# KINGSTON LAKE

# LAKE LOADING RESPONSE MODEL

Prepared by **FB Environmental Associates**

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**PREPARED FOR:**

TOWN OF KINGSTON

*In partnership with the Kingston Lake Association*
*and YMCA Camp Lincoln*

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## INTRODUCTION

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

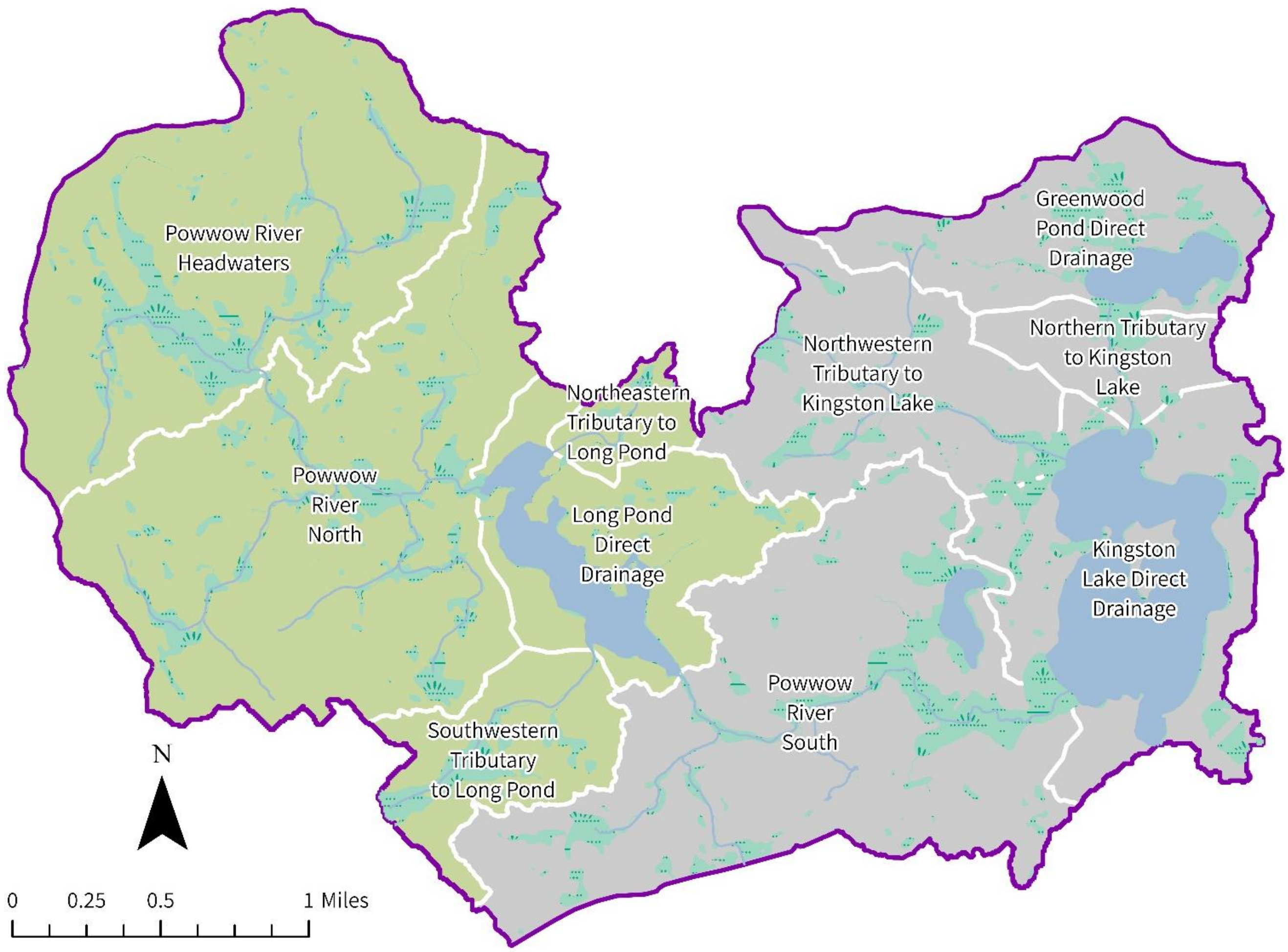


FIGURE 1. Boundaries for the Kingston Lake watershed (purple outline) and its respective sub-watersheds (white outline), including those for Long Pond and Greenwood Pond. A separate model was run for Long Pond (green-shaded sub-watersheds) for input into Kingston Lake (gray-shaded sub-watersheds). Teal areas represent wetlands. Blue areas and lines represent surface waters.

