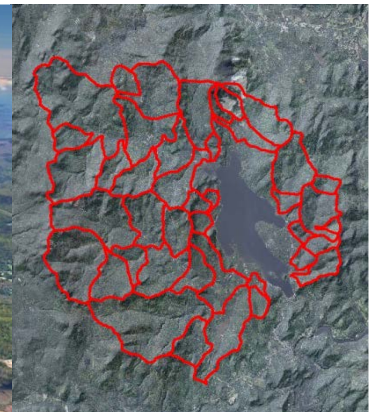
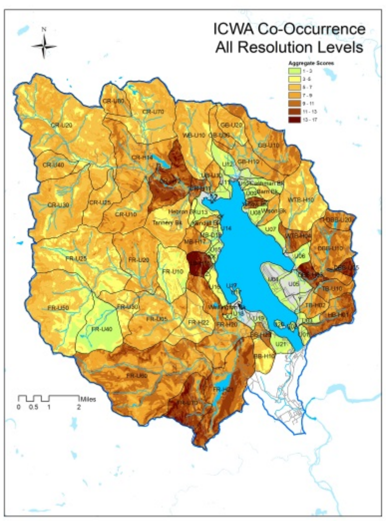
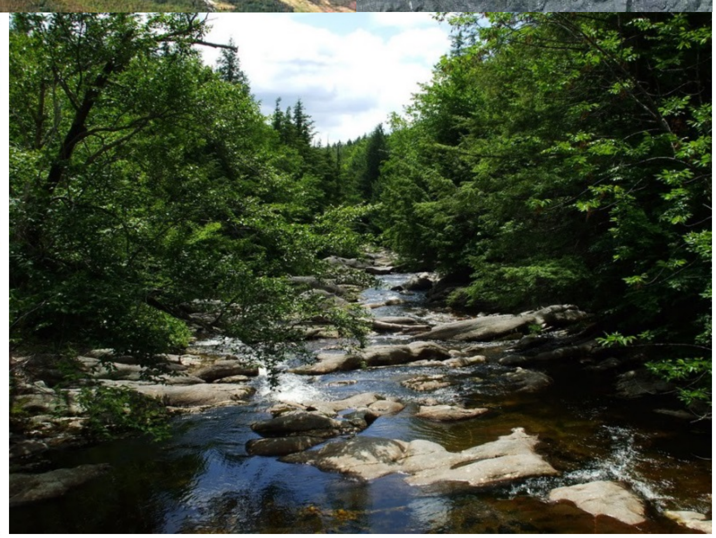
NEWFOUND LAKE WATERSHED MODELING REPORT (2013)

University of New Hampshire Center for Freshwater Biology
and University of New Hampshire Cooperative Extension



Prepared by the University of New Hampshire Center for Freshwater Biology
as part of the Newfound Lake Watershed Management Plan

A Project of the Newfound Lake Region Association with the following partners

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TABLE OF CONTENTS

PREFACE AND ACKNOWLEDGEMENTS

The Newfound Lakes Region Association (NLRA), in conjunction with the University of New Hampshire Center for Freshwater Biology (CFB) and the UNH Cooperative Extension Water Resources Program, undertook this watershed modeling effort as a compilation of a series of previous studies intended to provide a research-based assessment of the Newfound Lake watershed and Newfound Lake water quality. This project was undertaken to provide local decision-makers and the public the required analyses to develop a well-informed watershed management strategy in the form of a Watershed "Master Plan". This report builds upon the findings of two previous Newfound Lake Watershed Assessments (Craycraft and Schloss 2009, 2011). The earlier study was an extensive two year sampling effort that focused on Newfound Lake deep water stations, shallow water stations close to shore, embayed lake and tributary areas, additional selected tributary inlets and in-lake sediment conditions. The most recent study added additional analysis of the deep water lake sites, investigated historical lake station trends and also focused on the headwater stream subwatersheds within the lake's major contributing tributaries. The watershed modeling exercise, contained herein, relied on the Newfound Lake Tributary Assessment (Craycraft and Schloss, 2008) that characterized the water and phosphorus load into Newfound Lake during 2006 and 2007 to parameterize, calibrate and "truth" the watershed loading and lake response model.

The Newfound Lake Region Association, under the guidance of Boyd Smith (Executive Director) and Nikki Wooster-Goodwin (Program Director), was responsible for directing and coordinating this as well as all related project efforts pertaining to the Phase 3 Watershed Assistance Grant from the NH Department of Environmental Services (DES) with Clean Water Act Section 319 funds from the U.S. Environmental Protection Agency (EPA). Dan Sundquist, formerly with the Society for the Protection of New Hampshire Forests and currently with GreenFire GIS, offered guidance and provided digital mapping support, conducted spatial and landcover/landuse analyses at the subwatershed level, re-delineated watershed and subwatershed boundaries to accommodate historical and current focused monitoring efforts, digitized building locations and impacted areas, assisted in creating visualization of the data analyses and managed the extensive GIS based Newfound Lake and Watershed Natural Resources Inventory. Bob Craycraft, UNH Cooperative Extension Educational Program Coordinator, NH Lakes Lay Monitoring Program, assisted in reconciling and updating subwatershed boundaries and provided his extensive knowledge of the water quality and watershed conditions gained from directing and conducting the recent water quality monitoring efforts that this study used in its synthesis. Don Kretchmer, Senior Limnologist at AECOMM provided the LLRM model template used for this study.

Steve Landry, New Hampshire DES Merrimack Watershed Supervisor, acted as project liaison and provided input, guidance and assistance with the development and implementation of the Newfound Watershed Master Plan (WMP) initiative that will utilize the recommendations contained in this report in a watershed wide planning and management effort. Andy Chapman, NH DES Watershed Management Bureau, provided input regarding model choices for this undertaking. Jillian McCarthy, New Hampshire Department of Environmental Services (DES) Quality Assurance Coordinator, Vincint Perelli, New Hampshire DES Quality Assurance Manager, and Charles Porfert, Environmental Protection Agency (EPA) New England Quality Assurance Officer, provided technical support and reviewed the Site Specific Project Plan (SSPP) that documents the watershed modeling and lake response modeling procedures used in this study.

Project support at the Center CFB for this effort at the University of New Hampshire was provided by the UNH Cooperative Extension Natural Resources Program Team and the College of Life Sciences and Agriculture.

The sustained long-term monitoring of Newfound Lake and the recent nutrient/water budget and headwater sampling efforts are a testament to the critical contributions made by participants in the New Hampshire Lakes Lay Monitoring Program co-administered by UNH Cooperative Extension and the CFB . In addition, many UNH students contributed to these efforts working as laboratory, field and data-entry technicians. Each of the cited reports above contains a listing of the names of these volunteers and students. Their efforts made these projects possible in a cost-efficient manner while also providing real world experience for our students and empowering the local communities to become better informed on the status of their water resources and the range of stewardship efforts that they may employ.

EXECUTIVE SUMMARY

PURPOSE AND OBJECTIVES

Newfound Lake is a "high quality" water with deep water clarity, low productivity (algae and plant growth) and a healthy lake ecology. The Newfound Lake watershed, the land that contributes water to the lake, is located in the Towns of Alexandria, Bristol, Bridgewater, Danbury, Dorchester, Groton, Hebron, Plymouth and Orange. With continued development pressures facing local decision-makers in the nine towns, the need exists for scientifically-based information that will provide support for proactive natural resource based planning within the Newfound Lake watershed. This modeling project is a major component of the larger watershed master planning initiative that relies on expertise in land-use and watershed planning, survey design and interpretation, education and outreach. The collective expertise of the professionals involved in this project will help educate the public and local municipal officials and should help foster informed land-use planning decisions and allow for focused preventive and corrective actions at specific critical watershed sites that will benefit future generations by preserving the high quality waters that occur in Newfound Lake.

This 2013 Newfound Lake watershed modeling is a synthesis of historical and recent Newfound Lake and tributary water quality monitoring and analysis efforts that included:

- In-lake water quality sampling at seven Newfound Lake deep water sampling locations monitored since the late 1990's that added to the long-term database, facilitated continued trend detection and assessed Newfound Lake's trophic status.
- Tributary sampling at pre-existing and expanded headwater stream tributary sampling sites to document water quality variations among sampling locations and to screen for problem
- Paired watershed sampling in twelve selected stream inlets to investigate impacts of various levels of development within the watershed.
- Intensive near-shore water quality sampling at thirty shallow sampling stations.
- Artificial substrate sampling (at three in-lake sampling stations and one site located in the Fowler River) that mimics algae growth on rocks in the shallows to document that even low density development results in higher algae production compared to non-developed reference sites.
- Bottom sediment (benthic) core sampling at twenty three lake and stream sampling stations to check the potential for internal nutrient loading in the lake.

- An intensive 18-month Newfound Lake Watershed Assessment to develop a water/phosphorus budget by monitoring 23 tributaries and their corresponding subwatersheds, the outlet, and modeling 23 additional near shore "runoff" subwatersheds with no perennial water flow (Craycraft and Schloss, 2008)
- Long-term water quality monitoring on two Newfound Lake deep water sites since 1986 through the UNH based NH lakes Lay Monitoring Program.

It also relies on the analysis of an extensive geographical information system (GIS) spatial environmental database for Newfound Lake and its watershed lands that had been developed and maintained by the Society for the Protection of New Hampshire Forests and currently is managed by GreenFire GIS.

SCOPE

This modeling effort is primarily designed to provide an analysis of the various landscape and land use factors that control nutrient loadings to the lake that then drives the resulting productivity (algae and aquatic plant growth) of the lake. Our focus is on total phosphorus, the limiting (and thus, controlling) nutrient for aquatic plant and algal growth in New Hampshire lakes. While moderate levels of nutrients are important for providing the algae and plants that serve as the base of the aquatic food web of a healthy lake, nutrient overload will cause excessive productivity that can lead to algae blooms and poor lake water quality that in turn, can have negative effects on the lake's aquatic organisms as well as impacts on human health and lake use.

The major task for this synthesis effort was to parameterize and calibrate a watershed nutrient loading model that would provide input to a lake water quality response model. Oftentimes watershed and lake modelers can only use best estimates of the nutrient loadings for various land use conditions within the study watershed. For this study we had the luxury of a recently completed water/nutrient budget study that allowed us to better choose those land use loading coefficients as well as to calibrate water flows and nutrient attenuation within each of the major contributing subwatersheds.

The model, once calibrated can then allow for providing the answer to "what if" type of questions involving past, current and future population growth, development and land use changes. While some studies go to the extreme of predicting what would be the resulting lake water quality changes with full watershed build-out, as the Newfound Lake Watershed is exceptionally large and as Newfound Lake Region watershed communities are more focused on preserving the exceptional water quality that most areas of the lake currently exhibit, the development scenarios run in this analysis included:

1. Pre-development conditions- i.e. no development and all lands forested except for existing wetlands to indicate what Newfound Lake's most pristine conditions might be.

While most likely similar to pre-settlement conditions, as the Newfound outlet has a water control structure (dam) the current lake area and volume that the model incorporates may not have been equivalent to conditions before settlements were introduced.

2. Headwater stream (sub-watershed) annual forest cuts at a range of extent: 10% cut, 20% cut and 30% cut.
3. Approximate 30 year growth in low and medium density development throughout the watershed including estimates of additional septic system load for those development units within 250 feet from shore.

The Newfound Lake Region Association now has the ability to run additional model scenarios as the need arises assuming that the input data required is available. It can also update and re-calibrate the model as any missing or updated information is collected through continued monitoring and through surveying watershed conditions.

It should be noted that modeling septic system extent to estimate septic system phosphorus loading impact was not in the original scope of this project. It was undertaken as a result of feedback from local decision-makers and watershed stakeholders. Certain assumptions from Geographical Information System (GIS) analysis, other NH studies and best professional judgment were used for the estimate. However, a better estimate may be made if a shoreline survey of residents is undertaken to confirm those assumptions.

MODEL CALIBRATION: WHAT WE LEARNED

Average subwatershed slope, road density, stream density and extent (percent) of disturbed land (developed, agriculture, cleared greater than 5%) within the subwatershed were the landscape level watershed attributes that influenced total phosphorous (TP) attenuation (reduction of loading) negatively. Variable riparian buffer extent determined by stream order and the presence of greater than 1 percent of wetlands/water were landscape characteristics that have a positive effect on increasing TP attenuation. Calibration coefficients resulted in less than a 1 percent difference between the models and measures TP watershed loading rates. To maintain the current water quality of Newfound Lake the areal phosphorus loading for any area needs to be kept at or below 0.068 kg TP per hectare per year.

LAKE RESPONSE MODEL RESULTS

Newfound Watershed "pre-development" conditions as modeled had almost half of the current level of TP loading resulting in about half of the current Newfound in-lake TP concentration as well as half of the current mean chlorophyll *a* concentration. Predictions suggest the average water clarity would increase to 10.6 meters (almost 35 feet) and a maximum clarity of over 14 meters (over 47 feet!) could occur.

