# KNICKERBOCKER LAKE
## LAKE LOADING RESPONSE MODEL

**FINAL** February 2018

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# INTRODUCTION

The purpose of this report is to provide results from the Lake Loading Response Model (LLRM) developed for Knickerbocker Lake. The LLRM is an Excel-based model that uses environmental data to develop a water and phosphorus loading budget for lakes and their tributaries[1]. Water and phosphorus loads (in the form of mass and concentration) are traced from various sources in the watershed through tributary basins and into the lake. The model 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 Adams Pond and Knickerbocker Lake, 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):

- Stream flowlines in the northern portion of the watershed were shifted eastward based on feedback from BRWD.

- Stream flowlines on the east side of the watershed crossing under Back River Road were adjusted based on field confirmation by FBE. Downstream of the road crossing was
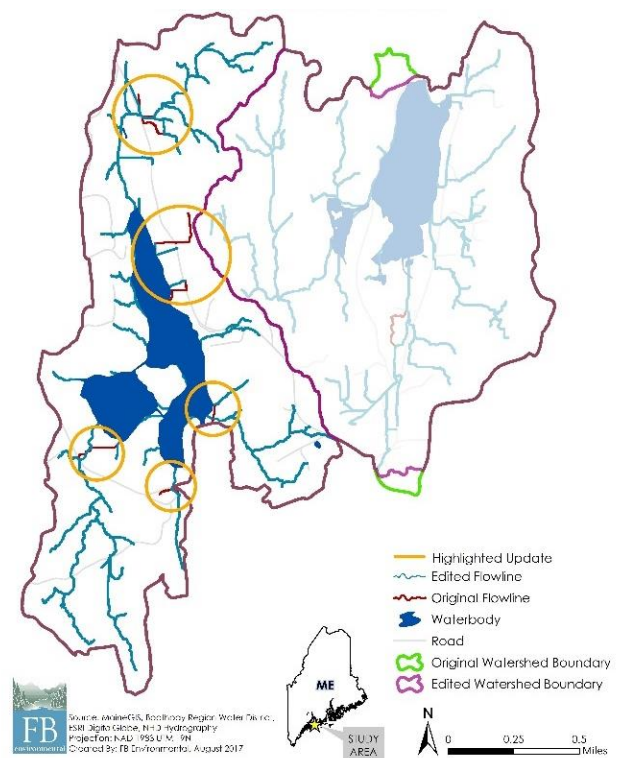


FIGURE 1. Comparison between "original" modeled stream flowlines and watershed files developed by Wright-Pierce Engineering and "edited" stream flowlines and watershed files ground-truthed and updated by FBE, BRWD, and STI. Updated flowlines were estimated.

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

determined to be perennial flow, while upstream of the road crossing across the hillslope was determined to be ephemeral flow. Sub-basins K5 and K5b were created to account for these perennial drainages.

- Stream flowlines near the outlet of the lake were re-directed from entering below the outlet of the lake to above the outlet based on field reconnaissance. This stream drains a large field.

- Stream flowlines located on the southern end of Knickerbocker Lake were re-directed to drain directly to the lake (not the outlet stream), per conversation from the BRWD and confirmed in the field by FBE.

- Stream flowlines entering Little Knickerbocker Lake were adjusted to flow directly north to the lake instead of cutting east, per information from the BRWD.

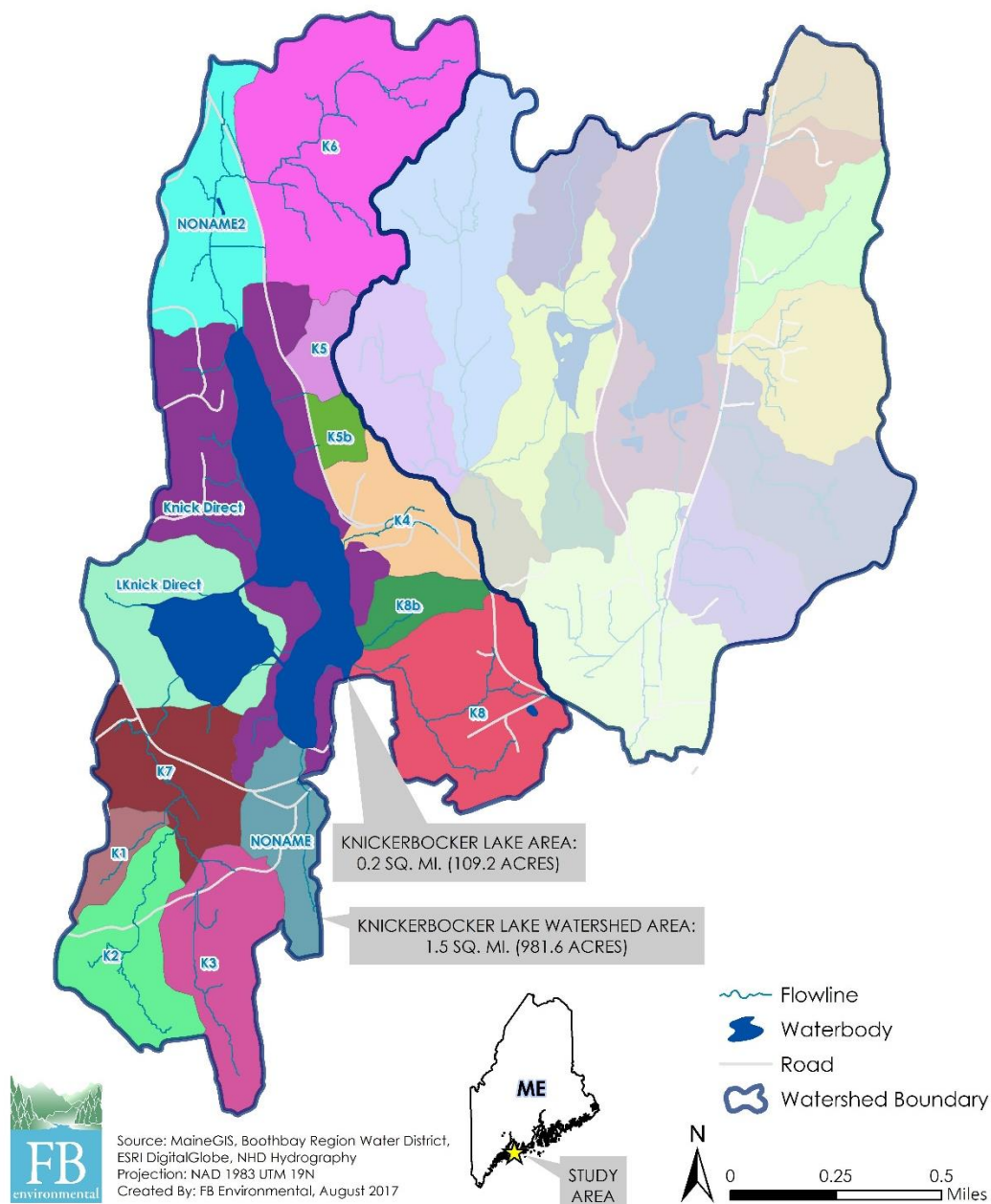The final sub-basin delineation is shown in Figure 2.



FIGURE 2. Final sub-basin boundaries for the Knickerbocker Lake 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 Knickerbocker Lake 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 7% of the watershed and contribute 57% of the total phosphorus watershed load to Knickerbocker Lake.



