MERRYMEETING RIVER & LAKE

LAKE LOADING RESPONSE MODEL REPORT

April 2019

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May 2019

PREPARED FOR:
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TABLE OF CONTENTS

Downing Pond. Photo Credit: FBE.

INTRODUCTION

The purpose of this report is to provide results from the Lake Loading Response Model (LLRM) developed for the Merrymeeting River and Lake watershed. The LLRM is an Excel-based model that uses environmental data to develop a water and phosphorus loading budget for lakes/ponds 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 and lake/pond sub-basins, to the confluence of the Merrymeeting River and Lake Winnipesaukee at Alton Bay. The model incorporates data about watershed and sub-basin boundaries, land cover, point sources (e.g., Powder Mill State Fish Hatchery), 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 inputs were determined and input to the model using available resources and GIS modeling, and presents annual average predictions[2] of total phosphorus, chlorophyll-a, Secchi disk transparency, and algae 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 a surface waterbody and the area of different land cover types contributing to nutrient loading. FBE completed preliminary delineation of sub-basins for the watershed using QGIS Desktop 3.4.1, an open source spatial mapping and analysis program[3]. FBE then used ESRI World Topo Map with 20-foot contours, as well as the location of sample sites, to manually confirm the modeled sub-basin boundary delineations, all of which were snapped to the overall watershed boundary. The overall watershed boundary was extracted from the USGS National Watershed Boundary Dataset (WBD) (HUC12 - 010700020102 Watson Brook-Alton Bay) and manually delineated to the Merrymeeting River outlet to Alton Bay (along the northwestern boundary). FBE performed ground-truthing in the watershed to identify flow directions through each sub-basin, especially in areas where stormwater systems redirected flows between sub-basins (Figure 1).

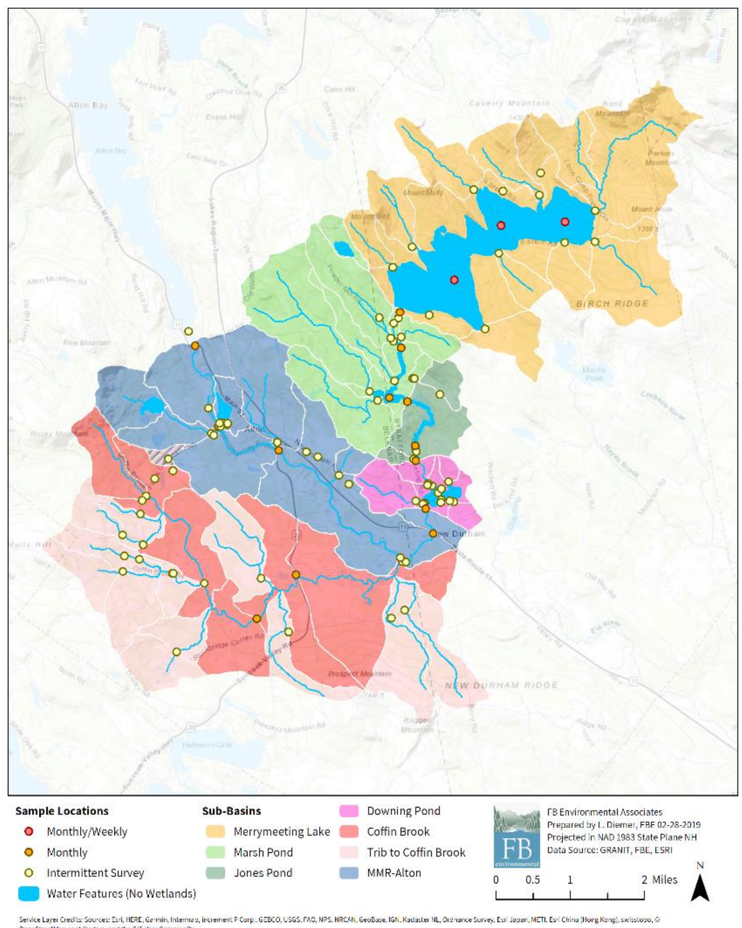

FIGURE 1. Final ground-truthed sub-basin boundaries for the Merrymeeting River and Lake watershed. Sub-basins were selected based on major junctions or outlets and sample locations.

Sub-basins were grouped by major waterbody for input to five models: Merrymeeting Lake (Model 1), Marsh Pond (Model 2), Jones Pond (Model 3), Downing Pond (Model 4), and Coffin Brook-MMR in Alton (Model 5) (Figure 2). Models 2-5 used the previous model's output as an upstream point source input. This approach allowed for better model parameterization and estimation of pollution source loads by land use type and source for each of the targeted waterbodies.

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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.

[3] Based on USGS/NRCS 3DEP 10 m resolution (1/3 arc-sec) topographic bare-earth surface, seamless image file (USGS_NED_13_n44w072_IMG.img) from https://www.usgs.gov/core-science-systems/ngp/tnm-delivery/gis-data-download?qt-science_support_page_related_con=0#qt-science_support_page_related_con – following processing toolboxes through GRASS commands [161 geoalgorithms].

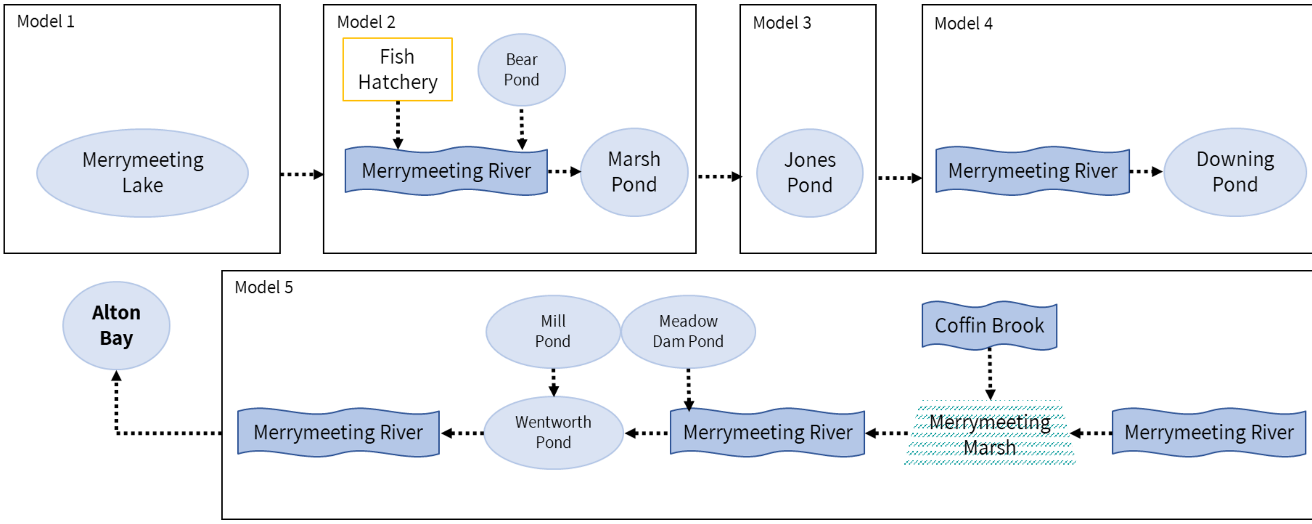

FIGURE 2. Conceptual diagram that illustrates the major flow paths through the Merrymeeting River and Lake watershed. Because of the hydrologic complexity of the watershed, the watershed was split into five separate but sequential models.

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

ESRI World Imagery dated 6/27/2016 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.
- Orchards and large gardens were labeled as Agric 2: Row Crop.
- Commercial lawns, cemeteries, and athletic fields were labeled as “Urban 5: Mowed Fields”; residential lawns were included in Urban 1.
- Shrubby (regenerating) or cleared areas that were the result of a recent logging operation were labeled as “Other 1: Logging”; areas that may or may not have been logged but had significant shrubby growth were labeled as “Open 2: Meadow.”
- 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 2: Unpaved Roads.”

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 Merrymeeting River and Lake watershed (refer to Figure 3 for zoomed-in examples of "before" and "after" modifications). The 2018 land cover area is shown in Figure 4.

Within the LLRM, export coefficients are assigned to each land cover to represent typical concentrations of phosphorus in runoff and baseflow from each land cover type (Attachment 3). Unmanaged forested land, for example, tends to deliver very little phosphorus downstream when it rains, while row crops and low to high density urban development export significantly more phosphorus due to fertilizer use, soil erosion, car and factory exhaust, pet waste, and many other sources. Smaller amounts of phosphorus are also exported to lakes and streams via groundwater under baseflow conditions. This nutrient load is delivered with groundwater directly to the lake/pond or indirectly to tributary streams; however, much of the phosphorus is adsorbed onto soil particles as water infiltrates to the ground. Attachment 3 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), East Pond TMDL Report (2001), Hutchinson Environmental Sciences Ltd (2014), and Schloss and Connor (2000), among others. High phosphorus export areas in the watershed are highlighted in Figure 5 and represent concentrations or clusters of dense development or agriculture. Note that Other 1: Logging was assigned a phosphorus export coefficient that was double Forest 1-3 but lower than Open 2: Meadow because most of the observed logging areas were regenerating or were select harvests and thus partially functioning as intact forests, especially when viewed long-term as average land cover conditions over the last decade. Figure 6 shows a breakdown of land cover by major category for the entire watershed (not including the surface areas of Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond), as well as the total phosphorus load by major land cover category. Developed areas cover 8% of the watershed and contribute 55% of the total phosphorus watershed load (land cover-derived only) to Merrymeeting River and Lake.

FIGURE 3. Examples of "before" (left) and "after" (right) land cover file modifications for the Merrymeeting River and Lake watershed for developed and agricultural areas.

FIGURE 4. 2018 land cover map for the Merrymeeting River and Lake watershed.