For the logging scenarios a 10 percent forest cut (1,835 hectares or about 4,500 acres of the entire watershed, or 10% of a subwatershed (realistic based on recent logging operations in Hebron and Groton) will increase the TP load from the watershed by almost 40 percent. The lake response would be an increase in productivity to almost moderate productivity levels (mesotrophic) and a loss in water clarity of over 1 meter.

Looking at the thirty year growth projections TP watershed load would be increased by 49 percent over current conditions and the chlorophyll *a* concentrations would be borderline mesotrophic (a moderate productivity level). Water clarity would be reduced by 1.6 meters over current conditions. As the first 30 year development projection kept the TP attenuation static with current levels this most likely would not be the case. Taking that into account the 30 year change in TP loading could be as much as a 91 percent increase- essentially a doubling of watershed TP load. Chlorophyll *a* would double over current conditions and clarity would be reduced by over 2 meters. In any case, development "as usual" will cause the water quality of Newfound Lake to degrade significantly.

INTEGRATED CRITICAL WATERSHED ANALYSIS

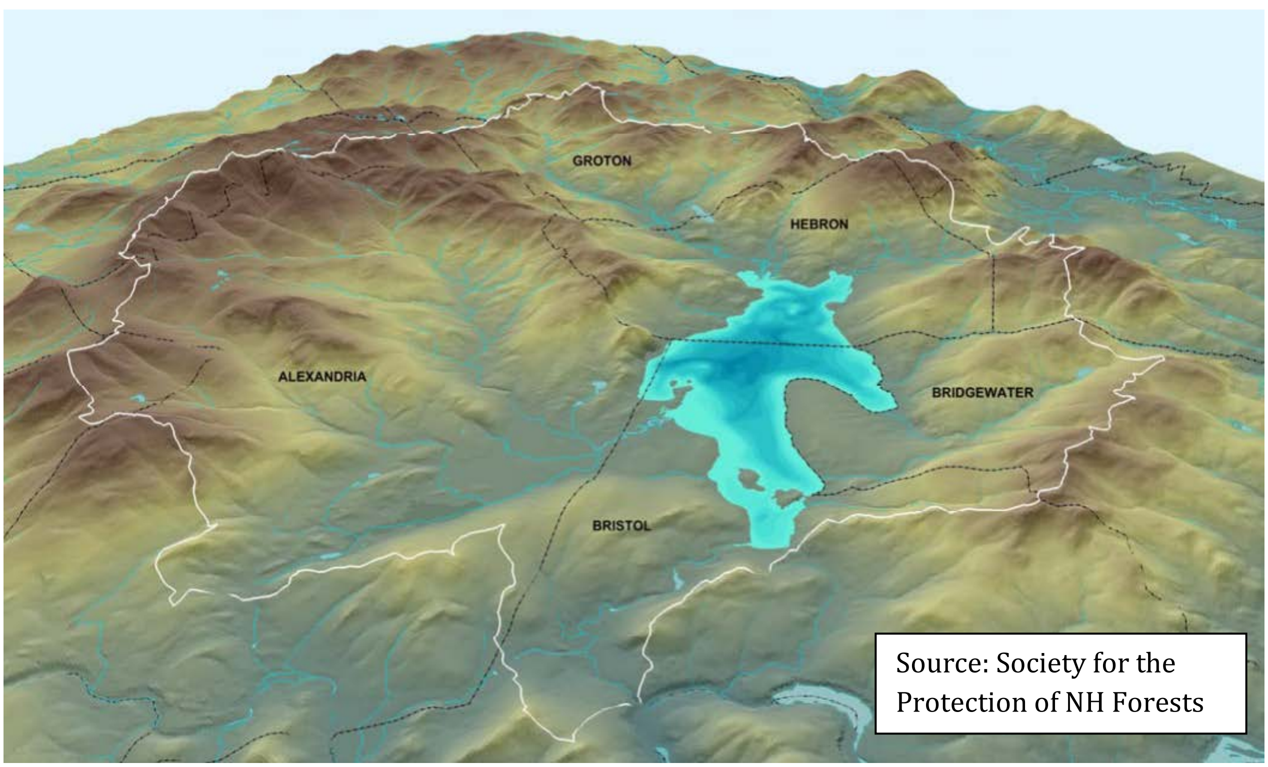
The analysis shows that the most critical watersheds for maintaining Newfound's high water quality currently include the Dick Brown Brook lower subwatershed (DBB-H3) and one of the headwater subwatersheds (DB-U5), Post Office Brook, the two lower Cockermouth River subwatersheds (CR-H11 and CR-H12), and the Ledges Brook subwatershed. Secondarily and close behind are Hemlock Brook, the lower Whittemore Brook, Yellow Brook, and the lower Fowler River and both Bog Brook. Any subwatersheds that feed into these critical subwatersheds should also be flagged for a higher level of land-use management if large land use change is being proposed. It should also be noted that both the 2008 water/nutrient budget and the model indicate that the major sources of TP loading come from the Fowler (48% of the channelized TP load), Cockermouth (18.8%), Georges Brook (4.3%), Dick Brown Brook (3.6%) and Whittemore Brook (3.2%).

WATERSHED LOAD AND LAKE RESPONSE MODELING

INTRODUCTION

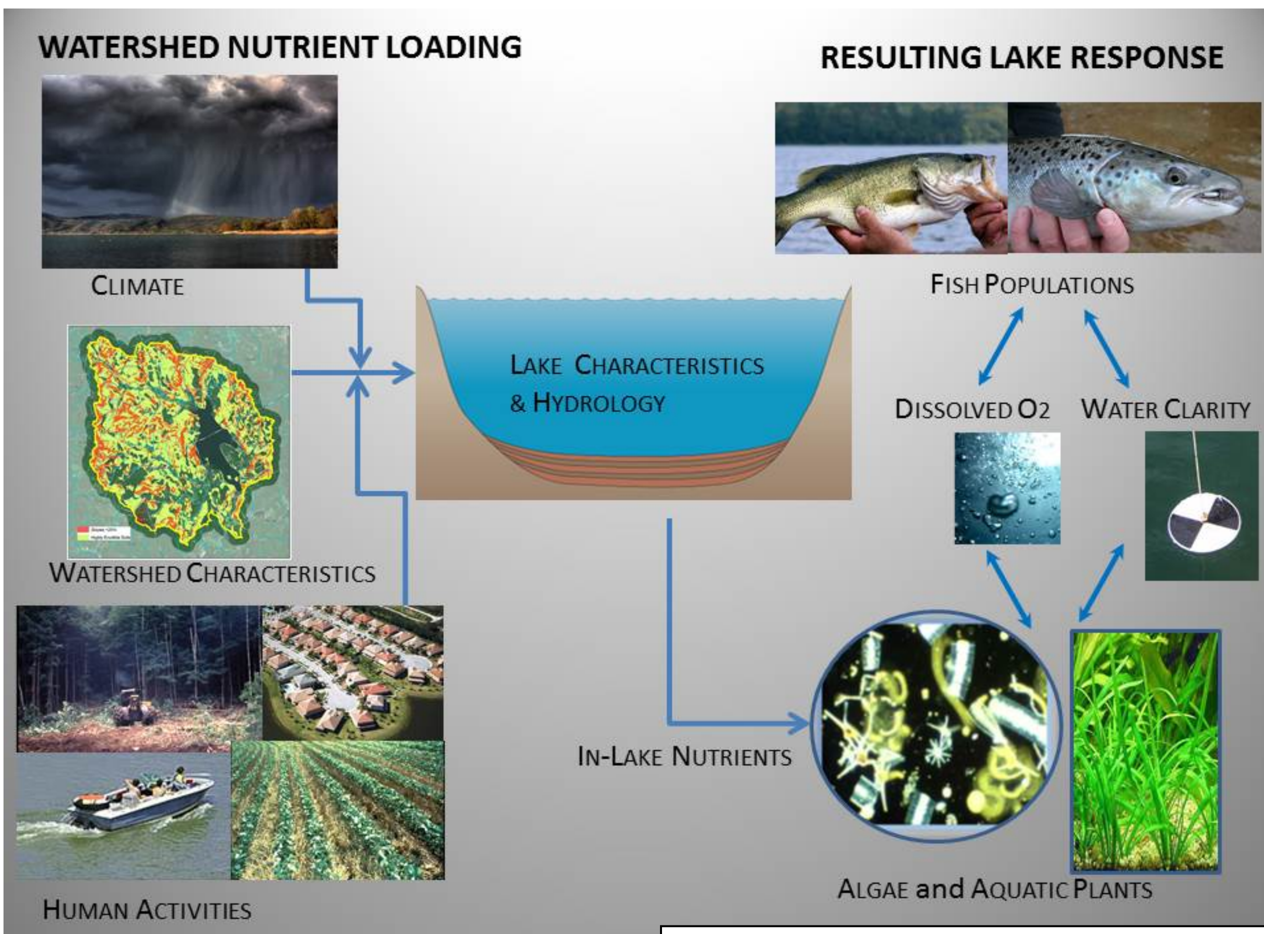
The Newfound Lake Watershed, the geographic area in which all rain and snowmelt water drains into Newfound Lake, is closely tied to water quality and quantity in Newfound Lake (Figure 1). Stated another way, a lake is a reflection of its watershed; what occurs in the watershed can have significant impacts on whether the water quality improves, degrades or remains the same. Newfound Lake currently contains some of the clearest and healthiest waters that can be found in New Hampshire and the New England Region. As population growth occurs in the Newfound Lake Region and the resulting pressures from development and recreational use ensue, there is growing concern over the potential for degradation of lake water quality. The subsequent impacts can include algal blooms, establishment of nuisance aquatic weeds, shoreline scums, and increased sedimentation at tributary outflows and within the lake. The consequent symptoms from these impacts would include: a loss of water clarity, a declining fishery (as well as a decline in the lake's overall ecological integrity), and an increase in public health concerns related to contact recreation (Figure 2). Thus, the pristine and high quality waters currently contained within Newfound Lake face a number of potential threats.

Figure 1. Shaded Relief map of the Newfound Lake Watershed



Of primary concern are the impacts of increased nutrient loading caused by human activities in the watershed that result in accelerated plant growth (submerged and emergent vascular plants, and planktonic or attached algae) within the lake. Nutrients can come from many sources and include surface runoff resulting from precipitation upon the natural and developed areas of the lake's watershed. Additional nutrients are transported into the lake through stream inflow, groundwater, septic system effluent that leaches into groundwater and even from precipitation and dry fallout (dust particles). Activities within the watershed, such as the construction of residential subdivisions, retail centers and factories, agricultural and logging activities, and road and highway construction result in removing or damaging protective vegetation, duff layers (leaf litter) and soils that, when left in an undisturbed and natural state, trap nutrients before they reach wetlands, streams, lakes and ponds. Roads, driveways and drainage ways are "impervious surfaces" that increase channelized flow that tends to transport more runoff volume and nutrient laden materials through the watershed and into the lake. Improper and unneeded fertilizer applications for agriculture and homeowner landscaping can also add to the nutrient load that reaches the lake.

Figure 2. Generalized Watershed Nutrient Loading and Lake Response Model Schematic



Substantially modified and expanded from Reckow et al. 1980.

The two nutrients most important to the growth of aquatic plants are nitrogen and phosphorus. It is generally observed that phosphorus is the more limiting to plant growth in lakes, and therefore the more important to monitor and control. Phosphorus is generally present in lower concentrations than nitrogen, and its sources arise primarily through human activity in a watershed. The total phosphorus discussed in this report includes dissolved phosphorus as well as phosphorus contained in or adhered to suspended particles such as sediment and plankton. Previous studies of the Newfound Lake Watershed (Craycraft and Schloss 2011) indicate that particulate phosphorus (phosphorus attached to sediments, soils, plankton and detritus) represents the majority of the phosphorus loading, 75 percent to 97 percent. This is contrary to the expected 50%:50% of other Northern New England studies in low density developments (Dennis 1986) but not surprising given the typically steep slopes and the predominately highly erodible soils found throughout the Newfound Lake watershed (see discussion in the Newfound Lake Watershed Master Plan). Particulate phosphorus lends itself to capture by vegetation (particularly upland woodland buffers) and settling within the tributaries but once in the lake it will settle out on the sediments and can be made available by processes at the sediment water interface whereas dissolved phosphorus is very chemically "sticky" and can attached itself to vegetation but once in the water has a greater tendency to be flushed out of the lake if not immediately used by aquatic plants or algae.

As little as 10 parts per billion of phosphorus in a lake can cause an algal bloom. Using a full Olympic swimming pool as an example, it would take 10 drops of water added to the approximately 130,000 gallons of water to equal 10 parts per billion. Extensive blooms will block sunlight and can depress oxygen levels in the water due to the death and subsequent microbial decomposition of plant and algal matter. Reduced oxygen concentrations can be detrimental to fish, plants and wildlife of the lake and can also result in the degradation of aesthetic quality due to events such as fish kills and accumulations of decaying material (muck) along the lake bottom. When the oxygen, dissolved in the water over the sediments, becomes reduced below two milligrams per liter (2 parts per thousand), phosphorus, the majority of which usually binds to the lake sediments and remains unreactive, can be released driving the productivity even higher.