**Land Use Category**
Agric 2: Row Crop
Agric 3: Grazing
Agric 4: Hayfield
Forest 1: Deciduous
Forest 2: NonDeciduous
Forest 3: Mixed
Forest 4: Wetland
Forest 5: Scrub-Shrub
Open 1: Open Water
Open 2: Meadow
Open 3: Excavation
Other 1: Freshwater Emergent Wetland
Other 2: Unpaved Road
Urban 1: Low Den Res
Urban 2: Mid Den Res/Comm
Urban 3: Roads
Urban 5: Open Space
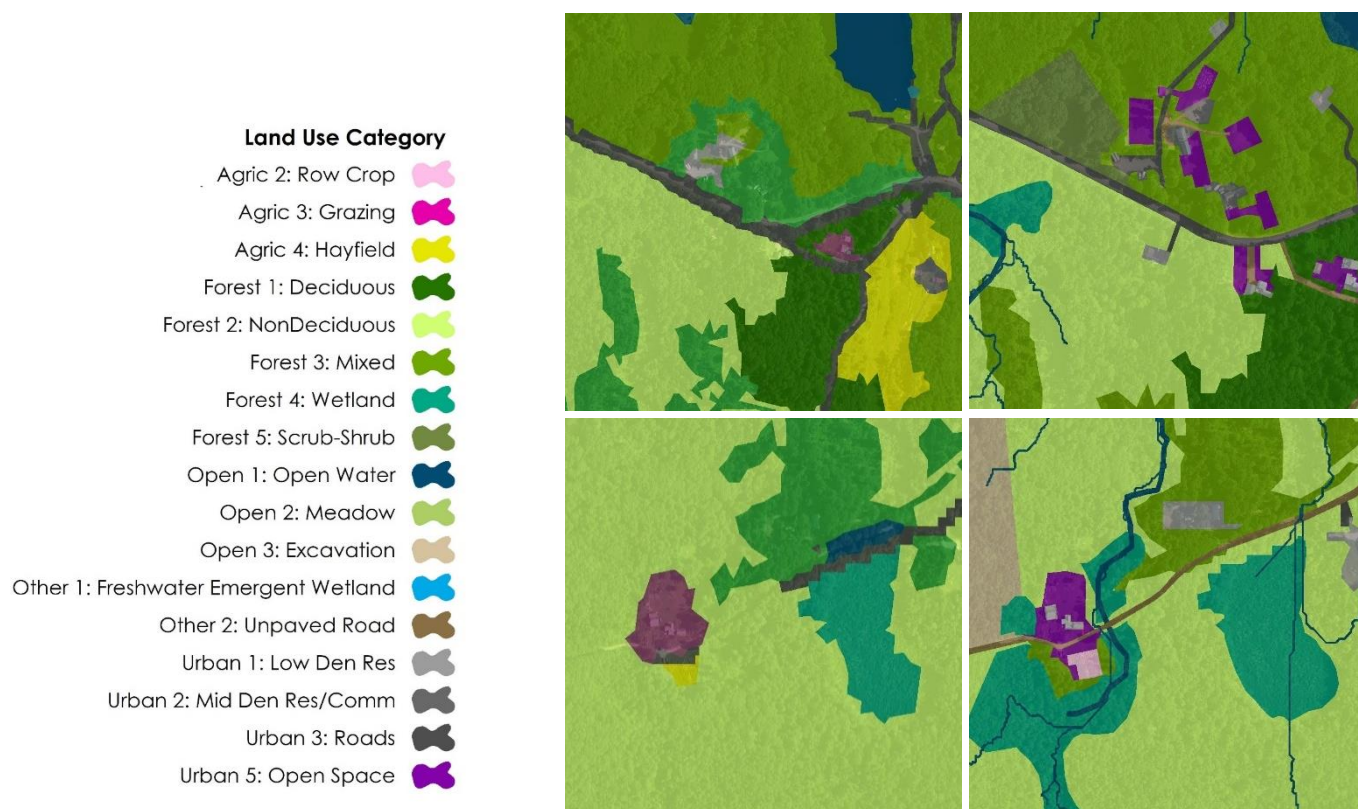
FIGURE 3. Examples of "before" and "after" land cover file modifications for the Knickerbocker Lake watershed for developed areas.

**Land Use Category**

Agric 2: Row Crop
Agric 3: Grazing
Agric 4: Hayfield
Forest 1: Deciduous
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Forest 3: Mixed
Forest 4: Wetland
Forest 5: Scrub-Shrub
Open 1: Open Water
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Other 1: Freshwater Emergent Wetland
Other 2: Unpaved Road
Urban 1: Low Den Res
Urban 2: Mid Den Res/Comm
Urban 3: Roads
Urban 5: Open Space

Source: MaineGIS, Boothbay Region Water District,
ESRI DigitalGlobe, NHD Hydrography
Projection: NAD 1983 UTM 19N
Created By: FB Environmental, August 2017
0      0.25      0.5
Miles

ME

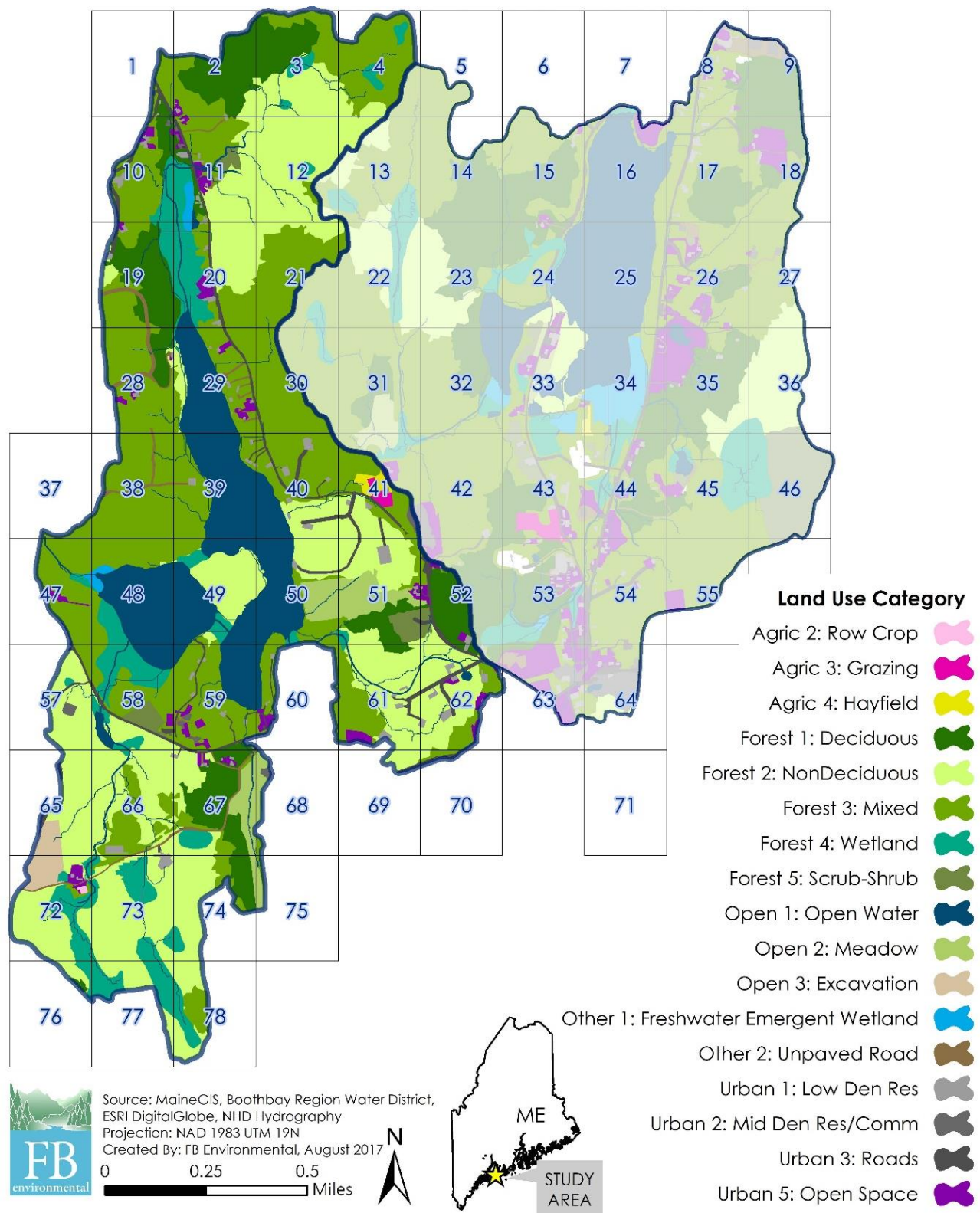STUDY AREA

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.

