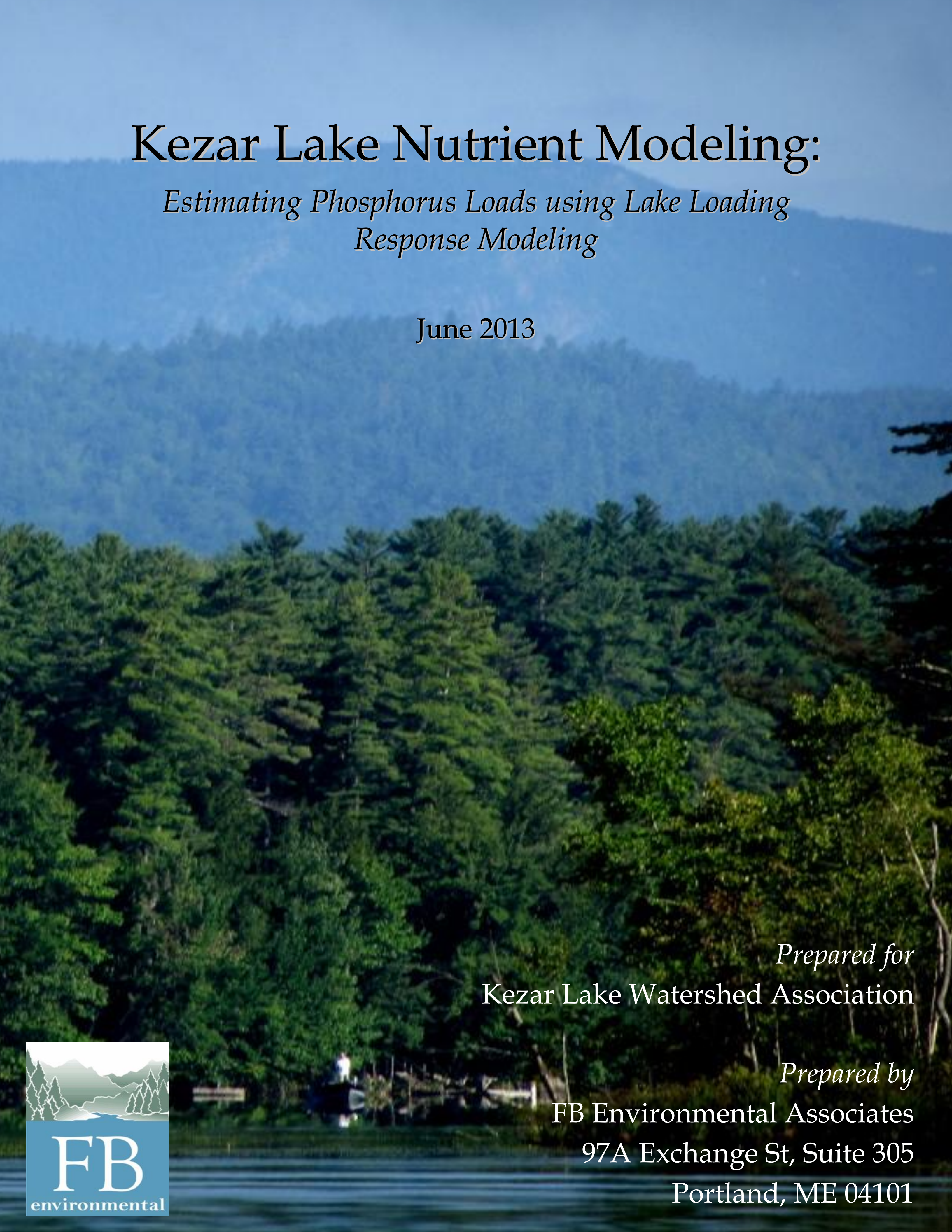

Kezar Lake Nutrient Modeling:

Estimating Phosphorus Loads using Lake Loading Response Modeling

June 2013

Prepared for
Kezar Lake Watershed Association

Prepared by
FB Environmental Associates
97A Exchange St, Suite 305
Portland, ME 04101

Kezar Lake Nutrient Modeling:

Estimating Phosphorus Loads using Lake Loading Response Modeling

For Kezar Lake, Lovell, ME

June 2013

FB Environmental Associates
97A Exchange St, Suite 305
Portland, ME 04101
(207) 221-6699
www.fbenvironmental.com

Table of Contents

Executive Summary

The Lake Loading Response Model (LLRM) estimates the water budget and phosphorus load to Kezar Lake based on land uses, population estimates, precipitation, waterfowl, and watershed boundaries. The model is in the form of two large Excel spreadsheets, one for upper basin and one for lower basin. To develop the model, new data were created, including detailed subwatershed boundaries, a land use layer, estimates of lake average depth and total volume, and estimates of new and old septic system based on US Census data. Key results:

- **Landscape runoff was estimated as the largest source of phosphorus to the lake**, at 64% for the upper basin, and 74% for the lower basin when the upper basin sources were factored in (of which 48% comes from lower basin watershed).
- **Rain falling directly on the lake surface was the second largest source** at 18% for the upper basin and 13% for the lower basin.
- **Septic systems were the third largest source** at 16% for the upper basin and 10% for the lower basin (4% of which is from the lower basin watershed).
- Waterfowl were a very small source at 2% or less.
- Upper basin provides 40% of lower basin's phosphorus.

Many years of data show that Kezar Lake has high water quality and low nutrient levels compared to many other Maine lakes. The long term trend for Kezar Lake has shown little to no change in water quality up to the present time. However, population and developed land continue to increase, which tends to put pressure on lake water quality. It is important for Kezar Lake watershed residents to be attentive to lake protection efforts to ensure that Kezar Lake remains a high quality gem.

