Province Lake Nutrient Modeling:

Estimating Phosphorus Loads using Lake Loading Response Modeling

March 2014

Prepared for
Province Lake Association

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Prepared by FB Environmental Associates
in cooperation with the Province Lake Association, the Acton Wakefield Watersheds Alliance and the New Hampshire Department of Environmental Services

March 2014

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Cover photo: Province Lake (Source: FBE)

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Executive Summary

The Lake Loading Response Model (LLRM) was used to estimate the water budget and phosphorus load to Province Lake based on land uses, population, precipitation, watershed boundaries, wastewater treatment, bathymetry, waterfowl, and other information about the Province Lake watershed. The model consists of a large Excel spreadsheet, which is supported by external data, maps, and scientific references. To develop the model, some new data were created, including detailed subwatershed boundaries, an updated land use layer, estimates of lake average depth and total volume, and a detailed estimate of the number of people using various wastewater systems based on a 2013 survey of residents. Key results:

- **The landscape was estimated as the largest source of phosphorus to the lake** at 66% of the total.
- **Wastewater systems (septic systems and other types) were the second largest source** at 17%. A surprisingly large population uses outhouses and cesspools.
- **Rain falling directly on the lake surface was the third largest source** at 16%.
- **Waterfowl** was a very small source at less than <1%.
- **Internal loading from heavy boat traffic** which stirs up polluted sediments into the water column is likely, but more local data and/or research is needed to adequately quantify that source.

Empirical water quality data were compared to the model results. There were more than 20 years of phosphorus concentration data for the lake and two large tributaries including the South River and unnamed southern tributary (Island Inlet). Additional sampling in the summer of 2013 was conducted at Hobbs Brook (n=2), unnamed south west tributary (campground, n=4), and unnamed eastern tributary (golf course, n=4). Overall in-lake total phosphorus (TP) model results closely matched to in-lake empirical data. In-stream TP model results for the South River and the unnamed southern tributary (Island Inlet) were lower than empirical data, which may be tied to sample collection method biased to dry weather and the low-flow summer season.

Based on the model, the three tributaries with the highest phosphorus loading per unit land area are the unnamed eastern tributary (golf course), the direct shoreline drainage, and the unnamed south west tributary (campground). This suggests that prioritizing lake protection efforts in these basins will yield the greatest benefit to the lake and may help focus phosphorus reduction efforts. Wastewater systems were estimated as a relatively high source of phosphorus to the lake. Eighty-one percent of the wastewater-specific loading is derived from old septic systems (>20 years old), outhouses, and cesspools. Wastewater systems which are inundated, even seasonally, by groundwater are especially likely to pollute the lake. It is essential for both lake quality and human health to ensure that all wastewater systems are functioning properly and well separated horizontally and vertically by good soils and/or treatment media from the lake and groundwater.

The model was used to evaluate the effect of future development, which was determined by a buildout analysis. In the intermediate term (year 2036), the in-lake TP concentration is expected to rise to 18.4 ppb, an increase of 29%. In 2060 at full buildout, the TP concentration is expected to rise to 24.5 ppb, an increase of 72% over current conditions. Best management practices in land use and septic system construction and maintenance can greatly reduce this predicted future phosphorus loading.

Introduction

Environmental modeling is the process of using mathematics to represent the natural world. Models are created to explain how a natural system works, to study cause and effect, or to make predictions under various scenarios. Environmental models range from very simple equations that can be solved with pen and paper, to highly complex computer software requiring teams of people to operate. The Lake Loading Response Model (LLRM) consists of an Excel spreadsheet using environmental data to develop a water and phosphorus loading budget for lakes and their tributaries. The model also makes predictions about chlorophyll-a concentrations and Secchi disk transparency. Water and phosphorus loads (in the form of mass and concentration) are traced from various sources in the watershed, through tributary basins, and into the lake. Since the model is spreadsheet-based, it uses numbers rather than maps as inputs and outputs. However, it requires detailed information about land uses in the watershed for several inputs, which in essence requires mapping as part of the modeling process.

Models such as the LLRM play a key role in the watershed planning process. The US Environmental Protection Agency (EPA) requires that a Watershed Based Plan be created for communities to be eligible for watershed assistance implementation grants. EPA guidelines for Watershed Based Plans require that both pollutant loads from the watershed, and the assimilative capacity of the waterbody be estimated. LLRM has also been applied to a total of 30 lakes in New Hampshire for Total Maximum Daily Load (TMDL) development and three lakes for watershed planning (Winnisquam, Granite, and Wentworth-Crescent). It has been applied for similar purposes to a number of other lakes and watersheds across the country. The TMDL for Forest Lake, NH (AECOM *et al*., 2011) is cited in particular, since it contains as an appendix a thorough guidance document to the LLRM.

The purpose of this modeling report is to describe the process by which FB Environmental (FBE) estimated phosphorus loads for Province Lake, as well as an explanation of the modeling results and limitations. The results of the model will be used help identify current and future pollution sources, to estimate pollution limits and water quality goals, and to guide watershed improvement projects.

Methods

Lake Loading Response Model

The Lake Loading Response Model (LLRM) consists of a large Excel spreadsheet that uses data regarding land cover, watershed boundaries, point sources, septic systems, waterfowl, rainfall, and an estimate of internal lake loading, combined with many coefficients and equations from scientific literature on lakes and nutrient cycles. The end result is a water and phosphorus loading budget for lakes and their tributaries. The model was originally developed as a university level teaching tool, and has been formerly known as SHEDMOD and ENSR-LRM. It has evolved over the years to incorporate new research on lake management. One of the key benefits of the model is its transparency. All equations in the modeling process are carried out by straightforward spreadsheet equations, and (with some patience) every result, and every intermediate calculation to obtain that result, can be traced from start to finish by visual inspection. There is no use of programming or opaque “behind the scenes” computer processing.

DATA INPUTS

The LLRM requires many inputs on a broad range of environmental conditions to calculate water and phosphorus loads for the lake. The accuracy of these input parameters has direct bearing on the validity of the final load estimates. Recent water quality data for Province Lake was used to the full extent possible to provide a reality check and was the basis of a straightforward calibration of the model results.

Watershed and Drainage Basins Boundaries

Watershed and tributary drainage basin boundaries are needed to calculate both the amount of water flowing into the tributaries and the lake, as well as helping determine what the various land uses are that contribute to nutrient loading in the watershed. A revised shapefile of watershed and drainage basin boundaries for this model was created using a Geographic Information System (ArcGIS) and data from the states of NH and Maine. The following sources of data were consulted to create this file:

- Hydrography (streams, lakes, watersheds) layer from USGS, 2012.
- Watershed layer from Province Lake Association, edited by FBE, 2013.
- Contour (elevation) data for the ME Office of GIS and NH GRANIT, 2012.
- Digital Elevation Model GIS layer from ME Office of GIS and NH GRANIT, 2012.
- Land Cover / Land Use from ME Office of GIS, 2004, and NH GRANIT, 2001.
- Bathymetry data layer from NHDES, 2012.
- 2010-2011 1-ft color aerial photos from NH GRANIT.
- 2011 NAIP orthophotos from ME Office of GIS.
- Road data from ME Office of GIS and NH GRANIT.