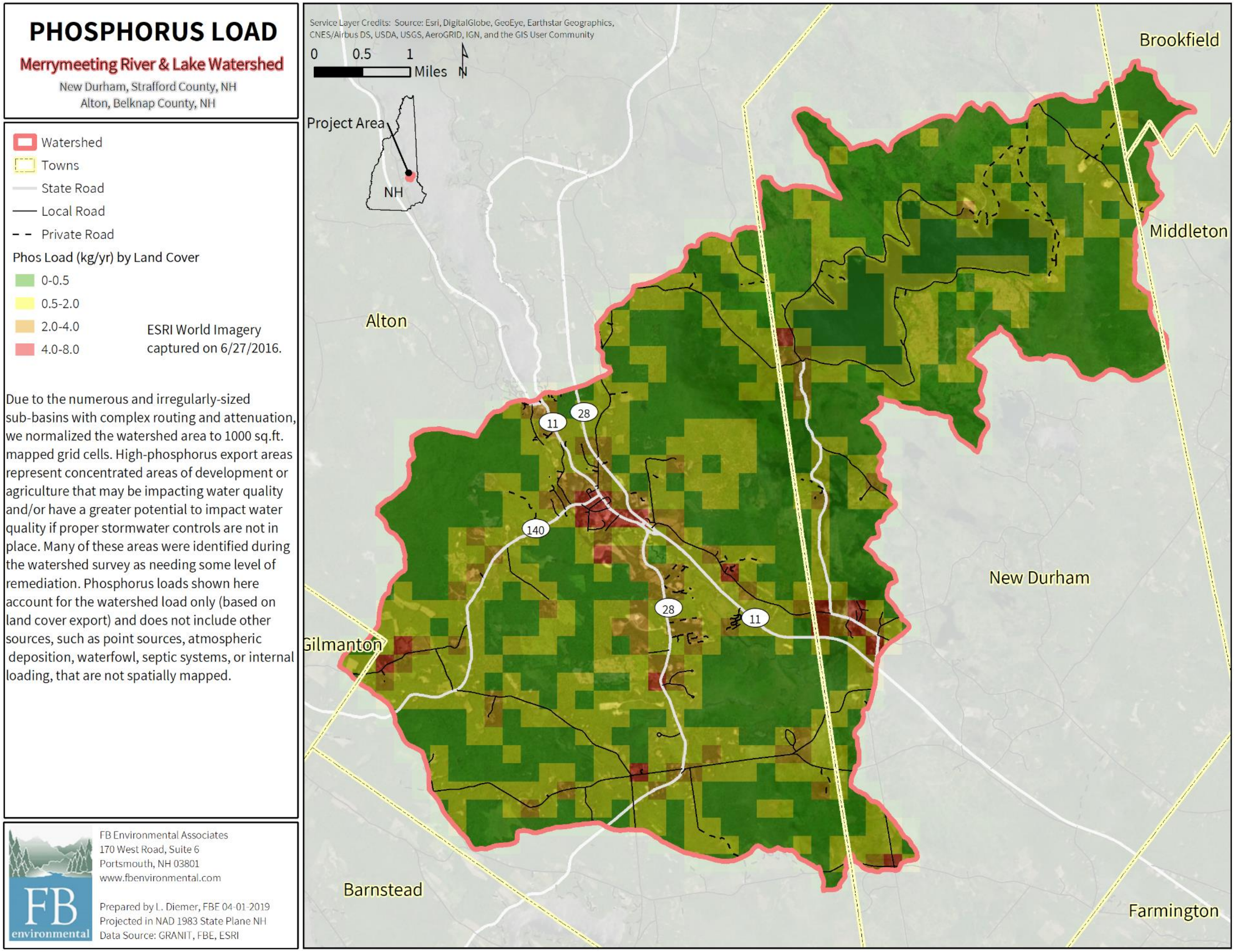

FIGURE 5. Total phosphorus (TP) watershed load based on export coefficients by land cover type within 1,000 square foot gridded cells.

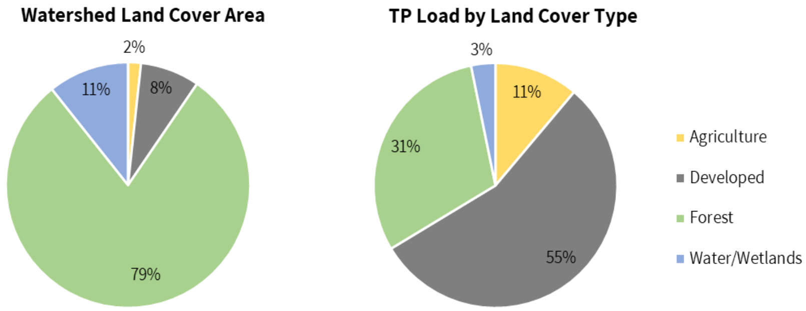

FIGURE 6. Watershed land cover area by general category (agriculture, developed, forest, and water/wetlands, not including the lake and ponds) and total phosphorus (TP) watershed load by general land cover type. This shows that developed areas cover 8% of the watershed and contribute 55% of the TP watershed load to Merrymeeting River and 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 Laconia, NH (Station ID: US1NHBK0007) weather station with data gaps covered by the weather station in Lakeport, NH (Station ID: USC00274480). The average annual precipitation from 2009-2018 was input to the model (49.40 in or 1.25 m). Generally, precipitation increases from January to July (with greatest variability in July), decreases in August and September (dry summer baseflow conditions), and spikes in October from large storm events (Figure 7). From 2009-2018, 2011 was the wettest year and 2016 (followed closely by 2012) was the driest year; 2017 and 2018 represent average annual precipitation conditions (Figure 7). Interannual variability in precipitation results in variable runoff to surface waters and thus variable water quality across years and seasons.

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 or pond volume estimates from the NH GRANIT file were within 0-19% relative percent difference of the NHDES Trophic Survey volume estimates (wherever available). The lake or pond surface area estimates from the NH GRANIT file were within 2-11% relative percent difference of the NHDES Trophic Survey area estimates (wherever available). Greater differences were observed for older trophic surveys completed in the 1980's; estimates from the NH GRANIT file were generally closer in agreement to estimates from more recent trophic surveys (2003-2005).

Data for septic systems within 250 feet of a surface water (including wetlands) were obtained from state and local records compiled by the Town of Alton (251 parcels) and the Cyanobacteria Mitigation Steering Committee (CMSC, 568 parcels). Data included information on the age, distance to surface water, and use (seasonal or year-round and occupancy) of septic systems, if present. Seasonal and year-round systems in Alton were determined using the occupied seasonal housing rate for the State of New Hampshire (10.4%) from the 2010 US Census.

Waterfowl counts were based on bird census data collected by volunteers through eBird (online) and the CMSC (who made observations every day from 8/23-11/29/18 at Merrymeeting Lake (west side, approx. 30% coverage), Marsh Pond (approx. 50% coverage), Jones Pond (approx. 50% coverage), and Downing Pond (approx. 40% coverage) and at least twice weekly at Merrymeeting Wildlife Management Area from the Rt. 28 traffic circle (approx. 20% coverage), Wentworth Pond (approx. 100% coverage), and Mill Pond (approx. 100% coverage). Volunteers logged large bird sightings, including ducks (11 species), herons (2 species), geese, cormorants, gulls, and loons. Data were summarized by day (average) and month (maximum). Best professional judgement was used when interpreting the counts and inputting a value to each model. It was assumed that counts for Merrymeeting Lake were likely underestimated given the size of the lake and the need for multiple observation points; instead, we estimated 0.3 bird units per hectare of lake area or 151 birds at Merrymeeting Lake with a residence time of 8 months per year. 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.

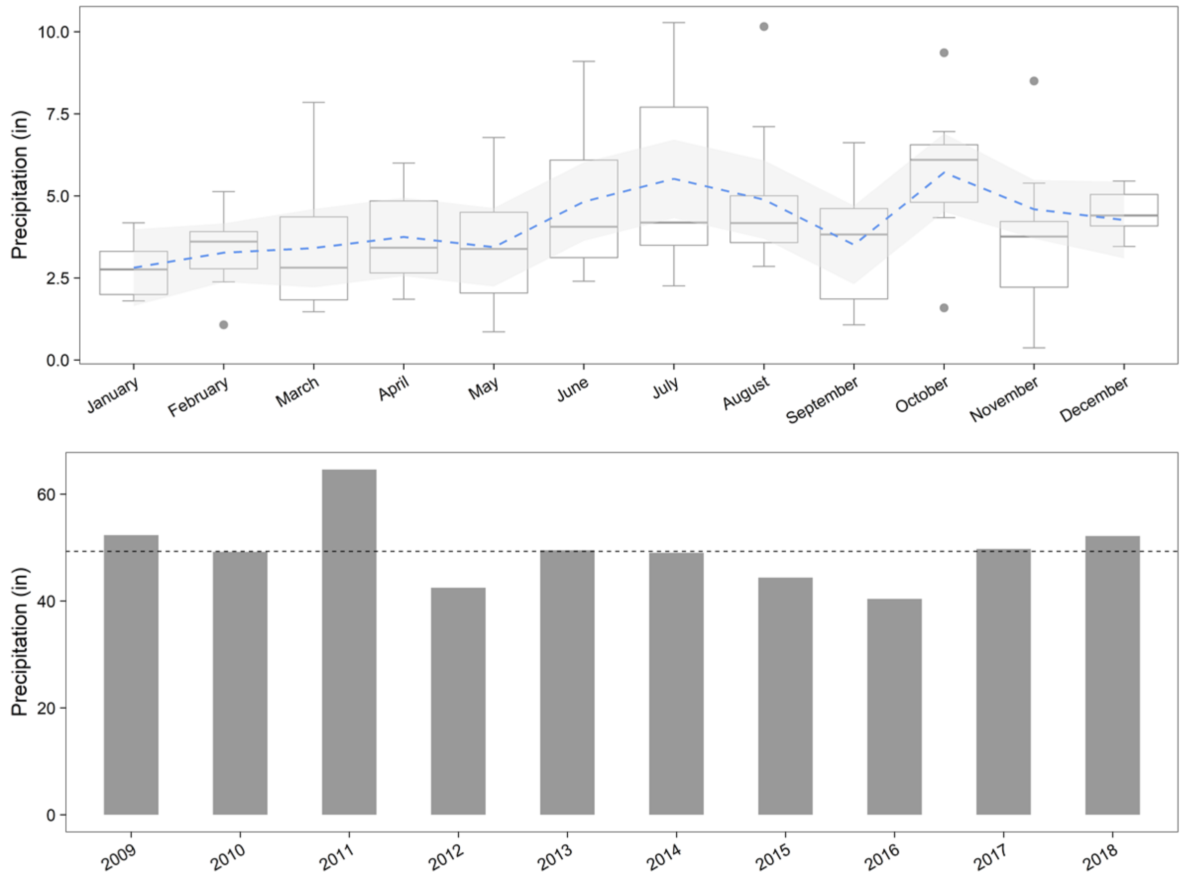

FIGURE 7. Monthly precipitation by month (top) and total precipitation by year (bottom) from 2009-2018. Gray shaded area shows confidence interval (alpha = 0.95) around locally-weighted regression (blue dashed line). Average annual precipitation of 49.3 in is shown as black dashed line. Data were obtained from NOAA NCEI for the Laconia, NH (Station ID: US1NHBK0007) weather station with a data gaps covered by the weather station in Lakeport, NH (Station ID: USC00274480).

