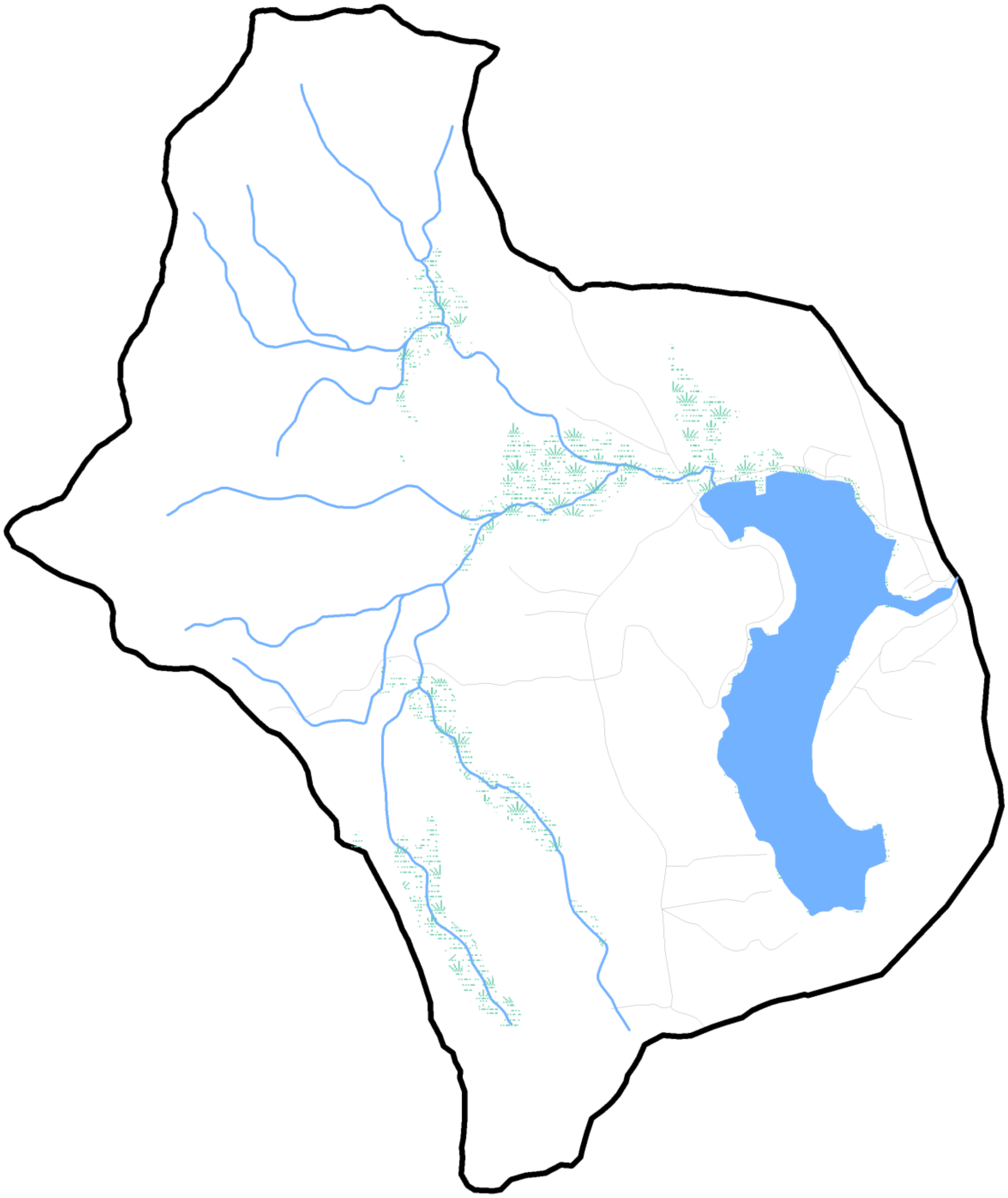
GREGG LAKE WATERSHED
LAKE LOADING RESPONSE MODEL



July 2019

GREGG LAKE WATERSHED

LAKE LOADING RESPONSE MODEL REPORT

Prepared by **FB Environmental Associates**
and **DK Water Resource Consulting**

July 2019

PREPARED FOR:
Town of Antrim
66 Main Street
Antrim, NH 03440

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INTRODUCTION

The purpose of this report is to provide results from the Lake Loading Response Model (LLRM) developed for Gregg Lake. The LLRM is an Excel-based model that uses environmental data to develop a water and phosphorus loading budget for lakes and their tributaries[1]. 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. The model incorporates data about watershed and sub-basin boundaries, land cover, point sources (if applicable), septic systems, waterfowl, rainfall, volume and surface area, and internal phosphorus loading. These data are combined with coefficients, attenuation factors, and equations from scientific literature on lakes, rivers, and nutrient cycles. The following describes the process by which critical model inputs were determined using available resources and GIS modeling, and presents annual average predictions[2] of total phosphorus, chlorophyll-a, Secchi disk transparency, and algal bloom probability. The model can be used to identify current and future pollution sources, estimate pollution limits and water quality goals, and guide watershed improvement projects.

WATERSHED AND SUB-BASIN DELINEATIONS

Watershed and tributary drainage basin (sub-basin) boundaries are needed to determine both the amount of water flowing into the lake and the area of different land cover types contributing to nutrient loading. FBE completed preliminary modeling of sub-basins for the watershed using ESRI Spatial Analyst, QGIS, and EPA BASINS. QGIS and EPA BASINS are both open source spatial mapping and analysis programs. FBE used 2-foot contour data developed from USGS 7.5-minute digital line graphs (hypsography), as well as the location of phosphorus sampling sites, to manually confirm the modeled sub-basin boundary delineations, all of which were snapped to the original watershed boundary obtained from NH GRANIT. FBE performed ground-truthing in the watershed to identify flow directions, esp. in areas where gentle hills and road shoulder ditches redirected flows. The final sub-basin delineations are shown in Figure 1.