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

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

## WATERSHED AND SUB-WATERSHED DELINEATIONS

Watershed and tributary drainage area (sub-watershed) boundaries are needed to determine both the amount of water flowing into a surface waterbody and the area of different land cover types contributing to nutrient loading. FB Environmental Associates (FBE) extracted the watershed boundary from the USGS National Watershed Boundary Dataset (WBD) (HUC12-010700020105) for the Powwow River drainage. FBE derived an initial version of the Kingston Lake watershed from StreamStats, an online watershed modeling tool developed by the USGS. This online tool integrates data collected through the National Hydrography Dataset (NHD). Then, FBE completed sub-watershed delineations according to an ArcGIS Pro workflow that uses a digital elevation model from the USGS to determine flow direction and accumulations. This analysis provided higher resolution flow paths and identified several flow paths that appeared to discharge to points outside of the watershed rather than into the watershed. Because of these discrepancies between the original Kingston Lake watershed and the flow paths from the digital elevation model, FBE staff visited the watershed three times to verify flow directions of streams and road and trail crossings. Field checks confirmed whether the digital elevation model or the NHD was correct for different locations near the watershed and sub-watershed boundaries (Figure 1). The final watershed boundary excludes one area to the north and one area to the south that were included in the preliminary watershed boundary. Additional details on the watershed and sub-watershed delineations are provided in Attachment 4.

## LAND COVER DATA

Land cover determines the movement of water and phosphorus from the watershed to surface waterbodies via surface runoff and baseflow (groundwater). A significant amount of time went into creating, reviewing, and refining the land cover data. First, available data such as the National Wetland Inventory, NHD, roads from the NHDOT roads layer (NH GRANIT), impervious surfaces in the coastal watershed of New Hampshire (NH GRANIT), coastal priority agricultural resources (NH GRANIT), and Microsoft building footprints were used as a base. Layers were buffered, if applicable, and assigned the proper LLRM land cover category. Next, rectangular grids (or quads) were created to break up the watershed into more manageable portions for editing. ESRI World imagery, 2015 1-ft Color Aerial Photos from NH GRANIT, and Google Earth satellite images were reviewed to create the updated land cover for Kingston Lake; the extent of different land uses was determined via aerial imagery and the layer was edited using the Editor tool for splitting polygons or editing vertices. Each new polygon was relabeled in the attribute table with the appropriate LLRM land cover category.

A few assumptions or actions were made during this process:

- Agricultural fields (whether row crops or hayfields) that were clearly not pasture were assigned to "Agric 2: Row Crop/Hayfield"; it was difficult to discern whether a field was used as a cover crop and so no cover crops were assigned in the watershed. FBE further refined land cover by distinguishing among hayfields ("Agric 2: Row Crop/Hayfield"), meadows that were scrub-shrub, non-wetland areas ("Open 2: Meadow"), or extensive lawns or athletic fields or cemeteries ("Urban 5: Open Space"); residential lawns were included in "Urban 1: Low Density Residential."
- Recently logged areas ("Other 1: Logging") were differentiated from upland forest areas ("Forest 1: Upland").
- Palustrine wetland areas from the NWI were added as "Forest 2: Wetlands."
- Open water areas and streams from the NHD were added as "Open 1: Water."
- Roads from the NHDOT roads layer (NH GRANIT) were added as "Urban 3: Roads" or "Other 1: Unpaved Roads".
- Major bare soil areas that were not associated with new residential home construction were labeled as "Open 3: Excavation."

Agricultural and developed lands were checked carefully since modeling coefficients (i.e., phosphorus export) are generally higher for those land cover types. Aerials were checked thoroughly for each major agricultural or developed area to distinguish between hayfields, grazing/pasture, lawns, and meadows. The resulting land cover file is a more accurate representation of current land cover within the Kingston Lake watershed compared to coarse-scale data such as the National Land Cover Dataset (NLCD) (refer to Figure 2 for comparison between the NLCD and FBE's land cover file).

Within the LLRM, export coefficients are assigned to each land cover to represent typical concentrations of phosphorus in runoff and baseflow from those land cover types (Attachment 1). Unmanaged forested land, for example, tends to deliver very little phosphorus downstream when it rains, while low to high density urban development export significantly more phosphorus due to impervious surfaces, fertilizer use, soil erosion, car and factory exhaust, pet waste, and many other sources. Smaller amounts of phosphorus are also exported to lakes and streams via groundwater under baseflow conditions. This nutrient load is delivered with groundwater to the lake directly or to tributary streams; however, much of the phosphorus is adsorbed onto soil particles as water infiltrates to the ground. Attachment 1 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 for each sub-watershed. These coefficients were based on values from Tarpey (2013), Johnes (1996), USEPA (2017), King et al. (2007), Hutchinson Environmental Sciences Ltd (2014), and Schloss et al. (2000), among others.