FBE delineated subwatersheds using contour vectors, digital elevation models, hydrography data, aerial photos, and roads layer using ArcMap 10 software. Subwatersheds were created for each major tributary. The subwatershed map developed for this modeling project is shown in Figure 1.

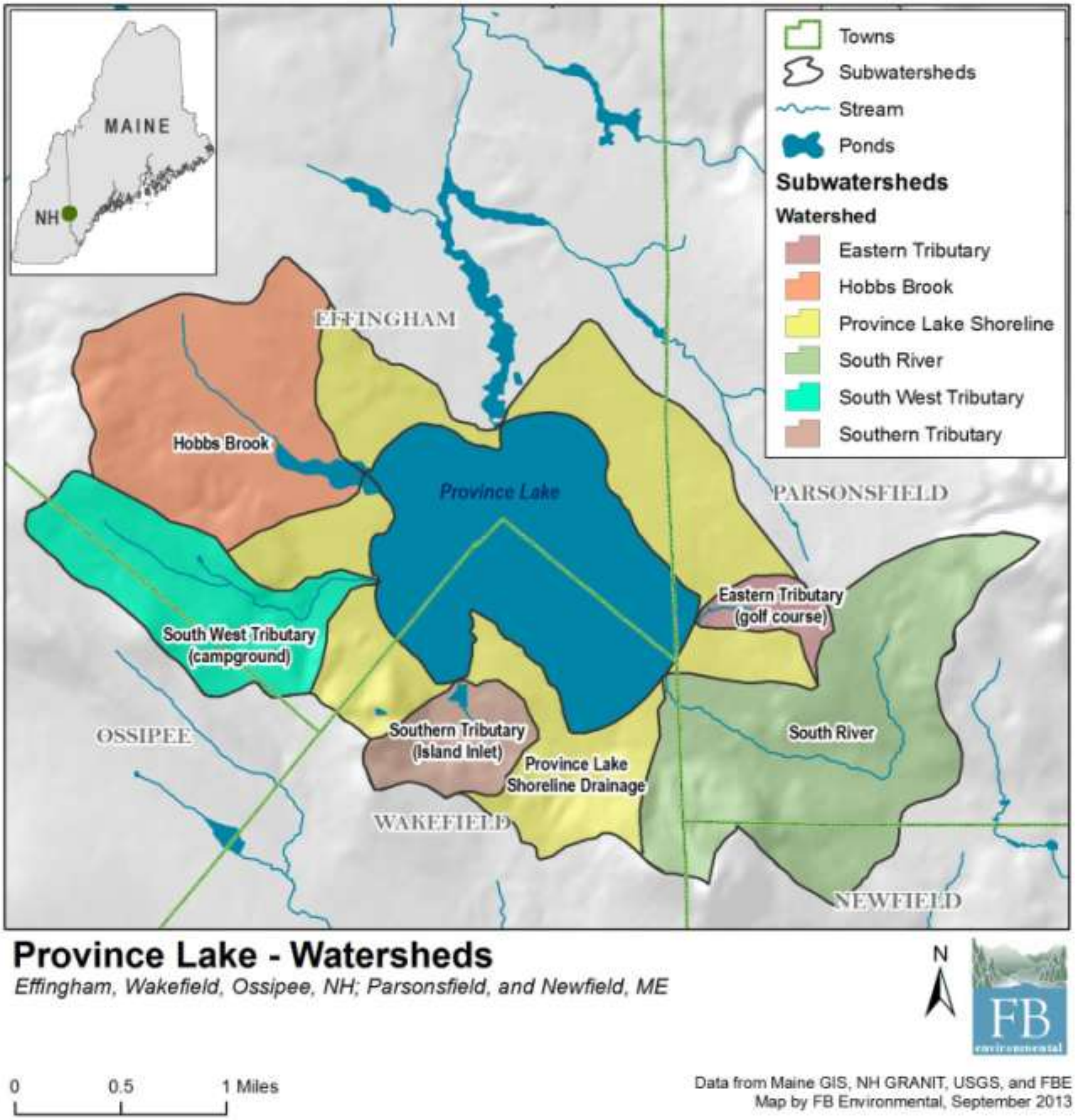

Figure 1: *Province Lake watershed and catchment basins.*

Land Use

Land use is an essential element in the Lake Loading Response Model (LLRM) in determining how much phosphorus is being contributed to the lake via stormwater runoff. Significant modeling effort went into reviewing and refining the land use data.

The 2004 ME and 2001 NH land cover datasets were modified in ArcGIS based 2011 NAIP aerial photos in Maine and 2010-2011 1-ft color aerial photos in NH, National Wetlands Inventory (NWI) data, roads data, as well as knowledge gained from watershed visits by FB Environmental (FBE) during watershed surveys and stream sampling in recent years. In addition, FBE manually digitized buildings in the watershed based on aerial photos, and used this data to refine the land use data. The purpose of these modifications was to update the existing land use data, and to match the land use categories in the land cover datasets to those used in the model. For example, in Maine, the land cover data coded agriculture as “cultivated crops” or “pasture/hay.” There are differences in phosphorus loading between pasture and hayfields, so every example of this land use category was reviewed using aerial photos to distinguish between pasture and hayfields. “Row crops” in the model has the highest level of phosphorus export, and was likewise reviewed carefully for accuracy. In addition, there were updates based on recent buildings and roads data. A quarter-acre area of “Urban 1” (low density residential) was created around each building, and a 24 foot width of “Urban 3” (roads) was created along each road. These steps ensured that each building and road would have at least a minimum land use area associated with it, though many buildings and roads were already correctly coded in the land use layer. Figure 2 depicts the final land use types throughout the watershed.

Within the LLRM, an export coefficient is assigned to each land use to represent typical concentrations of phosphorus in runoff from those land use types. Phosphorus export coefficients are based on results obtained by various researchers over the past several decades as published in scientific and technical journals. Unmanaged forested land, for example, tends to deliver very little phosphorus downstream when it rains, while row crops and high density urban land export significantly more phosphorus due to fertilizer use, soil erosion, car and factory exhaust, pet waste, and many other sources. Smaller amounts of phosphorus are also exported to lakes and streams during dry weather under baseflow conditions than in runoff conditions due to storms.

Table 1 presents the export coefficients for each land use category used in the model, along with the total land use area by category for Province Lake as hectares (ha) and percentage of total. One hectare is equivalent to 2.5 acres. Overall, 84% of the watershed is forested, 12% is developed, 2.7% is wetland, and 1.4% is agriculture (mostly hayfields).

