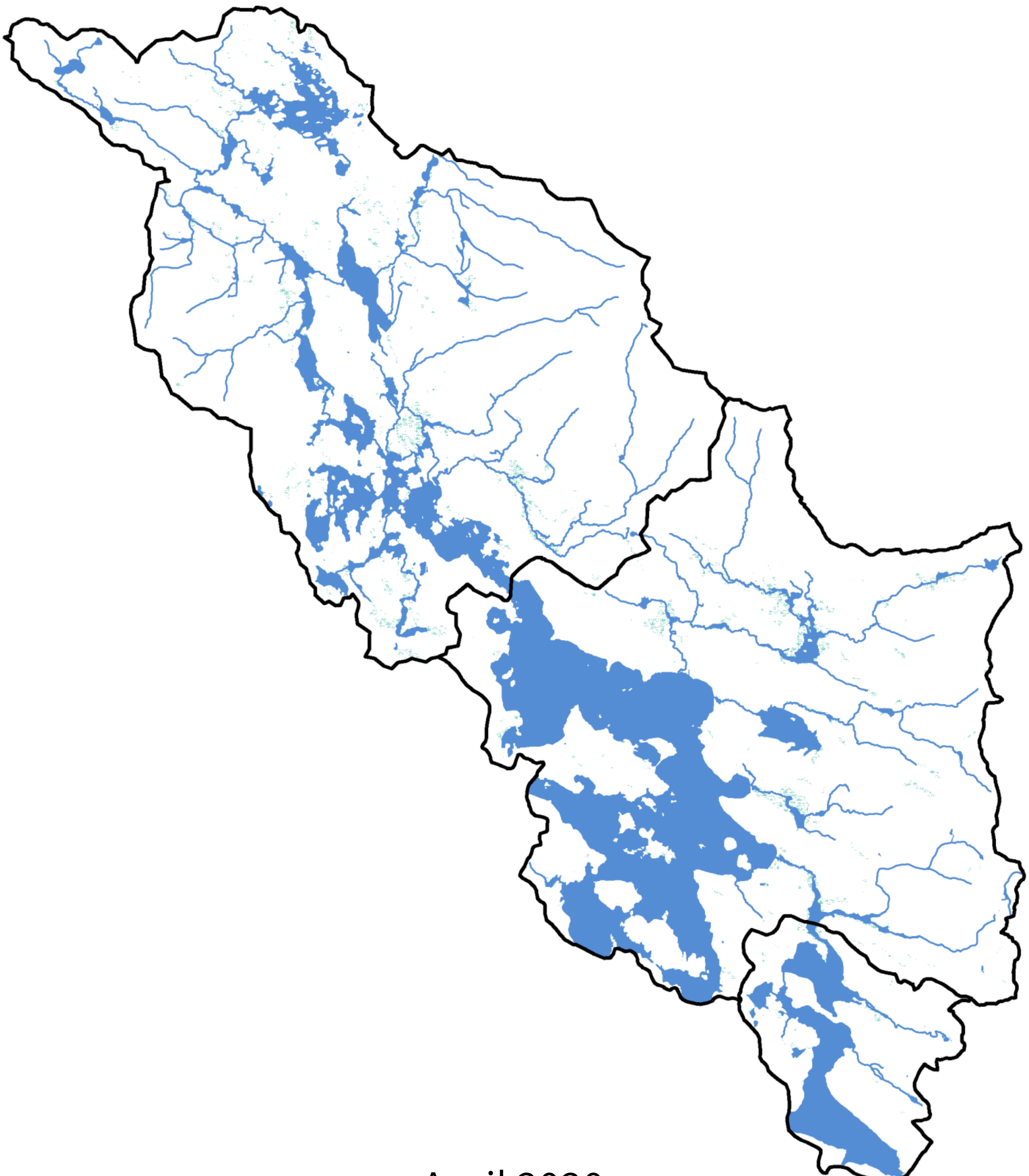
MOULTONBOROUGH BAY-WINTER HARBOR

LAKE LOADING RESPONSE MODEL



April 2020

MOULTONBOROUGH BAY-WINTER HARBOR
LAKE LOADING RESPONSE MODEL REPORT

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April 2020

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INTRODUCTION

The purpose of this report is to provide results from the Lake Loading Response Model (LLRM) developed for Moultonborough Bay and Winter Harbor. 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-watershed 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 pollutant sources, estimate pollutant limits and water quality goals, and guide watershed improvement projects.

SPECIAL NOTE: The watershed model as configured covers a large geographic area. The lake models cover two complex basins of Lake Winnipesaukee each of which include multiple tributaries, sub-basins, and embayments. While in-lake annual average predictions are accurate on a basin-wide scale, they may not represent localized conditions in the vicinity of tributaries, embayments, and along some shorelines. More detailed investigation may be warranted in these areas if water quality data and observations suggest that water quality is much poorer than the overall basin average. Local hotspots of phosphorus loading and associated benthic and free-floating algal growth are early warning signs of water quality degradation on a basin-wide scale. Addressing the local sources of phosphorus associated with these local hotspots will help prevent water quality decline in the greater basins and ultimately throughout Lake Winnipesaukee.

WATERSHED AND SUB-WATERSHED DELINEATIONS

Watershed and tributary drainage area (sub-watershed) 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.

FB Environmental Associates (FBE) extracted the overall watershed boundary from the USGS National Watershed Boundary Dataset (WBD) (HUC12-010700020106 Moultonborough Bay and HUC12-010700020107 The Broads), along with the final Moultonborough Bay Inlet (MBI) watershed used for modeling in its 2017 watershed management plan (FBE, 2016). FBE snapped the eastern edges of the Moultonborough Bay and Winter Harbor watersheds to the final Lake Wentworth / Crescent Lake watershed boundary (FBE, 2012), as well as the HUC12-010600020702 Beech River boundary to

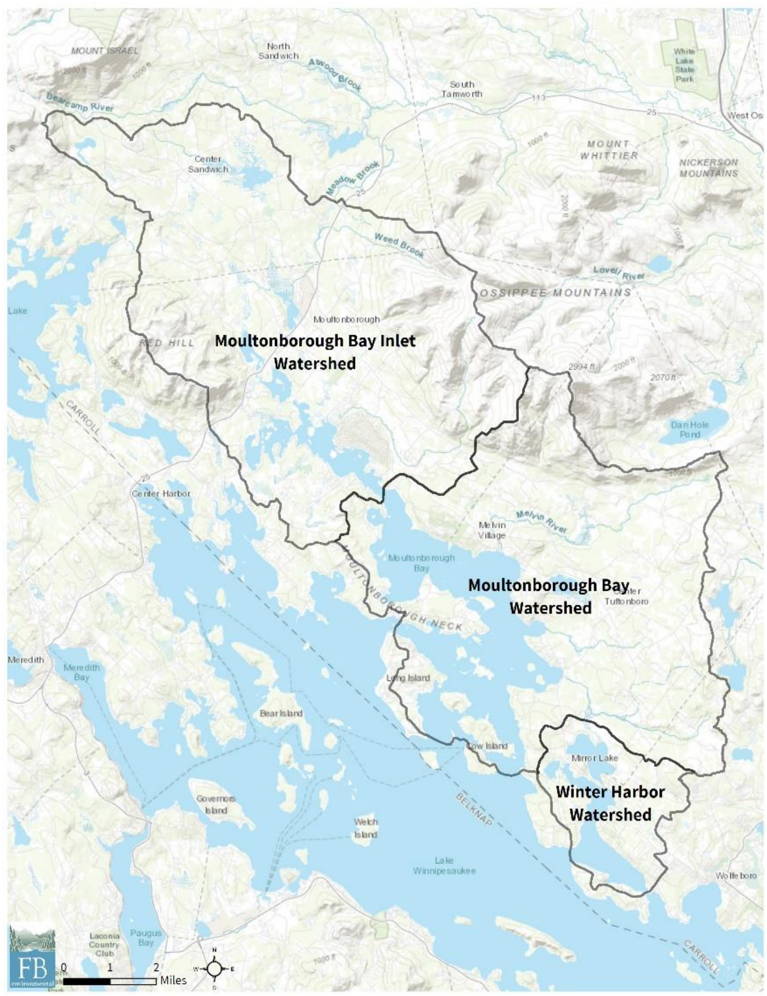

FIGURE 1. Final watershed boundaries for Moultonborough Bay (including the Inlet) and Winter Harbor.

[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.

include the area south of Upper Beech Pond that was confirmed to flow to Moultonborough Bay and not Lake Wentworth (FBE, 2012). FBE delineated the Winter Harbor outlet to the Broads of Lake Winnipesaukee using ESRI World Topo Map with 20-foot contours (Figure 1).

FBE completed preliminary delineation of sub-watersheds for the Moultonborough Bay and Winter Harbor watersheds using USGS 7.5-minute digital elevation models (DEMs) as input to ESRI ArcMap Spatial Analyst Hydrology tool. FBE then used ESRI World Topo Map with 20-foot contours to manually confirm the modeled sub-watershed boundary delineations, all of which were snapped to the overall watershed boundary. FBE ground-truthed accessible areas to confirm sub-watershed boundaries, especially in areas where stormwater systems may have redirected flows between sub-watersheds (Figure 2). The direct shoreline sub-watersheds will be used to help identify those areas with the greatest phosphorus loading to Moultonborough Bay and Winter Harbor and that which should be targeted for management efforts.