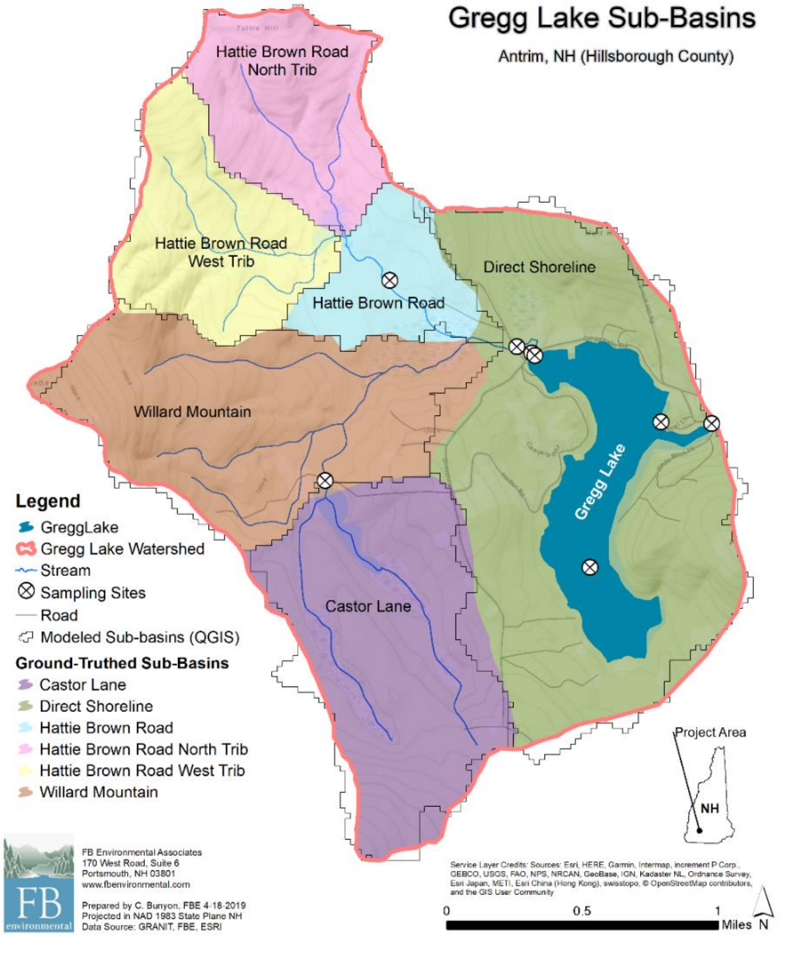

FIGURE 1. Comparison among modeled and final ground-truthed sub-basin boundaries for the Gregg Lake watershed. Sub-basins were selected based on available phosphorus data.

LAND COVER UPDATE

Land cover determines the movement of water and phosphorus from the watershed to surface waterbodies via surface runoff and baseflow (groundwater). A significant amount of time went into reviewing and refining the land cover data. The 2001 New Hampshire Landcover Database (NHLCD) accessed from NH GRANIT was used as a baseline for editing. First, the NHLCD categories were translated into similar LLRM land cover categories (refer to Attachment 1). Next, rectangular grids (or quads) were

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[1] AECOM (2009). LLRM Lake Loading Response Model Users Guide and Quality Assurance Project Plan. AECOM, Willington, CT.

[2] The model cannot simulate short-term weather or loading events.

created to break up the watershed into more manageable portions for review.

ESRI World imagery dated 6/12/2017 and Google Earth satellite images as recent as 9/11/2017 were reviewed for major land cover changes in each quad since the 2001 assessment. If discrepancies between the aerials and the NHLCD file were found, changes were made using the Topology tool for editing polygon vertices or the Editor tool for splitting polygons. Each new polygon was relabeled in the attribute table with the appropriate LLRM land cover category. FBE confirmed land cover areas in the field where desktop aerial review was inconclusive.

A few assumptions or actions were made during this process:

- Forest 3: Mixed was used as the default category for land assigned to forest.
- Agricultural fields that were clearly not pasture or row crops were defaulted to “Agric 4: Hayfield”; it was difficult to discern whether a field was hayfield or cover crop and so no cover crops were delineated in the watershed. FBE refined land cover by distinguishing among hayfields, meadows that were scrub-shrub, non-wetland areas (“Open 2: Meadow”), or extensive lawns/athletic fields such as those associated with camps (“Urban 5: Open Space”); residential lawns were included in Urban 1.
- Recent or historically logged areas were not differentiated from forested land cover types.
- Major bare soil areas (including beaches) that were not associated with new residential home construction were labeled as “Open 3: Excavation.”
- Palustrine wetland areas from the National Wetlands Inventory (NWI) were added as “Forest 4: Wetlands.”
- Unpaved roads from the NHDOT roads layer (NH GRANIT) were added as “Other 1: Unpaved Roads” and confirmed in the field, wherever accessible.

Agricultural and developed lands were checked carefully since modeling coefficients (i.e., phosphorus export) are generally higher for those land cover types. Aerials were checked thoroughly for each major agricultural or developed area to distinguish between hayfields, grazing/pasture, lawns, and meadows. Refer to Attachment 2 for examples of how some land cover categories were distinguished in the watershed. The resulting updated land cover file is a more accurate representation of current land cover within the Gregg Lake watershed (refer to Figure 2 for zoomed-in examples of “before” and “after” modifications). The final land cover is shown in Attachment 3.

Within the LLRM, export coefficients are assigned to each land cover to represent typical concentrations of phosphorus in runoff and baseflow from those land cover types (Attachment 4). Unmanaged forested land, for example, tends to deliver very little phosphorus downstream when it rains, while low to high density urban development export significantly more phosphorus due to lack of infiltration, 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 via groundwater under baseflow conditions. This nutrient load is delivered with groundwater to the lake directly or to tributary streams; however, much of the phosphorus is adsorbed onto soil particles as water infiltrates to the ground. Attachment 4 presents the runoff and baseflow phosphorus export coefficients for each land cover type used in the model, along with the total land cover area by land cover type and sub-basin. These coefficients were based on values from Tarpey 2013, 2001 East Pond TMDL Report, Reckhow et al. 1980, Hutchinson Environmental Sciences Ltd 2014, and Schloss and Connor 2000, among others.

Figure 3 shows a basic breakdown of land cover by major category for the entire watershed (not including lake area), as well as total phosphorus load by major land cover category. Developed areas cover 4% of the watershed and contribute 51% of the total phosphorus watershed load to Gregg Lake.

FIGURE 2. Example of "before" (left) and "after" (right) land cover file modifications for the Gregg Lake watershed.

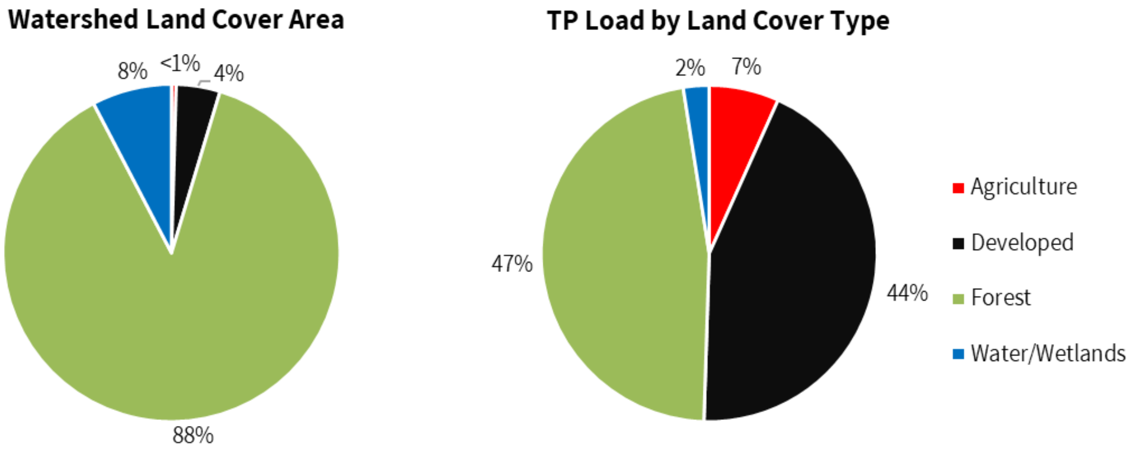

FIGURE 3. Watershed land cover area by general category (developed, agriculture, forest, and water/wetlands) and total phosphorus (TP) watershed load by general land cover type. This shows that developed areas cover 4% of the watershed and contribute 51% of the TP watershed load to Gregg Lake.