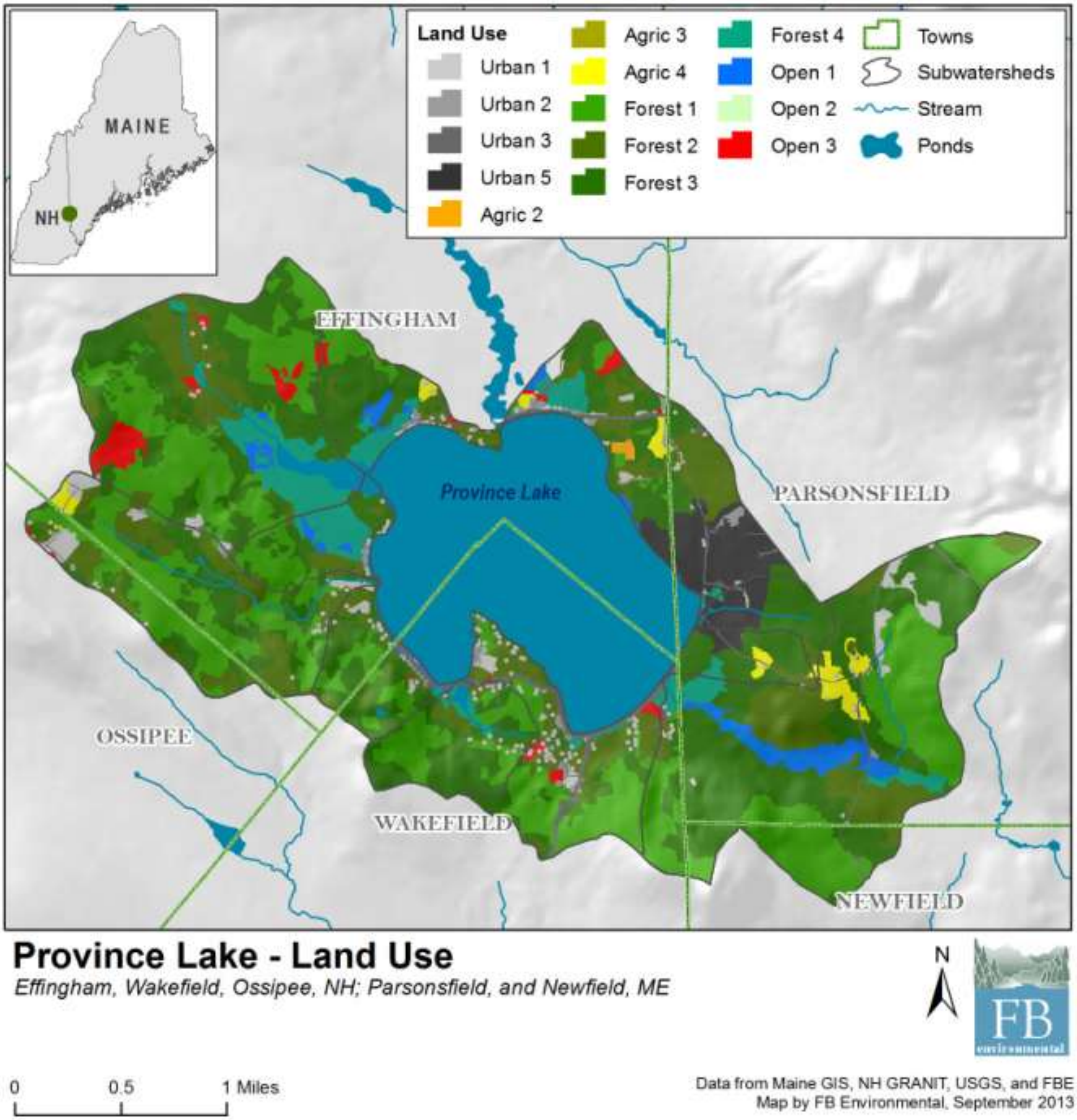

Figure 2: *Land uses in the Province Lake watershed. Land use codes in Table 1.*

Table 1: *Land use phosphorus export coefficients and overall lake watershed areas.*

LAND USE	Runoff P Export Coefficient *(kg/ha/yr)**	Baseflow P Export Coefficient *(kg/ha/yr)**	Province Lake Watershed *(ha)*	*(%)*
Urban 1 (Low Density Residential)	0.9	0.01	52.3	3.3%
Urban 2 (Mid Density Residential/Commercial)	1.1	0.01	9.0	0.6%
Urban 3 (Roads)	1.1	0.01	39.7	2.5%
Urban 4 (Industrial)	1.1	0.01	0.0	0.0%
Urban 5 (Mowed Fields)	1.1	0.01	60.0	3.8%
Agriculture 1 (Cover Crop)	0.8	0.01	0.0	0.0%
Agriculture 2 (Row Crop)	2.2	0.01	1.9	0.1%
Agriculture 3 (Grazing)	0.8	0.01	0.0	0.0%
Agriculture 4 (Hayfield)	0.64	0.01	20.5	1.3%
Forest 1 (Deciduous)	0.15	0.004	440.4	27.9%
Forest 2 (Non Deciduous)	0.093	0.004	250.2	15.8%
Forest 3 (Mixed)	0.093	0.004	547.7	34.7%
Forest 4 (Wetland)	0.082	0.004	92.2	5.8%
Open 1 (Wetland/Lake)	0.065	0.004	43.3	2.7%
Open 2 (Meadow)	0.2	0.004	0.0	0.0%
Open 3 (Excavation)	0.8	0.004	22.4	1.4%
Totals			**1,579**	**100%**

**1 kg/ha/year equals 0.9 lbs/acre/year.*

Lake Volume

Lake volume is an important modeling component, because it indicates the level of dilution of incoming phosphorus, which in turn helps calculate final in-lake phosphorus concentrations. It also contributes to calculation of the lake's flushing rate. NH DES used a GPS fathometer to gather lake bathymetry data in 2006, and used GIS to calculate a lake volume of 10,339,428 m^3 (S. Ashley, NH DES, pers. comm.). A map of the latest bathymetry data is shown in Figure 3.

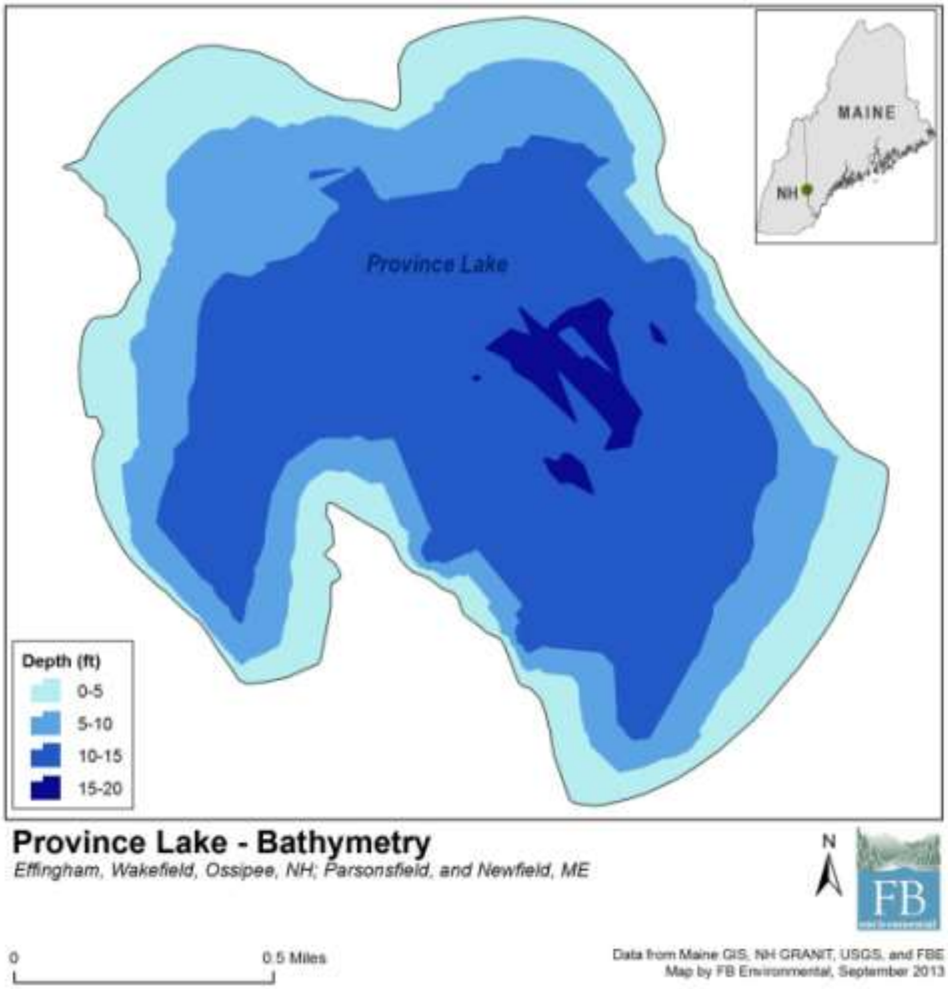

Figure 3: *Province Lake bathymetry data used to calculate lake volume (data source: NH DES).*