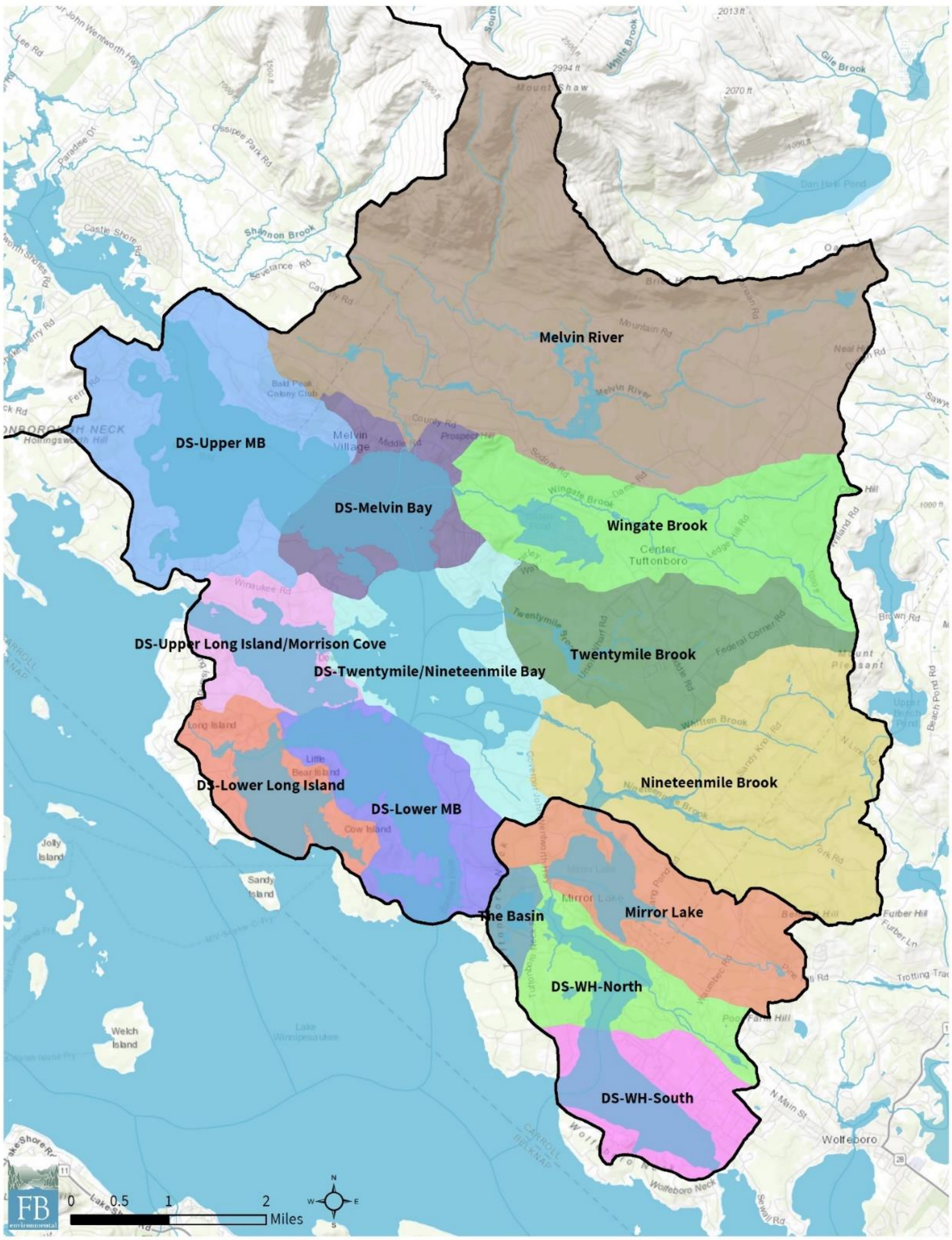

FIGURE 2. Final sub-watershed boundaries for the Moultonborough Bay and Winter Harbor watersheds. DS = Direct Shoreline.

BASIN DIVISIONS

Modeling Moultonborough Bay and Winter Harbor presents several challenges because the morphology (shape) and bathymetry (depth) of these waters are irregular, causing the formation of individual basins, bays, or inlets that likely have bidirectional flow (depending on seasonal flow and wind direction/strength) with multiple water inflows and/or outflows between basins and to the larger Lake Winnipesaukee system – all of which can influence water and nutrient movement through the study area.

We split Moultonborough Bay into six basins (Upper Moultonborough Bay, Melvin Bay, Twentymile & Nineteenmile Bay, Upper Long Island & Morrison Cove, Lower Long Island, and Lower Moultonborough Bay) and Winter Harbor into two basins (Winter Harbor-North and Winter Harbor-South) (Figure 3). However, analysis of recent, seasonal, epilimnetic total phosphorus concentrations showed no statistically significant difference among sites. Therefore, we modeled Moultonborough Bay and Winter Harbor as two single waterbodies. We also modeled the Basin separately before routing it as a point source to Winter Harbor. Mirror Lake (Geosyntec, 2012) and MBI (FBE, 2016) were modeled previously. Predictions from those models were used as input to the models created as a part of this project. See Point Sources in Other Major LLRM Inputs for further discussion.

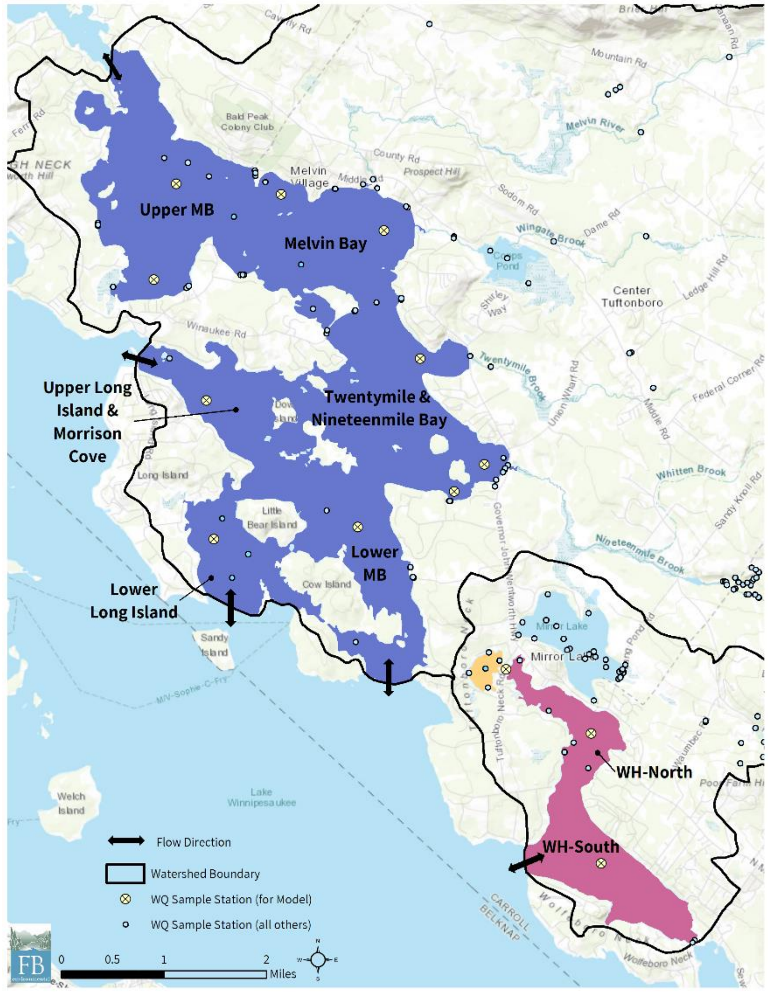

FIGURE 3. Basin divisions for Moultonborough Bay and Winter Harbor. Refer to Table 1 for water quality sites.

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 4/16/2017 and Google Earth satellite images dated 6/21/2018 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 assigned 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 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 Moultonborough Bay-Winter Harbor watershed (refer to Figure 4 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-watershed. 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.