## Watershed Land Cover Area
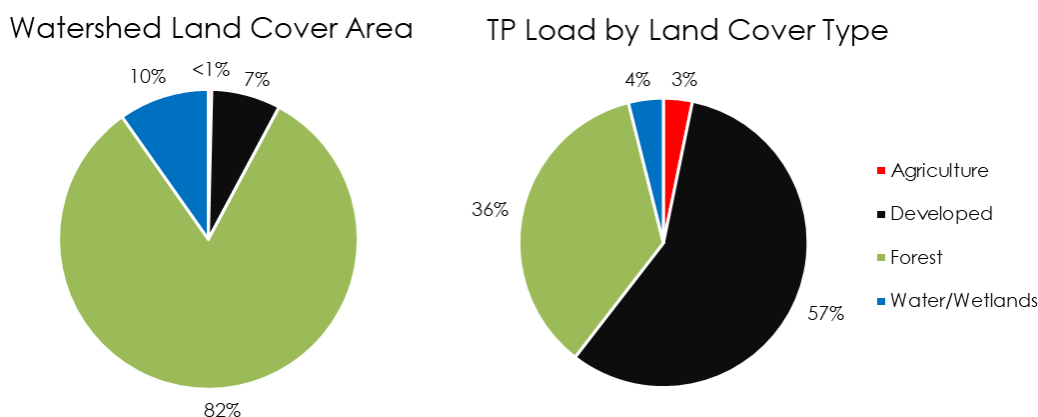
## TP Load by Land Cover Type



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 7% of the watershed, these areas are contributing 57% of the TP load to Knickerbocker Lake.

## 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 5% lower than the NHD bathymetry shapefile obtained from the Maine Office of GIS (based on sounding depths taken on 10/13/2011). The lake surface area estimate from the BRWD file was nearly the same as 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 Knickerbocker Lake 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 Knickerbocker Lake for drinking water use was calculated and input to the model. Water volume was based on 2016 withdrawal estimates from Knickerbocker Lake, 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 Knickerbocker Lake via groundwater). It was determined that only 1.4% 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 Knickerbocker Lake for part of the year.

- Internal loading estimates were derived from dissolved oxygen and temperature profiles taken at the deep spot of Knickerbocker Lake 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 Knickerbocker Lake from 2010-2017 (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 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.

- The direct shoreline of Little Knickerbocker Lake and the K7, K1, K2, and K3 sub-basins were input to a separate model for the Little Knickerbocker Lake. Results from the Little Knickerbocker Lake model were used as a source input to the main Knickerbocker Lake. Information from the Maine DEP and BRWD suggests that the two lakes (Little Knickerbocker Lake and Knickerbocker Lake) are connected by two narrow and shallow (~2 ft) channels that dry up and isolate the two portions of the lake for part of the year (~ 2 months).

## 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 Knickerbocker Lake 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.

| Lake | Sub-Basin | Water Attenuation Factor | Phos. Attenuation Factor | Reasoning |
|---|---|---|---|---|
| Knickerbocker Lake | K4 | 0.90 | 0.85 | Stream processes; some settling |
| | K5 | 0.90 | 0.90 | Default (small amount of removal by infiltration) |
| | K5b | 0.90 | 0.90 | Default (small amount of removal by infiltration) |
| | K6 | 0.90 | 0.85 | Stream processes; some settling |
| | K8 | 0.90 | 0.85 | Stream processes; some settling |
| | K8b | 0.90 | 0.90 | Default (small amount of removal by infiltration) |
| | Knick Direct | 0.90 | 0.95 | Direct drainage with little time for infiltration |
| | Noname | 0.90 | 0.85 | Stream processes; some settling |
| | Noname2 | 0.90 | 0.65 | Moderate wetlands; some settling |
| Little Knickerbocker Lake | K1 | 0.80 | 0.85 | Stream processes; some settling |
| | K2 | 0.90 | 0.85 | Stream processes; some settling |
| | K3 | 0.90 | 0.85 | Stream processes; some settling |
| | K7 | 0.90 | 0.85 | Stream processes; some settling |
| | Lknick Direct | 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 (KS11) 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., Coastal Maine Botanical Garden) 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 are 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 Knickerbocker Lake, 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. Data for Little Knickerbocker Lake were only available for 2017.
- **Septic system loading estimates are 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 are based on estimates.** In the future, a more precise bird census would help improve the model loading estimates.
- **Land cover export coefficients are estimates.** Literature values and best professional judgement were used in evaluating and selecting appropriate land cover export coefficients for Knickerbocker Lake. While these coefficients may be accurate on a larger scale, they are likely not representative on a site-by-site basis. Refer to documentation within the LLRM spreadsheet for specific citations.
- **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 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.

## RESULTS

### CURRENT LOAD ESTIMATION

The direct shoreline area to Knickerbocker Lake and the K8 sub-basin had the highest phosphorus export by total mass (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 phosphorus export. The other sub-basins showed relatively smaller amounts of phosphorus mass exported per year (< 2.3 kg/yr). Sub-basins with moderately-high phosphorus mass exported by area (> 0.1 kg/ha/yr) generally had more development or agriculture (e.g., K1, K4, direct shoreline to Knickerbocker Lake). K1 had the highest phosphorus mass exported by area because it accounted for 2017 excavation of the Coastal Main Botanical Garden expansion project. A few sub-basins did not have predicted phosphorus concentrations that matched well with measured phosphorus concentrations (e.g., K4, K6, K8, K7). 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.

| 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) |
|---|---|---|---|---|---|---|
| Knickerbocker Lake Watershed | 243.3 | 1,415,682 | 0.011 | | 15.9 | 0.07 |
| K4 | 18.5 | 109,232 | 0.018 | 0.093 | 2.0 | 0.11 |
| K5 | 6.3 | 37,562 | 0.006 | 0.003 | 0.2 | 0.04 |
| K5b | 5.6 | 33,338 | 0.007 | 0.009 | 0.2 | 0.04 |
| K6 | 65.3 | 383,238 | 0.006 | 0.021 | 2.3 | 0.04 |
| K8 | 41.2 | 240,887 | 0.013 | 0.030 | 3.1 | 0.07 |
| K8b | 8.5 | 49,461 | 0.011 | | 0.5 | 0.06 |
| Knick Direct | 52.9 | 307,526 | 0.016 | | 5.1 | 0.10 |
| Noname | 16.5 | 96,801 | 0.013 | | 1.3 | 0.08 |
| Noname2 | 28.5 | 157,637 | 0.006 | | 1.7 | 0.06 |
| Little Knickerbocker Lake Watershed | 109.8 | 625,115 | 0.012 | | 7.2 | 0.07 |
| K1 | 6.3 | 37,891 | 0.037 | 0.042 | 1.4 | 0.22 |
| K2 | 24.5 | 140,165 | 0.016 | 0.021 | 2.2 | 0.09 |
| K3 | 28.5 | 158,549 | 0.008 | 0.013 | 1.3 | 0.05 |
| K7 | 25.8 | 148,653 | 0.013 | 0.036 | 1.3 | 0.05 |
| LKnick Direct | 24.7 | 139,856 | 0.007 | | 1.0 | 0.04 |