Water quality data were obtained from the NHDES Environmental Monitoring Database (EMD) and Robert Craycraft, Lakes Monitoring Program Coordinator at the University of New Hampshire Cooperative Extension. Recent total phosphorus, chlorophyll-a, and Secchi Disk Transparency data from 2009-2018 were summarized by day, then month, then year for Merrymeeting Lake. Monthly data were flow-weighted (based on estimated monthly outflow from Merrymeeting Lake) for Marsh Pond, Jones Pond, Downing Pond, and Merrymeeting River at Alton Bay to obtain median annual water quality summaries for total phosphorus, chlorophyll-a (except Merrymeeting River at Alton Bay), and Secchi Disk Transparency (except Merrymeeting River at Alton Bay). Recent tributary or mainstem river data (largely from 2016-2018) were summarized by day, then month, then year to obtain median annual water quality summaries for total phosphorus. These data were used as general guidelines for setting attenuation factors and confirming overall model calibration.

For lakes without large point source or internal phosphorus loads, average summer total phosphorus concentrations in the epilimnion are generally (14-40%, median 20%) lower than average annual concentrations (Nurnberg, 1996; Nurnberg, 1998) because low baseflow periods in summer restrict phosphorus mobilization from the landscape to surface waters. In the case of Merrymeeting Lake, we used 4.2 ppb (20% higher than the observed median of 3.5 ppb for summer total phosphorus concentration in the epilimnion) to calibrate the model. A different approach for the downstream waterbodies (Models 2-5) had to be used to reflect the unique water quality conditions generated by the point source discharges from the Powder Mill State Fish Hatchery. The facility withdraws and discharges a near-constant water load containing phosphorus levels approximately 12 times higher than the outflow concentration from Merrymeeting Lake. The discharge from the facility in summer during low baseflow conditions increases the concentration of phosphorus in the river and downstream waterbodies (leading to algae and cyanobacteria blooms and excessive plant growth), while the discharge from the facility in other times of year during high-flow conditions is diluted by other sources of water with lower phosphorus concentrations, thus creating a reverse water quality pattern from that which is observed in Merrymeeting Lake. Because most data were collected from April-November, the best approach for adjusting the observed data to estimate an annual (and not seasonally-skewed) summary statistic was to weight monthly data by estimated monthly flow volumes (Table 1, Figure 8). Outflow phosphorus concentrations for Models 2-5 were set to match the predicted phosphorus concentrations.

TABLE 1. Modeled annual total phosphorus (TP), observed median TP (based on May 24-Sept 15, NHDES definition for seasonal summer period), observed median TP (based on Apr-Nov), and flow-weighted annual TP estimates for Models 2-5 (based on observed and estimated values).

Model	Waterbody	Modeled Annual TP (ppb)	Observed TP (May-Sep) (ppb)	Observed TP (Apr-Nov) (ppb)	Flow-Weighted Observed Annual TP (ppb)
2	Marsh Pond	16.9	43.1	30.7	17.7
3	Jones Pond	16.0	26.7	24.5	15.7
4	Downing Pond	15.6	25.2	24.9	15.3
5	Coffin Brook-MMR	15.2	--	16.2	14.3

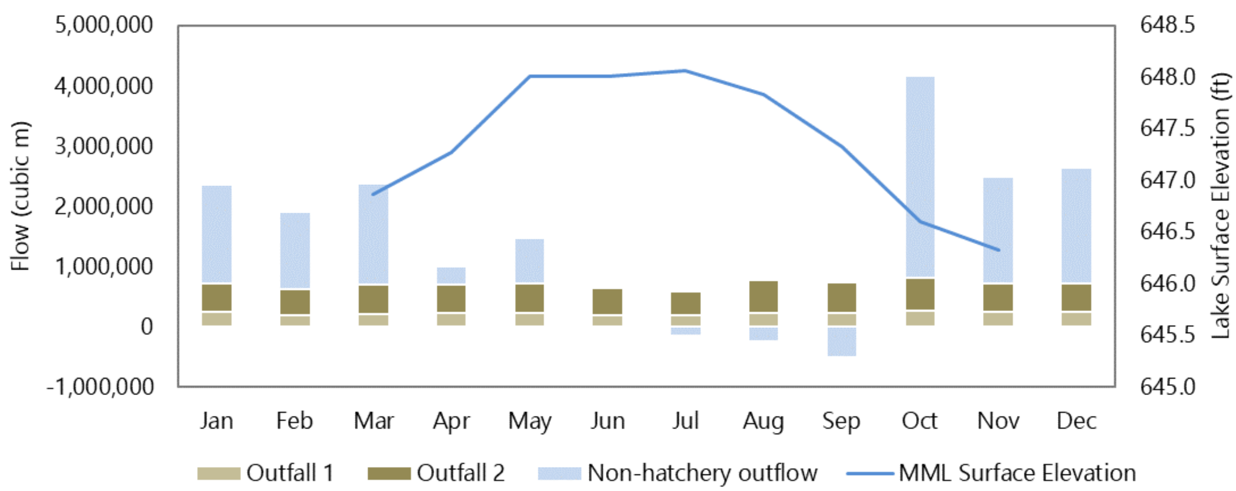

FIGURE 8. Average monthly flow volume discharged by the Powder Mill State Fish Hatchery (Outfalls #1 and #2), estimated monthly flow volume discharged directly from Merrymeeting Lake (non-hatchery outflow), and average monthly Merrymeeting Lake surface elevation (data obtained from Merrymeeting Lake Association). Negative non-hatchery outflow estimates from July-September suggest that both the hatchery and evaporation extract more water than what is replenished by precipitation.

Internal loading estimates were derived from dissolved oxygen and temperature profiles (to determine average annual duration and depth of anoxia defined as <1 ppm dissolved oxygen) and epilimnion/hypolimnion total phosphorus data (to determine average difference between surface and bottom phosphorus concentrations) collected at the deep spots of Merrymeeting Lake from 1977-2018 and Marsh, Jones, and Downing Ponds from 2017-2018. These estimates, along with anoxic volume and surface area, helped determine rate of release and mass of internal phosphorus loading per year.

There was no evidence of significant internal loading or an extended anoxic period in both Merrymeeting Lake and Downing Pond (Figure 9). Both Merrymeeting Lake and Downing Pond showed bottom phosphorus concentrations to be nearly the same as near-surface phosphorus concentrations and showed no anoxia in bottom waters. Minimum dissolved oxygen concentration in the deepest layer of Merrymeeting Lake ranged from 6-7 ppm at the three deep spots. Downing Pond is shallow (3 m at its deep spot) and flushed regularly (141 times per year) by large upstream flows from Merrymeeting Lake, Marsh Pond, and Jones Pond, preventing a stable thermal layer from forming in summer and causing consistent replenishment of oxygen-rich waters throughout the water column.

Marsh and Jones Pond had evidence of significant internal loading (Figure 9). Because of thermal stratification and lack of vertical profile mixing in summer, increases in bottom phosphorus from internal loading at Marsh and Jones Ponds were cumulative until system flushing in October when Merrymeeting Lake was drawn down to its winter level. Bottom phosphorus concentration in Jones Pond decreased in September (earlier than observed at Marsh Pond and before system flushing) likely due to a partial breakdown of thermal stratification and mixing of upper layers following a large rain event. A similar, though less pronounced, pattern was observed for Downing Pond, which is one meter shallower than Jones Pond and two meters shallower than Marsh Pond.

Outputs from Models 1-4 were simulated as **point sources** to the next downstream model. Total annual water load and predicted average annual total phosphorus concentration in Merrymeeting Lake (Model 1) were input to Marsh Pond (Model 2), whose output was input to Jones Pond (Model 3), whose output was input to Downing Pond (Model 4), whose output was input to Coffin Brook-MMR in Alton (Model 5). Point source inputs were routed either through sub-basins (i.e., MMR-1 for Model 2, MMR-Jones to Downing Pond for Model 4, and MMR-2 (Site 11) for Model 5) or routed directly to the pond (i.e., Model 3) depending on their position in the watershed. Two true point sources were also input to Model 2 (Marsh Pond) as Outfall #1 and Outfall #2 from the Powder Mill State Fish Hatchery. The NHFGD withdraws water from an intake approximately 50 feet deep in Merrymeeting Lake to supply cold, well-oxygenated water year-round for its fish rearing operations. These water withdrawals account for 42% of the average annual water volume outflow from Merrymeeting Lake (data summarized using 2014-2018 monthly average flow reported to EPA). Water from the facility is discharged via Outfall #1 (2,666,933 cubic m/yr) about 0.25 river miles from the lake outlet and Outfall #2 (5,762,681 cubic m/yr) located about 0.53 river miles from the lake outlet. Outfall #1 was routed through MMR-1 for Model 2, while Outfall #2 was routed directly to Marsh Pond. The annual water load discharged directly from Merrymeeting Lake to the Merrymeeting River was adjusted (reduced) to account for the water extracted and then discharged by the Powder Mill State Fish Hatchery.