Using the results from the model and methods used for many other lakes in Maine, the lake's assimilative capacity for phosphorus was estimated. Using a target phosphorus concentration that is protective of lake quality, results show that **10% too much phosphorus is entering lower basin**. To protect lower basin, phosphorus sources should be reduced in the entire watershed (upper and lower basin). Phosphorus reductions can be accomplished by preventing erosion, using phosphate-free detergents, and ensuring that all septic systems are functioning properly. Geographically, the most important areas to reduce phosphorus loading are (in order):

- Along the shore of Kezar Lake (both basins)
- Farrington Pond subwatershed
- Coffin Brook subwatershed
- Bradley Brook subwatershed
- Boulder Brook subwatershed
- Cold Brook subwatershed

Empirical water quality data were used to calibrate the model, meaning that loading estimates were adjusted to match available data. There are no empirical data for several large subwatersheds including Bradley Brook, Cold Brook, and Coffin Brook. In addition, there was an apparently large difference in the ability of Great Brook and Boulder Brook to attenuate phosphorus. This could be due to real ecological differences between the streams, or it could be caused by imperfect data. Measuring phosphorus concentrations of or in these currently unmonitored streams would be valuable to better understanding nutrient 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 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 the type of land uses in the watershed as 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 U.S. Environmental Protection Agency (EPA) requires that a Watershed Based Plan be created for communities to be eligible for watershed assistance 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 TMDL development and 2 lakes for watershed planning (Winnisquam and Granite). It has been applied for similar purposes to a number of other lakes and watersheds across the country. The Total Maximum Daily Load 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 Kezar Lake, as well as an explanation of the modeling results and limitations. The final outcome of this model will be used in the larger context of watershed management planning to 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 about 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. It is fortunate that there is a history of detailed water quality monitoring data for Kezar Lake, which contributes greatly to the model.

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 significant amount of effort went into creating a revised shapefile of watershed and drainage basin boundaries for this model using Geographic Information Systems (GIS). The following sources of data were consulted to create this file:

- Existing watershed map of Kezar Lake provided by Kezar Lakes Watershed Association (KLWA) to FBE in 2012.
- Subwatershed map of the six ponds located within the Kezar Lake watershed, provided by KLWA to FBE in 2012.
- Two foot vector contours (elevation) for the towns of Lovell, Stoneham, Stow and Mason Township from ME Office of GIS, 2012.
- Digital Elevation Model GIS layer from ME Office of GIS, 2012.
- Hydrography (streams, lakes, watersheds) layer from USGS, 2012.
- ME Land Cover Data layer from ME Office of GIS, 2004.
- Lake Depth Soundings data layer from ME Office of GIS, 2011.

FBE delineated additional subwatersheds using contour vectors, and the digital elevation model using ArcMap 9.3 software. Subwatersheds were created for each major tributary, and existing subwatersheds for ponds were retained. In the future, it might make sense to simplify the subwatershed map to eliminate very small subwatersheds in conservation areas (e.g., Mud Pond and Little Pond). The revised Kezar Lake subwatershed map developed for this modeling project is shown in Figure 1. The final GIS shapefile was provided to the Kezar Lake Watershed Association (KLWA).

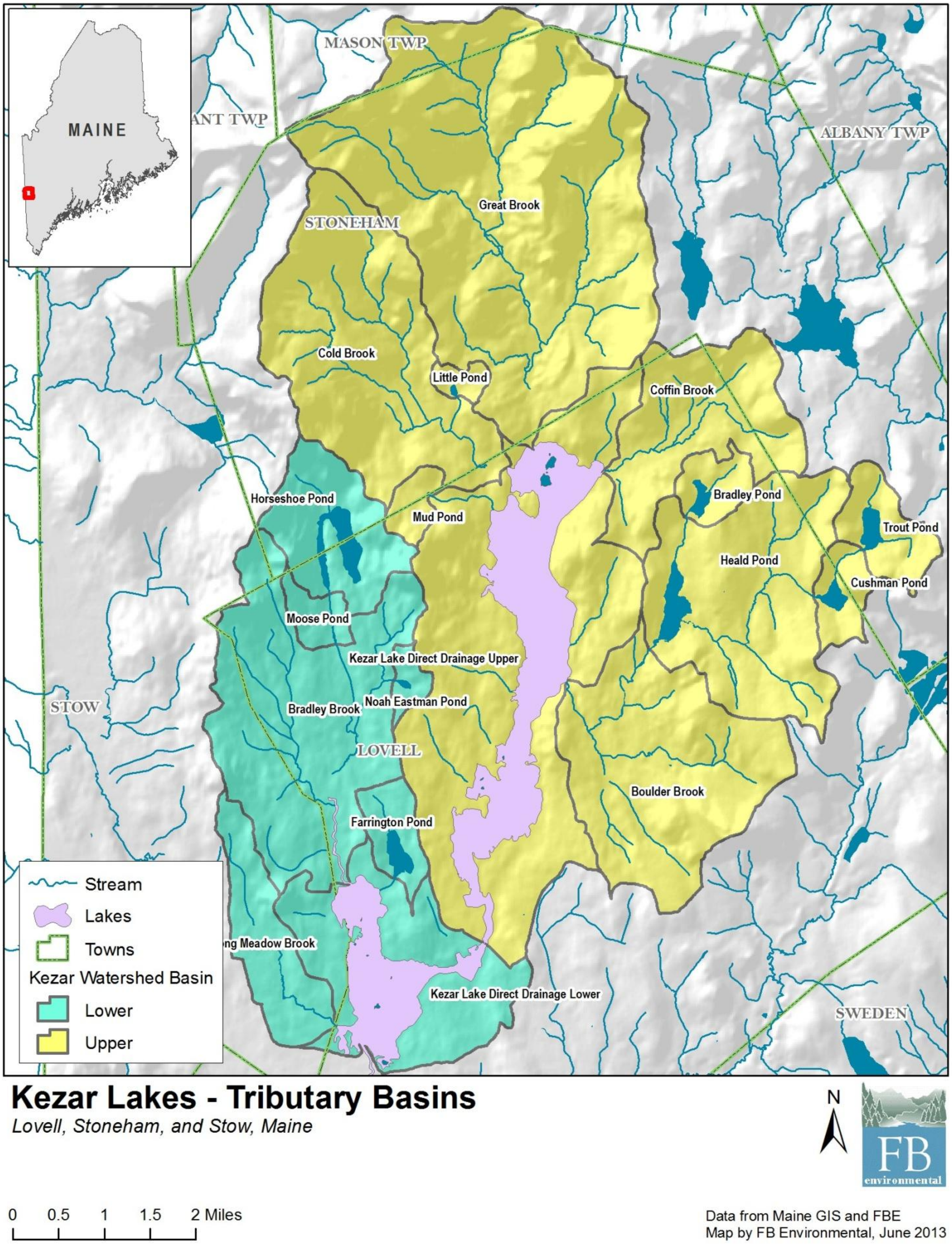

Figure 1: *Kezar Lake watershed and tributary drainage basins*

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 land cover data were modified in ArcGIS based 2011 NAIP Aerial Imagery, National Wetlands Inventory (NWI) data as well as knowledge gained from watershed visits by FB Environmental (FBE) during lake and stream sampling in recent years. The purpose of these modifications was to update the existing land use data, and to match the land use categories in the 2004 ME Land Cover Data to those used in the model. The 2004 ME 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 very carefully for accuracy. In addition, there were significant land use edits made to areas where new development has occurred since 2004. In many cases in the Kezar Lake watershed, new house lots, residential developments, urban development, and associated development were coded as forest land. These features were added to the land cover layer through reviewing aerial imagery. 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.