OTHER MAJOR LLRM INPUTS

The following presents a brief outline of other variable sources and assumptions input to the model. Refer to Limitations to the Model for further discussion.

- **Monthly precipitation data** were obtained from NOAA NCEI for the EDWARD MACDOWELL LAKE, NH (USC00275013) weather station with data gaps covered by weather stations in MARLOW, NH (USC00275150), PETERBORO 2 S, NH (USC00276697), and Jaffrey Municipal Airport Silver Ranch, NH (USW00054770). Average annual precipitation totals from 2009-2018 were input to the model (50.683 in or 1.287 m).
- **Lake volume and area estimates** were obtained from the New Hampshire Fish & Game Department (NHFGD) and New Hampshire Department of Environmental Services (NHDES) bathymetry shapefile (via NH GRANIT). The lake volume estimates from the NHFGD and NHDES were 3% and 4% greater than the VLAP volume estimate, respectively. The lake surface area estimates from the NHFGD and NHDES were both 1% greater than the VLAP area estimate. NHFGD bathymetry data were used for the model.
- **Septic system data** were obtained from a database of 55 lakeshore properties surveyed in July-December 2019 by the Town of Antrim. Any missing survey information was obtained from property cards. The survey results included information on the age and usage (seasonal or year-round and occupancy) of septic systems within 250 feet of the lake, which was used to calculate a water and phosphorus load to the lake from septic systems.
- **Water quality data** were obtained from NHDES Environmental Monitoring Database (EMD). The model was calibrated using tributary and lake samples taken between 2009 and 2018 (recent 10 years). Sites were only included if they were a close match to the outlet of a sub-basin used in the model. Data were summarized by day, then month, then all data to obtain median water quality summaries for total phosphorus, chlorophyll-a, and Secchi Disk Transparency. Data analysis can be found in the Gregg Lake Water Quality Summary Report prepared by the Gregg Lake Watershed Management Plan Committee (February 2019).
- **Waterfowl data** were acquired from eBird online. Species classified as “waterfowl” include the Canada goose, mallard, bald eagle, wood duck, common loon, and great blue heron. Fifteen individuals of these species were spotted from August-September 2018. However, a standard estimate of 0.3 birds per hectare of lake surface area (or 24 individuals) was used instead because the bird census data were deemed insufficient and likely underestimating the bird count. 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; even so, the phosphorus excreted may be in a form that can be readily used by algae and plants.
- **Internal loading estimates** were derived from dissolved oxygen and temperature profiles taken at the deep spot of Gregg Lake from 2009-2018 (to determine average annual duration and depth of anoxia defined as <1 ppm dissolved oxygen) and epilimnion/hypolimnion total phosphorus data taken at the deep spot of Gregg Lake from 2009-2018 (to determine average difference between surface and bottom phosphorus concentrations). These estimates, along with anoxic volume and surface area, helped determine rate of release and mass of annual internal phosphorus load.

CALIBRATION

Calibration is the process by which model results are brought into agreement with observed data and is an essential part of environmental modeling. 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-stream phosphorus concentrations were used as guideposts, but attenuation values were generally defaulted to reflect little attenuation because of the watershed’s steep slopes (Table 1). Observed in-lake phosphorus concentrations were given primacy during the calibration process, such that the ability of the model to accurately simulate annual average in-lake phosphorus concentrations was used as a leading indicator of acceptable model performance. Continued water quality sampling in the watershed can be designed to reduce the uncertainty encountered in modeling and help assess changes made during calibration.

The following key calibration input parameter values and modeling assumptions were made:

- The **standard water yield** coefficient was input as 2.0 cubic ft/sq. m, which is the high end of the range for New England but reflects the watershed’s steep slopes and high runoff potential.
- **Direct atmospheric deposition** phosphorus export coefficient was assumed to be 0.11 kg/ha/yr from Schloss et al. (2013) and represents a largely undeveloped watershed.

- Default **water and phosphorus attenuation factors** were used with a couple exceptions as noted in Table 1. Water can be lost through evapotranspiration, deep groundwater, and wetlands, while phosphorus can be removed by infiltration or uptake processes. We generally expected at least a 5% loss (95% passed through, default) in water and a 10% loss (90% passed through, default) in phosphorus for each sub-basin. Larger water losses (<95% passed through) were expected with lower gradient or wetland-dominated sub-basins. Additional infiltration, filtration, detention, and uptake of phosphorus will lower the phosphorus attenuation value, such as for sub-basins dominated by moderate/small ponds or wetlands (75%-85% passed through) or channel processes that favor uptake (85% passed through), depending on the gradient. Headwater systems were assumed to have a greater attenuation than higher order streams since the flow of water is lower, giving more opportunity for infiltration, adsorption, and uptake.
- The average of multiple **empirical formulas** for predicting annual in-lake phosphorus concentration included Vollenweider (1975) and Jones-Bachmann (1976) because results from those models best matched conditions observed in the lake over the past 10 years.

TABLE 1. Reasoning for water and phosphorus attenuation factors used by sub-basin.

Sub-Basin	Water Atten. Factor	Phos. Atten. Factor	Reasoning (water; phosphorus (P))
Castor Lane	0.95	0.85	Default water attenuation factor (due to steep slopes); slight increase in P attenuation due to moderate sized pond-wetland complex.
Direct Shoreline	0.95	0.90	Default water and P attenuation factor (due to steep slopes).
Hattie Brown Road	0.98	0.95	Less attenuation for higher order streams to account for cumulative retention (Hattie Brown Road North and West Tribs feed into this sub-basin).
Hattie Brown Road North Trib	0.95	0.90	Default water and P attenuation factor (due to steep slopes).
Hattie Brown Road West Trib	0.95	0.90	Default water and P attenuation factor (due to steep slopes).
Willard Mountain	0.95	0.90	Default water and P attenuation factor (due to steep slopes).

