakes, $\sigma = k_1$ (a constant); 2) the rate coefficient σ is inversely proportional to the hydraulic retention time, $\sigma = k_2/t_w$; where k_2 is a constant; 3) σ is related to the TP settling velocity (υ) and the mean lake depth by: $\sigma = \upsilon/z$; 4) σ is an inverse function of the lake's hydraulic residence time, $\sigma = k_4 t_w^{x4}$, where k_4 and x_4 are constants, and 5) the relationship between TP_{out} and other parameters is given by the equation proposed by Jones and Bachmann, $TP_{out} = aTP_{in}/1 + bt_w$ (Brett and Benjamin, 2008). In their analysis, Brett and Benjamin (2008) found that hypothesis (4) provided a better estimate of in-lake TP than the other relationships tested and that hypothesis (3) provided no better prediction for in-lake TP than hypothesis (1) which assumes that σ is the same for all lakes.

Ahlgren, Frisk, and Kamp-Nielson (1988) provide a description and analysis of the pros and cons of the empirical and dynamic theoretical models that have been developed to relate lake trophic state to external phosphorus loading. Ahlgren et al. (1988) state that various authors' reviews and critiques of the empirical models have raised doubts about the belief that trophic state can be described solely as a function of nutrient supply. The role and importance of phytoplankton consumers to assimilate nutrients has been the subject of several studies.

Mazumder and Lean (1994) found that the epilimnetic concentrations of phosphorus increase proportionately with increased loading of phosphorus, but that the trophic condition of the ecosystem indicated by algal biomass and water clarity varied under contrasting conditions of grazer communities.

Carpenter, Kitchell, and Hodgson (1985) investigated the concept of cascading trophic interactions (piscivore/planktivore/ herbivore/phytoplankton biomass) to explain the differences in productivity observed among lakes with similar nutrient supply but contrasting food webs. Carpenter et al. (1985) proposed that altering food webs by altering consumer populations might be a promising management tool for controlling lake eutrophication and suggested that the cascading trophic interactions are complementary to nutrient loading models, linking the principles of fisheries biology to those of limnology.

More advanced and complicated models have been developed to address the limitations of the static models. The newer models are dynamic (time-dependent) and have been found to predict in-lake TP concentrations with higher certainty than static models. One dynamic model, LakeMab, has the ability to predict P fluxes and particulate and dissolved P in both deep and shallow waters (Bryhn and Håkanson, 2007). However, the dynamic models demand more data, have more complex computing needs, and require special training to operate.

What is evident from the literature review is that the ecosystem of a lake is a complex interaction of physical, biological, and chemical processes which cannot be explained or predicted fully by one model, tool, or set of parameters. Therefore the purpose of utilizing the empirical in-lake predictive models is to help lake managers calibrate watershed phosphorus loading models by comparing the watershed P load output and resulting in-lake P prediction to actual in-lake TP data. Lake managers may then use the models to predict how land use change over time correlates with in-lake response, recognizing that an important limitation to most of the models is that they are based on mass balance equations and therefore represent steady-state conditions, which is not a realistic expectation for a freshwater ecosystem. However, their ease of use provides a useful tool to lake managers in their efforts to control or mitigate eutrophication.

2.2 Development of Nutrient Criteria

Because nutrient over enrichment consistently ranks as one of the top causes of water quality impairment, the U.S. EPA initiated a National Nutrient Criteria Program to develop guidance documents to assist States and Tribes in developing nutrient criteria to protect the designated uses of lakes, streams and rivers, estuaries, and other water resources (U.S. EPA, 2000a). Recognizing that geographic and climate conditions vary throughout the country, U.S. EPA requires nutrient criteria to be developed at the State or regional level, and as a first step towards this process established numeric nutrient criteria for each ecoregion of the country. The numeric nutrient criteria are meant to represent the conditions of surface waters minimally impacted by human development activities and form the basis for further development of nutrient criteria at the State level (U.S. EPA, 2000a).

Three approaches recommended by the U.S. EPA and considered scientifically defensible for setting numeric nutrient criteria are the reference condition approach, mechanistic modeling, and stressor-response analysis (U.S. EPA, 2010). The reference condition approach, adopted by the State of New Hampshire, establishes lake reference conditions to represent the least impacted condition by human activity or what is considered an attainable condition. For regions or states with a large inventory of lakes that can be considered reference lakes, EPA recommends using the upper 25th percentile from the distribution of measured variables as the criteria for the nutrients in question. If reference lake conditions are lacking, EPA suggests using a lower percentile from the distribution of measured variables from all lakes in a class to represent the better end of the distribution (U.S. EPA, 2000a).

Concern that if the nutrient criteria selected does not provide a good indicator of the designated use it is meant to protect, prompted Reckhow et al. (2005), to assess the reference condition approach proposed by EPA. A good scientific basis is needed for numeric nutrient criteria being enforced because failure to meet water quality standards places a lake on the impaired 303(d) list, resulting in expensive monitoring and planning actions to reduce the in-lake TP concentration to a level that supports the designated use (Bachmann et al., 2012; Reckhow et al., 2005). For this reason the probability of attainment was added as a response variable to the data sets developed in the prediction-based procedure of Reckhow et al. (2005).

The use of the reference condition by EPA in determining nutrient criteria has been raised as an issue in several studies (Bachmann et al., 2012; Dodds, Carney, & Angelo, 2006; Dodds and Oakes, 2004; Reckhow et al., 2005; Smith, Alexander, & Schwarz, 2003). Although knowing what the natural background nutrient concentrations should be for a waterbody is important in setting numeric nutrient criteria, no optimal method exists for determining those nutrient levels (Dodds and Oakes, 2004).

Smith et al. (2003) noted three major obstacles to using nutrient data from reference sites to define natural background conditions in rivers and streams: 1) pristine reference sites don't exist; if a site is used as a reference condition, then corrections must be made for cultural sources of nutrients, 2) nutrient yields at undeveloped reference sites may vary by more than 2 orders of magnitude due to variation in several characteristics such as climate, hydrology, natural vegetation, geology, and 3) most reference sites are located in small watersheds, which makes scaling up difficult.

In order to address these issues, Smith et al. (2003) used river and stream data from 63 minimally impacted watersheds to develop statistical models to estimate regional frequency distributions for mean annual background TN and TP yield and concentrations for streams and rivers. Runoff was the strongest predictor of both TN and TP yields and concentrations, with predicted background TP and TN decreasing with increasing basin size due to in-stream nutrient losses associated with travel time. They compared the predicted background concentrations from the models with EPA's

25th quartile of nutrient concentrations. In almost all regions the predicted TN corrected for deposition was half the EPA's 25th quartile, whereas the average TP results across the regions were about the same as the 25th quartile, but showed great variation within individual regions. Their results suggested that actual TN concentrations in streams and rivers exceeded natural background levels by a much larger factor than did TP concentrations.

Limitations in the strategies suggested by EPA for determining reference conditions prompted Dodds and Oakes (2004) to develop a statistical technique to distinguish human land-use effects from naturally variable stream nutrient concentrations. They performed statistical analyses on three data sets of streams from watersheds in four ecoregions in Kansas. Using multiple linear regression to establish relationships between land use and nutrient concentrations, they found no significant ecoregion effect on TP, but did with TN. The percentage of cropland and urban land were significantly related to TP concentrations and the percentage of cropland was the best predictor of TN within ecoregions. Limitations to the regression model were that it did not incorporate all sources of human impact, nor did the analysis account for drainage area or slope (Dodds and Oakes, 2004).

The importance of knowing what the natural background concentration of nutrients might be in setting nutrient criteria was illustrated in the study conducted by Bachmann et al. (2012) on Florida's lakes. An analysis of data from 1387 lakes led Bachmann et al. (2012) to conclude that most of Florida's eutrophic lakes are not the result of nonpoint source pollution, but rather are a natural part of the ecosystem. Applying a landscape development intensity index (LDI) developed for watersheds around wetlands in Florida and used by U.S. EPA to estimate nutrient inputs to Florida streams, they found no strong correlation between the LDI and concentrations of TP, TN, and Chl-*a*. In addition, paleolimnological analysis of sediment cores showed that many of Florida's lakes were eutrophic prior to 1900.

Consideration of the natural variability in lakes and reservoirs, both seasonally and inter-annually, in setting nutrient criteria was discussed by Knowlton and Jones (2006). Because conditions exceeding the criterion are often a typical feature of lakes, what constitutes an 'excursion' and the frequency and duration of the excursion, should be part of the criterion setting process and based on local understanding of the water resource. Frequent excursions or extreme events affect the ability to evaluate compliance with the numeric criteria (Knowlton and Jones, 2006).

In EPA's guidance document, it is suggested that criteria for causal and response variables must be met in 75% of the sampling events in two consecutive years. Knowlton and Jones (2006) applied this protocol to Missouri reservoirs and found differences of two fold among seasonal means in only six years of seasonal data. Acknowledging that the temporal variability may be very different among lakes and not well studied, he advocated that only long term data would provide a good indication of what the 'normal' condition is for any particular lake. In addition, Knowlton and Jones (2006) stated that regulatory language specifying nutrient criteria and compliance should explicitly recognize the need for long term data and statistical validity of results.

Other reviews of the nutrient criteria process have discussed the importance of including biological indicators and processes into the development of numeric nutrient criteria (Dodds and Oakes, 2004; Havens and Schelske, 2001; Soranno, et al., 2008). Dodds and Oakes (2004) suggested a biological approach using the functional response between indicators such as the community make up of algae and stream nutrient concentrations could be used in regions that have well developed biotic indices.

Although Havens and Schelske (2001) focused on setting appropriate total maximum daily loads (TMDL) for lakes in Florida, the reasoning described therein is applicable to setting appropriate nutrient criteria. They describe various biological processes that may affect the ability of a lake to assimilate P; TP loading, phytoplankton community, submerged plant biomass, macro-invertebrate and fish taxonomic structure and biomass. Each process has a potential impact on the net P sedimentation rate, which in turn affects the ability to assimilate P. If a higher net P sedimentation rate can be achieved, an in-lake phosphorus target might be met with a higher TMDL (Havens and Schelske, 2001).

Sorrano et al. (2008) developed a framework that integrates nutrient modeling to predict ecosystem expected conditions, biological thresholds, and current nutrient concentrations. The Biological Threshold Predictive Modeling (BTPM) framework uses specific biological responses as a surrogate for the designated use. In EPA's approach, biological integrity is not measured; it is assumed that aquatic life use is protected if the associated nutrient value reflects minimal human disturbance.

The BTPM framework models the expected in-lake TP condition based on hydrogeomorphology and land use, and models the expected in-lake TP for pre-development by setting the human land use/land cover (LULC) coefficient to zero. An allowance is added to the expected in-lake TP for the pre-development scenario to represent either model uncertainty or a minimal level of allowed human disturbance to the lake. The model incorporates BIO benchmarks to identify critical thresholds along a TP gradient where major changes in lake biology occur, with the TP values between two BIO benchmarks representing BIO zones. Lake specific TP criteria are derived by comparing the current observed in-lake TP to the expected in-lake TP with allowance and the BIO benchmarks.

They suggest that a critical advantage of this approach over others is that it addresses questions in the process of setting nutrient criteria such as "what is the natural background condition?, what is the effect of nutrients on biological responses?, what level of nutrients protects biological integrity?, and what is a reasonable level of protection? The framework allows nutrient criteria to be developed on an ecosystem specific basis instead of a single criterion for all lakes within a geographic region (Sorrano et al, 2008).

The Clean Water Act requires each State to report every two years on the water quality of its surface waters and to provide a list of surface waters not meeting water quality standards. The two reports are often referred to as the 305(b) report and the 303(d) list, referencing the applicable sections of the Clean Water Act. The reports and assessment methodology can be found in the "New Hampshire Consolidated Assessment and Listing Methodology" report (NH Department of Environmental Services, 2012).

In New Hampshire the protection of water quality is regulated through the Water Quality Standards, which include RSA 485-A:8 – the Classification of Water, and Env-Wq 1700 – the Surface Water Quality Regulations. RSA 485-A:8 establishes that all New Hampshire surface waters are classified as either Class A or Class B waters, and specifies certain minimum surface water quality criteria for each classification. The Surface Water Quality Regulations further protect and maintain New Hampshire's waters through the identification of designated uses, anti-degradation provisions, and additional numeric and narrative water quality criteria. The designated uses for New Hampshire waters are: aquatic life, fish and shellfish consumption, drinking water supply, primary contact recreation (swimming), secondary contact recreation (boating), and wildlife. For waters with multiple use designations, criteria must support the most sensitive use, i.e. aquatic life (U.S. EPA 2000a).

Surface waters are classified into assessment units (AU) for the purpose of evaluating and determining trophic state and reporting water quality assessments to the U.S. EPA.

AUs are intended to be representative of homogenous conditions; therefore sampling stations within an AU should be representative of the water quality of the segment, and one water quality standard should apply to the AU (NH Department of Environmental Services, 2012).

In 2010 the State of New Hampshire adopted numeric water quality thresholds for nutrients protective of the aquatic life designated use. The process of establishing numerical water quality standards began in 2005 with the analysis of existing data in the Environmental Monitoring Database (EMD). The 2005 analysis determined that the TP concentration associated with Chl-*a* impairments in lakes was approximately 20 µg L^{-1} (P. Trowbridge, personal communication, August 5, 2005). However, this analysis was considered preliminary pending further inclusion of data from the University of New Hampshire Lakes Lay Monitoring Program (UNH LLMP).

In 2009 NH DES issued a report titled "Assessment of Chlorophyll-*a* and Phosphorus in New Hampshire Lakes for Nutrient Criteria Development" (NH DES, 2009) which incorporated the UNH LLMP data to more accurately determine the median TP concentration associated with Chl-*a* impairments. For a lake to be considered impaired for Chl-*a*, more than 10% of the summer samples must have concentrations higher than 15 µg L^{-1}, which impairs the swimming designated use (NH DES, 2009).

Using data collected between 1975 and 2007, median values for Chl-*a* and TP were calculated for 233 lakes out of a total of 886 lakes in New Hampshire. In order to be included in the study, a minimum of 5 data points from each lake were necessary and only samples collected from the epilimnion between June and September were included in the analysis. NH DES used the reference concentration approach recommended by EPA to develop target ranges for TP and Chl-*a* for the oligotrophic and mesotrophic levels. This approach uses the 75th percentile of concentration in the reference lakes (limited human influence) as the upper limit, and the 25th percentile of concentrations of all lakes as the lower limit, or boundaries of the target criteria (NH DES, 2009). The results of this analysis determined that the TP criterion for oligotrophic lakes was between 5.4 $\mu g\ L^{-1}$ and 8.0 $\mu g\ L^{-1}$; and Chl-*a* criterion was 1.7-3.2 $\mu g\ L^{-1}$. The criteria for mesotrophic lakes was 8.0 to 11.0 $\mu g\ L^{-1}$ TP, and 3.4 - 5.0 $\mu g\ L^{-1}$ Chl-*a* (NH DES, 2009). A concentration of 8.0 $\mu g\ L^{-1}$ TP appeared to be the threshold at which an oligotrophic lake would begin the transition to mesotrophic status so this concentration was chosen as the nutrient criterion threshold for TP for oligotrophic lakes. Likewise, a concentration of 3.3 µg/L Chl-*a* represented the upper limit for oligotrophic lakes and the lower limit for mesotrophic lakes, and therefore was chosen as the nutrient standard for Chl-*a* for oligotrophic lakes.

An analysis of water quality TP data performed by EPA on the Northeastern Highlands ecoregion lakes in 2000 determined the range of 25th percentile concentration of all lakes to be 7.0 $\mu g\ L^{-1}$ - 10.0 $\mu g\ L^{-1}$ (EPA, 2000b). As EPA's criteria are meant to represent conditions of surface waters that are minimally impacted by human activities and protective of aquatic life (EPA, 2000b), the numeric nutrient thresholds for TP selected by the NH Department of Environmental Services are within the range recommended by EPA for the aquatic life designated use.

The review of the literature highlights that multiple approaches exist for setting State numeric nutrient thresholds. Each approach has limitations, but all are based on the assumption that the numeric nutrient thresholds selected can be appropriately applied as an indicator of whether designated uses are being met. Several factors such as natural background condition, the natural variability and seasonality of lakes, their hydrology, biological processes, and land cover should be considered when establishing the process.

2.3 Implications for lake management approaches

Lake management typically focuses on reducing nutrient loading because manipulation of a lake's hydraulic flushing rate or sedimentation rate is not possible or practical (Jones, Knowlton, and Obrecht, 2008). As mentioned in the previous section, AUs are the basic unit for reporting water quality and are meant to represent segments of homogenous physical, chemical, and biological conditions. The ability to accurately predict nutrient loading to the receiving waterbody or assessment unit with corresponding in-lake response is important for lake managers when developing strategies to reduce or limit nutrient loading in order for a waterbody to meet the established state nutrient criteria or water quality goals (Bachmann et al., 2012; Dodds et al., 2006; Johnes, 1996; Reckhow et al., 2005).

Since direct measurement of TP loading is impractical, a suite of nutrient loading models have been developed to estimate nutrient loading from a watershed. These models vary in complexity based on the number of parameters and data needed to run them.

Purpose of application, data requirements, rigor of analysis, and the required level of effort and modeling expertise of the user will determine model selection. Some of the models that are considered simple to use are the Spreadsheet Tool for Estimating Pollutant Load (STEPL), the Region 5 model, the Simple Method, Sediment and Phosphorus Prediction (SLOSS-PHOSPH), and Watershed. Many of the mid-range models and the complex models have the ability to simulate runoff, sediment delivery, and pollutant transport both spatially and temporally, and are capable of evaluating the effects of implementing a best management practice. Models which fall in the mid-range category include Agricultural Nonpoint Source Pollution Model (AGNPS) and Generalized Watershed Loading Function (GWLF). Some of the more complex models include Groundwater Loading Effects Agricultural Management System (GLEAMS), Soil and Water Assessment Tool (SWAT), and the Stormwater Management Model (SWMM) (U.S. EPA, 1997).

In simplest terms, nutrient loading can be estimated by multiplying export coefficients assigned to a land use by the acreage of that land use. Selection of the appropriate export coefficient should be representative of the watershed conditions, such as hydrology, topography, and geology (Reckhow, Beaulac, and Simpson, 1980). Because export coefficients are readily available in the published literature, this approach offers an inexpensive and simple method for estimating nutrient loading. An important limitation to this approach is that it cannot predict nutrient delivery through hydrological pathways, nor can it predict in real time (Johnes, 1996).

Spatial and temporal patterns of land use also influence runoff and thus nutrient loading. TP export and runoff per unit area generally decrease with increasing sub-watershed area (Smith et al., 2003; Soranno, Hubler, Carpenter, and Lathrop, 1996). Because of this, differentiation should be made between the contributing area and effective area of land when assessing the nutrient load from a watershed (Soranno et al., 1996). Soranno et al. (1996) defines the contributing area as the area of the watershed that potentially contributes TP loading by overland flow, and the effective area of land as that which actually contributes to runoff based on model calibration. To account for flow distance, they developed a P flux approach by adding a transmission coefficient which accounts for the amount of TP that is attenuated along the flow path and determines the effective land area (Soranno et al., 1996).

Sorrano et al. (1996) found that during low runoff years, only urban areas and areas adjacent to surface waters contributed significantly to loading, and differences in loading between high and low runoff years was greater than differences between land use scenarios. Results from this study support the view that failure to consider the spatial distribution of land uses and climatic variability may contribute to failures of management plans to improve water quality.

Weller, Watzin, and Wang (1996) studied the role of wetlands in reducing TP loading to surface waters in watersheds in the Lake Champlain basin by modeling the position or pattern of wetland position in the landscape. The coefficients derived from the model seemed to indicate that one hectare of riparian wetland is about 35 times more important in reducing TP load than a hectare of agricultural land is in producing phosphorus. While agriculture is not a significant land use in the Lake Winnipesaukee watershed, the results from this study emphasize the importance of wetlands to water quality, and support the protection of wetlands as a key lake management strategy.

A search of the literature on lake management approaches utilizing allocation scenarios resulted in a body of work associated with the development of total maximum daily load (TMDL) for impaired water bodies. TMDLs assist lake and river managers in identifying and targeting watershed areas requiring a reduction in nutrient loadings by establishing allowable loadings for the pollutant of concern in order to attain or meet water quality standards (U.S. EPA, http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/).

One case study found involving division of a lake into separate segments for assessment purposes was the Lake Champlain Basin Program, which was the result of development of a TMDL. A restoration plan for Lake Champlain was developed in 1996 to address excessive TP levels in the lake. The lake, which is morphologically complex with numerous bays, was divided into 13 segments for TP management purposes. In-lake TP concentrations varied greatly among the segments, from the low oligotrophic range of 0.009 - 0.012 mg L^{-1} to eutrophic values of 0.024-0.058 mg L^{-1} (Vermont Agency of Natural Resources, 2002). The plan adopted the establishment of in-lake TP concentration criteria and watershed-based TP loading targets by lake segment in order to achieve the water quality goals.

The criteria were developed using a mass balance model calibrated to the TP loadings by lake segment. Although significant seasonal differences in TP concentrations existed in some of the lake segments, the steady state modeling approach was chosen to represent the long term annual mean TP concentrations. The segment interfaces found in Lake Champlain range from narrow channels to wide open water situations where extensive mixing occurs. To account for the exchange of flows between lake segments, the exchange rates for each segment were calibrated using a mass balance equation for chloride (Smeltzer and Quinn, 1996).

The Lake Champlain Basin program applied target in-lake TP concentrations at the sub-basin or sub-watershed level of a lake; however Migliaccio, Haggard, Chaubey, and Matlock (2007) applied the same concept to a river watershed, linking watershed sub-basin characteristics to water quality parameters in the War Eagle Creek Watershed in Arkansas. They questioned EPA's approach to develop nutrient criteria at the ecoregion level, stating that such an approach implies that all catchments within an aggregate ecoregion should be held to the same criteria without consideration for land use, seasonal variability, or catchment size. The objective of the study was to characterize the water quality of the watershed by identifying strategic sampling sites while also comparing the results to suggested ecoregion nutrient criteria. The results showed that several sub-basins had significantly different constituent concentrations, which were linked to distance factors, land use, and point sources.

Several possible scenarios exist for achieving nutrient reductions as outlined in a nutrient management strategy for Falls Lake, VA (Falls Lake Stakeholder Project, 2009). The first approach involves uniform reductions for TN and TP across all land use types throughout the sub-watersheds. This approach has the benefit of being considered straightforward and fair, but less flexible. A second option applies different TP goals (and therefore necessary reductions) according to land use type. This option is more flexible and adaptable to the situation, and would allow for weighing cost-effectiveness of proposed measures. The perceived negative to this approach is a disproportionate share of loading reductions to certain sources. A third proposal suggests applying a single TN and TP at source (lb ac^{-1} yr^{-1}) loading to stream value for all land uses (flat unit-area loading rate) that yields annual mass loads that equal the percent reduction goal. Although this approach has the advantage of being a simple concept, opponents argue that it does not recognize the differing nature of sources, creates varying reduction burdens, and does not account for all nonpoint sources, such as from septic systems (Falls Lake Stakeholder Project, 2009). A fourth approach involves applying a watershed wide target for TP and TN regardless of pollutant contribution by sub-watershed, and the last scenario looks at applying separate TN and TP reductions to each sub-watershed that collectively will achieve the reductions needed (Falls Lake Stakeholder Project, 2009). Applying a watershed wide target for TP and TN does not specifically focus on the area(s) that may be contributing to the impairment, which suggests that management measures adopted may be less successful in achieving the goal.

As mentioned in the Introduction, the objective of this study is to assist the communities in the Lake Winnipesaukee watershed in their local water quality protection efforts by conducting a watershed and in-lake analysis of the sub-watersheds that will link the sub-watershed characteristics and land use to the observed in-lake water quality.

Utilizing established TP loading and in-lake response models, I intend to demonstrate how the differing characteristics of each sub-watershed, i.e. the morphology, hydrology, and land use affect in-lake response to nutrient loading.

One challenge to this approach will be to determine the watershed sub-basin characteristics of Lake Winnipesaukee due to the nature of its physical structure and shape. The watershed and in-lake analyses will help identify the relative contributions of the different sub-basins to the overall nutrient load to the lake and the potential sensitivity of a sub-basin to land use change.

I expect the results of the watershed and in-lake analyses to help answer the question whether Lake Winnipesaukee should remain classified as one assessment unit or whether the differing characteristics, land based influences, and associated in-lake responses in the sub-basins support re-classification for water quality assessment purposes.

3.0 Methods and Analysis

3.1 Description of the Study Area

a. Lake characteristics and morphology

The Lake Winnipesaukee watershed (Figure 4), located in Belknap and Carroll Counties in the lakes region of New Hampshire, drains to Lake Winnipesaukee, the largest freshwater body in the state with a size of 44,586 acres and total watershed area of 236,225 acres, or 369 square miles. The watershed encompasses land in 16 communities; eight of which are shorefront and account for 87% of the total land area. The northernmost end of the lake lies in Moultonborough, and the southernmost tip is located in Alton Bay.

The watershed boundary is characterized by the steep Ossipee Mountain range with elevations up to 2,990 ft at Mt. Shaw in the northeast, the floodplain of the Merrymeeting River with an elevation of 542 ft. in the southeast, the Belknap Mountain Range with elevations of approximately 2,400 ft. in the southwest, and hilly terrain in the northwest with average elevations of ~1,200 ft.

The lake, located at 43°35’56″ N Latitude and 71°19’23″ W Longitude, is highly irregular in shape encompassing approximately 240 miles of shoreline (includes the shoreline of islands over 5 acres in size). The surface water area of the lake occupies 44,586 acres; however water from lakes, ponds, streams and rivers in the watershed account for another 11,056 acres, for a total surface water area of approximately 55,642 acres, or 23.5% of the total watershed area. The major tributaries and waterbodies contributing large volumes of water to Lake Winnipesaukee include Lake Waukewan, Meredith; Lake Kanasatka, Lees Pond, and Shannon Brook, Moultonborough; Melvin River, Copps Pond, Twentymile Brook, Nineteenmile Brook, Mirror Lake, Tuftonboro; Lake Wentworth and Crescent Lake, Wolfeboro; Merrymeeting Lake and Merrymeeting River, Alton; Poor Farm Brook and Gunstock Brook, Gilford.

The lake has a maximum depth of 180 ft. in the Broads and a mean depth 43 feet. Water clarity is considered good with average main lake visibility of 27-29 ft. Most of the shoreline is characterized by boulders or sandy areas, with wetland areas limited to the more embayed or shallower areas of the lake (J. Viar, personal communication, October 2010).

Drainage flows through the Weirs channel into Paugus Bay. Although natural, the lake is raised by damming to an elevation of 504 ft, with the dam located at Lakeport at the southwesterly point of Paugus Bay. From this location water enters Opechee Lake and continues into the Winnipesaukee River which is diverted by a canal under the City of Laconia into Lake Winnisquam. Lake Winnisquam empties into Silver Lake, which then flows into the Winnipesaukee River. The river merges with the Pemigewasset River in Franklin to form the Merrimack River which then flows southward through Concord, Manchester, Merrimack, and Hudson into Massachusetts. In Massachusetts the Merrimack turns eastward and flows through Lowell eventually emptying into the Atlantic Ocean in Newburyport, MA.

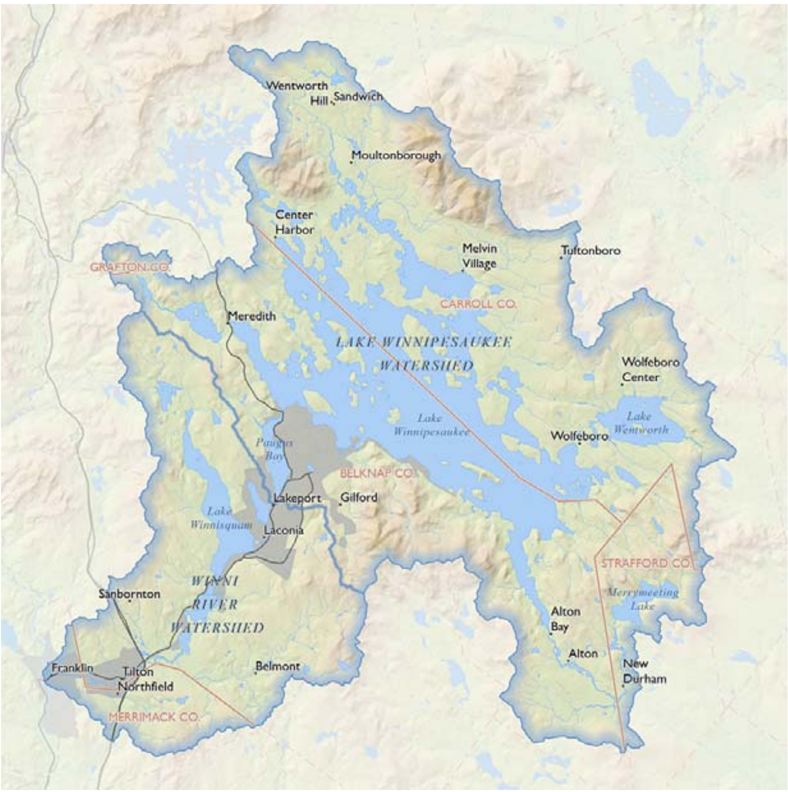


Figure 4. Map depicting the Lake Winnipesaukee and Winnipesaukee River watersheds.

b. Geology and Physiography

The lake and watershed are located in the New England Uplands region of the New England Physiographic Province (Flanagan, Nielson, Robinson, and Coles, 1999). This area is characterized by hilly topography with a range of elevation from below 1000 ft to above 2000 ft. Bedrock found in this area is mainly igneous and metamorphic rock formed and layered in the Devonian and Silurian age. Quartz diorite is the primary rock of the Winnipesaukee Basin.

The lake was formed during the late stages of the Pleistocene Epoch, often referred to as the Great Ice Age, approximately 14,000 years ago during the Wisconsin ice stage (Medalie and Moore, 1995). The glaciers left two major deposits; till and stratified drift. Till, composed of various sized sediments, ranging from boulders, gravel, sand, silt and clay, is the most extensive glacial deposit overlaying bedrock in the upland areas (Flanagan et al., 1999). The meltwater of the glaciers carried sand and gravel depositing it in the valley floors. Lake bottom sediments of the glacial meltwater lakes are composed of fine grained sediments adjacent to and intermingled with coarse grained sediments (Flanagan et al, 1999).

Climate in the Lakes Region of New Hampshire is considered continental due to prevailing westerly winds, and highly variable due to the mid latitude location. Four distinct seasons are experienced with wide ranges in both diurnal and annual temperatures (Flanagan et al., 1999). Due to this factor the lake is dimictic, turning over twice each year, once in the spring, and again in the fall, and will stratify during the summer months. Average annual precipitation is approximately 42 inches and is fairly equally distributed throughout the year.

Lake Winnipesaukee is located in the ecoregion called the Northeastern Highlands defined by EPA as regions having relatively similar characteristics of landform, land use, soil, and "potential natural vegetation" (considered to be the type of climax forest that would develop upon removal of humans and their activities) (Flanagan et al., 1999). The Northeastern Highlands are characterized by mountains, hills, northern hardwoods, spruce, fir, hemlock, and white pine; the land cover is forest and woodland.

3.2 Watershed Analyses

Factors affecting watershed phosphorus loading include climate (rainfall), watershed characteristics (slope, soil type), and land use. The ability of the receiving waterbody to assimilate the phosphorus load is related to the morphometry and hydrology of the waterbody and determines the observed in-lake TP concentration (Figure 5).

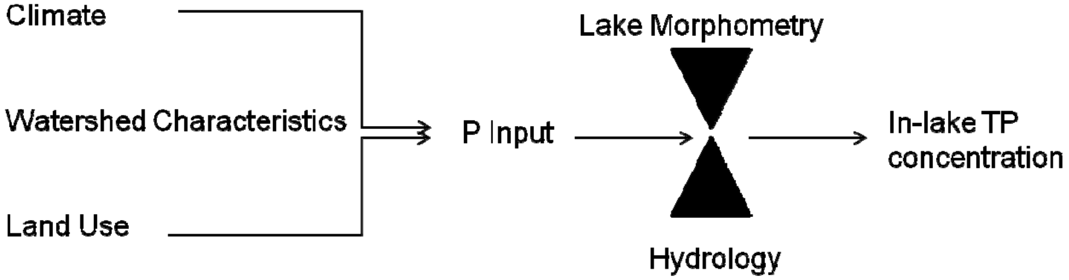


Figure 5. Diagram depicting the relationship between phosphorus loading to a lake and the in-lake TP response (redrawn from Reckhow (1980)).

TP loading comes from several sources; atmospheric deposition, point sources, watershed loading from tributary and direct runoff, groundwater, septic systems, and internal loading. Except for upstream basins which were treated as point sources, no other point sources were identified in this study. As data from internal loading of TP was unavailable, it was assumed to be negligible. Therefore the TP budget for each sub-watershed was determined from atmospheric, watershed, septic systems and TP loadings from upstream/adjacent basins. Groundwater inputs are accounted for in the watershed loading and are not broken out separately.

For purposes of discussion, the following results of the watershed loading and in-lake TP models are based on the rainfall, evaporation, and runoff parameters provided in the Spreadsheet Tool for Estimating Pollutant Load (STEPL) for Belknap County (Table 3).

	Belknap County (STEPL)
Average Annual Rainfall (in)	42.4
Average Annual Runoff (in)	20.1
Avg. Annual Evaporation (in)	22.3

Table 3. Average annual rainfall, runoff, and evaporation data for Belknap County as provided by STEPL

3.2 (a) Atmospheric Deposition

TP inputs from the atmosphere were estimated based on data collected at the Hubbard Brook Experimental Forest Station in North Woodstock, NH. Likens (1977) study on forested watersheds resulted in a coefficient of 10 mg P m^{-2} yr^{-1} for atmospheric deposition. Recent analysis of the precipitation data from four (4) forested and untreated watersheds at the Hubbard Brook site for the period of 2004-2007 resulted in an average of 4.5 µg L^{-1} P. Wetzel (2001) stated that the TP concentration of rainfall was generally low in undeveloped areas, less than 30 µg L^{-1}, but could reach significant levels in highly urbanized and agricultural environments, over 100 µg P L^{-1}. TP concentration in precipitation is a combination of wetfall and dry fall, with dry fall estimated to be approximately 20% of wetfall. Likens' coefficient is based on 0.008 g P m^{-2} yr^{-1} wetfall plus 0.0016 g P m^{-2} yr^{-1} dryfall (Likens, 1977; Resource Planning Associates Inc., 1977a). Wetzel gives a range of 0.01-.65 g P m^{-2} yr^{-1} for the atmospheric contribution, stating most values are in the 0.02 g P m^{-2} yr^{-1} range (Wetzel, 2001). For purposes of this study, Likens' value of 0.0096 g P m^{-2} yr^{-1}

was multiplied by the lake sub-basin area to estimate the annual atmospheric deposition TP load (Table 4).

Sub-watershed	Lake basin area, m^2 (A_o)	Atmos. P coefficient g m^{-2} yr^{-1}	Annual Atmospheric P (kg)
Waukewan	3,753,734.0	0.0096	36.0
Meredith Bay	10,474,765.5	0.0096	100.6
Center Harbor	32,733,775.2	0.0096	314.2
Saunders	21,050,008.0	0.0096	202.1
Paugus Bay	4,964,495.4	0.0096	47.7

Table 4. Estimated phosphorus loading from atmospheric deposition for each sub-basin.