Figure 3 shows a basic breakdown of land cover by major category for the watershed (not including lake area), as well as total phosphorus load by major land cover category for the watershed. Developed areas cover 16% of the watershed and contribute 80% of the total phosphorus watershed load to Kingston Lake.

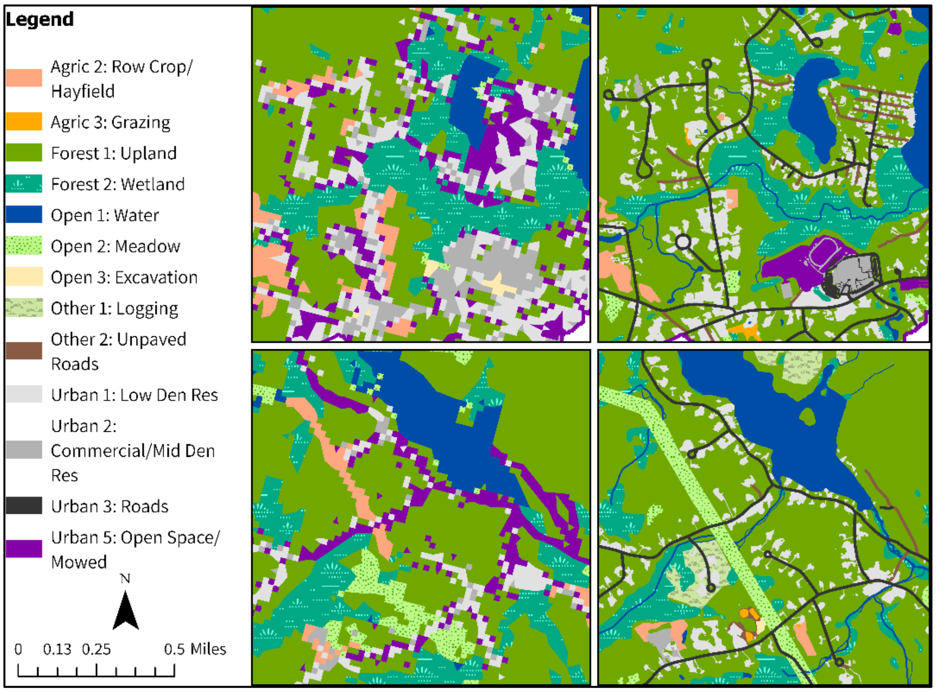


FIGURE 2. Examples of land cover file comparisons between the 2021 National Land Cover Dataset (NLCD) and FBE's modified land cover file for the Kingston Lake watershed.

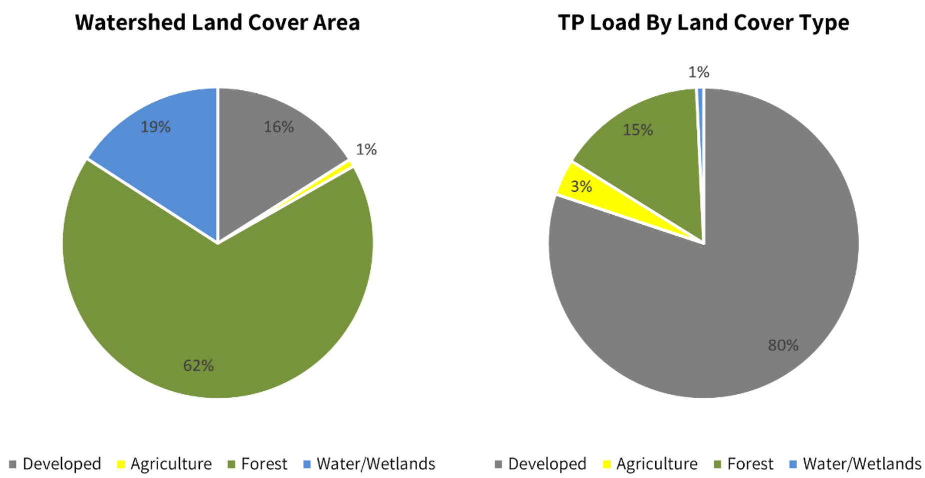


FIGURE 3. Kingston Lake watershed (including Long Pond watershed) land cover area by general category (developed, agriculture, forest, and water/wetlands) and total phosphorus (TP) watershed load by general land cover type. This shows that developed areas cover 16% of the watershed and contribute 80% of the TP watershed load to Kingston Lake. Water/wetlands category does not include the Kingston Lake and Long Pond surface areas, but does include other ponds.