*\* Median TP, 2010-2017 (as available); note that measured P concentrations for tributaries were collected only in 2017 and were skewed to high flow periods*
**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.*
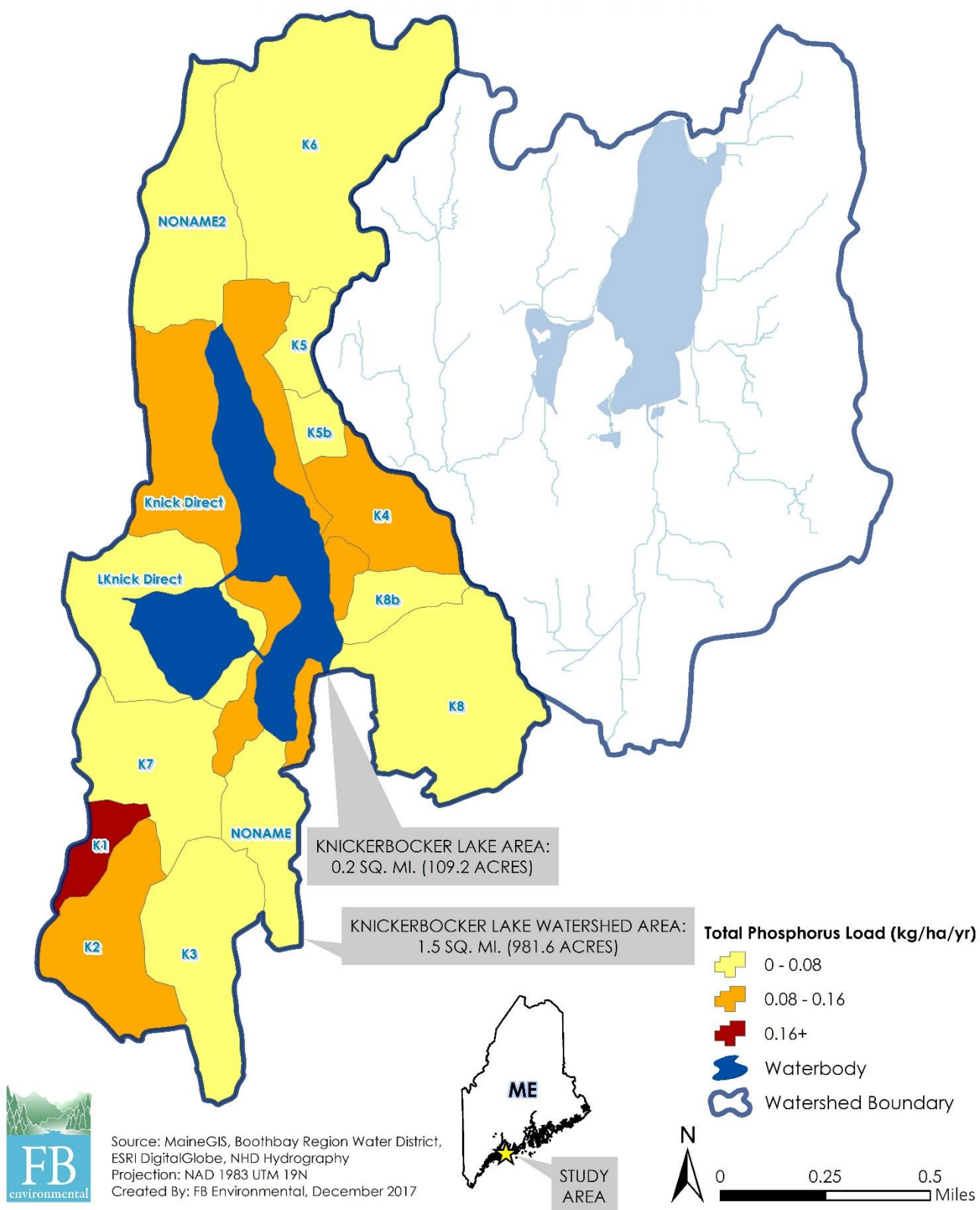
FIGURE 6. Total phosphorus mass loading (kg/ha/yr) for sub-basins to Knickerbocker Lake. Note that the portion of the NoName drainage from Barters Island Road to Knickerbocker Lake likely experiences a phosphorus loading more similar to the direct shoreline drainage of Knickerbocker Lake than the upper reaches of the NoName drainage.

Overall, watershed runoff and baseflow (28%) was the largest loading contribution across all sources to Knickerbocker Lake, followed by septic systems (21%), internal loading (20%), Little Knickerbocker Lake (18%), atmospheric deposition (11%), and waterfowl (2%) (Table 3; Figure 7). Internal loading (41%) was the largest loading contribution across all sources to Little Knickerbocker Lake, followed by watershed runoff and baseflow (35%), atmospheric deposition (13%), septic systems (9%), and waterfowl (2%). The Maine DEP Lake Report for Knickerbocker Lake rates the potential for phosphorus to leave bottom sediments (internal loading) as high and states that there has been an increase in bottom-water phosphorus levels. Seven (7) surface and bottom grab samples were collected from the deep spot of Little Knickerbocker Lake in 2017 between May and October; the difference between bottom and surface phosphorus concentrations ranged from 13 ppb to 45 ppb, with an average of 29 ppb. This represents a significant release of phosphorus from bottom sediments in Little Knickerbocker Lake that occurs over the entire summer season. The average difference between bottom and surface phosphorus concentrations for Knickerbocker Lake was about 11 ppb. Lake morphology (e.g., greater depth, less physical disturbance) and greater flushing of the main lake may help prevent phosphorus release from bottom sediments as compared to Little Knickerbocker Lake.

For Knickerbocker Lake, the model predicted in-lake phosphorus within 0% (relative percent difference) of observed median total phosphorus (Table 4). The model also predicted about 15% (higher) difference for observed mean chlorophyll-a and about 40% (lower) difference for observed mean water clarity (Secchi Disk Transparency) (Table 4). For Little Knickerbocker Lake, the model predicted 12% lower for observed median total phosphorus, 21% lower for observed mean chlorophyll-a, and 3% lower for observed mean water clarity. The Little Knickerbocker Lake model was not fully calibrated to observed measurements because only 2017 data were available. The higher-than-observed predictions for Knickerbocker Lake suggest 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 346%, from 13 kg/yr prior to European settlement to 58 kg/yr under current conditions, for Knickerbocker Lake and by 318%, from 5 kg/yr to 21 kg/yr for Little Knickerbocker Lake (Table 3; Figure 7). These additional phosphorus sources are coming from development in the watershed (especially in the direct shoreline of Knickerbocker Lake), 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 198%, from 58 kg/yr under current conditions to 173 kg/yr at full build-out under current zoning constraints, for Knickerbocker Lake and by 262%, from 21 kg/yr to 76 kg/yr for Little Knickerbocker Lake (Table 3; Figure 7). These additional phosphorus sources are coming from more development in the watershed (especially from K6, K2, K3, K7, K8, and the direct shoreline of Knickerbocker Lake), more septic systems, greater atmospheric dust, and enhanced internal loading.

For Knickerbocker Lake, the model predicted significantly higher (worse) phosphorus (37.8 ppb), higher (worse) chlorophyll-a (14.2 ppb), and shallower (worse) water clarity (1.4 m) compared to current conditions. For Little Knickerbocker Lake, the model predicted significantly higher (worse) phosphorus (51.8 ppb), higher (worse) chlorophyll-a (24.2 ppb), and shallower (worse) water clarity (1.1 m) compared to current conditions.

At full build-out under current zoning (base scenario), Knickerbocker Lake and Little Knickerbocker Lake 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. Knickerbocker Lake and Little Knickerbocker Lake would not support their designated uses and would likely be listed as impaired waterbodies. 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). These changes were incorporated to the model as Alternative Scenario #1. Changes were made to land cover, internal loading, and septic systems 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 decrease of 10 projected new buildings possible with the proposed zoning amendments for the Knickerbocker Lake watershed (19 were no longer within 250 feet of surface waters). Total phosphorus loading was estimated to be 3% lower, from 173 kg/yr under the future base scenario to 168 kg/yr under the future alternative scenario #1 (Table 3). The model predicted slightly lower (better) phosphorus (36.7 ppb), lower (better) chlorophyll-a (13.8 ppb), and deeper (better) water clarity (1.5 m) compared to the future base scenario (Table 4; Figure 8). The greatest increases in phosphorus watershed loading would still come from the K6 sub-basin (Table 5).

