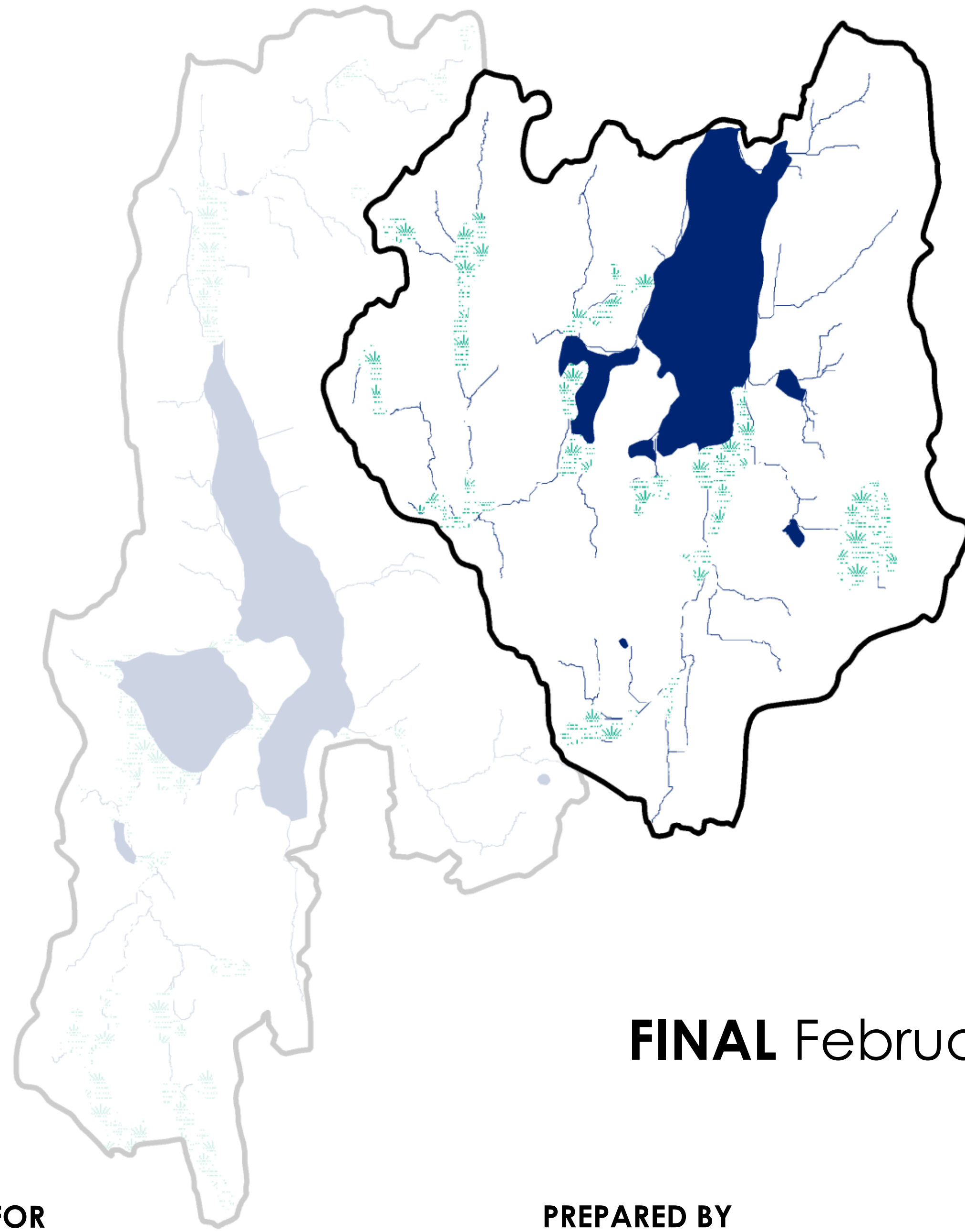
ADAMS POND

LAKE LOADING RESPONSE MODEL



FINAL February 2018

PREPARED FOR

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TABLE OF CONTENTS

INTRODUCTION

The purpose of this report is to provide results from the Lake Loading Response Model (LLRM) developed for Adams Pond. 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 requires detailed and accurate information about the waterbody, including the extent and number of sub-basins draining to the lake, the type and area of land covers within those sub-basins, water quality data for the deep spot and tributary outlets, lake volume, septic system loading estimates, and more.

The following describes the process by which these critical inputs were determined and input to the model using available resources and GIS modeling, and presents in-lake annual average predictions of total phosphorus, chlorophyll-a, and Secchi disk transparency. The outcome of this model can be used to identify current and future pollution sources, estimate pollution limits and water quality goals, and guide watershed improvement projects.

WATERSHED AND SUB-BASIN DELINEATIONS

Watershed and tributary drainage basin (sub-basin) boundaries are needed to determine both the amount of water flowing into the lake and the area of different land cover types contributing to nutrient loading. The Boothbay Region Water District (BRWD) provided FB Environmental Associates (FBE) with GIS files created by Wright-Pierce Engineering. These files included modeled sub-basin boundaries, watershed boundaries for both Knickerbocker Lake and Adams Pond, and modeled stream flowlines. FBE used 2-foot contour data developed from LiDAR imagery, as well as the modeled stream flowlines, to manually confirm the modeled sub-basin boundary delineations, some of which were manually snapped to the watershed boundary. FBE performed ground-truthing in the watershed to identify flow directions, especially in areas where stormwater systems redirected flows. The following describes changes to the original files (Figure 1):

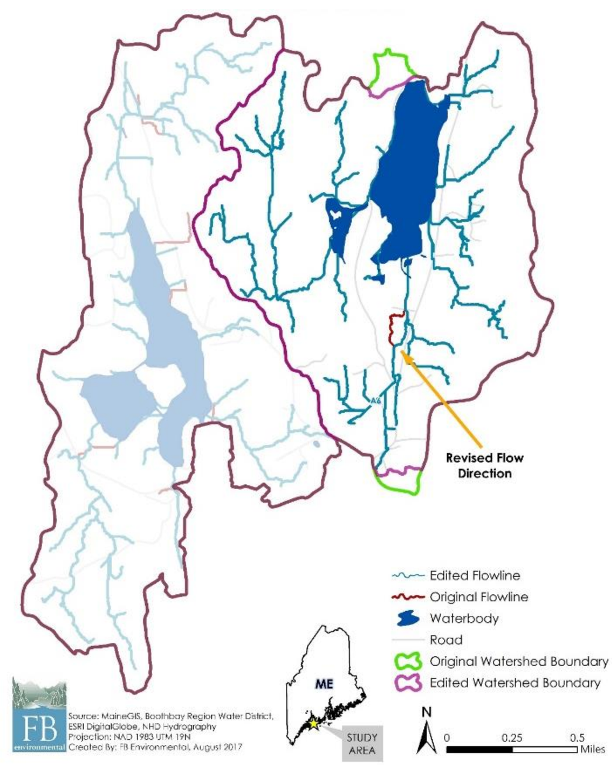


FIGURE 1. Comparison between "original" modeled stream flowlines and watershed files developed by Wright-Pierce Engineering and "edited" stream flowlines and watershed files ground-truthed and updated by FBE, BRWD, and STI. Updated flowlines were estimated.

- A section of land north of Adams Pond was removed from the watershed due to topographic assessment of 2-foot LiDAR imagery and ground-truthing.
- A section of land at the southern edge of the watershed was removed due to water re-routing from new development for the

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

Boothbay Harbor Country Club. These changes were supplied by Sebago Technics, Inc. (STI).

- Stream flowlines were shifted east to cross under the entrance to the Boothbay Fire Station instead of flowing around the west side of Big Al's Self Storage and the fire station. Stream crossings at key locations were confirmed in the field by FBE and reviewed by BRWD.
- Stream flowlines from a culvert crossing under Route 27 located just north of Boothbay Center and south of a funeral home parking lot were added based on comments from BRWD. Not noted on map (Figure 1).
- Direct drainage was incorporated to the sub-basin file and confirmed in the field. Attention was given to culvert crossings along Route 27. Boundaries near sub-basin outlets were manually updated based on ground-truthing.

The final sub-basin delineation is shown in Figure 2.