3.2 (b) Land Use Data

Land use data were developed by the Lakes Region Planning Commission (LRPC) based on town boundaries; as a result, the watershed-based analysis contains data sets developed at different times. For the Center Harbor Bay, Meredith Bay, Saunders Bay, and Paugus Bay sub-watersheds, 2006 1-foot color photography was primarily used along with town parcel data, zoning and local knowledge to determine land use. For three of the towns that lie within the Lake Waukewan sub-watershed, Ashland, Holderness, and New Hampton, a combination of 1998 black and white aerial photos, and 2003 aerial photos were used. It is important to note that the methodology used prior to 2006 to classify and quantify land use categories differs significantly from the methodology employed now. One of the major changes relates to how residential land use is calculated. Prior to 2006 just the digitized footprint of the building would have been classified as residential; now the building plus the lawn area is categorized as residential (LRPC, personal communication, October 8, 2010). In addition, the 1998 data set is based on black and white aerial photography at the 1:12,000 scale and therefore has a much lower resolution than the 2006 1-foot color photography used for most of the 2006 data (Table 5).

Center Harbor Bay Watershed Land Use		
	Total Land Area (ac)	
Land Use	1998	2006
Urban	1273.9	2321.8
Agriculture	252.4	294.6
Forest	9762.0	8687.2
Water	8724.9	8711.6
Total	20013.2	20015.2

Table 5. Comparison of land use results for the Center Harbor Bay sub-watershed using two different data sets and methodologies.

The five sub-watersheds range in total area of 7530 acres for Paugus Bay to 20,015 acres for Center Harbor Bay. The percent developed land ranges from a low of 11% for the Lake Waukewan watershed to 25% for the Paugus Bay sub-watershed. In all five sub-watersheds agriculture is not a significant land use, accounting for a maximum of 4% in Paugus Bay. Forest land accounts for the largest land use in all the study sub-watersheds, ranging from 43% in the Center Harbor Bay sub-watershed to 72% forest land in the Lake Waukewan sub-watershed (Table 6). Further breakdown of the urban land use category shows that single family residential is the largest urban land use, with transportation (roadways) second in four out of the five sub-watersheds (Table 7).

3.2 c Estimation of TP Loading from the Sub-Watersheds

The estimated TP loading for the five study sub-watersheds was determined using the Spreadsheet Tool for Estimating Pollutant Load (STEPL), based upon the land use data. The STEPL model, developed by Tetra Tech Inc. for the U.S. EPA's Grant Reporting and Tracking System uses simple algorithms to calculate nutrient and sediment loads from different land uses. The model estimates TN, TP, and 5 day biological oxygen demand (BOD_5) based on land use characteristics, rainfall and runoff data, and hydrologic soil type (STEPL 4.0 User's Guide, 2006). For projects funded through the Clean Water Act Section 319 program, an EPA approved method such as STEPL or Region 5 Model is to be used to quantify pollutant loads and reductions of nutrients unless the grant recipient has another program or model that can estimate pollutant loads more accurately (NH DES, 2012).

STEPL was chosen for this project for a number of reasons; first, LRPC as the grant recipient had limited financial and technical resources available which precluded subcontracting the land use and in-lake modeling to an environmental consultant. Secondly, LRPC and LWWA plan to work with the communities in the future to estimate the effectiveness of management practices implemented, as well as continue the modeling and in-lake analyses in the remaining sub-watersheds. In order for the communities, LRPC, and LWWA to be able to continue the watershed planning and management effort, a model that is relatively simple, user friendly and accessible for all needed to be adopted.

Table 6. Land Use data for the five study sub-watersheds

Subwatershed	Total Area (acres)	Urban Acres	Urban %	Agriculture Acres	Agriculture %	Forest Acres	Forest %	Water Acres	Water %	Other Acres	Other %
Lake Waukewan	8409.2	951	11	196.3	2	6014	72	1247.9	15	0	0
Center Harbor Bay	20015.2	2327	12	294.6	1	8687.2	43	8711.6	44	0	0
Meredith Bay	8822.9	1799	20	204.7	2	4180	47	2618.6	30	20.5	0
Saunders Bay	17943.6	2753	15	527.2	3	9312.4	52	5322.2	30	28.8	0
Paugus Bay	7529.7	1858	25	276.9	4	4096.5	54	1293.4	17	4.7	0

Table 7. Urban Land Use data for the sub-watershed study areas

Subwatershed	**Urban** Acres	**Commercial** Acres	**Commercial** %	**Industrial** Acres	**Industrial** %	**Transportation** Acres	**Transportation** %	**Multi Family** Acres	**Multi Family** %	**Single Family** Acres	**Single Family** %	**Urban Cultivated** Acres	**Urban Cultivated** %
Lake Waukewan	951	69.4	7	44.7	5	169.3	18	20.9	2	622.9	65	23.8	3
Center Harbor Bay	2327	132.5	6	28.8	1	266.1	11	26.9	1	1762.6	76	109.8	5
Meredith Bay	1799	206.9	12	45	3	287.8	16	176.3	10	975.1	54	108	6
Saunders Bay	2753	189.5	7	32.4	1	428	16	65.1	2	1844.3	67	193.7	7
Paugus Bay	1858	403.2	22	61.3	3	297.1	16	65.5	4	850.3	46	180.3	10

Several changes made to the STEPL model defaults include amending the soil hydrologic group, USLE parameters, reference runoff curve numbers and the initial abstraction factor. The values were modified to reflect conditions known or representative of the watershed; the rationale and justification for the changes are described in detail in Appendix B1. These variables can greatly affect the nutrient export predicted by the model and therefore represent potential sources of error.

Some of the key limitations to using the STEPL model are that it assumes land uses are evenly distributed throughout the watershed, it cannot predict nutrient delivery through hydrologic pathways, and it cannot predict in real time. In addition, due to lack of available information, sediment load from associated stream channel erosion within the study sub-watersheds was not accounted for.

In the Lake Waukewan, Meredith, Center Harbor, Paugus, and Saunders Bays sub-watersheds, of the total land area, urban land use ranged from 13 -30%, but contributed 55 - 87% of the TP load (excluding septic systems) based on the STEPL estimates. This compares to a range of 66-84% forested land use contributing 7-23% of the TP load. Although agriculture in all five sub-watersheds only accounts for 3-4% of the land use; it contributes 4-8% of the total phosphorus annual load (Table 8, Figure 6).

The results of the pollutant load modeling indicate that in order to prevent increasing TP levels in the lake, measures and actions should focus on limiting the TP load coming from urban areas.

Urban areas include the land use categories commercial, industrial, institutional, transportation, multi and single family residential, urban cultivated, vacant land, and open space. Urban cultivated includes cemeteries, outdoor public assembly areas, and recreational areas. Within urban land use, the transportation category (road network) and single family residential were the main sources of TP (Figure 7, Appendix B5). The transportation category is a large source of TP because it represents impervious areas that carry untreated stormwater from land surfaces to storm drains and catch basins that empty directly into associated waterbodies.

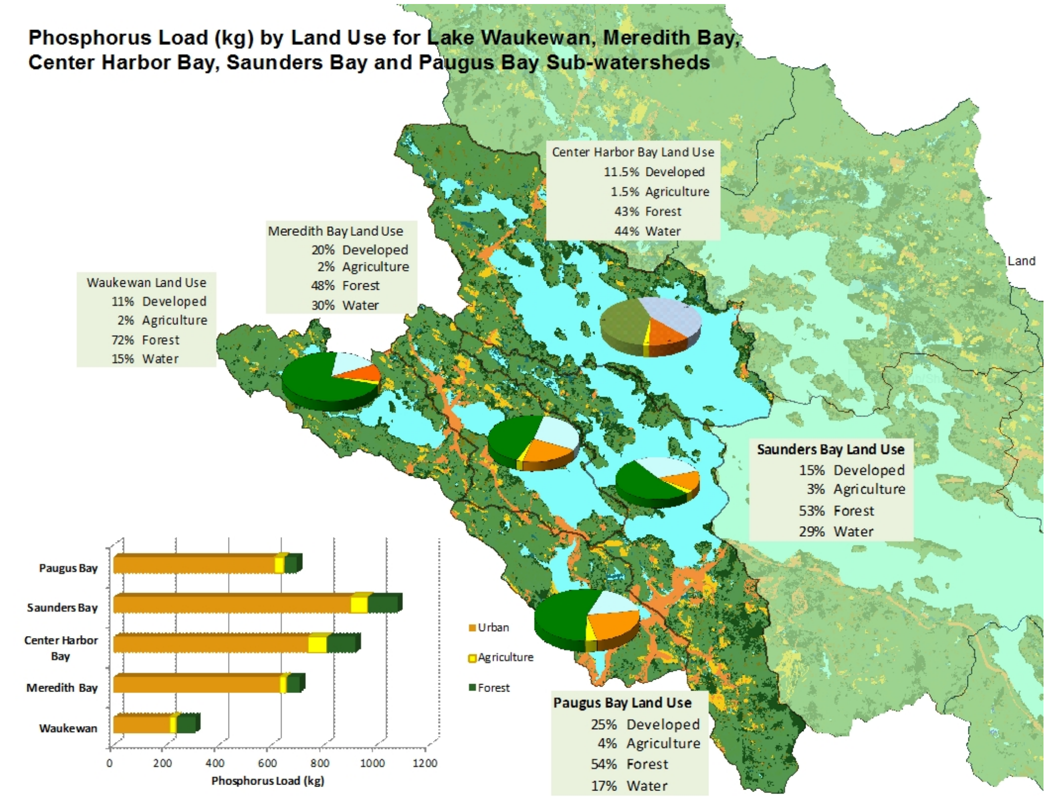


Figure 6. Estimated annual TP export (kg) by land use for the five sub-watersheds in the study area.

Sub-watershed	Land Area (hectares)	Annual Phosphorus Load (kg)						Source of Phosphorus Load				Land Use		
		Urban	Septics	Agr	Forest	Total P	P Loading kg ha^{-1} yr^{-1}	% Urban	% Septic	% Agr	% Forest	% Urban	% Agr	% Forest
Waukewan	2898	171.8	40.6	24.8	72.5	309.7	0.1	55	13	8	23	13	3	84
Meredith Bay	2511	573.6	56.0	26.0	50.5	706.1	0.3	81	8	4	7	29	3	67
Center Harbor Bay	4600	563.4	173.7	71.9	109.4	918.4	0.2	61	19	8	12	20	3	77
Saunders Bay	5107	800.7	99.2	64.0	114.2	1078.1	0.2	74	9	6	11	22	4	74
Paugus Bay	2524	605.6	5.7	35.7	49.4	696.4	0.3	87	1	5	7	30	4	66

Table 8. The total estimated annual P load (kg) by land use determined for the five study sub-watersheds. Percent land use and percent source of phosphorus load by land use are also provided.

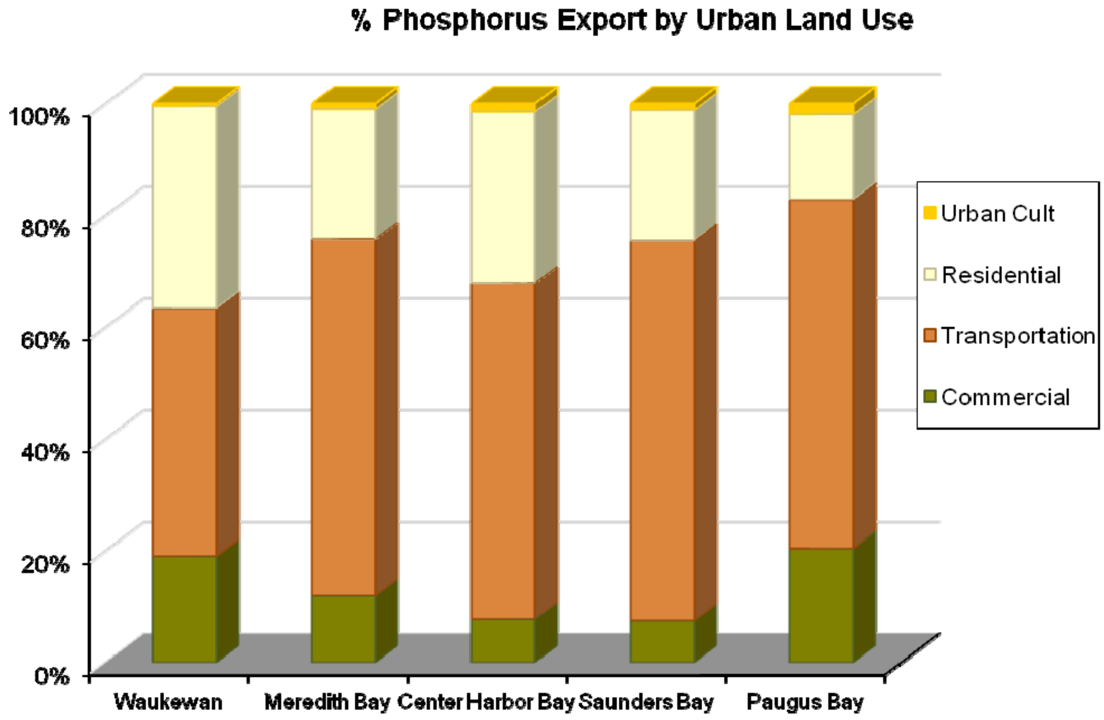


Figure 7. The graph displays the percentage of the TP load coming from the major urban land use categories. For purposes of graphing, the loads from Commercial, Industrial and Institutional land use were combined into the Commercial category, Multi-family and Single Family Residential loads were combined in the Residential, and Open Space and Urban Cultivated were combined.

TP export for all five sub-watersheds displayed as a function of load per hectare of land use shows how important forests are in the sub-watersheds at keeping the total nutrient load low. Although forest land accounts for 74% of the total land use in the study area, forest land exports on average 0.03 kg ha^{-1} yr^{-1} compared to 22% urban land use exporting on average 0.79 kg TP ha^{-1} yr^{-1} (Figure 8).

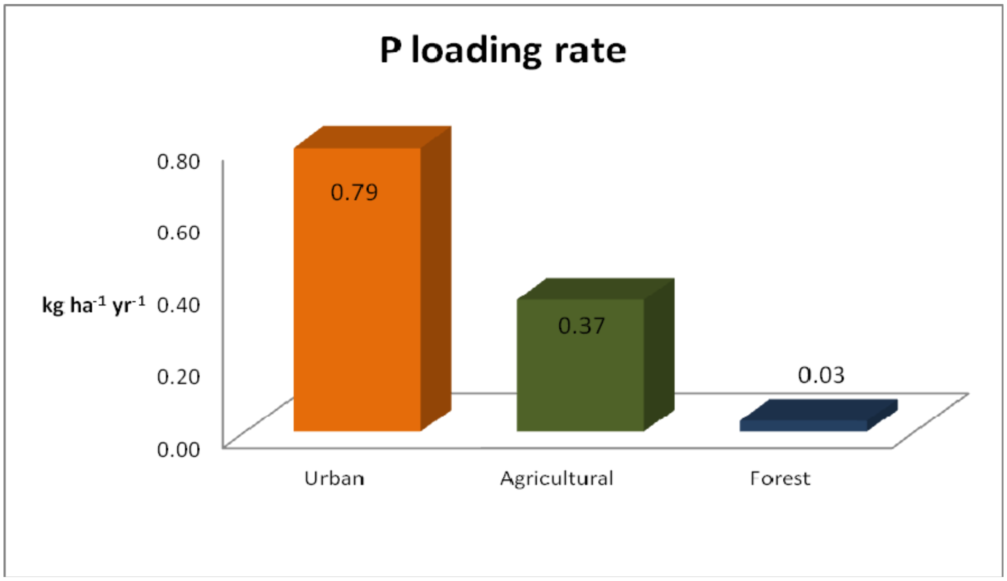


Figure 8. Estimated TP loading rate (kg ha^{-1} yr^{-1}) by land use for the five sub-watersheds in the study area.

Septic Systems

In order to estimate the pollutant load from septic systems only septic systems located within 250 ft. of a lake, pond, or stream were counted. The methodology for determining the phosphorous loading from septic systems can be found in Appendix B1. The septic counts resulted in a higher number of septic parcels in the Center Harbor and Saunders Bay sub-watersheds as a larger portion of these two sub-watersheds are not served by public sewer and include an estimated 306 and 200 island septic properties respectively.

There are a number of factors to consider in calculating the potential loading from septic systems; age of the system, distance from the waterbody, mean number of people on the system, and the number of days the system is in use. Although many of the systems may be seasonal, due to the summer influx of visitors and residents, the number of people on a system may actually be much greater than the average during the summer months.

A review of the property mailing lists for the shore front towns on Lake Winnipesaukee provided an indication of seasonal residency based on out of town or state mailing addresses; for example, 85% of Moultonborough property owners, 46% of Center Harbor residents, 75% of waterfront property owners and 57% water access owners in Meredith, and 76% of Gilford waterfront property owners have out of state or out of town mailing addresses. For purposes of estimating phosphorus loading from septic systems, a 75% seasonal use was assumed for mainland properties and 100% seasonal use assumed for island properties.

STEPL only accounts for the load from failing septic systems, however, septic systems do not attenuate all leachate, and therefore the septic load determined from STEPL likely underestimates the actual impact. For this reason, the septic methodology developed by AECOM for the Lake Loading Response Model (LLRM) was used to estimate phosphorus loading from septic systems (NH DES, personal communication, September 26, 2012).

Ten percent of the year round and seasonal systems were assumed to be over 20 yrs old and therefore in failure. According to EPA, failure rates for septic systems typically range between 1 and 5 percent each year but can be much higher in some regions (U.S. EPA). Although much of the shorefront in this study area is served by public sewer, potential impacts from failing septic systems were identified as one of the top concerns by the communities. A septic system risk analysis conducted by the town of Meredith in 2009 indicated 25% of the shorefront properties on Lake Waukewan either had no record on file or did not have an approved operational permit on file which indicates the assumed 10% failure rate may be low (Town of Meredith, 2009 unpublished).

The mean number of people on year round systems was assumed to be 2.5 people per household; the load from seasonal systems was based on a mean of 3.5 people per household and 90 days of use.

The TP septic load was calculated based on a mean of 8 mg L^{-1} TP concentration in domestic wastewater and a mean of 0.25 cubic meters of water use per person per day (Metcalf & Eddy, 1991). An attenuation factor (portion that reaches the lake) of 0.10 was applied to new systems, and the maximum attenuation factor of 0.50 was applied to the percentage of systems considered in failure (LLRM methodology).

Sub-watershed	**# of Septic Parcels**	**Estimated TP Load from Septic Systems (kg yr^{-1})**
Waukewan	311	40.6
Meredith Bay	430	56
Center Harbor Bay	1252	173.7
Saunders Bay	825	99.2
Paugus Bay	46	5.7

Table 9. Summary of septic system counts and estimated septic TP loading for the study sub-watersheds.

3.2 d TP Loading from Upstream Basins

The TP loading from upstream basins was treated as a point source. The calculated discharge from the sub-basin was multiplied by the average median summer phosphorus concentration of that basin to derive the estimated TP load from that source. For example, multiplying the discharge of 17,377,681 m^3 from Lake Waukewan to Meredith Bay by the 2009 median summer in-lake phosphorus concentration of 6.6 E-06 kg m^{-3} for Lake Waukewan results in an estimated additional 114.7 kg P entering Meredith Bay from Lake Waukewan.

There are no upstream basin sources for the Waukewan or Center Harbor Bay sub-watersheds; Meredith Bay receives water from Lake Waukewan, Saunders Bay receives water loading from both Center Harbor Bay and the Broads, and Paugus Bay receives the entire discharge from Lake Winnipesaukee. The calculations for determining the phosphorus loading from upstream basins is discussed in the following section.

3.3 Sub-watershed Nutrient Budgets

The total nutrient budget for TP for each of the study sub-watersheds determined from atmospheric, watershed, septic systems, and upstream loadings (Table 11, Figure 9) is discussed in the following paragraphs.

Waukewan Watershed: The total estimated TP load for the Waukewan watershed is 345.7 kg yr^{-1}. The major source of TP is from the urban land use category. Although urban land accounts for only 13% of the total land acreage, it contributes 55% of the TP load from the watershed; whereas forest land makes up 84% of the land use and contributes 23% of the TP load. The estimate load from septic systems accounts for 13% of the total TP watershed loading, and agricultural land use contributes 8%. The total watershed loading excluding septic inputs accounts for 77% of the total phosphorus budget, septic systems account for 12%, and atmospheric deposition contributes 10% of the total TP budget. There are no upstream basins contributing TP loading to the Lake Waukewan watershed.

Meredith Bay: The total estimated phosphorus load for the Meredith Bay watershed is 921.4 kg yr^{-1}. Atmospheric deposition contributes approximately 11% of the total TP load, upstream load from Lake Waukewan contributes 12%, watershed loading accounts for 71% and septic systems account for 6%. Within the watershed loading category, urban land use is the major source of the TP loading with an estimated 573.6 kg. Although the urban land use category only makes up 29% of the total land use, it accounts for 81% of the TP load from the watershed. Loading from septic systems is associated with the urban land use category, and for Meredith Bay, septic systems contribute an estimated 56 kg, accounting for 8% of the total loading from the watershed land area. Agriculture accounts for 3% of the land use and contributes 4% of the TP loading. Forest land at 67% of the land use contributes 7% of the total watershed phosphorus loading.

Center Harbor Bay: The total estimated phosphorus load for the Center Harbor Bay sub-watershed is 1232.9 kg yr^{-1}. Due to the large lake surface area of Center Harbor Bay, atmospheric deposition of P accounts for 26% of the total estimated TP load. TP loading from the watershed makes up the rest, with watershed land uses contributing 60% of the total P load and septic systems contributing 14% of the total TP load. There is no upstream basin associated with Center Harbor Bay.

The watershed land use breaks down similarly to the other sub-watersheds; 20% urban contributing 80% of the TP load, 3% agriculture accounting for 8% of the TP load, and 77% forest land accounting for 12% of the watershed TP load.

Saunders Bay: The Saunders Bay sub-watershed has two mainland areas; the northern end of the bay lies across the water in the community of Meredith, on Meredith Neck and is largely undeveloped. The majority of land lies in the southern half of the sub-watershed within the community of Gilford. Several islands are also located within the sub-watershed area.

The total estimated annual TP load for the Saunders Bay sub-watershed is 3895 kg TP; 202.1 kg TP (5%) from atmospheric deposition, 978.9 kg TP (25%) from watershed loading, 99.2 kg TP (3%) from septic systems, and 2614.8 kg TP (67%) from upstream basins.

Saunders Bay receives inflow from two basins; the Broads and Center Harbor Bay. As discussed in Section 3.4, an estimated 28% of Center Harbor Bay's water load discharges to Saunders Bay, with the remainder discharging to the Broads. To determine the TP loading from each of these point sources required estimation of the inflow from each area multiplied by the in-lake TP concentration (Table 10).

Upstream Sub-basin	Spring Ice Out TP (mg L^{-1})	Discharge (m^3 yr^{-1})	Volume Allocation (m^3)	TP Load (kg)
Center Harbor Bay	0.0058	41436675	11602269	67.3
Broads	0.0067	380229149	380229149	2547.5
			Total P load	2614.8

Table 10. Summary of input parameters used to calculate the estimated phosphorus loading from upstream basins to the Saunders Bay sub-watershed.

Total percent of land in urban use in the entire watershed is twenty two percent (22%) contributing an estimated 800.7 kg of TP (74%) annually, forest land which makes up 74% of the total land use contributes only 114.2 kg of TP or 11%, while agricultural land at 4% contributes 6% of the watershed TP load.

Paugus Bay: The total estimated annual TP load from all sources for Paugus Bay is 3578.5 kg. Seventy–nine percent (2834.4 kg) of the annual TP load is attributed to Lake Winnipesaukee, as Paugus Bay is the outlet for the lake. The median in-lake TP concentration for Lake Winnipesaukee of 6.1 $\mu g\ L^{-1}$ converted to 6.1 E-06 kg m^{-3} and multiplied by the calculated discharge of 464,655,297.8 m^3, results in the estimated 2834.4 kg TP coming from the lake.

The next highest source of phosphorus loading, 690.7 kg TP, is from the watershed. Of the five study sub-watersheds, Paugus Bay has the highest percent developed land, 30% urban. Urban land use classes contribute 605.6 kg or 87% of the phosphorus loading from the watershed; agriculture makes up 4% of the land use contributing 5% of the watershed TP load, and forest land makes up 66% of the land use contributing 7% of the watershed loading. Within urban land use, the highest loading of TP is associated with the transportation category. Transportation makes up 16% of the urban land use, but contributes 58% of the annual urban TP load. The loading from septic systems, 5.7 kg, is negligible as a large portion of the sub-watershed is on public sewer. Atmospheric deposition accounts for only 1% of the total TP input.

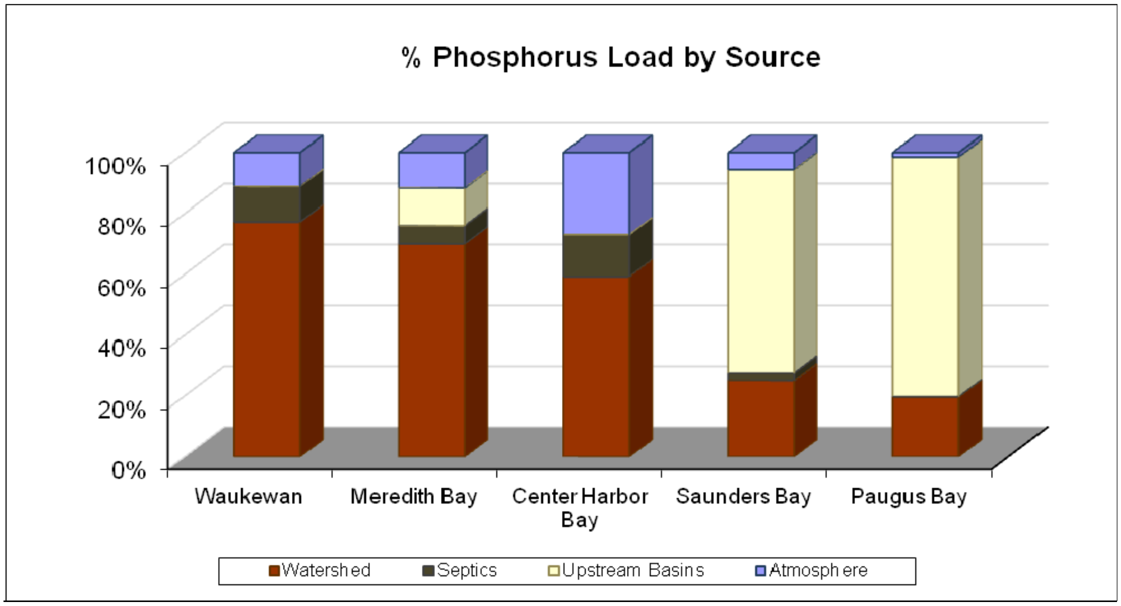


Figure 9. Percent TP load by source (watershed, septic systems, upstream basins, and atmosphere) is shown for each sub-watershed. Paugus Bay receives the largest TP load (79%) from Lake Winnipesaukee, its upstream basin source. Saunders Bay receives inflow from two upstream basins, the Broads and Center Harbor Bay, accounting for 67% of the TP load.

		Source of Phosphorus Load								
Sub-watershed	Land Area (hectares)	Atmospheric P (kg)	%	Watershed (kg)	%	Septic Systems (kg)	%	Upstream Basins (kg)	%	**Total P** (kg)
Waukewan	2898	36.0	10	269.1	78	40.6	12	0.0	0	**345.7**
Meredith Bay	2511	100.6	11	650.1	71	56.0	6	114.7	12	**921.4**
Center Harbor Bay	4600	314.2	26	745.0	60	173.7	14	0.0	0	**1232.9**
Saunders Bay	5107	202.1	5	978.9	25	99.2	3	2614.8	67	**3895.0**
Paugus Bay	2524	47.7	1	690.7	20	5.7	0	2834.4	79	**3532.1**

Table 11. Estimated nutrient budget for each of the study sub-watersheds.

3.4 Determination of the sub-basin morphometry and hydrology

As mentioned previously, the ability of a waterbody to assimilate nutrient loading is a function of the morphometry and hydrology of the receiving waterbody (Figure 5). Because this study is dealing with sub-basin areas of a lake, the NH Department of Environmental Services digitized the bathymetry of the entire lake to make estimations of area, volume, and mean depth for each sub-basin.

The mean depth, flushing rate, and hydraulic residence time show great variation among the sub-watersheds (Table 12). Within the sub-watersheds of Lake Winnipesaukee itself, mean depth ranges from 1.6 m in Moultonborough Bay Inlet to 19.5 m in the Broads, flushing rate from a low of 0.09 yr^{-1} in Center Harbor Bay to a high of 9.94 yr^{-1} for Moultonborough Bay Inlet, and hydraulic residence time ranges from 0.1 yr in Moultonborough Bay Inlet to over 11 yr in Center Harbor Bay.

The estimations of lake area (A) and volume (V) were used to determine annual water load (L), areal water load (qs), flushing rate (F), and hydraulic residence time (Tw). Due to the nature of dividing a lake along sub-watershed delineations, the calculated lake areas have to be considered a source of error. For the purposes of this study, the values for these parameters were considered "measured" and results should be critiqued accordingly (Appendix C1).

Annual water load for each sub-basin area was calculated using the following equation: Annual Water Load (L) = Ad*r+ Ao (P-E) where:

Ad = drainage area of the sub-basin in cubic meters (m^3)
r = average annual runoff in meters per year (m yr^{-1})
Ao = lake basin area in square meters (m^2)
P = average annual precipitation in meters per year (m yr^{-1})
E = average annual evaporation in meters per year (m yr^{-1})

Precipitation and runoff data obtained from STEPL based on the Bristol, NH weather station for Belknap County provided the inputs for average annual rainfall (1.077 m yr^{-1}), runoff (0.512 m yr^{-1}) and evaporation (0.565 m yr^{-1}).

The areal water load (m yr^{-1}) or surface overflow rate, qs, is determined by dividing the annual water load by the lake sub-basin area. To account for the volume of water flowing into the sub-basin area from upstream or neighboring bays, the water load from upstream basins was added to the estimated annual water load for the sub-basin to determine total areal water load. In the case of Center Harbor Bay, water flows into both Saunders Bay and the Broads; making it necessary to estimate the volume split between the two sub-basins.

Four areas were identified representing the most constrained areas for water passage between Center Harbor Bay to Saunders Bay and the Broads (Figure 11). The cross-sectional areas were determined by depth grid interpolation of a digitized bathymetric map of Lake Winnipesaukee (NH DES, personal communication, May 2, 2011).

Cross-sectional areas 1, 2, and 3 exchange water between Center Harbor Bay and Saunders Bay, and cross-sectional area 4 exchanges water with the Broads. The total area of the four cross-sections was 290,722 ft^2, with cross-sections 1, 2, and 3 accounting for 28% and cross-section 4 equal to 72% (Appendix C3).

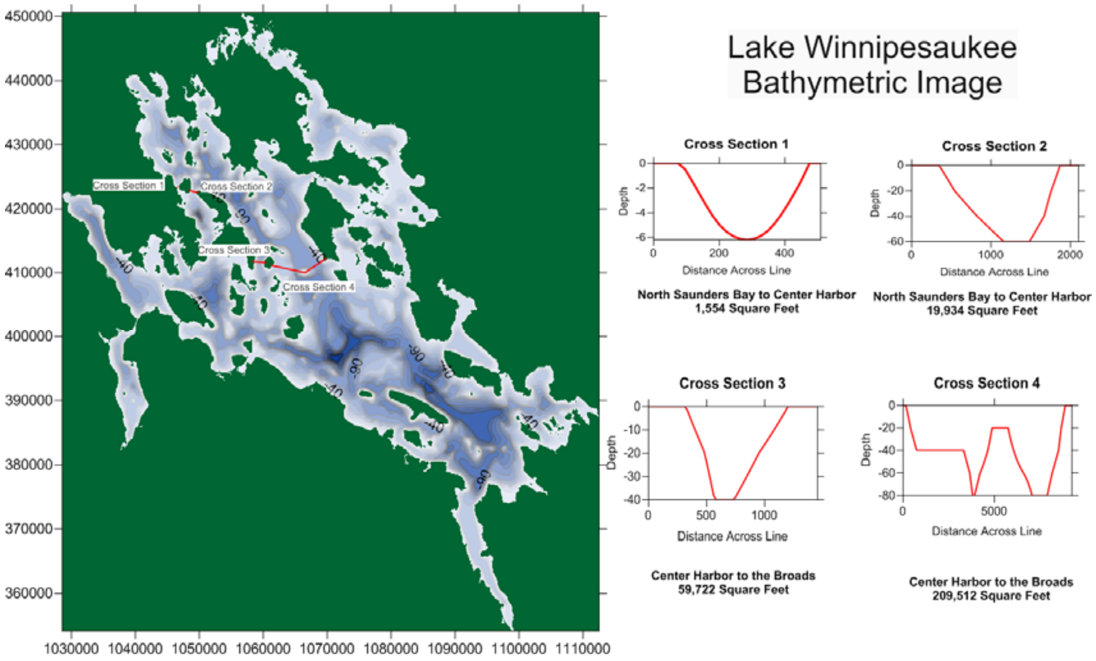


Figure 10. Bathymetric image of Lake Winnipesaukee provided by NH DES showing the four cross sectional areas of water exchange from Center Harbor Bay to Saunders Bay and the Broads.

Sub-watershed	**Drainage Basin Area, A_d (m^2)**	**Lake Sub-basin Area, A_o (m^2)**	**VOLUME (m^3)**	**Mean Depth (m)**	**Annual Water Load (m^3) (1)**	**Areal Water Load (m) (2)**	**Total Areal Water Load (m yr^{-1}) (3)**	**Discharge, Q (m^3 yr^{-1}) (4)**	**Flushing Rate (yr^{-1}) (5)**
Meredith Bay	25230372	10474765	133240894	12.7	18228901	1.74	3.40	35606582	0.27
Moultonborough Bay Inlet	123586518	4116306	6557455	1.6	65197400	15.84	15.84	65197400	9.94
Moultonborough Bay	96037883	24464425	155826920	6.4	61521248	2.51	5.18	126718648	0.81
Alton Bay	124316537	5473234	44510327	8.1	66262870	12.11	12.11	66262870	1.49
Wolfeboro Bay	141597310	7993576	75408337	9.4	76372131	9.55	9.55	76372131	1.01
The Broads	83896803	73476128	1430740132	19.5	80345176	1.09	5.16	379473977	0.27
Center Harbor Bay	48266227	32735022	442231098	13.5	41354378	1.26	1.26	41354378	0.09
Saunders Bay	51564601	21050008	257548207	12.2	37072662	1.76	18.92	398350713	1.55
Winnipesaukee Total	**694496251**	**179783464**	**2546064734**	**14.2**	**446354766**	**2.48**	**2.58**	**463732447**	**0.18**
Paugus Bay	25508097	4964495	45410673	9.1	15557477	3.13	96.54	479289924	10.55
Lake Waukewan	30284111	3753734	25150018	6.7	17377681	4.63	4.63	17377681	0.69

Table 12. Summary of the calculated morphometric and sub-basin hydrologic parameters for the Lake Winnipesaukee drainage sub-watersheds based on GIS analysis by NH DES and Belknap County rainfall/runoff data.