## OTHER MAJOR LLRM INPUTS

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

- **Yearly precipitation data** were obtained from NOAA NCEI for the EPPING, NH US (Station ID: USC00272800) weather station. Data gaps for 1993, 2000, and 2003-2005 were filled using the GREENLAND, NH US (Station ID: USC00273626) weather station. The average annual precipitation total from 2013-2022 was input as 1.10 m.
- **Lake volume and area estimates** were obtained from the NH GRANIT bathymetry shapefile.
- **Point sources** from other lake models were input to the Kingston Lake model. Long Pond was modeled separately; the outputs of water load and in-lake water quality concentrations from the Long Pond model were entered as a point source to the southern Powwow River sub-watershed of the Kingston Lake model. Water load was determined as the total water volume for Long Pond multiplied by its flushing rate, as was estimated by the LLRM and close to the flushing rate recorded in 1995 NHDES Trophic Survey Report for Long Pond. Total phosphorus load was estimated using the modeled annual average in-lake total phosphorus concentration in Long Pond multiplied by its annual water load.
- **Septic system data** were gathered from state and local property records. FBE staff researched 140 parcels within 250 feet of Kingston Lake and 67 parcels within 250 feet of Long Pond. FBE searched property records for pertinent information such as date house built, date of most recent septic installation or upgrade, number of bedrooms, and seasonal or year-round use, if available (otherwise assumed year-round). Some systems, especially those replaced in recent years, are sited outside of the 250-foot shoreland zone, if possible, based on the property lines. The exact location of each septic drainfield is available on the site plan and can reveal whether or not the system is within 250 feet of the waterbody. Systems located outside of the 250-foot shoreland zone were excluded from the dataset. From the surveyed information, the number of "old" (>25 years) and "young" (<25 years) shoreline septic systems used seasonally or year-round was determined and multiplied by the number of bedrooms (as a surrogate for the average number of persons using the septic systems) to determine the number of persons on septic systems around the lake and ultimately the associated water and total phosphorus load from them.
- **Water quality data** were gathered from NHDES Environmental Monitoring Database (EMD). Data were screened for relevant site locations and water quality parameters (Secchi disk transparency, chlorophyll-a, total phosphorus, dissolved oxygen, and temperature). The model was calibrated, as appropriate, using tributary and lake samples taken between 2013 and 2022. Sites were only included if they were a close match to the outlet of a sub-watershed used in the model. Data were summarized to obtain mean water quality summaries for total phosphorus, chlorophyll-a, and Secchi Disk Transparency and aggregated for multiple lake sites.
- **Waterfowl counts** for Kingston Lake were based on a standard estimate of 0.3 birds per hectare of lake surface area. This default value is based on best professional experience with modeling other similar lakes in the area. Waterfowl can be a direct source of nutrients to lakes; however, if they are eating from the lake and their waste returns to the lake, the net change may be less than might otherwise be assumed; even so, the phosphorus excreted may be in a form that can be readily used by algae and plants.
- **Internal loading estimates** were derived from dissolved oxygen and temperature profiles taken at the deep spots of Kingston Lake (to determine average annual duration and depth of anoxia defined as <2 ppm dissolved oxygen) and epilimnion/hypolimnion total phosphorus data taken at the deep spots of Kingston Lake (to determine average difference between surface and bottom phosphorus concentrations). These estimates, along with anoxic volume and surface area, helped determine rate of release and mass of annual internal phosphorus load. Data were limited during the late season (when internal loading is at its peak), meaning there was limited information about phosphorus dynamics and internal loading in Kingston Lake. Long Pond has been observed to stratify weakly or not at all, depending on the year. With few dissolved oxygen profiles and limited hypolimnion total phosphorus data, there is substantial uncertainty in the internal loading estimate until additional data can be collected. However, the few winter samples collected from Long Pond showed in-lake total phosphorus concentrations significantly lower than summer samples, suggesting internal phosphorus loading is possible. Long Pond is otherwise too shallow and well-mixed year-round for quantification of internal phosphorus loading in a similar manner as deep stratified lakes such as Kingston Lake.

# CALIBRATION

Calibration is the process by which model results are brought into agreement with observed data and is an essential part of environmental modeling. Usually, calibration focuses on the input data with the greatest uncertainty. Changes are made within a plausible range of values, and an effort is made to find a realistic explanation among environmental conditions for these changes. Minimal tributary phosphorus concentration data were available for the modeling period (2013-2022) and thus were only used as guideposts; however, tributary monitoring efforts have greatly improved in recent years and should be continued to improve model calibration in the future. Observed in-lake phosphorus concentrations were given primacy during the calibration process, such that the ability of the model to accurately simulate annual average in-lake phosphorus concentration was used as a leading indicator of acceptable model performance. Continued water quality sampling in the watershed can be designed to reduce the uncertainty encountered in modeling and help assess assumptions made during calibration.