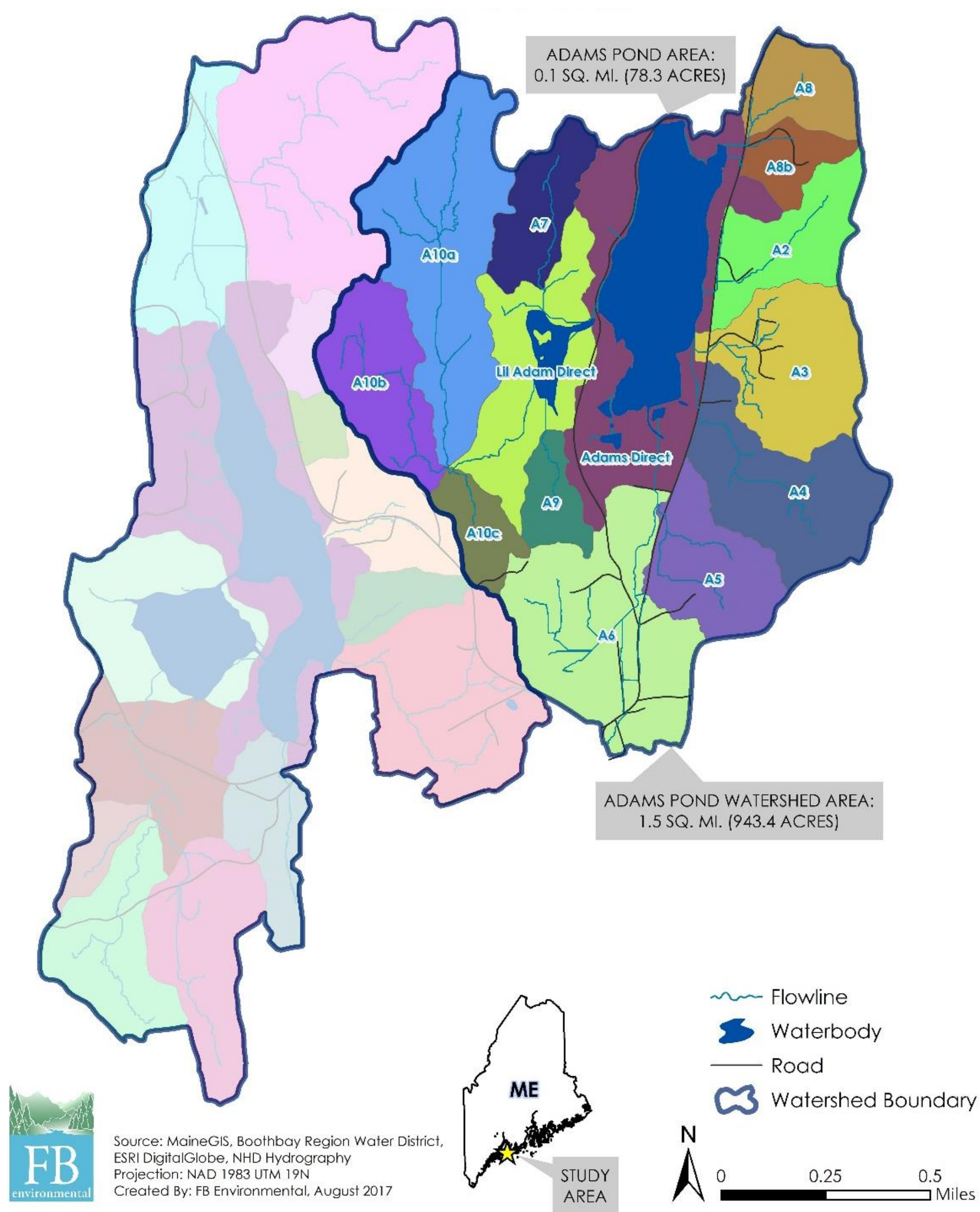


FIGURE 2. Final sub-basin boundaries for the Adams Pond watershed. The 14 sub-basins are shown in various contrasting colors and are labeled in blue with white shadowing.

LAND COVER UPDATE

Land cover is the essential element in determining how much phosphorus is contributing to a lake via stormwater runoff and baseflow. A significant amount of time went into reviewing and refining the land cover data. The 2004 Maine Landcover Database (MELCD) accessed from the Maine Office of GIS was used as a baseline for editing. First, the MELCD categories were plugged 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.

2015 NAIP aerials from USDA NRCS Geospatial Data Gateway were compared to Google Earth satellite images as recent as 5/9/2016 for major land cover changes in each quad. If discrepancies between the aerials and the MELCD 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. Land cover was reviewed and further refined based on feedback from BRWD. FBE confirmed trouble land cover areas in the field.

A few assumptions or actions were made during this process:

- Default for forested land cover was "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; BRWD helped to distinguish hayfields from private meadows ("Open 2: Meadow") or extensive lawns ("Urban 5: Open Space"); private meadows were mowed once per year while lawns or open space areas were mowed more than once per year
- Residential or commercial lawns, cemeteries, and athletic fields were labeled as "Urban 5: Open Space"
- Shrubby areas that were natural or may have been the result of a logging operation, but were regenerating were labeled as "Forest 5: Scrub-Shrub"
- Major bare soil areas 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"; a new category "Other 1: Freshwater Emergent Wetlands" was added due to significant coverage of this wetland type in the watershed
- Unpaved roads from the Maine 911 roads layer were added as "Other 1: Unpaved Roads"

The resulting updated land cover file is a more accurate representation of current land cover within the Adams Pond watershed. The most significant changes to land cover were the addition of agricultural areas and open space (lawns) and the refinement of developed areas (refer to Figure 3 for zoomed-in examples of "before" and "after" modifications). The final land cover is shown in Figure 4.

Agricultural and developed land were checked carefully since modeling coefficients (i.e., phosphorus export) are generally higher for these land cover types. Aerials were checked thoroughly for each major agricultural or developed area to distinguish between hayfields, grazing/pasture, lawns, and private meadows. Refer to Attachment 2 for examples of how some land cover categories were distinguished in the watershed.

Within the LLRM, an export coefficient is assigned to each land cover to represent typical concentrations of phosphorus in runoff and baseflow from those land cover types (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 to the lake directly or to tributary streams. 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, 2001 East Pond TMDL Report, Reckhow et al. 1980, Hutchinson Environmental Sciences Ltd 2014, and Schloss and Connor 2000, among others. 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 about 13% of the watershed and contribute 71% of the total phosphorus watershed load to Adams Pond.

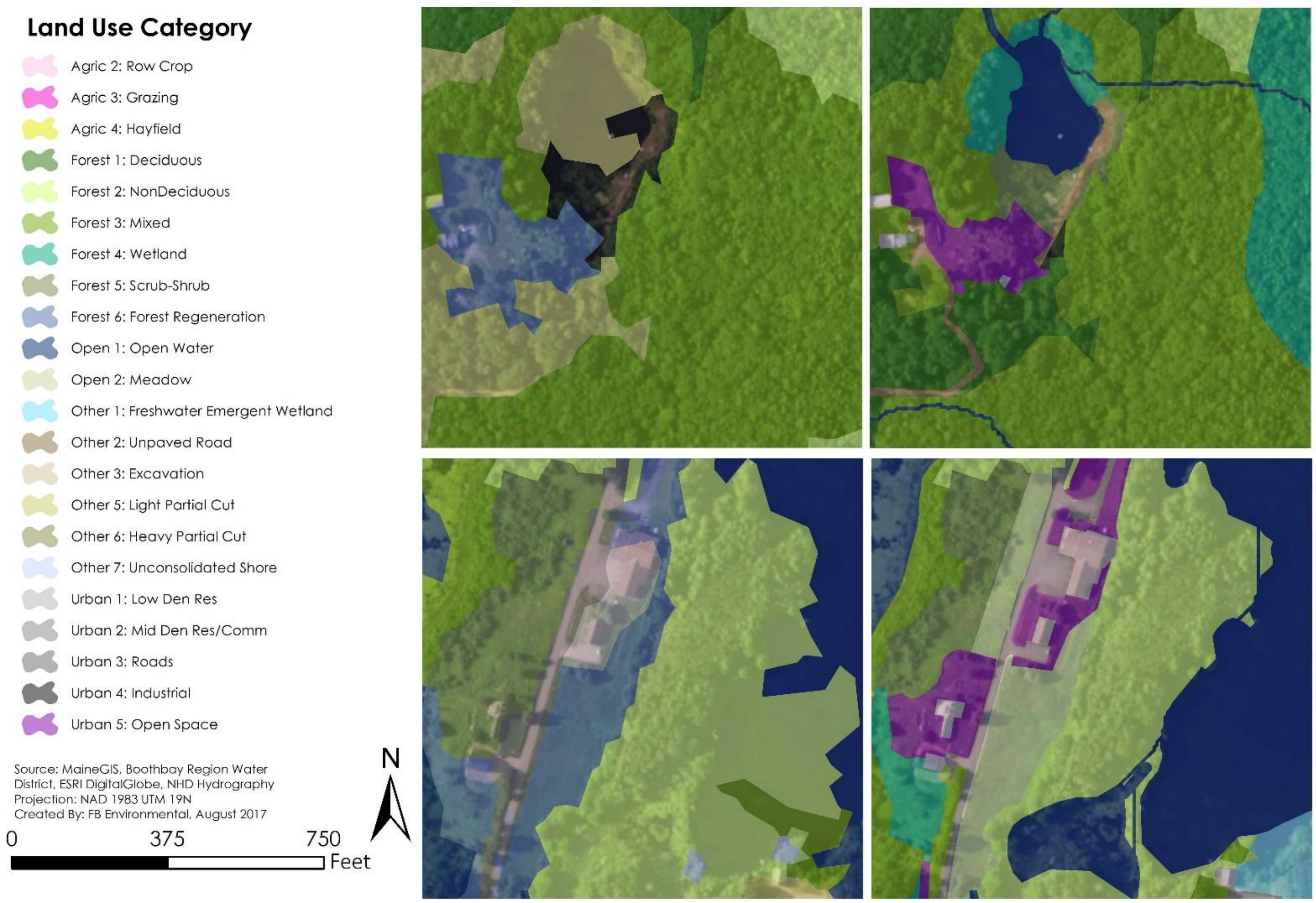


FIGURE 3. Examples of "before" and "after" land cover file modifications for the Adams Pond watershed for developed areas.