Thus, it is important to obtain an understanding of the sources and amounts of phosphorus supplied to a lake from its watershed in order to attempt the reduction and/or management of its input to the surface waters. The best method to achieve this is to conduct field sampling and derive a water and phosphorus budget. This has been achieved and summarized in a previous report (Craycraft and Schloss, 2008). While watershed modeling does not necessarily require a nutrient and water budget to make phosphorus loading and lake response estimates, having such data allows for a higher level of calibration and thus, greater confidence in using such a model.

This modeling effort and analysis represents the synthesis of long and short-term studies previously accomplished through the efforts of the Newfound Lake Region Association and its partnership with the UNH Center for Freshwater Biology and UNH Cooperative Extension (see Craycraft and Schloss 2008, 2009 and 2011) that included:

- In-lake water quality sampling at seven Newfound Lake deep water sampling locations monitored since the late 1990's that added to the long-term database, facilitated continued trend detection and assessed Newfound Lake's trophic status.
- Tributary sampling at pre-existing and expanded headwater stream tributary sampling sites to document water quality variations among sampling locations and to screen for problem
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It also relies on the analysis of an extensive geographical information system (GIS) database for Newfound Lake and its watershed lands that had been developed and maintained by the Society for the Protection of New Hampshire Forests and currently is managed by GreenFire GIS.

Watershed Loading and Lake Response Model Selection

There are two models that have been typically used in recent New Hampshire lake modeling projects: the Spreadsheet Tool for Estimating Pollutant Load (STEPL; US EPA 2006) and the Lake Loading Response Model (Kretchmer and Wagner 2011) formerly known as SHEDMOD or ENSR-LLRM. Both are midlevel spreadsheet models that lend themselves to relatively straightforward parameterization and allow for calibration by varying a number of factors. This study incorporates the LLRM model as it is the most straightforward in terms of setting the nutrient loading coefficients for specific land cover/land uses and it relies on separate attenuation settings to calibrate the water volume and the nutrient loading. STEPL relies on working through the universal soil loss equation modeling so loading coefficients and volumes are estimated from watershed factors that include rainfall, soil erodability, slope gradient, crop management and erosion management while calibration typically relies on modifying water runoff curve numbers for various land uses as well as manipulating a “rainfall initial abstraction factor” that takes into account rainfall retention by the landscape. There is some disagreement on setting this value or our regional conditions (see discussion in Tarpey 2013). Since STEPL has its major strength in dealing with predominately agricultural watersheds, and as the Newfound Watershed is predominately forested the LLRM was chosen to be more appropriate to use for the purposes of informing lake managers and the public.

DATA SOURCES USED IN WATER QUALITY MODELING

Geographic Information System (GIS) data for this study originating from various sources listed below were mostly obtained through the state’s GIS data clearinghouse, NH GRANIT (www.granit.sr.unh.edu). Dan Sundquist, formerly at the Society for the Protection of New Hampshire Forests (SPNHF) and now with GreenFire GIS performed the majority of subwatershed delineations and the spatial analyses at the subwatershed level used for modeling inputs.

- All water quality sampling stations were derived from high resolution Trimble Pathfinder hand-held Global Positioning System (GPS) measurements made on site and corrected to sub-meter accuracy using Pathfinder Office post-processing software and data from the NH Department of Transportation (NH DOT) GPS base station in Concord, NH.

- Gauged and ungauged drainages into Newfound Lake were digitized using US Geological Survey (USGS) stream catchment data derived from the SPARROW water quality modeling project in N.H. as an initial guide, and then refined using topographic contours to delineate watersheds using each sampling station as the “pour point” for the gauged subwatersheds and the lake for ungauged subwatersheds that represented the “runoff” drainages.

- Slope data were derived from USGS Digital Elevation Model data at 10-meter resolution, classified to match Natural Resources Conservation Service (NRCS) soils mapping slope classes.

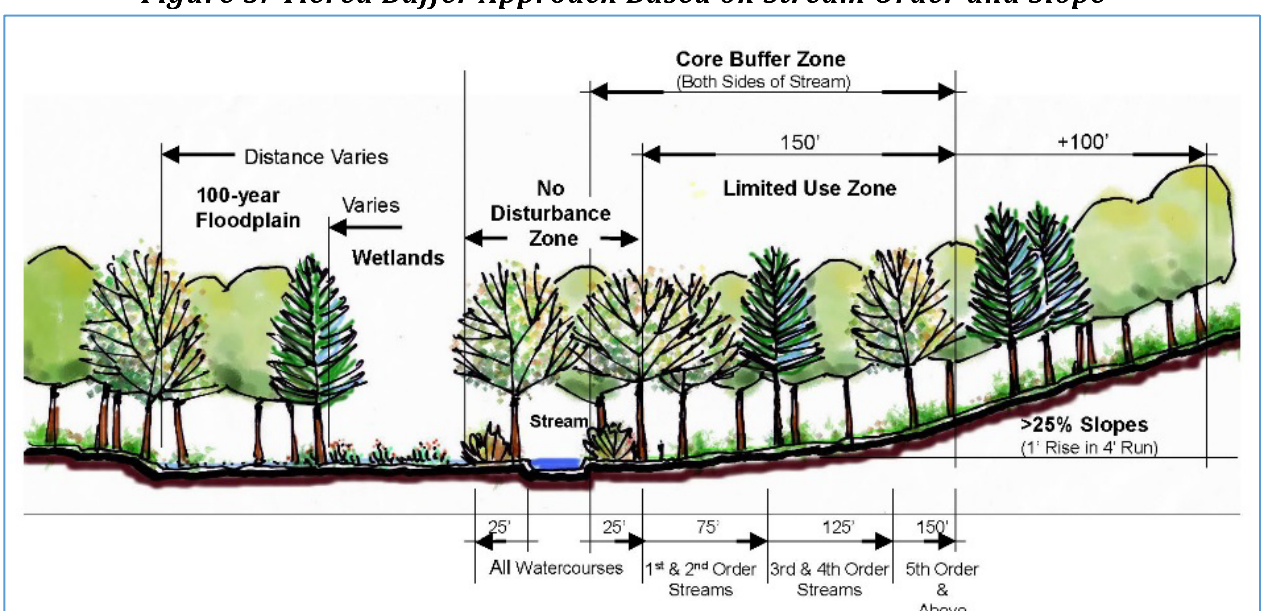
- Highly erodible soils were derived from NRCS digital soils mapping for Grafton County, and coded “highly erodible” by NRCS. Hydric soils were similarly derived from the NRCS spatial data set.

- Stream segments and gradient data were derived from the NH National Hydrography Dataset at a scale of 1:24,000.

- Road data was clipped from statewide NH DOT mapping of highways and roads (2010 NH GRANIT) and processed by type (state, local, private, unmaintained) as well as surface type (paved or unpaved). The impervious areas associated with roads are calculated from pavement width data associated with the NH DOT mapping.

- Buildings were manually digitized from 2012 National Agriculture Imagery Program (NAIP) aerial photography with a resolution of 1-meter.
- Land cover data was derived from 2006 USGS National Land Cover Dataset (NLCD) enhanced with National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) data (that employs wetlands inventory and aerial photography interpretation to improve wetland identifications) at a minimum resolution of 30-meters and an overall accuracy assessment of 85%. This data layer was further enhanced by overlaying the NH DOT road layer (cited above) including estimates of road width as well as incorporating the building analysis (above) which included estimates of the related disturbed/cleared areas from that development. This greatly improved the estimates of low density development throughout the watershed that tends to be under-reported in NLCD due to its 10 to 30 meter spatial resolution limitation and as the predominately forested landcover's leaf canopy often masks small areas of development.
- Riparian buffers data is an original dataset developed for the Newfound Lake Master Plan project using a tiered buffer approach based on stream order, as shown in Figure 3 below. This approach was adapted from the recommendations of Schueler and Holland (2000) from a publication from the Center for Watershed Protection.
- In lieu of employing windshield surveys throughout the watershed, given the great expanse of the Newfound Lake Watershed and the lack of adequate road networks to cover that area, the 2010-11 Statewide High Resolution (1 foot) Aerial Photography - True Color (RGB) web map service supplied by the GRANIT GIS server was employed in conjunction with the subwatershed boundaries data layer to examine land use and cover as well as shoreline and developed areas in detail throughout the watershed when necessary.

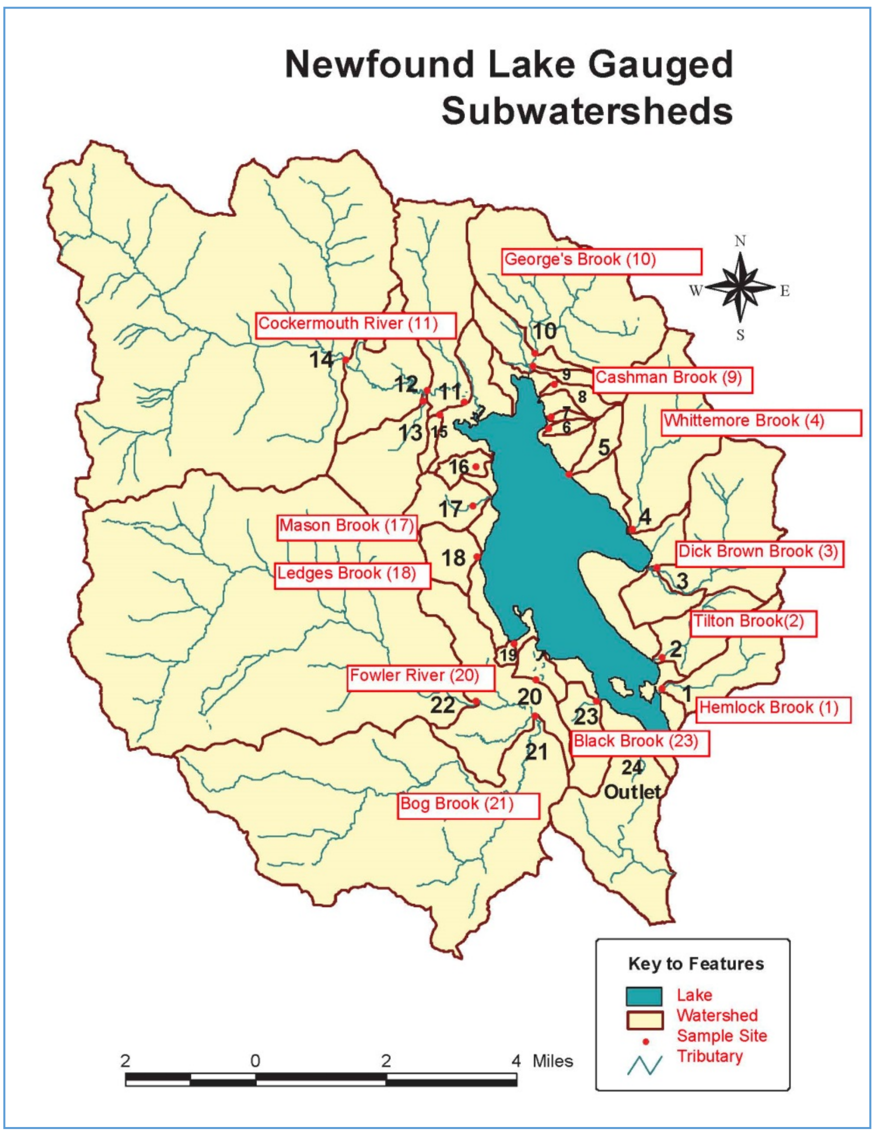
Figure 3.-Tiered Buffer Approach Based on Stream Order and Slope



(from Schueler and Holland 2000)