Internal Lake Loading

Phosphorus bound to sediments can enter the lake through tributaries, and settle to the bottom of the lake. This may occur over time without visible signs of stress to the lake, even if the sediments in the lake bed eventually contain a large quantity of phosphorus. So long as the phosphorus remains bound in the sediment, it will remain "locked away" and unavailable to nuisance algae and plants. Under at least two scenarios, however, this accumulated phosphorus can be released from the sediment and contribute to lake water quality problems. Under the first scenario, anaerobic conditions (zero dissolved oxygen) at the bottom of a lake causes phosphorus to be chemically unbound from the sediment, which then dissolves into the water column, providing a food source for algae and other plants. The second scenario for liberating phosphorus from lake sediments results from physical disturbance of the sediment such as by dredging, dragging of anchors or fishing gear, or possibly heavy boat traffic, especially due to propellers spinning in or very close to the sediments.

Province Lake is a shallow, wind driven system, so anaerobic conditions at the lake bottom are not observed. Therefore, internal lake loading from lack of oxygen at the sediments was not considered in the model.

Internal loading due to physical disturbance, on the other hand, was considered. It is possible that heavy boat traffic could be mechanically stirring up sediments, distributing phosphorus in the water column. Research which would allow a reasonable estimate of internal phosphorus loading by sediment disturbance from boat traffic, however, does not appear to be available for Province Lake. Nonetheless, man-made internal loading should be taken into account in lake protection efforts. Several studies indicate a net gain of in-lake phosphorus in response to motorboat activity, and an increased potential for phytoplankton growth (Wagner 1990). This includes research conducted by NHDES in New Hampshire Lakes which showed an increase on the order of 8-80 ppb (Schloss 1990), and another study in shallow lakes in Florida which showed a net gain between 7-166 ppb (Youseff *et al*. 1980). Further study of this possibility is recommended, and could be accomplished by monitoring the lake water column both before (Thursday afternoon), during, and after (Monday afternoon) heavy boat traffic weekends, or on holiday weekends. Phosphorus concentrations, turbidity, and Secchi disk transparency would provide valuable data to help answer the question of man-made mixing/internal loading as a result of boat traffic in the lake. While preventing the physical stirring up of sediments by boat traffic is especially important to Province Lake in order to reduce the potential for ongoing cyanobacteria blooms, it may also help prevent other negative effects of boating on the lake including increased turbidity, decreased water clarity, metal and gasoline inputs, shoreline erosion, effects on rooted aquatic plants, invertebrates, fish, waterfowl and other aquatic wildlife.

Septic System and Other Wastewater Loading

Septic systems and other wastewater systems are a source of both water and nutrients to the lake. Water travels through systems, then continues to move as groundwater, or subsurface flow above the level of groundwater, some of which flows into tributaries or the lake. The way septic systems prevent phosphorus from reaching surface waters can be varied, complex, and difficult to measure. Generally, the scientific literature shows phosphorus reduction of approximately 20% can occur in the septic tank via settling of solids, and between 23-99% in the leach field and immediately surrounding soils (Lombardo 2006, Lusk *et al.* 2011). Factors affecting the ability of septic systems to prevent phosphorus from entering surface waters include soil and groundwater pH, redox conditions, and mineral composition. In some cases, septic systems which had been operating for many decades were found to still retain 85% of the phosphorus within the first 30 cm of soil (Hartman *et al.* 1996, and Zanini *et al*. 1998). Several studies have found that phosphorus migrates through the soil much slower than other dissolved contaminants in wastewater, and that over a distance of between 10 to 100 meters, phosphorus was reduced to background levels (Robertson *et al.* 1998, and Weiskel *et al.* 1992). Weiskel *et al.* in particular found that the degree of phosphorus reduction was related to unsaturated infiltration distance, suggesting it is important to have septic systems well above the seasonal high groundwater table.

Despite the fact that phosphorus migrates through the soil much more slowly than groundwater or other contaminants, it is still possible that phosphorus may reach surface waters in certain cases. In unsaturated soils (i.e., above the groundwater table), relatively less phosphorus removal is likely in carbonite rich soils, though reduction of 20-50% is still possible. Another scenario which may promote phosphorus migration is in sandy aquifers with relatively rapid groundwater flow, though it is estimated it would take decades to travel typical setback distances (Lombardo 2006).

The LLRM uses a phosphorus (P) attenuation rate from septic systems. Based on the general 85% P retention rate cited above, newer systems were considered to retain 90% of phosphorus, while older systems were considered to retain 80%. This is consistent with research showing a range of failure rates from about 10% to 20% (Zanini *et al*. 1998, USEPA 2002). Research on outhouses and other forms of wastewater treatment are difficult to find, but the same principles of soil retention and the need for unsaturated soil above the seasonal high water table most likely apply. Outhouses may have fairly low loading rates, since they are usually not flushed with water. Cesspools (underground pits, tanks, or barrels lacking a separate disposal field or "leach field"), depend heavily on surrounding dry native soils to provide treatment and probably have highly variable levels of attenuation. For the purposes of this model, the cesspools and outhouses were assumed to have a 75% reduction in phosphorus. Portable toilets, electric toilets, and composting toilets (1.9% of total based on watershed septic survey) were assumed to have a 95% reduction, since in those cases waste would not generally be discharged via an aqueous solution. Unknown systems (1.4% of total) were assumed to have a 60% reduction in phosphorus, considering they are probably the least maintained of all systems.

Population figures and types and ages of wastewater systems are key in determining wastewater loading to the lake. Census tracts and municipal boundaries rarely coincide with watersheds, so these figures must be estimated. The Province Lake septic system survey conducted in the watershed in the summer of 2013 provided excellent data for this purpose. The survey included number of occupants, seasonal or year-round occupancy, type and age of wastewater system, and many other parameters. Using the survey responses, "full year equivalent occupants" was defined as the number of people times the percent of the year in the watershed. For example, a household with two occupants that spent one season at Province Lake would be treated as, 2 people x 25% of year = 0.5 full year equivalent occupants. Occupancy categories and seasonality were interpreted as follows:

- Survey answer "1-2 people" = 2;
- "3-4 people" = 3.5;
- "5-6 people" = 5.5;
- "more than 6 people" = 8;
- "more than 50 people" = 60;
- "more than 75 people" = 100;
- "one season" = 25% of year;
- "more than one season" = 50% of year; and
- "full year" =100% of year.