Notes:

1. Annual Water Load = A_d*r+ Ao (P-E)
2. Areal Water Load = Annual Water Load / Lake sub-basin area
3. Total areal water load includes upstream basins
4. Discharge (Q) = Volume * Flushing rate
5. Flushing rate = Total Annual Water Load / Volume

4.0 In-Lake Analyses

4.1 Predicted in-lake response to TP loading

To estimate in-lake response to TP loading from the land, seven widely accepted models that predict in-lake TP concentration were reviewed. The seven models (Table 14) represent various configurations or modifications to the original model proposed by Vollenweider: $TP = L/z(\sigma + p)$, where TP equals the concentration of in-lake TP, L equals the annual areal phosphorus loading, z equals the mean depth of the lake, σ represents the sedimentation coefficient, and p represents the flushing rate (Canfield and Bachmann, 1981). As was discussed in section 2.1, Canfield and Bachmann (1981) state the only substantial differences among the equations are the form of the empirical equation used to estimate phosphorus losses to the sediments; however that form is critical to the successful prediction of in-lake TP.

Dillon and Rigler (1974b) chose to use a phosphorus retention coefficient of the settling rate to represent the phosphorus lost to sediments. The phosphorus retention coefficient represents the difference between annual TP inputs and TP outputs divided by the annual TP input. The equation developed by Dillon and Rigler (1974b) is $TP = L(1-R)/qs$, where TP is the predicted in-lake TP concentration, L is the annual areal phosphorus load, R is the retention coefficient and qs represents the areal water load.

Larsen & Mercier's equation uses a P retention coefficient of the flushing rate. Larsen & Mercier suggested that the P retention coefficient could be better estimated by the inverse of 1 plus the square root of the hydraulic flushing rate; Rlm= 1/(1+F^0.5). Vollenweider's 1976 equation (Table 14) arrives at the same result as Larsen & Mercier (Canfield and Bachmann, 1981).

Canfield and Bachmann (1981) examined the input-output relationship of a large number of lakes to determine the general limnological factors that influence phosphorus sedimentation. They chose to model the sedimentation coefficient rather than the phosphorus retention coefficient as the sedimentation coefficient considers phosphorus losses to the sediments independent of losses through the outlet. Their analysis showed that the P sedimentation coefficients were significantly correlated with lake mean depth and areal water loading (Canfield and Bachmann, 1981).

Although internal TP loading is occurring in at least the Lake Waukewan watershed due to observed hypolimnetic TP concentrations, determination of the internal TP load was beyond the scope of this study, and therefore was assumed to be negligible and not included as an input parameter in the calculations (Table 13)(NH DES 2009).

Parameter	Symbol	Units	Equation
Lake area	A	m^2	measured
Lake volume	V	m^3	measured
Lake discharge	Q	m^3	Q=V/T
Hydraulic Residence Time	T	yr	T=V/Q
Flushing rate	F	yr^{-1}	Flushing Rate = 1/T
Total Phosphorus Influent, Inflow	TPin	ppm	model output or (L/Wi)/1000
Total Phosphorus Effluent, Outflow	TPout	ppm	measured data, if available
Suspended Fraction	S	N/A	Effluent TP/Influent TP
P Retention Coefficient, input/output	R	N/A	(TP in-TP out)/ TP in
Settling Velocity	Vs	m	Z(S)
P Retention Coefficient, settling rate	Rp	N/A	((Vs+13.2)/2)/(((Vs+13.2)/2)+q$_s$
P Retention Coefficient, flushing rate	Rlm	N/A	1/(1+F^0.5)
Mean depth	Z	m	measured
Watershed Annual Loading, phosphorus, WS	Pws	kg	measured
Upstream Basin Loading, phosphorus,	Pws (winni)	kg	measured
Internal Annual Loading, phosphorus	Pi	kg	measured
Total Annual Loading, phosphorus	L	kg	calculated sum
Areal Water Load or surface overflow rate	qs	m/yr	Z(F) or Z/T
Water inflow	Wi	m^3	Wi=qs*A
P Retention coefficient, Kirchner-Dillon	Rp	N/A	Rp=0.426exp(-0.271qs) + 0.574exp(-0.00949qs)
Total areal TP loading (L$_p$)	Lp	g/m^2/yr	L$_p$=P*1000/A
D-R Trophic Status		g/m2	L*T(1-R)
Mass Balance	Max Concentration	mg/L or g/m^3	P=Lp/(Z(F))

Table 13. Input parameters required for the predictive in-lake models (provided by NH DES).

Predictive In-Lake TP Response Model Equations			
Vollenweider, 1975, in-lake TP concentration	V	mg/L or g/m3	P=Lp/(Z*(S+F))
Vollenweider, 1976, in-lake TP concentration	V		$P = \frac{Lp}{qs}\left[\frac{1}{1+\sqrt{\frac{z}{qs}}}\right]$
Chapra, 1975	C		P=Lp(1-r)/(Z*F)
Dillon-Rigler, 1976, in-lake TP concentration	D-R		P=Lp*(1-Rp)/qs
Larsen-Mercier, 1976, in-lake TP concentration	L-M		P=Lp(1-Rlm)/qs
Jones-Bachman, 1976, in-lake TP concentration	J-B		P=0.84(Lp)/(Z(0.65+F))
Reckhow, 1977, in-lake TP concentration	Rg		P=Lp/(11.6+1.2(Z(F)))

Table 14. Comparison of the seven model equations used to predict in-lake TP concentrations (provided by NH DES).

The in-lake models predict in-lake TP levels at spring overturn, when the lake is fully mixed throughout the water column. Spring overturn occurs shortly after ice out; the lake water begins to thermally stratify in a relatively short time thereafter providing a small window of opportunity to collect water samples. As no spring overturn data existed for Lake Winnipesaukee, a spring sampling was conducted April 2, 2010 following the declaration of ice out on March 24, 2010. Staff from the NH Department of Environmental Services, Plymouth State University, University of New Hampshire Center for Freshwater Biology, and volunteers collected over 150 samples from 12 designated deep sampling stations at various depth intervals throughout the water column to determine TP values at spring overturn.

In addition to the spring sampling, a water quality sampling program was initiated in 2009 for the study sub-watersheds to compare the predicted in-lake TP to the observed summer median in-lake TP. Data collected from lake monitoring in the study areas provides a current snapshot of in-lake TP, which can be compared to the new state nutrient standards. The water quality report can be found in Appendix D.

Having determined the parameter inputs needed to run the models (Table 15), the predicted in-lake TP concentrations (Table 16) were plotted against both the 2010 spring in-lake TP and the 2009 summer median in-lake TP to assess model fit (Figures 12 and 13).

Sub-watershed	**z (m)**	**T (yr)**	**F (yr^{-1})**	**qs ($m\ yr^{-1}$)**	**Lp ($g\ m^{-2}\ yr^{-1}$)**	**LT/z ($mg\ L^{-1}$)**
Waukewan	6.7	1.45	0.69	4.62	0.0928	0.0201
Meredith Bay	12.7	3.70	0.27	3.43	0.0887	0.0259
Center Harbor Bay	13.5	11.11	0.09	1.22	0.0382	0.0314
Saunders Bay	12.2	0.65	1.55	18.93	0.1858	0.0098
Paugus Bay	9.1	0.09	10.55	96.01	0.7208	0.0075

Table 15. Nutrient Budget Model parameters for each of the study sub-watersheds.

Notes: z = mean depth (meters), T = hydraulic residence time (yr), F = flushing rate (yr^{-1}), qs = areal water load (meters yr^{-1}), Lp = annual areal phosphorus loading ($g\ m^{-2}\ yr^{-1}$), and LT/z = avg. influent P concentration ($mg\ L^{-1}$)

The predicted in-lake TP models resulted in a wide range of values with the Vollenweider (1975) model predicted in-lake TP concentrations at least 60% higher than the other predicted in-lake TP values. Predicted in-lake TP concentrations were identical for the Vollenweider (1976) and Larsen-Mercier models due to similar derivation of the phosphorus retention coefficient. In each sub-watershed, the Chapra (1975) model results matched the spring in-lake TP observed values, indicating the model represents best fit; however this is misleading.

The phosphorus retention coefficient (r) in Chapra's model equation, P= Lp (1-r)/(Z*F), is derived from TP influent and effluent data; r = (TPin – TPout)/TPin. If TP effluent data is unavailable then the model suggests using the average in-lake TP concentration predicted by the models. For this study, the spring observed in-lake TP concentrations were used to represent the TP effluent concentration.

If [(TPin – TPout)/TPin] is substituted in the above equation for (r), (P *1000/A) is substituted for Lp, qs substituted for (Z*F), [(L/Wi)/1000] substituted for TPin and (qs*A) substituted for Wi, Chapra's equation reduces to P = TPout, which explains why the model results in a value that matches whatever value is input for the TP effluent concentration.

Eliminating the Vollenweider (1975), Chapra (1975), and Larsen-Mercier models from consideration, the remaining four models were reviewed and assessed for best fit. Focus was placed on the predicted in-lake TP values for the Lake Waukewan and Paugus Bay sub-watersheds as these represent whole lake systems for which the models were designed.

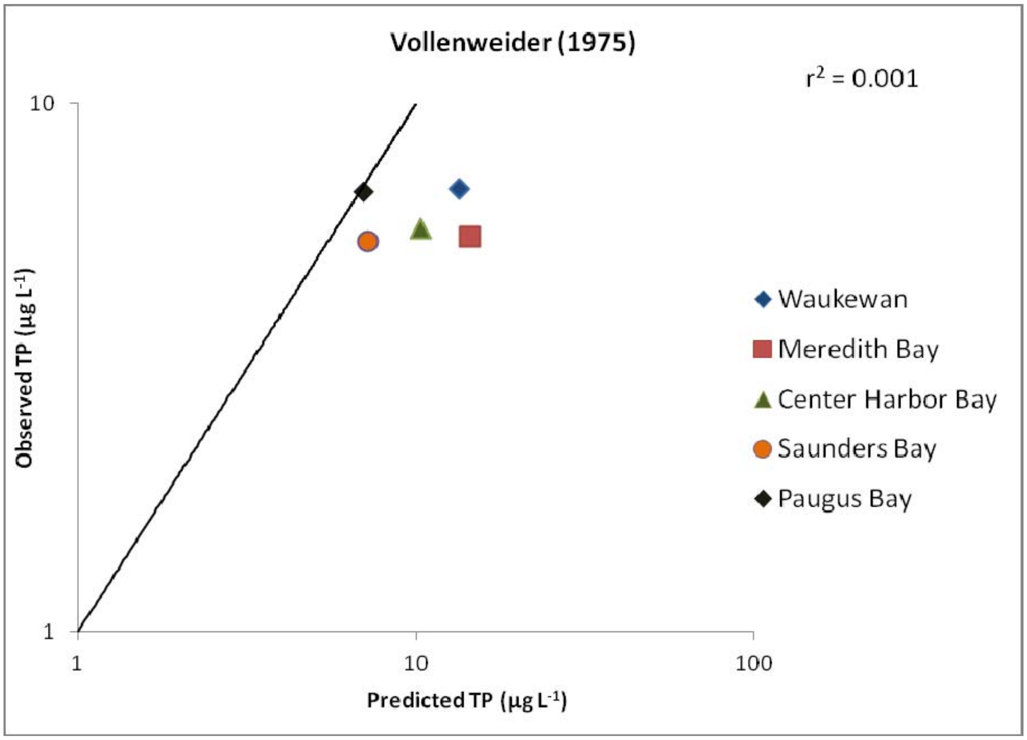
Although based on a limited data set, the Dillon and Rigler model appears to provide the best fit to both the observed spring and summer median in-lake TP concentrations for all the sub-watersheds with the exception of Center Harbor Bay. The Dillon-Rigler, Jones-Bachmann, and Reckhow models predicted in-lake TP concentrations for Center Harbor Bay from 0.0029 – 0.004 mg L^{-1} compared to the observed spring in-lake TP of 0.0058 mg L^{-1}, while the Vollenweider model predicted an in-lake TP concentration of 0.0073 mg L^{-1}.

	Predicted In-Lake TP (mg L^{-1})						
	Vollenweider (1975)	**Vollenweider (1976)**	**Chapra**	**Dillon - Rigler**	**Larsen-Mercier**	**Jones-Bachman**	**Reckhow**
	$P=\frac{Lp}{(Z*(S+F))}$	$P=\frac{Lp}{qs}\left[\frac{1}{1+\sqrt{\frac{z}{qs}}}\right]$	$P=\frac{Lp(1-r)}{(Z*F)}$	$P=\frac{Lp*(1-Rp)}{qs}$	$P=\frac{Lp(1-Rlm)}{qs}$	$P=\frac{0.84(Lp)}{(Z(0.65+F))}$	$P=\frac{Lp}{(11.6+1.2(Z(F)))}$
Sub-watershed							
Waukewan	0.0134	0.0091	0.0069	0.0066	0.0091	0.0087	0.0054
Meredith Bay	0.0144	0.0088	0.0056	0.0071	0.0088	0.0064	0.0056
Center Harbor Bay	0.0103	0.0073	0.0058	0.0040	0.0073	0.0032	0.0029
Saunders Bay	0.0072	0.0054	0.0055	0.0051	0.0054	0.0058	0.0054
Paugus Bay	0.0070	0.0057	0.0068	0.0058	0.0057	0.0059	0.0057

Table 16. The predicted in-lake TP values for each of the models based on the input parameters shown in Tables 12 and 15.

Sub-watershed	**WS Acres**	**Lp ($g\ m^{-2}\ yr^{-1}$)**	**In-Lake Response Models Range of Predicted TP ($mg\ L^{-1}$)**	**Dillon/Rigler Predicted In-Lake P ($mg\ L^{-1}$)**	**Spring Ice-Out 4/2/2010 ($mg\ L^{-1}$)**	**Summer Median TP 2009 ($mg\ L^{-1}$)**
Waukewan	8409	0.0928	0.0054 - 0.0091	0.0066	0.0069	0.0066
Meredith Bay	8823	0.0887	0.0056 - 0.0088	0.0071	0.0056	0.0067
Center Harbor Bay	20015	0.0382	0.0029 - 0.0073	0.0040	0.0058	0.0060
Saunders Bay	17944	0.1858	0.0051 - 0.0058	0.0051	0.0055	0.0056
Paugus Bay	7530	0.7208	0.0057 - 0.0059	0.0058	0.0068	0.0061

Table 17. Comparison of the Dillon/Rigler model results to actual observed in-lake phosphorus concentrations. The range of predicted in-lake TP values excludes results from the Vollenweider (1975), Chapra, and Larsen-Mercier models.



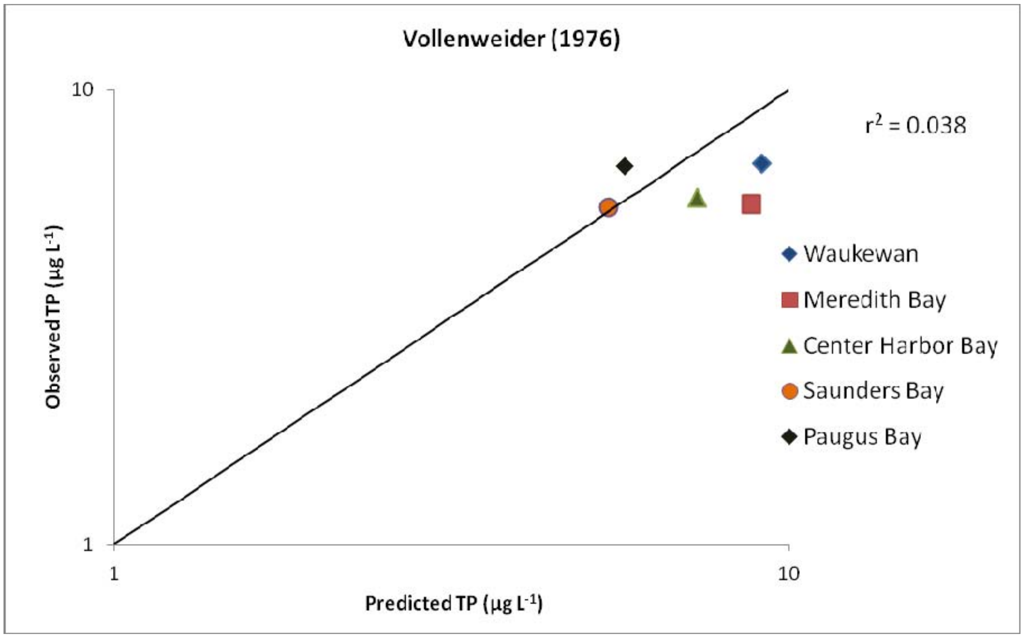
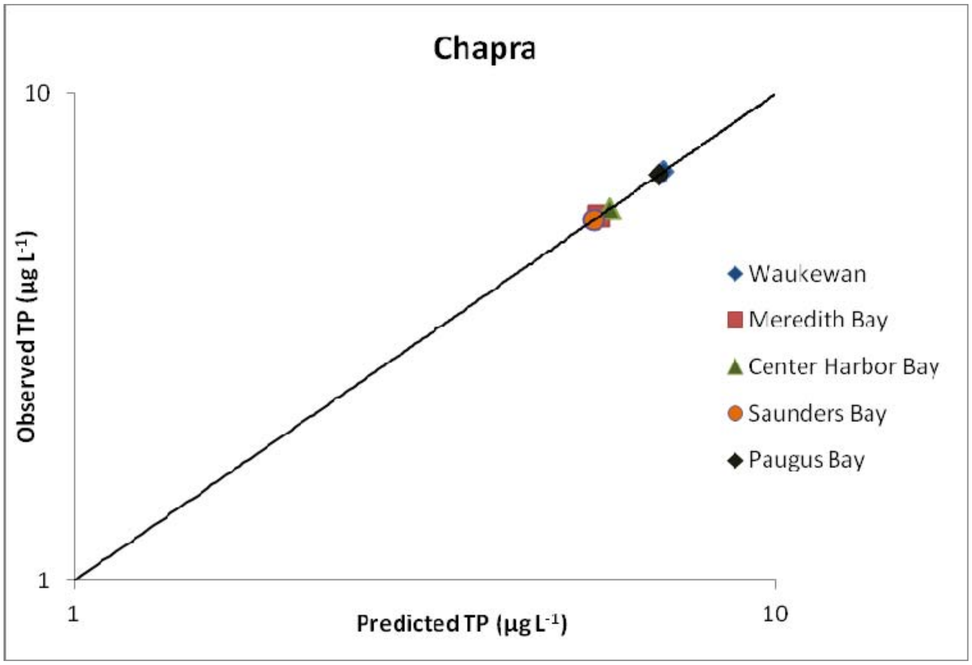


Figure 11. Observed Spring TP concentrations plotted against the in-lake predictive models for the five study sub-watersheds. The diagonal line in the plots represents a perfect fit between predicted and observed values.



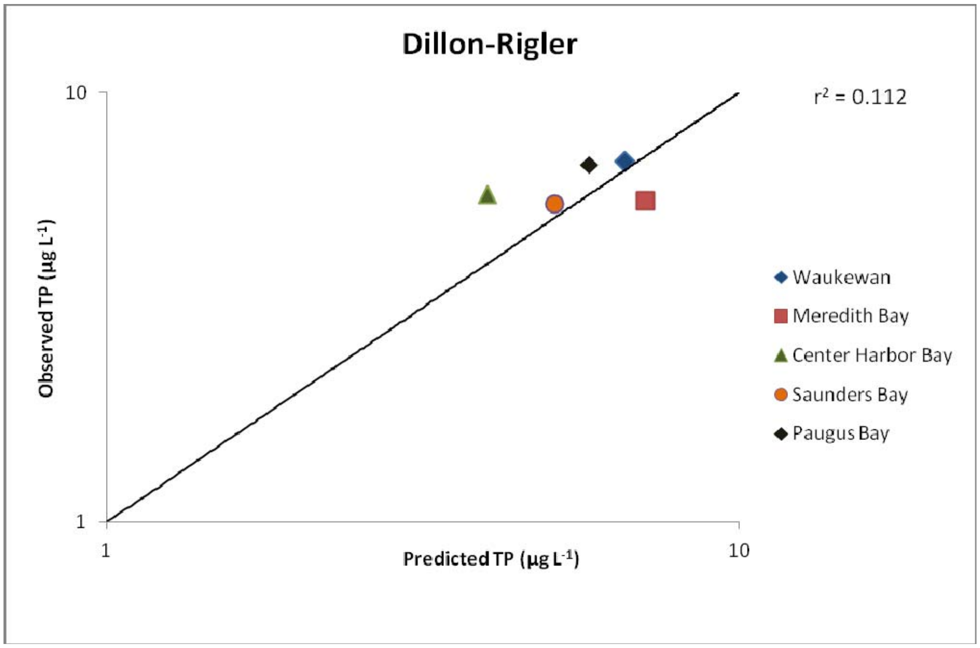
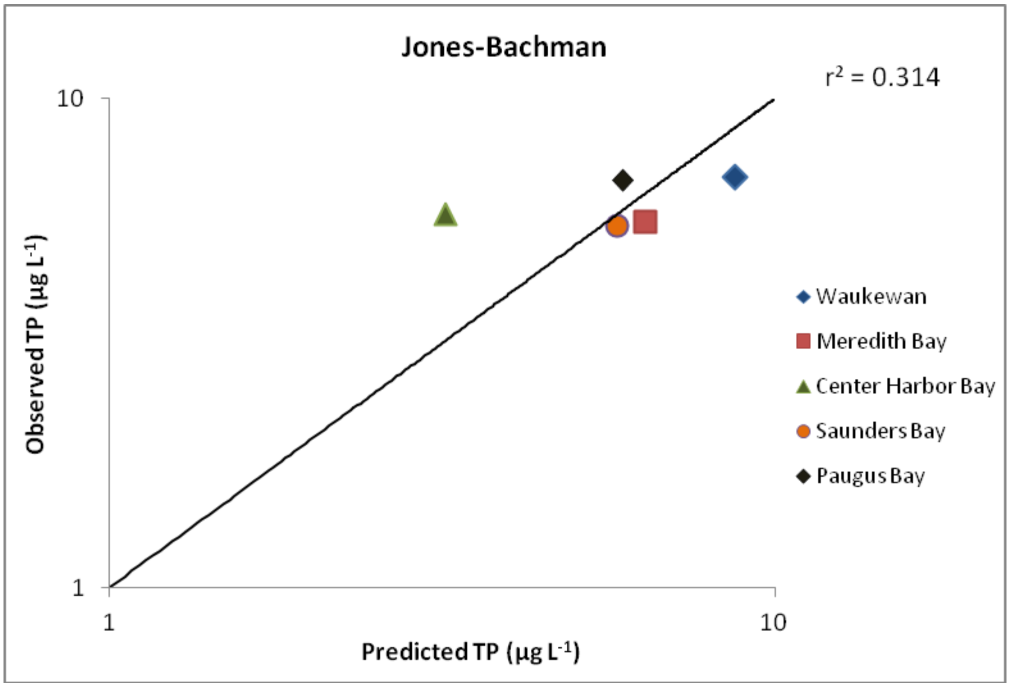


Figure 11 (continued). Observed Spring TP concentrations plotted against the in-lake predictive models for the five study sub-watersheds. The diagonal line in the plots represents a perfect fit between predicted and observed values.



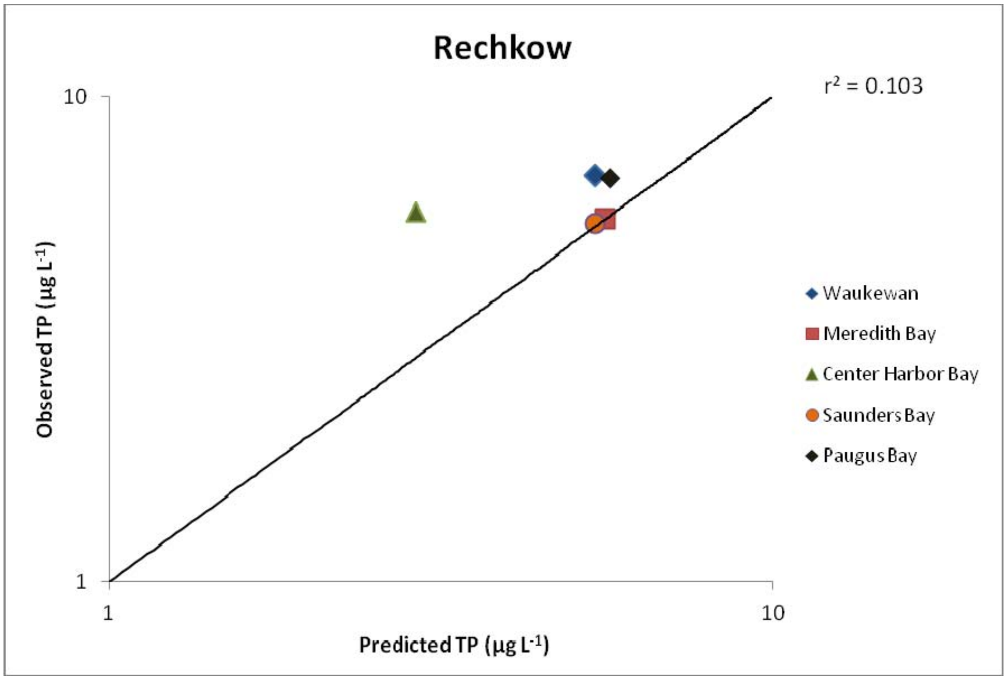
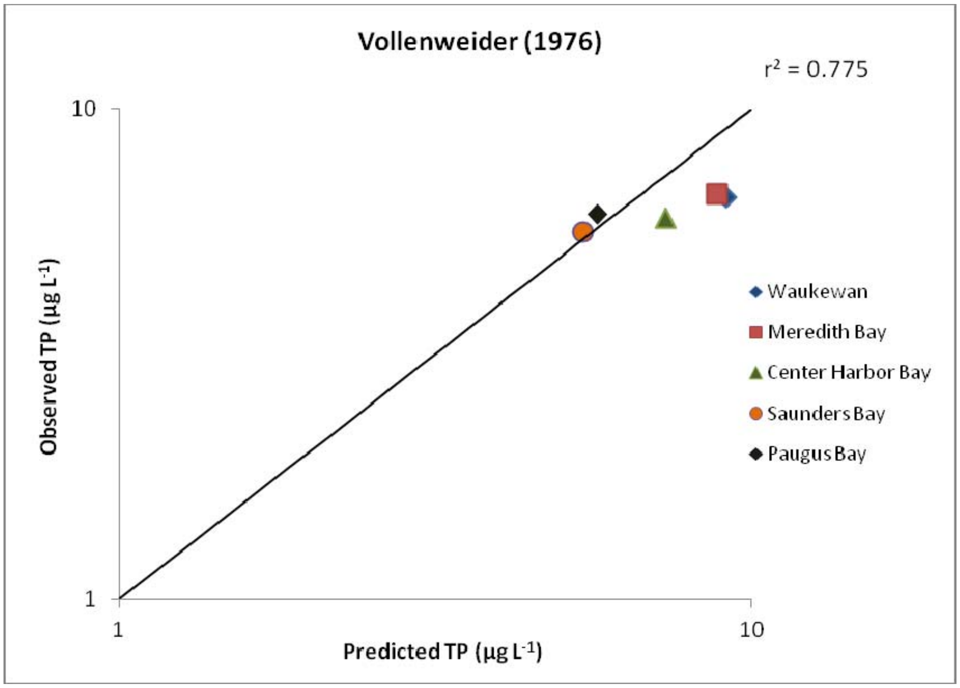


Figure 11 (continued). Observed Spring TP concentrations plotted against the in-lake predictive models for the five study sub-watersheds. The diagonal line in the plots represents a perfect fit between predicted and observed values.



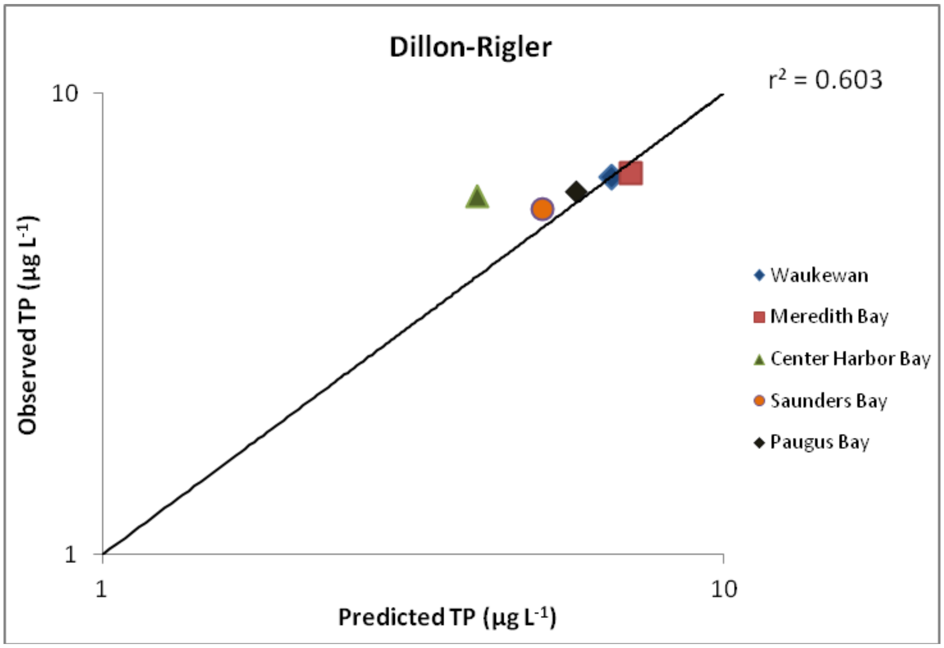
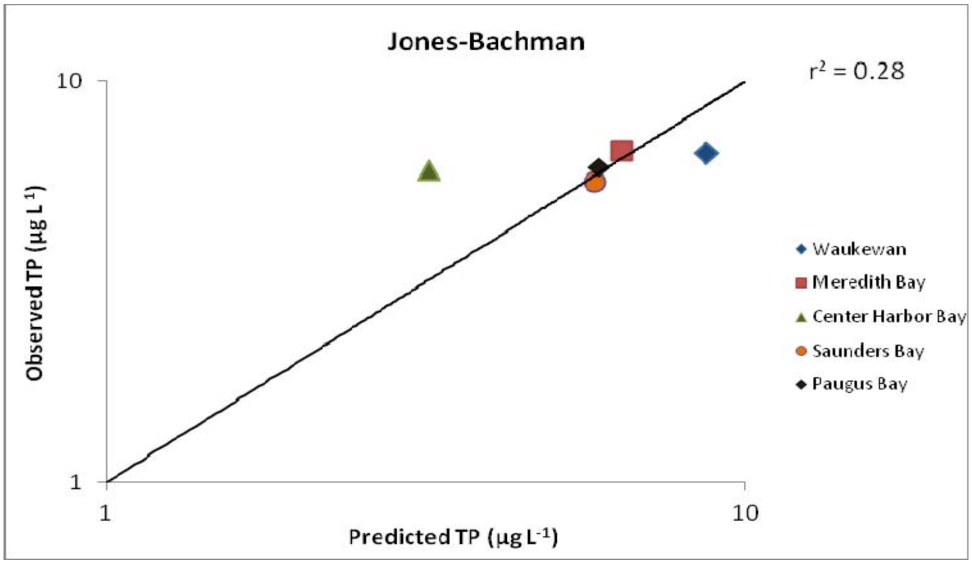


Figure 12. Observed Summer TP concentrations plotted against the in-lake predictive models for the five study sub-watersheds. The diagonal line in the plots represents a perfect fit between predicted and observed values.



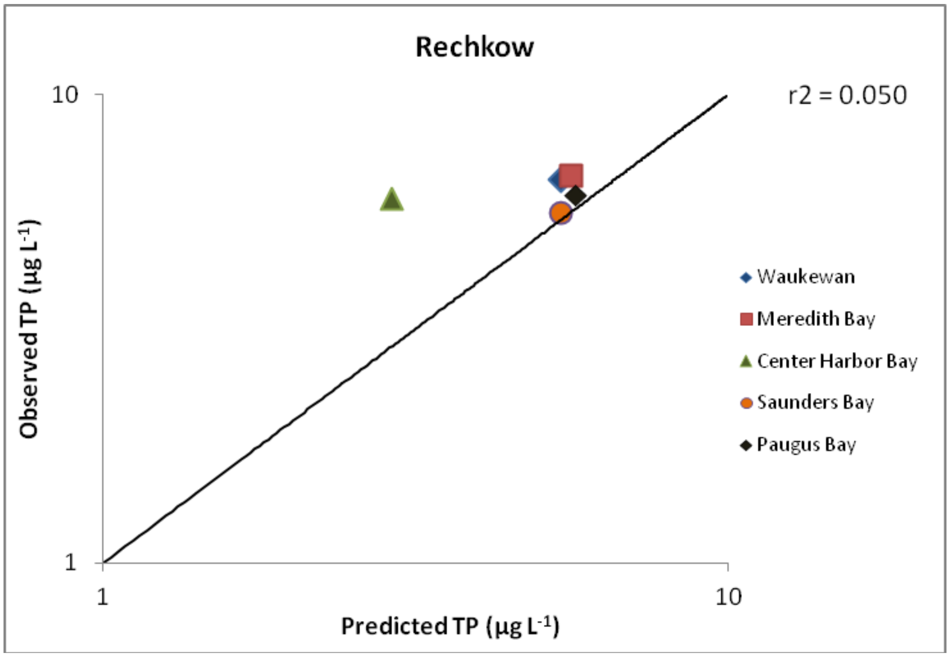


Figure 12 (continued). Observed Summer TP concentrations plotted against the in-lake predictive models for the five study sub-watersheds. The diagonal line in the plots represents a perfect fit between predicted and observed values.

4.2 Evaluation of Alternative Loading Scenarios

4.2 a. Pre-development Scenario

To help communities understand the potential impact on water quality from human development, it is necessary to determine the natural background TP levels for each sub-basin area (U.S. EPA, 2000a). The land use for the ten sub-watersheds in the Lake Winnipesaukee drainage watershed was set to 100% forest land in the STEPL model to calculate TP load for a pre-development scenario. The estimated watershed loads were then added to the atmospheric and upstream basin TP loads to arrive at the total TP load for each sub-watershed. In-lake TP concentrations in the Lake Winnipesaukee watershed ranged from 1.3 μg L^{-1} in Saunders Bay to 3.9 μg L^{-1} in Moultonborough Bay Inlet (Table 18).

The watershed loadings and predicted in-lake TP concentrations for the pre-development land conditions were compared to the 2009 land use conditions. For the non-study area sub-watersheds, the watershed TP loading for the 2009 land use was estimated by back calculation based on the observed spring in-lake TP concentrations. Increases in watershed TP loading ranged from two to almost five-fold among the sub-watersheds with corresponding increases in in-lake TP concentrations (Table 18).

Although the Lake Waukewan sub-watershed is only 13% developed with 3% total impervious surface area (Madorma, 2007), the 2009 land use scenario represents a 270% increase in TP loading and in-lake TP for Lake Waukewan over pre-development conditions. The observed spring in-lake TP concentration of 6.9 μg L^{-1} was the second highest recorded after Moultonborough Bay Inlet.

Based on the calculated morphometric and hydrologic characteristics for each of the Lake Winnipesaukee sub-watersheds, Moultonborough Bay Inlet appears to show similar sensitivity to development as the Lake Waukewan sub-watershed. At 100% forest land condition the estimated watershed TP loading is a low 0.03 kg ha^{-1} yr^{-1}, but corresponds to the highest predicted in-lake TP of 3.9 μg L^{-1}. The TP loading increased to an estimated 0.07 kg ha^{-1} yr^{-1} based on back calculation of the observed spring in-lake TP concentration of 8.9 μg L^{-1}, representing a 228% increase for both loading and in-lake TP response. Moultonborough Bay Inlet had the highest observed spring in-lake TP concentration and exhibits the highest observed summer median TP concentrations in Lake Winnipesaukee (refer to Table 1).