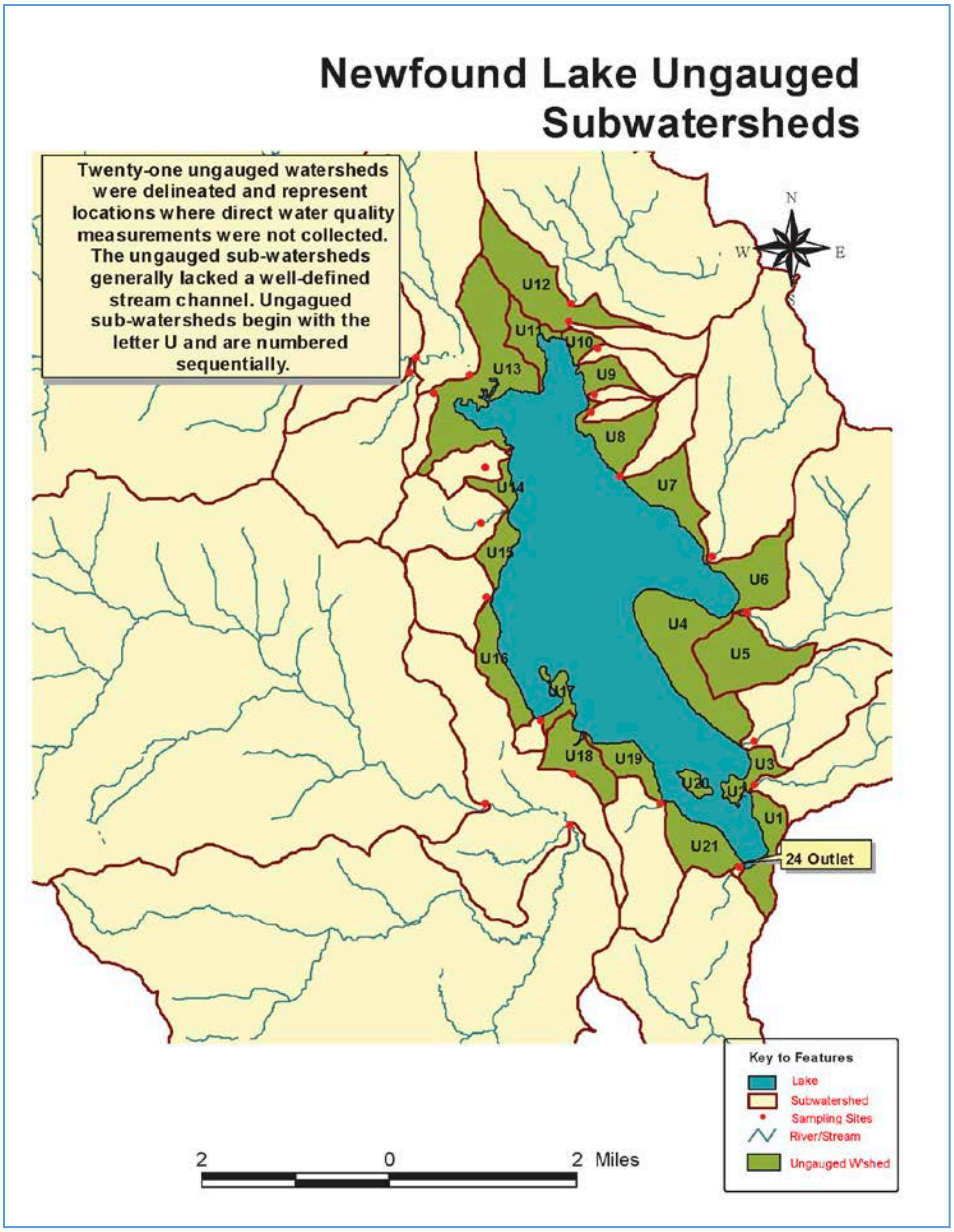
The original subwatersheds monitored for the water nutrient budget (Craycraft and Schloss 2008) were used in the modeling exercise except that some of the smaller sized subwatersheds that were minor contributors to both flow (as many were ephemeral brooks that dried out during some parts of the season) and relative phosphorus load were combined together (Figure 4; Additional descriptions in Appendix A). This resulted in a model with the twelve major subwatersheds represented independently, along with two subwatershed groups representing the smaller northeastern (subsheds 5-8) and western near-shore drainages (subsheds 15,16 & 19). Only one of the subwatersheds modeled, Bog Brook, was a subwatershed contained within a larger subwatershed (Fowler River). The LLRM model allows for accounting for this through a routing function. A final subwatershed model input representing all of the ungauged watersheds (shoreline and nearshore lands, Figure 5) from the 2008 study was also included to complete the model. This configuration allowed for a robust calibration since these fifteen (15) major subwatersheds had undergone extensive monitoring of both storm event and base flow conditions over an 18 month period.

Figure 4.-Newfound Lake -Gauged Subwatersheds Used in the Modeling



Any lessons learned from the modeling regarding landscape and land use factors that influence nutrient loading could then be applied to the higher resolution (i.e.: greater number of smaller sized subwatersheds) subwatershed delineations that resulted during the paired subwatershed and headwater subwatershed studies that followed the original water and nutrient budget study (Craycraft and Schloss 2009 and 2011). The calibration scheme (described later) should allow for future modeling to focus on these higher resolution subwatersheds if there is an interest or need.

Figure 5-Newfound Lake –Ungauged Subwatersheds areas



Land Use / Land Cover Nutrient Loading Coefficients

The basic process of estimating nutrient loading from a watershed entails the multiplication of a specific export coefficient for each land use (or land cover) by the total area that the land use occurs. The literature provides a long list of potential coefficients to use but for this study only regionally relevant coefficients (Dennis and Sage 1981, Dudley et al 1997, Reckow et al 1980, Schloss and Conner 2001) were analyzed for use. Care must be taken for the selection of the appropriate coefficients for each land use since they vary depending on watershed conditions including slope, hydrology, soils and geology. Unless done experimentally and by intercepting runoff using sample collectors directly within the land use/cover, the majority of export coefficients are derived from previous empirical studies where the particular land use/cover was the majority of the use/cover type but not 100%. It is also important to remember that the reported coefficients often are the "effective" export coefficients, in that they often represent what was measured at the stream, and thus, include whatever attenuation of nutrients before entering the receiving water that particular land area provided.

As forested lands (including Deciduous, Non-Deciduous, and Mixed Forest Cover) were the most predominate land cover (about 91%) in the Newfound Lake watershed, the coefficients chosen for those land cover types will have the greatest influence on the model results for total watershed loading. The various other land use coefficients selected are important to the model in the determination in the differences between the subwatersheds modeled and for predicting past and future land cover change scenarios. In a compendium of previous nutrient/water budget studies conducted in New Hampshire watersheds, using GIS analysis of subwatershed land cover characteristics, Schloss and Connor (2001) provided the range of coefficients measured for a number of land uses. Generally, the lower range for a given land cover, like forested, represented the most pristine condition with virtually no disturbance due to lack of human encroachment while the higher values for forest cover occurred in watersheds that had more extensive development and or disturbance nearby or even within as low density development is not always picked up by the satellite sensors typically used to create the land cover datasets (given their 10-30 meter spatial resolution. As discussed above, aerial photography interpretation and digitization of buildings was used to improve the estimation of low density development in the Newfound Lake watershed.

Since the majority of the Newfound watershed forest cover occurs in areas of relatively low disturbance, the coefficients chosen for each forest cover type were the average of the minimum and the median readings for that cover type found in Schloss and Connor (2001) Statistical Summary Table 4. For low density development and wetlands, past coefficients derived from studies of Newfound, Sunapee, Wentworth and Mendum's Pond (Table 5 in Schloss and Connor 2001) were averaged. The coefficient for hay fields was derived from an average of New Hampshire and Maine measurements (Schloss and Connor 2001, Dennis and Sage 1981). The remaining coefficients selected were consistent with recent modeling efforts where the LLRM model was used for New Hampshire lakes (Dalton et al 2012, Gendron and

Kretchmer 2011, Kretchmer and Wagner 2011, MacDougall et al 2011, Schloss et al 2009). While typically on the lower end of the total regional range, they never were the lowest of any previous study as the LLRM model incorporates a phosphorus attenuation factor term typically used in the model calibration. For open water (small lakes and ponds within the subwatersheds) the same precipitation wet and dryfall loading coefficient assumed for Newfound was used (0.11; see Additional Loading model Parameters and Assumptions below) and an attenuation factor of 0.6 was assumed (i.e. the small ponds and lakes within the subwatersheds passed on 60% of the total phosphorus that they received from aerial deposition). The attenuation they may have done to the phosphorus load passing through them from upwatershed is taken care of during the model calibration for each specific subwatershed modeled.

A summary of the total phosphorus nutrient coefficients used for each land use type in the Newfound Lake watershed modeling is documented in Table 1 below:

Table 1. Land Use Export Coefficients (in kg/ha/yr) used in the Newfound Lake Watershed Phosphorus Loading Model.

Land use export coefficients (kg/ha/yr) used in Newfound (Major Watersheds) phosphorus loading model

LLRM Land Use	Runoff P export coefficient range	Runoff P export coefficient used	Source	Baseflow P export coefficient range	Baseflow P export coefficient used**
Urban 1 (Low Density Residential)	0.19-6.23	0.42	Schloss and Connor 2000-Table 5	0.001-0.05	0.01
Urban 2 (Mid Density Residential/Commercial)	0.19-6.23	0.90	Reckhow et al. 1980	0.001-0.05	0.01
Urban 3 (Roads)	0.19-6.23	1.05	Dudley et al. 1997	0.001-0.05	0.01
Urban 4 (Industrial)	0.19-6.23	1.20	Reckhow et al. 1980	0.001-0.05	0.01
Urban 5 (Mowed Fields)	0.19-6.23	0.60	Reckhow et al. 1980	0.001-0.05	0.01
Agric 1 (Cvr Crop)	0.10-2.90	0.60	Reckhow et al. 1980	0.001-0.05	0.01
Agric 2 (Row Crop)	0.26-18.26	1.23	Reckhow et al. 1980	0.001-0.05	0.01
Agric 3 (Grazing)	0.14-4.90	0.80	Reckhow et al. 1980	0.001-0.05	0.01
Agric 4 (Hayfield)	0.35 - 0.64	0.50	Dennis and Sage 1981, Schloss and Connor 2000-Table 5	0.001-0.05	0.01
Forest 1 (Deciduous)	0.29 - 0.973	0.09	Schloss and Connor 2000- Table 4	0.001-0.010	0.004
Forest 2 (NonDeciduous)	0.01 - 0.14	0.05	Schloss and Connor 2000- Table 4	0.001-0.010	0.004
Forest 3 (Mixed)	0.01-0.138	0.07	Schloss and Connor 2000- Table 4	0.001-0.010	0.004
Forest 4 (Wetland)	0.02 - 0.83	0.04	Schloss and Connor 2000-Table 4	0.001-0.010	0.004
Open 1 (Wetland)	0.02 - 0.83	0.04	Schloss and Connor 2000-Table 5	0.001-0.010	0.004
Open 2 (Scrub/Shrub)	0.02 - 0.83	0.09	Reckhow et al. 1980	0.001-0.010	0.004
Open 3 (Cleared)	0.14- 4.90	0.80	Reckhow et al. 1980	0.001-0.010	0.004
Other 1 (Lake/Pond)	0.07 - 0.54	0.07	Precipitation Coefficient * Attenuation†	0.001-0.010	0.004

† attenuation factor set to 0.6 i.e. 40% attenuated
** all from ENSR Unpublished Data or Mitchell et al. 1989

SEPTIC SYSTEM LOADING ESTIMATES

While not originally in the scope of the work, local discussions with watershed stakeholders indicated an interest in the impact of shoreline septic systems on the lake nutrient loading. To be done accurately, a shoreline resident survey should be undertaken. The information required for an optimum estimation would include a survey undertaken for each shoreline residence and business that specified: type of system, age of system, location of leach field in relation to shoreline, most recent time of inspection/pump out of septic tank or holding tank, whether a clothes washer and/or dish washer is in use, whether a sink garbage disposal is installed and used, if a water softener is presently used, the number of persons in the household and the schedule of occupancy (i.e. if the residence is occupied seasonally, multiple seasons or year-round). Best case for localized modeling to subwatershed scale would be a Global Positioning System recorded location or a digitized tax map location. At a minimum, some locational information with the shoreline section of the lake matched to the survey entry would be useful. We encourage the Watershed Project Team to facilitate such a survey in the future (see also: Recommendations Section) to allow for a more informed estimate.

However, by examining the results of surveys done for other New Hampshire lakes (Schloss and Squam Lakes Association unpublished, Schloss et al 2006, Jesperson and Diemer 2011) and by utilizing the analysis of buildings within the shoreland zone along with the septic system suitability within that zone from this project's extensive GIS Watershed Ecological Resources Inventory we can make some assumptions and come up with a reasonable estimate to then compare to other sources of phosphorus loading in the watershed.

In all 577 building were located within the 250 foot shoreland zone. An argument may be made that a modern septic system should process a majority of the nutrients given a distance of 75 to 125 feet depending on soils and slope. A previous study at Lake Chocorua (Schloss 2000) confirmed that a 250 foot setback of all leach fields results in no discernible septic influence even in shallow groundwater inflows (confirmed by shallow well monitoring) thus buildings greater than 250 feet from shore were not included in the analysis. However, the suitability analysis (Appendix B) shows that over 62 percent of the shoreland zone has poorly suited soils for septic system function and most of the area is highly sloped. In addition, many shoreline areas have developments that were completed well before the state regulated septic system standards.