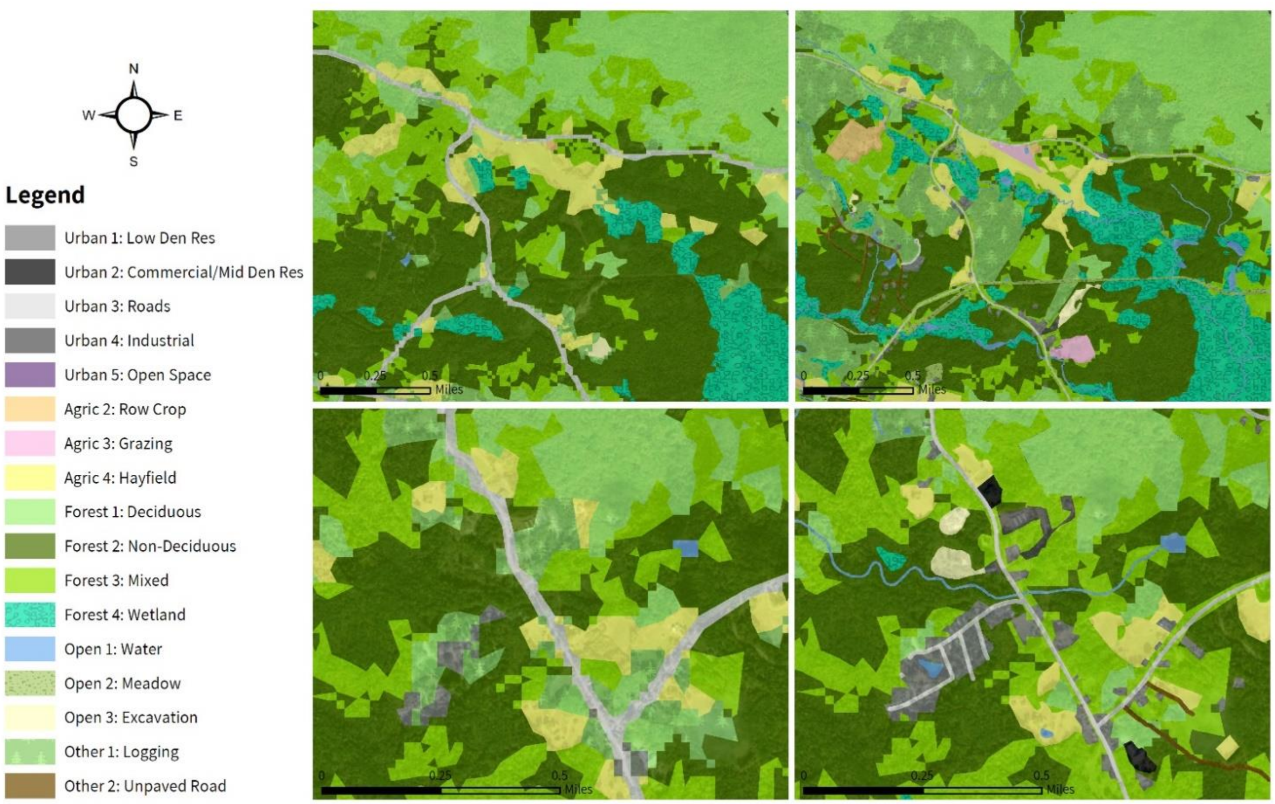

FIGURE 4. Example of "before" (left) and "after" (right) land cover file modifications for the Moultonborough Bay-Winter Harbor watershed.

Figure 5 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 8% and 17% of the watershed and contribute 35% and 75% of the total phosphorus watershed load to Moultonborough Bay and Winter Harbor, respectively.

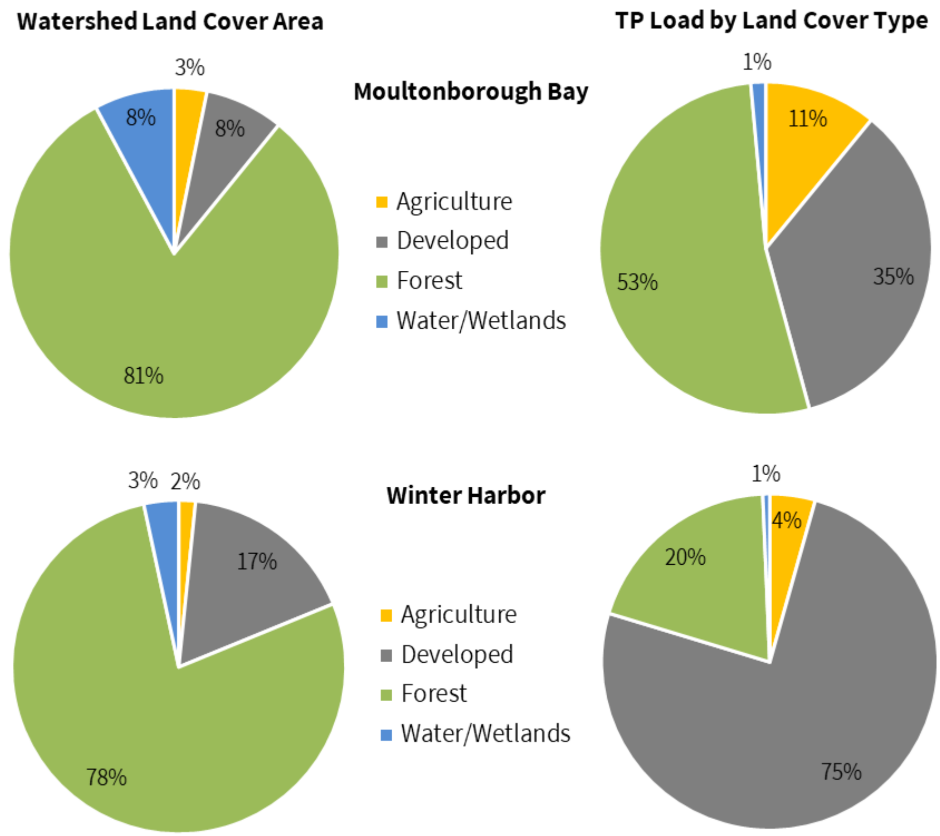

FIGURE 5. Watershed land cover area by general category (developed, agriculture, forest, and water/wetlands) and total phosphorus (TP) watershed load by general land cover type. This shows that developed areas cover 8% and 17% of the watershed and contribute 35% and 75% of the TP watershed load to Moultonborough Bay and Winter Harbor, respectively. Note: these estimates do not include the Basin, MBI, or Mirror 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 six stations: MEREDITH 2.9 SSW, NH US (US1NHBK0009), MEREDITH 3 NNE, NH US (USC00275350), LAKEPORT 2, NH US (USC00274480), LACONIA 7.9 E, NH US (US1NHBK0007), EAST SANDWICH, NH US (USC00272303), and CENTER HARBOR 3.7 SW, NH US (US1NHBK0012). The average of the average annual precipitation totals from 2009-2018 for the six stations were input to the model (49.48 in or 1.257 m).
- **Lake volume and area estimates** were obtained from the New Hampshire Department of Environmental Services (NHDES) bathymetry shapefile (via the Lake Winnipesaukee Association (LWA)) based on a 2010 survey.
- **Point sources** from other models were input to both models. The Basin was modeled separately and entered as a point source input to the Winter Harbor model. Model results were already determined for Mirror Lake as part of its 2012 watershed management plan (Geosyntec, 2012); therefore, we used the modeled water load and in-lake water quality concentrations from Mirror Lake as a point source to Winter Harbor. Similarly, model results were already determined for MBI as part of its 2017 watershed management plan (FBE, 2016); therefore, we used the modeled water load and in-lake water quality concentrations from MBI as a point source to Moultonborough Bay. We did not re-model or update the models for Mirror Lake or MBI as part of this project. We also input estimates of water and phosphorus loading to baseflow (groundwater) in the Nineteenmile Brook sub-watershed to Moultonborough Bay, based on review of documentation for the Rapid Infiltration Wastewater Disposal System (RIWDS) in the Town of Wolfeboro (Town of Wolfeboro, 2010, 2020; Normandeau, 2008, 2009, 2019). We also checked NPDES outfall locations through the NHDES One Stop Data Viewer and found none within the study area. After all other inputs were finalized, we estimated the contributing volume from Lake Winnipesaukee (at an observed total phosphorus concentration for the Broads-Deep Spot of 5.4 ppb) to both Moultonborough Bay and Winter Harbor, assuming that wind and current action in the larger lake system mixes with nearshore bays and inlets.
- **Septic system data** were estimated from property records. LWA coordinated with AmeriCorps volunteers to identify and research 870 parcels with buildings within 250 feet of Moultonborough Bay and 265 parcels with buildings within 250 feet of Winter Harbor. AmeriCorps volunteers searched property records for pertinent information such as date house built, date of most recent septic installation or upgrade, number of bedrooms, and seasonal or year-round use. From this information, LWA and AmeriCorps volunteers were able to determine the number of people using seasonal and year-round, old and new septic systems within 250 feet of the study waters, which was input to the models to estimate the total phosphorus load from septic systems.
- **Water quality data** were gathered from NHDES Environmental Monitoring Database (EMD) and the UNH Lakes Lay Monitoring Program via LWA. Data were screened for relevant site locations and water quality parameters (Secchi disk transparency, chlorophyll-a, total phosphorus, dissolved oxygen, and temperature). The model was calibrated using tributary and lake samples taken between 2010 and 2019 (or recent 10 years with available data in cases where 2008-2017 or 2009-2018 data were available). Sites were only included if they were a close match to the outlet of a sub-watershed used in the model. Data were summarized to obtain mean or median water quality summaries for total phosphorus, chlorophyll-a, and Secchi Disk Transparency and aggregated for multiple lake sites. We recommend that a single representative site be selected, if appropriate, for goal setting, and that a subset of secondary sites be selected for more targeted monitoring and remediation objectives.
- **Waterfowl data** were determined using a standard estimate of 0.3 birds per hectare of lake surface area. 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. The waterfowl estimate may not be accurate for small waterbodies (such as the Basin). Actual waterfowl counts in these areas would lead to more accurate estimates of phosphorus input from waterfowl.
- **Internal loading estimates** were derived from dissolved oxygen and temperature profiles taken at the deep spots of Moultonborough Bay and Winter Harbor from 2009-2019 (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 spots of Moultonborough Bay and Winter Harbor from 2009-2019 (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. Minimal in-stream phosphorus concentrations were available to be used as guideposts (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 assumptions made during calibration.