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 3 projected new buildings possible with the proposed zoning amendments for the Little Knickerbocker Lake watershed (1 of which was within 250 feet of surface waters). Total phosphorus loading was estimated to be 2.6% higher, from 76 kg/yr under the future base scenario to 78 kg/yr under the future alternative scenario #1 (Table 3). The model predicted slightly higher (worse) phosphorus (53.1 ppb), higher (worse) chlorophyll-a (24.9 ppb), and the same water clarity (1.1 m) compared to the future base scenario (Table 4; Figure 8). The greatest increases in phosphorus watershed loading would still likely come from the K2, K3, and K7 sub-basins (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 Knickerbocker Lake put in conservation (290 acres placed in "hypothetical conservation" in addition to the 30 acres in existing conservation for a total of 320 acres or 33% of the watershed in conservation). These changes were incorporated to the model as Alternative Scenario #2. Changes were made to land cover, internal loading, and septic systems 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 for Knickerbocker Lake, 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 92 projected new buildings possible with the hypothetical and existing conserved parcels (38 of which were within 250 feet of surface waters). Total phosphorus loading was estimated to be 23% lower, from 173 kg/yr under the future base scenario to 134 kg/yr under the future alternative scenario #2 (Table 3). The model predicted slightly lower (better) phosphorus (29.1 ppb), lower (better) chlorophyll-a (11.1 ppb), and deeper (better) water clarity (1.7 m) compared to the future base scenario (Table 4; Figure 8). The greatest increases in phosphorus watershed loading would still come from the K6 sub-basin (Table 5).

Under future alternative scenario #2 for Little Knickerbocker Lake, 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 34 projected new buildings possible with the hypothetical and existing conserved parcels (20 of which were within 250 feet of surface waters). Total phosphorus loading was estimated to be 24% lower, from 76 kg/yr under the future base scenario to 58 kg/yr under the future alternative scenario #2 (Table 3). The model predicted slightly lower (better) phosphorus (39.1 ppb), lower (better) chlorophyll-a (16.8 ppb), and deeper (better) water clarity (1.4 m) compared to the future base scenario (Table 4; Figure 8). The greatest increases in phosphorus watershed loading would still likely come from the K2, K3, and K7 sub-basins (Table 5).

Although future alternative scenario #2 results in better water quality compared to the future base scenario, Knickerbocker Lake and Little Knickerbocker Lake would still suffer from degraded water clarity and algae blooms. Both waterbodies would not support their designated uses and would likely be listed as an impaired waterbody. These results stress the importance of significant land conservation (greater than the 33% modeled here) in watersheds that drain to primary drinking water sources such as Knickerbocker Lake.

TABLE 3. Total phosphorus (TP) and water loading summary by source. LKL = Little Knickerbocker Lake. KL = Knickerbocker Lake.

| 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 | 3.4 | 25% | 180,168 | 6.2 | 11% | 180,168 | 9.2 | 5% | 214,014 | 9.2 | 6% | 214,014 | 9.2 | 7% | 214,014 |
| INTERNAL | 0.0 | 0% | 0 | 11.5 | 20% | 0 | 33.3 | 19% | 0 | 32.2 | 19% | 0 | 25.7 | 19% | 0 |
| WATERFOWL | 0.9 | 7% | 0 | 0.9 | 2% | 0 | 0.9 | 1% | 0 | 0.9 | 1% | 0 | 0.9 | 1% | 0 |
| SEPTIC SYSTEM | 0.0 | 0% | 0 | 12.1 | 21% | 7,861 | 50.3 | 29% | 34,796 | 46.1 | 27% | 31,838 | 37.8 | 28% | 25,922 |
| WATERSHED LOAD | 6.6 | 49% | 1,423,270 | 16.3 | 28% | 1,415,682 | 38.8 | 23% | 1,533,703 | 37.7 | 22% | 1,534,582 | 29.3 | 22% | 1,542,665 |
| DRINKING WATER EXTRACTION | | | | -2.2 | | -186,550 | -2.2 | | -186,550 | -2.2 | | -186,550 | -2.2 | | -186,550 |
| WATERSHED LOAD FROM LKL | 2.6 | 19% | 701,031 | 10.6 | 18% | 709,640 | 40.6 | 23% | 783,008 | 41.6 | 25% | 782,682 | 30.7 | 23% | 784,612 |
| *ATMOSPHERIC* | *1.5* | *29%* | *78,562* | *2.7* | *13%* | *78,562* | *4.0* | *5%* | *93,320* | *4.0* | *5%* | *93,320* | *4.0* | *7%* | *93,320* |
| *INTERNAL* | *0.0* | *0%* | *0* | *8.6* | *41%* | *0* | *30.5* | *40%* | *0* | *31.2* | *40%* | *0* | *23.0* | *40%* | *0* |
| *WATERFOWL* | *0.4* | *8%* | *0* | *0.4* | *2%* | *0* | *0.4* | *1%* | *0* | *0.4* | *1%* | *0* | *0.4* | *<1%* | *0* |
| *SEPTIC SYSTEM* | *0.0* | *0%* | *0* | *2.0* | *9%* | *1,226* | *15.3* | *20%* | *12,428* | *15.6* | *20%* | *12,633* | *10.7* | *19%* | *8,545* |
| *WATERSHED LOAD* | *3.1* | *63%* | *622,469* | *7.2* | *35%* | *629,851* | *26.2* | *34%* | *677,260* | *26.8* | *34%* | *676,729* | *19.4* | *34%* | *682,747* |
| *TOTAL LOAD TO LKL* | *5.0* | *100%* | *701,031* | *20.9* | *100%* | *709,640* | *76.4* | *100%* | *783,008* | *78.1* | *100%* | *782,682* | *57.6* | *100%* | *784,612* |
| TOTAL LOAD TO KL | 13 | 100% | 2,304,470 | 58 | 100% | 2,313,351 | 173 | 100% | 2,565,522 | 168 | 100% | 2,563,116 | 134 | 100% | 2,567,213 |
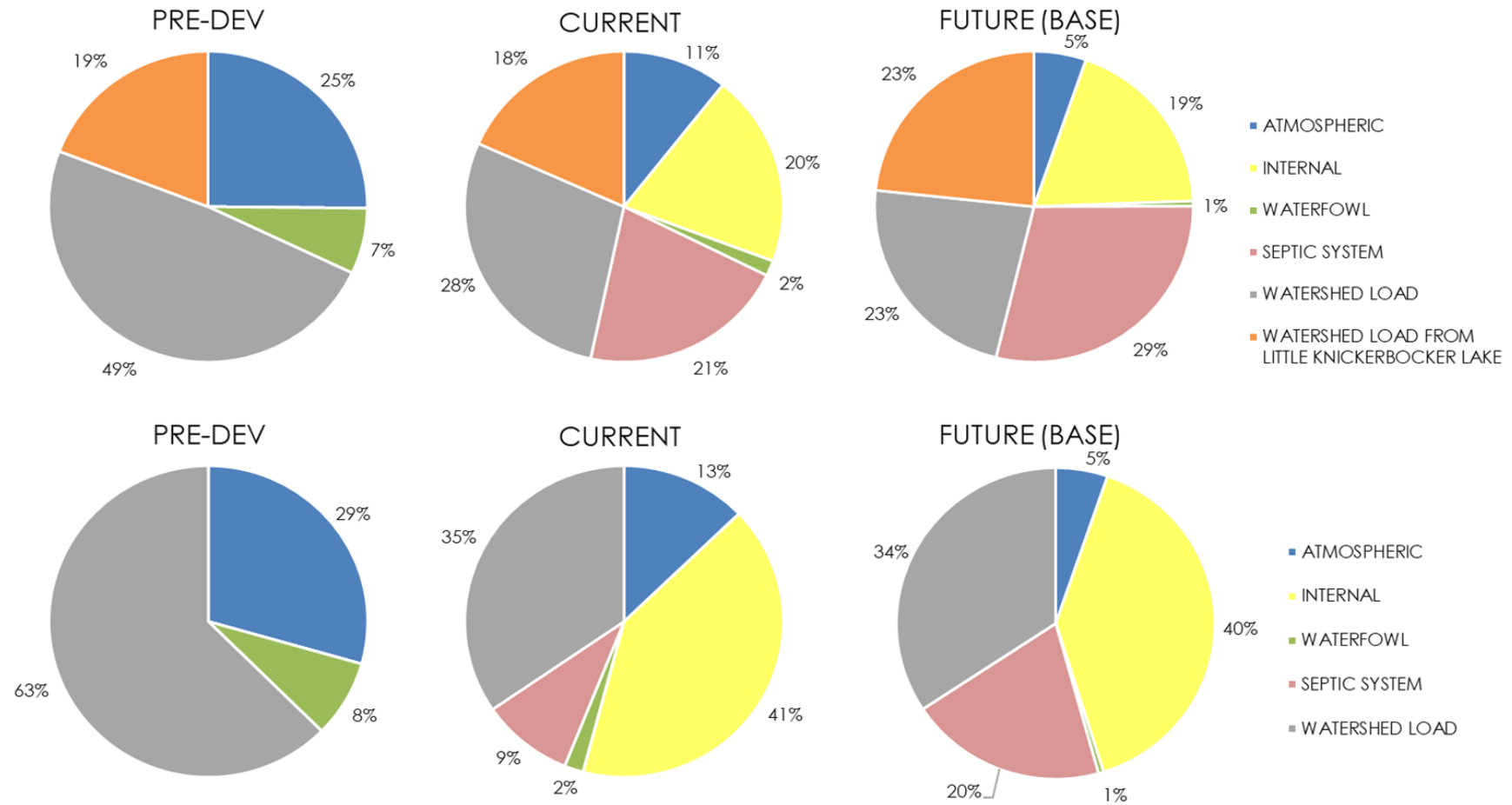
FIGURE 7. Percentage of total phosphorus (TP) loading (kg/yr) by source (atmospheric, internal loading, waterfowl, septic systems, watershed load). Top panels = Knickerbocker Lake. Bottom panels = Little Knickerbocker Lake.