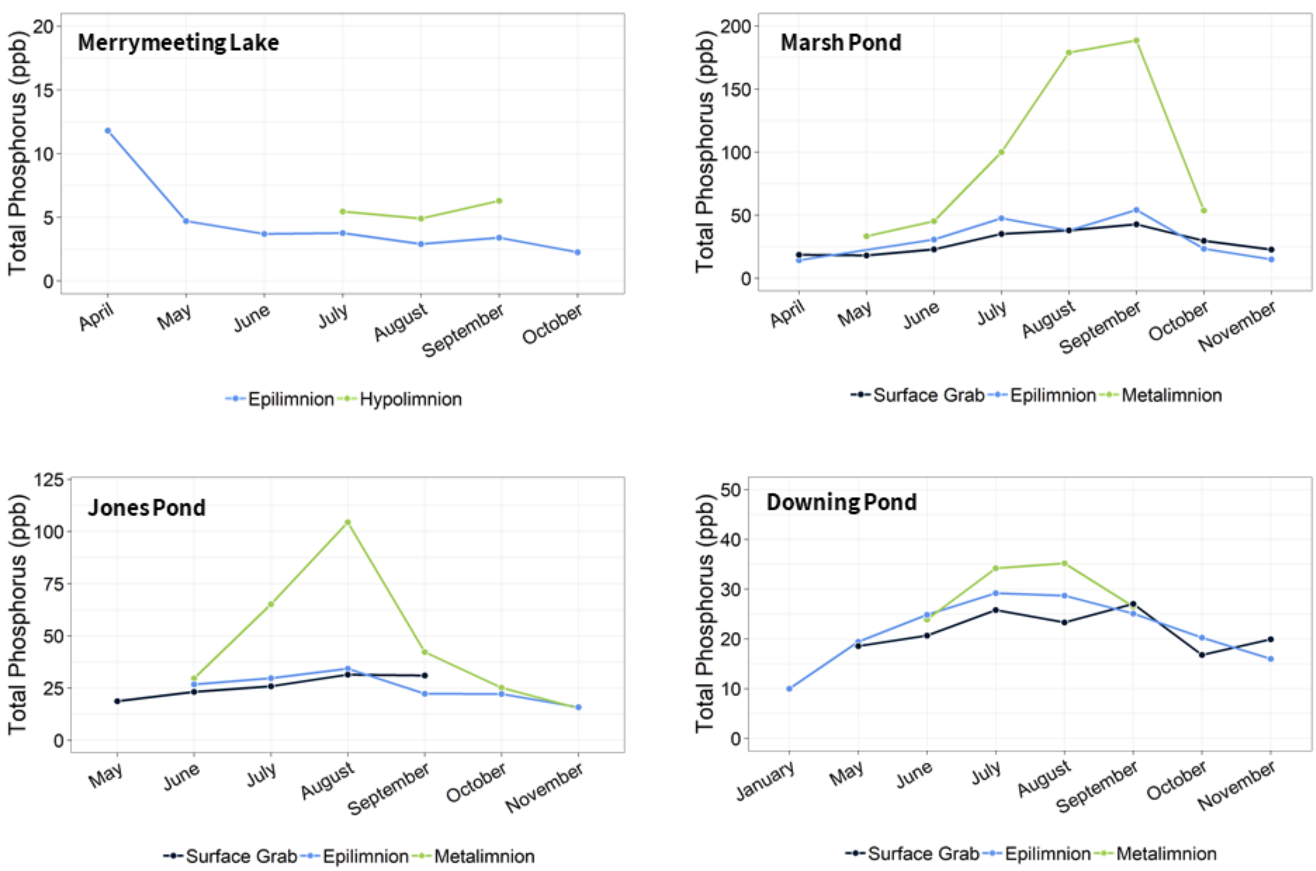

FIGURE 9. Median total phosphorus concentrations by month and by depth zone (surface, epilimnion, and metalimnion/hypolimnion) for Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond. Note differences in y-axis scales for total phosphorus for each waterbody. Significant internal loading was evident at Marsh and Jones Ponds.

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 and/or short channel lengths when routing loads from sub-basin to sub-basin (Table 2). Observed in-lake or pond phosphorus concentrations were given primacy during the calibration process, such that the ability of the model to accurately simulate annual average in-lake or pond phosphorus concentrations was used as a leading indicator of acceptable model performance. Continued water quality sampling (to include all seasons) 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.
- Direct atmospheric deposition load, internal load, waterfowl load, and septic system load were set to zero for the riverine Coffin Brook-MMR system (Model 5) because these sources are implicitly included in the watershed land cover export coefficients; loads from these sources are generally only applied as direct discharges to a lake or pond in the model.
- Default **water and phosphorus attenuation factors** were used, with exceptions noted in Table 2. 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 grade. Because of the numerous sub-basins and unique routing of all sub-basins to a single terminal discharge for Model 5, we adjusted the attenuation factors to distribute the predicted attenuation across the watershed according to stream order (Table 2). The net effect of attenuation through the sub-basins is approximately 0.85 for water and 0.80 for total phosphorus. Headwater systems were assumed to have a greater attenuation than the mainstem since the flow of water is lower relative to the mainstem, giving more opportunity for infiltration, adsorption, and uptake.
- The average of multiple **empirical formulas** for predicting annual in-lake phosphorus concentration excluded Vollenweider (1975) empirical formula for Merrymeeting Lake because the formula was predicting phosphorus concentrations that were higher than observed data or the other formulas. We also excluded Reckhow General (1977) and Jones-Bachmann (1976) for Marsh, Jones, and Downing Ponds because the formulas were predicting phosphorus concentrations lower than observed data or the other formulas. No empirical lake/pond formulas were used for Model 5, which represents a riverine system; thus, all sub-basins were routed to a single terminal discharge at MMR-5 (Rt. 11) that represents the total water volume and phosphorus load entering Alton Bay from the Merrymeeting River and Lake watershed.

TABLE 2. Reasoning for water and phosphorus attenuation factors used by sub-basin (not including default values).

Model-Sub-Basin	Water Atten. Factor	Phos. Atten. Factor	Reasoning
1-East Pine Point Brook	0.90	0.85	Attenuation by small wetlands on steep slopes covering 7% of sub-basin area.
1-Upper Goodwin Brook	0.90	0.80	Attenuation by small wetlands on steep slopes covering 6% of sub-basin area.
2-Bear Pond	0.85	0.80	Attenuation by small pond covering 15% of sub-basin area.
2-South Trib to Marsh Pond	0.85	0.80	Attenuation by wetlands in low-lying area covering 15% of sub-basin area.
2-West Trib to Marsh Pond	0.90	0.85	Attenuation by channel processes (~ 3 mi) and small wetlands covering 6% of sub-basin area.
2-MMR-1	1.00	1.00	Assumed little to no attenuation due to short distance (~0.53 mi) for channel processes to attenuate large inflows from Merrymeeting Lake (about 13% of which routes through Outfall #1 and discharges about halfway between Merrymeeting Lake outflow and Marsh Pond inflow.
3-PS-1 Marsh Pond	1.00	1.00	Not a true sub-basin; point source routed directly from Marsh Pond to Jones Pond with no attenuation.
4-South Trib to Downing Pond	0.80	0.75	Attenuation by wetlands in low-lying area covering 35% of sub-basin area.
4-MMR - Jones to Downing Pond	1.00	1.00	Assumed little to no attenuation due to short distance (~0.35 mi) for channel processes to attenuate large inflows from Jones Pond.
5-Headwater Streams	0.90	0.88	Coffin Brook-6, Coffin Brook-7 (Rt. 140), MMR-4 (Rt. 140) / Coffin Brook, Trib 1 to Coffin Brook, Trib 1E to Coffin Brook, Trib 1W to Coffin Brook, Trib 2 to Coffin Brook, Trib 2S to Coffin Brook, Trib 3 to Coffin Brook, Trib 4 to Coffin Brook, Trib 4S to Coffin Brook, Trib 5N to Coffin Brook, Trib 5S to Coffin Brook, Trib 5S-W to Coffin Brook, Trib 6 to Coffin Brook, Trib 6W to Coffin Brook, Trib to MMR-3 (Moore Farm)
5-Second Order Streams	0.93	0.91	Coffin Brook-5, Meadow Pond (Outflow @ Rt. 140), Trib 5 to Coffin Brook, Trib to MMR-4
5-Third Order Streams	0.95	0.93	Coffin Brook-1 (Outflow in marsh), Coffin Brook-2, Coffin Brook-3 (Rt. 28), Coffin Brook-4 (CBR)
5-Fourth Order Streams	0.98	0.96	MMR-4 (Rt. 140), MMR-5 (Rt. 11)
5-Ponds	0.85	0.80	Meadow Pond, Mill Pond
MMR-2 (Site 11)	0.99	0.99	Assumed little to no attenuation due to short distance (~0.35 mi) for channel processes to attenuate large inflows from Downing Pond.
MMR-3 (Rt. 28)	0.96	0.94	Attenuation by wetlands in low-lying area covering 32% of sub-basin area.

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 or pond 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 (such as to set regulatory limits) with full recognition of the model limitations and assumptions.
- **Missing bathymetry data for Marsh Pond.** No bathymetry data were available for Marsh Pond except for two known maximum depth points. Coarse volume estimates were made for model input, but volume estimates are likely underestimated for Marsh Pond. We recommend gathering higher-resolution bathymetry data for Marsh Pond (and possibly Jones and Downing Ponds) using sonar depth measurements. We performed a sensitivity analysis on the volume estimate for Marsh Pond; increasing the volume estimate for Marsh Pond by 50% decreased the predicted in-pond phosphorus concentration by 0.1 ppb.
- **Empirical formulas used in the model are near their practical application limit for highly-flushed, riverine systems like Marsh, Jones, and Downing Ponds.** The empirical formula predictions were not much different than a mass balance calculation because the ponds are not true lake systems, but rather small impoundments or wide spots in a highly-flushed river system with less opportunity for phosphorus settling than in a true lake system.

Similarly, the distributed attenuation by stream order for Model 5 represents gross approximations of loads at the individual sub-basin level (based only on proximity to the mainstem of the Merrymeeting River).

- **Point source phosphorus load from the Powder Mill State Fish Hatchery summarized for model input was 17 kg/yr higher than the value determined by NHDES.** The difference was attributable to the methods used to summarize the data for model input (we summarized by month, while NHDES summarized by quarter). We also assumed that the Powder Mill State Fish Hatchery was a closed system (inflows matched outflows with no water loss from the facility).
- **Water quality data were limited to recent years (2016-2018)** for Marsh, Jones, and Downing Ponds, Merrymeeting River mainstem, and tributaries (e.g., several tributary sub-basins were associated with sites sampled 1-3 times in 2018). The model generates an average annual prediction of water quality that accounts for interannual variation in water quality over many years; 1-3 years of water quality data may not represent long-term system dynamics in the Merrymeeting River and Lake watershed. However, 2017 and 2018 did represent average (or typical) annual precipitation conditions for the area and may be appropriate years to compare to predicted model values. Even so, observed data were used as general guidelines for setting attenuation factors and confirming overall model calibration. More data are needed to effectively calibrate the model to known observations for 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.
- **Water quality data were limited to the growing season (April-November).** Most data were collected from April-November and had to be flow-weighted to estimate an annual (and not seasonally-skewed) summary statistic for model calibration. Estimates were used for missing months (December-March) and calculated as 40% lower than November values (based on observed data from Downing Pond that showed an average concentration of 16 ppb in November and 10 ppb in January). Collecting samples under a variety of flow conditions (and measuring flow) in all seasons and across several years can help reduce model uncertainty and help inform assumptions on standard water yield, export coefficients, and attenuation factors used. 2017 and 2018 represented average precipitation conditions on an annual timescale but showed more variability and deviance from average precipitation conditions at a monthly timescale. 2017 experienced an extended wet spring in April and May and a dry November, while 2018 experienced a wet April, dry early summer in May, June, and July, but then a wet August and November (Figure 10). The timing and distribution of precipitation are two of several key factors driving response in biota; for instance, a wet spring that flushes nutrients from the landscape followed by a dry summer that increases residence time of nutrients can lead to greater bloom periods.