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

- The **standard water yield** coefficient was input as 1.9 cubic ft/sq. m, which is near 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 exceptions noted in Table 1. Water can be lost through evapotranspiration, 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-watershed. Larger water losses (<95% passed through) were expected with lower gradient or wetland-dominated sub-watersheds. Additional infiltration, filtration, detention, and uptake of phosphorus will lower the phosphorus attenuation value, such as for sub-watersheds 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 excluded Vollenweider (1975) and Reckhow General (1977) for all models, because results from the remaining 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-watershed.

Sub-Watershed	Water Atten. Factor	Phos. Atten. Factor	Reasoning (water; phosphorus (P))
Moultonborough Bay			
DS-Lower Long Island	0.95	0.95	Default water and low P attenuation factor (due to proximity to lake).
DS-Lower MB	0.95	0.95	Default water and low P attenuation factor (due to proximity to lake).
DS-Melvin Bay	0.95	0.95	Default water and low P attenuation factor (due to proximity to lake).
DS-Twentymile/Nineteenmile Bay	0.95	0.95	Default water and low P attenuation factor (due to proximity to lake).
DS-Upper Long Isl/Morrison Cove	0.95	0.95	Default water and low P attenuation factor (due to proximity to lake).
DS-Upper MB	0.95	0.95	Default water and low P attenuation factor (due to proximity to lake).
Melvin River	0.80	0.75	Attenuation by wetlands, ponds in low-lying area.
Nineteenmile Brook	0.90	0.85	Attenuation by small pond (Whitten Pond).
Twentymile Brook	0.90	0.85	Attenuation by channel processes and small wetlands.
Wingate Brook	0.85	0.80	Attenuation by wetlands, large pond in low-lying area.
MBI	1.00	1.00	Not a true sub-watershed; point source routed directly to lake with no attenuation.
The Broads	1.00	1.00	Not a true sub-watershed; point source routed directly to lake with no attenuation.
Winter Harbor			
The Basin (separate model)	0.95	0.95	Default water and low P attenuation factor (due to proximity to lake).
DS-WH-North	0.90	0.85	Attenuation by channel processes and small wetlands.
DS-WH-South	0.90	0.90	Default water and P attenuation factor (due to proximity to lake).
The Basin	1.00	1.00	Not a true sub-watershed; point source routed directly to lake with no attenuation.
Mirror Lake	1.00	1.00	Not a true sub-watershed; point source routed directly to lake with no attenuation.
The Broads	1.00	1.00	Not a true sub-watershed; point source routed directly to lake with no attenuation.

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 limitations to the model:

- **The watershed model as configured covers a large geographic area.** The lake models cover two complex basins of Lake Winnipesaukee each of which include multiple sub-basins and embayments. While in-lake annual average predictions are accurate on a basin-wide scale, they may not represent localized conditions in the vicinity of tributaries, in specific embayments, and along some shorelines. More detailed investigation may be warranted in these areas if water quality data and observations suggest that water quality is much poorer than the overall basin average.
- **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 water quality data were available.** Most sub-watersheds had a weak dataset ($n \approx 3$) available for model calibration; the dataset could be made stronger with continued data collection at existing sites. 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-watersheds. We recommend that the major tributaries be sampled further upstream to eliminate possible backflow from Moultonborough Bay as the immediate outlet areas are likely not representative during high winds or low flow periods. Until more data are available, we assumed that similar land cover coefficients and attenuation values used in other sub-watersheds with more certainty would be applicable to the sub-watersheds with less certainty due to limited data. No data were available for the deep spot of the Basin; thus, we relied on surface grab samples from the Basin outlet. We were also missing total phosphorus data from the Broads from 2017-2019, though it is also possible that these data were not collected and do not exist.
- **Bathymetry data were coarse.** We obtained 2010 NHDES bathymetry data from the LWA. The data were available in 20 ft contours which did not provide good resolution for more precisely estimating hypolimnion volume in the shallower bays. We used screen grabs and the measuring tool from Navionics®, which offers an online chart viewer with better contour resolution of lake bathymetry, to estimate surface area and depth measurements for target areas. See limitations for internal loading.
- **RIWDS point source nutrient load estimate is zero until confirmed otherwise.** We selected the upstream control site (19MB-1) and the downstream impacted site just before Whitten Pond (19MB-21) to tabulate total phosphorus data and delineate sub-drainage areas within the Nineteenmile Brook watershed. We modeled the expected water and phosphorus load and average annual phosphorus concentration for each site and compared to observed water quality data available from 2007-2008 (pre-RIWDS) and 2009-2019 (post-RIWDS). The difference between modeled and observed concentration (accounting for an increase in groundwater volume from the RIWDS) was assumed to reflect the approximate phosphorus load from the RIWDS. In this case, the difference in average phosphorus concentration between the control site (19MB-1) and the impacted site (19MB-21) was similar between pre- and post-RIWDS, suggesting negligible observed increase in phosphorus load to Nineteenmile Brook as a result of the RIWDS.
- **RIWDS point source nutrient load estimate did not include 2019 Normandeau Associates data.** We received 2019 total phosphorus data collected by Normandeau Associates and analyzed by Nelson Analytical, an accredited laboratory with reporting limit of 5 ppb (method SM4500 P F). These 10 data points were considerably higher (by one order of magnitude in some cases) than 111 other data points provided by the Town of Wolfeboro and analyzed by Eastern Analytical, also an accredited laboratory with reporting limit of 2 ppb (method EPA 365.1). Both laboratory methods are comparable and report the total phosphorus concentration as the P fraction. Therefore, it is unclear the cause of this discrepancy. Further consultation with the samplers at Normandeau Associates may be warranted to confirm sampling. As a test to ensure comparability of all future data collection in Nineteenmile Brook, we recommend that sampling teams from Normandeau Associates and the Town of Wolfeboro meet in the field to collect samples at both 19MB-1 and 19MB-

21 at the same time and each send split samples to both laboratories (Eastern Analytical and Nelson Analytical). Review of the results may help to shed light on whether the discrepancy is real and justified or whether there is a persistent field or laboratory error occurring. In the meantime, we did not include 2019 Normandeau Associates data in our estimation of the RIWDS nutrient load contribution because the data were higher than the majority of samples collected for several years prior to 2019, higher than the modeling expected based on existing land use, and higher than typical New Hampshire streams with similar land use. The 2019 Normandeau Associates data alone show an increase in phosphorus concentration (when modeling predicts a decrease) moving downstream between the control and impacted sites, which would suggest that the RIWDS may be a significant nutrient load source to Nineteenmile Brook. Understanding and justifying the discrepancy is therefore important to confirming the possible impact from the RIWDS. As an exercise in model sensitivity, we simulated an RIWDS nutrient load using the 2019 Normandeau Associates results and found that the in-lake total phosphorus concentration for Moultonborough Bay increased by 0.06 ppb, which falls within the margin of error for the model.