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

- **Predicted in-lake total phosphorus** for Kingston Lake was calibrated to the average observed fully mixed total phosphorus concentration in early spring, representing annual average conditions. Predicted in-lake total phosphorus for Long Pond was calibrated to the seasonal-weighted average of observed total phosphorus concentrations, representing annual average conditions.
- **Direct atmospheric deposition** phosphorus export coefficient of 0.20 kg/ha/yr was used based on the 1999 Great Pond Diagnostic/Feasibility Study (NHDES, 1999).
- Point source and sub-watershed **routing** for the Long Pond and Kingston Lake models is presented in Figure 1.
- Default **water and phosphorus attenuation factors** were first used before each sub-watershed's attenuation factors were adjusted to account for landscape features that would increase or decrease attenuation (Table 1). Water can be lost through evapotranspiration, groundwater, and wetlands, while phosphorus can be removed by infiltration or uptake processes. We generally expect at least a 5% loss (95% passed through, default) in water and a 10% loss (90% passed through, default) in phosphorus for each sub-watershed. Larger water losses (<95% passed through) can be expected with lower gradient or wetland-dominated sub-watersheds. Additional infiltration, filtration, detention, and uptake of phosphorus will lower the phosphorus attenuation value, such as for sub-watersheds dominated by moderate/small ponds or wetlands (75%-85% passed through) or channel processes that favor uptake (85% passed through), depending on the gradient. Headwater systems are assumed to have a greater attenuation than higher order streams since the flow of water is lower, giving more opportunity for infiltration, adsorption, and uptake.
- The average of multiple **empirical formulas** for predicting annual in-lake phosphorus concentration was used according to the most appropriate formulas for each lake.
    - Long Pond: Kirchner-Dillon (1975), Reckhow General (1977), and Nurnberg (1998) – other models were predicting too high for the in-lake data available for calibration.
    - Kingston Lake: Kirchner-Dillon (1975), Vollenweider (1975), Larsen-Mercier (1976), Jones-Bachmann (1976), Reckhow General (1977), and Nurnberg (1998) – all models were used for calibration.

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

| Sub-Watershed | Water Atten. Factor | Phos. Atten. Factor | Reasoning (water; phosphorus (P)) |
|---|---|---|---|
| **Long Pond** | | | |
| Powwow River Headwaters | 0.80 | 0.75 | Attenuation by wetlands and channel processes that promote uptake. |
| Powwow River North | 0.80 | 0.75 | Attenuation by wetlands and channel processes that promote uptake. |
| Long Pond – NE Tributary | 0.95 | 0.90 | Default water and P attenuation factor due to proximity to lake. |
| Long Pond – SW Tributary | 0.95 | 0.90 | Default water and P attenuation factor due to proximity to lake. |
| Long Pond Direct | 0.95 | 0.90 | Default water and P attenuation factor due to proximity to lake. |
| **Kingston Lake** | | | |
| Greenwood Pond Direct | 0.55 | 0.50 | Attenuation in large pond and wetlands. |
| Powwow River South | 0.80 | 0.75 | Attenuation by wetlands. |
| Kingston Lake – N Tributary | 0.80 | 0.75 | Attenuation by wetlands and channel processes that promote uptake. |
| Kingston Lake – NW Tributary | 0.90 | 0.85 | Attenuation by wetlands. |
| Kingston Lake Direct | 0.95 | 0.90 | Default water and P attenuation factor due to proximity to lake. |

## LIMITATIONS TO THE MODEL

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

- **The model represents a static snapshot in time based on the best information available at the time of model execution.** Factors that influence water quality are dynamic and constantly evolving; thus, the model should be regularly updated when significant changes occur within the watershed and as new water quality and physical data are collected. In this respect, the model should only be considered up-to-date on the date of its release. Model results represent annual averages and are best used for planning level purposes and should only be used with full recognition of the model limitations and assumptions.
- **Limited water quality data were available for calibration and internal loading estimates.** More data at the lake deep spots, lake outlet, and tributaries are needed to effectively calibrate the model to known observations and generate more accurate estimates of internal loading. We recommend that the model be re-evaluated after 5-10 years of robust data collection. Tributary data were only available for recent years and thus were used as guideposts during the calibration process. Conservative estimates were determined for internal phosphorus loading in Kingston Lake; the internal load could at times be much higher but was difficult to confirm with the limited data set, particularly due to lack of data in September-October when internal loading tends to peak in lakes. A lack of data led to substantial uncertainty in the internal loading estimates for both Kingston Lake and Long Pond.
- **Septic system loading was estimated based on default literature values and regional statistics.** Default literature values for daily water usage, phosphorus concentration output per person, and system phosphorus attenuation factors were used and may not reflect local watershed conditions.
- **Waterfowl counts were based on default estimates.** In the future, a large bird (e.g., geese, ducks, etc.) census throughout the year would help improve the model loading estimates.
- **Land cover export coefficients were estimates.** Literature values and best professional judgement were used in evaluating and selecting appropriate land cover export coefficients for Kingston 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.
- **Internal loading was estimated based on the limited available data for each waterbody.** Internal loading can vary throughout the growing season but tends to peak in late fall when the hypolimnion is at its most anoxic. Data for Kingston Lake and Long Pond was extremely limited across the growing season, leading to uncertainty in the estimates.