The number of full year equivalent occupants was calculated for each of the following types of systems, with assigned phosphorus attenuation rates:

- New septic system (less than 20 years old), 90% phosphorus attenuation;
- Old septic system (more than 20 years old), 80% phosphorus attenuation;
- Cesspool / outhouse, 75% phosphorus attenuation;
- Electric, composting, or portable toilet, 95% phosphorus attenuation; and

- Other / no response, 60% phosphorus attenuation.

The number of full year equivalent occupants accounted for in the septic survey, as described above, was 334. The survey focused only on the 250' shoreland zone around the lake and tributaries, and therefore not all watershed residents are accounted for by the survey. The septic survey was considered representative of conditions throughout watershed, and total population in the watershed was estimated as follows. The total number of households in the watershed was assumed to be 400, based on FBE counting 394 buildings in the watershed using aerial photos, and AWWA generating a list of 403 addresses in the watershed as they prepared for the septic survey. The number of households responding to the survey was 220. Dividing 220 responding households by 400 total households results an estimated 55% of the watershed population represented by the survey. Dividing 334 full year equivalent occupants accounted for in the survey by 55% of watershed households surveyed generates an estimate of 607 full year equivalent occupants in the watershed. The occupant and wastewater loading estimate for the entire watershed obtained from the above methods are presented in Table 2, with total phosphorus load from wastewater estimated at 81.4 kg per year, which was increased to 88.7 kg per year during overall model calibration.

Table 2: *Watershed population, and phosphorus and water loading from wastewater systems.*

Wastewater Category	Estimated Phosphorus Reduction	Full Year Equivalent Occupants	Water per Person per Day (m^3)	P Conc. (ppm)	Water Load (m^3/yr)	P Load (kg/yr)
New Septic System (<20 years old)	90%	174	0.25	8	15,927	12.7
Old Septic System	80%	251	0.25	8	22,895	36.6
Cesspool, Outhouse	75%	162	0.25	8	14,766	29.5
Electric, Composting, Portable Toilet	95%	11.6	0.01	8	42	<0.1
Other	60%	8.4	0.25	8	763	2.4
Totals		**607**			**54,394**	**81.4**

Waterfowl

The average annual number of waterfowl in the watershed were estimated at 35, present for half of the year, for Province Lake, based on observations made by FB Environmental on similar sized lakes in the White Mountains regions, and comments made by Province Lake Association members. Waterfowl can be a direct source of nutrients to lakes, however, if they are eating from the lake, and their waste returns to the lake, the net change may be less than might otherwise be assumed. If in the future, a more precise bird census is available, those numbers could easily be added to the model. Waterfowl load was estimated to be 3.5 kg TP per year.

Precipitation

Average annual precipitation was determined to be 48.65 in (1.24 m) per year based a weighted average of NOAA climate normals from the nearest six weather stations in the National Climatic Data Center database (NOAA 2014), as shown in Table 3. A climate normal encompasses thirty years of data (1981-2010).

Twenty four inches of precipitation per year was subtracted from the direct precipitation on the lake to account for evaporation (NOAA 1982). This adjustment did not reduce the estimate for atmospheric deposition of phosphorus, however, since evaporating water does not transport the nutrient away. Total atmospheric deposition load to the watershed was estimated to be 78.4 kg/year of TP.

***Table 3**: Precipitation data used in Province Lake LLRM.*

Stations	Latitude – Longitude	Distance to Province Lake (mi)	Direction from Lake to Station	Precipitation 1980-2010 (in/year)	Weighting
East Hiram ME	43.87861°, -70.75389°	17.6	east	49.94	17%
Tamworth 4 NH	43.8583°, -71.2597°	17.8	northwest	51.70	17%
West Buxton ME	43.6877°, -70.6127°	18.7	east	49.31	17%
North Conway NH	44.0302°, -71.1383°	23.9	north	49.60	17%
Rochester NH	43.27806°, -70.92222°	28.9	south	46.34	16%
Plymouth NH	43.78333°, -71.65°	33.3	west	44.33	15%

Other Data

Many model parameters, such as atmospheric deposition of phosphorus and water yield per unit land area, were considered regional in nature. Additional parameters were set as follows:

- Standard water yield (CFSM) = 1.7, default value within LLRM,
- Runoff and baseflow export coefficients (see above),
- Direct atmospheric deposition P export coefficient, and
- Water attenuation for each tributary basin was set according to guidance within LLRM documentation, ranging from 0.95 for areas with minimal wetlands and no ponds, 0.90 for tributary basins with medium sized wetlands or ponds, and 0.85 for those with large ponds or wetlands (see Table 4).

CALIBRATION

Calibration is the process by which model results are brought into agreement with observed data, and is an essential part of modeling. This process compares model predictions to empirical data obtained from many years of lake and tributary monitoring, then adjusts the model so its results better match empirical data. Usually, calibration focuses on the input data with the greatest uncertainty. Any changes made are kept within a plausible range of values, and an effort is made to find a realistic explanation among environmental conditions.

Tributary Phosphorus Concentrations

The first element reviewed is the in-stream phosphorus concentration for each tributary. The LLRM documentation indicates that typical in-stream attenuation factors for phosphorus range from 0.9 (10% removal of phosphorus) to 0.5 (50% removal), with lower values (i.e., more phosphorus removal) associated with large ponds and wetlands. Phosphorus loading is also influenced by water flow, with flow attenuation factors ranging from 0.95 (small to no ponds or wetlands) to 0.85 (large ponds or wetlands) being applied. (AECOM *et al*. 2011).

Two streams have been consistently monitored by VLAP since 1991, the South River (at the lake inlet near Route 153) and the Island Inlet, draining the unnamed southern tributary. These long-term data provide an excellent source of information to compare to the model results. A single year of data has been collected at three other sites over the summer of 2013; Hobbs Brook, the unnamed eastern tributary at the golf course, and the unnamed southwest tributary at the campground. While this dataset is very small and should not be considered representative of long term conditions, it nonetheless provides a basic reality check of model estimates.

The two tributaries with the most monitoring data show unusually high TP concentrations compared to what the uncalibrated model would predict. The South River has a very large wetland which runs virtually the entire length of the stream. Large wetlands like this tend to attenuate both flow and TP concentrations, and normally, this wetland would suggest that low attenuation factors for water (0.85) and phosphorus (0.50) be used. However, doing so results in a much lower predicted TP concentration (15 ppb) than that which is observed (33 ppb). Therefore, to calibrate the model in this basin, a lower water attenuation factor (0.75) and a larger phosphorus attenuation factor (0.85) were adopted. In other words, the wetland reduces flow a great deal, but does not reduce phosphorus very much. These figures bring the predicted in-stream concentration to 24 ppb TP.

Similarly, the unnamed southern tributary (at Island Inlet) has a large wetland near the mouth of the stream, which is expected to attenuate flow and TP. The uncalibrated model predicts TP of 16 ppb, while monitoring data indicate 35 ppb. Adjusting the flow attenuation factor to 0.80 and a phosphorus attenuation factor to 0.82 brings the predicted in-stream TP concentration to 22 ppb. These figures indicate somewhat less flow reduction and somewhat more phosphorus attenuation than in the South River, to account for the wetlands being smaller.