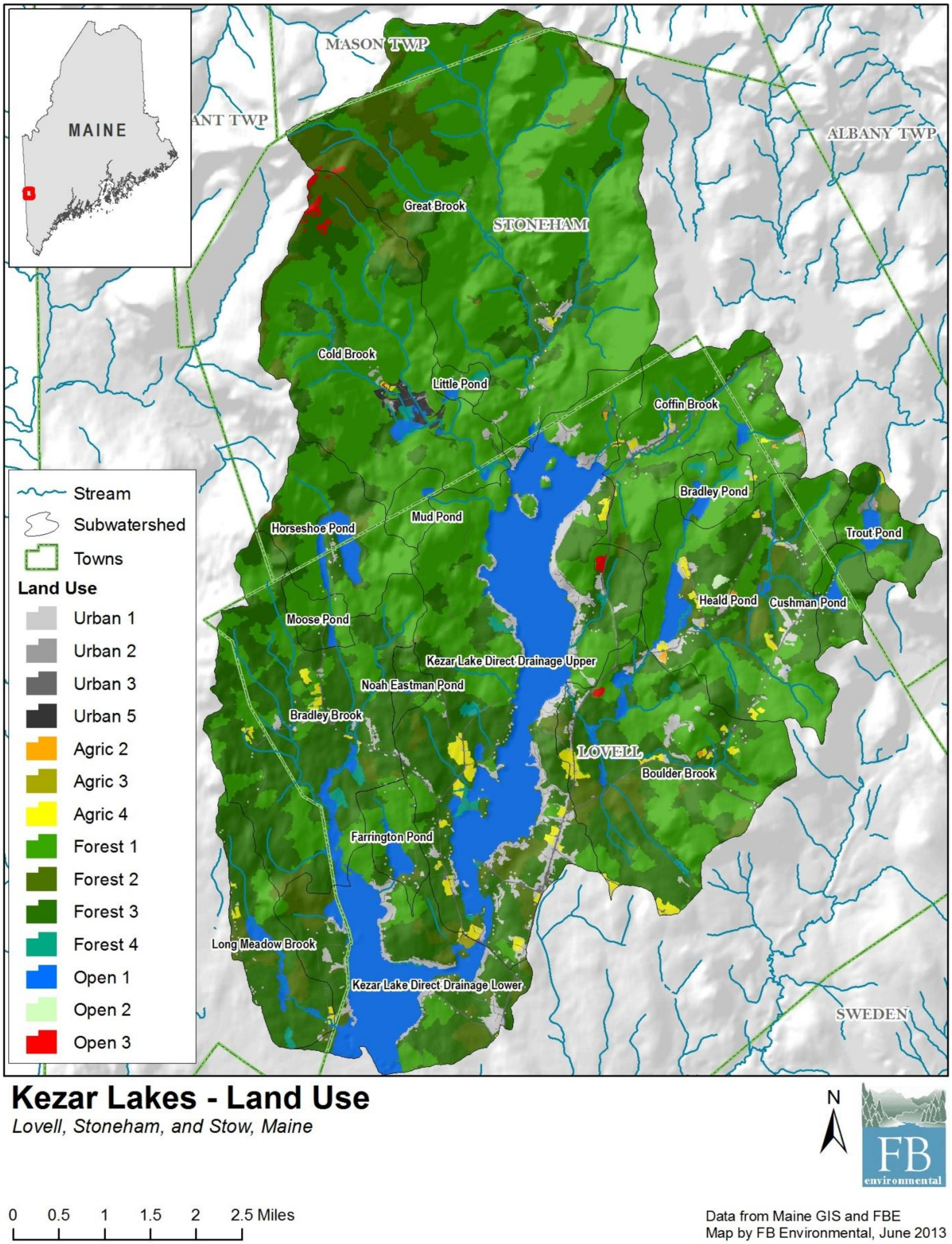

Figure 2: *Land uses in the Kezar Lake watershed. Land use codes in Table 1.*

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 and 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 base flow conditions. 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 the upper and lower basins of Kezar Lake as hectares (ha) and percentage of total. One hectare is equivalent to 2.5 acres.

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)**	Kezar Lake Upper Basins Area *(ha)*	*(%)*	Kezar Lake Lower Basin Area *(ha)*	*(%)*
Urban 1 (Low Density Residential)	0.9	0.01	196	3%	27.3	9%
Urban 2 (Mid Density Residential/Commercial)	1.1	0.01	29	<1%	18.5	6%
Urban 3 (Roads)	1.1	0.01	43	1%	17.4	6%
Urban 4 (Industrial)	1.1	0.01	0	0%	0.0	0%
Urban 5 (Mowed Fields)	1.1	0.01	64	1%	36.8	13%
Agriculture 1 (Cover Crop)	0.8	0.01	0	0%	0.0	0%
Agriculture 2 (Row Crop)	2.2	0.01	10	<1%	0.0	0%
Agriculture 3 (Grazing)	0.8	0.01	45	1%	0.0	0%
Agriculture 4 (Hayfield)	0.64	0.01	194	3%	0.0	0%
Forest 1 (Deciduous)	0.15	0.004	1,222	16%	15.8	5%
Forest 2 (Non Deciduous)	0.093	0.004	1,221	16%	36.4	12%
Forest 3 (Mixed)	0.093	0.004	3,980	52%	76.6	26%
Forest 4 (Wetland)	0.082	0.004	248	3%	2.8	1%
Open 1 (Wetland/Lake)	0.065	0.004	272	4%	60.9	21%
Open 2 (Meadow)	0.2	0.004	13	<1%	0.1	<1%
Open 3 (Excavation)	0.8	0.004	91	1%	0.3	<1%
Totals			**7,628**	**100%**	**293**	**100%**

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

Lake Volume Based on Lake Depth Soundings

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. Average lake depth was calculated using the 2011 lake depth soundings GIS layer from MEGIS. These data were used to calculate the volume of each basin by using the average of all depth soundings within each basin.