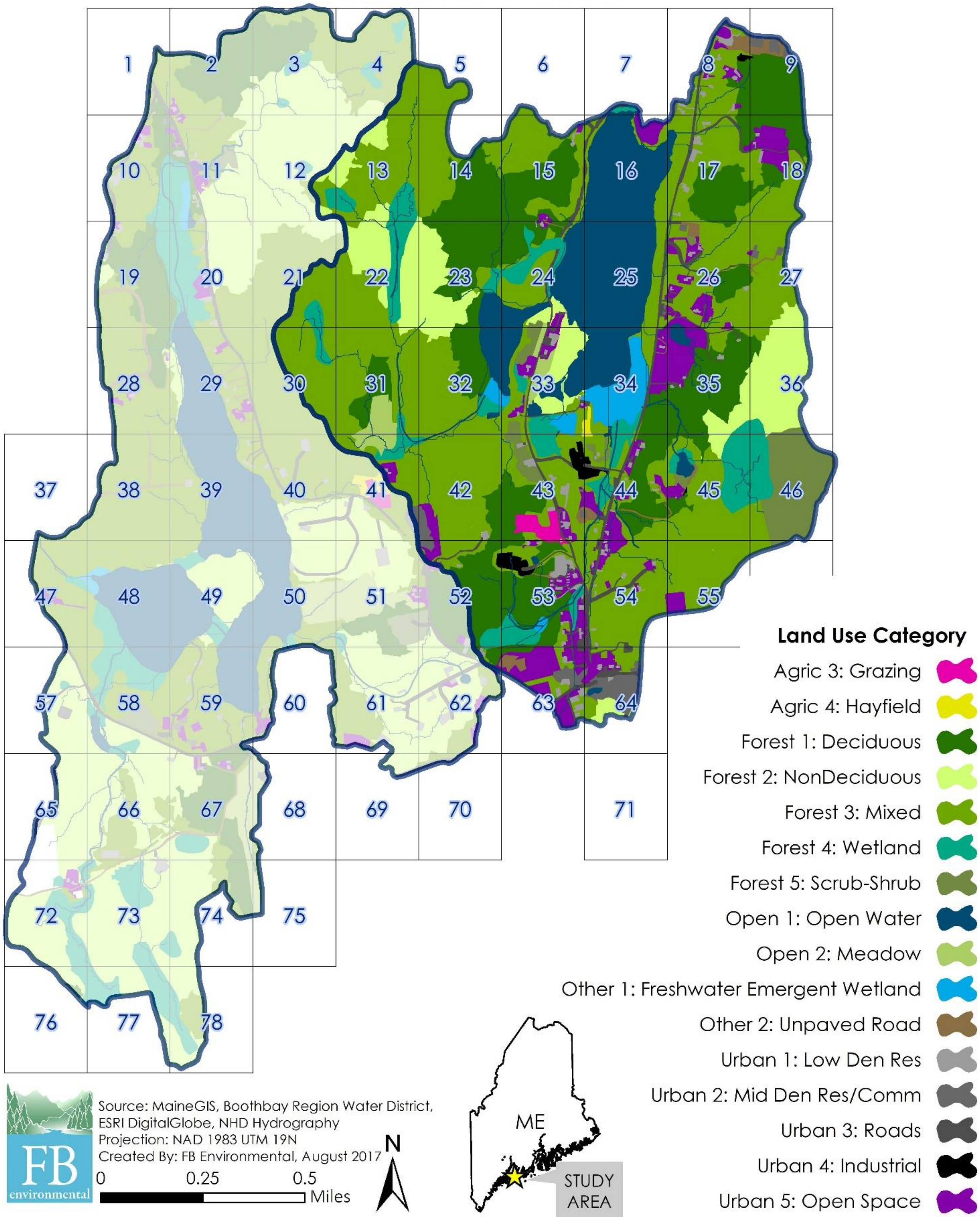


FIGURE 4. 2004 Maine Land Cover Database (MLCD) data with updated LLRM land cover categories. Notable differences include refined Urban 1 and 2 category delineations, overlay of new Other 1: Freshwater Emergent Wetland and Other 2: Unpaved Roads categories, and refinement of hayfield, grazing, lawn, and meadow areas. Quads 1-78 split the watershed into manageable sections for review.

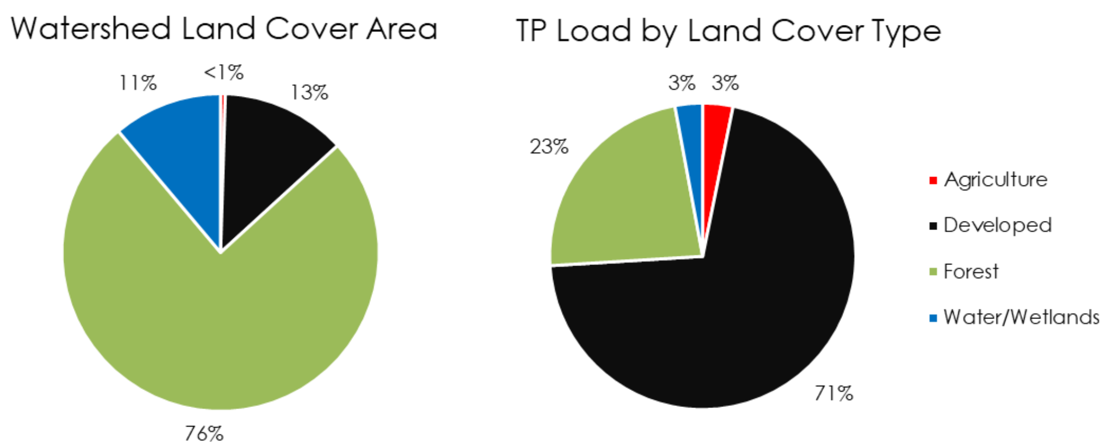


FIGURE 5. Watershed land cover area by general category (developed, agriculture, forest, and water/wetlands) and total phosphorus (TP) load by general land cover type. This shows that although developed areas cover 13% of the watershed, these areas are contributing 71% of the TP load to Adams Pond.

OTHER MAJOR LLRM INPUTS

The following presents a brief outline of other variable sources and assumptions input to the model:

- Annual precipitation data were obtained from the BRWD Water Treatment Plant weather station (Davis Vantage Pro 2, 43.889285, -69.634216). The average annual precipitation totals from 2008-2016 were input to the model (43.3 in or 1.1 m).
- Lake volume and area estimates were obtained from the BRWD bathymetry shapefile. The lake volume estimate from the BRWD file was 33% higher than the NHD bathymetry shapefile obtained from the Maine Office of GIS (based on sounding depths taken on 10/13/2011); the reason for this large difference was unclear, but the BRWD file was assumed to be more accurate. The lake surface area estimate from the BRWD file was within 1.8% difference of the NHD file.
- Septic system data were obtained from a Tanks_Septic.shp file given by Wright Pierce Engineering. The file contained survey information collected by BRWD. Points were selected by location within 250 feet of all water, including the pond, streams, and wetlands. Data were further reviewed by BRWD for year-round or seasonal status and annual water usage.
- Water quality data were obtained from the BRWD and Maine DEP. The model was calibrated using tributary and lake samples taken between 2010 and 2017 (recent 10 years, no data collected from 2008-2009). Sites were only included if they were a relatively close match to the outlet of a sub-basin used in the model. Data were summarized by day, then month, then all data to obtain median/mean water quality summaries for total phosphorus, chlorophyll-a, and Secchi Disk Transparency.
- Assumed 10 waterfowl (0.3 per hectare) were contributing to the phosphorus load for half the 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.
- Annual trout stocking data were obtained by the BRWD from the Maine Department of Inland Fisheries & Wildlife. The average annual mass of fish added to Adams Pond from 2007-2016 was used to estimate the mass of additional phosphorus that may be added to the system. This equated to a relatively insignificant amount.
- The water volume and mass of phosphorus extracted from Adams Pond for drinking water use was

calculated and input to the model. Water volume was based on 2016 withdrawal estimates from Adams Pond, provided by the BRWD. Mass of phosphorus was based on three raw water total phosphorus sample results in 2017 multiplied by the 2016 water volume withdrawal. Water volume and mass of phosphorus extracted was further refined (reduced) by accounting for recycled drinking water used by residences within the watershed (assuming that water returns to Adams Pond via groundwater). It was determined that only 0.45% of extracted water is recycled back to the system. The mass of phosphorus extracted was again refined (reduced) by also accounting for the loss of phosphorus during drinking water treatment (finish water total phosphorus was significantly less than raw water total phosphorus). These refinements were very minor and did not impact the overall model results. The water load from septic systems was also adjusted for those residences using water from Adams Pond for part of the year.