For simplicity sake, it was assumed that about a third of the households were year-round (365 days of use), a third multi-seasonal (100 days of use) and a third seasonal (60 days of use). This was based on previous survey results from the Squam Lake (discussed in Schloss et al. 2006) and more recently for Lake Wentworth (Jesperson and Diemer 2011). A second assumption was, on average, there were 2.6 persons per household, again based on recent studies. Three generalized situations were used given the fact that almost 68 percent of the buildings in the shoreland zone were located on soils with severe constraints:

- 60 percent of the residences had typical mid-age functioning septic systems.
- 20 percent of the residences had new, upgraded and/or raised bed septic systems.
- 20 percent of the septic systems were under-designed, not up to current code/standards, not properly maintained, and/or were marginal in their function.

The above most likely represents a conservative estimate (i.e. most likely underestimating actual loading) based on previous NH studies that used type of system, age of system, distance to lake, and site constraints to infer system functionality and the phosphorus assimilation capacity of the system (see Connor and Bowser 1997 and Schloss et al 2009).

The calculated results are displayed in Table 2 below:

Table2.

Septic system calculations in Newfound (Major Watersheds) model								
Category	**# of Dwellings**	**People/ Dwelling**	**# of Days**	**TP Trans. Factor**	**Mean TP Conc (mg/L)**	**P Load (kg/yr)**	**Water (m3/day)**	**Water Load (m3/yr)**
New or upgraded septic systems	115	2.6	175	0.1	8	10.5	0.25	13081
Marginal/Old septic systems	116	2.6	175	0.4	8	42.2	0.25	13195
Typical mid-age septic systems	346	2.6	175	0.25	8	78.7	0.25	39358
Total Septic System Loading						**131.4**		**65634**

The result of 131.4 kg phosphorus per year surpasses 16 of the 19 tributaries monitored and modeled. It represents about 7 percent (comparably with other inputs that include atmospheric deposition, tributary input, and near shore runoff) of the annual phosphorus load and is comparable to the near shore (ungauged watershed) lands runoff which comes in at about 8 percent of the total load. While the original water nutrient budget (Craycraft and Schloss 2008) did not directly measure shallow groundwater wells to estimate septic and groundwater loading, best professional judgment and solving the mass balance of total phosphorus for Newfound Lake estimated the groundwater influx at 110.3 kg phosphorus per year. This estimated the septic loading at about 6 percent of the total phosphorus load so the modeled result is very close to the previous estimate from the empirical study.

As the septic system loading is not evenly distributed throughout the year and the majority of the loading actually occurs during the growing season (late spring and summer), when home occupancy is at its peak, the impact of septic systems can have an even greater role in influencing lake productivity in the summer. This would especially be true during a dry growing season. Also, as discussed earlier, these calculations represent a conservative estimate which is why a more detailed calculation should be done after surveying shoreland residents.

Additional Modeling Parameters and Assumptions

The LLRM Model allows for point sources (such as sewage treatment outflows or other industrial NPDES permitted outflows) but none are known to occur in the Newfound Lake watershed. Other sources that can be modeled include waterfowl and internal nutrient loading from anoxic lake sediments. Project team personnel did not indicate that waterfowl are found in significant numbers on or near the lake to impact phosphorus loading. It was also assumed from extensive dissolved oxygen profiles taken over the years (LLMP 1986-2013) that the deep water volume of Newfound Lake remains oxygenated for the majority of each year and sometimes all through the year and the recent sediment phosphorus analyses as well as surface versus deep water phosphorus sampling (Craycraft and Schloss 2009 and 2011) keep the potential for internal nutrient loading very low.

The site with the greatest chance of providing internal loading is actually the Mayhew area, with some of the shallowest waters of the lake. However, the deep water phosphorus values are usually never greater than that measured as peak phosphorus concentrations in the surface waters. Nonetheless, as the Newfound Lake productivity increases over time or with future land use changes in the watershed the Mayhew, as well as the Pasquaney Bay area of the lake, could provide internal nutrient loading given the fact that those two lake areas are displaying a slight but increased trend in productivity (measures as chlorophyll *a* concentration, an indicator of planktonic algae biomass) as well as a decreased trend in water clarity while the other central and northerly deep sites of the lake are not (Craycraft and Schloss 2011). Thus, for the purposes of this modeling effort, internal nutrient loading was assumed to be insignificant but continued monitoring efforts on the lake should always check on deep water oxygen conditions and total phosphorus concentrations.

As the model was calibrated to the 2006-2007 water year that was the basis of the empirical water nutrient budget study (Craycraft and Schloss 2008) the total precipitation for that water year was used in the modeling (137 centimeters). Given the steep nature of the Newfound Lake Watershed (56% steeper than 15%, and 22% steeper than 25%) and the extensive network of tributary streams in the headwaters (i.e. atypically high stream density) the standard water yield (in cubic feet per second per square mile; CFSM) was set to 1.8. This is only slightly greater than most studies for northern New England lakes (typically 1.7 is used) and well within the range used in the LLRM model for regional studies (1.5-2.0 CFSM). Sensitivity analyses on the model that we conducted showed this factor to have very little impact on phosphorus loading estimates of the model. Also, using the 1.8 for the watershed water yield did allow for using reasonable water load attenuation estimates during the model calibration (see below).

Direct atmospheric deposition (wetfall through precipitation and dryfall from dust particles) of phosphorus was set at 0.11 kg/hectare year that was derived from weighting the percent watershed forest cover (about 91%) and the deposition typically measured at Hubbard Brook Forest (Likens 1977; 0.096 kg/hectare yr) with that of more developed New Hampshire watersheds and consistent with rainfall and dryfall phosphorus analysis in the Concord area by the New Hampshire Department of Environmental Services (as discussed in MacDougal et al 2011; 0.25 kg/hectare yr).

WATERSHED LOADING MODEL CALIBRATIONS- WATER VOLUME

Typically, most modeling studies rely on limited data of tributary phosphorus concentrations that are often biased to the summer season and/or measured more during storm flows as opposed to more complete monitoring of baseflow, stormflow as well as snowmelt runoff conditions. As discussed above, the earlier water and phosphorus budget (Craycraft and Schloss 2008) for the Newfound Lake Watershed, that provides both water and nutrient loads by subwatershed as measured over an 18 month period, allows for a robust calibration of the watershed loading model component of the LLRM model used. The calibration process essentially verifies the model estimates for watershed water loading and phosphorus loading based on the landuse/landcover data input into the model. The LLRM allows for each separate subwatershed placed into the model to be calibrated or "fine-tuned" through the selection of attenuation factors for water volume as well as phosphorus loading. If need be, calibration may also involve reselection of the water or nutrient loading coefficients used if the model results are way off of the measured values (that is to say if reasonable attenuation factors do not calibrate the model) but that was not the case for this study.

Water attenuation coefficients ranged from 0.75 through 1.10 and were consistent with previous coefficients used in modeling New Hampshire lakes. Generally, the greatest attenuation (i.e. the lower coefficients) occurred in the smaller subwatersheds with the lowest stream density (unit-less ratio of kilometers of stream per square kilometers of subwatershed) and the lowest attenuation occurred in the larger subwatersheds with higher stream densities. This would be expected as the smaller near-shore subwatersheds represent only first or second order streams and have a good amount of areas for which overland runoff is a significant factor. Overland runoff during storm events and snow melt would contribute less water to the lake than if intercepted by a stream, which acts as a highly efficient water and nutrient transport system. To align the model with actual measurements, the attenuation factors for both the Cockermouth River and the Fowler River, which provide roughly ___% of total tributary input to the lake, were set to 1.05. The model's lower water yield for these two major tributaries to Newfound Lake was most likely due to a combination of the extensive wetland and pond networks associated with those rivers. At certain times during a wet year, as the study year was, they could have contributed additional water yield with saturated water table conditions (Hewlett 1982). As the LLRM model does not allow for the modification of the baseflow coefficients by individual subwatershed (as was required here to account for the water volume loading) this factor was simply added to the water attenuation coefficients for just those two large river systems. Most recent water nutrient budget studies done on New

Hampshire lakes use estimates of groundwater inflow at 5 to 10 percent of the inflow monitored from the major tributaries so these adjustments are right on target. Post calibration, the modeled water volume was less than 1 percent different than the empirically derived measurements.

WATERSHED LOADING MODEL CALIBRATIONS- TOTAL PHOSPHORUS

For phosphorus loading, a similar exercise was undertaken for calibrating the model results to the empirically derived total phosphorus loading values of the water/nutrient budget (Craycraft and Schloss 2008). Attenuation values ranged from 0.50 to 0.85 (lower number implies higher total phosphorus attenuation percentage) and are well within values used in previous studies.

In an effort to discover which, if any, landscape level subwatershed characteristics have an effect on nutrient attenuation, either positive or negative, a schema was developed that could account for the majority of the subwatershed phosphorus attenuation coefficients. Critical landscape level factors that seemed to best influence phosphorus attenuation, positively and negatively, included:

1) Extent of riparian areas with at least the minimum buffer width as recommended for specific stream order (see Figure 3 and discussion in Schueler and Holland 2000). Subwatersheds with greater than 92% of stream riparian buffer extent meeting the variable width recommendations displayed a higher level of attenuation, if not the highest attenuation. The analysis suggests that having at least 92% riparian buffer extent improved attenuation in all cases. Subwatersheds that had 80% or less extent of riparian buffers reflected significantly less attenuation. Given the fact that the majority of total phosphorus loading to the lake is received in particulates one would expect riparian buffers to be very effective in reducing loadings.

2) Subwatersheds with at least 1 percent or more of wetlands and open water (ponds, lakes and higher order rivers) received nutrient attenuation benefits. Wetlands are known to act as nutrient "sinks", or at the least, shunt the nutrient supply by reducing spring and summer loadings by retaining nutrient flow until the fall and early winter (Schloss 2000).

3) Slope was considered a major factor in reducing attenuation particularly in subwatersheds with average slope greater than 20 percent. Increased slope increases water velocity and increases the particulate load in the runoff requiring larger vegetated areas (buffers) for treatment.

4) Road density (km road per square km subwatershed) was another negative factor with impacts reducing nutrient attenuation at values of 2.0 or higher. Along with being a possible surrogate for development intensity, roads crossing streams as well as road

culverts are primary vectors for the transport of nutrients into surface waters. Subwatersheds with road densities greater than 3.0 had even less attenuation capacity.

5) Subwatershed stream density (km streams per square km of subwatershed) had a negative influence reducing total phosphorus attenuation at values greater than 1.0. While low gradient streams would most likely provide greater nutrient attenuation the generally high gradient Newfound streams act more like a transport corridor for particulate total phosphorus to the lake and hence, the negative effect.

6) Percent disturbed area of a subwatershed (sum of developed, agriculture and cleared lands) had a negative phosphorus attenuation impact at levels greater than 5% of total subwatershed area. Seminal work on the impact of impervious surfaces on water quality (Schueler 1994, Arnold and Gibbons 1996) showed that as impervious surface extent approaches 10 percent of the watershed area, impairment of water quality and aquatic life occurs. As none of the Newfound tributaries should be considered impaired and not all disturbed areas are 100 percent impervious, the modeling suggests that percent disturbance at levels greater than 5 percent has a negative influence on nutrient attenuation by that watershed.

The attenuation coefficient selection schema assumed that for simplicity, each factor had an equivalent influence once past the impact threshold. Given the steepness of the watershed (average subwatershed slopes greater than 20 percent for the most part) it was assumed that the starting point for attenuation was at 0.60; that about 60 percent of the phosphorus generated in a subwatershed would be delivered to the tributary sampling point. The exception to this was the Black Brook Watershed which started with a base attenuation of 0.50 as the subwatershed slope was well under 10 percent (8.9 percent). All of the positive impact landscape characteristics were given a -0.10 factor to add to this base attenuation coefficient and all of the negative characteristics were given a factor of +0.10 except for subwatershed slopes between 18.9 and 20.1 which were given a +0.05 and stream densities of 3.0 or greater where a +0.20 factor was used.

Total Phosphorus attenuation factors for eight of the nine major tributaries could be explained through the schema. In the case of the Cockermouth River the attenuation factor used to balance the modeled vs. measured load was 0.50 and the schema predicted 0.55 for attenuation. In that case the 0.50 attenuation was employed in the model. The slight difference may be due to the effect of Spectacle Pond that occurs in that subwatershed. The pond is acting as more of a sink for TP loading than the model run at the current scale allows for. In the land cover/ land use export coefficient discussion above the assumption was that the areal loading from wetfall and dryfall directly into open water within the subwatersheds would be attenuated by about 60 percent. If the pond was also attenuating additional nutrients from up-watershed a small difference like we found could occur. Of course, the original empirical study could have slightly underestimated the actual total phosphorus loading.

In all cases except for Mason Brook and Ledges (see discussion below in "Comparisons) the modeled loadings were no more than 10 percent different plus or minus from the measured loads and 10 of the 14 subwatersheds modeled yielded a ratio of 1.0 for modeled load over measured load. Median and/or mean total phosphorus concentrations measured in the streams during the study period and from recent data showed similar results to model predictions for the majority of the major subwatersheds modeled but showed higher percentage differences than loadings. This suggests that actual measured loadings to be a better model calibration tool over average or mean TP concentrations.