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 certain scenarios, however, this accumulated phosphorus can be released from the sediment and contribute to lake water quality problems. 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. Internal phosphorus loading can also result from physical disturbance of the sediment such as by dredging, dragging of anchors or fishing gear, or possibly heavy boat traffic.

A careful review of the oxygen profiles over the past 26 years was used to assess the possibility of internal loading in Kezar Lake. Anoxia is defined as DO ≤ 1 mg/L. Based on the *Kezar Lake & Ponds Historical Trend Analysis* written by FBE in 2012, potential for internal loading within Kezar Lake is very low in the upper and middle basins, and intermediate in the lower basin. The possibility of phosphorus leaving sediments in the deepest areas of the lake and made available for algae uptake is low, as there are very few instances were dissolved oxygen falls below 1 mg/L at greater depths. However, intermediate potential of internal loading in the lower basin may be attributed to seasonal changes and shallow depths. Based on this assessment, internal loading was assumed to be zero for the purpose of phosphorus modeling in Kezar Lake.

Septic System Loading

Septic systems are a source of both water and nutrients to the lake. Water travels through the system, then continues to move as groundwater, or subsurface flow above the level of groundwater, some of which flows into tributaries or lakes.

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 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).

Waterfowl

The average annual number of waterfowl in the watershed were estimated at 100 for the upper basin and 75 for the lower basin, based on on-lake observations at Kezar Lake by FBE since 2008. 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 can be added to the model easily.

Precipitation

Average annual precipitation was determined to be 48.7 in (1.24 m) per year based on NOAA climate normals, which encompass thirty years of data (1981-2010). Twenty 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.

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
- 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 2).

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. Changes are made within a plausible range of values, and an effort is made to find a realistic explanation among environmental conditions for these changes. In the case of the Kezar Lake phosphorus loading model, the in-stream and in-lake phosphorus concentrations were used as guideposts, and phosphorus attenuation factors, both in the tributary drainages and in the overall model, were adjusted to better match the monitoring data, thereby calibrating the model.

Calibrating Tributary Phosphorus Concentrations

The first adjustment point 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 (AECOM *et al*., 2011). Two tributaries to Kezar Lake, Great Brook and Boulder Brook, have phosphorus data collected over the past 5 years. In addition, Bradley, Cushman, Farrington, Heald, Horseshoe, and Trout ponds all had in-pond phosphorus concentration data collected at least 7 years, and more than 30 years in the case of Kezar Lake. Mean values for these streams and ponds were entered into the model as a “reality check,” and were used to adjust the model results. For several tributaries to Kezar Lake, there were no monitoring data, and a significant degree of uncertainty remains regarding phosphorus loading in those areas.

FB Environmental has noted that in-stream phosphorus levels are typically higher than lake epilimnetic core sample phosphorus concentrations in New England. Since the model estimates in-stream concentrations, each available empirical in-lake concentration was multiplied by 1.33%, and the in-stream model predictions were calibrated to this somewhat higher value. Ideally, the model would be calibrated to phosphorus concentrations collected at the outlet of each pond. The complexity is due to the highly nested nature of the watershed (multiple upstream confluences of streams and ponds). Observations were made for phosphorus attenuation factors in each tributary watershed. The in-stream calibration values, along with relevant data discussed above, are presented below in Table 2.

Calibrating Lake Phosphorus Concentration

The second step in calibrating the model is comparing the in-lake predicted total phosphorus concentration with historical data. The mean epilimnetic core TP value for the upper basin is 6 ppb, and for the lower basin is 9 ppb, based on the recently completed historical trends analysis (FBE 2012). The trends analysis encompassed data from 1971-2011, with station 1 used for the upper basin and station 3 for the lower basin. Note that the range of values over this time period for both basins was quite high, at 3 to 19 ppb for the upper basin and 6 to 29 ppb for the lower basin. Although showing high year-to-year variability, the mean total phosphorus value was stable over time.

For both the upper and lower basin, the uncalibrated in-lake model predictions were well within the range of historical observations. An overall calibration coefficient was applied in each basin to bring the predicted value in agreement with the observed mean. For the upper basin, an overall calibration coefficient of 0.57 brought the uncalibrated prediction of 9.22 ppb to the observed mean of 6.0 ppb. For the lower basin, an overall calibration coefficient of 1.35 brought the uncalibrated prediction of 8.15 ppb to the observed mean of 9.0 ppb.

Table 2: *Tributaries, attenuation factors, modeled phosphorus concentration, and empirical data on phosphorus concentration. Shaded cells indicate tributary basins without empirical data, and therefore greater uncertainty.*

Tributary	Basin	Discharges To	Phosphorus Attenuation Features[1]	Attenuation Factor[2]	Calibrated Model Result (TP kg/year)	Calibrated Model Result (TP mg/L)	Empirical Data (TP mg/L, mean)
Boulder Brook	Upper	Kezar L. Upper	Small wetland	0.75	254.8	0.014	0.015
Bradley Pond	Upper	Heald Pond	Large pond	0.40*	9.9	0.012	0.009 [P]
Coffin Brook	Upper	Kezar L. Upper	Small wetland	0.50	77.9	0.016	no data
Cold Brook	Upper	Kezar L. Upper	Medium wetland	0.50	125.0	0.013	no data
Cushman Pond	Upper	Heald Pond	Large pond	0.60	17.2	0.008	0.007 [P]
Great Brook	Upper	Kezar L. Upper	Medium wetland	0.33*	145.0	0.007	0.008
Heald Pond	Upper	Boulder Brook	Large pond	0.50	121.6	0.013	0.010 [P]
Direct (upper)	Upper	Kezar L. Upper	Small wetlands	0.60	342.1	0.019	no data
Little Pond	Upper	Cold Brook	Large wetland & pond	0.50	4.0	0.012	no data
Mud Pond	Upper	Kezar L. (indirect)	Medium wetland & small pond	0.60	8.3	0.014	no data
Trout Pond	Upper	Cushman Pond	Large pond	0.30*	10.1	0.007	0.005 [P]
Bradley Brook	Lower	Kezar L. Lower	Large wetland	0.80	183.4	0.017	no data
Farrington Pond	Lower	Kezar L. Lower	Large pond	0.80	18.8	0.019	0.015 [P]
Horseshoe Pond	Lower	Moose Pond	Large pond	0.40*	26.7	0.010	0.007 [P]
Direct (lower)	Lower	Kezar L. Lower	Small wetlands	0.90	161.6	0.028	no data
Long Meadow Brook	Lower	Kezar L. Lower	Large wetland	0.75	37.8	0.017	no data
Moose Pond	Lower	Bradley Brook	Medium wetland	0.75	31.7	0.011	no data
Noah Eastman	Lower	Bradley Brook	Medium pond	0.75	4.9	0.013	no data