TABLE 4. In-lake water quality predictions for Knickerbocker Lake.

| Scenario | Median TP (ppb) | Predicted Median TP (ppb) | Mean Chl-a (ppb) | Predicted Mean Chl-a (ppb) | Mean SDT (m) | Predicted Mean SDT (m) |
|---|---|---|---|---|---|---|
| Knickerbocker Lake | | | | | | |
| Pre-Dev | -- | 3.0 | -- | 1.4 | -- | 9.8 |
| Current | 11.0 (13.2) | 13.2 | 4.6 | 5.4 | 4.8 | 3.2 |
| Future (Base) | -- | 37.8 | -- | 14.2 | -- | 1.4 |
| Future (Alt 1) | -- | 36.7 | -- | 13.8 | -- | 1.5 |
| Future (Alt 2) | -- | 29.1 | -- | 11.1 | -- | 1.7 |
| Little Knickerbocker Lake | | | | | | |
| Pre-Dev | -- | 3.7 | -- | 0.5 | -- | 8.5 |
| Current | 14.0 (16.8) | 14.9 | 5.9 | 4.8 | 3.0 | 2.9 |
| Future (Base) | -- | 51.8 | -- | 24.2 | -- | 1.1 |
| Future (Alt 1) | -- | 53.1 | -- | 24.9 | -- | 1.1 |
| Future (Alt 2) | -- | 39.1 | -- | 16.8 | -- | 1.4 |

*Median TP concentration of 11.0 and 14.0 represent existing in-lake epilimnion TP from observed data. Median TP concentration of 13.2 and 16.8 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*
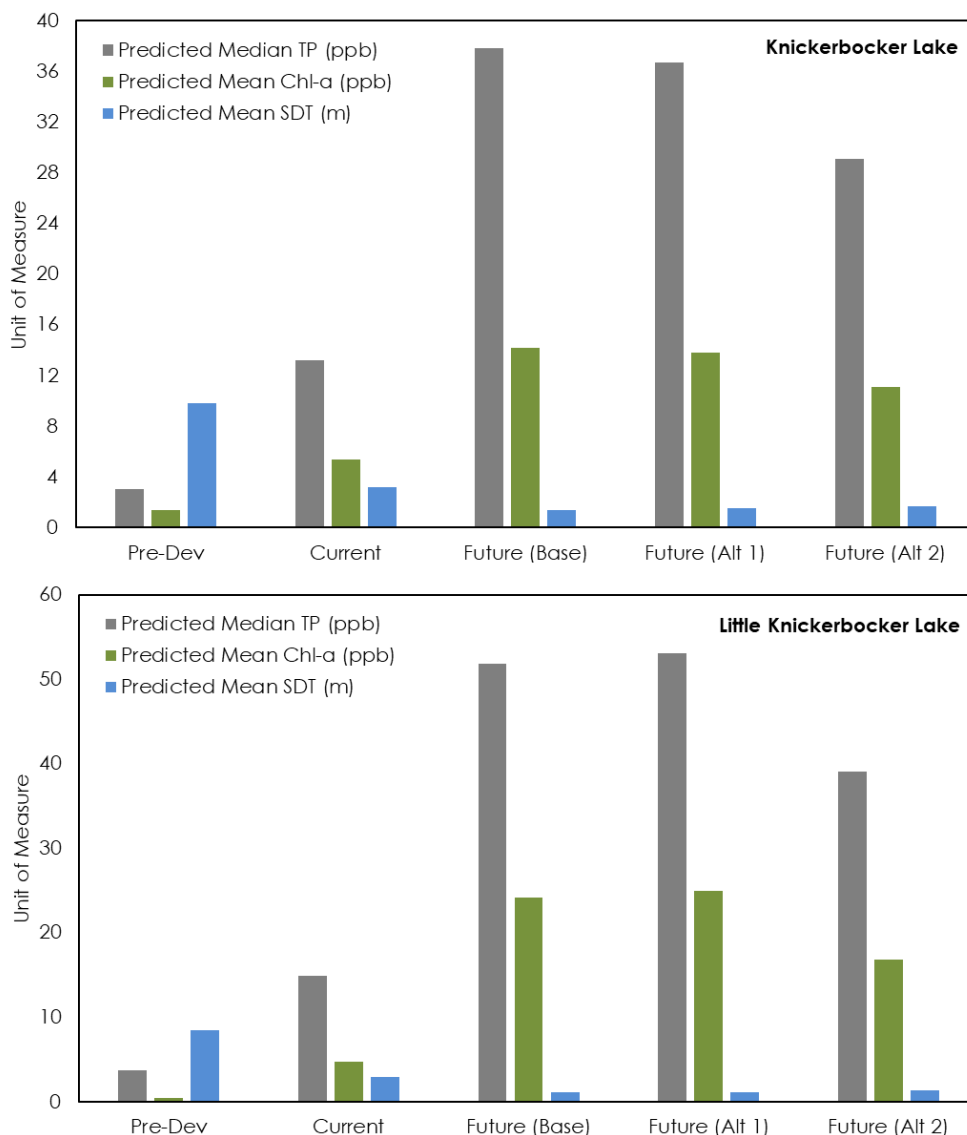


FIGURE 8. Predicted total phosphorus (TP), chlorophyll-a (Chl-a), and Secchi Disk Transparency (SDT) for pre-development, current, and future loading conditions to Knickerbocker Lake and Little Knickerbocker Lake.