- **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). We were unable to calculate a possible internal phosphorus load for the Basin due to a lack of water quality data at the deep spot; although the Basin's shallow nature may minimize the formation of a bottom anoxic layer (due to mixing from wind and wave action), the Basin may be susceptible to mechanical disturbance of and release of phosphorus from bottom sediments as a result of boat propeller action. Limited water quality data were available for stations in Moultonborough Bay and Winter Harbor. Using Navionics®, we estimated the hypolimnion volume for only deep spot areas with data showing anoxia. For Moultonborough Bay, we used Melvin Bay (WMO05ML), Twentymile Bay (WMO20ML), and Nineteenmile Bay (WMO19AL). For Winter Harbor, we used the deep spot in the southern half (WWH15WL). It is possible that the internal load estimates for both Moultonborough Bay and Winter Harbor are underestimated and do not reflect the behavior of Gloeotrichia, which can regulate their buoyancy to capture phosphorus from bottom sediments in shallow waters and transport that phosphorus up into the water column.
- **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 (e.g., geese, ducks, etc.) census throughout the year would help improve the model loading estimates. Waterfowl counts for the Basin are likely significantly underestimated and would benefit from local knowledge of seasonal bird residence observations.
- **Land cover export coefficients were estimates.** Literature values and best professional judgement were used in evaluating and selecting appropriate land cover export coefficients for Moultonborough Bay-Winter Harbor. 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.
- **Hydrologic flow assumptions were simplified.** A major initial assumption with the model was unidirectional, equal outflows through multiple outlets in some cases. It is more likely that flows are bidirectional depending on the time of year (driven by wind and flow patterns) and are unequally apportioned through multiple outlets. It may be possible to generate an apportioned flow estimate through these outflows and the narrow, connecting channels throughout the system based on channel dimensions and monthly annual lake level fluctuations, but obtaining and assessing seasonal changes in current strength and direction throughout the study area would be ideal for model parameterization. We recommend collecting depth and flow velocity measurements at set intervals across a transect at each of the major connecting channels of Moultonborough Bay and Winter Harbor at least twice in each season (including winter, if possible) to confirm flow direction and velocity. In the meantime, we determined the median phosphorus concentration for the Broads-Deep Spot and adjusted the input volume and associated phosphorus load from the main lake until we achieved near the observed target phosphorus concentration; the resulting volume serves as an approximation of the magnitude of mixing exchange with the larger Lake Winnipesaukee system. For example, it was assumed that about 34% of the volume entering Moultonborough Bay is exchanged annually with water from the larger lake system.
- **Previous modeled inputs represent older data.** Model results were already determined for Mirror Lake as part of its 2012 watershed management plan (Geosyntec, 2012) and for MBI as part of its 2017 watershed management plan (FBE, 2016). We did not re-model or update the models for Mirror Lake or MBI as part of this project. As such, modeled water and phosphorus loads from these inputs may not reflect current conditions.

RESULTS

CURRENT LOAD ESTIMATION

Overall, model predictions were in good agreement with observed data for 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 transport of phosphorus from the sediment-water interface to the water column by cyanobacteria, 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.

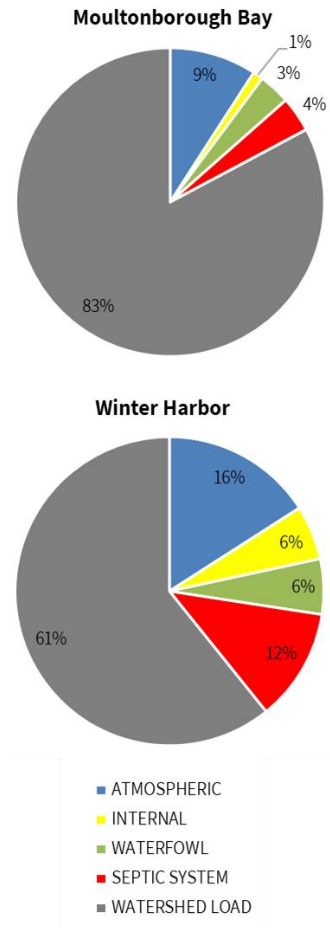

FIGURE 6. Summary of total phosphorus loading by major source for Moultonborough Bay and Winter Harbor. The loads from the Basin, Moultonborough Bay Inlet, Mirror Lake, and exchange with Lake Winnipesaukee are included in the watershed load. Refer to Table 3 for a breakdown.

Watershed runoff[3] combined with baseflow (83% and 61%) was the largest phosphorus loading contribution across all sources to Moultonborough Bay and Winter Harbor, respectively, followed by atmospheric deposition (9% and 16%), septic systems (4% and 12%), waterfowl (3% and 6%), and internal loading (1% and 6%) (Table 3; Figures 6, 7). 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 currently a minor source but a concern for Moultonborough Bay-Winter Harbor given that low dissolved oxygen in bottom waters is causing a release of phosphorus from bottom sediments (as evidenced by the moderate difference between bottom and surface phosphorus concentrations (5-28 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.

Normalizing for the size of a sub-watershed (i.e., accounting for its annual discharge and direct drainage area) better highlights sub-watersheds with elevated pollutant exports relative to their drainage area. Sub-watersheds with moderate-to-high phosphorus mass exported by area (> 0.1 kg/ha/yr) generally had more development (i.e., the direct shoreline to Melvin Bay and the Nineteenmile Brook sub-watershed for Moultonborough Bay and the Basin and Mirror Lake for Winter Harbor; Table 4, Figure 8). 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. Limited observed data were available for the outlets of the sub-watersheds. More data are needed to better confirm the coefficients and attenuation factors used for those sub-watersheds.

The model predicts that approximately 29% of the total phosphorus load to Moultonborough Bay comes from MBI (Table 3). Approximately 15% of the total phosphorus load to Winter Harbor comes from Mirror Lake and 3% comes from the Basin. We also estimated that about 34% of the volume of Moultonborough Bay mixes with the Broads of Lake Winnipesaukee, contributing 10% of the total phosphorus load; similarly, about 24% of the volume of Winter Harbor mixes with the Broads, contributing 6% of the total phosphorus load.

[3] Note that total phosphorus loads in the watershed load portion includes aggregated loads from the Basin, Moultonborough Bay Inlet, Mirror Lake, and exchange with Lake Winnipesaukee. Refer to Table 3 for a breakdown.

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 204%, from 971 kg/yr prior to European settlement to 2,951 kg/yr under current conditions, for Moultonborough Bay, and by 160%, from 104 kg/yr to 271 kg/yr, for Winter Harbor (Table 3; Figure 7). These additional phosphorus sources are coming from development in the watershed (especially from MBI, Nineteenmile Brook, and Melvin River for Moultonborough Bay and from the direct shoreline of Winter Harbor North for Winter Harbor), septic systems, atmospheric dust, and internal loading (Tables 3, 4). Water quality prior to settlement was likely excellent with extremely low phosphorus and chlorophyll-a concentrations and high water clarity (Table 2; Figure 7).

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 70%, from 2,951 kg/yr under current conditions to 5,008 kg/yr at full build-out (2072) under current zoning, for Moultonborough Bay (Table 3; Figure 7). Similarly, total phosphorus loading may increase by 93%, from 271 kg/yr under current conditions to 521 kg/yr at full build-out for Winter Harbor (Table 3; Figure 7). Additional phosphorus will be generated from more development in the watershed (especially from MBI, Melvin River, and Nineteenmile Brook for Moultonborough Bay and from Mirror Lake for Winter Harbor), greater atmospheric dust, more septic systems, and enhanced internal loading (Tables 3, 4). The model predicted significantly higher (worse) phosphorus (12.0 ppb), higher (worse) chlorophyll-a (3.2 ppb), and lower (worse) water clarity (3.4 m) compared to current conditions for both Moultonborough Bay and Winter Harbor (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 Moultonborough Bay-Winter Harbor. 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)
Moultonborough Bay						
Pre-Development	--	2.3	--	0.3	--	12.1
Current (2019)	6.0 (7.2)	7.1	1.6	1.3	5.7	5.1
Future (2072)	--	12.0	--	3.2	--	3.4
Winter Harbor						
Pre-Development	--	2.4	--	0.3	--	11.9
Current (2019)	5.1 (6.1)	6.2	1.1	1.0	9.3	5.7
Future (2072)	--	12.0	--	3.2	--	3.4

**Median TP concentration of 6.0 ppb and 5.1 ppb represent current in-lake epilimnion TP from observed data. Median TP concentration of 7.2 ppb and 6.1 ppb represent 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 for Moultonborough Bay-Winter Harbor. Italicized sources sum to the watershed load.

SOURCE	PRE-DEVELOPMENT			CURRENT (2019)			FUTURE (2072)		
	TP (KG/YR)	%	WATER (CU.M/YR)	TP (KG/YR)	%	WATER (CU.M/YR)	TP (KG/YR)	%	WATER (CU.M/YR)
Moultonborough Bay									
ATMOSPHERIC	171	18%	18,183,287	269	9%	18,183,287	612	12%	18,183,287
INTERNAL	0	0%	0	31	1%	0	53	1%	0
WATERFOWL	98	10%	0	98	3%	0	98	2%	0
SEPTIC SYSTEM	0	0%	0	109	4%	85,631	143	3%	111,745
WATERSHED LOAD	702	72%	192,343,553	2,443	83%	192,667,487	4,102	82%	193,251,685
RIWDS	*--*	*--*	*--*	*0*	*0%*	*497,403*	*0*	*0%*	*497,403*
MBI	*222*	*23%*	*76,441,784*	*846*	*29%*	*76,219,714*	*1,273*	*25%*	*76,697,288*
Exchange with Main Lake	*194*	*20%*	*54,000,000*	*292*	*10%*	*54,000,000*	*497*	*10%*	*54,000,000*
Direct Land Use Load	*286*	*29%*	*61,901,769*	*1,306*	*44%*	*61,950,371*	*2,332*	*47%*	*62,056,995*
TOTAL LOAD TO LAKE	**971**	**100%**	**210,526,840**	**2,951**	**100%**	**210,936,405**	**5,008**	**100%**	**211,546,717**
Winter Harbor									
ATMOSPHERIC	27	26%	2,912,447	43	16%	2,912,447	98	19%	2,912,447
INTERNAL	0	0%	0	15	6%	0	30	6%	0
WATERFOWL	16	15%	0	16	6%	0	16	3%	0
SEPTIC SYSTEM	0	0%	0	32	12%	24,030	42	8%	31,826
WATERSHED LOAD	61	59%	12,659,817	165	61%	12,664,414	336	64%	12,667,455
The Basin	*3*	*3%*	*762,060*	*9*	*3%*	*763,729*	*15*	*3%*	*763,761*
Mirror Lake	*25*	*24%*	*3,955,000*	*42*	*15%*	*3,955,000*	*120*	*23%*	*3,955,000*
Exchange with Main Lake	*11*	*10%*	*3,000,000*	*16*	*6%*	*3,000,000*	*28*	*5%*	*3,000,000*
Direct Land Use Load	*23*	*22%*	*4,942,757*	*98*	*36%*	*4,945,685*	*173*	*33%*	*4,948,694*
TOTAL LOAD TO LAKE	**104**	**100%**	**15,572,264**	**271**	**100%**	**15,600,892**	**521**	**100%**	**15,611,729**