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

[2] *Attenuation factor of 1 means no attenuation, 0 means all phosphorus is attenuated.*

[P] *Empirical phosphorus data is from epilimnetic core samples from pond rather than stream. In-stream model result calibrated 133% of this pond value.*

* *Attenuation factor outside of the typical 0.5 to 0.9 range indicated in the LLRM documentation.*

Results

LAKE LOADING RESPONSE MODEL RESULTS

Using GIS depth soundings data (described above), the volume of Kezar Lake was calculated as 118,975,732 m^3 for the upper basin, and 10,819,445 m^3 for the lower basin. 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 0.63 times per year for the upper basin, and 8.42 times per year for the lower basin. LLRM outputs 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 3. Water and phosphorus loading by category is presented in Table 4. The results below should be considered preliminary, as outlined in the discussion section below.

Table 3: *Post-calibration total phosphorus, chlorophyll-a and Secchi transparency values for Kezar Lake as predicted by the model (LLRM)*

	LLRM Upper Basin	**Upper Basin Trend Analysis 1971-2011**	**LLRM Lower Basin**	**Lower Basin Trend Analysis 1971-2011**
Total Phosphorus Concentrations (ppb)				
Mass Balance	11		11	
Mean Annual P using Kirchner-Dillon 1975	5		9	
Mean Annual P using Vollenweider 1975			10	
Mean Annual P using Larsen-Mercier 1976	6	**6.0 (mean)**	9	**9.0 (mean)**
Mean Annual P using Jones-Bachmann 1976	5		9	
Mean Annual P using Reckhow General 1977	5		7	
Mean Annual P using Nurnberg 1998	5		8	
Average Mean Annual P	**6.0**		**9.0**	
Chlorophyll-a Concentrations (ppb)				
Mean Annual Chl-a using Carlson 1977	1.2		2.1	
Mean Annual Chl-a Dillon and Rigler 1974	1.0		1.8	
Mean Annual Chl-a Jones and Bachmann 1976	1.1	**2.8 (mean)**	2.0	**2.4 (mean)**
Mean Annual Chl-a Oglesby and Schaffner 1978	0.5		2.3	
Mean Annual Chl-a Modified Vollenweider 1982	3.1		4.6	
Average Mean Annual Chl-a	**1.4**		**2.6**	
Secchi Transparency (m)				
Oglesby and Schaffner 1978 (Avg)	5.8	**7.6 (mean)**	4.3	**3.2 (mean)**
Modified Vollenweider 1982 (Max)	5.9		5.3	

Table 4: *Kezar Lake total phosphorus (TP) and water loading summary*

Loads to Upper Basin	**TP** *(kg/year)*	**TP** *(%)*	**Water** *(m^3/year)*	**Water** *(%)*
Atmospheric	149	18%	5,392,612	7%
Internal	0	0%	n/a	n/a
Waterfowl	20	2%	n/a	n/a
Septic System	132	16%	117,128	>0.2%
Watershed Load	539	64%	69,856,112	93%
Total Load To Upper Basin	**840**	**100%**	**75,365,852**	**100%**

Loads to Lower Basin	**TP** *(kg/year)*	**TP** *(%)*	**Water** *(m^3/year)*	**Water** *(%)*
Atmospheric	67	6%	2,408,215	2%
Internal	0	0%	n/a	n/a
Waterfowl	15	1%	n/a	n/a
Septic System	50	4%	43,996	>0.04%
Load from Upper Basin Inflow	452	40%	75,365,852	76%
Watershed Load	542	48%	21,351,049	22%
Total Load To Lower Basin	**1,080**	**100%**	**99,169,113**	**100%**

ASSIMILATIVE CAPACITY ANALYSIS RESULTS

Assimilative capacity refers to the amount of a substance that a waterbody may accept without causing impairment. The assimilative capacity for lakes in Maine is calculated using the Vollenweider model (Dillon and Rigler 1975), defined as:

Equation 1:

$$L = \frac{P(Azp)}{1-R}$$

Equation 2:

$$R = \frac{1}{1+\sqrt{p}}$$

Where:

L = external P load capacity (kg TP / year)
P = total P concentration (ppb); a target concentration expected to protect water quality
A = lake basin surface area (km^2)
z = mean depth of lake basin (m)
p = annual flushing rate
1 – R = P retention coefficient

In the above model, figures *a*, *z*, and *p* are taken from LLRM, and *P* is a target phosphorus concentration, typically chosen by regulators, which is considered protective of the lake. The target is typically set at 8 ppb, or the current concentration if it is less than 8 ppb. For Kezar Lake upper and lower basins, the assimilative capacity inputs and results are shown in Table ***5***.

Table 5: *Assimilative Loading Capacity Calculations for Kezar Lake Upper and Lower Basin*

	Kezar Lake Upper Basin	Kezar Lake Lower Basin
L = external P load capacity (kg TP/yr)	**1,020**	**980**
Current TP Loading Estimate (from LLRM)	**840**	**1,080**
P = total P concentration (ppb) *TARGET*	6	8
A = lake basin surface area (km^2)	7.455	3.329
z = mean depth of lake basin (m)	15.96	3.25
p = annual flushing rate	0.63	8.42
1-R = P retention coefficient	0.443	0.744
R = 1 / (1 + sq. rt. p)	0.557	0.256

Based on the current phosphorus loading model (LLRM) and the assimilative capacity calculations, the upper basin of Kezar Lake currently receives less total phosphorus than its assimilative capacity, while the lower basin receives more than its assimilative capacity. The upper basin receives an estimated 840 kg/TP/year, while the assimilative capacity for the upper basin alone is 1,020 kg/TP/year. Thus, upper basin is estimated to currently receive 82% of its assimilative capacity of phosphorus when considered alone. However, as will be described below, the overall analysis of Kezar Lake (upper and lower basin) shows that TP should nonetheless be reduced in the upper basin to protect the lower basin.