COMPARISONS:

LOADING MODEL RESULTS TO THE PREVIOUS NEWFOUND STUDY

As would be expected, post calibration model loading predictions are very similar to the original water nutrient budget (Craycraft and Schloss 2008). Figure 6 compares the breakdown of Total Phosphorus Loading into the lake from the various sources measured and modeled. The annual total phosphorus (TP) loading measured in 2006-2007 came in at 1926.29 kg of TP. The model result is 1914.90 kg of TP, less than a 0.6 percent difference.

The small differences between measured and modeled TP by source (less than 1 percent for most) are mostly the result of modeling septic systems instead of groundwater and small differences in between the GIS subwatershed boundaries for tributary areas versus runoff areas used in the original study and the resulting areas using the current GIS watershed boundaries that were re-delineated by SPNHF to provide a greater number of study subwatersheds for the headwaters and paired watershed studies. (Craycraft and Schloss 2009 and 2011) and that will also be used in the outreach, management and mitigation planning by the project team. The 2 percent decrease in atmospheric loading occurs as this loading was identical in both studies, but the relative percentage is reduced since the septic and tributary loads increased.

Figure 6. Comparison of Measured (a) and Modeled (b) Sources of Total Phosphorus Loadings to Newfound Lake.

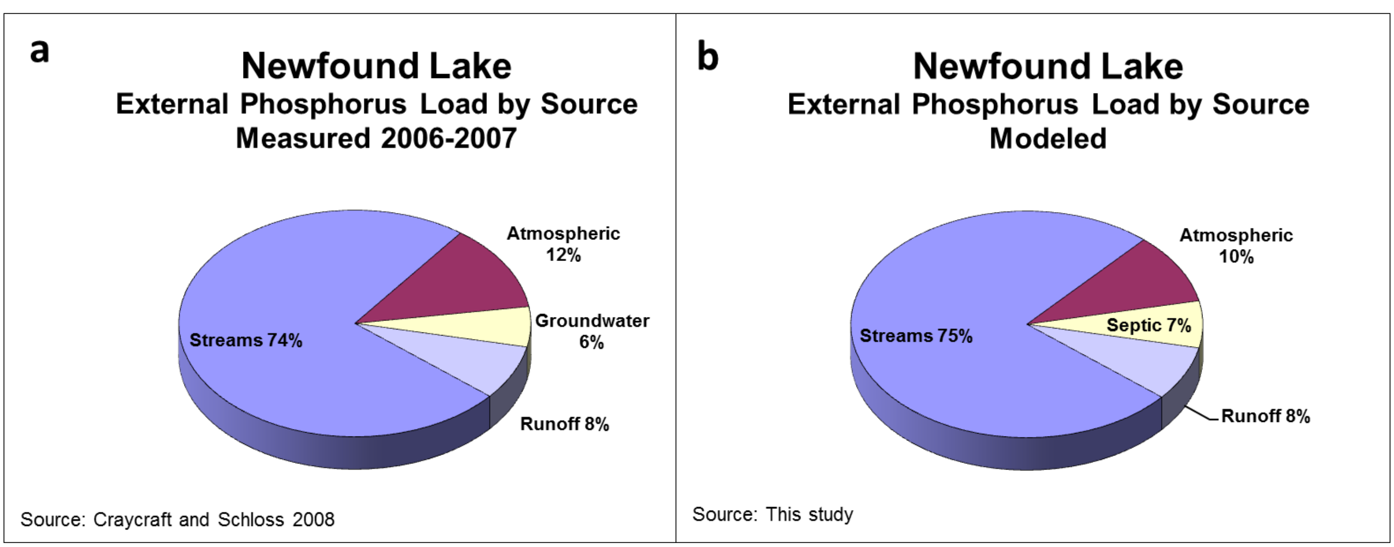
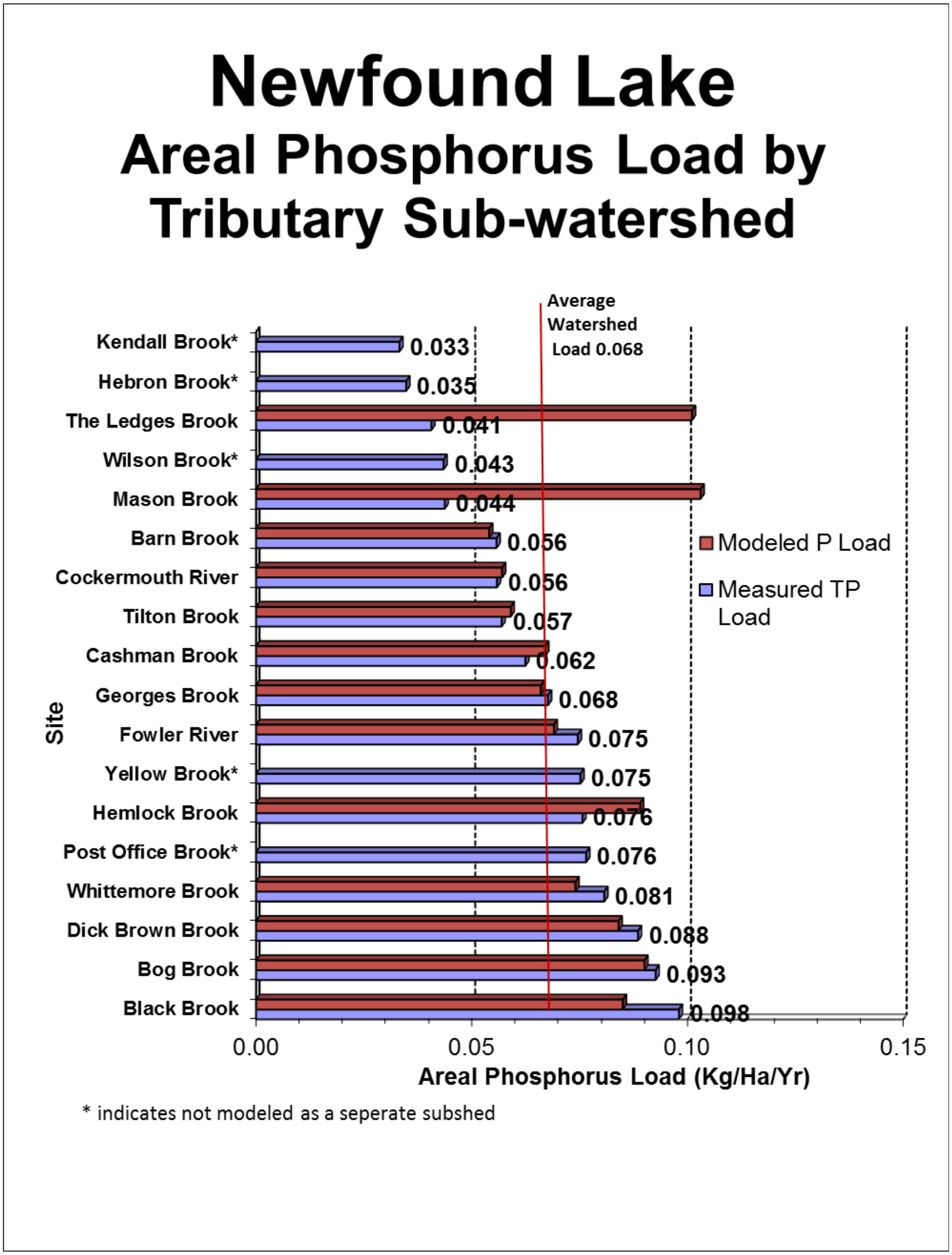


Figure 7 provides a comparison of the calculated yearly areal TP loading coefficients (amount of TP per unit area per year) broken down by study watershed from both the empirical study as well as the modeling. While most calculated tributary loadings are similar, there are large discrepancies between measured and modeled results for Mason Brook and Ledges Brook.

Figure 7: Comparison of Areal Loading of Total Phosphorus From Measured and Modeled Studies for the Newfound Lake Watershed Major Tributaries



For both of these subwatersheds the actual water sampling point was well above the shoreline areas that they border. A combination of lack of access for Mason near shore and the embayment of Newfound Lake water into the near-shore reaches of Ledges Brook necessitated sampling well upstream for both sites. In the case of Ledges almost half of the developed areas are down watershed from the sampling point and for Mason approximately half of the subwatershed lies below the sampling point. While the original water and nutrient loading study had only considered the upper Mason Brook subwatershed and had the remaining area lumped into the ungauged group, this current study modeled the total Mason Brook watershed so in this case that difference can be explained. That is not the case for Ledges. Previous studies (Craycraft and Schloss 2009) that monitored nitrates and sodium chloride (salts) at these stream sites did indicate a higher presence of these indicators of human disturbance at these sites. Thus, this is most likely the only cases where the significantly different modeled results may be closer to the actual true loading than the measured results for reasons stated above. Future monitoring should take a closer look at these sites.

Tributary watersheds besides Mason and Ledges that have smaller but noticeable differences should be examined. Those where modeled loading is less than the measured loading may have worse case conditions than those predicted by the typical land use/cover extent or have conditions that decrease attenuation more than predicted. Those where the modeled loading is more than that measured may have greater attenuation conditions than assumed by looking at just the landscape level characteristics of those watersheds or possibly more or better designed stewardship practices. In both cases, further examination may lead to both a refinement of the model as well as insight into how to better protect the lake water quality through informed watershed stewardship.

Figure 7 also indicates the weighted average of the TP areal loading coefficient, as not all subwatersheds that are associated with each tributary are comprised of equivalent area. It can be useful in many ways (See Model Synthesis section below for greater detail) but primarily it represents the required areal load to maintain the lake water quality in a similar condition to its quality today. Any added loading through development or land cover change must contribute less than or equal to this allocation on a per area basis.

Lake Response Modeling

Once all of the model inputs are entered and the loadings are calibrated, the LRRM spreadsheet outputs estimations of lake response using the modeled TP loadings and water yield combined with specific Newfound Lake specifics such as lake area, volume and TP concentration in the lake outflow. This results in estimates of in-lake phosphorus concentration that is then used to predict mean and peak chlorophyll *a* concentration (algae biomass) and water clarity (as secchi disk disappearance depth).

The LRRM spreadsheet contains a number of lake response models commonly used to estimate productivity indicators such as in-lake TP concentration, Chlorophyll and Water Clarity. Typical use of the models involves averaging the estimates from the models together as each model slightly differs in its interpretation of the relationship of lake characteristics and loadings to the in-lake TP concentration. For example the Kirshner-Dillon (1975) model relies on a calculated settling rate of TP to determine the fraction of TP that is retained to make up the in-lake concentration while the Larsen-Mercier model chooses the flushing rate to do so. The idea behind using an average of a number of models is that no one model usually works for every lake and if you are going to run various watershed scenarios that will estimate the lake response over changing conditions with resulting changes in characteristics and the level of lake productivity, there is a higher confidence in a multi-metric approach. It is still important to examine the results of each model estimate just in case any individual model seems to be well off of the actual in-lake concentration measured and therefore should be taken out of the predictive model.

The results of the modeling for the current in-lake TP conditions are displayed in Table 3. The average of the in-lake TP models, 4.0 ppb (parts per billion; equivalent to micro-grams per liter) does a very good job of predicating the measured lake response falling between the measured mean of 4.1 and the measured median of 3.9 for Newfound in-lake TP. In addition, the mass balance predicted concentration (Vollenweider 1968) of 9.0 ppb should represent the maximum measurement or close to it and the maximum measured deep site TP measurement during the study period was 8.6 ppb.

Table 3. Newfound Lake LRRM Predictions of In-Lake Total Phosphorus Concentrations

Predicted total phosphorus in-lake concentrations		
Empirical Equation	**Equation (see listing below for variables used)**	**Predicted TP (*u* g/L)**
Mass Balance	TP=L/(Z(F))*1000	9.0
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	4.2
Vollenweider 1975	TP=L/(Z(S+F))*1000	4.2
Larsen-Mercier 1976	TP=L(1-Rlm)/(Z(F))*1000	3.8
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	3.4
Reckhow General 1977	TP=L/(11.6+1.2(Z(F)))*1000	4.1
Nurnberg (1998)	TP=(L/Z(F))(1-(15/(18+Z(F)))) * 1000	4.5
Average of Above 6 Model Values		***4.0***
Observed Summer Epilimnion Mean	**Deep Site**	***4.1***
Observed Summer Epilimnion Median	**Deep Site**	***3.9***
Observed Annual Max	**Deep Site**	***8.6***

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

For the productivity response modeling (as previous discussion in the Introduction and as Figure 2 illustrates, the in-lake phosphorus drives the lake water quality conditions) in terms of chlorophyll *a* and water clarity, not all of the models worked as well (Table 4.) Most of the chlorophyll models grossly underestimated the TP to chlorophyll relationship indicating that Newfound Lake is much more sensitive to smaller increases in TP than many of the lakes used to develop those models. One model, the modified Vollenweider (1982), came very close to the measured median (1.8 compared to 1.9 ppb). While not originally in the LLRM spreadsheet, a recent NH DES analysis of NH Lakes Lay Monitoring Program and Volunteer Lake Assessment Program data for New Hampshire lakes developed a predictive equation for Chlorophyll using TP concentration in order to recommend trophic based numerical phosphorus criteria (Trowbridge 2009). That model was added to the model suite for predicting chlorophyll for this study as it also had a very positive result coming just slightly over the measured median (2.1 ppb compared to 2.0 ppb). Thus for mean chlorophyll predictions for Newfound Lake estimates, only the two models discussed above were averaged.