LIMITATIONS TO THE MODEL

There were several limitations to the model; literature values and best professional judgement were used in place of measured data, wherever appropriate. Acknowledging and understanding model limitations is critical to interpreting model results and applying any derived conclusions to management decisions. The model should be viewed as one of many tools available for lake management. Because the LLRM incorporates specific waterbody information and is flexible in applying new data inputs, it is a powerful tool that predicts annual average in-lake total phosphorus concentrations with a high degree of confidence; however, model confidence can be increased with more data. The following lists specific limitations to the model:

- **The model represents a static snapshot in time based on the best information available at the time of model execution.** Factors that influence water quality are dynamic and constantly evolving; thus, the model should be regularly updated when significant changes occur within the watershed and as new water quality and physical data are collected. In this respect, the model should only be considered up-to-date on the date of its release. Model results represent annual averages and are best used for planning level purposes and should only be used with full recognition of the model limitations and assumptions.
- **Limited data were available for sub-basins.** Most sub-basins had a weak dataset ($n \approx 3$) available for model calibration; the dataset could be made stronger with continued data collection at existing active sites, as well as at three sites with limited data (n = 1-4): Castor Lane, Craig Rd Bridge, Hattie Brown Brook, and Hattie Brown Rd. Collecting samples under a variety of flow conditions (and measuring flow) across several years can help reduce this uncertainty. More data are needed to effectively calibrate the model to known observations for these sub-basins. Until more data are available, we assumed that similar land cover coefficients and attenuation values used in other sub-basins with more certainty would be applicable to the sub-basins with less certainty due to limited data.
- **Internal loading estimates were based on data concentrated in recent years.** Phosphorus that enters the lake and settles to the bottom can be re-released from sediment under anoxic conditions, providing a nutrient source for algae and other plants. Internal phosphorus loading can also result from wind-driven wave action or physical disturbance of the sediment (boat props, aquatic macrophyte management activities). Dissolved oxygen and

temperature profiles were collected once a year from 1997 - 2001 and from 2005 - 2014. Sampling frequency increased in 2016 (once per month from June - August) and in 2017 and 2018 (once per month from April - October). Continuing a high sampling frequency would improve any future updates to the model.

- **Septic system loading was estimated based on default literature values.** Default literature values for daily water usage, phosphorus concentration output per person, and system phosphorus attenuation factors were used and may not reflect local watershed conditions.
- **Waterfowl counts were based on default estimates.** In the future, a large bird census throughout the year, not strictly August and September, would help improve the model loading estimates.
- **Land cover export coefficients were estimates.** Literature values and best professional judgement were used in evaluating and selecting appropriate land cover export coefficients for Gregg Lake. While these coefficients may be accurate on a larger scale, they are likely not representative on a site-by-site basis. Refer to documentation within the LLRM spreadsheet for specific citations.

RESULTS

CURRENT LOAD ESTIMATION

Overall, model predictions were in good agreement with observed data and were within <1% to 3% relative percent difference of observed mean annual total phosphorus, chlorophyll-a, and Secchi disk transparency (Table 2). It is important to note that the LLRM does not explicitly account for all the biogeochemical processes occurring within a waterbody that contribute to overall water quality and is less accurate at predicting chlorophyll-a and Secchi disk transparency. For example, chlorophyll-a is estimated strictly from nutrient loading, but other factors strongly affect algae growth, including low light from suspended sediment, grazing by zooplankton, presence of heterotrophic algae, and flushing effects from high flows. There were insufficient data available to evaluate the influence of these other factors on observed chlorophyll-a concentrations and Secchi disk transparency readings.

Watershed runoff combined with baseflow (72%) was the largest phosphorus loading contribution across all sources to Gregg Lake, followed by atmospheric deposition (9%), internal loading (9%), septic systems (6%), and waterfowl (4%) (Table 3; Figure 4). Development in the watershed is most concentrated around the shoreline where septic systems or holding tanks are located within a short distance to the water, leaving little horizontal (and sometimes vertical) space for proper filtration of wastewater effluent. Improper maintenance or siting of these systems can cause failures, which leach untreated, nutrient-rich wastewater effluent to the lake.

Internal loading is also a concern for Gregg Lake given that low dissolved oxygen in bottom waters is causing a significant release of phosphorus from bottom sediments (as evidenced by the moderate difference between bottom and surface phosphorus concentrations (7.8 ppb)). Low flushing rate in late summer may further exacerbate internal loading as both the duration of anoxia and the residence time for nutrients are prolonged.

The direct shoreline area to Gregg Lake had the highest phosphorus export by total mass, followed distantly by Willard Mountain (Table 4). Drainage areas directly adjacent to waterbodies have direct connection with the lake and are usually targeted for development, thus increasing the possibility for phosphorus export. Normalizing for the size of a tributary (i.e., accounting for its annual discharge and direct drainage area) better highlights sub-basins with elevated pollutant exports relative to their drainage area. Sub-basins with moderate-to-high phosphorus mass exported by area (> 0.1 kg/ha/yr) generally had more development (i.e., the direct shoreline; Table 4). Limited observed phosphorus data were available for the outlets of the sub-basins but observed data showed higher-than-predicted concentrations likely due to low flow, seasonal conditions under which the samples were collected. More data are needed to better confirm the coefficients and attenuation factors used for those sub-basins.

PRE-DEVELOPMENT LOAD ESTIMATION

Once the model is calibrated for current in-lake phosphorus concentration, we can then manipulate land cover and other factor loadings to estimate pre-development loading scenarios (e.g., what in-lake phosphorus concentration was prior to human development or the best possible water quality for the lake). Refer to Attachment 5 for details on methodology.

Pre-development loading estimation showed that total phosphorus loading increased by 118%, from 45 kg/yr prior to European settlement to 98 kg/yr under current conditions, for Gregg Lake (Table 3; Figure 4). These additional phosphorus sources are coming from development in the watershed (especially in the direct shoreline of Gregg Lake), septic systems, atmospheric dust, and internal loading (Tables 3, 5; Figure 4). Water quality prior to settlement was likely excellent with extremely low phosphorus and chlorophyll-a concentrations and high water clarity (Table 2).

FUTURE LOAD ESTIMATION

We can also manipulate land cover and other factor loadings to estimate future loading scenarios (e.g., what in-lake phosphorus concentration might be at full build-out under current zoning constraints or the worst possible water quality for the lake). Refer to Attachment 6 and the Build-out Analysis Report for details on methodology. Note: the future scenario did not assume a 10% increase in precipitation over the next century (NOAA Technical Report NESDIS 142-1, 2013), which would have resulted in a lower predicted in-lake phosphorus concentration; this is because the model does not consider the rate and distribution of the projected increase in precipitation. Climate change models predict more intense and less frequent rain events that may exacerbate erosion of phosphorus-laden sediment to surface waters and therefore could increase in-lake phosphorus concentration (despite dilution and flushing impacts that the model assumes).