The lower basin is estimated to currently receive 1,080 kg TP/year. Current loading equals 110% of the assimilative capacity for phosphorus. This result is consistent with data showing an average annual TP concentration for the lower basin of more than 8 ppb. A reduction of 100 kg TP/year may reduce the in-lake TP concentration by 1 ppb, or from 9 ppb to 8 ppb in the lower basin. However, given the large indirect input of TP from the upper basin (40% of the total load), management of phosphorus inputs from the upper basin will be needed. No historical TP data exists for the lower basin before 1987, so, while it is assumed that TP concentrations were less than 9 ppb in previous decades, it is unknown how much lower.

Previous use of the Vollenweider (Dillon and Rigler 1975) type empirical model for Maine lakes, e.g., Cobbossee, Madawaska, Sebasticook, East, China, Mousam, Highland (Falmouth), Webber, Threemile, Threecornered, Annabessacook, Pleasant, Sabattus, Toothaker, Unity, Upper Narrows, Highland (Bridgton), Little Cobbossee, Long (Bridgton), Togus, Duckpuddle, Lovejoy, Lilly, Sewall, Cross, Daigle, Trafton, Monson, Echo, Arnold Brook, and Wilson Pond PCAP-TMDL reports (EPA 2000-2007) have all shown this approach to be effective in linking watershed total phosphorus (external) loadings to existing in-lake total phosphorus concentrations.

Discussion

Evaluating Model Accuracy and Potential Improvements

The Kezar Lakes watershed is among the more hydrologically complex lake systems, with water cascading through multiple ponds, and in many cases large wetlands, before finally entering the lake. The phosphorus dynamics of this system are therefore also complex. All mathematical models necessarily create a simplified representation of the ecosystem.

To account for this complexity, LLRM incorporates the ability to check intermediate model results using empirical data, and adjust the model so it is in better agreement with the data. This comparison was completed for Great Brook and Boulder Brook. However, several tributaries within the watershed have no empirical data. In particular, Bradley, Cold, and Coffin Brooks provide large inputs to the lake, and lack monitoring data. The model could be strengthened by collecting phosphorus concentrations in those streams just upstream of their confluence with the lake.

There are other tributaries for which pond data was used in lieu of stream measurements, and there is some uncertainty how the pond values relate to stream values. Collecting phosphorus concentrations at the outlets of those ponds would provide a marginal improvement in "ground truthing" and calibrating the model.

In conducting the model calibration for the tributaries, there was a very wide range of phosphorus attenuation coefficients. Values typically range from 0.9 (90% of TP from stream is delivered to the lake) to 0.5 (50% of stream TP goes to lake) in the LLRM. For the Kezar Lakes model, this value ranged from highs of 0.9 for direct watershed drainage in lower basin and 0.75 in Boulder Brook, to lows of 0.33 for Great Brook and 0.30 for Trout Pond. This variability suggests that either the watershed is highly variable from one place to another in its ability to attenuate phosphorus, or that there is some unaccounted for factor that would explain the differences. This wide range of values makes it difficult to predict what a reasonable attenuation factor should be for tributaries without empirical data. Further monitoring and research could reduce this uncertainty.

The assimilative loading capacity of the two lake basins generally accords with empirical data over the past decades, as described in the **Results** section above.

SIGNIFICANCE OF MODEL RESULTS TO LAKE PROTECTION EFFORTS

The LLRM model results can be used to indicate which tributary subwatersheds are the largest source of phosphorus, and therefore are most in need of phosphorus reduction efforts. The tributary basins are sorted by phosphorus loading per hectare in Table 6. Note that most tributaries have no empirical data, therefore the loading estimates are less certain for those areas. Direct watershed drainages are typically the highest load areas in most lakes, given their close proximity to the lake itself. The direct shoreline to the lake deserves special attention in any lake protection plan.

The difference between the two major stream tributaries (both with empirical data), Boulder Brook and Great Brook, is striking. Boulder Brook has relatively high loading per unit area, while Great Brook has very low loading. Logically, this is understandable given that much of Great Brook drainage area is in conservation as part of the White Mountain National Forest.

The pond watersheds show great variation in phosphorus loading, with Farrington Pond near the top, and Cushman and Trout Ponds near the bottom. The remaining ponds and streams do not have empirical data to "ground truth" the model, and given the wider than usual variation in phosphorus attenuation coefficients, those results must be considered preliminary only.

The assimilative capacity analysis for the upper basin is based on a target phosphorus concentration of 6 ppb, which is the current long term average of that basin. Accepting this target, the upper basin has some degree of reserve assimilative capacity, if considered alone. However, TP should be reduced in the upper basin to protect the lower basin, as described below. A buildout analysis, which models development growth in the future, can be used to evaluate if and when the upper basin may approach or exceed the target concentration.

The lower basin, by contrast, has already exceeded the assimilative capacity for a target in-lake concentration of 8 ppb, which was chosen to be consistent with the targets concentration set at many lakes throughout Maine. Empirical data shows TP of 9.0 ppb as a long-term average. Efforts at reducing this phosphorus load should be undertaken soon to reduce phosphorus loading by about 10% in order to reach the target concentration of 8 ppb. Since 76% of the lower basin's water flow and 40% of the phosphorus comes from upper basin, this goal requires a watershed wide approach to phosphorus reductions to improve the water quality in the lower basin.

Table 6: *List of tributaries by watershed loading (TP kg/ha/year). Shaded cells indicate tributaries without empirical data.*

Tributary	Basin	Watershed Area (ha)	Calibrated Model Result (TP kg/year)	Watershed TP Loading (kg/ha/yr)	Calibrated Model Result (TP mg/L)	Empirical Data (TP mg/L, mean)
Direct (lower)	Lower	1019	162	**0.159**	0.028	no data
Direct (upper)	Upper	2788	342	**0.123**	0.019	no data
Farrington Pond	Lower	160	19	**0.117**	0.019	0.015 p
Coffin Brook	Upper	738	78	**0.106**	0.016	no data
Long Meadow Brook	Lower	396	38	**0.096**	0.017	no data
Mud Pond	Upper	91	8	**0.091**	0.014	no data
Bradley Brook	Lower	2053	183	**0.089**	0.017	no data
Boulder Brook	Upper	2884	255	**0.088**	0.014	0.015
Cold Brook	Upper	1440	125	**0.087**	0.013	no data
Noah Eastman	Lower	65	5	**0.076**	0.013	no data
Little Pond	Upper	54	4	**0.075**	0.012	no data
Heald Pond	Upper	1665	122	**0.073**	0.013	0.010 p
Bradley Pond	Upper	141	10	**0.070**	0.012	0.009 p
Horseshoe Pond	Lower	480	27	**0.056**	0.010	0.007 p
Moose Pond	Lower	582	32	**0.054**	0.011	no data
Great Brook	Upper	2952	145	**0.049**	0.007	0.008
Cushman Pond	Upper	377	17	**0.046**	0.008	0.007 p
Trout Pond	Upper	229	10	**0.044**	0.007	0.005 p