There remains a difference between predicted and observed in-stream TP values for the above streams, and in reviewing this difference, several factors were considered. First, a review of upland land use, recent satellite photos, and personal observation in the two subwatersheds did not indicate any sources of particularly high phosphorus inputs (e.g., row crops, high density neighborhoods, etc.) which could reasonably account for high in-stream concentrations despite large wetlands. Secondly, it was considered whether these wetlands could be among the exceptions which do not reduce TP concentrations. Ample research (Johnston 1991, Fisher and Acreman 2004, and Reddy *et al*. 1999) and FBE's experience in New England suggest that this is unlikely. Research by Zhang *et al*. (2012) suggests that in some cases, the ability of a wetland to attenuate flow may outpace the phosphorus attenuation, resulting in a higher in-stream concentration downstream of the wetland, although the overall load is reduced because there is also much less flow. Determining the true phosphorus dynamics in these wetlands could prove valuable as a future research project, although it is not necessarily recommended at this time.

A third factor considered was whether the in-stream sampling program may be measuring a higher TP concentration than the true annual average concentration. This possibility was considered the most plausible explanation, since discussion with the long-term volunteer water quality monitor indicated that samples were generally collected during dry weather and during the low-flow summer season. As a result, concentrations could have appeared higher if dilution by stream flow was consistently low.

Finally, the most important factor considered in calibrating the tributary TP concentrations was the model's ability to predict in-lake phosphorus concentrations. As described in the following section, the in-lake prediction for TP was acceptable based on the in-stream TP predictions described here. Both the model results and the empirical data suggest that the South River and the unnamed southern tributary may have relatively low phosphorus attenuation, which is possible given certain soil conditions (e.g., highly transmissive sandy soils). Another potential explanation is that human influenced activities and/or practices in the watershed tend to generate high phosphorus loading into the streams, such as onsite wastewater systems buried below seasonal high water table, use of phosphorus fertilizer on lawns, use of detergents containing phosphorus, and lack of adequate erosion control practices.

Data for other tributaries in the watershed is extremely limited (2013 only with n=4), and therefore maximum caution should be used in interpreting these results. Given the small sample size, only very minor adjustments were made to the modeled results in order to calibrate the empirical data in-lake TP concentration to the modeled results. The sampling data nonetheless provide a valuable initial comparison with modeled results.

- The south west tributary (campground) data showed an average of 11 ppb TP. Given that the campground is directly adjacent to the stream and extends all the way to the lake, relatively low attenuation settings were entered for the model. In-stream modeled TP concentration was 22 ppb.
- The eastern tributary (golf course) sampling data indicated an average TP concentration of 36 ppb. Flow attenuation was considered moderate, given the two detention ponds near the stream outlet. Phosphorus attenuation was considered very low. The in-stream modeled TP was high at 65 ppb, however, it was the second smallest mass load (16 kg/year) given its small basin size.
- Hobbs Brook in-stream modeled TP concentration of 22 ppb, compared to monitoring data average of 12 ppb.
- There are no data relating to direct shoreline drainage, however, the high modeled TP concentration of 43 ppb is reasonable given the proximity of this drainage area to the lake.

The in-stream calibration values, along with relevant data discussed above, are presented below in Table 4.

In- Lake Phosphorus Concentration

The second step in calibrating the model is comparing the in-lake predicted total phosphorus concentration with historical data. The median epilimnetic core TP value for Province Lake based on the past 10 years of data is 14.3 ppb, as documented in the recently completed water quality data analysis (FBE 2013). The model uses the in-stream phosphorus calculations, along with several other parameters such as lake volume, surface area, flushing rate, mean depth, and estimates in-lake phosphorus concentration as the average of several published methodologies. These include Kirchner-Dillon (1975), Larsen-Mercier (1976), Jones-Bachmann (1976), Reckhow General (1977), and Nurnberg (1998). Vollenweider (1975) and Mass Balance methods were excluded, as they tend to predict much higher values than the other models. The overall LLRM in-lake prediction matched the empirical data median of 14.3 ppb TP, due to the minor in-stream calibration adjustments described above. The final in-lake TP concentration was made to be exactly equal to the empirical data in order to avoid any confusion in subsequent analyses based on the model, such as phosphorus loading under future buildout conditions, watershed restoration scenarios, or natural conditions.

Table 4: *Empirical and modeled phosphorus concentrations, and attenuation factors.*

Tributary	Empirical Data (TP mg/L, mean)	Phosphorus Attenuation Features[1]	Phosphorus Attenuation Factor[2]	Flow Attenuation Factor[2]	Model Result (TP kg/year)	Model Result (TP mg/L)
Eastern Tributary (golf course)	0.036*	Small ponds	0.87	0.90	16.0	0.065
Hobbs Brook	0.012**	Large wetland	0.82	0.80	40.6	0.022
Province Lake Direct Drainage	no data	Small wetland	0.92	0.95	158.2	0.043
South River (Rte. 153)	0.033	Large wetland	0.80	0.75	54.4	0.024
South West Tributary (campground)	0.011*	None	0.90	0.90	35.6	0.027
Southern Tributary (Island Inlet)	0.035	Large wetland	0.82	0.80	10.1	0.022

[1] *Indicated size of feature is relative to subwatershed size.*

[2] *Attenuation factor of 0 means all phosphorus or flow is attenuated, 1 means no attenuation, >1 means phosphorus loading exceeds initial model result.*

** 2013 data only, n=4*

*** 2013 data only, n=2*

Results

LAKE LOADING RESPONSE MODEL RESULTS

Using NHDES bathymetry data (described above), the volume of Province Lake was calculated as 10,701,066 m^3. Given this lake volume and the water loading calculated by LLRM from atmospheric, runoff, and septic system sources, the flushing rate is estimated by the model to be 1.1 times per year. This compares to a flushing rate of once per year reported in NHDES trophic reports.

LLRM calculations are entered into a series of lake models which estimate phosphorus concentration, chlorophyll-a concentration, and Secchi disk transparency. The average of this series of models is the output of the LLRM model, and is summarized in Table 5. Water and phosphorus loading by category is presented in Table 6.

Table 5: *Phosphorus, chlorophyll-a and Secchi transparency for Province Lake based on LLRM.*

	Province Lake Model Estimate	**Province Lake Water Quality Data 2003-2012**
Total Phosphorus Concentrations (ppb)		
Mass Balance	38*	
Mean Annual P using Kirchner-Dillon 1975	12	
Mean Annual P using Vollenweider 1975	30*	
Mean Annual P using Larsen-Mercier 1976	20	**14.3 (median) 14.6 (mean)**
Mean Annual P using Jones-Bachmann 1976	21	
Mean Annual P using Reckhow General 1977	8	
Mean Annual P using Nurnberg 1998	11	
Average Mean Annual P	**14.3**	
Chlorophyll-a Concentrations (ppb)		
Mean Annual Chl-a using Carlson 1977	4.1	
Mean Annual Chl-a Dillon and Rigler 1974	3.4	
Mean Annual Chl-a Jones and Bachmann 1976	3.9	**3.8 (median)**
Mean Annual Chl-a Oglesby and Schaffner 1978	5.3	
Mean Annual Chl-a Modified Vollenweider 1982	7.2	
Average Mean Annual Chl-a	**4.8**	
Secchi Transparency (m)		
Oglesby and Schaffner 1978 (Avg)	3.0	**2.6 (mean)**
Modified Vollenweider 1982 (Max)	4.6	