The effect of TP loading in the Moultonborough Bay Inlet sub-watershed and its associated in-lake response is in sharp contrast to the TP loading and in-lake response exhibited by the Broads. Pre-development conditions estimated a total TP loading of 0.11 kg ha^{-1} yr^{-1} which results in an in-lake TP concentration of 1.5 μg L^{-1}; back calculation of the observed spring in-lake TP concentration of 6.7 μg L^{-1} corresponds to an estimated increase in the watershed TP loading to 0.52 kg ha^{-1} yr^{-1}. The Broads with a volume of 1,430,740,132 m^3 and mean depth of 19.5 m has the capacity to assimilate the phosphorus inputs associated with the annual water loading from Center

Harbor Bay, Moultonborough Bay, Wolfeboro Bay, and Alton Bay, and still maintain an observed in-lake TP concentration below the state nutrient threshold of 8 $\mu g\ L^{-1}$.

Similar comparisons can be made in the Meredith Bay and Saunders Bay sub-watersheds. Twenty-two percent of the land in the Saunders Bay sub-watershed has been developed; but the associated estimated TP loading and in-lake TP response has increased fourfold. The same fourfold increase is seen in the Meredith Bay sub-watershed which is 29% developed.

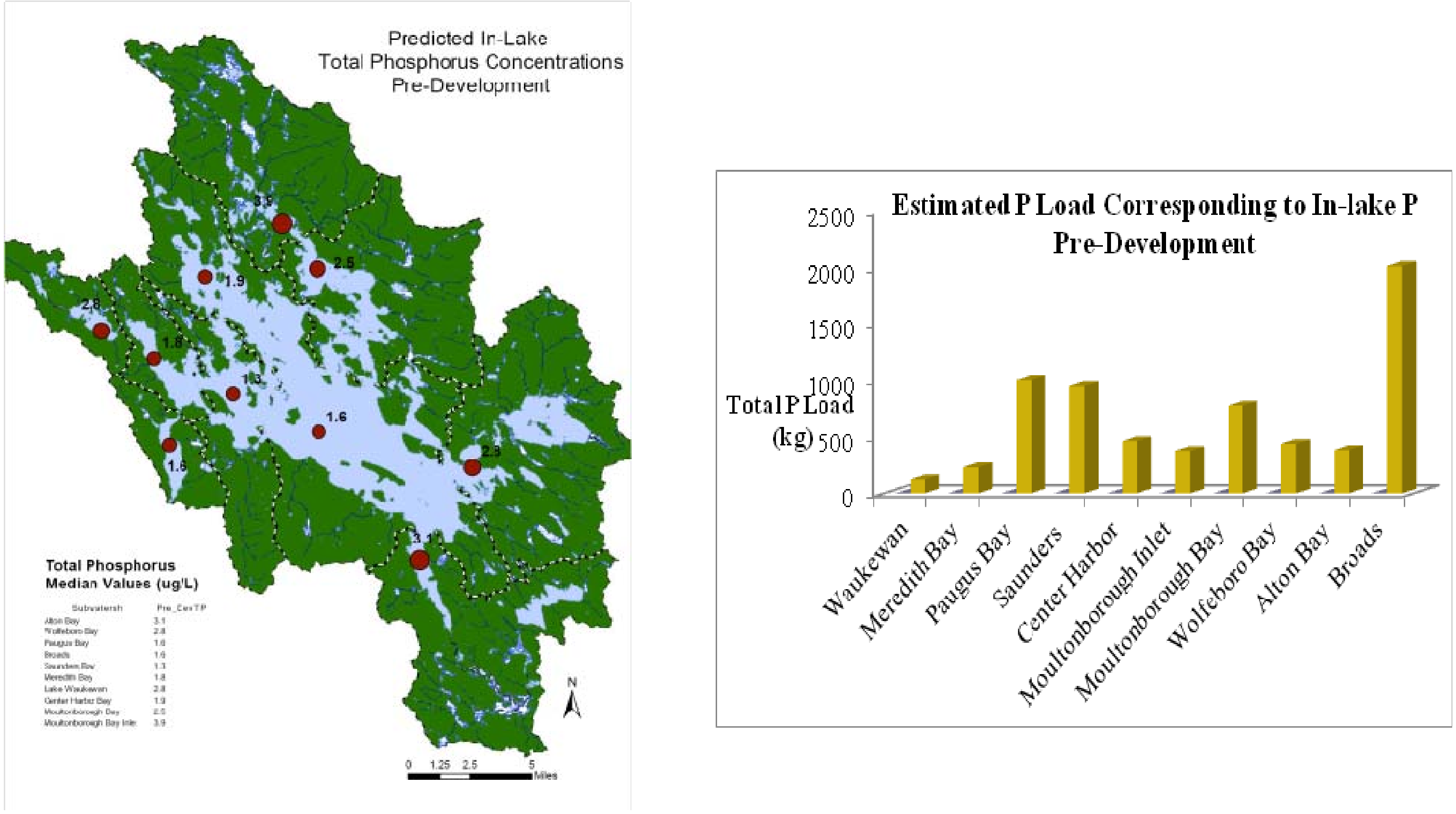


Figure 13 (a). Map of the Lake Winnipesaukee watershed showing estimated in-lake TP (µg L^{-1}) based on estimated TP load (kg) from 100% forest land conditions.

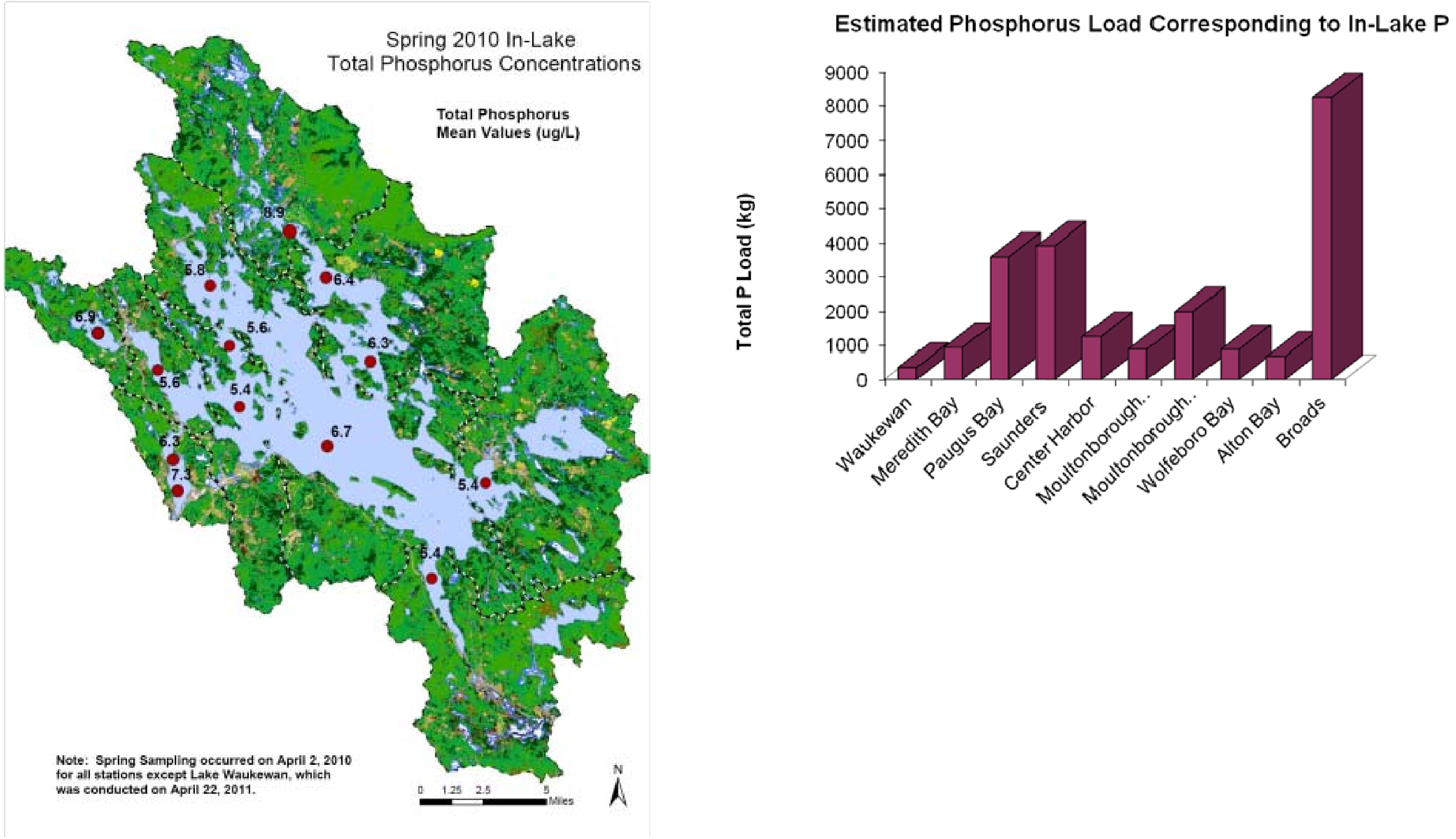


Figure 13 (continued). Map (b) of the Lake Winnipesaukee watershed showing observed spring in-lake TP (µg L^{-1}) based on estimated 2009 watershed TP load (kg). Note the change in scale for the estimated TP load compared to Figure 13 (a).

Sub-watershed	z (m)	T (yr)	F (yr^{-1})	qs ($m\ yr^{-1}$)	100% Forest Land Watershed TP Loading ($kg\ ha^{-1}\ yr^{-1}$)	100% Forest Land Lp ($g\ m^{-2}\ yr^{-1}$)	100% Forest Land P_{pred} ($mg\ L^{-1}$)	2009 Land Use Watershed TP Loading ($kg\ ha^{-1}\ yr^{-1}$)	2009 Land Use Lp ($g\ m^{-2}\ yr^{-1}$)	2009 Land Use P_{pred} ($mg\ L^{-1}$)	2009 Land Use Spring P_{obs} ($mg\ L^{-1}$)
Waukewan	6.7	1.45	0.69	4.62	0.04	0.0333	0.0028	0.10	0.0928	0.0066	0.0069$^{(3)}$
Meredith Bay	12.7	3.70	0.27	3.43	0.06	0.0221	0.0018	0.26	0.0887	0.0071	0.0056
Center Harbor Bay	13.5	11.11	0.09	1.22	0.06	0.0145	0.0019	0.15	0.0382	0.0040	0.0058
Moultonborough Inlet$^{(2)}$	1.6	0.10	9.94	15.94	0.03	0.0938	0.0039	0.07	0.2126		0.0089
Moultonborough Bay$^{(2)}$	6.4	1.23	0.81	5.18	0.07	0.0321	0.0025	0.16	0.0810		0.0064
Alton Bay$^{(2)}$	8.1	0.67	1.49	12.07	0.03	0.0720	0.0031	0.05	0.1233		0.0054
Wolfeboro Bay$^{(2)}$	9.4	0.99	1.01	9.49	0.03	0.0562	0.0028	0.06	0.1088		0.0054
The Broads$^{(2)}$	19.5	3.70	0.27	5.27	0.11	0.0251	0.0015	0.52	0.1123		0.0067
Saunders Bay	12.2	0.65	1.55	18.93	0.13	0.0454	0.0013	0.54	0.1858	0.0051	0.0055
Paugus Bay	9.1	0.09	10.55	96.01	0.33	0.203	0.0016	1.18	0.7215	0.0058	0.0068

Abbreviation Key

z	mean depth (m)
T	hydrologic residence time (yr)
F	flushing rate (yr^{-1})
qs	Areal water load or surface overflow rate ($m\ yr^{-1}$)
Lp	annual areal TP loading to the lake($g\ m$-$^{2}\ yr^{-1}$)
P_{obs}	Spring observed in-lake TP concentration ($mg\ L^{-1}$) at ice-out on 4/2/10
P_{pred}	predicted in-lake TP concentration ($mg\ L^{-1}$)

Notes

1. TP loads based on Belknap County rainfall and runoff data
2. Lp value is back calculated based on the P_{obs} spring value
3. P_{obs} spring value for Lake Waukewan is from data collected on 4/22/11

Table 18. Comparison of the watershed TP loading, areal TP loading, and predicted in-lake TP response for
100% forest land and the 2009 land use conditions.

4.2 b. Influence of Lake Winnipesaukee on the water quality of Paugus Bay

As discussed in the section 3.3, 79% of the total P load for Paugus Bay is attributable to inflow from Lake Winnipesaukee which is reflected in the areal water load, qs, of 96.01 m yr^{-1}.

Municipal officials with the City of Laconia in which Paugus Bay is located, have commented that as Paugus Bay is the outlet for Lake Winnipesaukee, there is little the City can do to mitigate or improve the water quality of Paugus Bay, when the water flowing into Paugus Bay from the 'Big Lake' is assumed to have the greatest impact or influence. To assess what impact the annual water load and associated phosphorus loading from Lake Winnipesaukee has on the water quality in Paugus Bay, the in-lake response models were run for Paugus Bay without the contribution of Lake Winnipesaukee as a point source. Surprisingly, although the total estimated TP load is reduced from 3578.50 kg to 744.1 kg, which reduces the areal P loading from 0.7208 g m^{-2} yr^{-1} to 0.1499 g m^{-2} yr^{-1}, the predicted in-lake TP concentration increases in Paugus Bay; ranging from 9.8 µg L^{-1} to 17.8 µg L^{-1} (Table 19). Without the volume of inflow from Lake Winnipesaukee, the areal water load is reduced from 96.01 m yr^{-1} to 3.09 m yr^{-1}, which increases the mean influent TP concentration from 0.0074 mg L^{-1} to 0.0484 mg L^{-1}. The inflow from Lake Winnipesaukee is effectively diluting the TP loading from the Paugus Bay watershed which results in a positive impact on the water quality of Paugus Bay. However, this may not always be the case if the median in-lake TP concentration for Lake Winnipesaukee should increase significantly.

	Paugus Bay with Lake Winni	**Paugus Bay**
Flushing rate, F (yr^{-1})	10.55	0.34
Hydraulic residence time, T (yr)	0.09	2.94
TP load (kg)	3578.50	744.10
Areal water load, qs ($m\ yr^{-1}$)	96.01	3.09
Annual areal P loading, Lp ($g\ m^{-2}\ yr^{-1}$)	0.7208	0.1499
Avg. influent P concentration, LT/z ($mg\ L^{-1}$)	0.0075	0.0484
Range of predicted In-lake TP ($mg\ L^{-1}$)	0.0057-0.0059	0.0098-0.0178
Dillon/Rigler Predicted In-Lake TP ($mg\ L^{-1}$)	.0058	.0125

Table 19. Comparison of the impact of the areal water load and areal phosphorus loading from Lake Winnipesaukee on the predicted in-lake TP concentrations in Paugus Bay.

4.2 c. Alternative Rainfall/Runoff Scenarios

The initial areal water loads were estimated using rainfall, evaporation, and runoff data for Belknap County. As Lake Winnipesaukee lies in both Belknap and Carroll Counties, which experience different average annual precipitation, evaporation, and runoff amounts, additional scenarios were run to determine the sensitivity of the STEPL and predictive in-lake response models to varying amounts of precipitation and runoff. The STEPL model provided U.S.G.S. precipitation and runoff data for Belknap and Carroll County based on the Bristol weather station. A third scenario was run using the precipitation and evaporation data obtained from the National Climatic Data Center for the Lakeport 2 station located at the Weirs, Laconia, NH for the period of April 1, 2009 through March 31, 2010, which coincided with the collection of water quality monitoring data. A pan coefficient of 0.77 was applied to the evaporation data to account for the ratio of lake evaporation to pan evaporation (Table 20).

	Belknap County (STEPL)	Carroll County (STEPL)	4/1/09-3/31/10 (Lakeport)
Average Annual Rainfall (in)	42.4	49.0	57.6
Average Annual Runoff (in)	20.1	28.9	36.3
Avg. Annual Evaporation	22.3	20.1	21.3

Table 20. Average annual rainfall, runoff, and evaporation data for Belknap and Carroll Counties compared to observed precipitation and evaporation figures for the period 4/1/09 to 3/31/10.

As the areal water load and flushing rates in the sub-watersheds are significantly impacted by the rainfall and runoff parameters, selection of appropriate rainfall and runoff data is important to obtaining valid model results (Table 21).

	Total Areal Water Load (m yr^{-1})			**Flushing Rate (yr^{-1})**		
Sub-watershed	Belknap Cty	Carroll Cty	4/1/09-3/31/10	Belknap Cty	Carroll Cty	4/1/09-3/31/10
Meredith Bay	3.40	4.89	6.14	0.27	0.38	0.48
Moultonborough Inlet	15.84	22.77	28.60	9.94	14.30	17.96
Moultonborough Bay	5.18	7.45	9.35	0.81	1.17	1.47
Alton Bay	12.11	17.41	21.86	1.49	2.14	2.69
Wolfeboro Bay	9.55	13.74	17.25	1.01	1.46	1.83
The Broads	5.16	7.43	9.33	0.27	0.38	0.48
Center Harbor Bay	1.26	1.82	2.28	0.09	0.13	0.17
Saunders Bay	18.92	27.21	34.18	1.55	2.22	2.79
Winnipesaukee Total	2.58	3.71	4.66	0.18	0.26	0.33
Paugus Bay	96.54	138.81	167.80	10.55	15.18	18.35
Lake Waukewan	4.63	6.66	8.36	0.69	0.99	1.25

Table 21. Comparison of the total areal water load and flushing rates estimated for each sub-watershed based on three different rainfall/runoff scenarios. Refer to Table 20 for the rainfall/runoff data.

The range of total estimated areal TP loads and resulting in-lake TP concentrations for each of the rainfall/runoff scenarios are shown in Table 22 for four of the five study areas, as modeling analysis of the Center Harbor Bay sub-watershed was added subsequent to this analysis. Rainfall and runoff data for Belknap County were used for the watershed loading and predictive in-lake models as the observed spring and summer median TP concentrations closely relate to the predicted values. However, the increased areal TP loading predicted by higher rainfall/runoff data are an indication of the in-lake TP response that might be expected in very wet years.

	Total Estimated Areal TP Load ($g\ m^{-2}\ yr^{-1}$)			**Predicted In-lake TP ($\mu g\ L^{-1}$)**		
Sub-watershed	Belknap Cty	Carroll Cty	4/1/09-3/31/10	Belknap Cty	Carroll Cty	4/1/09-3/31/10
Lake Waukewan	0.0928	0.1171	0.1779	7.2	7.9	10.3
Meredith Bay	0.0887	0.1125	0.1546	6.9	7.9	9.8
Saunders Bay	0.1858	0.2531	0.3378	5.4	5.6	6.3
Paugus Bay	0.7208	1.0879	1.6376	5.9	6.3	8.0

Table 22. Comparison of the total areal TP loads and predicted in-lake TP concentrations based on the various rainfall/runoff scenarios.

5.0 Discussion

The watershed and in-lake analyses conducted for this study support the statement that the sub-watersheds of Lake Winnipesaukee exhibit a wide range of land use and morphometic and hydrologic characteristics which influence the ability of each sub-basin to assimilate nutrient loading.

Although the volume, lake sub-basin area, and mean depth calculations for each sub-watershed are based on GIS delineations made through water, the modeling results from the study area correlated fairly well with the observed in-lake TP concentrations. However, this could be a significant source of error in the watershed and in-lake analyses conducted.

Calculated mean depths for the entire Lake Winnipesaukee watershed range from 1.6 m in Moultonborough Bay Inlet to 19.5 m in the Broads. Flushing rates range from a low of 0.09 yr^{-1} in Center Harbor Bay to a high of 10.55 yr^{-1} in Paugus Bay, with corresponding hydraulic residence times of 11 and 0.09 yrs. respectively. A factor of the drainage area, precipitation and runoff, and the water load from upstream basins, the areal water load, qs, ranges from 1.22 m yr^{-1} in Center Harbor Bay to 96.01 m yr^{-1} in Paugus Bay.

Despite the varying watershed characteristics, land use, morphometry and hydrology exhibited by the sub-watersheds of Lake Winnipesaukee, and the varying in-lake response due to these characteristics, the lake should remain classified as one assessment unit. Although the watershed and in-lake analyses was not conducted for the entire Lake Winnipesaukee watershed, it is clear that the water load (and associated phosphorus load) contributed from upstream basins potentially has a significant impact on the water quality of the downstream basin. For example, the positive influence of the inflow from Lake Winnipesaukee on the water quality of Paugus Bay was demonstrated; however Paugus Bay and Lake Winnipesaukee are classified as two separate assessment units.

The 208A Interim Water Quality Report (Normandeau, 1977) recommended that Moultonborough Bay Inlet be assessed separately from the rest of Lake Winnipesaukee as it exhibited mesotrophic qualities. If Moultonborough Bay Inlet were classified as a separate assessment unit and categorized as mesotrophic, it would be subject to a higher in-lake TP threshold. Moultonborough Bay Inlet has an estimated flushing rate of 9.94 yr^{-1} due to it areal water load of 15.94 m yr^{-1}. Allowing a higher TP threshold would result in a higher influent TP concentration to Moultonborough Bay, the downstream basin, potentially jeopardizing the ability of Moultonborough Bay to meet the State nutrient threshold for an oligotrophic waterbody.

Because Lake Winnipesaukee is assessed as a whole, individual areas of the lake, which exhibit poorer water quality, like Moultonborough Bay Inlet, are not subject to the state nutrient thresholds, and therefore there is no legal requirement to reduce the nutrient loading until the entire lake is considered impaired. With respect to a lake the size and shape of Winnipesaukee, this presents a conundrum and emphasizes the importance of the sub-watershed approach to lake management.

Determining the correct approach for managing nutrient loading to the lake is the challenge the communities will face in the future. Should uniform TP reductions apply to all land use types across all sub-watersheds? Should TP reductions be allocated according to land use type? Should a TP loading rate (lb ac^{-1} yr^{-1}) be applied for all land uses? Should a watershed wide target in-lake TP goal be set for Lake Winnipesaukee or should target goals be set at the sub-basin level? These are some of the questions that the State and the communities within the watershed will need to address as the management planning process moves forward. The completion of the watershed and in-lake analyses for the remaining sub-watersheds will help answer these questions and assist in targeting and prioritizing nutrient reduction and management activities.

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APPENDICES

APPENDICES A

Appendix A1.

Lake Winnipesaukee Sub-watershed Geomorphologic Characteristics

Sub-watershed (1)	Watershed Area (m^2)	Total Water Area (m^2)	Lake Sub-basin Area (m^2)	Watershed Area to Lake Sub-basin Area Ratio	Drainage Basin Area (m^2)	Drainage Basin Area:Lake Basin Area	Volume (m^3) (3)	Mean Depth (m) (4)
Meredith Bay	35705137	10835395	10474765	3.4	25230372	2.4	133240894	12.7
Center Harbor Bay	81001249	35573323	32733775	2.5	48267474	1.5	442231098	13.5
Moultonborough Inlet	127702824	12486789	4116306	31.0	123586518	30.0	6557455	1.6
Moultonborough Bay	120502308	27312169	24464425	4.9	96037883	3.9	155826920	6.4
Wolfeboro Bay	149590886	26566794	7993576	18.7	141597310	17.7	75408337	9.4
Alton Bay	129789771	16563628	5473234	23.7	124316537	22.7	44510327	8.1
The Broads	157372931	76242957	73476128	2.1	83896803	1.1	1430740132	19.5
Saunders Bay	72614609	22213795	21050008	3.4	51564601	2.4	257121869	12.2
Winnipesaukee Total (2)	874279715	227794850	179782219	4.9	694497496	3.9	2288515162	14.2
Paugus Bay	30472592	5742904	4964495	6.1	25508097	5.1	45410673	9.1
Waukewan	34037845	5099942	3753734	9.1	30284111	8.1	25150018	6.7

Notes:

1. Sub-watershed delineations and calculations were determined using GIS data layers obtained from NH GRANIT
2. Values for Winnipesaukee do not include Paugus Bay or Lake Waukewan.
3. Volumes for each sub-watershed lake area were determined by NH DES digitized bathymetry
4. Mean depth was determined by dividing lake basin volume (m^3) by lake basin area (m^2)

Appendix A2.
Land Use Data for the Study Subwatershed Areas

Sub-watershed	Total Area (acres)	Urban		Agriculture		Forest		Water		Other	
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Waukewan	8409.2	951	11.3	196.3	2.3	6014	71.5	1247.9	14.8	0	0
Center Harbor Bay	20015.2	2327	11.6	294.6	1.5	8687.2	43.4	8711.6	43.5	3.7	0.0
Meredith Bay	8822.9	1799	20.4	204.7	2.3	4180	47.4	2618.6	29.7	20.5	0.2
Saunders Bay	17943.6	2753	15.3	527.2	2.9	9312.4	51.9	5322.2	29.7	28.8	0.2
Paugus Bay	7529.7	1858	24.7	276.9	3.7	4096.5	54.4	1293.4	17.2	4.7	0.1

Appendix A3.

Urbaan Land Use Data for the Five Study Sub-watershed Areas (1)

	Urban	**Commercial**		**Industrial**		**Transportation**		**Multi Family**		**Single Family**		**Urban Cultivated**	
Sub-watershed	Acres	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Waukewan	951	69.4	7.3	44.7	4.7	169.3	17.8	20.9	2.2	622.9	65.5	23.8	2.5
Center Harbor Bay	2327	132.5	5.7	28.8	1.2	266.1	11.4	26.9	1.2	1762.6	75.7	109.8	4.7
Meredith Bay	1799	206.9	11.5	45	2.5	287.8	16.0	176.3	9.8	975.1	54.2	108	6.0
Saunders Bay	2753	189.5	6.9	32.4	1.2	428	15.5	65.1	2.4	1844.3	67.0	193.7	7.0
Paugus Bay	1858	403.2	21.7	61.3	3.3	297.1	16.0	65.5	3.5	850.3	45.8	180.3	9.7

1. Source: LRPC utilizing best available Land Use/Land Cover data from 1998 to 2009

APPENDICES B

Appendix B1. Land Use and STEPL Methodology

1. Development of the Land Use Data

The table below summarizes the land use/land cover data developed in 2009 by Lakes Region Planning Commission. The data is based on the resources available at the time of development; either 1998 black & white aerial photography, or 2006 color photography, as well as the method of land use classification in effect at the time. Prior to 2006 a simpler classification scheme of only 14 classes was used, while the 2009 date represents a classification scheme of 58 classes. Land use data were developed based on town boundaries; as a result, it contains data sets developed at different times.

Land Use/Land Cover

Town	**Date of data development**	**Data Sources**
Meredith	2009	2006 color photos, 2008 color photos, town parcel data, zoning, sewers, local knowledge
Laconia	2009	2006 color photos, 2008 color photos, town parcel data, zoning, local knowledge
Gilford	2009	2006 color photos, 2008 color photos, town parcel data, zoning, sewers, local knowledge
Center Harbor	2009	2006 color photos, 2008 color photos, parcel data (where available), zoning, local knowledge
Holderness	2006	2003 color photos, local knowledge
Ashland	2000	1998 black and white photos
New Hampton	2000	1998 black and white photos
Moultonborough	2009	2006 color photos, 2008 color photos, town parcel data, zoning, local knowledge

Table B1. Data sources used to develop the land use/land cover data set used for the STEPL model.

Data Limitations

A different methodology existed at the time the 2000 data set was developed; only building footprints were digitized, whereas now, the entire visual extent of a land use is digitized. An effect of this change is to greatly increase the estimated acreage in some of the developed categories. For example, in the past a single house on an acre of mown lawn might have been calculated as 0.05 acres of residential; today, the entire acre of lawn would be digitized and calculated as 1.0 acre of residential land use. In addition, the 1998 black and white aerial photography used as the basis for the 2000 classification is done at the 1:12,000 scale and therefore has a much lower resolution than the 2006 1-foot color photography used for most of the 2009 data. As a result, the analyst developing the 2009 data was more likely to be able to see and capture scattered residential development such as individual houses (LRPC, personal communication, October 8, 2010).

2. Model for Estimating Phosphorus Loading - Spreadsheet Tool for Estimating Pollutant Load (STEPL)

STEPL Model Parameterization

The STEPL input sheet is composed of 9 input tables; the first four require users to input or change the initial values, and the next five tables are initially hidden but contain default values that the user may choose to change.

Users select the state, county, and weather station nearest to the watershed, and then input data on land use in acres, numbers of agricultural animals by type and number of months per year that manure is applied to cropland, and septic system parameters including number of systems, population per septic system, septic failure rate, and direct wastewater discharges. The fourth table allows the user to amend the Universal Soil Loss Equation (USLE) parameters associated with the selected county.

The tables which are considered optional and that the user may choose to amend the default values include selection of the soil hydrologic group, reference runoff curve number, nutrient concentration in runoff, urban land use distribution, and irrigation area (acres) and amount (inches).

I. Input Data Worksheet

Input watershed land use and precipitation information

A. Individual STEPL spreadsheets were created for each sub-watershed
B. Sub-watersheds were not treated as all part of a single sub-watershed
C. Groundwater load calculations were included
D. Precipitation and Rain correction factors were based on the Bristol weather station

Input Agricultural Animals

Information on agriculture was obtained from the NH Department of Agriculture and the Belknap County Conservation District. Figures are estimates for the community, and not necessarily specific to the watershed.

Table B2. Summary of agricultural livestock for the communities within the study sub-watersheds.

Livestock								
	Cattle	Pig farm	Sheep	Horse	Chicken farm	Camelid farm	Goat farm	Game bird farm
Gilford	236	1	205	10		1		
Laconia	24	1	10	5			1	
Meredith	12	2		5	2	1		1
Total	**272**			**20**				
Total, assuming 10 animals/farm		**40**	**215**	**20**	**20**	**20**	**10**	**10**

Input Septic Systems

	Lake Waukewan	**Meredith Bay**	**Paugus Bay**	**Saunders Bay**	**Center Harbor Bay**
Ashland	1				0
Center Harbor	65	8			10
Gilford		36	6	472	18
Laconia		2	31	1	0
Meredith	113	384	9	352	237
Moultonborough					987
New Hampton	132				0
Grand Total	311	430	46	825	1252

Table B3. Estimated count of septic systems within 250’ of shoreline in the study sub-watersheds.

Methodology:

First, a 250’ buffer was applied to the shoreline of all waterbodies in the NH Hydrography Dataset – lakes, ponds, and streams, but not wetlands – within the 5-sub-watershed study area (“BufferArea_Septic”). A point shapefile was created to represent estimated septic locations within this buffer (“Septic_points_250buf”). The points were developed differently for each town, depending on the presence of town sewer, parcel data, etc. (LRPC, personal communication, January 25, 2010).

Ashland: Points were manually located by examining 2006 1-foot aerial photography.

Center Harbor: To try to identify which parcels are not served by town sewer, sewer lines were buffered by 250’, and any parcels that did not intersect with the buffer were considered septic parcels. Points were then manually located and verified by examining 2006 1-foot aerial photography.

Gilford: To try to identify which parcels are not served by town sewer, sewer lines were buffered by 250’, and any parcels that did not intersect with the buffer were considered septic parcels. Parcels that had text PID values (“ROAD”, “ROW”, or “CEMETERY”) were excluded. A point shapefile representing the centroid of each septic parcel polygon was created, and any points that fell within BufferArea_Septic were appended to Septic_points_250buf.

Laconia: To try to identify which parcels are not served by town sewer, sewer lines were buffered by 250’, and any parcels that did not intersect with the buffer were considered septic parcels. Parcels with a STYLE_DESC of “Vacant Land” were excluded. A point shapefile representing the centroid of each septic parcel polygon was created, and any points that fell within BufferArea_Septic were appended to Septic_points_250buf.

Meredith: Parcels were considered septic users if their UTIL_DESC did not include the word “Sewer” and if their USE_DESC did not include the word “VACANT.” A point shapefile representing the centroid of each septic parcel polygon was created, and any points that fell within BufferArea_Septic were appended to Septic_points_250buf.

Moultonborough: As all of Moultonborough relies on onsite wastewater disposal systems, parcels within the 250’ buffer with buildings on the property were manually located by examining 2006 1-foot aerial photography.

New Hampton: A point shapefile representing the centroid of each septic parcel polygon was created. Points representing roads were removed, and any remaining points that fell within BufferArea_Septic were appended to Septic_points_250buf. Because the original parcel shapefile did not align well with the boundaries of waterbodies from aerial photographs and the NH Hydrography Dataset, some points were manually adjusted (i.e., if their source parcel was within 250’ of the waterbody as drawn in the

> parcel layer itself, its associated point was added or moved to fall within BufferArea_Septic.)

A review of the property mailing lists for the lake front towns on Winnipesaukee provided an indication of seasonal residency based on out of town or state mailing addresses; for example, 85% of Moultonborough property owners, 46% of Center Harbor residents, 75% of waterfront property owners and 57% water access owners in Meredith, and 76% of Gilford waterfront property owners have out of state or out of town mailing addresses. For purposes of estimating phosphorus loading from septic systems, a 75% seasonal use was assumed for mainland properties and 100% seasonal use assumed for island properties.

As STEPL only accounts for the load from failing septic systems, the septic methodology developed by AECOM for the Lake Loading Response Model (LLRM) was used to estimate phosphorus loading from septic systems.

Several assumptions were made in determining the nutrient load from septic systems; the number of seasonal systems, the mean number of people on year round or seasonal systems, and the percentage of systems that are new vs. old (over 20 yrs). Ten percent of the year round and seasonal systems were assumed to be over 20 yrs old and therefore in failure.

The mean number of people on year round systems was assumed to be 2.5 people per household; the load from seasonal systems was based on a mean of 3.5 people per household and 90 days of use.

The TP septic load was calculated based on a mean of 8 mg L^{-1} TP concentration in domestic wastewater and a mean of 0.25 cubic meters of water use per person per day (Metcalf & Eddy, 1991). An attenuation factor (portion that reaches the lake) of 0.10 was applied to new systems, and the maximum attenuation factor of 0.50 was applied to the percentage of systems considered in failure (LLRM methodology provided by NH DES, September 26, 2012).

Table B4. Septic System Model Calculations

Category of Septic System	Days of Occupancy Yr^{-1}	Total # Dwellings	People/ Dwelling	TP Atten. Factor	Mean TP Conc. (mg L^{-1})	Water (m^3 day^{-1})	P Load (kg yr^{-1})
Center Harbor Sub-watershed							
Year Round New	365	340.0	2.5	0.1	8	0.25	62.1
Year Round Old	365	38.0	2.5	0.5	8	0.25	34.7
Seasonal New	90	787.0	3.5	0.1	8	0.25	49.6
Seasonal Old	90	87.0	3.5	0.5	8	0.25	27.4
Totals		**1252.0**					**173.7**
Waukewan							
Year Round New	365	70.0	2.5	0.1	8	0.25	12.8
Year Round Old	365	8.0	2.5	0.5	8	0.25	7.3
Seasonal New	90	210.0	3.5	0.1	8	0.25	13.2
Seasonal Old	90	23.0	3.5	0.5	8	0.25	7.2
Totals		**311.0**					**40.6**
Meredith Bay							
Year Round New	365	96.0	2.5	0.1	8	0.25	17.5
Year Round Old	365	11.0	2.5	0.5	8	0.25	10.0
Seasonal New	90	291.0	3.5	0.1	8	0.25	18.3
Seasonal Old	90	32.0	3.5	0.5	8	0.25	10.1
Totals		**430.0**					**56.0**
Paugus Bay							
Year Round New	365	10.0	2.5	0.1	8	0.25	1.8
Year Round Old	365	1.0	2.5	0.5	8	0.25	0.9
Seasonal New	90	32.0	3.5	0.1	8	0.25	2.0
Seasonal Old	90	3.0	3.5	0.5	8	0.25	0.9
Totals		**46.0**					**5.7**
Saunders Bay							
Year Round New	365	140.0	2.5	0.1	8	0.25	25.6
Year Round Old	365	16.0	2.5	0.5	8	0.25	14.6
Seasonal New	90	602.0	3.5	0.1	8	0.25	37.9
Seasonal Old	90	67.0	3.5	0.5	8	0.25	21.1
Totals		**825.0**					**99.2**

USLE Parameters

The STEPL model provides USLE (Universal Soil Loss Equation) parameters for each state and county. USDA NRCS has developed the Universal Soil Loss Equation, $A = R * K * L * S * C * P$, to predict erosion and soil loss from various ground covers.