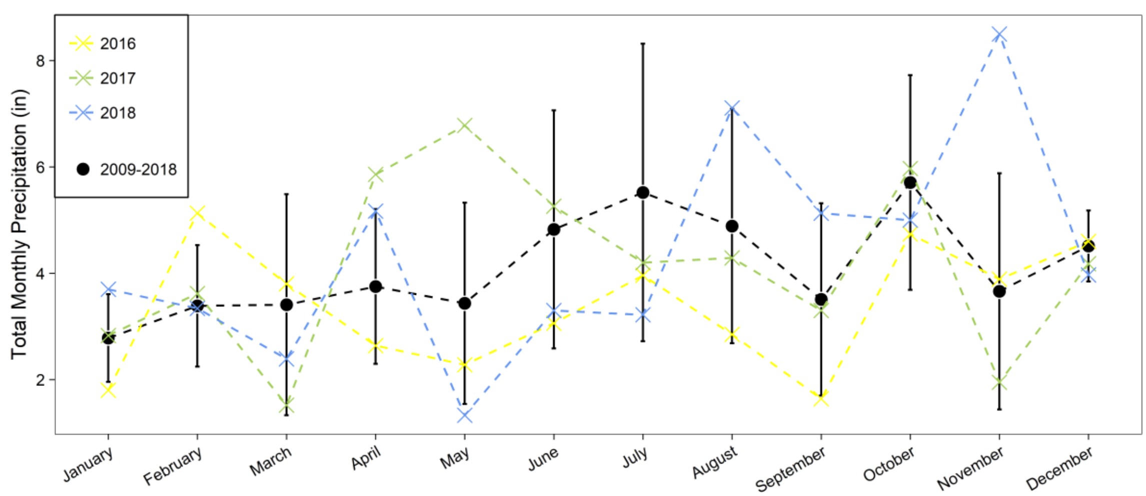

FIGURE 10. Average monthly precipitation for 2009-2018 (black) with errors bars depicting one standard deviation compared to total monthly precipitation for 2016 (yellow), 2017 (green), and 2018 (blue). Data were obtained from NOAA NCEI for the Laconia, NH (Station ID: US1NHBK0007) weather station with a data gaps covered by the weather station in Lakeport, NH (Station ID: USC00274480).

- **Internal loading estimates were based on limited data.** 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) or occur under oxic conditions if anoxic sediment releases phosphorus to overlying oxygenated water via water flow along the sediment surface. It was unclear whether and to what extent internal loading was occurring under oxic conditions at any time in these waterbodies. It was also unclear if a portion of bottom phosphorus concentrations was derived not from internal loading but possibly from the sinking and downstream movement of cold (dense), high-phosphorus water discharged from the Powder Mill State Fish Hatchery to Marsh Pond where low flushing and thermal stratification prevent vertical mixing. Dissolved oxygen and temperature profiles, as well as epilimnion and metalimnion/hypolimnion phosphorus data, were also only available for 2017 and 2018 for Marsh, Jones, and Downing Ponds. Continued monthly profiles and sampling of the epilimnion and metalimnion/hypolimnion would improve the model. Since we are likely underestimating internal loading to Marsh and Jones Ponds, we performed a sensitivity analysis on the internal loading estimate for Marsh Pond; maximizing the possible internal loading to 41.35 kg/yr[4] increased the predicted phosphorus concentration in Marsh Pond by 1.2 ppb (7%), indicating that internal loading is a small source of phosphorus relative to the discharge from the Powder Mill State Fish Hatchery. However, when the phosphorus load from the Powder Mill State Fish Hatchery is reduced, the internal load in Marsh Pond is expected to become a larger percentage of the total phosphorus budget, possibly limiting Marsh Pond's response to a reduction in external loads.
- **Land cover export coefficients were estimates.** Literature values and best professional judgement were used in evaluating and selecting appropriate land cover export coefficients for the watershed. 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.
- **Percent load split from sub-basin MMR-4 (Rt. 140)/Coffin Brook were unknown.** For model simplicity, loads from sub-basin MMR-4 (Rt. 140)/Coffin Brook were diverted entirely to sub-basin MMR-4 (Rt. 140), but some unknown portion of the loads from sub-basin MMR-4 (Rt. 140)/Coffin Brook split between sub-basins Coffin Brook-6 and MMR-4 (Rt. 140). Such a small drainage area diversion would not impact the model in any significant way but should be noted as a limitation.
- **Septic system loading was estimated based on record surveys and default literature values.** We assumed that the number of bedrooms represented the number of people using the septic system; some commercial businesses may be underestimated depending on the presence and use of public restrooms. Several properties (93 or 11%) had missing records; these properties were assumed to have septic systems with characteristics and usage similar to those properties with known records. Default literature values for daily water usage per person, phosphorus concentration output per person, and system phosphorus attenuation factors were used and may not reflect local watershed conditions. The true functioning of individual septic systems in the watershed is unknown.
- **Waterfowl counts were based on limited data.** Continued collection of bird counts would help improve the model loading estimates, especially for Merrymeeting Lake, Jones Pond, and Downing Pond, which were largely limited to one year (2018) of data.

RESULTS

CURRENT LOAD ESTIMATION

Overall, model predictions were in good agreement with observed data and were within 0-6% (relative percent difference) of observed median annual total phosphorus (Table 3). Differences in predicted and observed values for chlorophyll-a and Secchi disk transparency were more variable. 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.

[4] Assumed 8 kg/ha/yr under anoxic conditions multiplied by the anoxic volume of Marsh Pond and 2 kg/ha/yr under oxic conditions multiplied by the total volume minus the anoxic volume of Marsh Pond. Note: the anoxic volume of Marsh Pond was based on a coarse estimate due to lack of bathymetry data.

Watershed runoff and baseflow (56-100%) were the largest loading contribution across all sources for Models 1-5, followed by atmospheric deposition (<1-19%), septic systems (1-18%), waterfowl (1-7%), and internal loading (0-1%) (Table 4; Figure 11). Waterbodies downstream of Merrymeeting Lake were dominated (50-93%) by the upstream load (including the point source load from the Powder Mill State Fish Hatchery that discharges to the river below the outlet to Merrymeeting Lake). The percent contribution of the direct watershed load greatly increased for Model 5 (Coffin Brook-MMR) at Alton Bay because of the large watershed input from Coffin Brook and along the Merrymeeting River mainstem through Alton (while the upstream load was diluted and attenuated through the river system before discharging to Alton Bay).

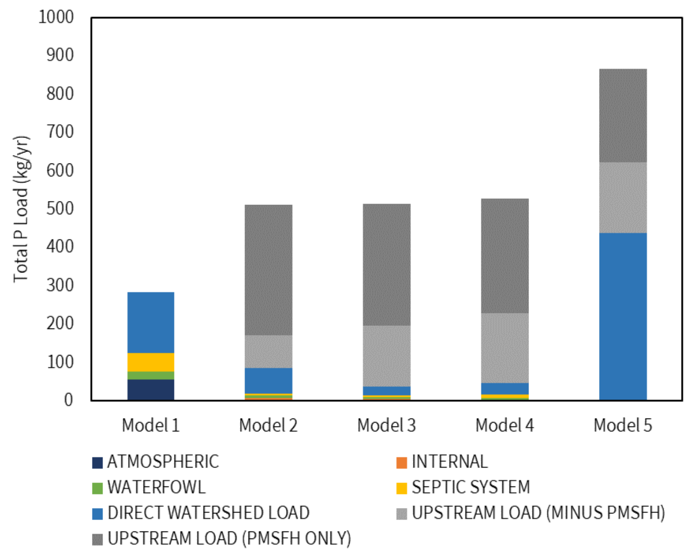

FIGURE 11. Total phosphorus (TP) load (kg/yr) by source (atmospheric, internal loading, waterfowl, septic systems, watershed load) for Models 1-5.

Although small relative to the point source load from the Powder Mill State Fish Hatchery, pollutant load contribution from development in the watershed, including septic systems, is an important and manageable source of phosphorus to surface waters in the watershed. Development in the watershed is largely concentrated around or near shorelines 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 surface waters.

Internal loading is also a concern given that low dissolved oxygen in bottom waters of Marsh and Jones Ponds is causing a significant release of phosphorus from bottom sediments (as evidenced by the large difference between bottom and surface phosphorus concentrations). 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 percent contribution of internal phosphorus load to Marsh and Jones Ponds (relative to other sources) will be more significant when the point source load from the Powder Mill State Fish Hatchery is remediated; future internal load from legacy point source loading will also continue to be a significant source despite remediation and may need to be addressed separately.

The direct shoreline areas to Merrymeeting Lake (76.3 kg/yr, 48%), Jones Pond (17.5 kg/yr, 77%), and Downing Pond (9.6 kg/yr, 33%) had the highest (or second highest in the case of Downing Pond) watershed phosphorus load export by total mass within their respective drainage areas (Table 5). Drainage from areas directly adjacent to waterbodies does not have adequate treatment time or area and are usually targeted for development, thus increasing the possibility for phosphorus export. The direct shoreline area to Marsh Pond (4.9 kg/yr, 7%) had minimal watershed phosphorus load export by total mass (which was dominated by the West Trib to Marsh Pond (20.3 kg/yr, 31%) and Bear Pond Brook (17.1 kg/yr, 26%)) because of the minimal development directly adjacent to Marsh Pond. The FJ Trib to Downing Pond (12.3 kg/yr, 43%) had the highest watershed phosphorus load export by total mass to Downing Pond because of residential and agricultural land uses. The sub-basins contributing the highest watershed phosphorus load export by total mass to Model 5 (Coffin Brook/MMR) were MMR-3 (Rt. 28) (75.0 kg/yr, 14%), Trib to MMR-4 (44.5 kg/yr, 8%), and Coffin Brook-3 (Rt. 28) (47.5 kg/yr, 9%).

Normalizing for the size of a sub-basin (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 (> 0.15 kg/ha/yr) generally had more development or agriculture (Table 5; Figure 5). MMR-2 (Site 11), MMR-1, and Mill Pond had the highest watershed phosphorus mass exported by area because of concentrated mid-to-high density development within their relatively small drainage areas (13-66 ha).

TABLE 3. Predictions for Models 1-5. TP = total phosphorus. Chl-a = chlorophyll-a. SDT = Secchi disk transparency.

Model	Waterbody	Annual TP (ppb)*	Predicted Annual TP (ppb)	Observed Mean Chl-a (ppb)	Predicted Mean Chl-a (ppb)	Observed Mean SDT (m)	Predicted Mean SDT (m)
1	Merrymeeting Lake	3.5 (4.2)	4.2	0.8	0.7	10.3	7.6
2	Marsh Pond	17.7	16.9	4.7	6.3	4.0	2.6
3	Jones Pond	15.7	16.0	4.8	5.9	3.2	2.8
4	Downing Pond	15.3	15.6	3.4	5.7	3.1	2.8
5	Coffin Brook-MMR	14.3	15.2	--	--	--	--

**Observed annual TP of 3.5 ppb and 4.2 ppb for Merrymeeting Lake represents median in-lake epilimnion TP and 20% adjusted increase from median in-lake epilimnion TP, respectively. Most lake data are collected in summer when TP concentrations are typically lower than annual average concentrations for which the model predicts. Observed annual TP for Models 2-5 are flow-weighted based on both observed and estimated data (see OTHER MAJOR MODEL INPUTS).*

TABLE 4. Total phosphorus (TP) and water loading summary by source for Models 1-5.