Future loading estimation showed that total phosphorus loading may increase by 115%, from 98 kg/yr under current conditions to 211 kg/yr at full build-out (2180) under current zoning, for Gregg Lake (Table 3; Figure 4). Additional phosphorus will be generated from more development in the watershed (especially from the direct shoreline of Gregg Lake, followed by Willard Mountain and Hattie Brown Road sub-basins), greater atmospheric dust, more septic systems, and enhanced internal loading (Table 3, 5; Figure 4). The model predicted significantly higher (worse) phosphorus (17.6 ppb), higher (worse) chlorophyll-a (8.8 ppb), and lower (worse) water clarity (2.6 m) compared to current conditions (Table 2). Any new increases in phosphorus to a lake can disrupt the ecological balance in favor of increased algal growth, resulting in degraded water clarity. The impact from new buildings and septic systems can be greatly reduced by implementing low impact development (LID) techniques and ensuring that all new septic systems are well separated from surface waters both horizontally and vertically (above seasonal high groundwater in suitable soil).

TABLE 2. In-lake water quality predictions for Gregg Lake. TP = total phosphorus. Chl-a = chlorophyll-a. SDT = Secchi disk transparency.

Model Scenario	Median TP (ppb)	Predicted Median TP (ppb)	Mean Chl-a (ppb)	Predicted Mean Chl-a (ppb)	Mean SDT (m)	Predicted Mean SDT (m)
Pre-Development	--	3.4	--	2.0	--	8.3
Current (2018)	6.8 (8.2)	8.2	4.3	4.2	4.7	4.6
Future (2180)	--	17.6	--	8.8	--	2.6

**Median TP concentration of 6.8 ppb represents existing in-lake epilimnion TP from observed data. Median TP concentration of 8.2 ppb represents 20% greater than actual median values as the value used to calibrate the model. Most lake data are collected in summer when TP concentrations are typically lower than annual average concentrations for which the model predicts*

TABLE 3. Total phosphorus (TP) and water loading summary by source.

SOURCE	PRE-DEVELOPMENT			CURRENT (2018)			FUTURE (2180)		
	TP (KG/YR)	%	WATER (CU.M/YR)	TP (KG/YR)	%	WATER (CU.M/YR)	TP (KG/YR)	%	WATER (CU.M/YR)
ATMOSPHERIC	6	13%	629,700	9	9%	629,700	20	10%	629,700
INTERNAL	0	0%	0	9	9%	0	28	13%	0
WATERFOWL	3	7%	0	3	4%	0	3	2%	0
SEPTIC SYSTEM	0	0%	0	6	6%	4,874	13	6%	10,428
WATERSHED LOAD	36	80%	7,538,936	71	72%	7,542,824	146	69%	7,551,326
TOTAL LOAD TO LAKE	**45**	**100%**	**8,168,636**	**98**	**100%**	**8,177,398**	**211**	**100%**	**8,191,454**

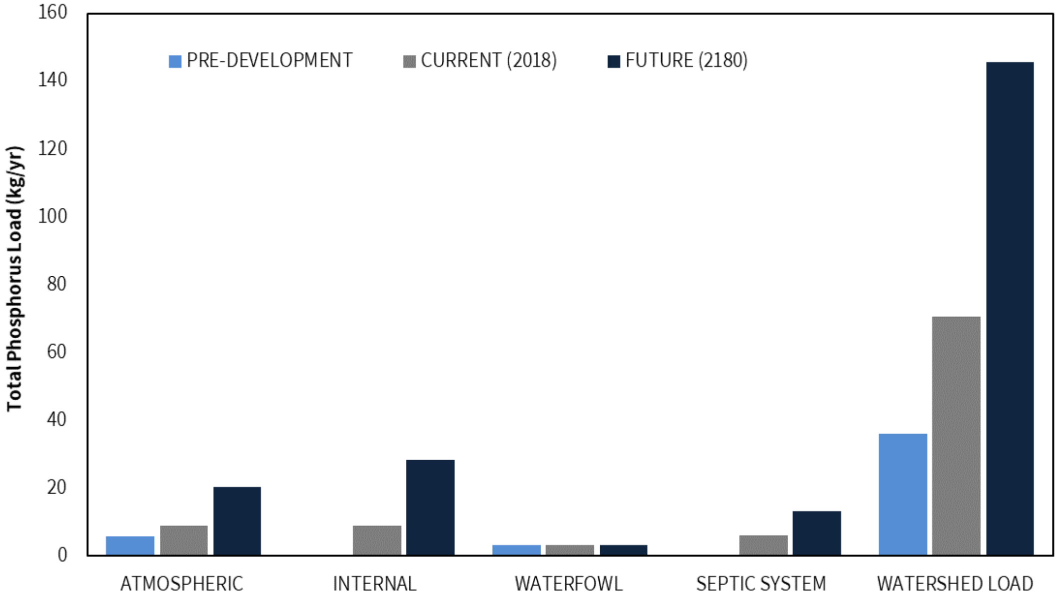

FIGURE 4. Total phosphorus (TP) loading (kg/yr) by source (atmospheric, internal loading, waterfowl, septic systems, watershed load) for pre-development, current, and future modeling scenarios.

TABLE 4. Summary of land area, water flow, and total phosphorus (TP) loading by sub-basin (non-cumulative if a sub-basin contributes to another sub-basin, except for water flow).

	Watershed Loads					
Sub-Basin	Land Area (ha)	Water Flow (m3/year)	Calculated P Concentration (mg/L)	Measured P Concentration (mg/L)	P mass (kg/year)	P mass by area (kg/ha/year)
Castor Lane	205.7	0	0.005	0.018	8.0	0.04
Direct Shoreline	336.6	2,450,887	0.018	*no data*	43.9	0.13
Hattie Brown Road	64.5	2,083,323	0.004	0.011	2.6	0.04
Hattie Brown Road North Trib	109.2	0	0.004	*no data*	3.3	0.03
Hattie Brown Road West Trib	118.1	0	0.004	*no data*	3.7	0.03
Willard Mountain	226.0	3,008,613	0.006	0.014	10.2	0.05

TABLE 5. Total phosphorus (TP) watershed loading summary (total mass and total mass per area) by sub-basin for pre-development, current, and future modeling scenarios.