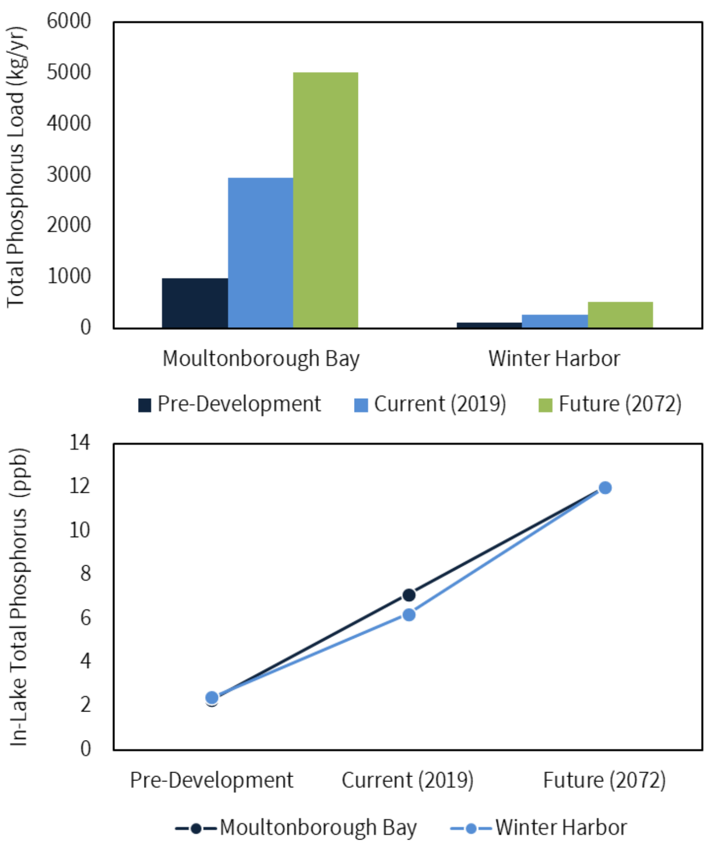

FIGURE 7. Change in total phosphorus load (kg/yr, **TOP**) and in-lake total phosphorus concentration (ppb, **BOTTOM**) for Moultonborough Bay and Winter Harbor from pre-development to current (2019) to future (2072) conditions.

TABLE 4. Summary of land area, water flow, and total phosphorus (TP) loading by sub-watershed for Moultonborough Bay-Winter Harbor. Land area does not include the area of the lake or pond of interest. Italicized text highlight sub-watersheds that were input as point sources to the model and for which TP mass by area cannot be calculated; the loads represent outputs (after settling/retention within the system) and not total direct inputs.

Sub-Watershed	Land Area (ha)	**Pre-Development Watershed Loads**				**Current (2019) Watershed Loads**					**Future (2072) Watershed Loads**			
		Water Flow (m^3/year)	Calculated P Concentration (mg/L)	P mass (kg/year)	P mass by area (kg/ha/year)	Water Flow (m^3/year)	Calculated P Concentration (mg/L)	Measured P Concentration (mg/L)	P mass (kg/year)	P mass by area (kg/ha/year)	Water Flow (m^3/year)	Calculated P Concentration (mg/L)	P mass (kg/year)	P mass by area (kg/ha/year)
Moultonborough Bay														
DS-Lower Long Island	262	1,855,066	0.005	8	0.03	1,849,792	0.016		29	0.11	1,853,672	0.036	68	0.26
DS-Lower MB	346	2,459,290	0.005	11	0.03	2,459,150	0.011		26	0.08	2,463,844	0.030	73	0.21
DS-Melvin Bay	281	2,000,544	0.005	10	0.03	1,981,536	0.030		60	0.21	1,986,638	0.056	111	0.39
DS-Twentymile/Nineteenmile Bay	386	2,752,627	0.005	13	0.03	2,749,650	0.021		59	0.15	2,754,302	0.038	105	0.27
DS-Upper Long Island/Morrison Cove	242	1,727,586	0.005	8	0.03	1,715,781	0.026		45	0.19	1,719,919	0.050	87	0.36
DS-Upper MB	775	5,503,982	0.006	31	0.04	5,474,808	0.023		128	0.17	5,490,500	0.052	285	0.37
Melvin River	3,602	21,250,453	0.005	96	0.03	21,307,492	0.017	0.018	364	0.10	21,333,162	0.028	604	0.17
Nineteenmile Brook	1,665	11,084,534	0.004	49	0.03	11,641,612	0.030	0.016	349	0.21	11,661,900	0.046	541	0.32
Twentymile Brook	921	6,094,940	0.004	27	0.03	6,093,642	0.019	0.009	117	0.13	6,106,253	0.039	236	0.26
Wingate Brook	1,157	7,172,747	0.004	32	0.03	7,174,311	0.018	0.014	130	0.11	7,184,208	0.031	223	0.19
MBI	*12,618*	*76,441,784*	*0.003*	*222*	*NA*	*76,219,714*	*0.011*		*846*	*NA*	*76,697,288*	*0.017*	*1273*	*NA*
The Broads	*NA*	*54,000,000*	*0.004*	*194*	*NA*	*54,000,000*	*0.005*		*292*	*NA*	*54,000,000*	*0.009*	*497*	*NA*
Winter Harbor														
DS-WH-North	394	2,638,561	0.005	12	0.03	2,638,007	0.019		50	0.13	2,639,371	0.032	83	0.21
DS-WH-South	340	2,304,196	0.005	10	0.03	2,307,679	0.021		48	0.14	2,309,323	0.039	90	0.26
The Basin	*85*	*762,060*	*0.004*	*3*	*NA*	*763,729*	*0.011*		*9*	*NA*	*763,761*	*0.020*	*15*	*NA*
Mirror Lake	*694*	*3,955,000*	*0.006*	*25*	*NA*	*3,955,000*	*0.011*		*42*	*NA*	*3,955,000*	*0.030*	*120*	*NA*
The Broads	*NA*	*3,000,000*	*0.004*	*11*	*NA*	*3,000,000*	*0.005*		*16*	*NA*	*3,000,000*	*0.009*	*28*	*NA*