MODEL & SOURCE LOAD	CURRENT		
	P (kg/yr)	%	Water (cu.m/yr)
Model 1 - Merrymeeting Lake			
ATMOSPHERIC	55	19%	3,722,937
INTERNAL	0	0%	0
WATERFOWL	20	7%	0
SEPTIC SYSTEM	50	18%	43,181
WATERSHED LOAD	158	56%	16,544,959
TOTAL LOAD TO LAKE	**284**	**100%**	**20,311,078**
Model 2 - Marsh Pond			
ATMOSPHERIC	2	0%	135,221
INTERNAL	6	1%	0
WATERFOWL	6	1%	0
SEPTIC SYSTEM	5	1%	3,623
DIRECT WATERSHED LOAD	66	13%	7,858,621
UPSTREAM LOAD (FROM MML)	85	17%	11,848,464
UPSTREAM LOAD (FROM PMSFH)	342	67%	8,462,614
TOTAL LOAD TO LAKE	**513**	**100%**	**28,308,544**
Model 3 - Jones Pond			
ATMOSPHERIC	3	0%	172,000
INTERNAL	3	0%	0
WATERFOWL	3	1%	0
SEPTIC SYSTEM	6	1%	4,288
DIRECT WATERSHED LOAD	22	4%	1,692,302
UPSTREAM LOAD (FROM MARSH)	159	31%	19,845,929
UPSTREAM LOAD (FROM PMSFH)	320	62%	8,462,614
TOTAL LOAD TO LAKE	**515**	**100%**	**30,177,132**
Model 4 - Downing Pond			
ATMOSPHERIC	2	0%	161,176
INTERNAL	0	0%	0
WATERFOWL	6	1%	0
SEPTIC SYSTEM	9	2%	6,606
DIRECT WATERSHED LOAD	29	5%	1,732,592
UPSTREAM LOAD (FROM JONES)	183	35%	21,714,518
UPSTREAM LOAD (FROM PMSFH)	299	57%	8,462,614
TOTAL LOAD TO LAKE	**528**	**100%**	**32,077,507**
Model 5 - Coffin Brook/MMR			
DIRECT WATERSHED LOAD	438	50%	27,839,805
UPSTREAM LOAD (FROM JONES)	186	21%	21,554,828
UPSTREAM LOAD (FROM PMSFH)	243	28%	7,724,371
TOTAL LOAD TO RIVER	**867**	**100%**	**57,119,004**

TABLE 5. Summary of land area, water flow, and total phosphorus (TP) loading by sub-basin for Models 1-5.

Sub-Basin	Current (2018) Watershed Load					
	Land Area (ha)	Water Flow (m^3/yr)	Calculated P Concentration (mg/L)	Measured P Concentration (mg/L)	P mass (kg/yr)	P mass by area (kg/ha/yr)
Model 1 - Merrymeeting Lake						
Adder Hole Brook	65	461,937	0.005	0.011	2.5	0.04
Broad Cove Brook	133	947,576	0.006	0.009	5.6	0.04
Direct Shoreline MML	600	4,276,621	0.017		76.3	0.13
East Durgin Brook	87	621,559	0.007	0.004	4.3	0.05
East Pine Point Brook	122	811,852	0.006	0.014	5.1	0.04
Mount Bet Brook	77	549,712	0.008	0.004	4.5	0.06
Peter Brook	318	2,267,367	0.006	0.014	13.4	0.04
Pleasant Cove Brook	155	1,102,360	0.005	0.011	5.5	0.04
Trib to Upper Goodwin Brook	135	960,094	0.008		8.2	0.06
Unnamed Trib to MML	73	520,338	0.009	0.008	4.4	0.06
Upper Goodwin Brook	487	3,265,025	0.007	0.010	24.3	0.05
West Durgin Brook	123	879,625	0.006	0.007	5.7	0.05
Model 2 - Marsh Pond						
Bear Pond	52	322,470	0.007		2.3	0.04
Bear Pond Brook	208	1,474,889	0.011	0.006	17.1	0.08
Brackett Rd Culvert Drainage	17	118,409	0.006	0.425	0.7	0.04
Direct Drainage to Marsh Pond	103	681,628	0.007		4.9	0.05
MMR-1	13	96,976	0.010		4.4	0.33
North Trib to Marsh Pond	84	587,855	0.005	0.012	3.0	0.04
Rattlesnake Mountain Brook	73	518,990	0.007	0.003	3.9	0.05
South Trib to Marsh Pond	232	1,428,783	0.007		9.3	0.04
West Trib to Marsh Pond	396	2,644,745	0.008	0.009	20.3	0.05
Model 3 - Jones Pond						
Culvert Drainage to Jones Pond	59	417,200	0.011	0.008	4.6	0.08
Direct Drainage to Jones Pond	166	1,167,186	0.014		17.5	0.11
Trib to Jones Pond	18	128,776	0.006	0.018	0.7	0.04
Model 4 - Downing Pond						
Direct Drainage to Downing Pond	59	414,652	0.023		9.6	0.16
FJ Trib to Downing Pond	107	755,941	0.016	0.013	12.3	0.12
MMR - Jones to Downing Pond	34	255,033	0.016	0.037	2.6	0.08
North Trib to Downing Pond	19	134,160	0.004	0.006	0.6	0.03
South Trib to Downing Pond	32	172,806	0.022	0.019	3.8	0.12
Model 5 - Coffin Brook/MMR						
Coffin Brook-1 (Outflow in marsh)	81	516,043	0.013	0.022	7.1	0.09
Coffin Brook-2	430	2,858,758	0.014		36.9	0.09
Coffin Brook-3 (Rt. 28)	319	2,197,825	0.014	0.021	47.5	0.15
Coffin Brook-4 (CBR)	206	1,408,399	0.013	0.026	19.1	0.09
Coffin Brook-5	251	1,643,035	0.013		15.3	0.06
Coffin Brook-6	128	850,055	0.010	0.020	11.3	0.09
Coffin Brook-7 (Rt. 140)	154	1,040,183	0.007	0.023	7.3	0.05
Meadow Pond	159	996,140	0.004		4.4	0.03
Meadow Pond (Outflow @ Rt. 140)	102	697,455	0.008	0.006	9.4	0.09
Mill Pond	66	399,561	0.045	0.033	17.9	0.27
MMR-2 (Site 11)	58	405,407	0.016	0.020	27.7	0.48
MMR-3 (Rt. 28)	609	4,049,749	0.015	0.015	75.0	0.12

Sub-Basin	Current (2018) Watershed Load					
	Land Area (ha)	Water Flow (m^3/yr)	Calculated P Concentration (mg/L)	Measured P Concentration (mg/L)	P mass (kg/yr)	P mass by area (kg/ha/yr)
MMR-4 (Rt. 140)	233	1,623,459	0.015	0.015	33.0	0.14
MMR-4 (Rt. 140) / Coffin Brook	22	142,523	0.027		3.9	0.18
MMR-5 (Rt. 11)	243	1,743,015	0.015	0.014	30.5	0.13
Trib 1 to Coffin Brook	45	272,812	0.015		6.8	0.15
Trib 1E to Coffin Brook	190	1,276,769	0.018	0.006	23.1	0.12
Trib 1W to Coffin Brook	187	1,264,503	0.010	0.006	12.3	0.07
Trib 2 to Coffin Brook	37	228,341	0.016		4.2	0.11
Trib 2S to Coffin Brook	95	638,871	0.016	0.003	10.0	0.11
Trib 3 to Coffin Brook	206	1,372,296	0.011	0.037	14.8	0.07
Trib 4 to Coffin Brook	91	606,570	0.010		6.4	0.07
Trib 4S to Coffin Brook	135	863,908	0.010	0.014	8.9	0.07
Trib 5 to Coffin Brook	69	458,272	0.018	0.021	7.1	0.10
Trib 5N to Coffin Brook	107	715,754	0.030	0.017	21.8	0.20
Trib 5S to Coffin Brook	155	1,042,000	0.014	0.016	12.7	0.08
Trib 5S-W to Coffin Brook	106	713,435	0.017	0.009	12.4	0.12
Trib 6 to Coffin Brook	92	605,837	0.017	0.034	8.9	0.10
Trib 6W to Coffin Brook	62	418,478	0.020	0.017	8.5	0.14
Trib to MMR-3	37	249,245	0.024	0.057	6.0	0.16
Trib to MMR-4	291	2,002,798	0.022	0.023	44.5	0.15

CONCLUSION

Based on model analysis of current water quality conditions, the Merrymeeting River and Lake watershed downstream of Merrymeeting Lake experiences degraded water quality (Figure 12), largely as a result of the point source discharge from the Powder Mill State Fish Hatchery (refer to Figure 11); however, phosphorus loading from current and future development in the watershed (including septic systems and internal cycling from legacy loading) will be important sources to address along with remediation of the point source. Given the area'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. Specific recommendations for protecting the water quality of the Merrymeeting River and Lake will be provided in the final watershed management plan.