** Excluded from averages.*

Table 6: *Province Lake total phosphorus (TP) and water loading summary*

Loads	TP (kg/year)	TP (%)	Water (m^3/year)	Water (%)
Atmospheric	78.4	16%	2,826,216	22%
Internal	0.0	0%	n/a	n/a
Waterfowl	3.5	<1%	n/a	n/a
Septic System	81.4	17%	54,394	<1%
Watershed Load	315.0	66%	9,806,021	77%
Total Load	**478.2**	**100%**	**12,686,632**	**100%**

Table 7: *Phosphorus loading to Province Lake by land use category.*

Land Use Category	Area		Phosphorus Sources by Land Use Type*	
	(ha)	(%)	(kg/year)	(%)
Developed	183	12%	166.3	53%
Agriculture	22	1%	15.2	5%
Forest	1,331	84%	130.9	42%
Wetlands	43	3%	2.5	<1%
Totals	**1,579**	**100%**	**294.8**	**100%**

**Accounts for in-stream attenuation through the various watersheds.*

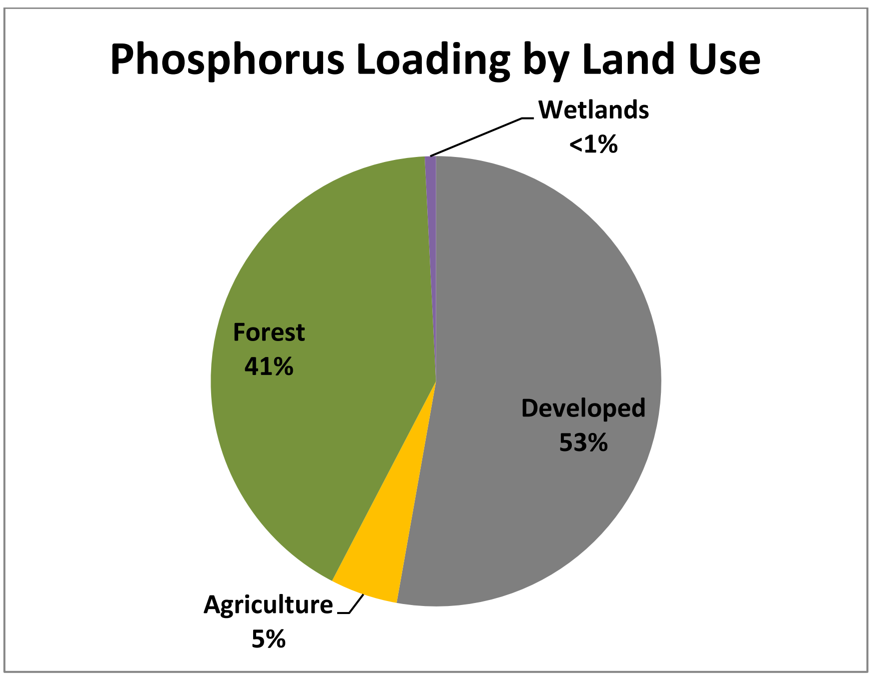

Figure 4: *Phosphorus loading by land use category.*

Discussion

EVALUATING RESULTS AND POTENTIAL FOR FURTHER MONITORING

Applying the LLRM model to Province Lake revealed several interesting points. First, the possibility of internal phosphorus loading due to mechanical (man-made) re-suspension of sediments by heavy boat traffic remains an open question. The little research available on this topic indicates an increase in phosphorus and increased potential for phytoplankton growth in shallow lakes. Future monitoring before, during, and after weekends with heavy boat traffic (including holiday weekends) might help determine whether boat traffic is increasing the phosphorus concentration in the lake, and by how much. This could have important lake management implications.

Secondly, LLRM predicts lower TP concentration in the South River and the unnamed southern tributary/Island Inlet than is shown in the two decades of monitoring data. The model predicts low TP concentrations in those streams, because there are large wetlands in each area. The wetlands may be providing significant phosphorus attenuation by reducing water flow, leaving a fairly high phosphorus concentration but low mass loading. Also, the monitoring program could be missing periods of the year where the TP concentration is lower, such as spring runoff, and the model could be accurately predicting the average annual TP concentration. One cause for concern is whether there are any wastewater systems installed below the seasonal high water table, which could cause pollutants including phosphorus and bacteria to travel further despite the wetland. Expanding the monitoring of these streams to include wet weather and/or springtime, and looking more closely for possible wastewater systems in wet areas could help clarify the true level of phosphorus loading from these streams.

SIGNIFICANCE OF MODEL RESULTS TO LAKE PROTECTION EFFORTS

The model estimates which tributary subwatersheds are the largest sources of phosphorus, and therefore are most in need of phosphorus reduction efforts. The tributary basins are sorted by phosphorus loading per hectare in Table 8, and shown geographically in Figure 5. Note that several tributaries have extremely limited empirical data, therefore the loading estimates are uncertain for those areas.

The largest per hectare land use loading, based on the model, comes from the unnamed eastern tributary, where the golf course is located. Based on the very limited water quality data available, the golf course seems to have a somewhat lower phosphorus loading rate than typical golf courses, which is good news. Nonetheless, this small catchment area still contributes the most phosphorus per unit area, and should be a high priority for lake protection efforts.

Direct shoreline drainages are typically among the highest load areas for most lakes given their close proximity to the lake. The model indicates that the shoreline drainage area provides the second highest phosphorus load per unit area to Province Lake. The direct shoreline to the lake deserves special attention in any lake protection plan, and Province Lake is no exception.

Both the model and the limited data from the unnamed south west tributary (campground) suggest that phosphorus concentrations are relatively high. The development pattern leaves very little natural vegetated buffer around the tributary and lake. Therefore, this basin should be included among the high priority areas.

Continued monitoring is an essential part of ensuring that wastewater systems and other lake protection practices in this densely populated area are working as designed.

The next two tributaries in order of phosphorus loading per area are unnamed southern tributary (Island Inlet) and the South River. Both the southern tributary and the South River have a long history of empirical data, which suggest a relatively high phosphorus concentration despite the model results. Flow in these streams could be lower than the model predicts, and flow monitoring could determine if that were the case. Alternately, phosphorus loading could be unusually high in those areas. Inspections by qualified personnel of wastewater treatment systems in those areas could determine whether onsite wastewater systems are inundated by spring high groundwater, a condition which compromises the system and greatly increases the transport of both nutrients and bacteria to the lake. Hobbs Brook also has very little empirical data, but both the model and the two data points indicate that this catchment sends the least amount of phosphorus per unit area to the lake. Hobbs Brook is a large catchment area, and deserves continued monitoring to confirm its low loading rate.