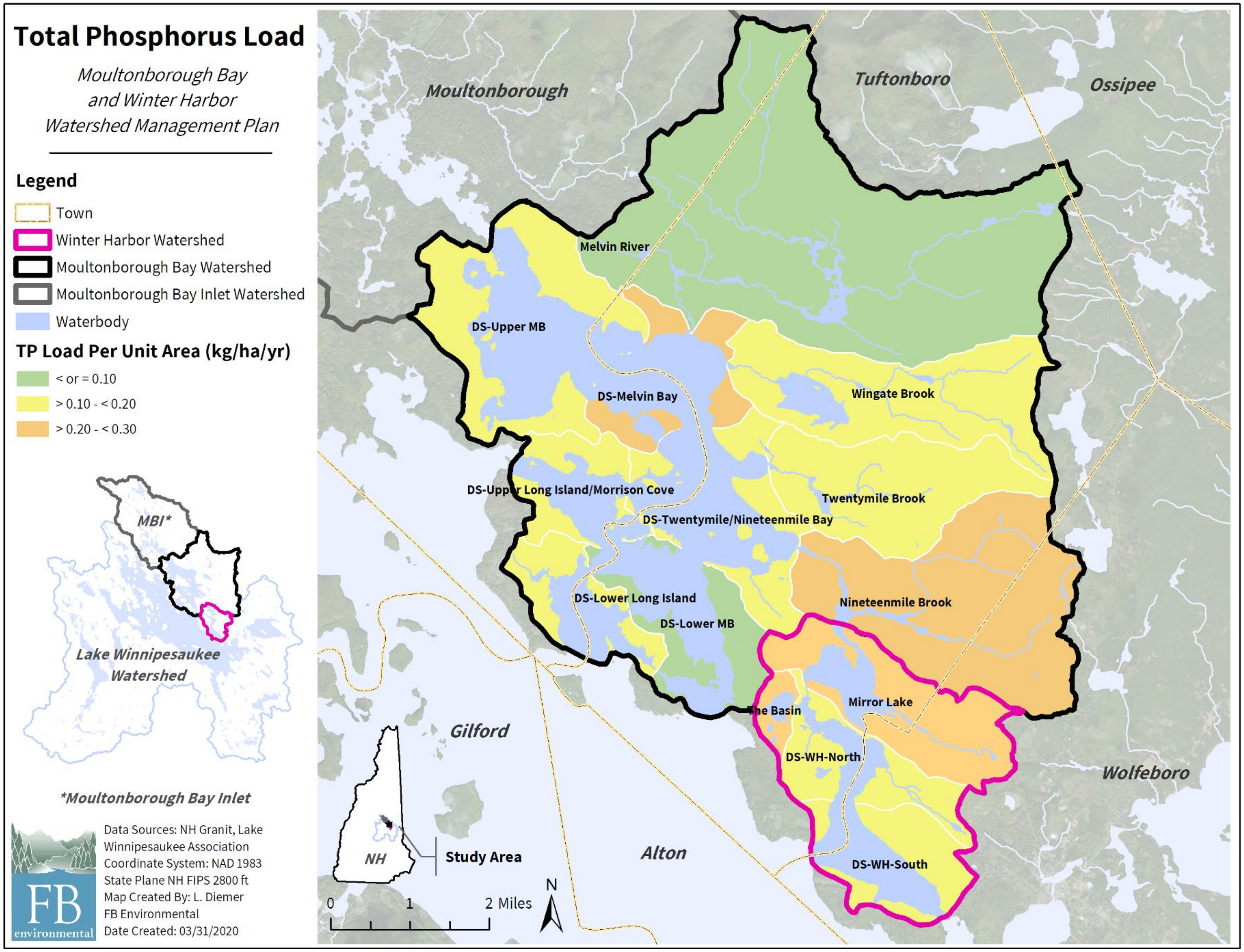

FIGURE 8. Map of current total phosphorus load per unit area (kg/ha/yr) for each sub-watershed in the Moultonborough Bay and Winter Harbor watersheds. The Basin and Mirror Lake sub-watersheds were included as separate calculations different from the values presented in Table 4 (see explanation in caption).

CONCLUSION

Based on model analysis of pre-development, current, and future water quality conditions, both Moultonborough Bay and Winter Harbor are 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 bays. 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 LID techniques on existing and new development.

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ATTACHMENT 1: Land cover File Update Workflow Record

LLRM Land Cover Update Workflow
4/23/2019 C. Bunyon
Project #447: Moultonborough-Winter Harbor WMP
Task #: 16, 18a, 18b, 19

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

ESRI World Imagery dated 4/16/17
Google Earth Imagery dated 6/21/18

Land cover file from NH GRANIT: nhlc01
ArcToolbox >Data Management Tools > Raster > Raster Processing > Clip
Extent clipped to "watershed_union"
File = "nhlc01_MBWH"
ArcToolbox >Conversion Tools > From Raster > Raster to Polygon
File = "nhlc01_MBWH_vector"
Geoprocessing > Clip
Extent clipped to "watershed_union"
File = "nhlc01_MB_WH_before"

Add text field to attribute table of "nhlc01_MB_WH_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 Moultonborough Bay – Winter Harbor 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
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_MBWH_before" > Rename "nhlc01_MBWH_after"
Import symbology to match "nhlc01_MBWHh_before" shapefile
Set display transparency to 70%

Data Management Tools > Sampling > Create Fishnet
Created 10x10 grid
Deleted grids not covering watershed area
Labeled quads #0-73

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 Emergent Wetland (PEM) → Forest 4: Wetland
Freshwater Pond (PUB) → Open 1: Water
Freshwater Forested/Shrub Wetland (PFO/PSS) → Forest 4: Wetland
Riverine (R5UBH) → Open 1: Water
Upland (U) → Removed
Geoprocessing > Union > Input " nhlc01_MBWH_after" and "nwi_clip" -> " nhlc01_MBWH_after_nwi "
Unchecked “Gaps Allowed”
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]
Relabel all former Open 1: Water or Forest 4: Wetland polygons to default Forest 3: Mixed

ADD STREAMS

Download National Hydrography Dataset from NH GRANIT
Clip to watershed -> “NHDFlowlines_MBWH”
Geoprocessing > Buffer > Input "NHDFlowlines_MBWH"; buffer = 15 ft -> "NHDFlowlines_MBWH_buff15ft.shp"
Geoprocessing > Union > Input " nhlc01_MBWH _after_nwi " and "NHDFlowlines_MBWH _buff15ft" -> "nhlc01_MBWH_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 > “MBWH _roads”
Geoprocessing > Buffer > Input " MBWH_roads"; buffer = 25 ft -> " MBWH_roads_buff25ft.shp"
Geoprocessing > Union > Input "nhlc01_MBWH_after_nwi_flow" and " MBWH_roads_buff25ft" -> "nhlc01_MBWH_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_MBWH_after_nwi_flow_rds”
Output: “nhlc01_MBWH_after_nwi_flow_rds _single”
ArcCatalog > Copy " nhlc01_MBWH_after_nwi_flow_rds _single" > Rename "MBWH_landcover_v1"

LAND COVER ANALYSIS

Step 1: Zoom to Quad #X; compare “MBWH_landcover_v1” to most recent aerials
Step 2: If changes needed, use 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”