- Internal loading estimates were derived from dissolved oxygen and temperature profiles taken at the deep spot of Adams Pond from 2010-2017 (to determine average annual duration and depth of anoxia or <1 ppm) and epilimnion/hypolimnion total phosphorus data taken at the deep spot of Adams Pond from 2001-2006 (to determine average difference between surface and bottom phosphorus concentrations). Bottom total phosphorus samples were not collected any more recently at Adams Pond. These estimates, along with anoxic volume and surface area, helped determine rate of release and mass of internal phosphorus loading per year. An alternative method of calculating internal phosphorus loading was deemed inappropriate due to lack of profile data during post-turnover.

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 the case of the Adams Pond LLRM, the in-stream and in-lake phosphorus concentrations were used as guideposts, and phosphorus attenuation factors in the tributary drainages, were adjusted to better match the monitoring data (if adequate data in recent years were available; Table 1). Future monitoring can be designed to reduce the uncertainty encountered in modeling and help assess changes made during calibration.

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

Sub-Basin	Water Attenuation Factor	Phos. Attenuation Factor	Reasoning
Adams Direct	0.90	0.95	Direct drainage with little time for infiltration
Little Adams Direct	0.90	0.65	Moderate wetlands; some settling
A2	0.90	0.85	Stream processes; some settling
A3	0.90	0.85	Stream processes; some settling
A4	0.90	0.65	Moderate wetlands; some settling
A5	0.90	0.85	Stream processes; some settling
A6	0.90	0.50	Several wetlands; some settling
A7	0.90	0.90	Default (small amount of removal by infiltration)
A8	0.90	0.85	Stream processes; some settling
A8b	0.90	0.85	Stream processes; some settling
A9	0.90	0.90	Default (small amount of removal by infiltration)
A10a	0.90	0.65	Moderate wetlands; some settling
A10b	0.90	0.65	Moderate wetlands; some settling
A10c	0.90	0.85	Stream processes; some settling

LIMITATIONS TO THE MODEL

There were several limitations to the model based on lack of multi-year data; literature values and best professional judgement were used in place of measured data, wherever appropriate. Acknowledging and understanding these 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. The model results should be considered draft or interim until more information is collected and input to the model. Because the LLRM incorporates specific waterbody information and is flexible in applying new data inputs (i.e., drinking water withdrawals), it is a powerful tool that predicts in-lake total phosphorus concentrations with a high degree of confidence; however, model confidence can be increased with more data. The following lists specific limitations to the model:

- **Data were only available for 2017 for sub-basins.** Most tributary data were collected in 2017; discharge was determined at several sites for many sample events. Comparing total discharge to the flushing rate of the lake outlet (AP0) showed that the data were skewed to high flow rate times of year. This was carefully considered when determining attenuation values and overall model calibration. To better represent annual average concentrations in tributaries, samples must be collected under a variety of flow conditions and across several years. Some areas of the watershed have undergone significant development (e.g., Boothbay Harbor Country Club) in recent years, which may be reflected in 2017 sub-basin data, but not necessarily in recent, 10-year whole lake averages. These conditions were also carefully considered when determining attenuation values and overall model calibration.
- **Data were not available for all sub-basins.** More data are needed to effectively calibrate the model to known observations for some tributary sub-basins. Until more data are available, we had to make assumptions based on land cover or other contributing factors. Discharge estimates should also continue to be made at each site, whenever feasible.
- **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 waves or physical disturbance of the sediment. While dissolved oxygen and temperature profiles were available for most years at Adams Pond, extrapolation of the depth of anoxia was necessary to inform the model. More frequent profiles and sampling of the epilimnion and hypolimnion during late season (August-November) conditions would improve the model.
- **Septic system loading estimates were based on default literature values.** BRWD supplied survey data with an inventory of septic systems in the watershed, which serves as a great resource that should be updated periodically for future model runs. 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 estimates.** In the future, a more precise bird census would help improve the model loading estimates.
- **Land cover export coefficients were estimates.** Literature values and best professional judgement were used in evaluating and selecting appropriate land cover export coefficients for Adams Pond. 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.
- **Average of empirical formulas for predicting TP concentration limited to four of six available models.** Two of the empirical formulas for predicting in-lake TP were predicting in-lake concentrations much higher than those observed in Adams Pond. This may be because the data set used to derive these formulae were collected from more nutrient-rich lakes. Given this, we selected the four formulas

predicting the lowest in-lake TP (Larsen-Mercier 1976, Kirchner-Dillon 1975, Reckhow General 1977, and Nurnberg 1998) for averaging.

- **Assumed median standard water yield and slightly more water attenuation than standard factor.** Water can be lost through evapotranspiration, deep groundwater, and wetlands. We generally expect at least a 5% loss (0.95) for each tributary. Larger losses (<0.95) can be expected with lower gradient or wetland-dominated landscapes. In this case, we assumed a water attenuation factor of 0.90 due to some minor additional loss to wetlands and deep groundwater. See Table 1.
- **Assumed standard factors for P attenuation factors unless adequate data available to calibrate model.** The model uses a default of 0.90 to represent a small amount of P removal by infiltration or uptake processes. Additional infiltration, filtration, detention, and uptake will lower the attenuation value, such as sub-basins dominated by moderate/small ponds or wetlands (0.65-0.75), larger ponds or wetlands (0.5), or channel processes that favor uptake (0.85). For this model, small sub-basins or the direct shoreline were given higher P attenuation factors to represent little removal of P. Low-lying areas and sub-basins with significant wetlands and waterbodies were assigned a lower P attenuation factor.
- **High or low modeled TP compared to measured TP in select sub-basins.** Two sub-basins with real data (A7 and A9) had low modeled TP compared to measured TP, while two other sub-basins (A8 and A8b) had high modeled TP compared to measured TP. These represent discrepancies in the coefficients assigned to certain land cover types in these four sub-basins. Further investigation is needed to determine where additional phosphorus may be coming from (in the case of low modeled TP) or what coefficients may be too high (in the case of high modeled TP). It should also be noted that measured data are limited to only one year; more data are needed to determine better coefficients and attenuation factors for the Adams Pond watershed.

RESULTS

CURRENT LOAD ESTIMATION

The A6 sub-basin and direct shoreline area to Adams Pond had the highest phosphorus export by total mass, while the A8 and A10c sub-basins had the highest phosphorus export per hectare (Table 2, Figure 6). Drainage areas directly adjacent to waterbodies do not have adequate treatment time and are usually targeted for development, thus increasing the possibility for greater phosphorus export. The other sub-basins showed relatively smaller amounts of phosphorus mass exported per year (< 2.4 kg/yr). Sub-basins with moderately-high phosphorus mass exported by area (> 0.1 kg/ha/yr) generally had more development at or more than 24% of the drainage (e.g., A8, A10c, A8b, A6). A few sub-basins did not have predicted phosphorus concentrations that matched well with measured phosphorus concentrations (e.g., A7, A8b, and A9). More data are needed to better adjust the coefficients and attenuation factors used for those sub-basins before the predicted phosphorus export can be compared to other sub-basins.

TABLE 2. Summary of land area, water flow, and total phosphorus (TP) loading by sub-basin. Sampling site AS10 was used as a reality check for sub-basin A10c, located downstream of sub-basins A10a, A10b, and A10c. Sub-basins A10a and A10b are largely forested, while sub-basin A10c is more developed and likely contributes more to the elevated phosphorus measured at site AS10.

Watershed	Watershed Loads					
	Land Area (ha)	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)
Adams Pond Watershed	350.6	2,012,602	0.017		33	0.09
Adams Direct	40.5	225,107	0.030		4.0	0.10
Little Adams Direct	31.0	171,315	0.006		0.9	0.03
A2	19.6	116,020	0.019	0.014	2.2	0.11
A3	29.9	175,222	0.013	0.013	2.3	0.08
A4	32.7	184,715	0.009	0.009	1.7	0.05

	Watershed Loads					
Watershed	Land Area (ha)	Water Flow (m³/year)	Calculated P Concentration (mg/L)	Measured P Concentration (mg/L)*	P mass (kg/year)	P mass by area (kg/ha/year)
A5	21.8	127,878	0.019	0.018	2.4	0.11
A6	48.3	274,416	0.024	0.020	6.5	0.13
A7	15.1	89,252	0.005	0.016	0.5	0.03
A8	13.4	77,335	0.031		2.4	0.18
A8b	8.4	49,060	0.024	0.009	1.2	0.14
A9	8.4	49,357	0.012	0.022	0.6	0.07
A10a	48.6	280,525	0.004		1.1	0.02
A10b	23.6	137,479	0.004		0.6	0.02
A10c	9.4	54,921	0.028	0.026	1.6	0.17

** Median TP, 2010-2017 (as available)*

NOTE*: Totals are NOT summed across sub-basins. As water passes through sub-basins, both water and phosphorus are attenuated (or lost via uptake, infiltration, etc.), making the total load to the lake* ***less*** *than the sum of the individual loads.*