Table 4. Newfound Lake LRRM Predictions of Deep Site Chlorophyll Concentrations Only the yellow highlighted models were averaged for the prediction.

Predicted in-lake chlorophyll a concentrations		
Empirical Equation	**Equation**	**Predicted Value**
Mean Chlorophyll		***u* g/L**
Carlson 1977	Chl=0.087*(Pred TP)^1.45	0.7
Dillon and Rigler 1974	Chl=10^(1.449*LOG(Pred TP)-1.136)	0.6
Jones and Bachmann 1976	Chl=10^(1.46*LOG(Pred TP)-1.09)	0.6
Oglesby and Schaffner 1978	Chl=0.574*(Pred TP)-2.9	-0.6
Modified Vollenweider 1982	Chl=2*0.28*(Pred TP)^0.96	2.1
NH DES 2009	Chl='10^(2.468+(0.925*LOG10(Pred TP/1000)))	1.8
Average of Model Values	**(Modified Vollenweider and NH DES only)**	**2.0**
Observed Summer Mean		***2.0***
Observed Summer Median		**1.9**

For the models predicting peak (maximum) Chlorophyll *a* concentrations (Table 5.) all models overestimated the maximum deep site chlorophyll concentration measured. However, there is a larger dataset for measured chlorophyll concentrations from the NH LLMP monitoring by Newfound volunteers for the other deep sections of the lake (Pasquaney Bay and Mayhew). Looking at both data records a maxima occurred at the Mayhew site that was very close to the predictions of the Vollenweider models (1982). The difference between these models is one uses the predicted TP concentration and the other uses the predicted chlorophyll concentration (mean) as the basis of the peak estimate. Therefore, the average of both of those models was used for the peak chlorophyll estimates.

Table5. Newfound Lake LRRM Predictions of Peak Chlorophyll Concentrations Only the highlighted models were used in the prediction.

Predicted peak chlorophyll a concentrations		
Empirical Equation	**Equation**	**Predicted Value**
		***u* g/L**
Peak Chlorophyll		***u* g/L**
Modified Vollenweider (TP) 1982	Chl=2*0.64*(Pred TP)^1.05	5.5
Vollenweider (CHL) 1982	Chl=2.6*(AVERAGE(Pred Chl))^1.06	5.3
Modified Jones, Rast and Lee 1979	Chl=2*1.7*(AVERAGE(Pred Chl))+0.2	6.9
Average of Model Values	**Averaging Vollenweider (TP) and (CHL) only**	**5.4**
Observed Summer Maximum (Deep)		***3.9***
Observed Summer Maximum (Mayhew)		**5.4**
Bloom Probability		***% of Summer***
Probability of Chl >15 *u* g/L	See Walker 1984 & 2000	0.00%

For water clarity, secchi disk transparency models for mean and maximum are included in the LLRM spreadsheet (Table 6). Surprisingly, the maximum model estimated a lower clarity than the mean model. As the mean model came in about 8 percent higher than the measured mean but averaging of both models resulted in an exact match to current conditions (mean of 7.3 meters), and as the Vollenweider (1982) models were working well for the other estimates for TP and Chlorophyll *a*, an average of both models was tried. If there is a significant difference that occurs between the two models under any scenario modeling the fall-back model to use could be the Oglesby and Schaffner (1978) model alone. As neither model seems to predict maximum clarity in the lake sufficiently, a simple prediction of using the percent difference between the mean clarity and the maximum clarity (50.7%) for all modeling scenarios that predict less clear conditions and the addition of the difference between the maximum and mean secchi disk depths (+3.7m) for scenarios that predict an increase in clarity. This most likely overestimates the maximum for the former and underestimates the maximum for the latter. Thus, for all estimates the model projections are conservative.

Table 6. Newfound Lake LRRM Predictions of lake water clarity (as Secchi Disk Depth)

Empirical Equation	**Equation**	**Predicted Value**
Secchi Transparency		***m***
Mean: Oglesby and Schaffner 1978	SDT=10^(1.36-0.764*LOG(Pred TP))	7.9
Max: Modified Vollenweider 1982	SDT=9.77*Pred TP^-0.28	6.6
Average of Model Values		**7.3**
Observed Summer Mean		***7.3***
Observed Summer Maximum		***11***

SCENARIO TESTING

LAND USE / LAND COVER CHANGES MODELED

With both watershed loading and lake response modeling calibrated for the particulars of the Newfound Lake Watershed and Newfound Lake, a series of scenarios of land use change were run. While some studies go to the extreme of predicting what would be the resulting lake water quality changes with a full watershed build-out, as the Newfound Lake Watershed is exceptionally large and as Newfound Lake Region watershed communities are more concerned on preserving the exceptional water quality that most areas of the lake currently exhibit, the development scenarios run in this analysis focused on predicting the original baseline condition for the lake as well as investigating impacts of logging and projected development in the near future. Specifically the scenarios included:

1. Pre-development conditions- i.e. no development and all lands forested except for existing wetlands and waters to indicate what Newfound Lake's most pristine conditions might be. While most likely similar to pre-settlement conditions, as the Newfound outlet has a water control structure (dam) the current lake area and volume that the model incorporates may not have been equivalent to conditions before settlements were introduced. However, it does represent a baseline estimate for full forest cover conditions. The pre-development condition took all cleared, disturbed, agriculture and developed areas and converted them back to forest cover at the same relative areas of forest cover type that are currently occurring in each subwatershed modeled. Attenuation factors were adjusted for those subwatersheds that had reduced attenuation due to development, road density and reduced recommended variable riparian buffer extent.

2. Headwater stream forest cuts at a range of extent: 10% cut, 20% cut and 30% annual cut, distributed within the modeled area, simulated by change in land cover from forested to cleared. These scenarios assume that the recommended variable buffer widths and low impact practices covered in "Good Forestry in the Granite State" (Bennett (ed.) 2010) are employed. Initial cut areas were converted to "cleared" so the initial impacts would be worse immediately after the cut with a slight reduction in loadings as new vegetation takes hold. No near-shore watersheds were changed in this modeling effort, only the larger subwatersheds with headwater forests had their forest cover reduced. A straight percentage cut was assumed for all three forest cover classes (Deciduous, Non-deciduous and Mixed) for simplicity.

3. Approximate 30 year growth in low and medium density development throughout the watershed including estimates of additional septic system load for those development units within 250 feet from shore. This scenario assumed about the same increase in watershed dwellings in the next 30 years, 1500 units, as seen in the past 30 years (1672 units, Dan Sundquist/GreenFire GIS, personal communication). The number of dwellings by development

intensity added to the watershed consisted of 1000 low density dwellings, 350 medium density dwellings and 150 high density dwellings. Of those, 293 would occur in the shoreland zone and thus impact the septic system load. As the current pattern of newer development occurs nearest areas already developed and development occurs at about the same intensity as the past development (low density by low density, medium density by medium density…etc.) the increase in dwellings were distributed according to existing development extent and for simplicity the developments were assumed to displace the mixed class of forest cover as this was typically the most dominant land cover in most subwatersheds.

Two runs of this scenario were analyzed - the first with no assumed changes in attenuation factors and the second accounting for the loss of phosphorus attenuation with the loss of forest to development and an increase in road density. Except for the near-shore areas that are expected to undergo the largest land use changes and the likely loss of most riparian areas, most of the larger and headwater subwatershed phosphorus attenuation factors were only reduced by about 10 percent (i.e. a factor of +0.1 using the schema previously discussed).

A number of additional assumptions were made to insure reasonable predictions and these included:

- For all scenarios no internal nutrient loading was assumed even though it would be expected with increasing lake productivity, particularly in the Pasquaney and Mayhew areas of the lake. That level of lake sub-basin analysis was beyond the original scope of the GIS service provider. Better impact estimates can be made in the future by considering the major deep basins of the lake as separate "reaction vessels" as the aforementioned sections of the lake will definitely show impacts well before the deepest central basin will. Therefore it is important to understand that the predicted water quality decline is a very conservative (best case) estimate and indicates a more integrated lake condition. There would be areas in the lake (embaymemts and shallow areas) that would display even greater productivity and water quality decline.

- An additional important assumption was that the difference between the in-lake TP concentration and the outflow TP concentrations remained at about the same relationship – that is to say that the lake acted as a "sink" for nutrients at a constant rate (about 66 percent of the concentration as is currently occurring) rather than being TP- concentration dependent. This assumption holds very well at the typical lower concentration of nutrients that the lake currently contains but as watershed loading increases and lake productivity increases to more moderate levels, the lake could reduce its capture of TP by the sediments resulting in a larger in-lake concentration expressed. Thus again, the scenarios of increasing productivity are most likely a "best case" response.

MODEL PREDICTIONS

Table 7 contains a summary of the model predictions for the current, pre-development, 10 percent, 20 percent and 30 percent forest cuts, and the 30 year growth projections for both no TP attenuation change and a decreased attenuation. TP loading from watershed and septic system sources, the total watershed TP loading to the lake, in-lake TP, chlorophyll and water clarity model estimates are included for the comparison.

Table 7. Comparison of Current Newfound Lake Watershed and Lake Conditions with LLRM Modeled Scenarios

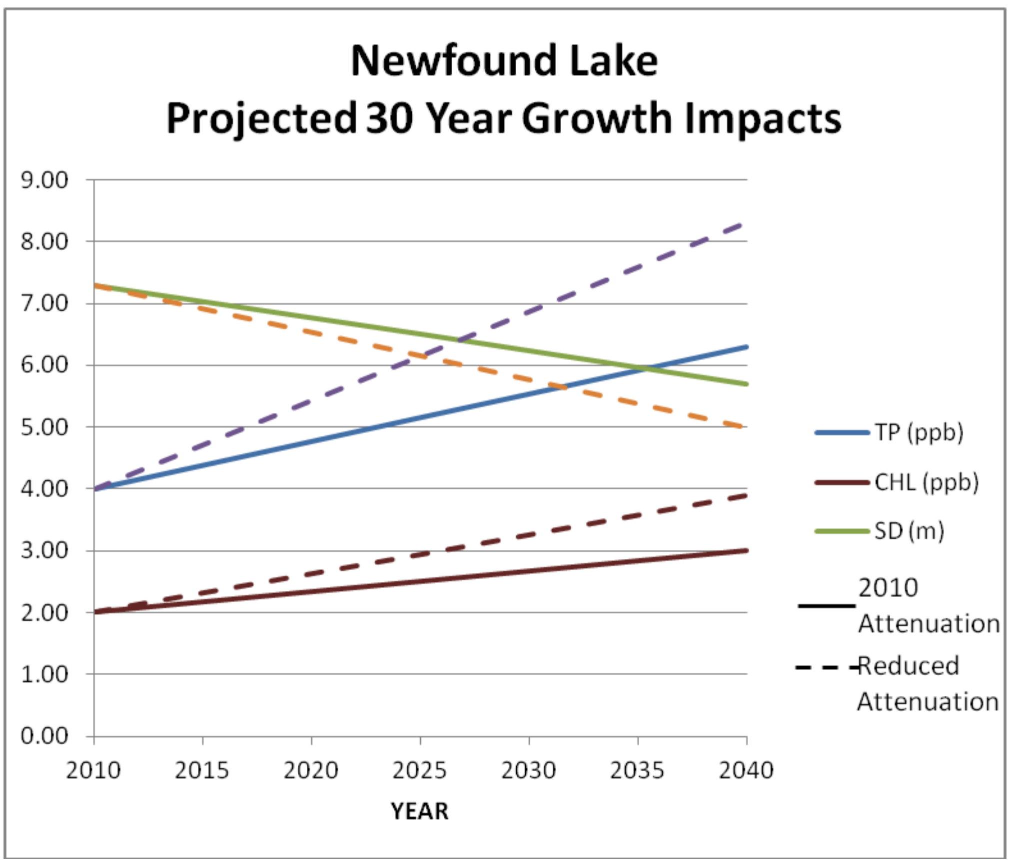
Comparison of Current Conditions and LLRM Modeled Scenarios								
		Pre-Development	**Current Conditions**	Loggging 10% cut	Loggging 20% cut	Loggging 30% cut	30 Year Growth	30 Year Growth attenuation reduced
Loading								
Watershed Load TP	KG/YR	866	**1585**	2341	3099	3856	2485	3306
Septic Systems	KG/YR	0	**131**	131	131	131	161	161
Total Load TP	KG/YR	992	**1915**	2671	3428	4186	2844	3665
Percent Increase (Decrease)	%	-48		39	79	119	49	91
In-Lake								
Predicted in-lake TP	ppb	2.1	**4**	5.5	6.9	8.2	6.3	8.4
Predicted Chlorophyl a	ppb	1	**2**	2.6	3.2	3.9	3.0	3.9
Predicted Peak Chlorophyll	ppb	2.7	**5.4**	7.4	9.4	11.3	8.6	11.4
Predicted Secchi Depth	m	10.6	**7.3**	6.2	5.5	5.0	5.7	5
Predicted Secchi Maximum	m	14.3	**11**	9.3	8.3	7.5	8.6	7.5

Newfound Watershed "pre-development" conditions as modeled had almost half of the current level of TP loading resulting in about half of the current Newfound in-lake TP concentration as well as half of the current mean chlorophyll *a* concentration. Predictions suggest the average water clarity would increase to 10.6 meters (almost 35 feet) and a maximum clarity of over 14 meters (over 47 feet!) could occur.