Factors related to rainfall (R), soil erodability (K), slope length (L), slope gradient (S), crop management (C), and erosion management (P) are used in the equation to determine soil loss per unit area (A). The STEPL values for Belknap County were used with only one change made to the C value for Cropland. The cropping management factor, C, is the ratio of soil loss from a field with specified cropping and management to that from tilled land under clean-tilled continuous fallow conditions (Sonneveld and Nearing, 2003). According to the NH Natural Resource Conservation Service state office, the C value for cultivated cropland should be between 0.25 and 0.49; the STEPL default was 0.02 (K. Dudley, personal communication, November 17, 2010). A value of 0.37 was used, which represents the mean of the range.

STEPL Input Data Sheet – Table 4.	STEPL Defaults					User Defined (Belknap County)				
USLE Parameters	R	K	LS	C	P	R	K	LS	C	P
Cropland	110	0.215	1.076	0.2	0.983	110	0.2	0.338	0.37	1
Pastureland	110	0.215	1.076	0.04	1.0	110	0.23	0.828	0.01	1
Forest	110	0.215	1.076	0.003	1.0	110	0.21	--	--	--

Table B5. Summary of changes made to the defaults for USLE parameters on the Input Data sheet of STEPL.

Soil Hydrologic Group (SHG)

The mixture or composition of soil components (clay, loam, sand, silt) impacts the ability of the soil to infiltrate water, and thus reduce runoff. The USDA Natural Resource Conservation Service (NRCS) groups soils into four main hydrologic soil categories (A, B, C, D) based on estimates of runoff potential (U.S.D.A Natural Resource Conservation Service, 2007).

The majority of soils in Belknap County fall within Hydrologic Soil Group C. Group C soils have a slow infiltration rate when thoroughly wet and therefore a moderately high runoff potential. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures (U.S.D.A Natural Resource Conservation Service, 2007).

SHG “C” was chosen as representative for Belknap County based on NRCS data from web soil survey. This is the dominant soil hydrologic group based on mapping with:

Soil N concentration % set at 0.10
Soil P concentration % set at 0.044

Reference Runoff Curve numbers

The Natural Resource Conservation Service (NRCS) Curve Number (CN) method, formulated in 1954, was developed to estimate streamflow volume generated from large rain events. CN values are based on land use cover and soil type; higher CN values are assigned to land areas with poorly drained soils or more impervious cover, which results in increased runoff (NH Department of Environmental Services, 2008). The adaptation and use of the CN method in nonpoint source water quality models to predict runoff from average rain events, as well as daily time series, is a misapplication of the method and will lead to a misinterpretation of the results (Garen and Moore, 2005).

A weighted CN value was calculated for the Urban category based on all the Urban land use categories within the sub-watershed (see Appendix B2). This method was applied to each of the five sub-watersheds in the study area, resulting in different overall Urban CN values for each sub-watershed. Table 6 compares the STEPL default values to those used for each sub-watershed to estimate pollutant loads.

The largest change to the default CN was made in the forest land category. The default value of 73 for forested watersheds was considered too low as actual runoff predicted by the model was zero when the initial abstraction factor was set to 0.2 (see discussion below on selection of the initial abstraction factor). Using data from watersheds at the Hubbard Brook Experimental Forest, a curve number was estimated to approximate runoff for forested watersheds in this region. Four gaged forested watersheds, which have not received any treatments since the establishment of Hubbard Brook in 1955, were selected from the Hubbard Brook dataset to compare rainfall and runoff volume from individual storm events. Storm events from three different years were evaluated, 1990, 1998, and 2008, with average combined CN values from each year calculated at 88, 82, and 85 respectively. The calculations can be found in Appendix B3. For the purposes of this study, a CN of 82 was chosen for the forest land category. According to a study by the USGS, the CN method has never been formally adapted to estimate runoff in forested watersheds and therefore alternative methods should be employed to independently confirm runoff estimates (USGS, 2007).

As a result of modifying the CN value for Forest land to 82, any CN value for a land use category that by default was less than 82 had to be amended, as the Forest Land CN value should represent best land cover and runoff condition. The CN value for Pastureland was amended from 79 to 84, which is the CN value for pasture land in fair condition for soil hydrologic group D; CN for Single Family Residential was amended from 81 to 85, which is the CN for single family residential for SHG D, and the CN for Open Space was amended from 79 to 84, which is the CN for open space in fair condition for soil hydrologic group D (IOWA DNR, 2008).

SHG C	**STEPL Default**	**Waukewan**	**Meredith**	**Center Harbor**	**Paugus**	**Saunders**
Urban	92	87	89	87	89	88
Cropland	85	85	85	85	85	85
Pastureland	79	84	84	84	84	84
Forest	73	82	82	82	82	82

Table B6. Curve Number values based on Soil Hydrologic Group C determined for the Sub-watersheds compared to STEPL defaults.

II. Land & Rain Worksheet

Rainfall Initial Abstraction Factor

On the Land and Rain worksheet of the STEPL model, Table 1 provides rainfall correction factors for the weather stations listed for each state in a separate excel spreadsheet "RainCoFactor.xls". It also allows for a "rainfall initial abstraction factor" to be input in this table. STEPL provides the following definition for this term: "Rainfall Initial Abstraction Factor: A factor that determines initial rainfall retention on the land surface ranges from 0 to 0.2."

The rainfall initial abstraction factor is derived out of the USDA Natural Resource Conservation Service (formerly known as SCS, Soil Conservation Service) Engineering Field Manual for determining runoff volume. Ia is the initial abstraction, in inches, of all losses before runoff begins. NRCS hypothesized that $Ia = \lambda S$, with λ equal to the initial abstraction ratio or coefficient, and $S = (1000/CN)-10$. S is the potential retention (max) after runoff begins (J. Tenley, personal communication, May 5, 2010). Values of λ ranged from 0.095 to 0.38 determined from a 10 yr rainfall/runoff dataset collected on small experimental watersheds in the 1940-50's (USGS, 2007) NRCS chose 0.2 as the initial abstraction ratio and this value has not changed. Recently however, this ratio has been questioned, and a value of 0.05 proposed as more appropriate for use in runoff calculations (Woodward, 2003). An inquiry to the New Hampshire State Office of the USDA NRCS resulted in this statement, "Our National Hydraulic Engineer (Claudia Hoeft) said that our agency has not moved forward toward implementing the recommended changes (Ia & CN) stated in the Woodward report. Therefore the NRCS is currently using the existing 0.2 factor and CNs, thus remaining conservative." (P. Failing, personal communication, May 21, 2010).

The STEPL model uses a default value of "0" for the initial abstraction ratio. Changing this default value significantly impacts the estimated pollutant loads by land use. Based on the input from NRCS staff and reluctance to assign a different Ia factor than is currently universally used, the Ia factor of 0.2 was chosen. It was considered more appropriate to change the CN for Forest land rather than manipulate the Ia factor. To validate this decision, a comparison of the different export TP loads predicted for the forest land use category is shown in the table below.

P Export - Forest Land	**STEPL Defaults**	**Model Calibrations**
Per Unit Area	CN=73, Ia = 0	CN=82, Ia = 0.2
kg ha^{-1} yr^{-1}	0.17	0.03
mg m^{-2} yr^{-1}	16.65	2.98

Table B7. Comparison of the predicted TP exported from forest land using STEPL model default values for Curve Number and Initial abstraction factor to model calibrations.

Previous literature reviews regarding TP export values indicate there is a wide range in nutrient export values for different watershed land uses (Hegman, 1999; Resource Planning Associates Inc., 1977a) In an update to the estimation of TP loading to Lake Champlain, an export coefficient of 0.04 kg ha^{-1} yr^{-1} was found to be adequate for forest land (Hegman, 1999). Dillon & Kirchner (1975a) found that the range of TP export from forested watersheds overlying igneous bedrock was 2.5 -7.7 mg m^{-2} yr^{-1}, with a mean of 4.8 mg m^{-2} yr^{-1}. A review of the literature and compilation of nutrient export coefficients by Reckhow (1980) lists 0.019 kg ha^{-1} yr^{-1} for Watershed 6 at

Hubbard Brook Experimental Forest, NH. The TP export load predicted by the use of a CN of 82 for forest land, and an Ia factor of 0.2 are within the published literature values for the geology and forest type of this region; therefore I am confident in the changes made to the model.

Appendix B2. Weighted Calculation of Urban CN
Land & Rain Worksheet
Based on SHG "C"

Watershed	Land use	Acres	% of Total land area	CN	Weighted CN
Waukewan	Commercial	69.4	7.3	0.94	6.9
	Industrial	44.7	4.7	0.91	4.3
	Transportation	169	17.8	0.92	16.4
	Multi Family	21	2.2	0.9	2.0
	Single Family	623	65.5	0.85	55.7
	Urban Cultivated	5	0.5	0.85	0.4
	Open Space	19	2	0.85	1.7
Total		**951.1**	**100.0**		**87**
Meredith	Commercial	206.9	11.5	0.94	10.8
	Industrial	45.0	2.5	0.91	2.3
	Transportation	287.8	16.0	0.98	15.7
	Multi Family	176.3	9.8	0.9	8.8
	Single Family	975.1	54.2	0.85	46.1
	Urban Cultivated	32.4	1.8	0.85	1.5
	Open Space	75.6	4.2	0.85	3.6
Total		**1799.0**	**100.0**		**88.8**
Center Harbor	Commercial	132.5	5.69	0.94	5.4
	Industrial	28.8	1.24	0.91	1.1
	Transportation	266.1	11.44	0.98	11.2
	Multi Family	26.9	1.16	0.9	1.0
	Single Family	1762.6	75.76	0.85	64.4
	Urban Cultivated	109.8	4.72	0.85	4.0
	Open Space	0.0	0.00	0.85	0.0
Total		**2326.7**	**100.00**		**87.1**
Paugus	Commercial	403.2	21.7	0.94	20.4
	Industrial	61.3	3.3	0.91	3.0
	Transportation	297.1	16.0	0.98	15.7
	Multi Family	65.5	3.5	0.9	3.2
	Single Family	850.3	45.8	0.85	38.9
	Urban Cultivated	152.4	8.2	0.85	7.0
	Open Space	27.9	1.5	0.85	1.3
Total		**1858**	**100.00**		**89.4**
Saunders	Commercial	189.5	6.9	0.94	6.5
	Industrial	32.4	1.2	0.91	1.1
	Transportation	428	15.5	0.98	15.2
	Multi Family	65.1	2.4	0.9	2.1
	Single Family	1844.3	67.0	0.85	56.9
	Urban Cultivated	33	1.2	0.85	1.0
	Open Space	160.7	5.8	0.85	5.0
Total		**2753**			**87.8**

Reference: Table 2: NRCS runoff curve numbers (CN) for selected urban land use from Section 2C-5 - NRCS TR-55 Methodology (Iowa DNR, 2008)

Appendix B3. Hubbard Brook Precipitation and Runoff - CN Calculations

Watershed	3	South		6	South		7	North		8	North	
Area (ha)	42.4	104.71 ac		13.2	32.69 ac		77.4	191.18 ac		59.4	146.7 ac	
Date	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN
6/26/1990	0	2.19		0	1.97		0	2.35		0	1.75	
6/27/1990	0	1.43		0	1.32		0	1.59		0	1.18	
6/28/1990	0	1.07		0	0.98		0	1.20		0	0.92	
6/29/1990	36.2	3.90		35	3.65		33.5	2.69		32.7	2.72	
6/30/1990	0.5	7.76		0.8	6.92		0.5	6.48		0.6	6.76	
7/1/1990	2.9	3.68		3.9	3.51		3.5	3.57		3.5	2.91	
7/2/1990	0	2.50		0	2.46		0	2.61		0	1.96	
7/3/1990	0	1.63		0	1.65		0	1.78		0	1.31	
subtotal	39.6	14.12	**86.5**	39.7	13.29	**85.7**	37.5	11.13	**85.0**	36.8	11.06	**85.4**
9/11/1990	0	0.09		0	0.21		0	0.13		0	0.14	
9/12/1990	0.6	0.07		0	0.17		0.3	0.1		0.2	0.12	
9/13/1990	0	0.07		0	0.18		0	0.09		0	0.14	
9/14/1990	1.2	0.07		0.5	0.16		0.8	0.09		0.7	0.13	
9/15/1990	22	1.28		24.2	1.66		21.2	0.74		20.9	0.75	
9/16/1990	0	0.49		0	0.53		0	0.26		0	0.4	
9/17/1990	0	0.27		0	0.31		0.8	0.15		0.9	0.22	
9/18/1990	0	0.19		0	0.27		0	0.12		0	0.15	
subtotal	23.2	1.95	**81.5**	24.7	2.13	**80.6**	22	0.91	**78.8**	22.5	0.95	**78.5**

Appendix B3. Hubbard Brook Precipitation and Runoff - CN Calculations

Watershed	3	South		6	South		7	North		8	North	
Area (ha)	42.4	104.71 ac		13.2	32.69 ac		77.4	191.18 ac		59.4	146.7 ac	
Date	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN
10/20/1990	0	3.85		0	4.3		0	4.15		0	3.68	
10/21/1990	0	2.68		0	2.92		0	2.8		0	2.4	
10/22/1990	0	2.2		0	2.3		0	2.21		0	1.88	
10/23/1990	28.3	4.19		26	4.5		30	4.67		29.9	5.14	
10/24/1990	23.8	24.24		24.7	23.95		21.4	25.72		22.2	28.71	
10/25/1990	0	7.17		0	6.56		0	7.08		0	5.86	
10/26/1990	0	4.08		0	3.82		0	3.9		0	3.23	
10/27/1990	0	2.85		0	2.84		0	2.72		0	2.26	
subtotal	**52.1**	**31.53**	**91.4**	**50.7**	**30.17**	**91.4**	**51.4**	**33.09**	**92.6**	**52.1**	**35.8**	**93.6**
11/3/1990	0	1.34		0	1.45		0	1.15		0	0.95	
11/4/1990	0	1.23		0	1.31		0	1.05		0	0.85	
11/5/1990	0	1.12		0	1.19		0	0.94		0	0.79	
11/6/1990	21.9	5.16		20.9	5.22		20	3.46		19.7	4.32	
11/7/1990	0	3.26		0	3.43		0	2.81		0	2.92	
11/8/1990	0	2.19		0	2.34		0	2		0	1.85	
11/9/1990	0	1.75		0	1.88		0	1.62		0	1.41	
	21.9	**7.88**	**92.2**	**20.9**	**8.11**	**93.0**	**20**	**6.13**	**91.6**	**19.7**	**7.34**	**93.1**
Seasonal average			**88**			**88**			**87**			**88**

CN = 1000/[10 + 5*P + 10*Q - 10*(Q^2 + 1.25*Q*P)^0.5]   (inches)
CN = 25400/[254 + 5*P + 10*Q - 10*(Q^2 + 1.25*Q*P)^0.5]   (mm)

where P is precipitation in inches and Q is runoff in inches
measured pairs of rainfall volume (P) and runoff volume (Q) from an individual storm event

CN =   1000/[5(P+2Q-(4Q^2+5PQ)^0.5) + 10]   (from USGS 2007)

Appendix B3. Hubbard Brook Precipitation and Runoff - CN Calculations

Watershed	3	South		6	South		7	North		8	North	
Area (ha)	42.4	104.71 ac		13.2	32.69 ac		77.4	191.18 ac		59.4	146.7 ac	
Date	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN
6/23/1998	0.3	1.20		0.5	1.47		1.3	1.07		1.2	1.07	
6/24/1998	0	0.88		0	1.05		0	0.78		0	0.78	
6/25/1998	3.9	0.67		4.2	0.81		3.6	0.63		3.7	0.60	
6/26/1998	27.3	1.40		31.2	1.74		25.4	2.10		25.3	1.47	
6/27/1998	34.9	20.78		38	24.89		47.2	32.93		46.5	33.21	
6/28/1998	0.1	6.73		0	6.66		0	7.44		0	5.92	
6/29/1998	0	3.31		0	3.30		0	3.24		0	2.49	
6/30/1998	0	2.42		0	2.44		0	2.21		0	1.72	
subtotal	66.2	31.29	**84.5**	73.4	34.98	**83.3**	77.5	44.79	**86.7**	76.7	41.82	**85.6**
6/28/1998	0.1	6.73		0	6.66		0	7.44		0	5.92	
6/29/1998	0	3.31		0	3.30		0	3.24		0	2.49	
6/30/1998	0	2.42		0	2.44		0	2.21		0	1.72	
7/1/1998	28	9.61		28.6	10.36		43.5	18.24		43.4	22.22	
7/2/1998	0	4.92		0	4.91		0	6.55		0	5.54	
7/3/1998	0	2.52		0	2.51		0	2.86		0	2.38	
subtotal	28	9.79	**89.9**	28.6	10.47	**90.2**	43.5	21.02	**89.6**	43.4	24.99	**92.1**
7/17/1998	3.4			2.5	0.25		22.2	0.48		21	0.34	
7/18/1998	0	0.22		0	0.24		0	0.79		0	0.77	
7/19/1998	0	0.15		0	0.16		0	0.37		0	0.39	
7/20/1998	19.7	0.64		21.8	0.97		20.6	1.19		21	1.17	
7/21/1998	0	0.61		0	0.65		0	0.99		0	1.09	
7/22/1998	0	0.30		0	0.33		0	0.55		0	0.50	
subtotal	19.7	1.11	**81.9**	21.8	1.47	**81.2**	20.6	1.63	**82.9**	21	1.58	**82.3**

Appendix B3 (continued). Hubbard Brook Precipitation and Runoff - CN Calculations

Watershed	3	South		6	South		7	North		8	North	
Area (ha)	42.4	104.71 ac		13.2	32.69 ac		77.4	191.18 ac		59.4	146.7 ac	
Date	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN
7/21/1998	0	0.61		0	0.65		0	0.99		0	1.09	
7/22/1998	0	0.30		0	0.33		0	0.55		0	0.50	
7/23/1998	21.5	0.85		22.1	0.97		33.2	1.82		31.5	2.03	
7/24/1998	0.6	1.35		0.9	1.25		0.8	5.77		0.7	5.44	
7/25/1998	0	0.57		0	0.54		0	1.88		0	1.29	
7/26/1998	0	0.35		0	0.38		0	1.06		0	0.70	
7/27/1998	0	0.25		0	0.29		0	0.75		0	0.48	
subtotal	22.1	1.91	**82.3**	23	1.81	**81.2**	34	8.33	**84.2**	32.2	7.45	**84.4**
8/20/1998	0	0.10		0	0.08		0	0.10		0	0.11	
8/21/1998	0	0.09		0	0.08		0	0.09		0	0.11	
8/22/1998	0	0.09		0	0.08		0	0.09		0	0.11	
8/23/1998	3.2	0.12		3.8	0.13		2.6	0.09		2.6	0.11	
8/24/1998	30.2	0.78		33.7	1.12		31.2	0.49		30	0.66	
8/25/1998	10.7	1.46		11.8	1.86		22.5	1.66		20.8	2.11	
8/26/1998	0.5	1.32		0.5	1.11		0.5	1.85		0.5	2.47	
8/27/1998	0	0.47		0	0.44		0.3	0.54		0.2	0.74	
8/28/1998	0	0.26		0	0.27		0	0.25		0	0.37	
8/29/1998	0.7	0.17		0.8	0.21		0.5	0.15		0.5	0.25	
8/30/1998	0	0.14		0	0.21		0.3	0.10		0.3	0.21	
subtotal	45.3	3.99	**69.6**	50.6	4.71	**67.7**	57.9	4.43	**63.0**	54.9	6.09	**67.5**
Seasonal average			**82**			**81**			**81**			**82**

CN = 1000/[10 + 5*P + 10*Q - 10*(Q^2 + 1.25*Q*P)^0.5] (inches)
CN = 25400/[254 + 5*P + 10*Q - 10*(Q^2 + 1.25*Q*P)^0.5] (mm)

where P is precipitation in inches and Q is runoff in inches
measured pairs of rainfall volume (P) and runoff volume (Q) from an individual storm event

CN = 1000/[5(P+2Q-(4Q^2+5PQ)^0.5) + 10] (from USGS 2007)

Appendix B3. Hubbard Brook Precipitation and Runoff - CN Calculations

Watershed	3	South		6	South		7	North		8	North	
Area (ha)	42.4	104.71 ac		13.2	32.69 ac		77.4	191.18 ac		59.4	146.7 ac	
Date	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN
6/7/2008	0	0.9		0	1.06		0	1.07		0	1.34	
6/8/2008	0	0.43		0	0.51		0	0.69		0	0.66	
6/9/2008	0	0.25		0	0.34		0	0.52		0	0.41	
6/10/2008	21.4	0.27		26.6	0.62		24.4	0.67		23.4	0.49	
6/11/2008	0.6	1.03		0.8	1.95		0.8	1.64		0.8	1.99	
6/12/2008	0	0.4		0	0.61		0	0.78		0	0.78	
6/13/2008	0	0.21		0	0.35		0	0.51		0	0.46	
6/14/2008	0.3	0.14		0.3	0.21		0	0.39		0	0.32	
Subtotal	**22**	**0.95**	**79.0**	**27.4**	**2.16**	**78.4**	**25.2**	**1.53**	**78.3**	**24.2**	**2.03**	**80.8**
7/22/2008	0	0.66		0	0.97		0	1.09		0	1.5	
7/23/2008	13.9	0.63		12.2	0.89		15.6	0.97		14.8	0.92	
7/24/2008	45.8	15.2		46.6	19.36		48.2	24.16		46.7	28.04	
7/25/2008	0	6.81		1.3	8.18		0.5	8.25		0.7	9.28	
7/26/2008	0	2.44		0	2.53		0	2.3		0	3.32	
7/27/2008	1.8	1.38		3.1	1.46		2.7	1.49		2.6	1.65	
7/28/2008	0	0.83		0	0.88		0	1.15		0	0.93	
7/29/2008	0	0.44		0	0.6		0	0.84		0	0.63	
7/30/2008	0	0.35		0	0.44		0	0.62		0	0.45	
subtotal	**61.5**	**23.51**	**81.7**	**63.2**	**27.96**	**83.9**	**67**	**32.5**	**84.9**	**64.8**	**38.62**	**89.3**
7/31/2008	23.9	1.91		22.9	1.99		23.7	2.11		22.3	1.68	
8/1/2008	0	2.22		0	1.88		0	2.29		0	1.98	
8/2/2008	43.3	9.91		45.8	10.8		86.4	69.5		82.6	60.02	
8/3/2008	11.3	13.74		12.7	16.74		30.8	28.25		29.6	33.19	
8/4/2008	0	5.63		0	5.42		0	7.33		0	6.55	
8/5/2008	4.8	3.29		5.1	3.25		3.1	3.84		3.7	3.06	
8/6/2008	44	23.17		44.2	27.57		61.3	30.5		60.3	35.21	
8/7/2008	8.9	12.39		9.3	11.7		13.5	16.54		13.7	13.1	
8/8/2008	7	9.35		6.7	8.75		5.7	12.57		5.5	12.31	
8/9/2008	0.6	5.95		0.5	5.77		0.3	6.99		0.3	7.9	
subtotal	**143.8**	**87.56**	**79.7**	**147.2**	**93.87**	**81.0**	**224.8**	**179.92**	**85.4**	**218**	**175**	**85.9**

Appendix B3. Hubbard Brook Precipitation and Runoff - CN Calculations

Watershed	3	South		6	South		7	North		8	North	
Area (ha)	42.4	104.71 ac		13.2	32.69 ac		77.4	191.18 ac		59.4	146.7 ac	
Date	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN	(P) Rainfall Storm depth (mm)	(Q) Accumulative Daily Discharge (mm)	CN
10/13/2008	0	0.72		0	0.85		0	0.85		0	0.58	
10/14/2008	0	0.69		0	0.78		0	0.78		0	0.52	
10/15/2008	0	0.69		0	0.78		0	0.75		0	0.51	
10/16/2008	13.7	1.49		13	1.6		14.1	1.28		13.9	0.81	
10/17/2008	0	1.55		0	1.63		0	1.37		0	0.94	
10/18/2008	0	1.11		0	1.25		0	1.09		0	0.75	
10/19/2008	0	0.9		0	1.05		0	0.96		0	0.63	
10/20/2008	0	0.83		0	0.93		0	0.87		0	0.58	
subtotal	**13.7**	**2.43**	**91.4**	**13**	**2.46**	**92.1**	**14.1**	**1.62**	**89.2**	**13.9**	**1.01**	**87.4**
10/23/2008	0	0.8		0	0.97		0	0.75		0	0.5	
10/24/2008	0	0.72		0	0.94		0	0.72		0	0.48	
10/25/2008	62.8	8.24		70.8	10.48		70.3	4.82		71.4	11.03	
10/26/2008	8.6	34.18		4.3	34.98		2.8	33.75		2.6	37.24	
10/27/2008	0	6.53		0	6.36		0	5.53		0	4.82	
10/28/2008	12.6	5.2		14.9	5.72		15.3	4.81		14.8	4.28	
10/29/2008	3.9	4.84		4.8	5.49		4.3	4.81		4.1	4.58	
10/30/2008	0	3.08		0	3.46		0	3.09		0	2.57	
10/31/2008	0	2.58		0	3.04		0	2.4		0	2.02	
11/1/2008	0	2.35		0	2.89		0	2.43		0	1.92	
11/2/2008	0	1.9		0	2.29		0	1.99		0	1.88	
11/3/2008	0	1.66		0	2.01		0	1.65		0	1.65	
11/4/2008	0	1.54		0	1.83		0	1.48		0	1.27	
11/5/2008	0	1.43		0	1.7		0	1.37		0	1.09	
subtotal	**71.4**	**46.79**	**90.4**	94.8	82.16	**95.6**	92.7	69.6	**91.6**	92.9	75.33	**93.8**
annual average			**84**			**86**			**86**			**87**

CN Calculations
CN = 1000/[10 + 5*P + 10*Q - 10*(Q^2 + 1.25*Q*P)^0.5]   (inches)
CN = 25400/[254 + 5*P + 10*Q - 10*(Q^2 + 1.25*Q*P)^0.5]   (mm)

where P is precipitation in inches and Q is runoff in inches
measured pairs of rainfall volume (P) and runoff volume (Q) from an individual storm event

CN =   1000/[5(P+2Q-(4Q^2+5PQ)^0.5) + 10]   (from USGS 2007)

Appendix B4.

Estimated Phosphorus Export by Land Use (1)

		Annual Phosphorus Load (kg)[2]						Source of Phosphorus Load				Land Use		
Subwatershed	Land Area (hectares)	Urban	Septics	Agricultural	Forest	Total	P load kg ha^{-1} yr^{-1}	% Urban	% Septic	% Agr	% Forest	% Urban	% Agr	% Forest
Waukewan	2898	171.8	40.6	24.8	72.5	309.7	0.1	55.5	13.1	8.0	23.4	13	3	84
Meredith Bay	2511	573.6	56.0	26.0	50.5	706.1	0.3	81.2	7.9	3.7	7.2	29	3	67
Center Harbor Bay	4600	563.4	173.7	71.9	109.4	918.4	0.2	61.3	18.9	7.8	11.9	20	3	77
Saunders Bay	5107	800.7	99.2	64.0	114.2	1078.1	0.2	74.3	9.2	5.9	10.6	22	4	74
Paugus Bay	2524	605.6	5.7	35.7	49.4	696.4	0.3	87.0	0.8	5.1	7.1	30	4	66

1. Source: LRPC. Detailed land use data for Meredith, Paugus, Saunders Bays and Lake Waukewan was completed in 2009 by LRPC for the MPSB Subwatershed Management Plan

LRPC completed an updated land use analysis for Center Harbor Bay in 2012

2. Groundwater is included in the values for Urban, Agricultural, and Forest land

Appendix B5.
Estimated Phosphorus Export by Urban Land Use

Subwatershed	Total Urban hectares	Total kg	Commercial kg	Industrial kg	Transportation/ Utilities kg	Multi-Family kg	Single Family kg	Urban Cultivated kg	Open Space kg
Waukewan	385	171.8	18.6	14.1	76.2	5.0	57.2	0.3	0.5
Meredith Bay	728	573.7	54.3	13.9	366.1	44.7	88.9	2.7	3.2
Center Harbor Bay	940	563.4	35.3	8.5	338.3	6.0	166.9	8.4	0.0
Saunders Bay	1114	800.0	50.1	10.0	543.3	16.8	170.3	2.4	7.1
Paugus Bay	752	605.1	105.1	18.5	377.8	15.5	76.4	10.7	1.2

Appendix B6.
Estimated Phosphorus Budget

		Source of Phosphorus Load				
Sub-watershed	Land Area Acres	Atmospheric P (kg)	Watershed (kg)	Septics (kg)	Upstream Basins (kg)	Total P (kg)
Waukewan	7162	36	269.1	40.6	0.0	345.7
Center Harbor Bay	11226	314.2	745.0	173.7	0.0	1232.9
Meredith Bay	6204	100.6	650.1	56.0	114.7	921.4
Saunders Bay	12621	202.1	978.9	99.2	2614.8	3895.0
Paugus Bay	6236	47.7	690.7	5.7	2834.4	3578.5

Notes:

1. Atmospheric P calculation based on coefficient of 10 mg $m-^{2}$ yr^{-1} (Likens, 1977)
2. Phosphorus loads based on Belknap County rainfall and runoff data
3. Internal Loading was assumed to be negligible.