# RESULTS

### CURRENT LOAD ESTIMATION

Overall, model predictions were in good agreement with observed data for total phosphorus (1-3%), chlorophyll-a (5-9%), and Secchi disk transparency (6-31%) (Table 2). It is important to note that the LLRM does not explicitly account for all the biogeochemical processes occurring within a waterbody that contribute to overall water quality and is less accurate at predicting chlorophyll-a and Secchi disk transparency. For example, chlorophyll-a is estimated strictly from nutrient loading, but other factors strongly affect algae growth, including transport of phosphorus from the sediment-water interface to the water column by cyanobacteria, low light from suspended sediment, grazing by zooplankton, presence of heterotrophic algae, and flushing effects from high flows. There were insufficient data available to evaluate the influence of these other factors on observed chlorophyll-a concentrations and Secchi disk transparency readings.

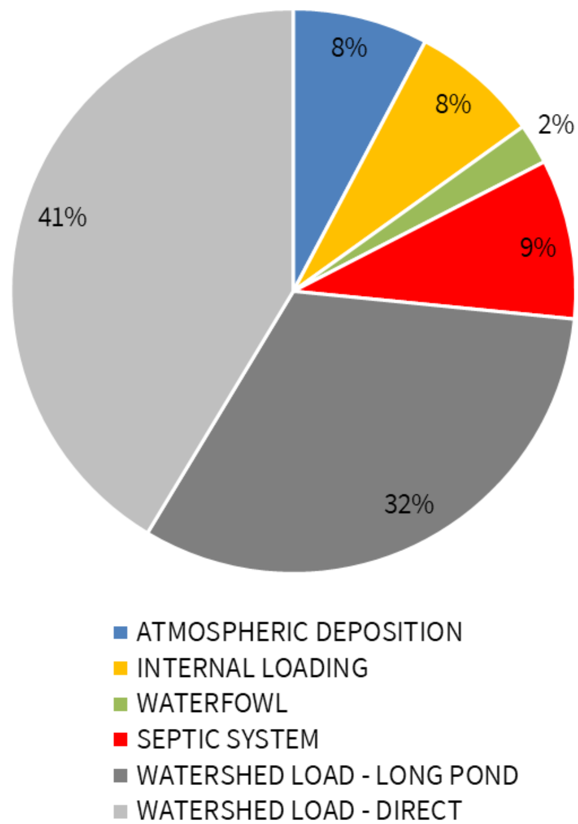


FIGURE 4. Summary of total phosphorus loading by major source for Kingston Lake. Refer to Table 3 for a breakdown.

Watershed runoff combined with baseflow (73%) was the largest phosphorus loading contribution across all sources to Kingston Lake, followed by shorefront septic systems at 9%, atmospheric deposition at 8%, and internal loading at 8% (Table 3; Figure 4). Waterfowl (2%) were a relatively minor source. The watershed load includes the watershed load from Long Pond (32%) and the direct land area to Kingston Lake (41%). Greenwood Pond and Halfmoon Pond were not modeled separately, and their watershed land areas were therefore included in the Kingston Lake model. Development in the watershed is most concentrated in pockets near waterbodies, particularly between Greenwood Pond and Kingston Lake, the Great Pond Park area, and around lake shorelines where septic systems are located within a short distance to the water, leaving little horizontal (and sometimes vertical) space for proper filtration of wastewater effluent. Improper maintenance or siting of these systems can cause failures, which leach untreated, nutrient-rich wastewater effluent to the lake. Note that 1) the estimate for the septic system load is only for those systems directly along the shoreline and potentially short-circuiting minimally treated effluent to the lake; and 2) the load from septic systems throughout the rest of the watershed is inherent to the coefficients used to generate the watershed load. Internal loading, whereby low dissolved oxygen in bottom waters is causing a release of phosphorus from sediments, was estimated as a relatively minor source of phosphorus to the lake; however, the limited amount of dissolved oxygen and total phosphorus data in the hypolimnion add uncertainty to internal loading estimates. Although internal loading is not estimated to be a major source of phosphorus, careful monitoring of the severity and extent of anoxia in Kingston Lake should be monitored both to gauge the potential for internal loading and for the protection of aquatic life. In the meantime, watershed protection efforts should focus on reducing the watershed and septic system loads.