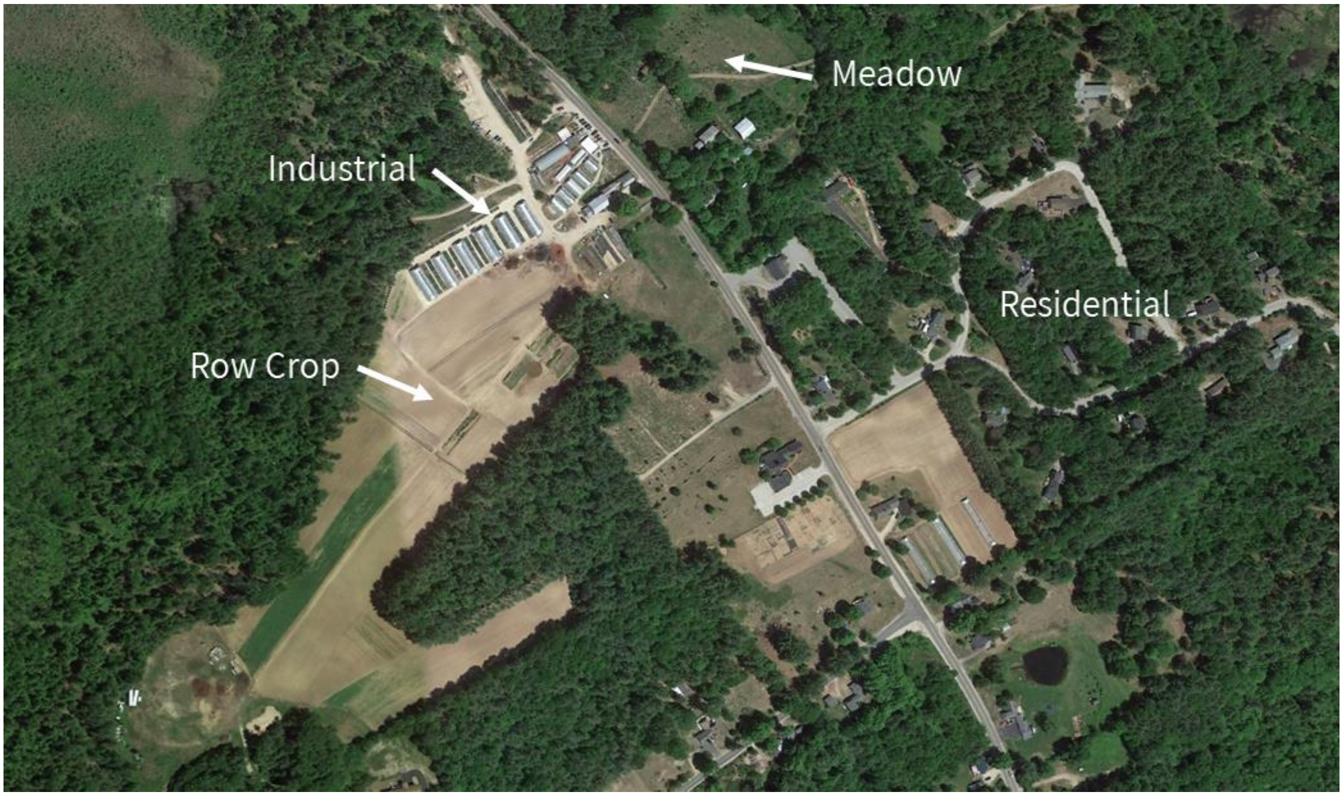
FINAL FILES

"MB_wshed_update"; “WH_wshed_update” = final watershed boundary

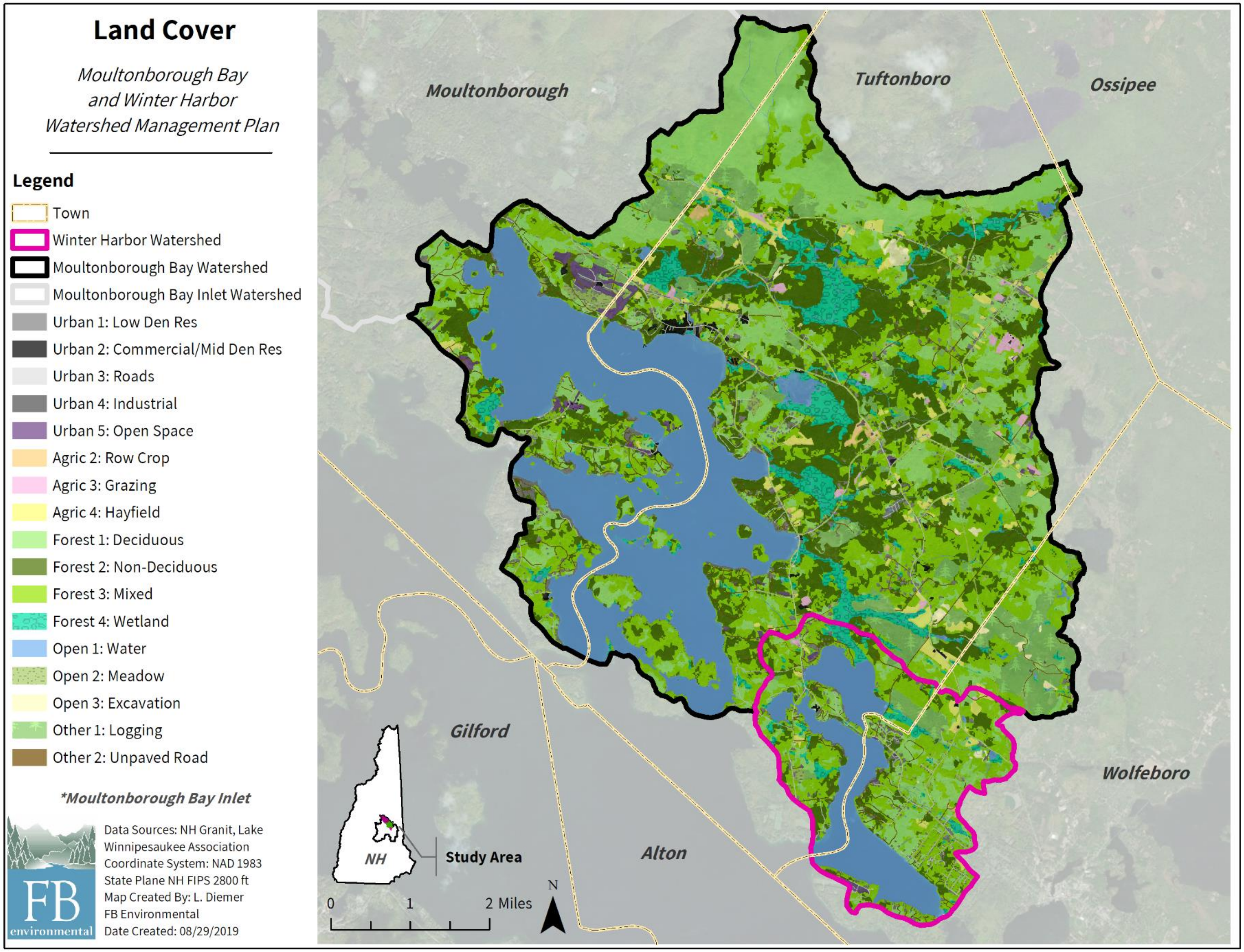
"MB_subwat_v5"; “WH_subwat” = final sub-watershed boundaries

"MBWH_landcover_v3" = final land cover

ATTACHMENT 2: Examples of Distinguishing Land Cover in Aerials



ATTACHMENT 3: Final Land Cover Map



ATTACHMENT 4: Land Cover by Sub-watershed

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

Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	Area (hectares)									
			DS-Lower Long Island	DS-Lower MB	DS-Melvin Bay	DS-Twentymile/ Nineteenmile Bay	DS-Upper Long Is./Morr. Cove	DS-Upper MB	Melvin River	Nineteenmile Brook	Twentymile Brook	Wingate Brook
Urban 1 (Low Dens Res)	0.79	0.010	17.7	8.0	22.5	31.5	37.3	38.5	48.2	19.1	31.4	19.1
Urban 2 (Mid Den Res/Comm)	0.90	0.010	1.5	0.0	21.3	1.6	0.0	3.7	2.7	6.9	2.0	3.4
Urban 3 (Roads)	0.30	0.010	3.9	3.4	11.8	14.5	6.7	15.3	38.7	7.5	20.5	16.5
Urban 4 (Industrial)	0.90	0.010	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.3	1.9	1.8
Urban 5 (Mowed Fields)	0.60	0.010	0.0	3.4	8.8	3.6	0.0	55.8	10.8	0.3	2.9	2.5
Agric 1 (Cvr Crop)	0.00	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agric 2 (Row Crop)	0.37	0.010	0.0	0.0	0.0	0.0	0.0	0.1	10.8	0.2	3.0	12.3
Agric 3 (Grazing)	1.50	0.010	0.0	0.0	0.0	0.0	0.0	0.8	19.9	5.4	3.5	24.6
Agric 4 (Hayfield)	0.37	0.010	0.0	1.6	3.5	7.5	0.0	8.4	95.8	55.7	35.7	18.8
Forest 1 (Deciduous)	0.03	0.004	51.6	45.8	42.2	54.5	44.9	160.9	1266.1	161.2	100.8	223.4
Forest 2 (NonDeciduous)	0.03	0.004	28.7	79.2	63.9	93.3	55.8	179.4	748.6	258.2	289.8	326.5
Forest 3 (Mixed)	0.03	0.004	141.0	185.0	87.7	152.0	81.0	213.6	677.6	593.7	260.3	275.4
Forest 4 (Wetland)	0.03	0.004	10.5	11.9	6.1	7.8	2.4	26.6	263.0	105.5	83.4	101.0
Open 1 (Water)	0.01	0.004	0.0	0.0	0.0	0.0	0.0	0.0	54.5	20.3	8.5	52.5
Open 2 (Meadow)	0.20	0.004	0.0	0.2	4.2	2.6	2.9	33.9	40.4	10.9	5.2	10.9
Open 3 (Excavation)	0.80	0.010	0.0	0.0	0.1	0.0	0.0	0.9	23.4	20.2	1.9	0.6
Other 1 (Logging)	0.74	0.004	0.0	0.1	0.1	0.0	0.0	7.7	280.5	371.8	64.3	57.9
Other 2 (Unpaved Road)	0.83	0.010	6.6	7.8	8.5	17.2	10.8	29.1	20.0	25.5	5.8	10.1
		TOTAL	**261.6**	**346.2**	**280.8**	**386.2**	**241.7**	**774.9**	**3601.8**	**1664.6**	**921.0**	**1157.4**

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

Land Cover	Runoff P export coefficient used	Baseflow P export coefficient used	Area (hectares)		
			The Basin	DS-Winter Harbor North	DS-Winter Harbor South
Urban 1 (Low Dens Res)	0.79	0.010	6.0	28.0	24.6
Urban 2 (Mid Den Res/Comm)	0.90	0.010	0.0	1.2	0.0
Urban 3 (Roads)	0.30	0.010	3.3	15.3	20.8
Urban 4 (Industrial)	0.90	0.010	0.0	0.0	0.0
Urban 5 (Mowed Fields)	0.60	0.010	0.0	2.6	6.2
Agric 1 (Cvr Crop)	0.00	0.000	0.0	0.0	0.0
Agric 2 (Row Crop)	0.37	0.010	0.0	2.3	0.0
Agric 3 (Grazing)	1.50	0.010	0.0	0.3	0.0
Agric 4 (Hayfield)	0.37	0.010	0.0	4.1	5.2
Forest 1 (Deciduous)	0.03	0.004	15.7	90.7	68.0
Forest 2 (NonDeciduous)	0.03	0.004	12.5	38.4	45.8
Forest 3 (Mixed)	0.03	0.004	39.5	165.6	152.3
Forest 4 (Wetland)	0.03	0.004	6.1	21.7	3.0
Open 1 (Water)	0.01	0.004	0.0	0.0	0.0
Open 2 (Meadow)	0.20	0.004	0.0	6.4	0.0
Open 3 (Excavation)	0.80	0.010	0.1	0.4	0.7
Other 1 (Logging)	0.74	0.004	1.2	3.6	0.9
Other 2 (Unpaved Road)	0.83	0.010	0.7	13.7	12.9
		TOTAL	**85.1**	**394.2**	**340.3**

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-watershed. 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-watershed 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-watershed. A total of 0.24-0.36 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-watershed, 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 and loads from exchange with the Broads, and Mirror Lake. We assumed a similar magnitude increase in future loading from these sources as compared to the increase in future total load to the lake.
7. Used MBI model results for future development scenario to update MBI point source load.
8. Roughly matched outflow TP to predicted in-lake TP.
9. Kept all else the same.