APPENDICES C

Appendix C1(a) Lake Winnipesaukee Morphologic Variables

Belknap County	inches yr^{-1}	meters yr^{-1}
Avg. Annual Rainfall (P)	42.4	1.077
Avg. Annual Evaporation (E)	22.3	0.566
Avg. Annual Runoff (r)	20.1	0.511

Sub-watershed	Total Watershed Area (GIS) (m^2)	Lake Sub-basin Area, A_o (m^2)	VOLUME (m^3)	Drainage Basin Area, A_d (m^2)	Mean Depth (m)	Annual Water Load (m^3) [(1)]	Areal Water Load (m) [(2)]
Meredith Bay	35705137	10474765	133240894	25230372	12.7	18228901	1.74
Moultonborough Inlet	127702824	4116306	6557455	123586518	1.6	65197400	15.84
Moultonborough Bay	120502308	24464425	155826920	96037883	6.4	61521248	2.51
Alton Bay	129789771	5473234	44510327	124316537	8.1	66262870	12.11
Wolfeboro Bay	149590886	7993576	75408337	141597310	9.4	76372131	9.55
The Broads	157372931	73476128	1430740132	83896803	19.5	80345176	1.09
Center Harbor	81001249	32735022	442231098	48266227	13.5	41354378	1.26
Saunders	72614609	21050008	257548207	51564601	12.2	37072662	1.76
Winnipesaukee Total	**874279715**	**179783464**	**2546064734**	**694496251**	**14.2**	**446354766**	**2.48**
Paugus Bay	30472592	4964495	45410673	25508097	9.1	15557477	3.13
Waukewan	34037845	3753734	25150018	30284111	6.7	17377681	4.63

Notes:

1. Annual Water Load = A_d*r+ Ao (P-E)
2. Areal Water Load = Annual Water Load / Lake sub-basin area
3. Total areal water load includes upstream basins
4. Discharge (Q) = Volume * Flushing rate
5. Flushing rate = Total Annual Water Load / Volume

Appendix C1(a) (continued) Lake Winnipesaukee Morphologic Variables

Belknap County	inches yr^{-1}	meters yr^{-1}
Avg. Annual Rainfall (P)	42.4	1.077
Avg. Annual Evaporation (E)	22.3	0.566
Avg. Annual Runoff (r)	20.1	0.511

Sub-watershed	Total Areal Water Load (m yr^{-1}) (3)	Discharge, Q (m^3 yr^{-1}) (4)	Flushing Rate (yr^{-1}) (5)	Flushing Rate Comments
Meredith Bay	3.40	35606582	0.27	includes Waukewan annual water load
Moultonborough Inlet	15.84	65197400	9.94	
Moultonborough Bay	5.18	126718648	0.81	includes Moultonborough Inlet annual water load
Alton Bay	12.11	66262870	1.49	
Wolfeboro Bay	9.55	76372131	1.01	
The Broads	5.16	379473977	0.27	includes annual water load from 72%CH, MB, WB and AB
Center Harbor	1.26	41354378	0.09	
Saunders	18.92	398350713	1.55	includes annual water load from Broads, 28% CH, MB Inlet, MB, WB, AB
Winnipesaukee Total	**2.58**	**463732447**	**0.18**	
Paugus Bay	96.54	479289924	10.55	includes estimated annual water load from Winnipesaukee
Waukewan	4.63	17377681	0.69	

Notes:

1. Annual Water Load = A_d*r+ Ao (P-E)
2. Areal Water Load = Annual Water Load / Lake sub-basin area
3. Total areal water load includes upstream basins
4. Discharge (Q) = Volume * Flushing rate
5. Flushing rate = Total Annual Water Load / Volume

Appendix C1(b). Lake Winnipesaukee Morphologic Variables

Carroll County	inches yr^{-1}	meters yr^{-1}
Avg. Annual Rainfall (P)	49.0	1.245
Avg. Annual Evaporation (E)	20.1	0.511
Avg. Annual Runoff (r)	28.9	0.734

Sub-watershed	Total Watershed Area (GIS) (m^2)	Lake Sub-basin Area, A_o (m^2)	VOLUME (m^3)	Drainage Basin Area, A_d (m^2)	Mean Depth (m)	Annual Water Load (m^3) (1)	Areal Water Load (m) (2)
Meredith Bay	35705137	10474765	133240894	25230372	12.7	26209713	2.50
Moultonborough Inlet	127702824	4116306	6557455	123586518	1.6	93741535	22.77
Moultonborough Bay	120502308	24464425	155826920	96037883	6.4	88455924	3.62
Alton Bay	129789771	5473234	44510327	124316537	8.1	95273479	17.41
Wolfeboro Bay	149590886	7993576	75408337	141597310	9.4	109808686	13.74
The Broads	157372931	73476128	1430740132	83896803	19.5	115521174	1.57
Center Harbor	81001249	32733775	442231098	48267474	13.5	59459777	1.82
Saunders Bay	72614609	21050008	257548207	51564601	12.2	53303480	2.53
Winnipesaukee Total	874279715	179782217	2546064734	694497498	14.2	641773768	3.57
Paugus Bay	30472592	4964495	45410673	25508097	9.1	22368711	4.51
Waukewan	34037845	3753734	25150018	30284111	6.7	24985821	6.66

Notes:

1. Annual Water Load = A_d*r+ Ao (P-E)
2. Areal Water Load = Annual Water Load / Lake sub-basin area
3. Total areal water load includes upstream basins
4. Discharge (Q) = Volume * Flushing rate
5. Flushing rate = Total Annual Water Load / Volume

Appendix C1(b) (continued). Lake Winnipesaukee Morphologic Variables

Carroll County	inches yr^{-1}	meters yr^{-1}
Avg. Annual Rainfall (P)	49.0	1.245
Avg. Annual Evaporation (E)	20.1	0.511
Avg. Annual Runoff (r)	28.9	0.734

Sub-watershed	Total Areal Water Load ($m\ yr^{-1}$) (3)	Discharge, Q (m^3) (4)	Flushing Rate (yr^{-1}) (5)	Flushing Rate Comments
Meredith Bay	4.89	51195533	0.38	includes Waukewan annual water load
Moultonborough Inlet	22.77	93741535	14.30	
Moultonborough Bay	7.45	182197459	1.17	includes Moultonborough Inlet annual water load
Alton Bay	17.41	95273479	2.14	
Wolfeboro Bay	13.74	109808686	1.46	
The Broads	7.43	545611837	0.38	includes annual water load from 72%CH, MB, WB and AB
Center Harbor	1.82	59459777	0.13	
Saunders Bay	27.21	572753015	2.22	includes annual water load from Broads, 28% CH, MB Inlet, MB, WB, AB
Winnipesaukee Total	3.71	666759588	0.26	
Paugus Bay	138.81	689128299	15.18	includes estimated annual water load from Winnipesaukee and Waukewan
Waukewan	6.66	24985821	0.99	

Notes:

1. Annual Water Load = A_d*r+ Ao (P-E)
2. Areal Water Load = Annual Water Load / Lake sub-basin area
3. Total areal water load includes upstream basins
4. Discharge (Q) = Volume * Flushing rate
5. Flushing rate = Total Annual Water Load / Volume

Appendix C1(c). Lake Winnipesaukee Morphologic Variables

April 1, 2009 - March 31, 2010	inches yr^{-1}	meters yr^{-1}
Avg. Annual Rainfall (P)	57.6	1.463
Avg. Annual Evaporation (E)	21.3	0.541
Avg. Annual Runoff (r)	36.3	0.922

Sub-watershed	Total Watershed Area (GIS) (m^2)	Lake Sub-basin Area, A_o (m^2)	VOLUME (m^3)	Drainage Basin Area, A_d (m^2)	Mean Depth (m)	Annual Water Load (m^3) (1)	Areal Water Load (m) (2)
Meredith Bay	35705137	10474765	133240894	25230372	12.7	32920850	3.14
Moultonborough Inlet	127702824	4116306	6557455	123586518	1.6	117744558	28.60
Moultonborough Bay	120502308	24464425	155826920	96037883	6.4	111105538	4.54
Alton Bay	129789771	5473234	44510327	124316537	8.1	119668765	21.86
Wolfeboro Bay	149590886	7993576	75408337	141597310	9.4	137925789	17.25
The Broads	157372931	73476128	1430740132	83896803	19.5	145100990	1.97
Center Harbor	81001249	32733775	442231098	48267474	13.5	74684772	2.28
Saunders	72614609	21050008	257548207	51564601	12.2	66952122	3.18
Winnipesaukee Total	874279715	179782217	2546064734	694497498	14.2	806103383	4.48
Paugus Bay	30472592	4964495	45410673	25508097	9.1	28096339	5.66
Waukewan	34037845	3753734	25150018	30284111	6.7	31383574	8.36

Notes:

1. Annual Water Load = A_d*r+ Ao (P-E)
2. Areal Water Load = Annual Water Load / Lake sub-basin area
3. Total areal water load includes upstream basins
4. Discharge (Q) = Volume * Flushing rate
5. Flushing rate = Total Annual Water Load / Volume

Appendix C1(c) (continued). Lake Winnipesaukee Morphologic Variables

April 1, 2009 - March 31, 2010	inches yr^{-1}	meters yr^{-1}
Avg. Annual Rainfall (P)	57.6	1.463
Avg. Annual Evaporation (E)	21.3	0.541
Avg. Annual Runoff (r)	36.3	0.922

Sub-watershed	Total Areal Water Load (m yr^{-1}) (3)	Discharge, Q (m^3) (4)	Flushing Rate (yr^{-1}) (5)	Flushing Rate Comments
Meredith Bay	6.14	64304424	0.48	includes Waukewan annual water load
Moultonborough Inlet	28.60	117744558	17.96	
Moultonborough Bay	9.35	228850096	1.47	includes Moultonborough Inlet annual water load
Alton Bay	21.86	119668765	2.69	
Wolfeboro Bay	17.25	137925789	1.83	
The Broads	9.33	685318675	0.48	includes annual water load from 72%CH, MB, WB and AB
Center Harbor	2.28	74684772	0.17	
Saunders Bay	34.18	719409497	2.79	includes annual water load from Broads, 28% CH, MB Inlet, MB, WB, AB
Winnipesaukee Total	4.66	837486957	0.33	
Paugus Bay	167.80	833285857	18.35	includes estimated annual water load from Winnipesaukee and Waukewan
Waukewan	8.36	31383574	1.25	

Notes:

1. Annual Water Load = A_d*r+ Ao (P-E)
2. Areal Water Load = Annual Water Load / Lake sub-basin area
3. Total areal water load includes upstream basins
4. Discharge (Q) = Volume * Flushing rate
5. Flushing rate = Total Annual Water Load / Volume

Appendix C2. Nutrient Budget Model Calculations

Precipitation **1.08 meters rainfall per year** (1)

Subwatershed	z (m)	T (yr)	F (yr^{-1})	qs ($m\ yr^{-1}$)	Lp ($g\ m^{-2}\ yr^{-1}$)	LT/z ($mg\ L^{-1}$)	P_{pred} (2,3) ($mg\ L^{-1}$)	P_{obs} ($mg\ L^{-1}$) Spring	P_{obs} ($mg\ L^{-1}$) Summer Median
Waukewan	6.7	1.45	0.69	4.62	0.0928	0.0201	0.0066	0.0069 (5)	0.0067
Meredith Bay	12.7	3.70	0.27	3.43	0.0887	0.0259	0.0071	0.0056	0.0067
Center Harbor Bay	13.5	11.11	0.09	1.22	0.0382	0.0314	0.004	0.0058	0.006
Moultonborough Inlet (4)	1.6	0.10	9.96	15.94	0.2126	0.0133		0.0089	
Moultonborough Bay (4)	6.4	1.23	0.81	5.18	0.0810	0.0156		0.0064	
Alton Bay (4)	8.1	0.67	1.49	12.13	0.1233	0.0102		0.0054	
Wolfeboro Bay (4)	9.4	0.99	1.01	9.49	0.1088	0.0115		0.0054	
The Broads (4)	19.5	3.70	0.27	5.27	0.1123	0.0213		0.0067	
Saunders Bay	12.2	0.65	1.55	18.93	0.1858	0.0098	0.0051	0.0055	0.0056
Winnipesaukee Total	14.2	5.56	0.18	2.58					
Paugus Bay	9.1	0.09	10.55	96.01	0.7208	0.0075	0.0058	0.0068	0.0061

Abbreviation Key

z	mean depth (meters)
T	hydrologic residence time (yr)
F	flushing rate (yr^{-1})
qs	Areal water load or surface overflow rate ($m\ yr^{-1}$)
Lp	annual areal phosphorus loading ($g\ m^{-2}\ yr^{-1}$)
LT/z	average influent phosphorus concentration ($mg\ L^{-1}$)
P_{obs}	Spring observed in-lake phosphorus concentration ($mg\ L^{-1}$) at ice-out on 4/2/10
P_{pred}	predicted in-lake phosphorus concentration ($mg\ L^{-1}$)

Notes

1. Average Belknap County rainfall figures (Source: STEPL, Bristol weather station)
2. Value derived from the Dillon-Rigler model
3. No Internal phosphorus loading input was included
4. Lp is back calculated based on the P_{obs} Spring value
5. P_{obs} Spring value for Lake Waukewan is from data collected on 4/22/11

Appendix C3. Lake Winnipesaukee Basin Cross Section Areas

Summary

Cross Section	Area (ft^2)	to Saunders Bay	% of total Area	to Broads	% of total Area
1: N. Saunders	1,554				
2: N. Saunders	19,934	21,488	0.07		
3: Saunders	59,722	81,210	0.28	269,234	0.93
4: Broads	209,512			209,512	0.72
Total	290,722				

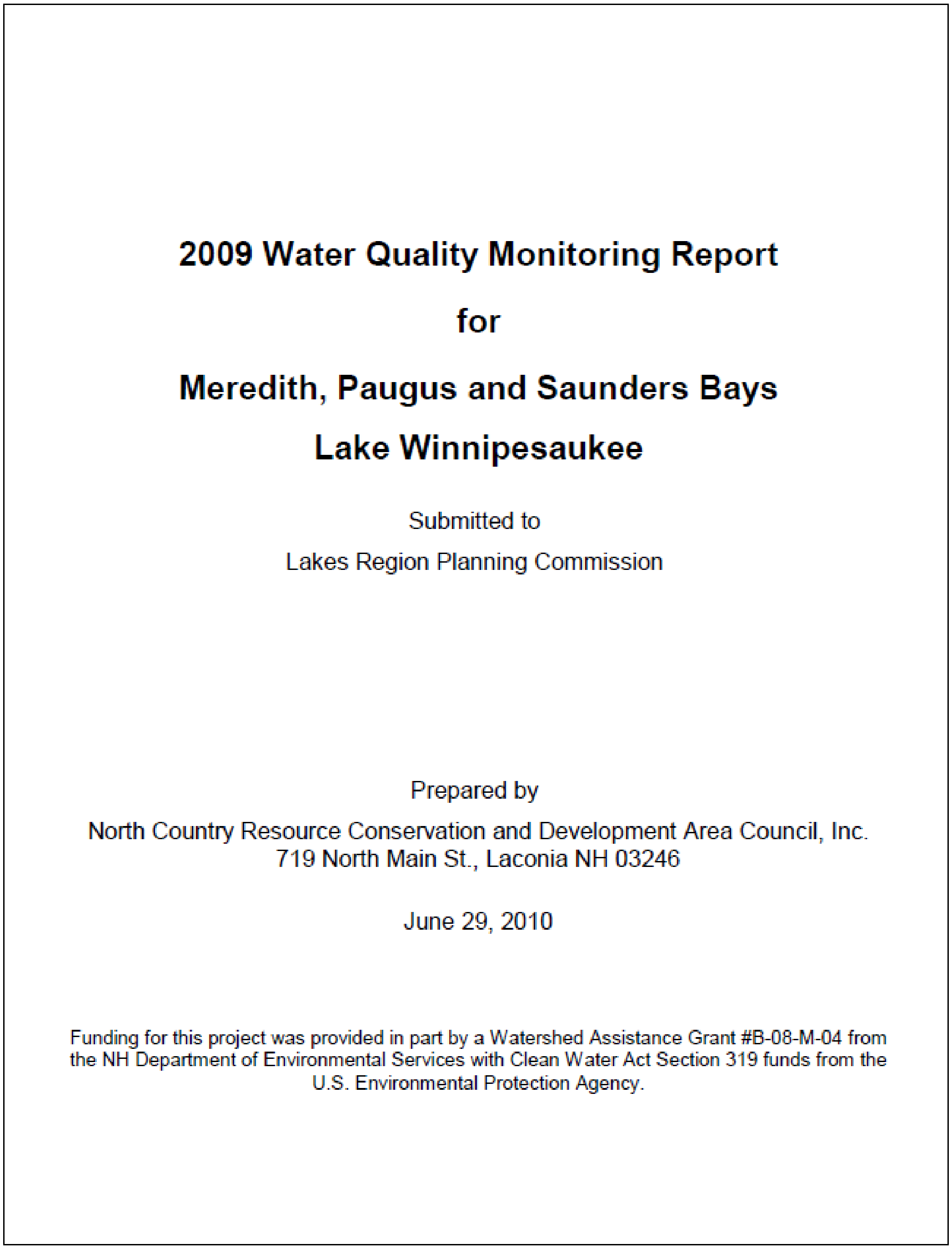
Appendix C4. Comparison of In-Lake Trophic Response Models to actual observed in-lake phosphorus concentrations

Subwatershed	WS Acres	Lp ($g\ m^{-2}\ yr^{-1}$)	In-Lake Response Models Range of Predicted TP ($mg\ L^{-1}$)	Dillon/Rigler Predicted In-Lake P ($mg\ L^{-1}$)	Spring Ice-Out 4/2/2010 ($mg\ L^{-1}$)	Summer Median TP 2009 ($mg\ L^{-1}$)
Waukewan	8409	0.0928	0.0054 - 0.0091	0.0066	0.0069	0.0066
Meredith Bay	8823	0.0887	0.0056 - 0.0088	0.0071	0.0056	0.0067
Center Harbor Bay	20015	0.0382	0.0029 - 0.0073	0.0040	0.0058	0.006
Saunders Bay	17944	0.1858	0.0051 - 0.0058	0.0051	0.0055	0.0056
Paugus Bay	7530	0.7208	0.0057 - 0.0059	0.0058	0.0068	0.0061

Notes:

1. Phosphorus loads based on Belknap County Rainfall and runoff data
2. Spring Ice-Out value for Lake Waukewan collected on 4/22/11

APPENDIX D



2009 Water Quality Monitoring Report

for

Meredith, Paugus and Saunders Bays

Lake Winnipesaukee

Submitted to

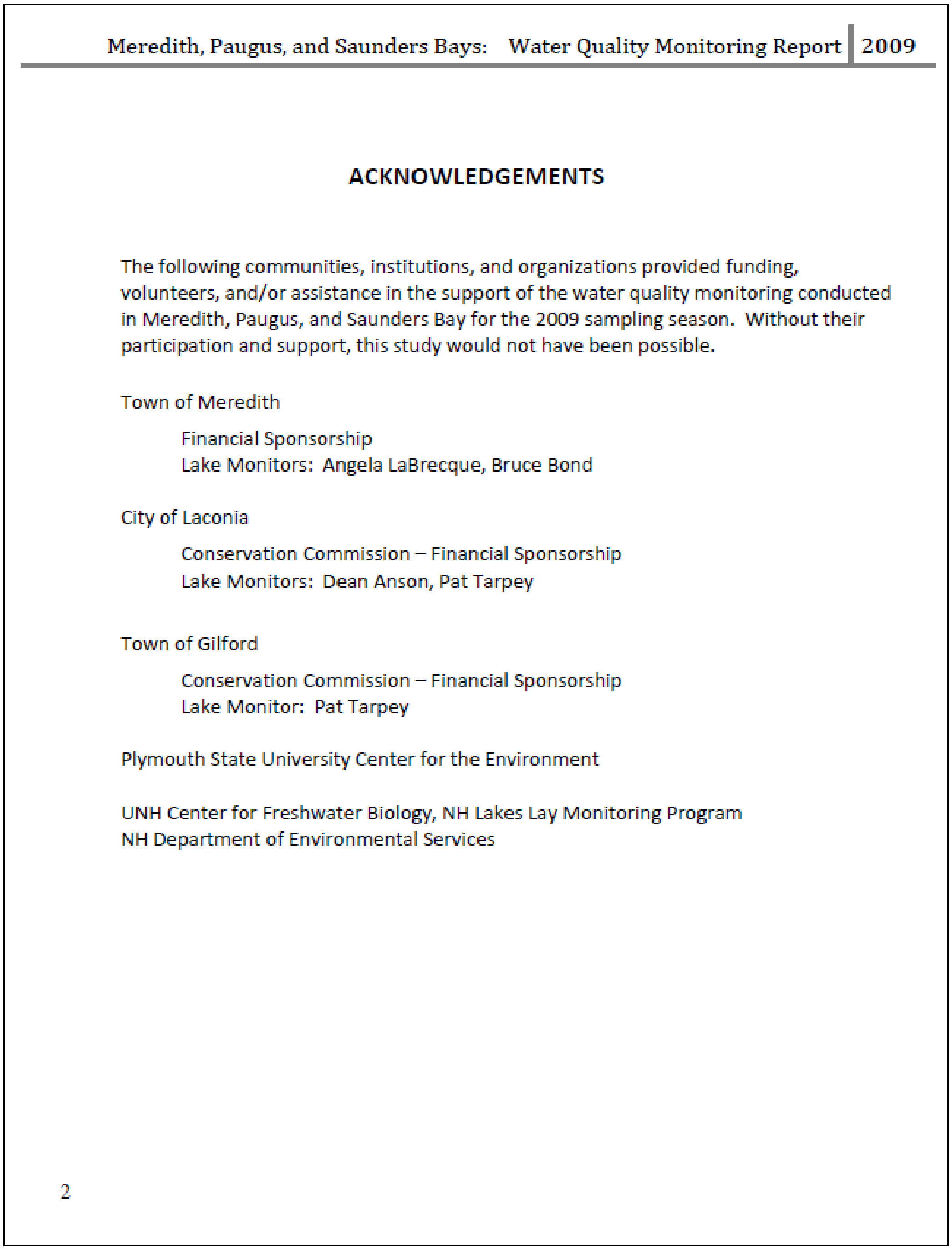
Lakes Region Planning Commission

Prepared by

North Country Resource Conservation and Development Area Council, Inc.
719 North Main St., Laconia NH 03246

June 29, 2010

Funding for this project was provided in part by a Watershed Assistance Grant #B-08-M-04 from the NH Department of Environmental Services with Clean Water Act Section 319 funds from the U.S. Environmental Protection Agency.



ACKNOWLEDGEMENTS

The following communities, institutions, and organizations provided funding, volunteers, and/or assistance in the support of the water quality monitoring conducted in Meredith, Paugus, and Saunders Bay for the 2009 sampling season. Without their participation and support, this study would not have been possible.

Town of Meredith

Financial Sponsorship
Lake Monitors: Angela LaBrecque, Bruce Bond

City of Laconia

Conservation Commission – Financial Sponsorship
Lake Monitors: Dean Anson, Pat Tarpey

Town of Gilford

Conservation Commission – Financial Sponsorship
Lake Monitor: Pat Tarpey

Plymouth State University Center for the Environment

UNH Center for Freshwater Biology, NH Lakes Lay Monitoring Program
NH Department of Environmental Services

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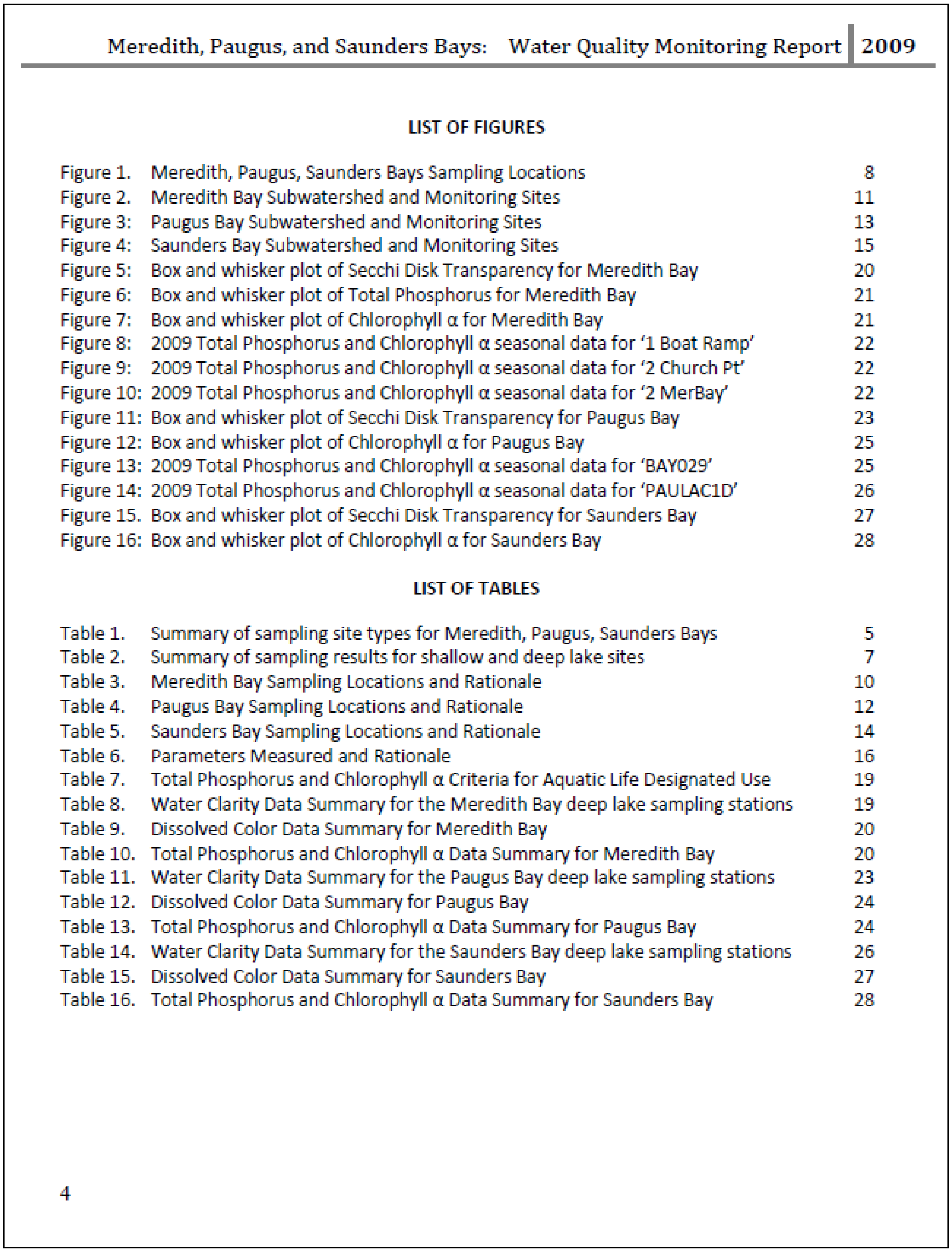

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1. Executive Summary

This monitoring program was conducted in support of a NH DES 319 grant awarded to the Lakes Region Planning Commission in 2008 for the development of the "Lake Winnipesaukee Watershed Management Plan, a Subwatershed Approach". In order to be able to measure potential improvements in water quality due to the implementation of best management practices as part of the management plan, data needed to be obtained to serve as an initial characterization of the water quality in the three (3) subwatershed areas under study in the grant; specifically, Meredith Bay, Paugus Bay and Saunders Bay of Lake Winnipesaukee. The monitoring design focused on tributary, near shore and deep lake samples, and followed the protocols and standard operating procedures in the quality assurance project plans (QAPP) in place with the NH Volunteer River Assessment Program (VRAP) for tributary sampling, and the UNH NH Lakes Lay Monitoring Program (LLMP) for near shore and deep lake sampling.

Selection of the tributaries, near shore and deep lake sites was done in collaboration with UNH Center for Freshwater Biology, and the local communities. Some of the tributaries and deep lake sites represent ongoing local monitoring efforts, and some sites were added as part of this study. The selection of sites was based on:

- obtaining deep lake samples from each subwatershed bay area
- samples from shallow sites located near the outlet of tributaries
- tributary sites that represent various development patterns/land uses, and/or outflows that contribute a fairly large volume of water to the lake.

The following table represents a summary of the number and type of sampling locations for each subwatershed. Each community contributed financially to the sampling study and provided input as to the number and selection of tributary sites monitored.

Table 1. 2009 Summary of sampling conducted in Meredith, Paugus, and Saunders Bays

Meredith Bay	Paugus Bay	Saunders Bay
3 Deep sites	2 Deep sites	4 Deep sites
5 Shallow sites (*2008 only)	4 Shallow sites	5 Shallow sites
5 Tributaries (*2008 only)	12 Tributaries	3 Tributaries

*Note: 2008 Meredith Bay shallow and tributary monitoring is mentioned for informational purposes only; no data analysis is included in this study.

Tributary Sampling Summary

Tributaries were monitored biweekly beginning in June and ending in September for pH, turbidity, temperature, dissolved oxygen, conductivity, and total phosphorus. As the complete report of the tributary monitoring conducted in 2009 in Paugus and Saunders Bay subwatersheds can be found in Appendix A, "2009 Lake Winnipesaukee Tributaries Water Quality Report", this report will only highlight the summary of results, site selection, rationale, and maps of the tributary monitoring.

Dissolved oxygen readings not meeting NH Class B standards were recorded at tributary station 01-XSB (refer to Table 5, Figure 4); which empties into Saunders Bay. As this tributary consistently had very low flows, it is not surprising that the dissolved oxygen readings were below the state standard. This station also had pH readings below the Class B New Hampshire standard of 6.5 -8.0 pH units. Many of the tributary sampling sites/stations had pH values recorded below the NH Class B standard. In fact of the 85 measurements taken during the sampling season, 42 fell below the state standard.

Turbidity levels (refer to Table 6) were low for all stations sampled; the only station that recorded turbidity measurements close to or above 10 NTUs was 01-XSB. Station 01-XSB (refer to Table 5, Figure 4) was fairly stagnant at each sampling event, and exhibited iron rust in the water, which would contribute to higher turbidity readings.

Specific conductance (refer to Table 6) levels ranged from 52 to 975 us/cm in the Paugus Bay tributaries, and 55 to 493 us/cm in Saunders Bay. The higher reading of 975 us/cm was recorded at the only outfall sampled in Paugus Bay, OUT-001 at the end of Mass Ave., Laconia (refer to Table 4, Figure 3). Higher readings in an outfall would be expected due to road runoff containing salts, fertilizer, and metals. The high reading of 493 us/cm was recorded at Station 02-AHB, Adder Hole Brook, Gilford (refer to Figure 4). Adder Hole Brook is a wetland area that is fairly stagnant; it receives road runoff from Route 11.

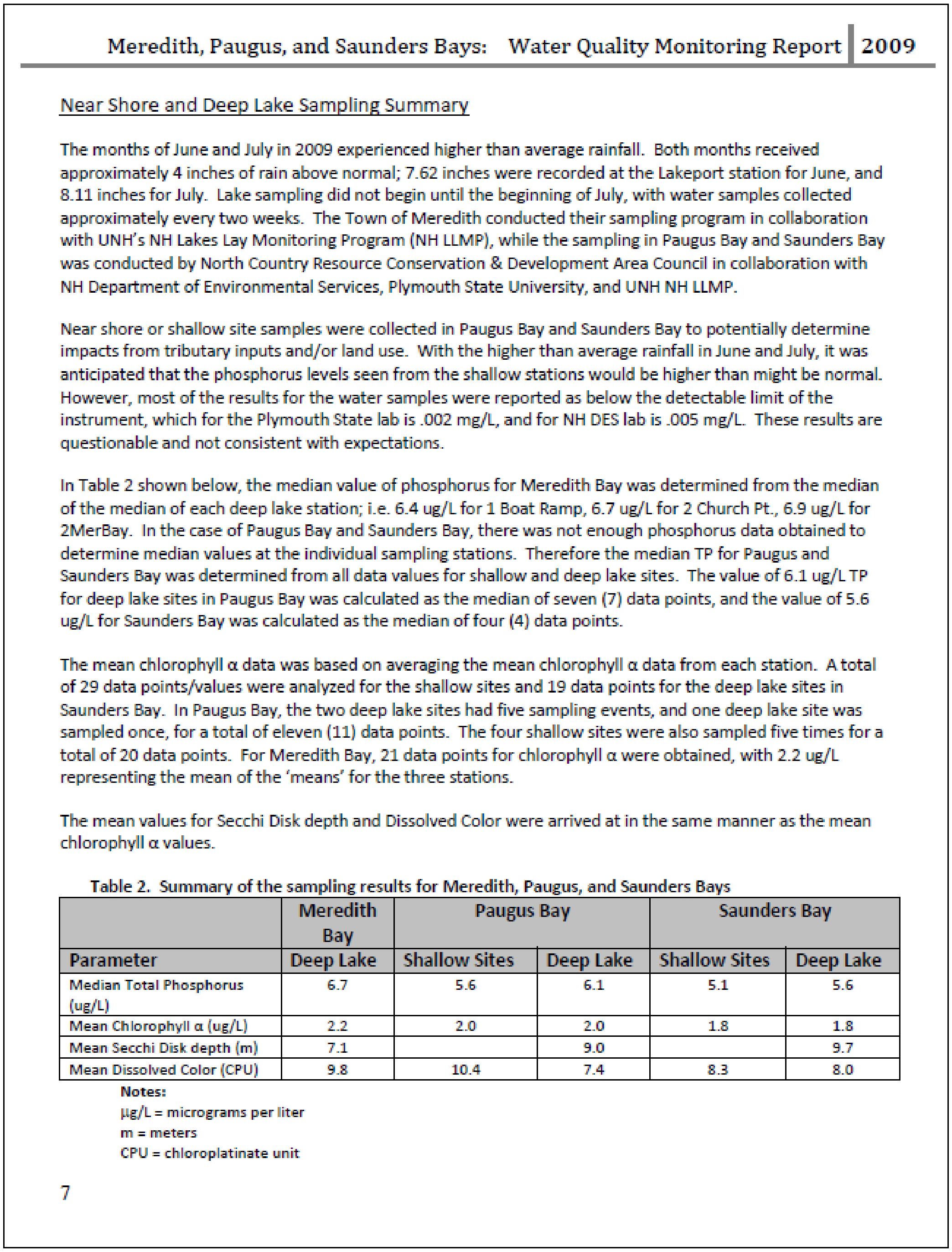
At least one phosphorus measurement was obtained from each tributary sampling station. Although New Hampshire does not have any Class B numeric standard for total phosphorus for tributaries, the NH DES level of concern is 0.05 mg/L. Only two measurements out of 69 were above DES' level of concern; one reading at TRIB-24, Langley Brook in Laconia; and the other at TRIB-25, an unnamed tributary inlet to Moulton Cove in Laconia (refer to Figure 3).

Excerpted from the NH VRAP Tributary Report (see Appendix A):

> "Although there is no numeric standard for nitrate/nitrite, the median NO3+NO2 value for New Hampshire rivers and streams is 0.17 mg/L (based on VRAP and other NHDES data collected 2004 - 2008). Three stations (04-GSK, TRIB-013A, and TRIB-014) had one or more measurement that exceeded the NO3+NO2 state median."

Station 04-GSK (refer to Figure 4) is the most downstream site sampled on Gunstock Brook. It is located on Old Lakeshore Road; previous sampling done at this site in 2004 and 2005 also shows higher nitrate readings than the majority of other tributary sampling stations. This site is located downstream from an agricultural farming operation and fertilizers may be the source of the higher nitrate. Stations TRIB-013A and TRIB-014 (refer to Figure 3) are located in South Down along the west side of Paugus Bay in Laconia. Further monitoring and investigation of the surrounding area is needed to determine the source of higher nitrate levels.

The last parameter measured at the tributary sites was chloride. As high conductivity readings are indicative of salts, metals, and/or fertilizers, chlorides were measured to eliminate or identify salt as a possible source or cause of high conductivity readings. Of the 48 samples collected, all measurements met the NH water quality standard for chloride; 230 mg/L Chronic condition, and 860 mg/L Acute criteria. One sampling event for chlorides was collected at the outfall station, OUT-001 in Laconia (refer to Figure 3), which is not subject to the water quality standards as it is not a tributary. The chloride measurement at OUT-001 was 260 mg/L on the one occasion it was analyzed. This would not be surprising, as the outfall collects storm water road runoff from the surrounding residential area.



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Near Shore and Deep Lake Sampling Summary

The months of June and July in 2009 experienced higher than average rainfall. Both months received approximately 4 inches of rain above normal; 7.62 inches were recorded at the Lakeport station for June, and 8.11 inches for July. Lake sampling did not begin until the beginning of July, with water samples collected approximately every two weeks. The Town of Meredith conducted their sampling program in collaboration with UNH's NH Lakes Lay Monitoring Program (NH LLMP), while the sampling in Paugus Bay and Saunders Bay was conducted by North Country Resource Conservation & Development Area Council in collaboration with NH Department of Environmental Services, Plymouth State University, and UNH NH LLMP.

Near shore or shallow site samples were collected in Paugus Bay and Saunders Bay to potentially determine impacts from tributary inputs and/or land use. With the higher than average rainfall in June and July, it was anticipated that the phosphorus levels seen from the shallow stations would be higher than might be normal. However, most of the results for the water samples were reported as below the detectable limit of the instrument, which for the Plymouth State lab is .002 mg/L, and for NH DES lab is .005 mg/L. These results are questionable and not consistent with expectations.

In Table 2 shown below, the median value of phosphorus for Meredith Bay was determined from the median of the median of each deep lake station; i.e. 6.4 ug/L for 1 Boat Ramp, 6.7 ug/L for 2 Church Pt., 6.9 ug/L for 2MerBay. In the case of Paugus Bay and Saunders Bay, there was not enough phosphorus data obtained to determine median values at the individual sampling stations. Therefore the median TP for Paugus and Saunders Bay was determined from all data values for shallow and deep lake sites. The value of 6.1 ug/L TP for deep lake sites in Paugus Bay was calculated as the median of seven (7) data points, and the value of 5.6 ug/L for Saunders Bay was calculated as the median of four (4) data points.

The mean chlorophyll α data was based on averaging the mean chlorophyll α data from each station. A total of 29 data points/values were analyzed for the shallow sites and 19 data points for the deep lake sites in Saunders Bay. In Paugus Bay, the two deep lake sites had five sampling events, and one deep lake site was sampled once, for a total of eleven (11) data points. The four shallow sites were also sampled five times for a total of 20 data points. For Meredith Bay, 21 data points for chlorophyll α were obtained, with 2.2 ug/L representing the mean of the 'means' for the three stations.

The mean values for Secchi Disk depth and Dissolved Color were arrived at in the same manner as the mean chlorophyll α values.