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

| Sub-Basin | Watershed Load | | | | |
|---|---|---|---|---|---|
| | Pre-Dev | Current | Future (Base) | Future (Alt1) | Future (Alt2) |
| Knickerbocker Lake Watershed | | | | | |
| K4 | 0.5 | 2.0 | 2.8 | 2.8 | 2.7 |
| K5 | 0.2 | 0.2 | 1.2 | 0.9 | 0.2 |
| K5b | 0.2 | 0.2 | 1.4 | 0.9 | 0.2 |
| K6 | 1.9 | 2.3 | 11.4 | 11.6 | 9.2 |
| K8 | 1.2 | 3.1 | 7.4 | 7.3 | 5.3 |
| K8b | 0.3 | 0.5 | 1.1 | 1.2 | 0.6 |
| Knick Direct | 1.7 | 5.1 | 9.2 | 9.3 | 6.4 |
| Noname | 0.5 | 1.3 | 3.4 | 2.8 | 3.3 |
| Noname2 | 2.1 | 1.7 | 3.0 | 3.0 | 3.0 |
| Little Knickerbocker Lake Watershed | | | | | |
| K1 | 0.2 | 1.4 | 3.4 | 3.4 | 3.4 |
| K2 | 0.7 | 2.2 | 7.2 | 6.6 | 6.6 |
| K3 | 0.8 | 1.3 | 5.9 | 6.5 | 3.3 |
| K7 | 0.7 | 1.3 | 5.9 | 6.3 | 5.0 |
| LKnick Direct | 0.7 | 1.0 | 3.8 | 4.0 | 1.2 |

# SUMMARY & RECOMMENDATIONS

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

The lake's unique morphology isolates Little Knickerbocker Lake from the main lake for part of the year as low summer lake levels dry up the narrow, shallow connecting channels. The smaller volume and shallower depth of Little Knickerbocker Lake makes it more vulnerable to water quality degradation following additional phosphorus inputs. Additional phosphorus loading from the watershed and internal sediments will likely accelerate water quality degradation of the main lake.

Given Knickerbocker Lake'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 33% 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. Improving regulations is possibly even more critical given that much of the direct shoreline of Knickerbocker Lake is currently in private, unprotected ownership. The proposed zoning amendments (as shown in future alternative scenario #1) would likely still significantly degrade the water quality of Knickerbocker Lake and Little Knickerbocker Lake. As such, the proposed amendments are not protective enough to prevent a significant water quality decline of Knickerbocker Lake in the future.

The DEP currently classifies Knickerbocker Lake 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 Knickerbocker Lake 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 14-15 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 2-3 ppb increase in in-lake total phosphorus concentration in the main Knickerbocker Lake and no room for increase in in-lake total phosphorus concentration in Little Knickerbocker Lake, which is already experiencing degraded water clarity at 3 meters and elevated chlorophyll-a above 7 ppb. Allowable

loading increases will be easily surpassed based on both current and proposed zoning as development continues throughout the watershed.

Recently, a large development in the Knickerbocker Lake watershed diverted 3.4 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.
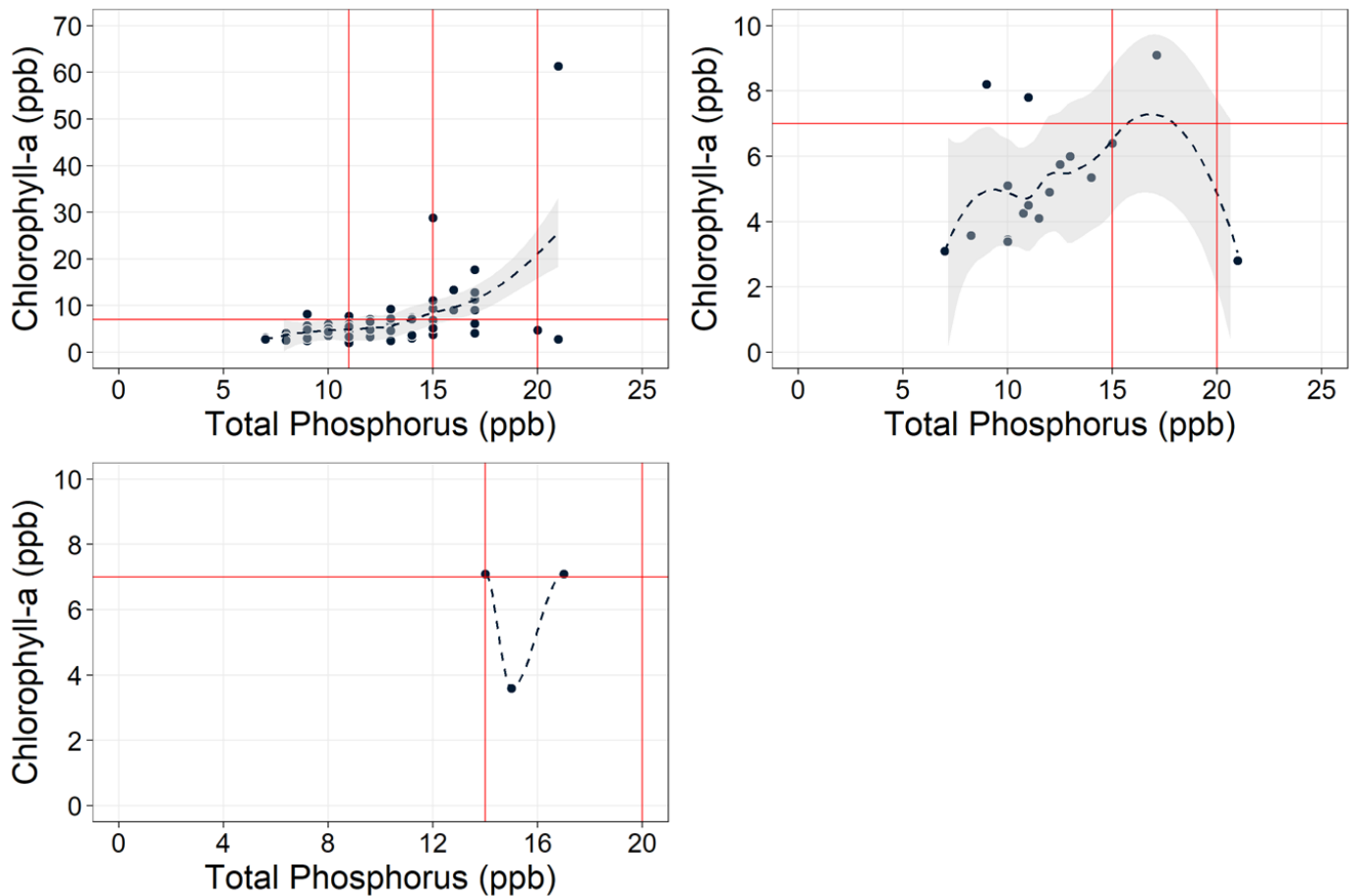


FIGURE 9. Chlorophyll-a (measure of algae) generally increases in response to increased in-lake total phosphorus concentration. Maximum limits for mesotrophic waterbodies are set at 7 ppb for chlorophyll-a and 20 ppb for total phosphorus, but the relationship between chlorophyll-a and total phosphorus in Knickerbocker Lake (top panels) and Little Knickerbocker Lake (bottom panel) for all data (left panel) and yearly data (right panel) shows a possible threshold of chlorophyll-a response at 14-15 ppb total phosphorus for both waterbodies.