Normalizing for the size of a sub-watershed (i.e., accounting for its annual discharge and direct drainage area) better highlights sub-watersheds with elevated pollutant exports relative to their drainage area. Sub-watersheds with moderate-to-high phosphorus mass exported by area (> 0.20 kg/ha/yr) generally had more development (i.e., the direct shoreline area to Kingston Lake, the northern tributary to Kingston Lake, and the northern and southern reaches of the Powwow River; Table 4, Figure 5). Drainage areas directly adjacent to waterbodies have direct connection to lakes and are usually targeted for development, thus increasing the possibility for phosphorus export.

### PRE-DEVELOPMENT LOAD ESTIMATION

Once the model is calibrated for current in-lake phosphorus concentration, we can then manipulate land cover and other loading factors to estimate pre-development loading scenarios (e.g., what in-lake phosphorus concentration was prior to human development or the best possible water quality for the lake). Refer to Attachment 2 for details on methodology. Pre-development loading estimation showed that total phosphorus loading to Kingston Lake increased by 444%, from 53.1 kg/yr prior to European settlement to 289.0 kg/yr under current conditions (Table 3). These additional phosphorus sources are coming from development in the watershed (especially from the direct shoreline of Kingston Lake and Long Pond), internal loading, septic systems, and atmospheric dust (Tables 3, 4). Water quality prior to settlement was predicted to be excellent with extremely low phosphorus and chlorophyll-a concentrations and high water clarity (Table 2).

**FUTURE LOAD ESTIMATION**

We can also manipulate land cover and other factors to estimate future loading scenarios (e.g., what in-lake phosphorus concentration might be at full build-out under current zoning constraints or the worst possible water quality for the lake). Refer to Attachment 3 and the 2024 Kingston Lake Watershed Build-out Analysis Report for details on methodology. Note: the future scenario did not assume a 10% increase in precipitation over the next century (NOAA Technical Report NESDIS 142-1, 2013), which would have resulted in a lower predicted in-lake phosphorus concentration; this is because the model does not consider the rate and distribution of the projected increase in precipitation. Climate change models predict more intense and less frequent rain events that may exacerbate erosion of phosphorus-laden sediment to surface waters and therefore could increase in-lake phosphorus concentration (despite dilution and flushing impacts that the model assumes).

Future loading estimation showed that total phosphorus loading to Kingston Lake may increase by 23%, from 289.0 kg/yr under current conditions to 356.1 kg/yr at full build-out (2110) under current zoning (Table 3). Additional phosphorus will be generated from more development in the watershed (especially from suburban and undeveloped areas near tributaries to Long Pond and Kingston Lake), enhanced internal loading, and greater atmospheric dust (Tables 3, 4). The buildout analysis predicted very few new residences within the direct shoreline zone of Long Pond (3) and Kingston Lake (0). There is unlikely to be major increases in phosphorus loading from shoreline septic systems aside from the conversion of the final remaining seasonal properties to year-round use; however, converting to year-round usage would require designing and installing a new septic system on the property, which would likely be an upgrade compared to the older systems on these parcels. At full buildout, the model predicted higher (worse) phosphorus (19.9 ppb), higher (worse) chlorophyll-a (5.6 ppb), and lower (worse) water clarity (2.3 m) compared to current conditions for Kingston Lake (Table 2). The number of bloom days may increase from an average of 21 days currently to an average of 60 days at full build-out (Table 2).

TABLE 2. In-lake water quality predictions for Long Pond and Kingston Lake. TP = total phosphorus. Chl-a = chlorophyll-a. SDT = Secchi disk transparency. Bloom Days represent average annual probability of chlorophyll-a exceeding 8 ppb.

| Model Scenario | Median TP (ppb) | Predicted Median TP (ppb) | Mean Chl-a (ppb) | Predicted Mean Chl-a (ppb) | Mean SDT (m) | Predicted Mean SDT (m) | Bloom Days |
|---|---|---|---|---|---|---|---|
| **Long Pond** | | | | | | | |
| Pre-Development | -- | 3.4 | -- | 0.5 | -- | 9.0* | 0 |
| Current -2022 | 15.3 | 15.5 | 4.1 | 4.3 | 2.7 | 2.8 | 25 |
| Future (2110) | -- | 19.3 | -- | 5.9 | -- | 2.4 | 73 |
| **Kingston Lake** | | | | | | | |
| Pre-Development | -- | 2.9 | -- | 0.3 | -- | 10.0 | 0 |
| Current -2022 | 15.7 | 16.1 | 3.7 | 4.1 | 3.7 | 2.7 | 21 |
| Future (2110) | -- | 19.9 | -- | 5.6 | -- | 2.3 | 60 |

**The maximum depth of Long Pond is around 3 meters. The model predicts the mean Secchi disk transparency (SDT) based on the predicted total phosphorus concentration and other lake variables, which do not include the maximum depth of the pond. For the pre-development model scenario for Long Pond, the mean SDT is predicted at a deeper depth than the lake bottom. For lake management purposes, the predicted mean SDT in the pre-development scenario should be considered as the lake bottom.*