Table 2. Summary of the sampling results for Meredith, Paugus, and Saunders Bays

	Meredith Bay	Paugus Bay		Saunders Bay	
Parameter	**Deep Lake**	**Shallow Sites**	**Deep Lake**	**Shallow Sites**	**Deep Lake**
Median Total Phosphorus (ug/L)	6.7	5.6	6.1	5.1	5.6
Mean Chlorophyll α (ug/L)	2.2	2.0	2.0	1.8	1.8
Mean Secchi Disk depth (m)	7.1		9.0		9.7
Mean Dissolved Color (CPU)	9.8	10.4	7.4	8.3	8.0

Notes:
µg/L = micrograms per liter
m = meters
CPU = chloroplatinate unit

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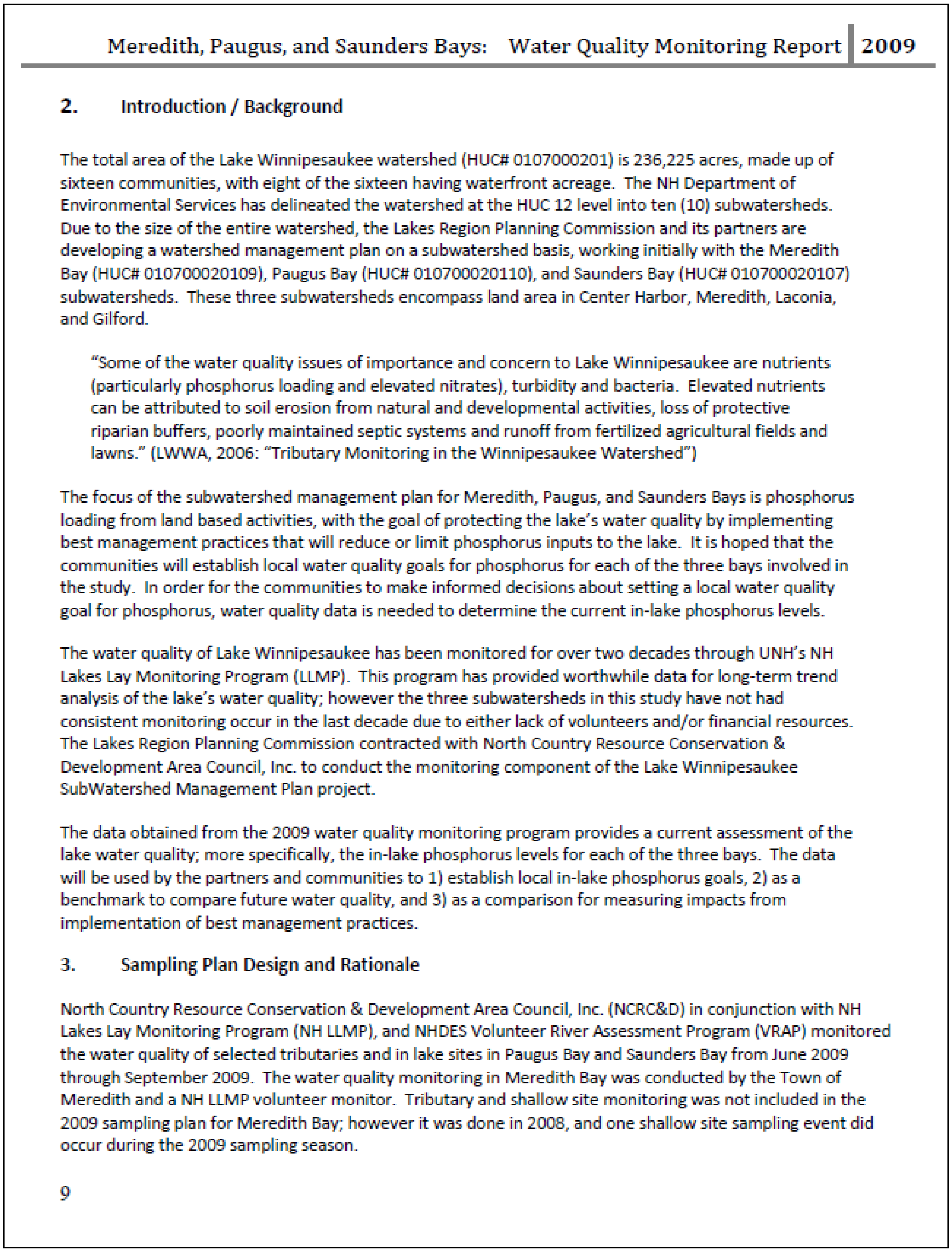
Figure 1. 2003 aerial photograph depicting the tributary, near shore, and deep lake sampling stations for Meredith, Paugus, and Saunders Bays.

Meredith, Paugus, and Sanders Bay
Sampling Locations



2. Introduction / Background

The total area of the Lake Winnipesaukee watershed (HUC# 0107000201) is 236,225 acres, made up of sixteen communities, with eight of the sixteen having waterfront acreage. The NH Department of Environmental Services has delineated the watershed at the HUC 12 level into ten (10) subwatersheds. Due to the size of the entire watershed, the Lakes Region Planning Commission and its partners are developing a watershed management plan on a subwatershed basis, working initially with the Meredith Bay (HUC# 010700020109), Paugus Bay (HUC# 010700020110), and Saunders Bay (HUC# 010700020107) subwatersheds. These three subwatersheds encompass land area in Center Harbor, Meredith, Laconia, and Gilford.

> "Some of the water quality issues of importance and concern to Lake Winnipesaukee are nutrients (particularly phosphorus loading and elevated nitrates), turbidity and bacteria. Elevated nutrients can be attributed to soil erosion from natural and developmental activities, loss of protective riparian buffers, poorly maintained septic systems and runoff from fertilized agricultural fields and lawns." (LWWA, 2006: "Tributary Monitoring in the Winnipesaukee Watershed")

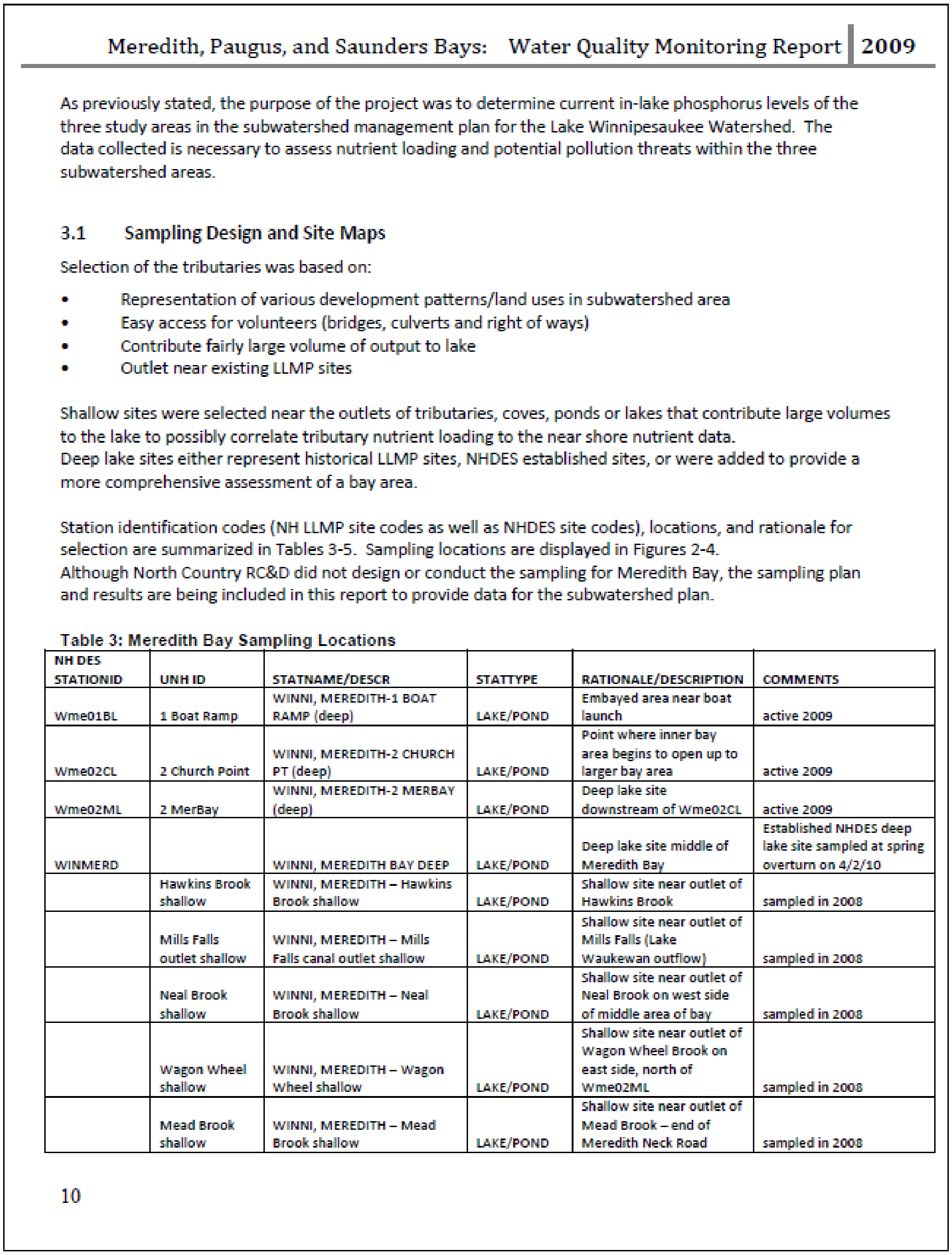
The focus of the subwatershed management plan for Meredith, Paugus, and Saunders Bays is phosphorus loading from land based activities, with the goal of protecting the lake's water quality by implementing best management practices that will reduce or limit phosphorus inputs to the lake. It is hoped that the communities will establish local water quality goals for phosphorus for each of the three bays involved in the study. In order for the communities to make informed decisions about setting a local water quality goal for phosphorus, water quality data is needed to determine the current in-lake phosphorus levels.

The water quality of Lake Winnipesaukee has been monitored for over two decades through UNH's NH Lakes Lay Monitoring Program (LLMP). This program has provided worthwhile data for long-term trend analysis of the lake's water quality; however the three subwatersheds in this study have not had consistent monitoring occur in the last decade due to either lack of volunteers and/or financial resources. The Lakes Region Planning Commission contracted with North Country Resource Conservation & Development Area Council, Inc. to conduct the monitoring component of the Lake Winnipesaukee SubWatershed Management Plan project.

The data obtained from the 2009 water quality monitoring program provides a current assessment of the lake water quality; more specifically, the in-lake phosphorus levels for each of the three bays. The data will be used by the partners and communities to 1) establish local in-lake phosphorus goals, 2) as a benchmark to compare future water quality, and 3) as a comparison for measuring impacts from implementation of best management practices.

3. Sampling Plan Design and Rationale

North Country Resource Conservation & Development Area Council, Inc. (NCRC&D) in conjunction with NH Lakes Lay Monitoring Program (NH LLMP), and NHDES Volunteer River Assessment Program (VRAP) monitored the water quality of selected tributaries and in lake sites in Paugus Bay and Saunders Bay from June 2009 through September 2009. The water quality monitoring in Meredith Bay was conducted by the Town of Meredith and a NH LLMP volunteer monitor. Tributary and shallow site monitoring was not included in the 2009 sampling plan for Meredith Bay; however it was done in 2008, and one shallow site sampling event did occur during the 2009 sampling season.



As previously stated, the purpose of the project was to determine current in-lake phosphorus levels of the three study areas in the subwatershed management plan for the Lake Winnipesaukee Watershed. The data collected is necessary to assess nutrient loading and potential pollution threats within the three subwatershed areas.

3.1 Sampling Design and Site Maps

Selection of the tributaries was based on:

- Representation of various development patterns/land uses in subwatershed area
- Easy access for volunteers (bridges, culverts and right of ways)
- Contribute fairly large volume of output to lake
- Outlet near existing LLMP sites

Shallow sites were selected near the outlets of tributaries, coves, ponds or lakes that contribute large volumes to the lake to possibly correlate tributary nutrient loading to the near shore nutrient data.
Deep lake sites either represent historical LLMP sites, NHDES established sites, or were added to provide a more comprehensive assessment of a bay area.

Station identification codes (NH LLMP site codes as well as NHDES site codes), locations, and rationale for selection are summarized in Tables 3-5. Sampling locations are displayed in Figures 2-4.
Although North Country RC&D did not design or conduct the sampling for Meredith Bay, the sampling plan and results are being included in this report to provide data for the subwatershed plan.

Table 3: Meredith Bay Sampling Locations

NH DES STATIONID	UNH ID	STATNAME/DESCR	STATTYPE	RATIONALE/DESCRIPTION	COMMENTS
Wme01BL	1 Boat Ramp	WINNI, MEREDITH-1 BOAT RAMP (deep)	LAKE/POND	Embayed area near boat launch	active 2009
Wme02CL	2 Church Point	WINNI, MEREDITH-2 CHURCH PT (deep)	LAKE/POND	Point where inner bay area begins to open up to larger bay area	active 2009
Wme02ML	2 MerBay	WINNI, MEREDITH-2 MERBAY (deep)	LAKE/POND	Deep lake site downstream of Wme02CL	active 2009
WINMERD		WINNI, MEREDITH BAY DEEP	LAKE/POND	Deep lake site middle of Meredith Bay	Established NHDES deep lake site sampled at spring overturn on 4/2/10
	Hawkins Brook shallow	WINNI, MEREDITH – Hawkins Brook shallow	LAKE/POND	Shallow site near outlet of Hawkins Brook	sampled in 2008
	Mills Falls outlet shallow	WINNI, MEREDITH – Mills Falls canal outlet shallow	LAKE/POND	Shallow site near outlet of Mills Falls (Lake Waukewan outflow)	sampled in 2008
	Neal Brook shallow	WINNI, MEREDITH – Neal Brook shallow	LAKE/POND	Shallow site near outlet of Neal Brook on west side of middle area of bay	sampled in 2008
	Wagon Wheel shallow	WINNI, MEREDITH – Wagon Wheel shallow	LAKE/POND	Shallow site near outlet of Wagon Wheel Brook on east side, north of Wme02ML	sampled in 2008
	Mead Brook shallow	WINNI, MEREDITH – Mead Brook shallow	LAKE/POND	Shallow site near outlet of Mead Brook – end of Meredith Neck Road	sampled in 2008

01-HAW	Me1	WINNI, MEREDITH – Hawkins Brook	TRIBUTARY	Commercial development, runs by town transfer station	sampled in 2008
02-MFB	Me2	WINNI, MEREDITH – Mills Falls canal	TRIBUTARY	Outflow of Lake Waukewan	sampled in 2008
01-NBK		WINNI, MEREDITH – Neal Brook	TRIBUTARY	Seasonal and year round Residences	sampled in 2008
01-XMB		WINNI, MEREDITH – Wagon Wheel	TRIBUTARY	Seasonal and year round Residences	sampled in 2008
01-MBK		WINNI, MEREDITH – Mead Brook	TRIBUTARY	Seasonal and year round Residences	sampled in 2008

Figure 2: Meredith Bay near shore and deep lake sampling locations

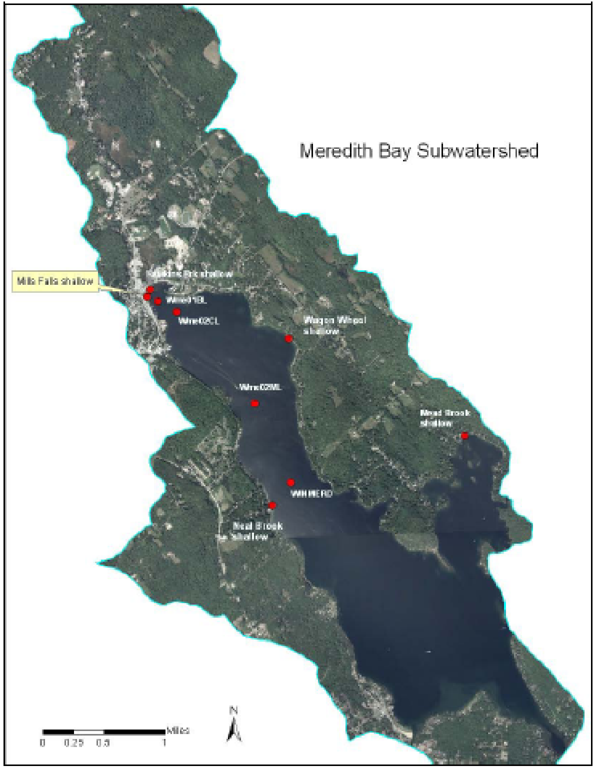


Table 4. Paugus Bay Sampling Locations

NH DES STATION ID	STATNAME/ DESCRIPTION	STATTYPE	RATIONALE/DESCRIPTION
BAY-029	MIDDLE PAUGUS BAY	LAKE/POND	UPSTREAM OF LACONIA WATER WORKS INTAKE
PAULAC1D	PAUGUS BAY - STATION 1 DEEP SPOT	LAKE/POND	DEEP LAKE SITE
LRPCPBMC1	PAUGUS BAY - MOULTON COVE SHALLOW	LAKE/POND	NEAR OUTLET OF MOULTON COVE, POTENTIAL LARGE VOLUME INPUT TO BAY
LRPCPBPC1	PAUGUS BAY - PICKEREL COVE SHALLOW	LAKE/POND	NEAR OUTLET OF PICKEREL COVE, SOURCE OF LARGE VOLUME INPUT TO BAY
LRPCPBLC1	PAUGUS BAY - LANGLEY COVE SHALLOW MIDDLE OF LANGLEY COVE	LAKE/POND	COVE WITH MILFOIL INFESTATION
LRPCPBBB1	PAUGUS BAY - BLACK BRK SHALLOW	LAKE/POND	SHALLOW SITE NEAR SPINNAKER COVE AND OUTLET OF BLACK BROOK. MILFOIL ISSUE
OUT-001	OUTFALL PIPE OF STORM DRAIN AT END OF MASS AVE. SOUTHWEST SIDE OF BAY	OUTFALL	DENSE RESIDENTIAL AREA
TRIB-011	STREAM DISCHARGES THROUGH A PIPE ADJACENT TO RAILROAD TRACKS, NEAR INTERSECTION PAUGUS PARK RD AND NORTH ST	TRIBUTARY	TRIBUTARY RUNS THROUGH GOLF COURSE POTENTIAL SOURCE PESTICIDES, FERTILIZERS
TRIB-012	DRAINAGE DITCH ADJACENT TO RAILROAD TRACK, NORTH ON PAUGUS PARK ROAD.	TRIBUTARY	POTENTIAL SECOND TRIBUTARY COLLECTING RUNOFF FROM GOLF COURSE
TRIB-013A	UPSTREAM OF OUTERBRIDGE DRIVE IN SOUTH DOWN DEVELOPMENT	TRIBUTARY	RUNOFF FROM DENSE RESIDENTIAL DEVELOPMENT
TRIB-014	OUTLET OF PONDS TO PAUGUS BAY THROUGH SOUTH DOWN (WEST SIDE OF BAY)	TRIBUTARY	DETENTION PONDS RECEIVING TRIBUTARY FLOW THROUGH SOUTH DOWN COMMUNITY BEFORE OUTLET TO BAY
TRIB-016	PAUGUS BAY STATE FOREST TRIBUTARY, NORTHWEST SIDE OF BAY	TRIBUTARY	REPRESENTS FORESTED LAND USE – MAY BE USED AS REFERENCE SITE
TRIB-018	INLET TO PICKEREL COVE –NORTHWEST SIDE OF BAY	TRIBUTARY	TRIBUTARY DRAINS LARGE WETLAND AREA
TRIB-019	OUTLET OF PICKEREL COVE, NORTHWEST SIDE OF BAY	TRIBUTARY	SEASONAL & YEAR ROUND HOMES. POTENTIAL TO CONTRIBUTE LARGE VOLUME OF FLOW TO BAY
BB1	BLACK BROOK-1, UPSTREAM SIDE OF CULVERT ENTRANCE TO WALMART	TRIBUTARY	OUTLET OF LILY POND
TRIB-21	BLACK BROOK-GILFORD PLAZA, SOUTHEAST SIDE OF BAY (behind CVS)	TRIBUTARY	RUNOFF FROM LARGE COMMERCIAL AREAS. SITE ADJACENT TO REMEDIATED LEAKING UNDERGROUND GASOLINE TANK SITE (FORMER GAS STATION
TRIB-22	OUTLET OF BLACK BROOK, UNION AVE, SOUTHEAST SIDE OF BAY	TRIBUTARY	TRIBUTARY FLOWS ALONG ROUTE 11, AND UNION AVE. RUNOFF FROM LARGE COMMERCIAL AND IMPERVIOUS AREAS
TRIB-24	LANGLEY BROOK, EAST SIDE OF PAUGUS BAY, EMPTIES INTO LANGLEY COVE. DRAINS LARGE WETLAND UPSTREAM	TRIBUTARY	STREAM HAS ORIGIN IN LARGE WETLAND, TRAVELS MOSTLY THROUGH FORESTED AREA UNTIL NEARS OUTLET - RESIDENTIAL AREAS
TRIB-25	UNNAMED TRIB, INLET TO MOULTONS COVE, UPSTREAM SIDE OF HILLIARD RD.	TRIBUTARY	NEW DEVELOPMENT PROPOSED UPSTREAM.

Figure 3. Paugus Bay Subwatershed Sampling Locations – Tributary, Near Shore, and Deep Lake

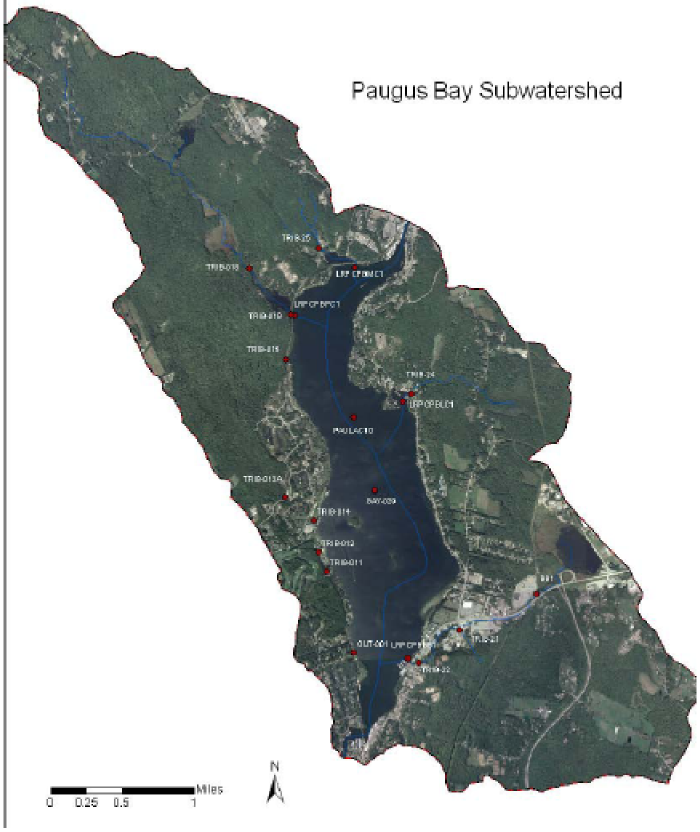
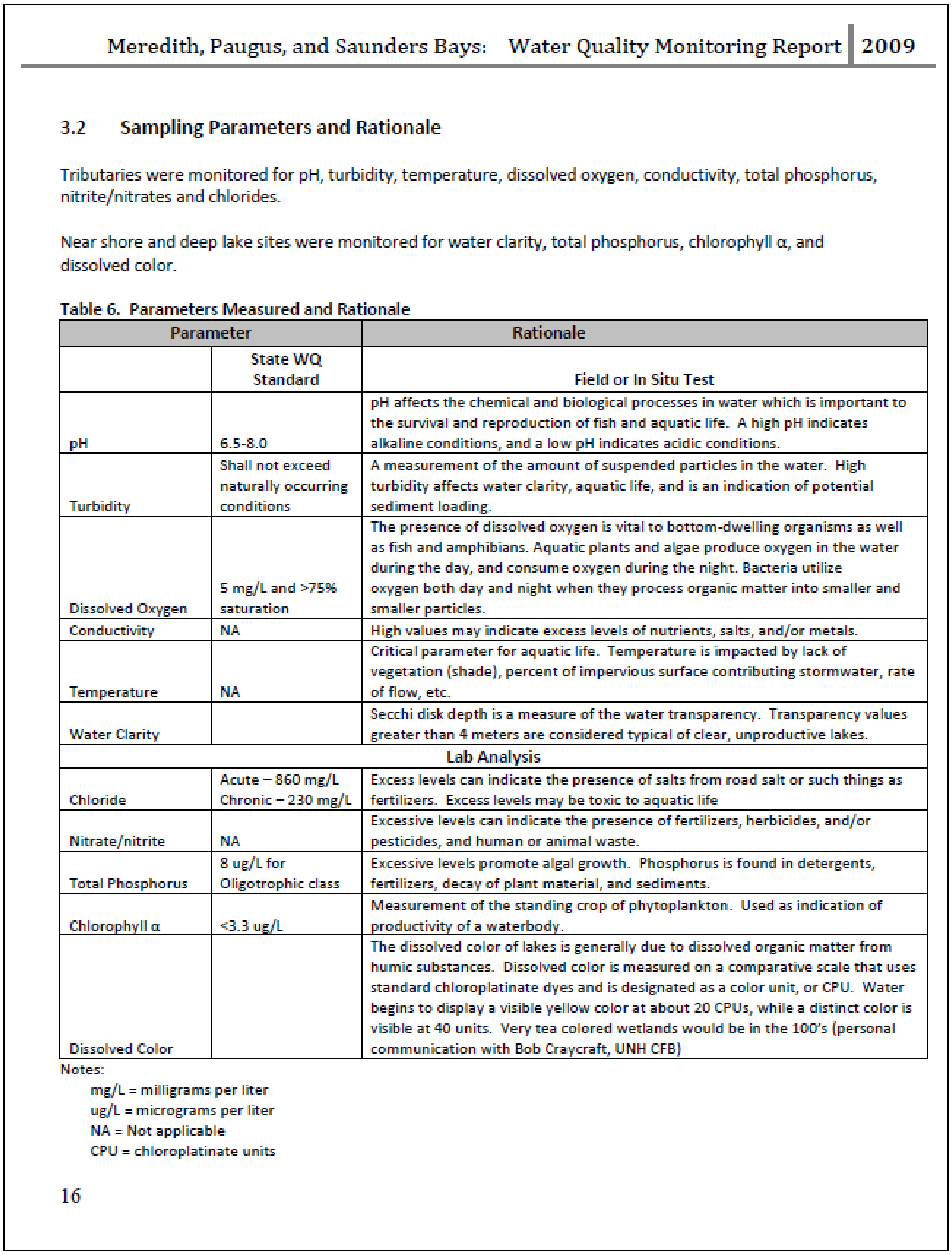


Table 5. Saunders Bay Sampling Locations

STATIONID	UNH ID	STATNAME/DESCRIPTION	STATTYPE	RATIONALE/DESCRIPTION
WGI02GL	GI2	WINNI, GOV. ISL-GI2	LAKE/POND	Shallow site southwest side of Governor's Island
WGI05GL	GI5	WINNI, GOV. ISL-GI5	LAKE/POND	Shallow site southeast side of Governor's Island
WGI0BGL	GIB	WINNI, GOV. ISL-GIB	LAKE/POND	Established LLMP deep site
WGI0CGL	GIC	WINNI, GOV. ISL-GIC	LAKE/POND	Established LLMP deep site
WGI0DGL	GID	WINNI, GOV. ISL-GID	LAKE/POND	Established LLMP deep site
WINGGILD		LK WINNIPESAUKEE, GOV ISLAND-DEEP SPOT	LAKE/POND	Established NHDES deep site
LRPCSB2	SB2	WINNI, SAUNDERS BAY-STATION 2	LAKE/POND	middle of Saunders Bay
LRPCSB3	SB3	WINNI, SAUNDERS BAY-STATION 3, shallow	LAKE/POND	outlet of Mountain View Marina
LRPCSB4	SB4	WINNI, SAUNDERS BAY-STATION 4 shallow	LAKE/POND	near outlet of Adder Hole Brook
LRPCSB5	SB5	WINNI, SAUNDERS BAY-STATION 5 shallow	LAKE/POND	near outlet of unnamed trib 01-XSB
04-GSK	Gi1	GUNSTOCK BROOK - OLD LAKESHORE RD	TRIBUTARY	empties into Mountain View marina
06-GSK		GUNSTOCK BROOK - HENDERSON RD	TRIBUTARY	upstream site from 04-GSK
12-GSK		GUNSTOCK BROOK - HOYT RD	TRIBUTARY	first road crossing of stream downstream from sand & gravel ops
01-AHB		ADDER HOLE BROOK	TRIBUTARY	brook and large wetland flows behind B'Maes and along Harris Shore Rd.
02-AHB		ADDER HOLE BROOK	TRIBUTARY/ WETLAND	sampling at foot bridge behind Fireside Inn
01-XSB		UNNAMED STREAM	TRIBUTARY	unnamed stream flows from wetland near abandoned landfill -outlets near Laconia/Gilford T/L

Figure 4. Saunders Bay Sampling Locations



3.2 Sampling Parameters and Rationale

Tributaries were monitored for pH, turbidity, temperature, dissolved oxygen, conductivity, total phosphorus, nitrite/nitrates and chlorides.

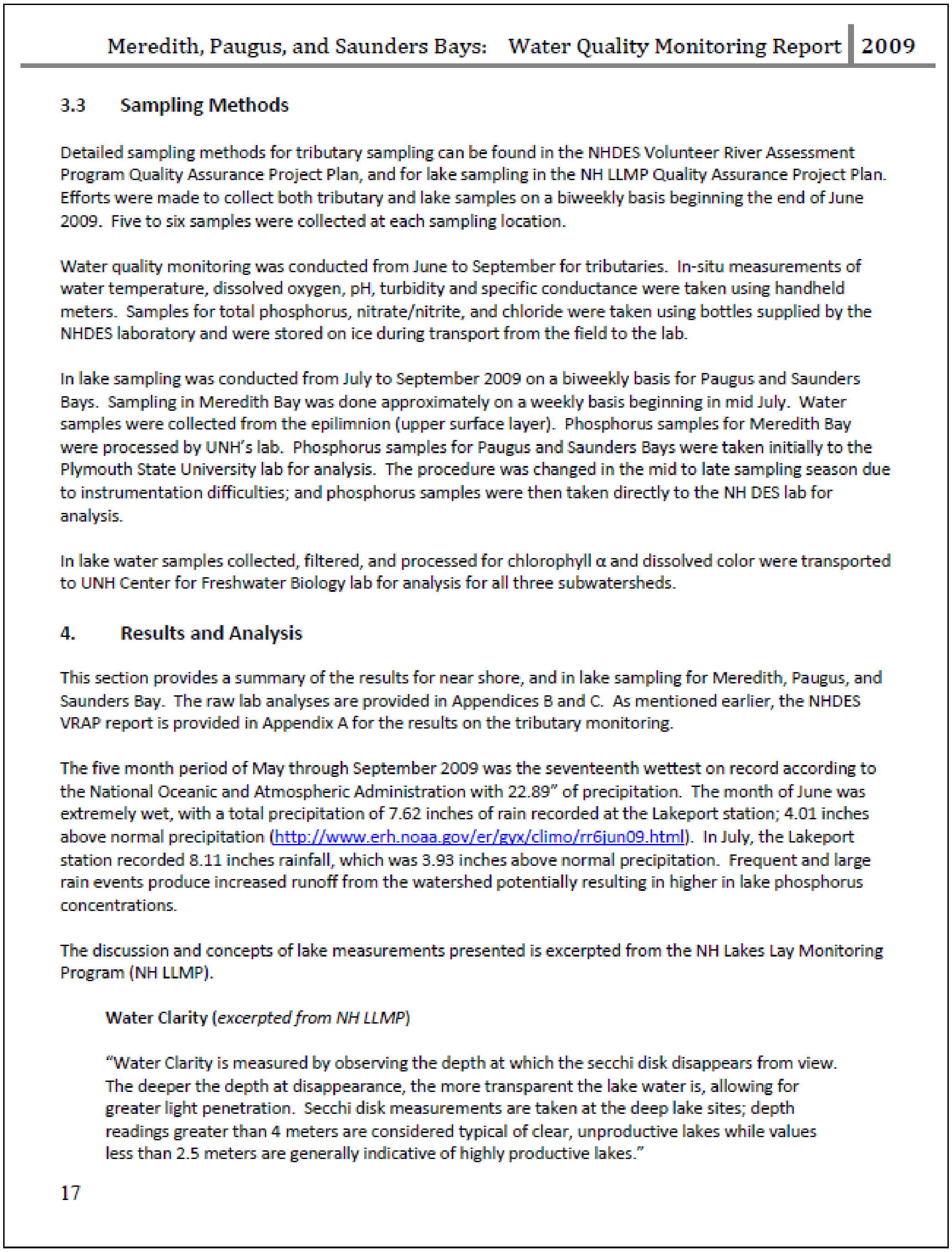
Near shore and deep lake sites were monitored for water clarity, total phosphorus, chlorophyll α, and dissolved color.

Table 6. Parameters Measured and Rationale

Parameter		Rationale
	State WQ Standard	Field or In Situ Test
pH	6.5-8.0	pH affects the chemical and biological processes in water which is important to the survival and reproduction of fish and aquatic life. A high pH indicates alkaline conditions, and a low pH indicates acidic conditions.
Turbidity	Shall not exceed naturally occurring conditions	A measurement of the amount of suspended particles in the water. High turbidity affects water clarity, aquatic life, and is an indication of potential sediment loading.
Dissolved Oxygen	5 mg/L and >75% saturation	The presence of dissolved oxygen is vital to bottom-dwelling organisms as well as fish and amphibians. Aquatic plants and algae produce oxygen in the water during the day, and consume oxygen during the night. Bacteria utilize oxygen both day and night when they process organic matter into smaller and smaller particles.
Conductivity	NA	High values may indicate excess levels of nutrients, salts, and/or metals.
Temperature	NA	Critical parameter for aquatic life. Temperature is impacted by lack of vegetation (shade), percent of impervious surface contributing stormwater, rate of flow, etc.
Water Clarity		Secchi disk depth is a measure of the water transparency. Transparency values greater than 4 meters are considered typical of clear, unproductive lakes.
Lab Analysis		
Chloride	Acute – 860 mg/L Chronic – 230 mg/L	Excess levels can indicate the presence of salts from road salt or such things as fertilizers. Excess levels may be toxic to aquatic life
Nitrate/nitrite	NA	Excessive levels can indicate the presence of fertilizers, herbicides, and/or pesticides, and human or animal waste.
Total Phosphorus	8 ug/L for Oligotrophic class	Excessive levels promote algal growth. Phosphorus is found in detergents, fertilizers, decay of plant material, and sediments.
Chlorophyll α	<3.3 ug/L	Measurement of the standing crop of phytoplankton. Used as indication of productivity of a waterbody.
Dissolved Color		The dissolved color of lakes is generally due to dissolved organic matter from humic substances. Dissolved color is measured on a comparative scale that uses standard chloroplatinate dyes and is designated as a color unit, or CPU. Water begins to display a visible yellow color at about 20 CPUs, while a distinct color is visible at 40 units. Very tea colored wetlands would be in the 100's (personal communication with Bob Craycraft, UNH CFB)

Notes:

mg/L = milligrams per liter
ug/L = micrograms per liter
NA = Not applicable
CPU = chloroplatinate units



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3.3 Sampling Methods

Detailed sampling methods for tributary sampling can be found in the NHDES Volunteer River Assessment Program Quality Assurance Project Plan, and for lake sampling in the NH LLMP Quality Assurance Project Plan. Efforts were made to collect both tributary and lake samples on a biweekly basis beginning the end of June 2009. Five to six samples were collected at each sampling location.

Water quality monitoring was conducted from June to September for tributaries. In-situ measurements of water temperature, dissolved oxygen, pH, turbidity and specific conductance were taken using handheld meters. Samples for total phosphorus, nitrate/nitrite, and chloride were taken using bottles supplied by the NHDES laboratory and were stored on ice during transport from the field to the lab.

In lake sampling was conducted from July to September 2009 on a biweekly basis for Paugus and Saunders Bays. Sampling in Meredith Bay was done approximately on a weekly basis beginning in mid July. Water samples were collected from the epilimnion (upper surface layer). Phosphorus samples for Meredith Bay were processed by UNH's lab. Phosphorus samples for Paugus and Saunders Bays were taken initially to the Plymouth State University lab for analysis. The procedure was changed in the mid to late sampling season due to instrumentation difficulties; and phosphorus samples were then taken directly to the NH DES lab for analysis.

In lake water samples collected, filtered, and processed for chlorophyll α and dissolved color were transported to UNH Center for Freshwater Biology lab for analysis for all three subwatersheds.

4. Results and Analysis

This section provides a summary of the results for near shore, and in lake sampling for Meredith, Paugus, and Saunders Bay. The raw lab analyses are provided in Appendices B and C. As mentioned earlier, the NHDES VRAP report is provided in Appendix A for the results on the tributary monitoring.