## 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
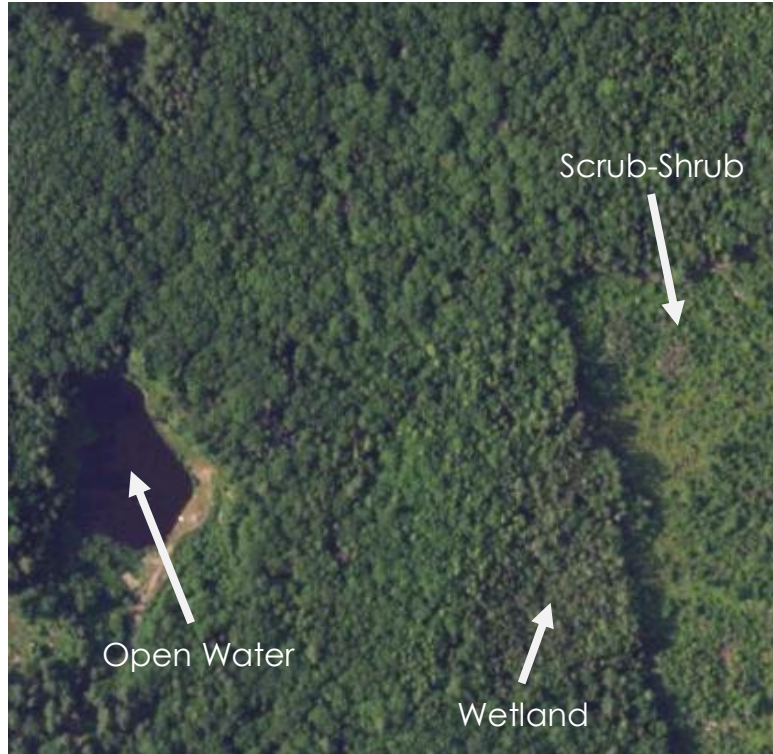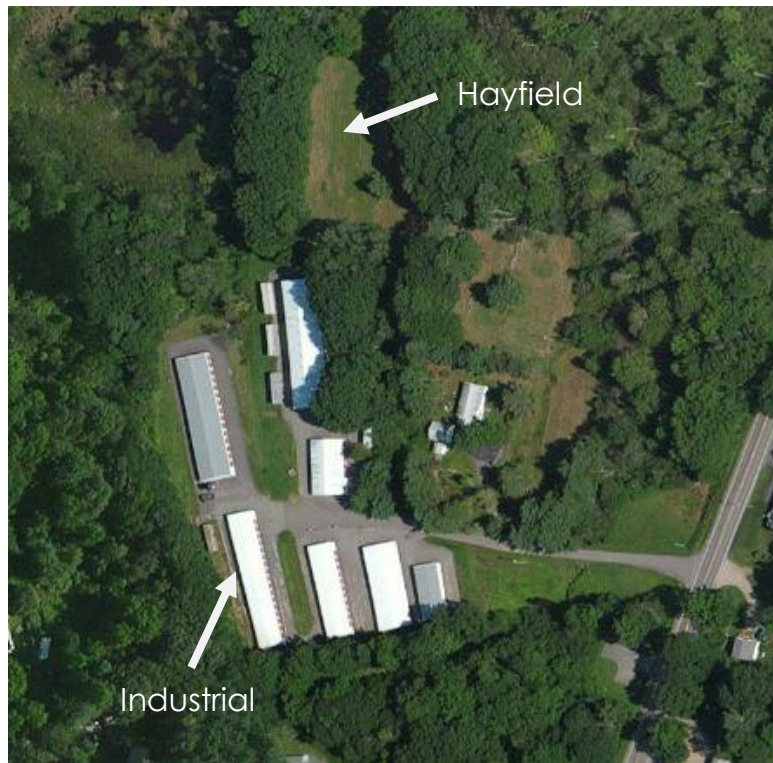
## ATTACHMENT 3: Land Cover by Sub-Basin

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

| Land Cover | Runoff P export coefficient used | Baseflow P export coefficient used | Area (ha) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | K4 | K5 | K5b | K6 | K8 | K8b | Knick Direct | NONAME | NONAME2 | K1 | K2 | K3 | K7 | LKnick Direct |
| Urban 1: Low Den Res | 0.79 | 0.01 | 0.5 | | 0.0 | 0.1 | 1.1 | 0.3 | 0.9 | 0.2 | 0.8 | | 0.2 | 0.3 | 0.0 | 0.1 |
| Urban 2: Mid Den Res/Comm | 0.90 | 0.01 | 0.3 | | | | | | 0.1 | 0.2 | 0.1 | | | | 0.3 | |
| Urban 3: Roads | 0.30 | 0.01 | 1.5 | 0.1 | 0.2 | 0.1 | 2.2 | 0.3 | 1.3 | 0.3 | 1.4 | 0.2 | | 0.0 | 1.0 | 0.3 |
| Urban 4: Industrial | 0.90 | 0.01 | | | | | | | | | | | | | | |
| Urban 5: Open Space | 0.60 | 0.01 | 0.0 | | | 0.4 | 1.3 | 0.0 | 1.6 | 0.4 | 0.6 | | 0.4 | | 0.2 | 0.3 |
| Agric 1: Cvr Crp | 0.80 | 0.01 | | | | | | | | | | | | | | |
| Agric 2: Row Crop | 2.20 | 0.01 | | | | | | | | | | | 0.1 | | | |
| Agric 3: Grazing | 0.80 | 0.01 | 0.6 | | | | | | | | | | 0.0 | | | |
| Agric 4: Hayfield | 0.37 | 0.01 | 0.6 | | | | | | | | | | | | | |
| Forest 1: Deciduous | 0.03 | 0.004 | | | | 9.8 | 6.3 | | 2.6 | 6.7 | 7.5 | | 0.2 | 0.5 | 0.1 | |
| Forest 2: NonDeciduous | 0.03 | 0.004 | 5.0 | | | 30.0 | 16.6 | 4.2 | 8.2 | 0.8 | 0.6 | 4.2 | 14.8 | 16.9 | 14.0 | 1.4 |
| Forest 3: Mixed | 0.03 | 0.004 | 9.8 | 6.1 | 5.4 | 21.2 | 8.3 | 0.5 | 33.6 | 3.6 | 10.2 | | 1.8 | 3.9 | 5.7 | 18.1 |
| Forest 4: Wetland | 0.03 | 0.004 | | | | 1.8 | 0.3 | | 1.6 | | 5.4 | | 4.8 | 6.1 | 2.1 | 3.4 |
| Forest 5: Scrub-Shrub | 0.03 | 0.004 | | | | 0.6 | 1.6 | | | | | | | | 1.2 | |
| Open 1: Open Water | 0.02 | 0.004 | 0.2 | 0.1 | 0.0 | 1.1 | 1.1 | 0.1 | 1.0 | 0.3 | 1.0 | 0.1 | 0.7 | 0.4 | 1.1 | 0.6 |
| Open 2: Meadow/Clearing | 0.03 | 0.004 | | | | | 2.3 | 3.0 | 0.1 | 3.7 | | | | | | |
| Other 1: Freshwater Emergent Wetland | 0.02 | 0.004 | | | | | | | | | 0.6 | | | | | 0.5 |
| Other 2: Unpaved Road | 0.83 | 0.01 | | 0.0 | 0.0 | 0.2 | | | 1.8 | 0.4 | 0.4 | | 0.2 | 0.4 | 0.0 | |
| Other 3: Excavation | 0.80 | 0.01 | | | | | | | | | | 1.8 | 1.2 | | | |
| | | TOTAL | 18.5 | 6.3 | 5.6 | 65.3 | 41.2 | 8.5 | 52.9 | 16.5 | 28.5 | 6.3 | 24.5 | 28.5 | 25.8 | 24.7 |

## 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 calculated areas of Urban 1-5 and Other 1 per new building (based on current land cover areas and number of existing buildings) were multiplied by the number of new buildings in each sub-basin. A total of 0.20 ha was converted per new building for Knickerbocker Lake sub-basins and 0.46 ha for Little Knickerbocker Lake sub-basins.
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. The percent settled TP load resuspended under current conditions was calculated. 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.
8. **Roughly matched outflow TP to predicted in-lake TP.**
9. **Kept all else the same, including drinking water withdrawals.**