For the logging scenarios a 10 percent forest cut (1,835 hectares or about 4,500 acres) will increase the TP load from the watershed by almost 40 percent. The lake response would be an increase in productivity to almost moderate productivity levels (mesotrophic) and a loss in water clarity of over 1 meter. An economic analysis of various waterfront housing markets in New Hampshire found that as little as a 1 meter decrease in water clarity can reduce housing prices by as much as 20 percent (Gibbs et al. 2002). Also remember that these scenarios assume all best management practices are employed and the riparian buffer extent is protected. In this modeling the lands were assumed to be left as cleared for forest regeneration but if the cuts were made in conjunction with conversion to development the impacts would be even greater. By the time 20 percent of the forest is cleared the lake would be well into mesotrophic conditions.

Looking at the thirty year growth projections TP watershed load would be increased by 49 percent over current conditions and the chlorophyll *a* concentrations would be borderline mesotrophic. Water clarity would be reduced by 1.6 meters over current conditions. As the first 30 year development projection kept the TP attenuation static with current levels this most likely would not be the case. Taking that into account the 30 year change in TP loading could be as much as a 91 percent increase- essentially a doubling of watershed TP load. Chlorophyll *a* would double over current conditions and clarity would be reduced by over 2 meters. Assuming a relative consistent increase year to year towards reaching projected developed conditions Figure 8 models the Newfound Lake water quality degradation over time. The solid lines indicate the preserved attenuation state and the dotted lines represent the more likely reduced TP attenuation state scenario. In any case, development "as usual" will cause the water quality of Newfound Lake to degrade significantly.

Figure 8. Water Quality Degradation Trend Predicted for 30 Year Growth in the Newfound Lake Watershed for in-lake Total Phosphorus (TP), Chlorophyll (CHL) and Secchi Disk Water Clarity (SD).



Solid lines depict no change in TP attenuation within the watershed and dotted lines represent more than likely (modeled?)reduced TP attenuation changes.

MODEL SYNTHESIS:
PRIORITIZING WATERSHED MITIGATION EFFORTS

As the local economy and quality of life depend on Newfound's clean water and this analysis predicts water quality degradation under reasonable land-use scenarios, proactive efforts are required to protect the pristine waters of Newfound Lake. With such a large watershed area to deal with a method of prioritization is extremely important to achieve effective results in minimizing watershed total phosphorus loadings.

Earlier direct monitoring efforts (Craycraft and Schloss 2009 and 2011) pointed out a number of suspected problem areas for investigation and mitigation. In addition, the empirically derived nutrient water budget (Craycraft and Schloss 2008) also provided data for the prioritization of subwatersheds by their total TP loadings and areal TP loadings. This modeling effort not only allows us to project the potential outcome of change in land use and land cover and the resulting lake response, but during the calibration process it also allowed for the determination of what influence landscape-level characteristics played in the delivery of TP throughout the watershed. Understanding the landscape-level dynamics of TP loading can allow us to examine the watershed at a higher spatial resolution than that for which we initially monitored. Additionally, while beyond the scope of this work product, there is a greater concern for the shallow and embayed areas of the lake and the moderately deep basins that are currently showing a slight but negative decline in water quality and perhaps they can eventually be modeled for lake response to get a better handle on the urgency of taking action.

INTEGRATED CRITICAL WATERSHED ANALYSIS

Thus, the monitoring, analysis and modeling allows us to catalogue a number of existing conditions and factors that impact TP generation and loading in the Newfound watershed as well as in-lake response and localized concerns. With the use of GIS visualization these conditions and factors can be combined to create a co-occurrence product that represents an Integrated Critical Watershed Analysis (ICWA). This analysis product allows for the determination of critical subwatersheds and even more localized areas of concern. Table 8 lists a number of potential attributes for generating a useful analysis product. For each attribute used a coding scheme needs to be set where the level of severeness or negative /positive impact is scaled numerically. Generally a scale of 0 to 3 or 0 to 4 works with 0 representing the condition below the threshold of impact or the optimum condition and the number increases as impact has more influence. In some case it may be a presence or absence kind of attribute with a 0 or 1. If there are attributes that are more critical or important they can be weighted higher or attributes might be combined (for example you may not use an individual water quality parameter but integrate them together so if more than one parameter falls above or below a known impact threshold it would receive a 1 for each time this happens and the water quality score is the composite of those points. In other cases it may be decided that if any of a number of related parameters occur a point is assigned. Note that for demonstration purposes all attributes were weighted the same.

Table 8. Attribute List for the Integrated Critical Watershed Analysis

Integrated Critical Watershed Analysis: Potential Attributes for Co-occurrence Analysis
Direct Locational Attributes (high resolution)
Steep Slopes
Highly Erodible Soils
Constrained Soils (poor for septic or development)*
Development Intensity
Agricultural Activity
Shoreland Development Intensity (250 foot)*
Subwatershed Landscape Attributes (medium resolution)
Road Density
Stream Density
Variable Width Riparian Zone Analysis
Average subwatershed slope
Major and Tributary Level Attributes (lower resolution)
Existing Water Quality Concerns- Tributary
Areal TP loading (measured)
Event Mean TP concentration, Average or Median (measured)
Land Use Impact Indicator
Specific Conductivity Chloride/Sodium Nitrogen/ Nitrate Bacteria
Existing Lake Water Quality or In-Lake Concerns

** indicates attribute specific to near-shore areas*

Figure 9. Final Integrated Critical Watershed Analysis Co-Occurrence with All Resolutions Combined.

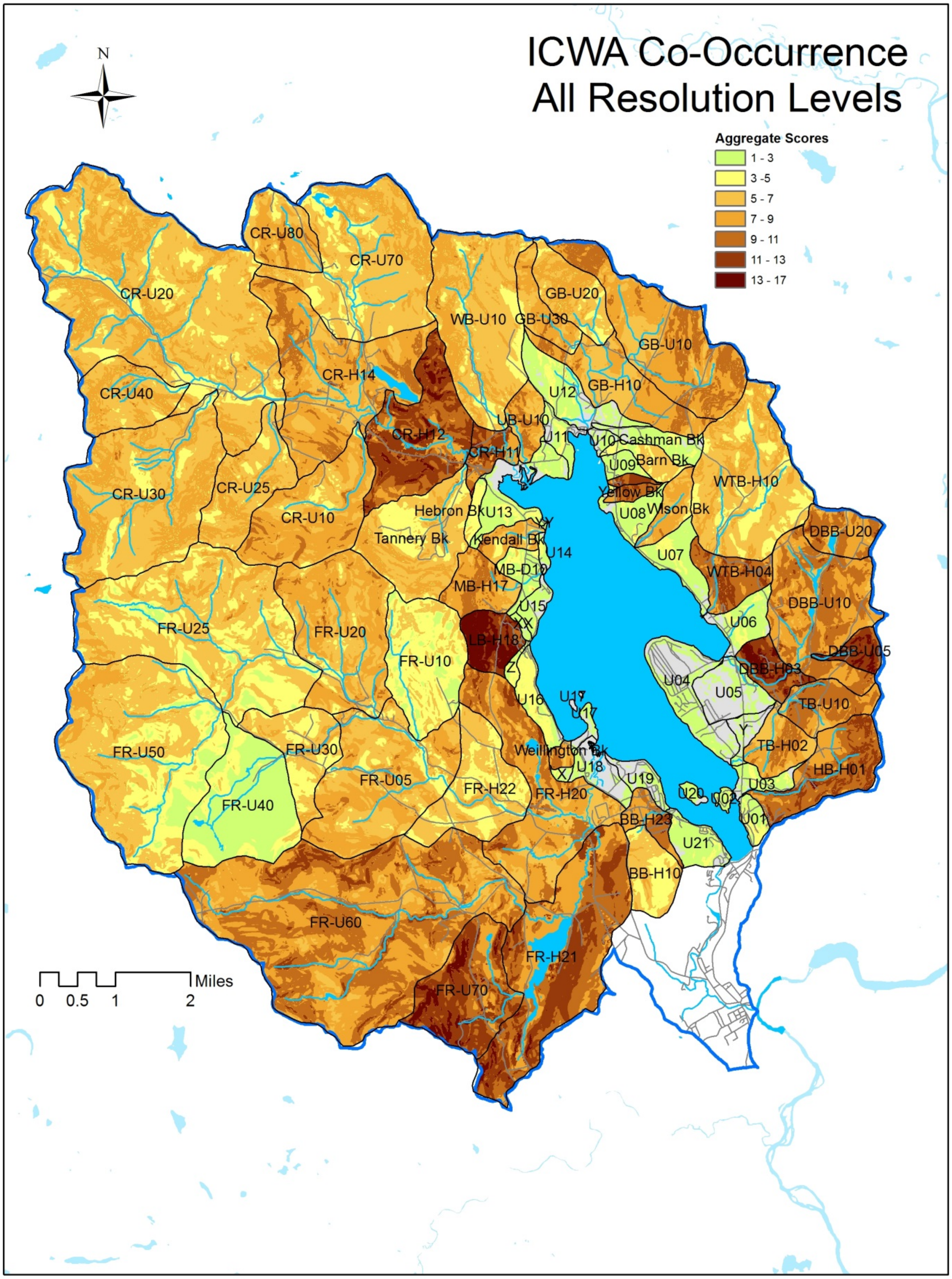


Figure 9 contains the co-occurrence analysis results. For the purposes of the analysis done for this study it was assumed that no weighting needed to occur. For the lowest resolution data a composite score was created for each major tributary that tributary TP loading (whether it was above the 0.068 kg/hectare year the watershed average areal loading; See figure 7.), if it flagged for significantly high nitrate or chloride levels and if the tributary outflow directly entered the lower Mayhew section of the lake. For medium resolution scoring all of the attributes in table 8 were employed as well as average subwatershed slope. The final high resolution scoring was done with the steep slope (coded range at the soil unit resolution), highly erodible soils (yes/no), development intensity (range), and agricultural activity type (range). Create a summary table for these numbers; clear how factors effect water quality.

The analysis shows that the most critical watersheds for water quality include the Dick Brown Brook lower subwatershed (DBB-H3) and one of the headwater subwatersheds (DB-U5), Post Office Brook, the two lower Cockermouth River subwatersheds (CR-H11 and CR-H12), and the Ledges Brook subwatershed. Secondarily and close behind are Hemlock Brook, the lower Whittemore Brook, Yellow Brook, and the lower Fowler River and both Bog Brook subwatersheds. Any subwatersheds that feed into these critical subwatersheds should be flagged also if large land use change is being proposed. It should also be noted that both the 2008 water/nutrient budget and the model indicate that the major sources of TP loading come from the Fowler (48% of the channelized TP load), Cockermouth (18.8%), Georges Brook (4.3%), Dick Brown Brook (3.6%) and Whittemore Brook (3.2%).

A similar analysis will be run for the ungauged shoreline areas once the GIS contractor performs an interpretive land use analysis of the shoreline.

With a list of priority watersheds the project team can plan a strategy for trying to improve and protect the critical watershed areas. For the whole of the watershed an effort to maintain the current riparian buffer extent as with such steep watershed areas this is providing for attenuation in a major way. For each of the priority watersheds above, the action may require further on-site reconnaissance or a look at the monitoring, analysis or model results. Is there a low TP attenuation coefficient? Is the areal loading well above, above or approaching close to the watershed wide areal loading? Was there a storm event sample or mean TP concentration that was high?

The ICWA visualization can also be useful for intra-subwatershed triage when decision-makers are considering development projects. Is the proposed development or land conversion activity adjacent or up watershed to a critical area within the watershed? Can the proposed plans be sure to not allow for those dark colored areas to receive significant water runoff or TP loading? Can low impact development be directed to the lightest colored areas within the subwatershed? Can connections between critical areas be avoided?

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