	Watershed Load					
	Pre-Development		Current (2018)		Future (2180)	
Sub-Basin	TP Load (kg/yr)	TP Load (kg/ha/yr)	TP Load (kg/yr)	TP Load (kg/ha/yr)	TP Load (kg/yr)	TP Load (kg/ha/yr)
Castor Lane	6.2	0.03	8.0	0.04	12.2	0.06
Direct Shoreline	14.2	0.04	43.9	0.13	73.3	0.22
Hattie Brown Road	2.0	0.03	2.6	0.04	13.4	0.21
Hattie Brown Road North Trib	3.3	0.03	3.3	0.03	9.1	0.08
Hattie Brown Road West Trib	3.7	0.03	3.7	0.03	9.2	0.08
Willard Mountain	7.6	0.03	10.2	0.05	30.6	0.14

CONCLUSION

Based on model analysis of pre-development, current, and future water quality conditions, Gregg Lake is at risk for water quality degradation from future development under current zoning. Additional phosphorus loading from the watershed and internal sediments will likely accelerate water quality degradation of the lake, though the relationship between total phosphorus and chlorophyll-a appears to not be directly causal[3] at least at a seasonal scale when most samples were collected (Figure 5). However, the model predicted both total phosphorus and chlorophyll-a well at the annual average scale, indicating that total phosphorus is still an important driver of chlorophyll-a concentrations in Gregg Lake. Gregg Lake has already surpassed the maximum oligotrophic criterion for chlorophyll-a at 3.3 ppb despite the relatively low total phosphorus concentration in the lake that shows a remaining assimilative capacity of 0.4 ppb. Given Gregg Lake's recreational and aquatic habitat value in the region, it will be crucial to both maximize land conservation of intact forestland and consider zoning ordinance amendments that encourage low impact development techniques on existing and new development.

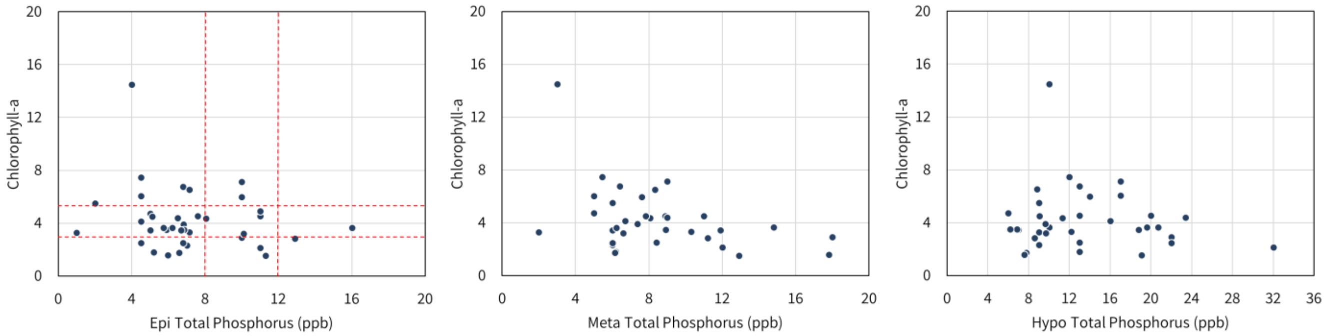

FIGURE 5. The relationship between chlorophyll-a and total phosphorus in Gregg Lake deep spot (GREANTD) shows that chlorophyll-a (measure of algae) in unresponsive to changes in total phosphorus concentration in the epilimnion, metalimnion, and hypolimnion, at least as a seasonal scale when most samples were collected. Thresholds (red lines) for chlorophyll-a and total phosphorus for oligotrophic (3.3 ppb Chl-a, 8 ppb TP) and mesotrophic (5 ppb Chl-a, 12 ppb TP) waterbodies per NHDES are shown for epilimnion chlorophyll-a and total phosphorus figure only.

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[3] We recommend including total nitrogen analyses as part of the regular monitoring program.

ATTACHMENT 1: Land cover File Update Workflow Record

LLRM Land Cover Update Workflow
5/15/2018 C. Bunyon
Project #396 Gregg Lake WMP

All data projected in NAD 1983 State Plane NH FIPS 2800 feet

ESRI World Imagery dated 6/12/2017
Google Earth Imagery dated 9/11/2017

Land cover file from NH GRANIT: nhlc01
- ArcToolbox >Data Management Tools > Raster > Raster Processing > Clip
  - Extent clipped to "gregg_wshed"
  - File = "nhlc01_gregg"
- ArcToolbox >Conversion Tools > From Raster > Raster to Polygon
  - File = "nhlc01_gregg_before"

- Add text field > "LLRM_code" (open attribute table, table options, Add field..)
- Rename land cover classes to match LLRM categories
  - *Note: the following list displays relevant LLRM codes and NHLC01 Gridcodes that may or may not exist in the Gregg Lake watershed*
  - **LLRM_code / NHLC01 GRIDCODE**
  - "Urban 1: Low Den Res" / 110
  - Urban 2: Commercial/Mid Den Res / NA
  - Urban 3: Roads / 140
  - Urban 4: Industrial / NA
  - Urban 5: Open Space/Mowed / NA
  - Agric 1: Cover Crop / NA
  - Agric 2: Row Crop / 211, 221
  - Agric 3: Grazing / NA
  - Agric 4: Hayfield / 212
  - Forest 1: Deciduous / 412, 414, 419
  - Forest 2: Non-Deciduous / 421, 422, 423, 424
  - Forest 3: Mixed / 430
  - Forest 4: Wetland / 610
  - Open 1: Water / 500, 620
  - Open 2: Meadow / NA
  - Open 3: Excavation / 710
  - Other 1: Logging / 790
  - Other 2: Unpaved Road / NA
  - Other 3: Bedrock / 720

- Apply symbology to LLRM categories

ArcCatalog > Copy "nhlc01_gregg_before" > Rename "nhlc01_gregg_after"
- Import symbology to match "nhlc01_gregg_before" shapefile
- Set display transparency to 70%

Data Management Tools > Feature Class > Create Fishnet
- Created 10x10 grid
- Deleted grids not covering watershed area

Labeled quads #0-99

ADD PAVED & UNPAVED ROADS

- Downloaded “NH DOT Roads” from GRANIT and clipped to watershed area > “gregg_roads”
- Geoprocessing > Buffer > Input "gregg_roads"; buffer = 25 ft -> "gregg_roads_buff25ft.shp"
- Geoprocessing > Union > Input "nhlc01_gregg_after" and "gregg_roads_buf25ft" -> "nhlc01_gregg_after_rds"
    - Unchecked “Gaps Allowed”
- Relabeled all former “Urban 3: Roads” to default “Forest 3: Mixed”
- Relabeled added road polygons as "Urban 3: Roads” under "LLRM_code" for paved roads [SURF_TYPE] OR as "Other 2: Unpaved Roads” under "LLRM_code" for unpaved roads [SURF_TYPE]

ADD WETLANDS

- Download NWI Wetlands (https://www.fws.gov/wetlands/data/mapper.html)
- Clip to watershed -> “nwi_clip”
- Add text field > “LLRM”
    - Lake (L1UBH) → Open 1: Water
    - Freshwater Pond (PUB) → Open 1: Water
    - Freshwater Forested/Shrub Wetland (PFO/PSS) → Forest 4: Wetland
    - Upland (U) → Removed
    - PEM → Forest 4: Wetland
- Geoprocessing > Union > Input " nhlc01_gregg_after_rds " and "nwi_clip" -> "nhlc01_gregg_after_rds_nwi"
    - Unchecked “Gaps Allowed”
- Relabeled all former “Open 1: Water” to default “Forest 3: Mixed Forest”
- Relabeled added nwi polygons as "Open 1: Water” under "LLRM_code" for open water [LLRM] OR as "Forest 4: Wetland” under "LLRM_code" for wetlands [LLRM]