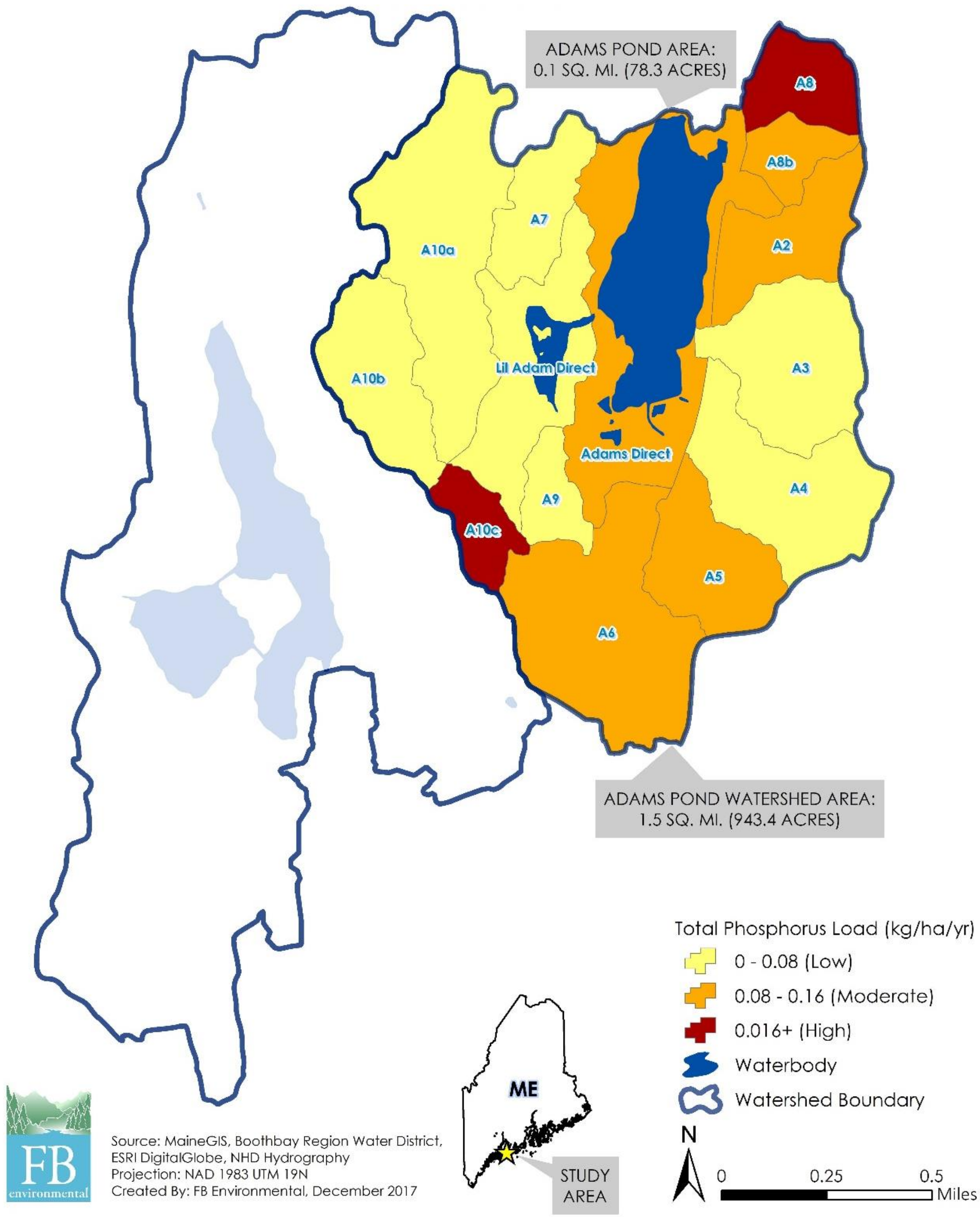


FIGURE 6. Total phosphorus mass loading (kg/ha/yr) for sub-basins to Adams Pond.

Overall, watershed runoff and baseflow (65%) was the largest loading contribution across all sources, followed by septic systems (16%), atmospheric deposition (13%), waterfowl (2%) and internal loading (4%) (Table 3; Figure 7).

The model predicted in-lake phosphorus within 2% (relative percent difference) of observed median total phosphorus (Table 4). The model also predicted about 10% (higher, worse) difference for observed mean chlorophyll-a and about 42% (lower, worse) difference for observed mean water clarity (Secchi Disk Transparency) (Table 4). This suggests that in-lake processes may be assimilating phosphorus more efficiently than equations predict or algae growth is limited by another element. It is important to note that the LLRM does not fully account for all the biogeochemical processes occurring within the lake that contribute to the overall water quality condition. 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.

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 conditions (e.g., what in-lake phosphorus concentration was prior to human development or the best possible water quality for the lake). Refer to Attachment 4 for details on methodology.

Pre-development estimation showed that total phosphorus loading increased by 264%, from 14 kg/yr prior to European settlement to 51 kg/yr under current conditions (Table 3; Figure 7). These additional phosphorus sources are coming from development in the watershed (especially in the A6 and direct shoreline sub-basins), septic systems, atmospheric dust, and internal loading. Water quality was estimated to be excellent with very low phosphorus and chlorophyll-a concentrations and deep water clarity (Table 4; Figure 8; Table 5).

FUTURE LOAD ESTIMATION (BASE SCENARIO)

We can also manipulate land cover and other factor loadings to estimate future loading conditions (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 5 and the Build-out Analysis Report for details on methodology. Note: the future loading model assumed a 10% increase in precipitation over the next century (NOAA Technical Report NESDIS 142-1, 2013), which improved in-lake phosphorus concentration by 1-2 ppb; however, 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 131%, from 51 kg/yr under current conditions to 118 kg/yr at full build-out under current zoning constraints (Table 3; Figure 7). These additional phosphorus sources are coming from more development in the watershed (especially in the sub-basins A3 and A10a that have large tracts of developable forests), more septic systems, greater atmospheric dust, and enhanced internal loading. The model predicted significantly higher (worse) phosphorus (25.1 ppb), higher (worse) chlorophyll-a (9.7 ppb), and shallower (worse) water clarity (2.0 m) compared to current conditions. At full build-out under current zoning (base scenario), Adams Pond would suffer from degraded water clarity and algae blooms. Any new increases in phosphorus to a lake can disrupt the ecological balance in favor of increased algae growth, resulting in degraded water clarity.

Adams Pond would not support its designated uses and would likely be listed as an impaired waterbody. While development will continue to expand throughout the watershed, 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).

FUTURE LOAD ESTIMATION (ALTERNATIVE SCENARIO #1)

The build-out analysis was re-run with proposed amendments to current zoning (refer to the Build-out Analysis Report). The proposed zoning amendments would create new zones within the watershed: Residential, Water Supply Protection, Boothbay Village Center, Boothbay Village Fringe, and Boothbay Village Mixed Use. A small portion of the Adams Pond watershed would also be in the Commercial Corridor and Manufacturing Business zones. These changes were incorporated to the model as Alternative Scenario #1. Changes were made to land cover, septic systems, and internal loading estimates only (based on differences in building number and placement in the watershed). All other variables and assumptions were kept the same as the base scenario for future loading.

Under future alternative scenario #1, some sub-basins decreased in the number of projected new buildings, while others increased, with a net total increase of 39 projected new buildings possible with the proposed zoning amendments (20 of which were within 250 feet of surface waters). Total phosphorus loading was estimated to be 8% higher, from 118 kg/yr under the future base scenario to 127 kg/yr under the future alternative scenario #1 (Table 3). The model predicted slightly higher (worse) phosphorus (27.0 ppb), higher (worse) chlorophyll-a (10.4 ppb), and shallower (worse) water clarity (1.8 m) compared to future base scenario (Table 4; Figure 8). The greatest increases in phosphorus watershed loading (from current conditions) would likely come from sub-basins A3, A4, A5, and A10a (Table 5).

FUTURE LOAD ESTIMATION (ALTERNATIVE SCENARIO #2)

The build-out analysis was re-run under current zoning constraints, but with large parcels of currently forested land nearest to Adams Pond put in conservation (164 acres placed in "hypothetical conservation" in addition to the 168 acres in existing conservation for a total of 332 acres or 35% of the watershed in conservation). These changes were incorporated to the model as Alternative Scenario #2. Changes were made to land cover, septic systems, and internal loading estimates only (based on differences in building number and placement in the watershed). All other variables and assumptions were kept the same as the base scenario for future loading under current zoning constraints.

Under future alternative scenario #2, sub-basins remained unchanged or decreased in the number of projected new buildings compared to the future base scenario, with a net total decrease of 87 projected new buildings possible with the hypothetical and existing conserved parcels (45 of which were within 250 feet of surface waters). Total phosphorus loading was estimated to be 15% lower, from 118 kg/yr under the future base scenario to 100 kg/yr under the future alternative scenario #2 (Table 3). The model predicted slightly lower (better) phosphorus (21.1 ppb), lower (better) chlorophyll-a (8.3 ppb), and deeper (better) water clarity (2.2 m) compared to future base scenario (Table 4; Figure 8). Sub-basins A2, A3, and A10a would still be most at risk for increased phosphorus loading (Table 5). Although future alternative scenario #2 results in better water quality compared to the future base scenario, Adams Pond would still suffer from degraded water clarity and algae blooms. Adams Pond would not support its designated uses and would likely be listed as an impaired waterbody. These results stress the importance of significant land conservation (greater than the 35% modeled here) in watersheds that drain to primary drinking water sources such as Adams Pond.