The five month period of May through September 2009 was the seventeenth wettest on record according to the National Oceanic and Atmospheric Administration with 22.89" of precipitation. The month of June was extremely wet, with a total precipitation of 7.62 inches of rain recorded at the Lakeport station; 4.01 inches above normal precipitation (http://www.erh.noaa.gov/er/gyx/climo/rr6jun09.html). In July, the Lakeport station recorded 8.11 inches rainfall, which was 3.93 inches above normal precipitation. Frequent and large rain events produce increased runoff from the watershed potentially resulting in higher in lake phosphorus concentrations.

The discussion and concepts of lake measurements presented is excerpted from the NH Lakes Lay Monitoring Program (NH LLMP).

> **Water Clarity** (*excerpted from NH LLMP*)
>
> "Water Clarity is measured by observing the depth at which the secchi disk disappears from view. The deeper the depth at disappearance, the more transparent the lake water is, allowing for greater light penetration. Secchi disk measurements are taken at the deep lake sites; depth readings greater than 4 meters are considered typical of clear, unproductive lakes while values less than 2.5 meters are generally indicative of highly productive lakes."

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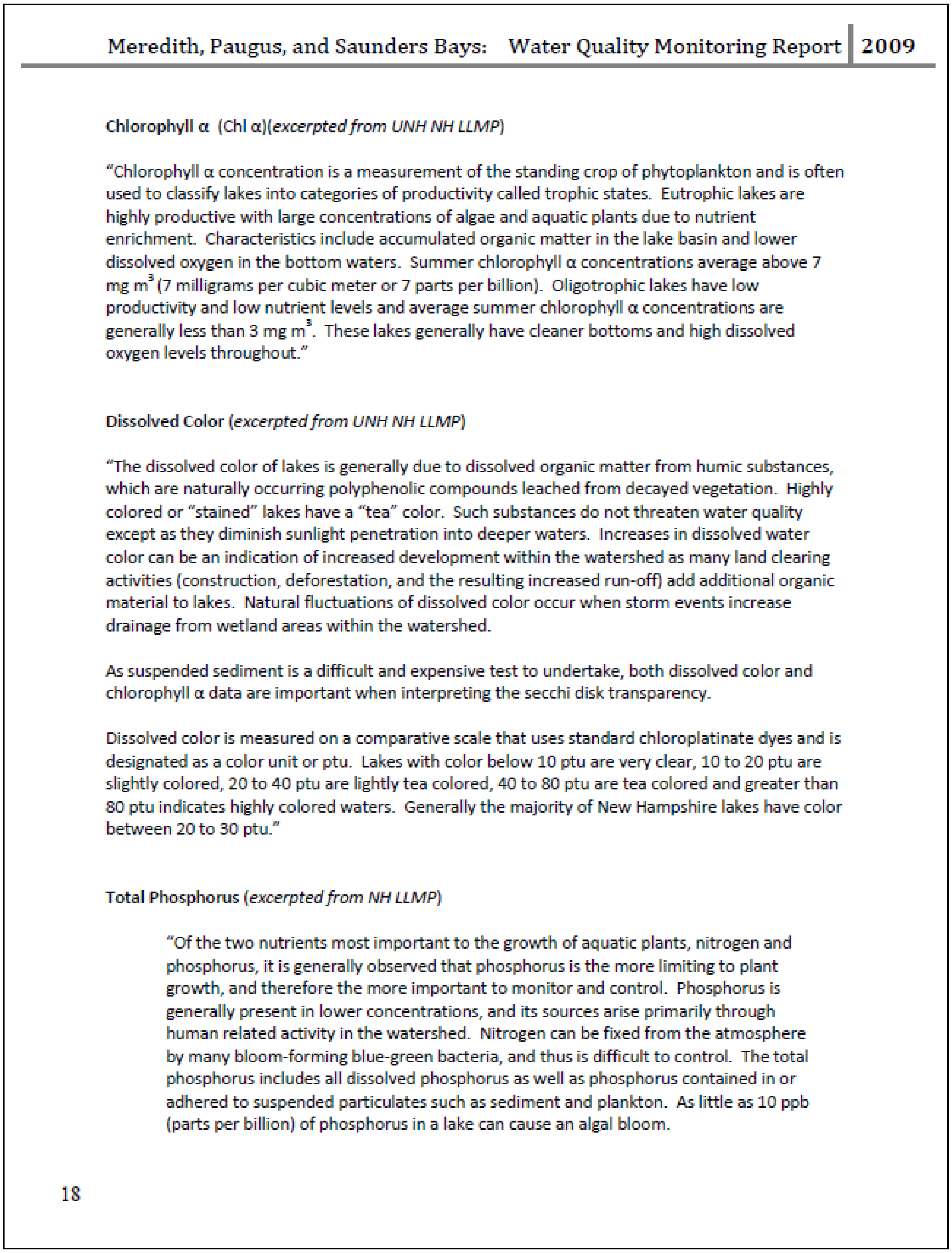


Chlorophyll α (Chl α)(*excerpted from UNH NH LLMP*)

"Chlorophyll α concentration is a measurement of the standing crop of phytoplankton and is often used to classify lakes into categories of productivity called trophic states. Eutrophic lakes are highly productive with large concentrations of algae and aquatic plants due to nutrient enrichment. Characteristics include accumulated organic matter in the lake basin and lower dissolved oxygen in the bottom waters. Summer chlorophyll α concentrations average above 7 mg m^3 (7 milligrams per cubic meter or 7 parts per billion). Oligotrophic lakes have low productivity and low nutrient levels and average summer chlorophyll α concentrations are generally less than 3 mg m^3. These lakes generally have cleaner bottoms and high dissolved oxygen levels throughout."

Dissolved Color (*excerpted from UNH NH LLMP*)

"The dissolved color of lakes is generally due to dissolved organic matter from humic substances, which are naturally occurring polyphenolic compounds leached from decayed vegetation. Highly colored or "stained" lakes have a "tea" color. Such substances do not threaten water quality except as they diminish sunlight penetration into deeper waters. Increases in dissolved water color can be an indication of increased development within the watershed as many land clearing activities (construction, deforestation, and the resulting increased run-off) add additional organic material to lakes. Natural fluctuations of dissolved color occur when storm events increase drainage from wetland areas within the watershed.

As suspended sediment is a difficult and expensive test to undertake, both dissolved color and chlorophyll α data are important when interpreting the secchi disk transparency.

Dissolved color is measured on a comparative scale that uses standard chloroplatinate dyes and is designated as a color unit or ptu. Lakes with color below 10 ptu are very clear, 10 to 20 ptu are slightly colored, 20 to 40 ptu are lightly tea colored, 40 to 80 ptu are tea colored and greater than 80 ptu indicates highly colored waters. Generally the majority of New Hampshire lakes have color between 20 to 30 ptu."

Total Phosphorus (*excerpted from NH LLMP*)

> "Of the two nutrients most important to the growth of aquatic plants, nitrogen and phosphorus, it is generally observed that phosphorus is the more limiting to plant growth, and therefore the more important to monitor and control. Phosphorus is generally present in lower concentrations, and its sources arise primarily through human related activity in the watershed. Nitrogen can be fixed from the atmosphere by many bloom-forming blue-green bacteria, and thus is difficult to control. The total phosphorus includes all dissolved phosphorus as well as phosphorus contained in or adhered to suspended particulates such as sediment and plankton. As little as 10 ppb (parts per billion) of phosphorus in a lake can cause an algal bloom.

> Generally, in more pristine lakes, phosphorus values are higher after spring melt when the lake receives the majority of runoff from its surrounding watershed. The nutrient is used by the algae and plants which in turn die and sink to the lake bottom causing surface water phosphorus concentrations to decrease as summer progresses. Lakes with nutrient loading from human activities and sources (agriculture, logging, sediment erosion, septic systems, etc.) will show greater concentrations of nutrients as the summer progresses or after major storm events."

Total phosphorus concentrations are one of the initial focuses of the watershed management plan, as phosphorus is considered the most limiting nutrient for plant growth in freshwater. New Hampshire has recently set nutrient water quality standards for lakes and ponds based on trophic status. The table below summarizes the criteria developed for supporting aquatic life designated use. Increased levels of phosphorus result in more nutrient available for plant growth; which can be correlated through the measurement of Chl α.

Table 7. Total Phosphorus (TP) and Chlorophyll α Criteria for Aquatic Life Designated Use

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

4.1 Meredith Bay

Water Clarity

Secchi disk measurements were only taken at the deep lake sites. The average reading for each of the three sites was above 4.0 meters, with the shallower site, "1 Boat Ramp", located nearer to shore having the lowest secchi disk readings.

Table 8. Water Clarity Data Summary for the Meredith Bay deep lake sampling stations

UNH Station ID	# Samples Collected	Seasonal Average (meters)	Data Range (m)
1 Boat Ramp	7	6.3	5.1 – 7.4
2 Church Pt	8	7.3	6.3 – 8.2
2 MerBay	5	7.8	6.8 – 8.2

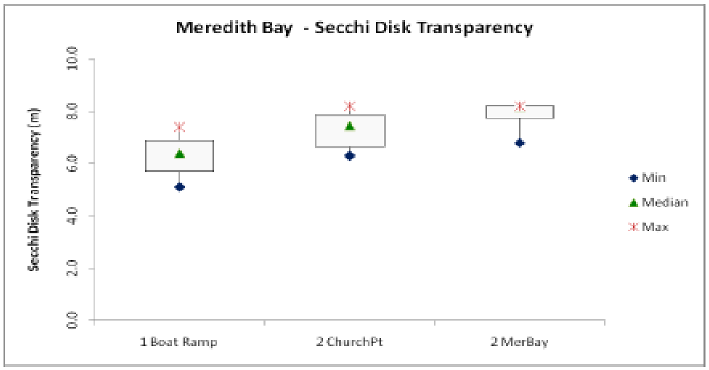


Figure 5. Box and whisker plot showing secchi disk transparency comparison among deep lake stations during the summer of 2009 sampling season. The box area depicts the lower 25th and upper 75th percentile of values.

Dissolved Color

Table 9. Dissolved Color Data Summary for Meredith Bay

Station ID	#Samples Collected	Mean Dissolved Color (CPU)	Data Range
1 Boat Ramp	8	11.3	7.8 – 15.6
2 Church Pt	8	9.2	7.8 – 12.2
2 MerBay	5	8.2	7.0 – 9.6

Total Phosphorus (TP) and Chlorophyll α (Chl α)

The town of Meredith sampled lake sites only in 2009. The first sampling date of the season, July 17th, included the five shallow near shore sites; however, the town decided to discontinue near shore sampling for the remainder of the sampling season.

Table 10. Total Phosphorus and Chlorophyll α data summary for Meredith Bay

UNH Station ID	#Samples Collected	Median TP (ug/L)	Data Range	Mean Chl α	Data Range
1 Boat Ramp	8	6.4	5.3 – 12.1	2.7	1.8 – 3.8
2 Church Pt	8	6.7	4.6 – 11.5	2.1	1.6 – 2.7
2 MerBay	5	6.9	4.7 – 9.5	1.9	1.4 – 2.3
Hawkins Brook shallow	1		8.1		5.2
Mead Brook shallow	1		7.1		1.7
Neal Brook shallow	1		8.9		2.4
Wagon Wheel shallow	1		7.6		2.3
Waukewan outlet	1		8.0		2.6

Note: Total Phosphorus and chlorophyll α were processed and analyzed at the UNH lab.

The seasonal total phosphorus concentrations were generally below the state standard of 8 ug/L; however the first sampling event on July 17 resulted in the highest TP measurement observed for "1 Boat Ramp" of 12.1 ug/L and the second highest measurement for "2 Church Pt"; of 8.5 ug/L. The single sampling event for the shallow sites on July 17th resulted in total phosphorus levels from 7.1 to 8.9 ug/L.

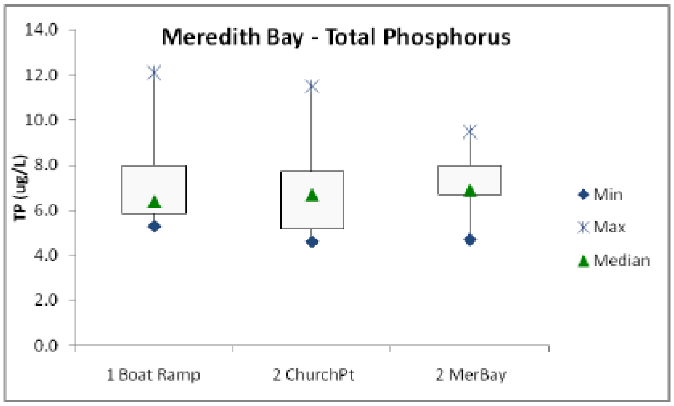


Figure 6. Box and whisker plot showing total phosphorus comparison among deep lake stations in Meredith Bay for the summer 2009 sampling season. The box area depicts the lower 25th and upper 75th percentile of values.

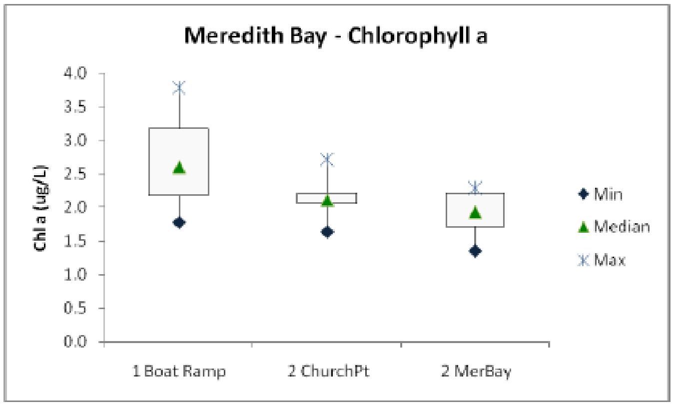


Figure 7. Box and whisker plot showing chlorophyll a comparison among deep lake stations in Meredith Bay for the summer 2009 sampling season. The box area depicts the lower 25th and upper 75th percentile of values.

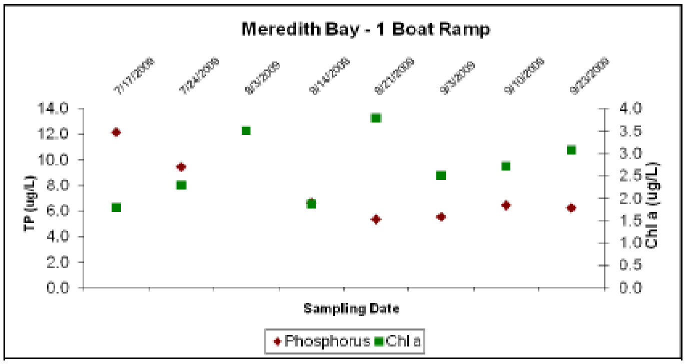


Figure 8. 2009 Total Phosphorus and Chl a seasonal data for Station "1 Boat Ramp"

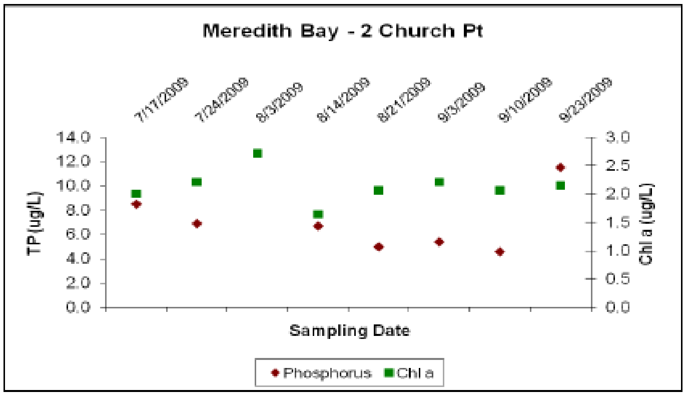


Figure 9. 2009 Total Phosphorus and Chl a seasonal data for Station "2 Church Pt"

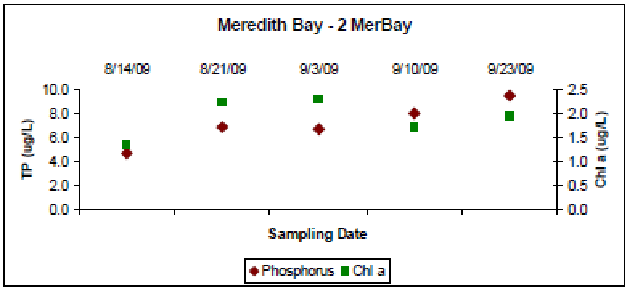


Figure 10. 2009 Total Phosphorus and Chl a seasonal data for Station "2 MerBay"

4.2 Paugus Bay

Sampling in Paugus Bay was conducted beginning in June for tributary monitoring and July for in lake stations. The results for the in lake phosphorus, chlorophyll α, dissolved color and water clarity will be reported here. The detailed results and report for the tributary sampling can be found in Appendix A.

Water Clarity

Secchi disk measurements were only taken at the deep lake sites. Station "Bay029" is located approximately in the middle of Paugus Bay, site "PAULAC1D" is upstream from "Bay029", and represents the deepest area in the bay. At least 5 readings/measurements were taken at each site; both sites were above 4.0 meters for all measurements.

Table 11. Water Clarity data summary for the Paugus Bay Deep lake sampling stations

Station ID	# Samples Collected	Seasonal Average (meters)	Data Range (meters)
BAY029	6	9.1	8.3-10.3
PAULAC1D	5	8.8	7.3-10.3
PAULAC2D	1		7.2

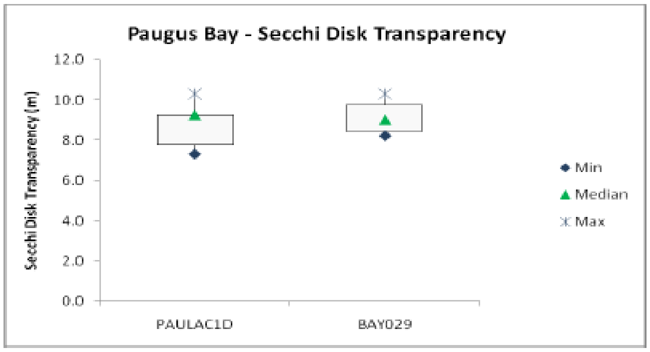


Figure 11. Box and whisker plot showing secchi disk transparency comparison among the two deep lake stations on Paugus Bay sampled during the summer of 2009. The box area depicts the lower 25th and upper 75th percentile of values.

Dissolved Color

Water samples were analyzed for dissolved color by the UNH lab. The mean dissolved color for all stations was below 20 CPUs, and below 10 CPUs for the majority of sites indicating relatively clear water. The four shallow sites showed the highest coloration, which is probably influenced by the vegetation found at those sites.

Table 12. Dissolved Color data summary for Paugus Bay

Station ID	#Samples Collected	Mean Dissolved Color (CPU)	Data Range
PAULAC1D	5	7.5	7.0 – 8.7
PAULAC2D	1		9.6
BAY029	5	7.3	6.1 – 8.7
LRPCPBBB1	5	7.8	7.0 – 9.6
LRPCPBLC1	5	10.8	6.1 – 19.1
LRPCPBMC1	5	8.0	4.3 – 13.0
LRPCPBPC1	5	15.1	6.1 – 33.9

Total Phosphorus (TP) and Chlorophyll α (Chl α)

Water samples collected in Paugus Bay and Saunders Bay were taken to the Center for the Environment lab at Plymouth State University (PSU) for phosphorus analysis. As a key partner in the Winnipesaukee Watershed Management Plan project, PSU agreed to analyze 100 water samples at no cost to the project. Unfortunately, the head staff person at PSU's lab left employment as sampling began, and a NH DES intern was brought in to run the lab on a part time basis. During the sampling season problems arose with the instrument that analyzes total phosphorus, requiring samples to be brought to the NHDES lab in Concord.

As mentioned previously, results obtained from the Plymouth State lab were not consistent with expectations. The summer season was an especially rainy one, and most of the lab data results received from PSU showed no phosphorus detected or below detectable limit of 0.002 mg/L. Compared to results obtained from the Meredith Bay sampling, and personal communication with the UNH lab on other lake data, it appears that the PSU lab data may not be valid.

Table 13. Total Phosphorus and Chlorophyll a data summary for Paugus Bay

Station ID	#Samples Collected	Median TP (ug/L)	Data Range*	Mean Chl α (ug/L)	Data Range
PAULAC1D	5	6.0	ND, 6.0, 6.4, 5.2	2.0	1.6 – 2.3
PAULAC2D	1	----	6.6		1.6
BAY029	5	6.1	ND, 6.0, 6.1, 7.7	2.0	1.6 – 2.6
LRPCPBBB1	5	5.6	ND, 5.9, 5.3	2.0	1.4 – 3.4
LRPCPBLC1	5	----	ND, 5.6	2.2	1.4 – 3.8
LRPCPBMC1	5	5.4	ND, 5.6, 5.1	1.7	1.1 – 2.0
LRPCPBPC1	5	----	ND	2.0	1.4 – 2.4

Note:

ND = Not detected, below detectable limit

* Data range reports all phosphorus results received.

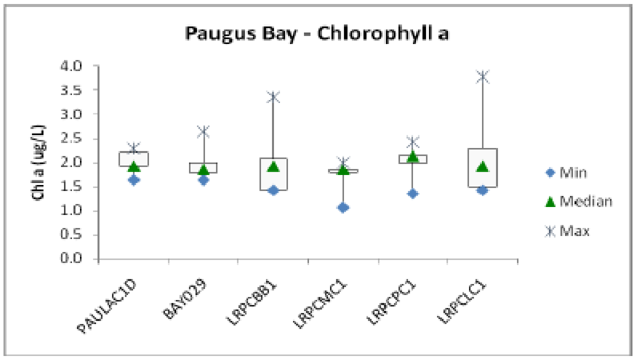


Figure 12. Box and whisker plot showing the comparison of Chlorophyll α among the stations in Paugus Bay for the 2009 summer sampling season. The box area depicts the lower 25th and upper 75th percentile of values.

The graphs below show the total phosphorus (TP) and chlorophyll a data for the two deep lake sites by sampling date. TP values reported as below detection or not detected are not shown in the graphs.

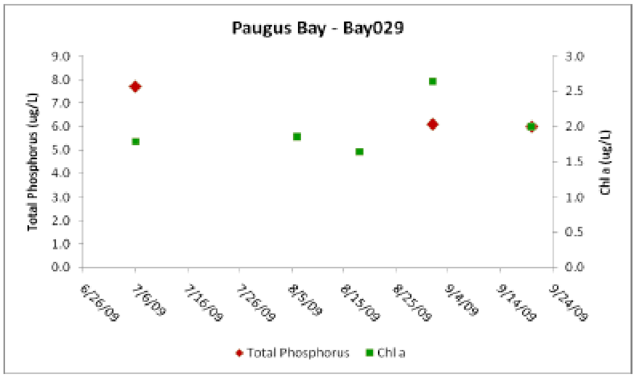


Figure 13. 2009 Total Phosphorus and Chl α seasonal data for Station "Bay029"

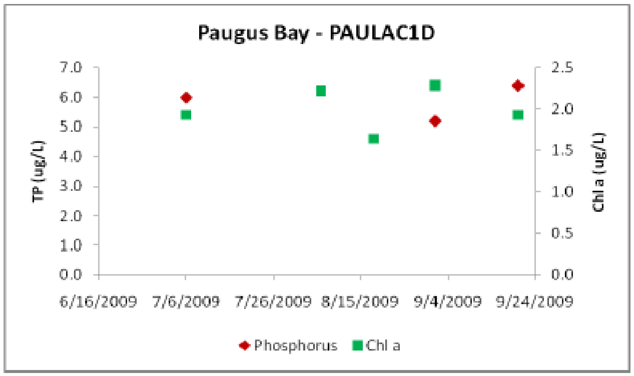


Figure 14. 2009 Total Phosphorus and Chl a seasonal data for Station "PAULAC1D"

4.3 Saunders Bay

Sampling in Saunders Bay was conducted beginning in July for in-lake stations. The results for the in lake phosphorus, chlorophyll α and water clarity will be reported here. Tributary monitoring results can be found in Appendix A.

Water Clarity

Secchi disk measurements were only taken at the deep lake sites. The four deep lake sites all had readings above 9.0 m for the seasonal average. Station "WGI0CGL", the deepest of the four sites at approximately 90'; only had two readings taken due to the difficulty encountered anchoring at this site.

Table 14. Water Clarity data summary for the Saunders Bay deep lake sampling stations

Station ID	**# Samples Collected**	**Seasonal Average (meters)**	**Data Range (m)**
LRPCSB2	6	9.4	8.5 – 10.0
WGI0DGL (GID)	6	9.5	8.4 – 11.2
WGI0CGL (GIC)	2	9.9	9.3, 10.6
WGI0BGL (GIB)	5	10	9.3 – 11.6

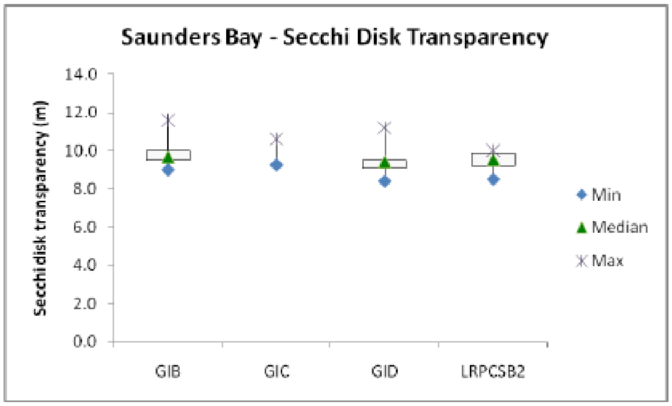


Figure 15. Box and whisker plot showing comparison of secchi disk transparency among the deep lake stations in Saunders Bay for the 2009 sampling season. The box area depicts the lower 25th and upper 75th percentile of values.

Dissolved Color

Water samples were analyzed for dissolved color by the UNH lab.

Table 15. Dissolved Color data summary for Saunders Bay

Station ID	#Samples Collected	Mean Dissolved Color (CPU)	Data Range
WGI0BGL (GIB)	5	8.0	7.0 – 9.6
WGI0CGL (GIC)	2	9.1	8.7, 9.6
WGI0DGL (GID)	6	7.7	6.1 – 8.7
WGI02GL (GI2)	6	7.5	6.1 – 9.6
WGI05GL (GI5)	6	7.7	7.0 – 8.7
LRPCSB2	6	7.2	5.2 – 8.7
LRPCSB3	6	9.8	7.8 – 13.0
LRPCSB4	6	9.1	7.8 – 11.3
LRPCSB5	5	7.3	6.1 – 8.7

Total Phosphorus (TP) and Chlorophyll α (Chl α)

Limited total phosphorus data was obtained for the 2009 sampling season in Saunders Bay shown in Table 16 below. However, chlorophyll α data, which was obtained for all sampling dates at all stations, shows the mean chl α value for both shallow and deep lake sites ranging from 1.3 to 2.0 ug/L.

Table 16. Total Phosphorus and Chlorophyll a data summary for Saunders Bay

Station ID	#Samples Collected	Median TP (ug/L)	Data Range	Mean Chl α (ug/L)	Data Range
WGI0BGL (GIB)	5		ND	1.9	1.6 – 2.3
WGI0CGL (GIC)	2		ND, 5.7	1.3	0.8, 1.9
WGI0DGL (GID)	6		ND, 6.3	1.9	1.3 – 3.2
WGI02GL (GI2)	6		ND	1.8	1.3 – 2.2
WGI05GL (GI5)	6		ND	1.5	0.8 – 2.3
LRPCSB2	6		ND, 5.4, 5.4	2.0	1.4 – 2.4
LRPCSB3	6		ND, 6.0	1.8	1.3 – 2.5
LRPCSB4	6		ND, 5.0	1.9	1.4 – 2.5
LRPCSB5	5		ND, 5.1	2.0	1.1 – 2.9

Note:
ND – not detected (below the detectable limit)

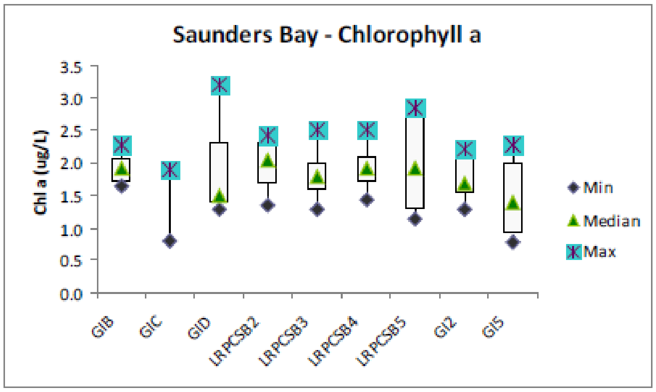
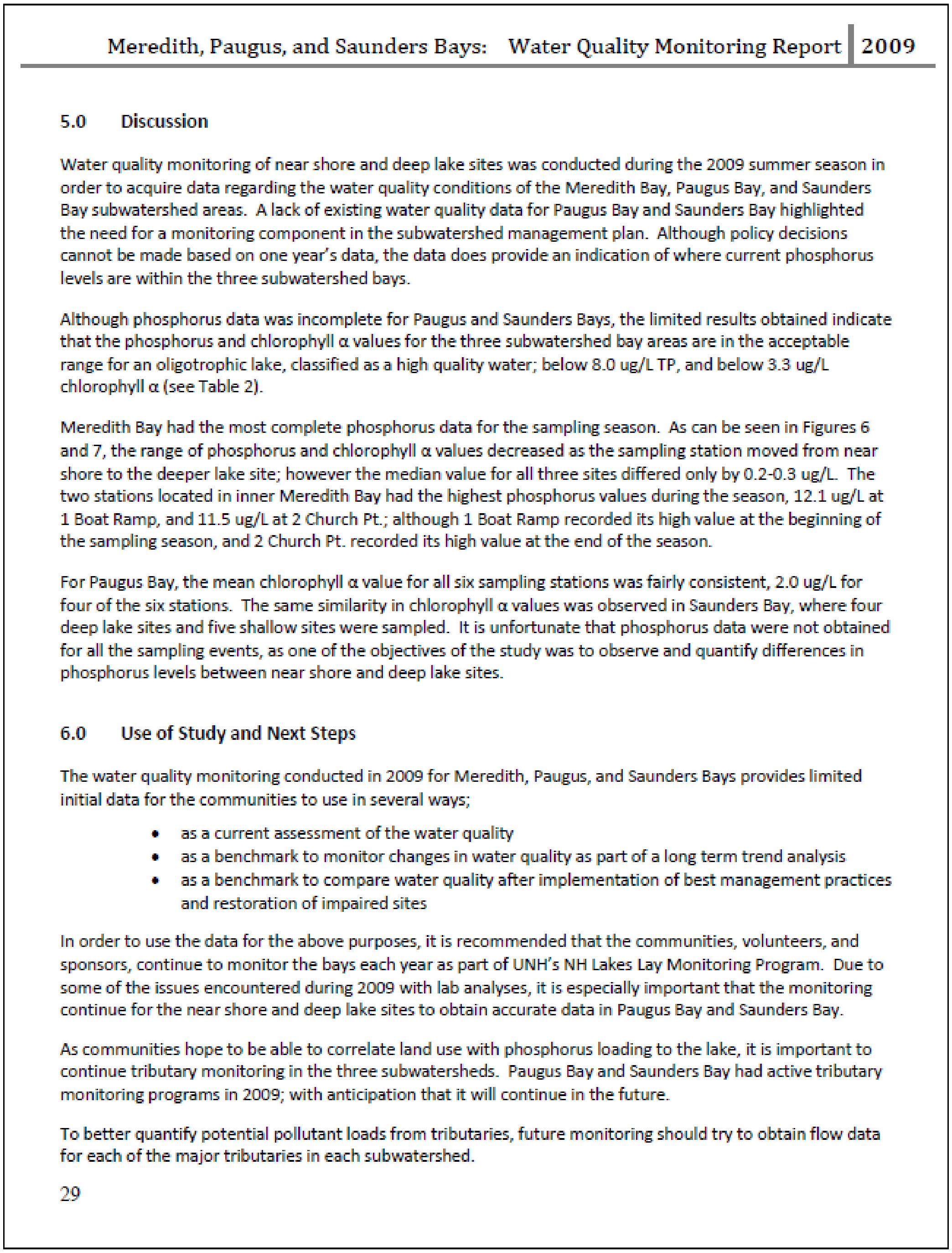


Figure 16. Box and whisker plot showing comparison of chlorophyll α data among stations in Saunders Bay for the 2009 sampling season. The box area depicts the lower 25th and upper 75th percentile of values.



5.0 Discussion

Water quality monitoring of near shore and deep lake sites was conducted during the 2009 summer season in order to acquire data regarding the water quality conditions of the Meredith Bay, Paugus Bay, and Saunders Bay subwatershed areas. A lack of existing water quality data for Paugus Bay and Saunders Bay highlighted the need for a monitoring component in the subwatershed management plan. Although policy decisions cannot be made based on one year's data, the data does provide an indication of where current phosphorus levels are within the three subwatershed bays.

Although phosphorus data was incomplete for Paugus and Saunders Bays, the limited results obtained indicate that the phosphorus and chlorophyll α values for the three subwatershed bay areas are in the acceptable range for an oligotrophic lake, classified as a high quality water; below 8.0 ug/L TP, and below 3.3 ug/L chlorophyll α (see Table 2).

Meredith Bay had the most complete phosphorus data for the sampling season. As can be seen in Figures 6 and 7, the range of phosphorus and chlorophyll α values decreased as the sampling station moved from near shore to the deeper lake site; however the median value for all three sites differed only by 0.2-0.3 ug/L. The two stations located in inner Meredith Bay had the highest phosphorus values during the season, 12.1 ug/L at 1 Boat Ramp, and 11.5 ug/L at 2 Church Pt.; although 1 Boat Ramp recorded its high value at the beginning of the sampling season, and 2 Church Pt. recorded its high value at the end of the season.

For Paugus Bay, the mean chlorophyll α value for all six sampling stations was fairly consistent, 2.0 ug/L for four of the six stations. The same similarity in chlorophyll α values was observed in Saunders Bay, where four deep lake sites and five shallow sites were sampled. It is unfortunate that phosphorus data were not obtained for all the sampling events, as one of the objectives of the study was to observe and quantify differences in phosphorus levels between near shore and deep lake sites.

6.0 Use of Study and Next Steps

The water quality monitoring conducted in 2009 for Meredith, Paugus, and Saunders Bays provides limited initial data for the communities to use in several ways;

- as a current assessment of the water quality
- as a benchmark to monitor changes in water quality as part of a long term trend analysis
- as a benchmark to compare water quality after implementation of best management practices and restoration of impaired sites

In order to use the data for the above purposes, it is recommended that the communities, volunteers, and sponsors, continue to monitor the bays each year as part of UNH's NH Lakes Lay Monitoring Program. Due to some of the issues encountered during 2009 with lab analyses, it is especially important that the monitoring continue for the near shore and deep lake sites to obtain accurate data in Paugus Bay and Saunders Bay.

As communities hope to be able to correlate land use with phosphorus loading to the lake, it is important to continue tributary monitoring in the three subwatersheds. Paugus Bay and Saunders Bay had active tributary monitoring programs in 2009; with anticipation that it will continue in the future.

To better quantify potential pollutant loads from tributaries, future monitoring should try to obtain flow data for each of the major tributaries in each subwatershed.

APPENDIX A

2009 Lake Winnipesaukee Tributaries
Water Quality Report

APPENDIX B

Laboratory Data Results