ADD STREAMS

- Download National Hydrography Dataset from NH GRANIT
- Clip to watershed -> “NHDFlowlines_GL”
- Geoprocessing > Buffer > Input "NHDFlowlines_GL"; buffer = 15 ft -> "gregg_streams_buff15ft.shp"
- Geoprocessing > Union > Input " nhlc01_gregg_after_rds_nwi " and "NHDFlowlines_GL" -> "nhlc01_gregg_after_rds_nwi_flow"
    - Unchecked “Gaps Allowed”
- Relabeled added stream polygons as "Open 1: Water” under "LLRM_code" for streams

MULTIPART TO SINGLEPART

- Data Management Tools > Features > Multipart to Singlepart
    - Input: “nhlc01_gregg_after_rds_nwi_flow”
    - Output: “nhlc01_gregg_after_rds_nwi_flow_single”
- ArcCatalog > Copy "nhlc01_gregg_after_rds_nwi_flow_single" > Rename "gregg_landcover_v1"

LAND COVER ANALYSIS

- Step 1: Zoom to Quad #X; compare “gregg_landcover_v1” to most recent aerials
- Step 2: If changes needed, used Topology tool to edit vertices or Editor tool to split polygons; relabel polygons in attribute table to appropriate LLRM land cover category

ASSUMPTIONS

- Alterations to add in forested land cover was defaulted to “Forest 3: Mixed”
- Agricultural fields that were clearly not pasture or row crops were defaulted to “Agric 4: Hayfield”; it was difficult to discern whether a field was hayfield or cover crop and so no cover crops were delineated in the watershed
- Commercial lawns, and athletic/ camp fields were labeled as “Urban 5: Open Space/Mowed Fields”; residential lawns are included in Urban 1

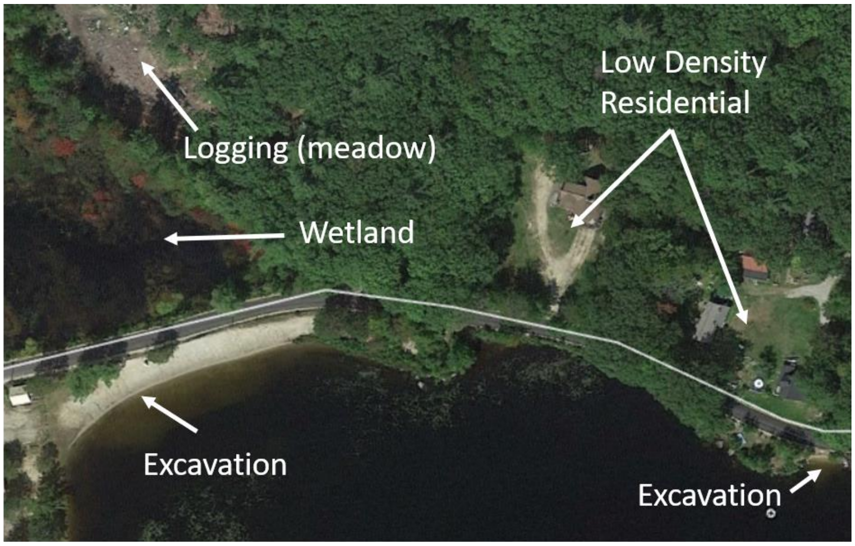
Shrubby areas that may or may not have been the result of a logging operation (and regenerating) were labeled as "Open 2: Meadow"

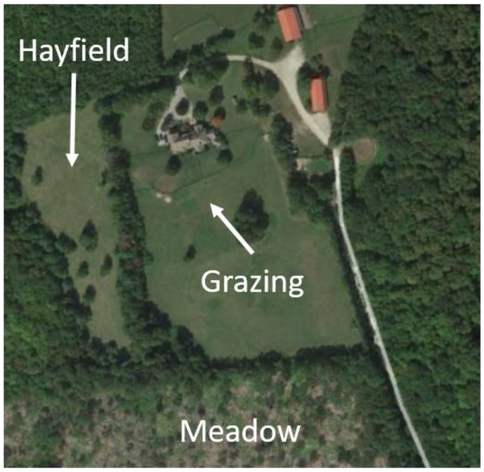
Major bare soil areas that were not associated with new residential home construction were labeled as "Open 3: Excavation"

FINAL FILES

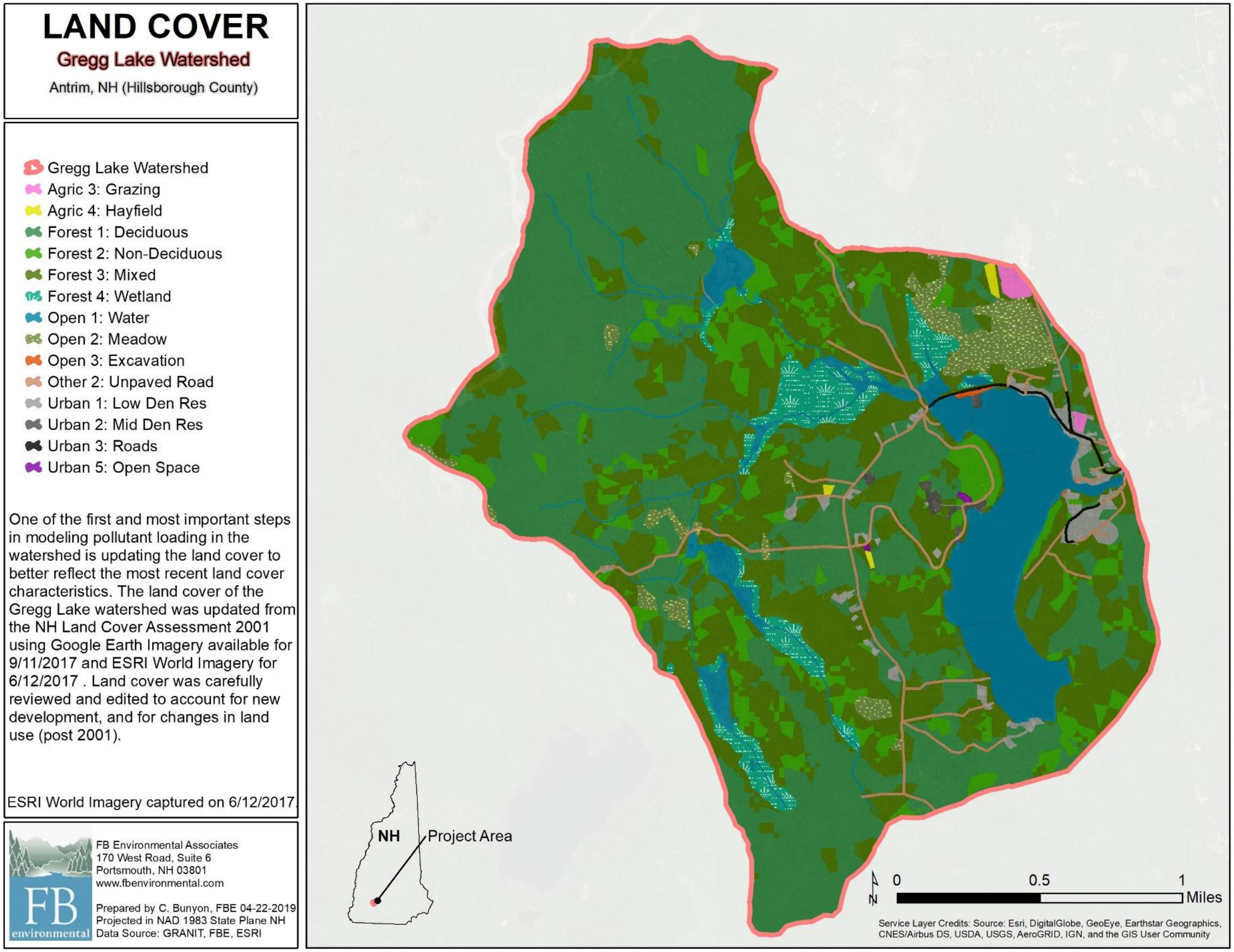
"GreggLake_wshed.shp" = final watershed boundary
"Gregg_subbas.shp" = final sub-basin boundaries
"Gregg_LandCover_final.shp" = final land cover