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

INPUT CATEGORY	PRE-DEV			CURRENT			FUTURE (BASE)			FUTURE (ALT1)			FUTURE (ALT2)		
	P (KG/YR)	%	WATER (CU.M/YR)	P (KG/YR)	%	WATER (CU.M/YR)	P (KG/YR)	%	WATER (CU.M/YR)	P (KG/YR)	%	WATER (CU.M/YR)	P (KG/ YR)	%	WATER (CU.M/YR)
ATMOSPHERIC DEPOSITION	3.5	26%	188,930	6.5	13%	188,930	9.7	8%	224,422	9.7	8%	224,422	9.7	10%	224,422
INTERNAL LOAD	0	0%	0	1.8	4%	0	3.9	3%	0	3.7	3%	0	3.4	3%	0
WATERFOWL LOAD	1	7%	0	1.0	2%	0	1.0	1%	0	1.0	1%	0	1.0	1%	0
SEPTIC SYSTEM LOAD	0	0%	0	8.3	16%	5,653	44.8	38%	35,337	49.6	39%	39,192	34.1	34%	26,663
WATERSHED LOAD	9.2	67%	2,024,365	33.4	65%	2,012,602	58.9	50%	2,196,703	62.7	49%	2,194,593	52.0	52%	2,201,534
TOTAL LOAD TO LAKE	**14**	**100%**	**2,213,295**	**51**	**100%**	**2,207,186**	**118**	**100%**	**2,456,462**	**127**	**100%**	**2,458,207**	**100**	**100%**	**2,452,620**
DRINKING WATER EXTRACTION				-4.8		-574,838	-4.8		-574,838	-4.8		-574,838	-4.8		-574,838

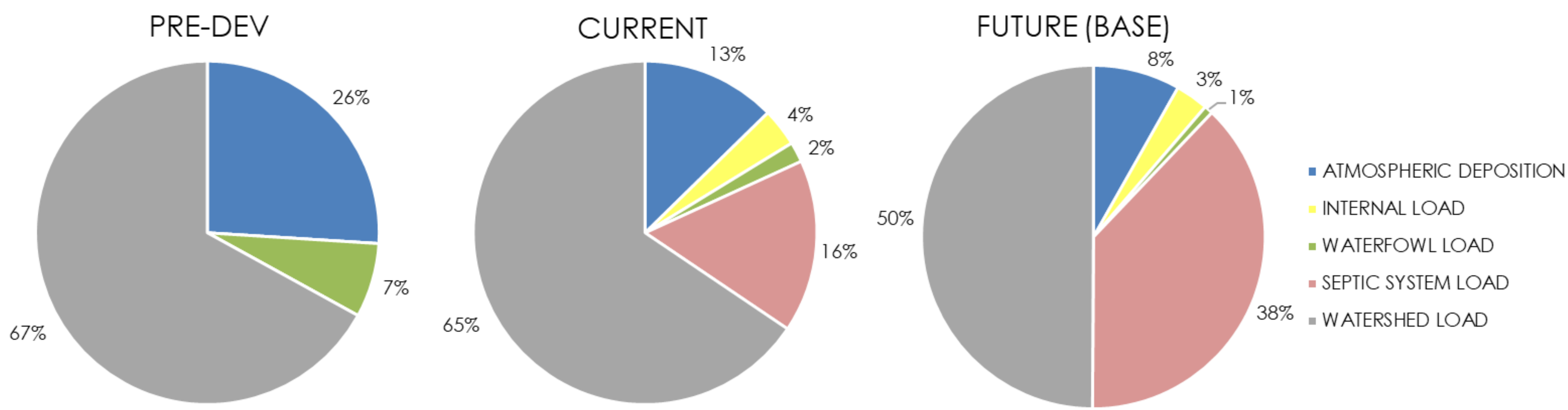


FIGURE 7. Percentage of total phosphorus (TP) loading (kg/yr) by source (atmospheric, internal loading, waterfowl, septic systems, watershed load).

TABLE 4. In-lake water quality predictions for Adams Pond.

Scenario	Median TP (ppb)*	Predicted Median TP (ppb)	Mean Chl-a (ppb)	Predicted Mean Chl-a (ppb)	Mean SDT (m)	Predicted Mean SDT (m)
Pre-Dev	--	2.8	--	1.3	--	10.6
Current	9.0 (10.8)	11.0	4.1	4.5	5.6	3.7
Future (Base)	--	25.1	--	9.7	--	2.0
Future (Alt 1)	--	27.0	--	10.4	--	1.8
Future (Alt 2)	--	21.1	--	8.3	--	2.2

**Median TP concentration of 9.0 represents existing in-lake epilimnion TP from observed data. Median TP concentration of 10.8 represents 20% greater than actual median values as the value used to calibrate the model. Most lake data are collected in summer when TP concentrations are typically lower than annual average concentrations for which the model predicts.*

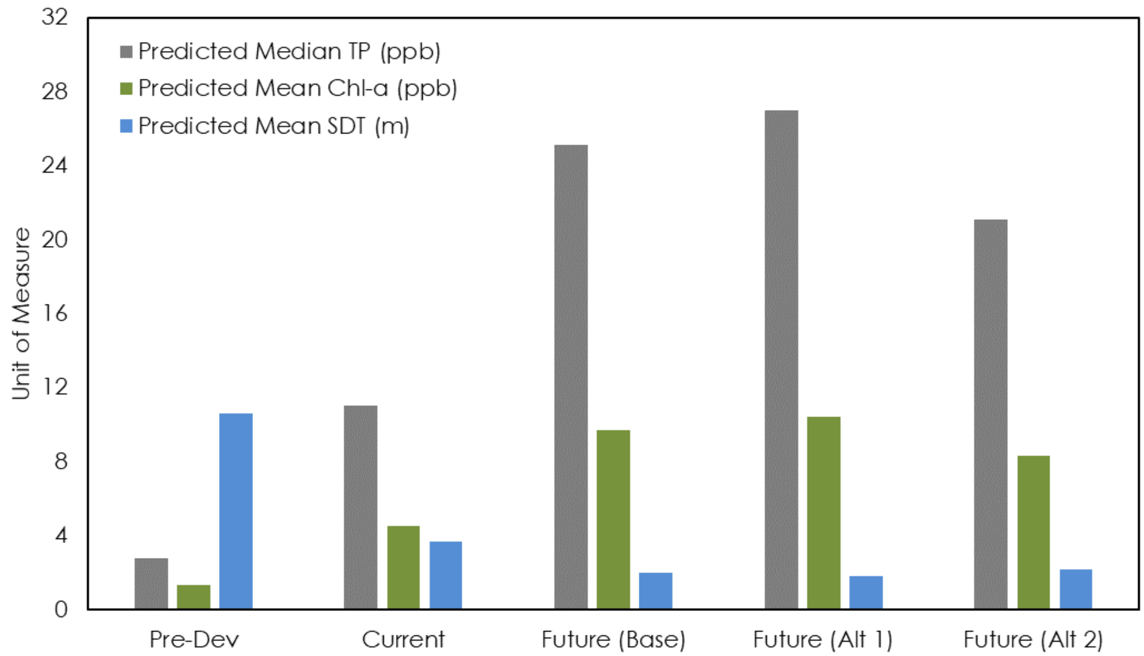


FIGURE 8. Predicted total phosphorus (TP), chlorophyll-a (Chl-a), and Secchi Disk Transparency (SDT) for pre-development, current, and future loading conditions to Adams Pond.

TABLE 5. Total phosphorus (TP) watershed loading summary by sub-basin.

Sub-Basin	Watershed Load				
	Pre-Dev	Current	Future (Base)	Future (Alt1)	Future (Alt2)
Adams Direct	1.2	4.0	4.8	4.5	4.8
Little Adams Direct	0.6	0.9	2.3	2.0	1.0
A2	0.6	2.2	4.5	4.4	4.5
A3	0.9	2.3	5.8	5.9	4.5
A4	0.7	1.7	4.7	4.9	3.3
A5	0.6	2.4	5.1	6.3	4.2
A6	0.8	6.5	7.4	8.5	7.4
A7	0.5	0.5	1.1	1.2	1.1
A8	0.4	2.4	3.9	3.8	3.9
A8b	0.2	1.2	2.4	2.4	2.4
A9	0.3	0.6	1.1	1.3	1.1
A10a	1.1	1.1	4.4	4.5	3.1
A10b	0.5	0.6	2.7	3.0	2.1
A10c	0.3	1.6	2.7	3.1	2.4

SUMMARY & RECOMMENDATIONS

Based on model analysis of pre-development, current, and future water quality conditions, Adams Pond is at great risk for water quality degradation from development under both current and proposed zoning constraints. The Maine DEP also identified Adams Pond as "Most at Risk from New Development" in Chapter 502 of the Maine Stormwater Law.

Given Adams Pond's use as a major public water supply to the area, it will be crucial to both maximize land conservation of intact forestland (e.g., running future alternative scenario #2 where 35% of the watershed was conserved still resulted in degraded water quality at full build-out) and consider zoning ordinance amendments that encourage low impact development techniques on existing and new development. The proposed zoning amendments (as shown in future alternative scenario #1) would likely degrade the future water quality of Adams Pond even further. As such, the proposed amendments are not protective enough to prevent a significant water quality decline of Adams Pond in the future.