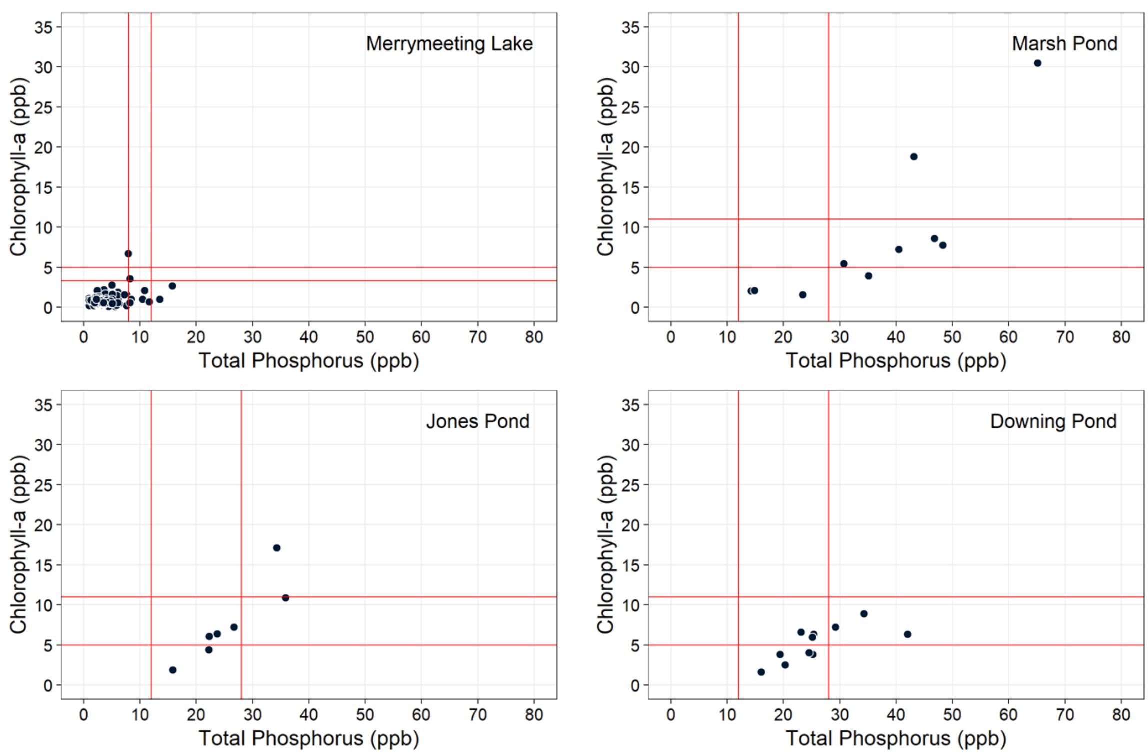

FIGURE 12. The relationship between chlorophyll-a and total phosphorus in Merrymeeting Lake (top left), Marsh Pond (top right), Jones Pond (bottom left), and Downing Pond (bottom right) shows that chlorophyll-a (measure of algae) generally increases in response to greater total phosphorus concentrations. Thresholds (red lines) for chlorophyll-a and total phosphorus for oligotrophic (3.3 ppb Chl-a, 8 ppb TP), mesotrophic (5 ppb Chl-a, 12 ppb TP), and/or eutrophic (11 ppb Chl-a, 28 ppb TP) waterbodies per NHDES.

ATTACHMENT 1: Land Cover File Update Workflow Record

LLRM Land Cover Update Workflow
11/30/2018 L. Diemer, C. Bunyon, M. Burns
Project #401: Merrymeeting River & Lake WMP

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

ESRI World Imagery dated 6/27/16
Google Earth Imagery dated 9/11/17

Land cover file from NH GRANIT: nhlc01
    ArcToolbox >Data Management Tools > Raster > Raster Processing > Clip
        Extent clipped to "Merrymeeting_wshed"
        File = "nhlc01_mmw"
    ArcToolbox >Conversion Tools > From Raster > Raster to Polygon
        File = "nhlc01_mmw_vector"
    Geoprocessing > Clip
        Extent clipped to "Merrymeeting_wshed"
        File = "nhlc01_mmw_before"

    Add text field to attribute table of "nhlc01_mmw_before" > "LLRM_code"
    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 Merrymeeting River & 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, 419
        Forest 2: Non-Deciduous / 421, 422, 423
        Forest 3: Mixed / 430
        Forest 4: Wetland / 610, 620
        Open 1: Water / 500
        Open 2: Meadow / NA
        Open 3: Excavation / 710
        Other 1: Logging / 790
        Other 2: Unpaved Road / NA

    Apply symbology to LLRM categories

ArcCatalog > Copy "nhlc01_mmw_before" > Rename "nhlc01_mmw_after"
    Import symbology to match "nhlc01_mmw_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 #1-68

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_mmw_after" and "nwi_clip" -> "nhlc01_spofford_after_nwi"
Unchecked “Gaps Allowed”
Relabel all former “Open 1: Water” to default “Forest 3: Mixed”
Relabel 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_mmw”
Geoprocessing > Buffer > Input "NHDFlowlines_mmw"; buffer = 15 ft -> "NHDFlowlines_mmw_buff15ft.shp"
Geoprocessing > Union > Input " nhlc01_mmw_after_nwi " and "NHDFlowlines_mmw_buff15ft" -> "nhlc01_mmw_after_nwi_flow"
Unchecked “Gaps Allowed”
Relabel added stream polygons as "Open 1: Water” under "LLRM_code" for streams

ADD PAVED & UNPAVED ROADS

Download “NH DOT Roads” from NH GRANIT and clip to watershed area > “mmw_roads”
Geoprocessing > Buffer > Input "mmw_roads"; buffer = 25 ft -> "mmw_roads_buff25ft.shp"
Geoprocessing > Union > Input "nhlc01_mmw_after_nwi_flow" and "mmw_roads_buff25ft" -> "nhlc01_mmw_after_nwi_flow_rds"
Unchecked “Gaps Allowed”
Relabel all former “Urban 3: Roads” to default “Forest 3: Mixed”
Relabel 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]

MULTIPART TO SINGLEPART

Data Management Tools > Features > Multipart to Singlepart
Input: “nhlc01_mmw_after_nwi_flow_rds”
Output: “nhlc01_mmw_after_nwi_flow_rds _single”
ArcCatalog > Copy " nhlc01_mmw_after_nwi_flow_rds _single" > Rename "mmw_landcover_v1"

LAND COVER ANALYSIS

Step 1: Zoom to Quad #X; compare “mmw_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

ATTACHMENT 2: Examples of Distinguishing Land Cover in Aerials

ATTACHMENT 3: Land Cover by Sub-Basin

(1 of 6) Land cover phosphorus (P) export coefficients and land cover areas for sub-basins in the Merrymeeting River and Lake watershed. Summed areas of sub-basins equal total watershed area minus the surface area of Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond.

			Area (hectares)									
			Model 1	Model 1	Model 1	Model 1	Model 1	Model 1	Model 1	Model 1	Model 1	Model 1
Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	Adder Hole Brook	Broad Cove Brook	Direct Shoreline MML	East Durgin Brook	East Pine Point Brook	Mount Bet Brook	Peter Brook	Pleasant Cove Brook	Trib to Upper Goodwin Brook	Unnamed Trib to MML
Urban 1 (Low Density Residential)	0.79	0.010	0.1	0.9	54.9	0.2		0.4	0.0	0.1	0.9	2.0
Urban 2 (Mid Density Res/Comm)	0.90	0.010			5.2				0.3			
Urban 3 (Roads)	0.30	0.010		0.5	18.7	0.2	0.0	0.0		0.3	0.5	0.3
Urban 4 (Industrial)	0.90	0.010										
Urban 5 (Mowed Fields)	0.60	0.010			0.3				1.6			
Agric 2 (Row Crop)	0.37	0.010										
Agric 3 (Grazing)	1.50	0.010										
Agric 4 (Hayfield)	0.37	0.010									0.7	
Forest 1 (Deciduous)	0.03	0.004	60.9	64.3	229.8	32.0	47.7	67.4	178.5	68.7	56.2	35.1
Forest 2 (NonDeciduous)	0.03	0.004		0.3	18.7		5.6	0.6	1.2	4.4	0.5	0.6
Forest 3 (Mixed)	0.03	0.004	2.8	38.8	169.7	16.0	31.8	4.8	73.4	76.4	43.8	14.5
Forest 4 (Wetland)	0.03	0.004		1.2	0.7	0.2	7.6		4.1	2.6	3.4	
Open 1 (Water)	0.01	0.004			0.0		1.4	0.7	1.8	1.8	1.1	0.6
Open 2 (Meadow)	0.20	0.004			0.4			0.3				
Open 3 (Excavation)	0.80	0.010			2.7	0.4	0.7			0.0		
Other 1 (Logged)	0.06	0.004		26.7	89.1	37.6	26.1		56.1		24.6	19.5
Other 2 (Unpaved Road)	0.83	0.01	0.7		9.4	0.3	0.7	2.6	1.6	0.9	3.3	0.3
		TOTAL	64.5	132.8	599.6	86.8	121.7	76.9	318.5	155.1	135.1	73.0

(2 of 6) Land cover phosphorus (P) export coefficients and land cover areas for sub-basins in the Merrymeeting River and Lake watershed. Summed areas of sub-basins equal total watershed area minus the surface area of Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond.

			Area (hectares)									
			Model 1	Model 1	Model 2	Model 2	Model 2	Model 2	Model 2	Model 2	Model 2	Model 2
Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	Upper Goodwin Brook	West Durgin Brook	Bear Pond	Bear Pond Brook	Brackett Rd Culvert Drainage	Direct Drainage to Marsh Pond	MMR-1	North Trib to Marsh Pond	Rattlesnake Mountain Brook	South Trib to Marsh Pond
Urban 1 (Low Density Residential)	0.79	0.010	4.4	0.2	0.6	7.3		0.9	1.0		1.6	1.3
Urban 2 (Mid Density Res/Comm)	0.90	0.010	0.2	0.7		5.2		0.4	3.4		0.2	
Urban 3 (Roads)	0.30	0.010	3.8	0.0		3.7	0.2	1.3	1.1		0.5	
Urban 4 (Industrial)	0.90	0.010										
Urban 5 (Mowed Fields)	0.60	0.010										
Agric 2 (Row Crop)	0.37	0.010										
Agric 3 (Grazing)	1.50	0.010										
Agric 4 (Hayfield)	0.37	0.010										
Forest 1 (Deciduous)	0.03	0.004	219.3	92.5	8.7	98.7	14.2	28.6	2.7	52.1	49.3	63.2
Forest 2 (NonDeciduous)	0.03	0.004	32.2	0.0	2.3	4.3		4.1	0.1	0.4		9.1
Forest 3 (Mixed)	0.03	0.004	159.7	25.5	14.7	81.3	1.3	29.6	4.2	20.4	8.8	29.5
Forest 4 (Wetland)	0.03	0.004	18.5	0.1	0.1	2.2		29.7	0.5	5.5	1.9	24.4
Open 1 (Water)	0.01	0.004	12.3	1.6	8.0	2.4		0.1	0.6	1.2	1.3	9.7
Open 2 (Meadow)	0.20	0.004	0.7	1.2	0.3	0.9				2.4		
Open 3 (Excavation)	0.80	0.010	5.5									
Other 1 (Logged)	0.06	0.004	24.9		17.4	1.4	0.6	7.7	0.0	1.8	10.0	94.5
Other 2 (Unpaved Road)	0.83	0.01	5.4	1.5	0.3	0.7	0.1	0.4				0.1
		TOTAL	486.8	123.3	52.4	208.0	16.5	102.7	13.4	83.8	73.5	231.9

(3 of 6) Land cover phosphorus (P) export coefficients and land cover areas for sub-basins in the Merrymeeting River and Lake watershed. Summed areas of sub-basins equal total watershed area minus the surface area of Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond.