ATTACHMENT 2: Examples of Distinguishing Land Cover in Aerials





ATTACHMENT 3: Final Land Cover Map



One of the first and most important steps in modeling pollutant loading in the watershed is updating the land cover to better reflect the most recent land cover characteristics. The land cover of the Gregg Lake watershed was updated from the NH Land Cover Assessment 2001 using Google Earth Imagery available for 9/11/2017 and ESRI World Imagery for 6/12/2017 . Land cover was carefully reviewed and edited to account for new development, and for changes in land use (post 2001).

ESRI World Imagery captured on 6/12/2017.

FB Environmental Associates
170 West Road, Suite 6
Portsmouth, NH 03801
www.fbenvironmental.com

Prepared by C. Bunyon, FBE 04-22-2019
Projected in NAD 1983 State Plane NH
Data Source: GRANIT, FBE, ESRI

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

ATTACHMENT 4: Land Cover by Sub-Basin

Land cover phosphorus (P) export coefficients and land cover areas for sub-basins in the Gregg Lake watershed. Summed areas of sub-basins equal total watershed area minus the surface area of Gregg Lake.

Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	Area (hectares)					
			Castor Lane	Direct Shoreline	Hattie Brown Road	Hattie Brown Road North Trib	Hattie Brown Road West Trib	Willard Mountain
Urban 1 (Low Density Residential)	0.79	0.010	0.9	14.6	0.0	0.0	0.0	1.0
Urban 2 (Mid Density Residential/Commercial)	0.90	0.010	0.0	3.0	0.0	0.0	0.0	0.0
Urban 3 (Roads)	0.30	0.010	0.0	3.0	0.0	0.0	0.0	0.0
Urban 5 (Mowed Fields)	0.60	0.010	0.0	0.4	0.0	0.0	0.0	0.0
Agric 3 (Grazing)	1.50	0.010	0.0	3.2	0.0	0.0	0.0	0.0
Agric 4 (Hayfield)	0.37	0.010	0.0	1.3	0.0	0.0	0.0	0.3
Forest 1 (Deciduous)	0.03	0.004	85.8	102.5	1.7	77.3	93.3	109.4
Forest 2 (NonDeciduous)	0.03	0.004	17.1	32.5	17.7	3.1	6.0	16.8
Forest 3 (Mixed)	0.03	0.004	69.0	122.7	34.5	22.8	11.4	70.9
Forest 4 (Wetland)	0.03	0.004	16.6	7.2	6.2	1.0	0.6	12.6
Open 1 (Water)	0.01	0.004	11.4	4.4	3.7	4.6	5.7	7.3
Open 2 (Meadow)	0.20	0.004	3.1	25.8	0.0	0.4	1.0	5.2
Open 3 (Excavation)	0.80	0.010	0.0	0.5	0.0	0.0	0.0	0.0
Other 2 (Unpaved Road)	0.83	0.010	1.8	15.6	0.8	0.0	0.1	2.5
		TOTAL	**205.7**	**336.6**	**64.5**	**109.2**	**118.1**	**226.0**

ATTACHMENT 5: Estimating Pre-Development Phosphorus Load

1. Converted all human land cover to mixed forest (Forest 3) and updated model.
2. Removed all septic inputs (set population to zero).
3. Removed internal loading, assuming internal loading was the result of excess nutrient loading from human activities in the watershed.
4. Reduced atmospheric loading coefficient to 0.07 kg/ha/yr.
5. Roughly matched outflow TP to predicted in-lake TP.
6. Kept all else the same, assuming waterfowl counts and precipitation input did not change (though they likely did).

ATTACHMENT 6: Estimating Future Phosphorus Load at Full Build-Out

1. Estimated number of new buildings at full buildout by sub-basin. CommunityViz software uses model inputs such as population growth rates, zoning, wetlands, conservation lands, and other constraints to construction, and generates a projected number of new buildings in the future. The new building count was generated for each sub-basin at full buildout.
2. Calculated developed land coverage after full buildout projection. Each new building was assumed to generate new developed land uses, including buildings, roads, etc. Specifically, the calculated areas of Urban 1-5, Agric 3-4, Open 3, and Other 2 per new building (based on current land cover areas and number of existing buildings) were multiplied by the number of new buildings in each sub-basin. A total of 0.39 ha was converted per new building.
3. Incorporated land use changes to LLRM for P loading predictions. Added the new developed land use figures to the LLRM. Within each sub-basin, existing un-developed land uses were replaced with areas equal to added developed land.
4. Incorporated septic system loading to LLRM for P loading predictions. The number of new buildings within 250 feet of water was estimated from the CommunityViz output shapefile of projected new buildings. All other assumptions were kept the same.
5. Increased atmospheric loading coefficient to 0.25 kg/ha/yr.
6. Calculated potential increase in internal loading. We assumed a similar magnitude increase in future internal loading as compared to the increase in future total load to the lake.
7. Roughly matched outflow TP to predicted in-lake TP.
8. Kept all else the same.