The DEP currently classifies Adams Pond as a mesotrophic waterbody because it falls within the following ranges: 4-8 meters Secchi Disk Transparency, 4.5-20 ppb total phosphorus, and 1.5-7 ppb chlorophyll-a. Values above the maximum of these ranges would place Adams Pond in a higher trophic category (eutrophic) that experiences higher probabilities for severe algae blooms and inadequate drinking water supply. Setting a maximum desirable chlorophyll-a concentration at 7 ppb shows that a maximum of 10-11 ppb for in-lake total phosphorus would be acceptable to maintain water quality conditions favorable for aquatic health and drinking water supply (Figure 9). This leaves room for a 1-2 ppb increase in in-lake total phosphorus concentration in Adams Pond. This will be easily surpassed based on both current and proposed zoning as development continues throughout the watershed.

Recently, a large development in the Adams Pond watershed diverted acres of surface runoff to outside of the watershed to meet its DEP allowable phosphorus export for the project, effectively reducing the watershed size and the quantity of water reaching the lake. Although this mitigation technique reduced the amount of polluted runoff that enters the watershed, this approach also results in less water overall and a reduced flushing rate (that would increase residence time of pollutants) that would impair aquatic health and become unsustainable for meeting public water demand over time. Future zoning ordinance amendments should consider addressing this concern in the update.

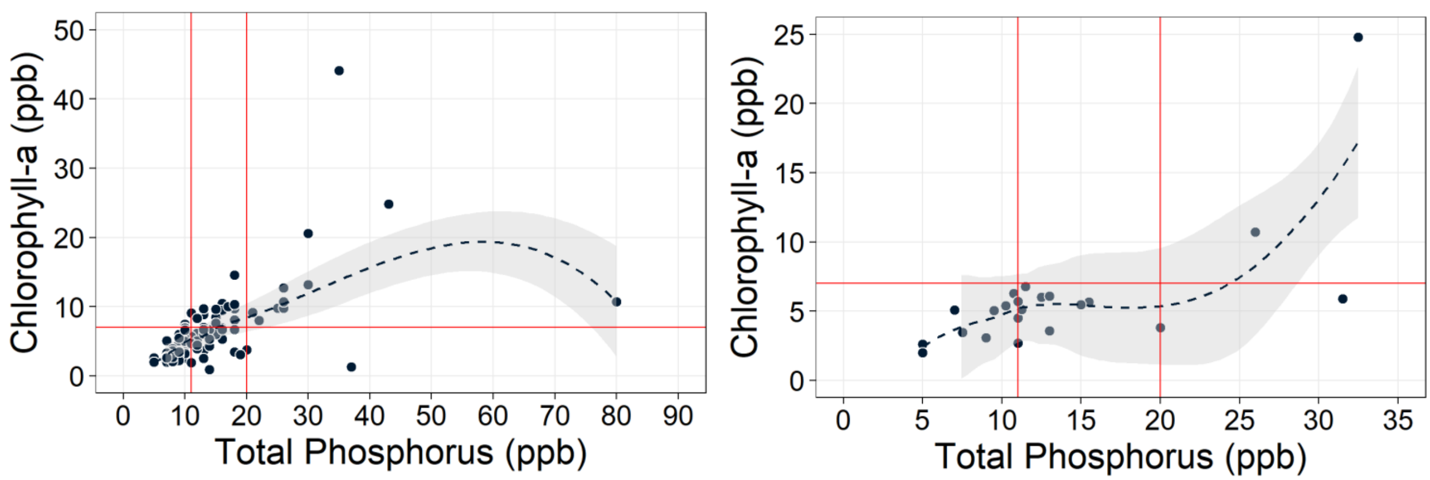


FIGURE 9. Chlorophyll-a (measure of algae) generally increases in response to increased in-lake total phosphorus concentration. Maximum limits for mesotrophic waterbodies are set at 7 ppb for chlorophyll-a and 20 ppb for total phosphorus, but the relationship between chlorophyll-a and total phosphorus in Adams Pond for all data (left panel) and yearly data (right panel) shows a possible threshold of chlorophyll-a response at 10-11 ppb total phosphorus.

ATTACHMENT 1: Land cover File Update Workflow Record

LLRM Land Cover Update Workflow
3/13/2017 M. Burns
Project #337: Boothbay LLRM & Buildout (Knickerbocker Lake and Adams Pond)

All data projected in NAD 1983 UTM Zone 19N

2015 NAIP Imagery (Quads 25,26,27,33,34,35 in Lincoln County)
From: https://datagateway.nrcs.usda.gov

Land cover file from Maine Office of GIS: MECLD_LandCover_2004.
Conversion Tools > From Raster > Raster to Polygon
Clipped land cover file to watershed: "KnickAdamsWshed".
File from Wright-Pierce Engineering.
Renamed file "lndcvr_KnickAdam_before".

Renamed land cover classes to match LLRM categories.

LLRM CAT/MELCD04 GRIDCODE
Urban 1 (Low Den Res) / 4
Urban 2 (Mid Den Res/Comm) / 2, 3
Urban 3 (Roads) / 16
Urban 5 (Open Space) / 5
Agric 2 (Row Crop) / 6
Agric 3 (Grazing) / 7
Agric 4 (Hayfield) / 8
Forest 1 (Deciduous) / 9
Forest 2 (NonDeciduous) / 10
Forest 3 (Mixed) / 11, 24, 25, 26
Forest 5 (Scrub-Shrub) / 12
Open 1 (Open Water) / 21
Open 3 (Excavation) / 19

Made a copy and renamed to "lndcvr_KnickAdam_after".
Set display transparency to 70%

Created Grids using Data Management > Feature Class > Create Fishnet
Created 10x10 grid
Deleted grids not covering watershed area
Labeled quads #1-78

ADD ROADS
Downloaded "NG 911 Roads" from MEGIS and cropped to watershed area
Selected "Private" from RdClass in attribute table > "NGRoads_clip_PrivateOnly.shp"
(Overlay between land cover file and NG911 roads layer showed that private roads were missing from the land cover delineation).
Geoprocessing > Buffer > Input "NGRoads_clip_PrivateOnly.shp"; buffer = 25ft -> "NGRoads_clip_PrivateOnly_buf25ft.shp"
Geometry errors in files. Corrected using Data Management > Feature > Correct Geometry. New file "LandCover_Boothbay_before_geom.shp".
Geoprocessing > Union > Input " LandCover_Boothbay_before_geom.shp " and " NGRoads_clip_PrivateOnly.shp " -> " LandCover_Boothbay_before_geom_rds.shp "
Unchecked "Gaps Allowed"
Relabeled added road polygons as "Urban 3: Roads" under "LLRM_CAT"
No unpaved roads feature available for Maine; manually separated out unpaved roads from paved roads based on review of aerial imagery.

ADD WETLANDS

Downloaded NWI Wetlands (https://www.fws.gov/wetlands/data/mapper.html)
Clipped to watershed -> "NWIWetlands_Boothbay.shp"

Lake → Open 1: Open Water
Freshwater Pond → Open 1: Open Water
Riverine → Open 1: Open Water
Freshwater Forested/Shrub Wetland → Forest 4: Wetland
Estuarine/Marine Deepwater → Open 1: Open Water
(only one very small polygon on north side of Adams Lake)
Freshwater Emergent Wetland → Other 1: Freshwater Emergent Wetland

Geoprocessing > Union > Input "LandCover_Boothbay_before_geom_rds.shp" and "NWIWetlands_Boothbay.shp" -> "LandCover_Boothbay_before_geom_rds_nwi.shp"
Unchecked "Gaps Allowed"
Reclassified master LLRM_Cat attribute

MULTIPART TO SINGLEPART

Separated out LLRM categories by parcel with Data Management/Multipart → Singlepart
"LandCover_Boothbay_before_geom_rds_nwi.shp" -
"LandCover_Boothbay_before_geom_rds_nwi_v2.shp"
(This separated out all polygons into individual features)

ArcCatalog > Copy "LandCover_Boothbay_before_geom_rds_nwi_v2.shp" > Rename
"LandCover_Boothbay_after.shp "

LAND COVER ANALYSIS

Step 1: Zoom to Quad #X; compare 2015 NAIP aerials to 5/9/2016 Google Earth satellite images for major land cover changes
Step 2: Compare 2015 NAIP aerials to "Landcover_Boothbay_after" land cover file
Step 3: If changes needed, used Topology tool to edit vertices or Editor tool to split polygons; relabel polygons in attribute table