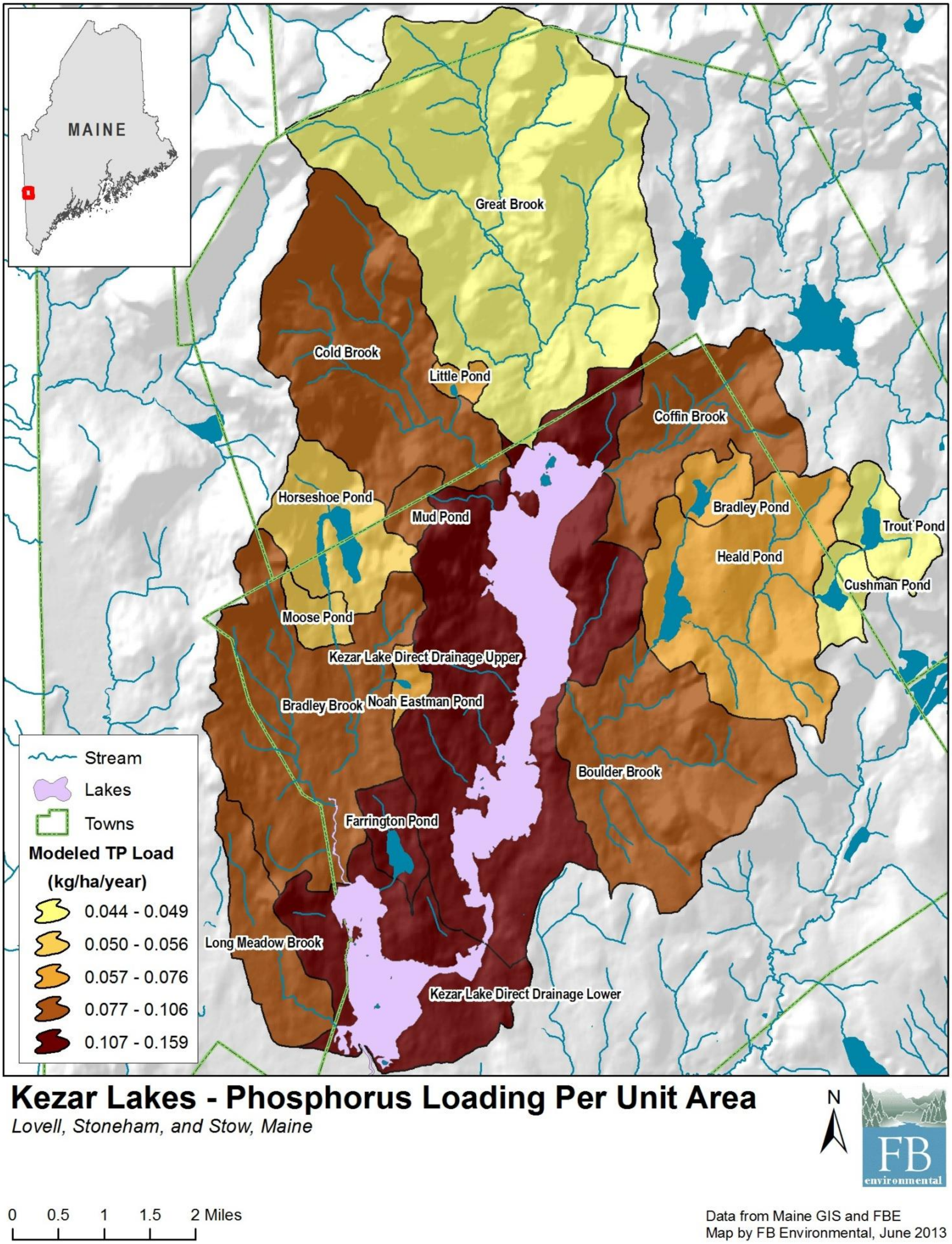

Figure 3: *Total Phosphorus loading by unit watershed area.*

References

AECOM and NHDES. January 2011. Total Maximum Daily Load for Forest Lake, Winchester, NH. Original AECOM Document Number: 09090-107-13, July 2009; final revisions made by NH Department of Environmental Services, January 2011. Prepared for EPA Region 1, Project: EPA-SMP-07-002.

Dillon, P.J. and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. Journal of the Fisheries Research Board of Canada 32:1519-1531.

Harman, J, W. Robertson, J. Cherry, L. Zanini. 1996. Impacts on a sand aquifer from an old septic system: nitrate and phosphate. Ground Water, vol. 34, n. 6, pages 1105-1114, 1996.
via SCOPE Newsletter. 2006. Special Issue: fate of phosphorus in septic tanks. No. 63. January 2006. Accessible online: http://www.ceep-phosphates.org/Files/Newsletter/Scope%20Newsletter%2071.pdf

FB Environmental Associates (FBE). 2012. Kezar Lake & Ponds Historical Trend Analysis. Lovell, ME. FB Environmental Associates, July 2012.

Lombardo P. 2006. Phosphorus Geochemistry in Septic Tanks, Soil Absorption Systems, and Groundwater. Prepared by Lombardo Associates, Inc., Newton, MA.

Lusk, M., G.T. Toor, and T. Obreza. 2011. Onsite Sewage Treatment and Disposal Systems: Phosphorus. University of Florida IFAS Extension. Series Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, SL349. Originally published July 2011. Accessible online: http://edis.ifas.ufl.edu/ss551

Johnson, K., and A. Atwater. 1988. Role of saturated and unsaturated zone in soil disposal of septic tank effluent. Can. J. Civ. Eng., vol. 15, 1988, pages 709-716.

National Oceanic and Atmospheric Administration (NOAA). 2013. Summary of Monthly Normals 1981-2010 for station Fryeburg Eastern Slopes Regional Airport, Maine. Accessed online May 30, 2013: http://www.ncdc.noaa.gov/cdo-web/quickdata

US Environmental Protection Agency (USEPA). 2002. Onsite Wastewater Treatment Manual. EPA/625/R-00/008

U.S. Environmental Protection Agency. 2000a. Cobbossee (Cobbosseecontee) Lake TMDL Final Approval Documentation #1. US-EPA/NES, January 26, 2000.