			Area (hectares)									
			Model 2	Model 3	Model 3	Model 3	Model 4	Model 4	Model 4	Model 4	Model 4	Model 5
Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	West Trib to Marsh Pond	Culvert Drainage to Jones Pond	Direct Drainage to Jones Pond	Trib to Jones Pond	Direct Drainage to Downing Pond	FJ Trib to Downing Pond	MMR - Jones to Downing Pond	North Trib to Downing Pond	South Trib to Downing Pond	Coffin Brook-1 (Outflow in marsh)
Urban 1 (Low Density Residential)	0.79	0.010	3.2	2.8	11.6	0.1	3.0	5.8	1.2		2.1	
Urban 2 (Mid Density Res/Comm)	0.90	0.010	1.1		1.1		6.7				2.2	0.8
Urban 3 (Roads)	0.30	0.010	2.7	0.0	3.6	0.0	2.0	1.4	0.7		1.4	1.0
Urban 4 (Industrial)	0.90	0.010										
Urban 5 (Mowed Fields)	0.60	0.010										0.5
Agric 2 (Row Crop)	0.37	0.010	0.2				0.1	0.1				0.2
Agric 3 (Grazing)	1.50	0.010	1.0		0.2			1.7				
Agric 4 (Hayfield)	0.37	0.010	1.7					8.0				
Forest 1 (Deciduous)	0.03	0.004	142.3	45.9	62.1	13.2	7.4	48.4	12.7	14.1	0.7	0.8
Forest 2 (NonDeciduous)	0.03	0.004	13.1		0.7		12.4	0.9		1.3	2.7	16.3
Forest 3 (Mixed)	0.03	0.004	88.4	5.7	58.2	2.2	25.1	37.1	8.8	3.4	10.2	15.0
Forest 4 (Wetland)	0.03	0.004	17.2	2.3	8.5	0.2	0.8	2.1			11.1	40.9
Open 1 (Water)	0.01	0.004	6.7	0.1	0.0		1.5	1.4	0.6	0.1		0.4
Open 2 (Meadow)	0.20	0.004		1.1				0.0				0.5
Open 3 (Excavation)	0.80	0.010	0.1		0.3	0.0						2.6
Other 1 (Logged)	0.06	0.004	117.9	0.2	17.0	2.3	0.1		10.1	0.0	1.3	0.5
Other 2 (Unpaved Road)	0.83	0.01	0.8	0.9	2.5		0.0	0.0				1.8
		TOTAL	396.3	59.1	165.7	18.1	59.2	106.9	34.1	18.8	31.7	81.3

(4 of 6) Land cover phosphorus (P) export coefficients and land cover areas for sub-basins in the Merrymeeting River and Lake watershed. Summed areas of sub-basins equal total watershed area minus the surface area of Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond.

			Area (hectares)									
			Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5
Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	Coffin Brook-2	Coffin Brook-3 (Rt. 28)	Coffin Brook-4 (CBR)	Coffin Brook-5	Coffin Brook-6	Coffin Brook-7 (Rt. 140)	Meadow Pond	Meadow Pond (Outflow @ Rt. 140)	Mill Pond	MMR-2 (Site 11)
Urban 1 (Low Density Residential)	0.79	0.010	22.4	19.9	12.8	5.8	5.3	2.9	0.2	3.6	4.6	1.5
Urban 2 (Mid Density Res/Comm)	0.90	0.010	2.7	4.2	0.1					2.2	16.7	8.7
Urban 3 (Roads)	0.30	0.010	6.4	10.6	6.2	1.0	2.7	0.7		0.9	7.3	3.6
Urban 4 (Industrial)	0.90	0.010										
Urban 5 (Mowed Fields)	0.60	0.010		8.3								3.0
Agric 2 (Row Crop)	0.37	0.010	0.6		0.0							
Agric 3 (Grazing)	1.50	0.010	1.7	5.7	0.9							8.2
Agric 4 (Hayfield)	0.37	0.010	0.3	1.9	1.2	0.3						5.7
Forest 1 (Deciduous)	0.03	0.004	85.3	56.3	57.9	10.7	20.9	101.4	120.2	51.7	7.0	0.3
Forest 2 (NonDeciduous)	0.03	0.004	44.5	20.0	5.0	3.4	3.8	2.1	0.2		0.2	0.4
Forest 3 (Mixed)	0.03	0.004	141.0	106.8	86.6	68.2	35.7	33.6	23.9	25.7	19.4	15.5
Forest 4 (Wetland)	0.03	0.004	111.5	38.2	34.2	61.4	13.6	0.2	2.6	2.0		9.6
Open 1 (Water)	0.01	0.004	4.5	3.0	1.3	3.2	0.5	1.9	12.0	7.0	10.8	0.6
Open 2 (Meadow)	0.20	0.004	3.5	1.0		2.5						
Open 3 (Excavation)	0.80	0.010				0.3	2.7	0.5	0.2	0.8	0.1	
Other 1 (Logged)	0.06	0.004	5.4	39.2		94.3	42.3	10.7		6.3		
Other 2 (Unpaved Road)	0.83	0.01	0.5	4.0	0.2		0.4			1.6	0.1	0.6
		TOTAL	430.2	319.1	206.3	251.1	128.0	154.0	159.2	101.8	66.3	57.7

(5 of 6) Land cover phosphorus (P) export coefficients and land cover areas for sub-basins in the Merrymeeting River and Lake watershed. Summed areas of sub-basins equal total watershed area minus the surface area of Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond.

			Area (hectares)									
	Runoff P export coefficient used	Baseflow P export coefficient used	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5
Land Cover			MMR-3 (Rt. 28)	MMR-4 (Rt. 140)	MMR-4 (Rt. 140) / Coffin Brook	MMR-5 (Rt. 11)	Trib 1 to Coffin Brook	Trib 1E to Coffin Brook	Trib 1W to Coffin Brook	Trib 2 to Coffin Brook	Trib 2S to Coffin Brook	Trib 3 to Coffin Brook
Urban 1 (Low Density Residential)	0.79	0.010	31.3	5.3	2.8	14.0	6.9	11.3	3.9	2.3	5.4	2.5
Urban 2 (Mid Density Res/Comm)	0.90	0.010	15.6	19.9	0.5	7.9					1.2	
Urban 3 (Roads)	0.30	0.010	13.3	2.7	0.9	7.4	0.9	3.1	1.2	0.1	2.4	0.1
Urban 4 (Industrial)	0.90	0.010										
Urban 5 (Mowed Fields)	0.60	0.010	3.5	4.8		1.5						1.6
Agric 2 (Row Crop)	0.37	0.010	0.2					0.3	0.1			
Agric 3 (Grazing)	1.50	0.010	2.4					3.0	1.3	1.0	0.3	
Agric 4 (Hayfield)	0.37	0.010	7.1					10.7			0.5	0.6
Forest 1 (Deciduous)	0.03	0.004	40.5	52.0	5.1	103.4	0.1	60.8	113.3		44.3	23.0
Forest 2 (NonDeciduous)	0.03	0.004	46.3	4.2		8.1	8.1	12.0	8.4	8.1	0.6	2.3
Forest 3 (Mixed)	0.03	0.004	217.1	92.2	8.1	59.7	11.3	66.4	39.0	13.0	25.1	61.2
Forest 4 (Wetland)	0.03	0.004	185.5	40.1	2.6	15.3	15.3	0.7	0.8	10.5	1.1	19.3
Open 1 (Water)	0.01	0.004	7.5	3.5		7.7	1.5	3.1	2.0	1.1	2.0	3.6
Open 2 (Meadow)	0.20	0.004	2.4	0.4				0.0	3.7	0.5	1.3	0.1
Open 3 (Excavation)	0.80	0.010	4.0	1.7	0.0	0.0						5.2
Other 1 (Logged)	0.06	0.004	25.9	5.8	0.8	14.7		16.2	12.0	0.0	9.6	86.7
Other 2 (Unpaved Road)	0.83	0.01	7.0	0.1	1.0	3.3	0.8	2.0	1.6	0.2	1.5	0.1
		TOTAL	609.4	232.5	21.8	243.0	44.9	189.9	187.4	36.8	95.3	206.4

(6 of 6) Land cover phosphorus (P) export coefficients and land cover areas for sub-basins in the Merrymeeting River and Lake watershed. Summed areas of sub-basins equal total watershed area minus the surface area of Merrymeeting Lake, Marsh Pond, Jones Pond, and Downing Pond.

			Area (hectares)									
			Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5	Model 5
Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	Trib 4 to Coffin Brook	Trib 4S to Coffin Brook	Trib 5 to Coffin Brook	Trib 5N to Coffin Brook	Trib 5S to Coffin Brook	Trib 5S-W to Coffin Brook	Trib 6 to Coffin Brook	Trib 6W to Coffin Brook	Trib to MMR-3	Trib to MMR-4
Urban 1 (Low Density Residential)	0.79	0.010	2.8	5.6	3.1	10.1	6.6	6.6	3.6		3.1	11.0
Urban 2 (Mid Density Res/Comm)	0.90	0.010	0.4									17.8
Urban 3 (Roads)	0.30	0.010	0.8	1.8	1.4	2.9	1.5	2.4	2.3	0.1	0.1	10.8
Urban 4 (Industrial)	0.90	0.010										
Urban 5 (Mowed Fields)	0.60	0.010										0.0
Agric 2 (Row Crop)	0.37	0.010				0.2		0.1	0.0			0.3
Agric 3 (Grazing)	1.50	0.010	0.6	0.4	1.2	4.7	0.7	1.4	1.1	0.5	0.6	1.3
Agric 4 (Hayfield)	0.37	0.010			1.2	9.8	6.3	5.1	5.5	19.4	2.9	22.4
Forest 1 (Deciduous)	0.03	0.004	10.8	30.2	7.6	25.3	60.7	38.3	11.8	16.4	7.9	114.4
Forest 2 (NonDeciduous)	0.03	0.004	0.5	3.8	0.7	0.7		0.4	5.8	2.3	5.5	4.4
Forest 3 (Mixed)	0.03	0.004	49.7	62.7	29.4	41.9	69.3	46.6	49.4	22.4	13.1	88.0
Forest 4 (Wetland)	0.03	0.004	5.4	29.7	11.0	1.6	3.3	1.1	7.3	0.8	0.3	9.6
Open 1 (Water)	0.01	0.004	1.4	0.7	1.0	2.3	1.1	0.7	2.4		0.6	3.5
Open 2 (Meadow)	0.20	0.004		0.5	1.7	6.1	0.0	2.8			1.7	1.1
Open 3 (Excavation)	0.80	0.010										
Other 1 (Logged)	0.06	0.004	18.8	0.0	10.3		5.3		2.7	0.0		3.4
Other 2 (Unpaved Road)	0.83	0.01	0.2	0.1		1.6	0.5	0.4	0.0	0.0	1.3	2.7
		TOTAL	91.4	135.4	68.6	107.1	155.2	106.1	91.9	61.9	37.1	290.6