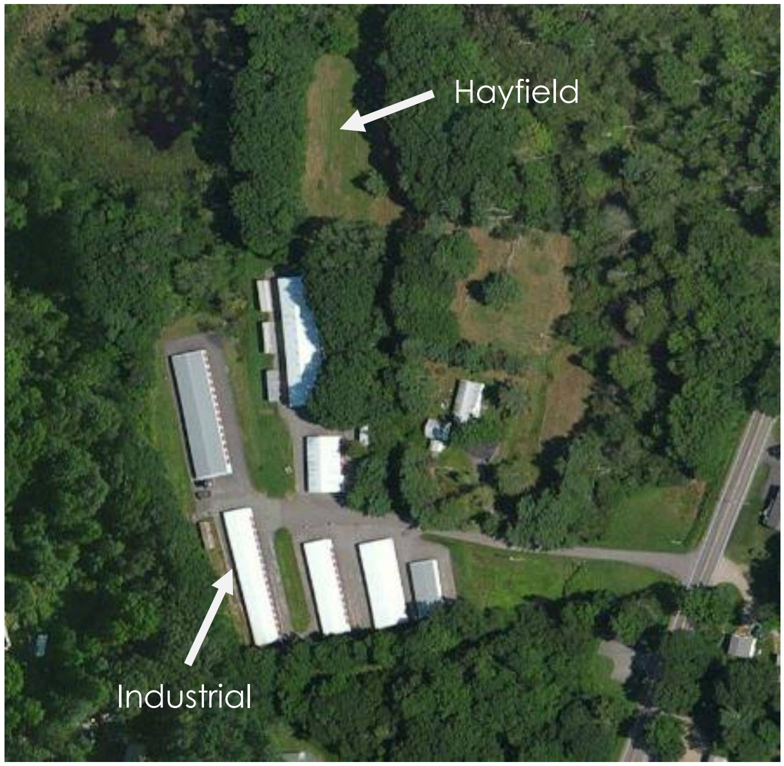
CHANGES

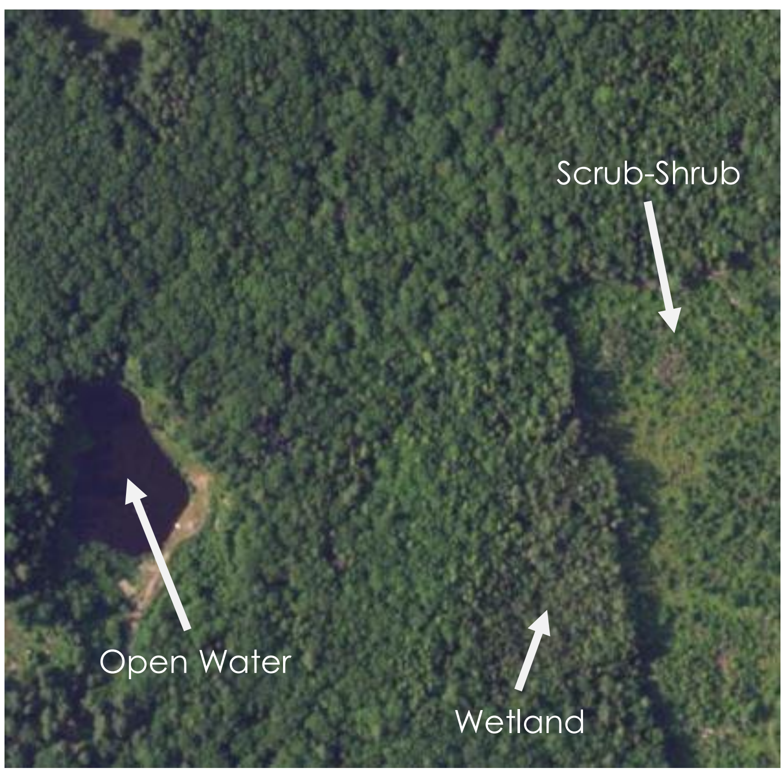
Default: Mixed Forest
Forest 5: Scrub-Shrub category added from 2004 Maine Landcover Database
Agric 1: Cover Crop = Too difficult to distinguish from Row Crop, Not used
Urban 5: Changed from "Mowed Field" to represent all Urban Open Space.
Other 1: Emergent Wetlands added. Distinguished from forested wetlands because represented a significant land area in the watershed.

FINAL FILES

"KnickAdamsWatershed_FBE_STI.shp" = watershed boundary for LLRM. Adjusted by FBE for discrepancy on north side of Adams Pond and by STI surveyors for new development south of Adams Pond.
"Landuse_Boothbay_26Jul2017" = editable and most recent land cover

ATTACHMENT 2: Examples of Distinguishing Land Cover in Aerials





ATTACHMENT 3: Land Cover by Sub-Basin

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

			AREA (ha)													
LAND COVER	**Runoff P export coefficient used**	**Baseflow P export coefficient used**	**Adams Direct**	**Little Adams Direct**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A8b**	**A9**	**A10a**	**A10b**	**A10c**
Urban 1: Low Den Res	0.79	0.01	0.8	0.1	0.2	0.2	0.1	0.4	2.2		0.6	0.4	0.0		0.0	0.0
Urban 2: Mid Den Res/Comm	0.9	0.01	0.1		0.3	0.0			2.8		0.6					0.9
Urban 3: Roads	0.3	0.01	3.0	0.2	1.0	0.4	0.2	0.9	3.3		0.6	0.4			0.0	0.1
Urban 4: Industrial	0.9	0.01	0.5				0.0		1.2		0.1					
Urban 5: Open Space	0.6	0.01	1.5	0.6	1.6	2.5	2.3	2.4	6.6		0.6	1.2	0.1		0.1	1.2
Agric 3: Grazing	0.8	0.01							1.0				0.4			
Agric 4: Hayfield	0.37	0.01	0.3													
Forest 1: Deciduous	0.03	0.004	5.7	6.5	2.7	7.6	5.3	3.1	11.8	10.4	6.3	2.8	2.7	2.6	1.5	0.1
Forest 2: NonDeciduous	0.03	0.004	3.8	1.9		9.8	1.3		0.8	0.1				12.9	0.0	
Forest 3: Mixed	0.03	0.004	13.4	12.1	13.1	7.9	7.8	14.3	13.4	4.4	3.5	3.6	4.2	27.5	18.0	6.9
Forest 4: Wetland	0.03	0.004	3.4	2.5		0.7	5.2	0.1	2.6	0.0			0.0	4.4	1.5	0.1
Forest 5: Scrub-Shrub	0.03	0.004	0.9	0.8	0.1		9.4						0.8			
Open 1: Open Water	0.02	0.004	1.8	5.6	0.2	0.8	1.0	0.4	1.5	0.2	0.1	0.1	0.1	1.0	0.4	0.1
Open 2: Meadow	0.03	0.004	0.7	0.3										0.2	2.1	
Other 1: Fresh. Emerg. Wetland	0.02	0.004	4.6	0.6					0.2							
Other 2: Unpaved Road	0.83	0.01	0.0	0.0	0.4	0.0	0.1	0.2	0.8		0.9					
		Total	**40.5**	**31.0**	**19.6**	**29.9**	**32.7**	**21.8**	**48.3**	**15.1**	**13.4**	**8.4**	**8.4**	**48.6**	**23.6**	**9.4**

ATTACHMENT 4: 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 drinking water extraction and fish stocking estimates (set to zero).
4. Removed internal loading, assuming internal loading was the result of excess nutrient loading from human activities in the watershed.
5. Roughly matched outflow TP to predicted in-lake TP.
6. Reduced atmospheric loading coefficient to 0.11 kg/ha/yr.
7. Kept all else the same, assuming waterfowl counts and precipitation input did not change (though they likely did).

ATTACHMENT 5: Estimating Future Phosphorus Load at Full Build-Out

1. **Estimated number of new buildings at full buildout by sub-basin.** CommunityViz software uses model inputs such as population growth rates, zoning, wetlands, conservation lands, and other constraints to construction, and generates a projected number of new buildings in the future. The new building count was generated for each sub-basin at full buildout.
2. **Calculated developed land coverage after full buildout projection.** Each new building was assumed to generate new developed land uses, including buildings, roads, etc. Specifically, the values of 0.02 ha of Urban 1, 0.02 ha of Urban 2, 0.04 ha of Urban 3, 0.01 ha of Urban 4, 0.09 ha of Urban 5, and 0.01 ha of Other 1 were multiplied by the number of new buildings in each sub-basin (total 0.19 ha converted per new building).
3. **Incorporated land use changes to LLRM for P loading predictions.** Added the new developed land use figures to the LLRM. Within each sub-basin, existing agricultural and un-developed land uses were replaced with areas equal to added developed land in the following order of priority: Agric 4: Hayfield, Agric 3: Grazing, Open 2: Meadow, Forest 1: Deciduous, Forest 2: Non-Deciduous, Forest 3: Mixed.
4. **Incorporated septic system loading to LLRM for P loading predictions.** The number of new buildings within 250 feet of water within each sub-basin (by residential and commercial zones) was estimated from the CommunityViz output shapefile of projected new buildings. All other assumptions were kept the same.
5. **Adjusted precipitation data based on potential climate change scenarios for the time frame of the projected build-out.** By the end of the century (2099), annual mean precipitation is expected to increase by approximately 10%.
6. **Increased atmospheric loading coefficient to 0.3 kg/ha/yr.**
7. **Calculated potential increase in internal loading.** Determined the total TP load to the lake (minus internal load) corrected for the retention coefficient (settling rate) for current and future scenarios (29.4 kg/yr and 63.5 kg/yr, respectively). The percent settled TP load resuspended under current conditions was calculated at 6.2%. Assuming a similar magnitude release in the future relative to the amount of bottom TP available, this percentage was multiplied by the future settled TP load to the lake to derive an estimate of future annual internal TP load (3.9 kg/yr).
8. **Roughly matched outflow TP to predicted in-lake TP.**
9. **Kept all else the same, including drinking water withdrawals.**