U.S. Environmental Protection Agency. 2000b. Madawaska Lake TMDL Final Approval Documentation #2. US-EPA/NES, July 24, 2000.

U.S. Environmental Protection Agency. 2001a. Sebasticook Lake TMDL Final Approval Documentation #3. US-EPA/NES, March 8, 2001.

U.S. Environmental Protection Agency. 2001b. East Pond (Belgrade Lakes) TMDL Final Approval Documentation #4. US-EPA/NES, October 9, 2001.

U.S. Environmental Protection Agency. 2001c. China Lake TMDL Final Approval Documentation #5. US-EPA/NES, November 5, 2001.

U.S. Environmental Protection Agency. 2003a. Highland (Duck) Lake PCAP-TMDL Final Approval Documentation #6. US-EPA/NES, June 18, 2003.

U.S. Environmental Protection Agency. 2003b. Webber Pond PCAP-TMDL Final Approval Documentation #7. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003c. Threemile Pond PCAP-TMDL Final Approval Documentation #8. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003d. Threecornered Pond PCAP-TMDL Final Approval Documentation #9. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003e. Mousam Lake PCAP-TMDL Final Approval Documentation #10. US-EPA/NES, September 29, 2003.

U.S. Environmental Protection Agency. 2004a. Annabessacook Lake PCAP-TMDL Final Approval Documentation #11. US-EPA/NES, May 18, 2004.

U.S. Environmental Protection Agency. 2004b-c. Pleasant (Mud) Pond PCAP-TMDL Final Approval Documentation #12-13. US-EPA/NES, May 20, 2004 (also Cobbossee Stream).

U.S. Environmental Protection Agency. 2004d. Sabattus Pond PCAP-TMDL Final Approval Documentation #14. US-EPA/NES, August 12, 2004.

U.S. Environmental Protection Agency. 2004e. Highland Lake (Bridgton) PCAP-TMDL Final Approval Documentation #15. US-EPA/NES, August 12, 2004.

U.S. Environmental Protection Agency. 2004f. Toothaker Pond (Phillipston) PCAP-TMDL Final Approval Documentation #16. US-EPA/NES, September 16, 2004.

U.S. Environmental Protection Agency. 2004g. Unity (Winnecook) Pond PCAP-TMDL Approval Documentation #17. US-EPA/NES, September 16, 2004.

U.S. Environmental Protection Agency. 2005a. Upper Narrows Pond PCAP-TMDL Final Approval Documentation #18. US-EPA/NES, January 10, 2005.

U.S. Environmental Protection Agency. 2005b. Little Cobbossee Lake PCAP-TMDL Final Approval Documentation #19. US-EPA/NES, March 16, 2005.

EPA Final Review Document – April 2008 Long Pond PCAP-TMDL Report 55

U.S. Environmental Protection Agency. 2005c. Long Lake (Bridgton) PCAP-TMDL Final Approval Documentation #20. US-EPA/NES, May 23, 2005.

U.S. Environmental Protection Agency. 2005d. Togus (Worrontogus) Pond PCAP-TMDL Final Approval Documentation #21. US-EPA/NES, September 1, 2005.

U.S. Environmental Protection Agency. 2005e. Duckpuddle Pond PCAP-TMDL Final Approval Documentation #22. US-EPA/NES, September 1, 2005.

U.S. Environmental Protection Agency. 2005f. Lovejoy Pond PCAP-TMDL Final Approval Documentation #23. US-EPA/NES, September 21, 2005.

U.S. Environmental Protection Agency. 2006a. Lilly Pond PCAP-TMDL Final Approval Documentation #24. US-EPA/NES, December 29, 2005. Corrected and approved April 1, 2008.

U.S. Environmental Protection Agency. 2006b. Sewall Pond PCAP-TMDL Final Approval Documentation #25. US-EPA/NES, March 10, 2006.

U.S. Environmental Protection Agency. 2006c-d. Daigle Pond PCAP-TMDL Final Approval Documentation #26-27. US-EPA/NES, September 28, 2006 (also Daigle Brook).

U.S. Environmental Protection Agency. 2006e-f. Cross Lake PCAP-TMDL Final Approval Documentation #28-29. US-EPA/NES, September 28, 2006 (also Dickey Brook).

U.S. Environmental Protection Agency. 2007a. Trafton Lake PCAP-TMDL Final Approval Documentation #30. US-EPA/NES, October 26, 2006.

U.S. Environmental Protection Agency. 2007b. Monson Pond PCAP-TMDL Final Approval Documentation #31. US-EPA/NES, November 28, 2006.

U.S. Environmental Protection Agency. 2007c. Echo Lake PCAP-TMDL Final Approval Documentation #32. US-EPA/NES, February 5, 2007.

U.S. Environmental Protection Agency. 2007d. Arnold Brook Lake PCAP-TMDL Final Approval Documentation #33. US-EPA/NES, February 5, 2007.

U.S. Environmental Protection Agency. 2007e. Wilson Pond PCAP-TMDL Final Approval Documentation #34. US-EPA/NES, August 29, 2007.

Weiskel and Howes. 1992. Differential transport of sewage-derived nitrogen and phosphorus through a coastal watershed, Environ. Sci. Technol., vol. 26, n. 2, P. Weiskel, Geology Dept., Boston University; B. Howes, Biology Dept., Woods Hole Oceanographic Institution, Woods Hole, MA

Woods, JSA. 1993. Migration of septic-system contaminated groundwater to a lake in a Precambrian shield overburden setting, MSc Thesis University of Waterloo Ontario, Geochemistry.
via SCOPE Newsletter. 2006. Special Issue: fate of phosphorus in septic tanks. No. 63. January 2006.
Accessible online: http://www.ceep-phosphates.org/Files/Newsletter/Scope%20Newsletter%2071.pdf

Zanini, L., W. Robertson, C. Ptacek, S. Schiff, T. Mayer .1998. Phosphorus characterization in sediments impacted by septic effluent at four sites in central Canada, Journal of Contaminant Hydrology 33, pages 405-429.
via SCOPE Newsletter. 2006. Special Issue: fate of phosphorus in septic tanks. No. 63. January 2006.
Accessible online: http://www.ceep-phosphates.org/Files/Newsletter/Scope%20Newsletter%2071.pdf