Table 8: *Tributaries by watershed loading (TP kg/ha/year).*

Tributary	Watershed Area (ha)	P Loading Model Result (TP kg/year)	P Conc. Model Result (TP mg/L)	Empirical Data (TP mg/L)	Watershed TP Loading (kg/ha/yr)
Eastern Tributary (golf course)	38	16.0	0.065	0.036*	0.43
Province Lake Shoreline	553	158.2	0.043	no data	0.30
South West Trib. (campground)	205	35.6	0.027	0.011*	0.18
Southern Tributary (Island In.)	82	10.1	0.022	0.035	0.13
South River	420	54.4	0.024	0.033	0.13
Hobbs Brook	314	40.6	0.022	0.012**	0.13

** 2013 data only, n=4*
*** 2013 data only, n=2*

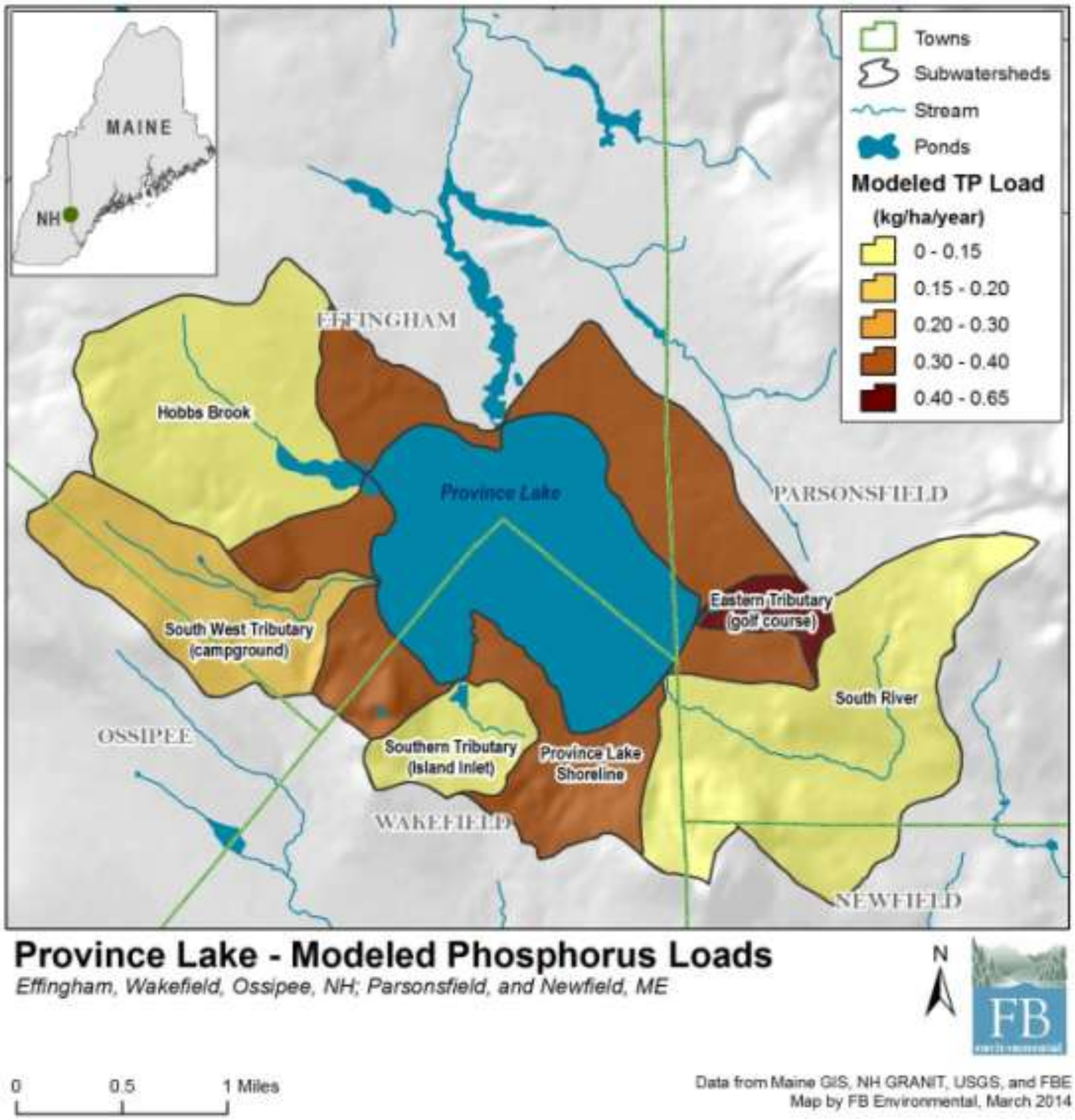

Figure 5: *Total Phosphorus loading by unit watershed area.*

Wastewater system phosphorus loading was modeled as the second largest source of phosphorus to the watershed. Results in Table 2 show that the combined categories of old septic systems, cesspools, and outhouses were estimated to provide over 81% (66.2 kg) of TP loading from the wastewater category. The single biggest risk for wastewater treatment failure is inundation of systems by groundwater, which greatly enhances the transport of phosphorus and pathogens from the system to the lake. It is critical to ensure not only adequate setbacks (horizontal distance) from the lake, but also good vertical separation from the seasonally high groundwater table. A strong wastewater inspection and maintenance program can reduce phosphorus and bacteria loading to Province Lake.

PHOSPHORUS LOADING UNDER NATURAL CONDITIONS AND BUILDOUT SCENARIOS

The LLRM was used to estimate how much phosphorus loading would occur to Province Lake under natural conditions. To do this, the area of developed land (residential, roads, agriculture, etc) was set to zero hectares, and an equivalent area of forest was added for each basin. Loading associated with wastewater systems was also set to zero. No changes were made to atmospheric or waterfowl sources, and the same calibration settings were used as for current condition modeling. The results were a total phosphorus load of 219 kg/year and an in-lake TP concentration of 6.6 ppb. Water load was also slightly reduced due to lower runoff coefficients for natural areas. Overall loading results are shown in Table 9.

Table 9: *Province Lake total phosphorus (TP) and water loading estimates for natural conditions.*

Loads	**TP** *(kg/year)*	**TP** *(%)*	**Water** *(m^3/year)*	**Water** *(%)*
Atmospheric	78.4	33%	2,826,216	22%
Internal	0.0	0%	n/a	n/a
Waterfowl	3.5	<2%	n/a	n/a
Septic System	0.0	0%	0	0%
Watershed Load	154.0	65%	9,977,278	78%
Total Load	**235.9**	**100%**	**12,803,494**	**100%**

The model was used to evaluate the effect of future construction, which was determined by a buildout analysis using CommunityViz software and information on zoning, wetlands, population and growth rates. In the intermediate term (year 2036), the in-lake TP concentration is expected to rise to 18.4 ppb, an increase of 29% In 2060 at full buildout, the TP concentration is expected to rise to 24.5 ppb, an increase of 72% over current conditions. Best management practices in land use and septic system construction and maintenance can greatly reduce this predicted future phosphorus loading. Details on the buildout analysis and associated phosphorus loading estimates can be found in a separate report by FBE. A summary of loading under natural, current, and buildout scenarios is presented in Table 10.

Table 10: *Phosphorus loading to Province Lake under natural, current, and buildout scenarios.*

	Source Category					**Province Lake**		
	Atmospheric *kg/year*	Internal Loading *kg/year*	Waterfowl *kg/year*	Septic Systems *kg/year*	Watershed *kg/year*	Total TP Load *kg/year*	In-Lake TP Conc. *ppb*	TP Load *kg/ha*
Natural Conditions	78	0	3.5	0	154	**236**	**6.9**	0.15
Current Conditions	78	0	3.5	81	315	**478**	**14.3**	0.30
Buildout in Year 2036	78	0	3.5	154	391	**627**	**18.4**	0.39
Buildout in Year 2060	78	0	3.5	237	518	**837**	**24.5**	0.52

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