TABLE 3. Total phosphorus (TP) and water loading summary by source for Long Pond and Kingston Lake.

| SOURCE | PRE-DEVELOPMENT | | | CURRENT (2022) | | | FUTURE (2110) | | |
|---|---|---|---|---|---|---|---|---|---|
| | TP (KG/YR) | % | WATER (CU.M/YR) | TP (KG/YR) | % | WATER (CU.M/YR) | TP (KG/YR) | % | WATER (CU.M/YR) |
| **LONG POND** | | | | | | | | | |
| ATMOSPHERIC | 3.0 | 8% | 252,563 | 8.6 | 5% | 252,563 | 10.8 | 5% | 252,563 |
| INTERNAL | 0.0 | 0% | 0 | 4.3 | 3% | 0 | 5.4 | 3% | 0 |
| WATERFOWL | 2.6 | 7% | 0 | 2.6 | 1% | 0 | 2.6 | 1% | 0 |
| SEPTIC SYSTEM | 0.0 | 0% | 0 | 10.1 | 6% | 8,325 | 11.1 | 5% | 9,630 |
| WATERSHED LOAD | 31.0 | 85% | 5,761,873 | 140.4 | 85% | 5,717,707 | 176.1 | 86% | 5,701,534 |
| **TOTAL LOAD TO LAKE** | **36.6** | **100%** | **6,014,435** | **166.0** | **100%** | **5,978,595** | **205.9** | **100%** | **5,963,726** |
| **KINGSTON LAKE** | | | | | | | | | |
| ATMOSPHERIC | 7.8 | 15% | 655,572 | 22.4 | 8% | 655,572 | 27.9 | 8% | 655,572 |
| INTERNAL | 0.0 | 0% | 0 | 21.3 | 8% | 0 | 26.2 | 7% | 0 |
| WATERFOWL | 6.7 | 13% | 0 | 6.7 | 2% | 0 | 6.7 | 2% | 0 |
| SEPTIC SYSTEM | 0.0 | 0% | 0 | 26.5 | 9% | 21,804 | 28.8 | 8% | 23,681 |
| WATERSHED LOAD | 38.5 | 72% | 9,884,603 | 212.2 | 73% | 9,795,802 | 266.5 | 75% | 9,763,161 |
| *Long Pond* | *20.6* | | | *92.7* | | | *115.1* | | |
| *Direct Land Use Load* | *17.9* | | | *119.5* | | | *151.4* | | |
| **TOTAL LOAD TO LAKE** | **53.1** | **100%** | **10,540,175** | **289.0** | **100%** | **10,473,179** | **356.1** | **100%** | **10,442,565** |

TABLE 4. Summary of land area, water flow, and total phosphorus (TP) concentration and loading by sub-watershed for Long Pond and Kingston Lake. Land area does not include the area of the lake.

| Sub-Watershed | Land Area (ha) | Pre-Development Watershed Loads | | | | Current (2022) Watershed Loads | | | | | Future (2110) Watershed Loads | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Water Flow ($m^3$/year) | Calc. P Conc. (mg/L) | P mass (kg/year) | P mass by area (kg/ha/year) | Water Flow ($m^3$/year) | Calc. P Conc. (mg/L) | Measured P Conc. (mg/L) | P mass (kg/year) | P mass by area (kg/ha/year) | Water Flow ($m^3$/year) | Calc. P Conc. (mg/L) | P mass (kg/year) | P mass by area (kg/ha/year) |
| **Long Pond** | **1,123.0** | **6,014,435** | **0.006** | **36.6** | **0.03** | **5,978,595** | **0.028** | **--** | **166.0** | **0.15** | **5,963,726** | **0.035** | **205.9** | **0.18** |
| Powwow River Headwaters | 387.6 | 1,970,543 | 0.005 | 10.2 | 0.03 | 1,956,476 | 0.020 | 0.015 | 38.8 | 0.10 | 1,949,225 | 0.027 | 52.0 | 0.13 |
| Powwow River North* | 441.8 | 2,258,766 | 0.006 | 12.8 | 0.03 | 2,241,210 | 0.031** | 0.076 | 69.1 | 0.16 | 2,237,399 | 0.036 | 81.3 | 0.18 |
| Northeastern Tributary | 31.3 | 190,310 | 0.005 | 0.9 | 0.03 | 189,963 | 0.017 | -- | 3.2 | 0.10 | 189,703 | 0.026 | 4.9 | 0.16 |
| Southwestern Tributary | 96.9 | 582,612 | 0.006 | 3.5 | 0.04 | 574,339 | 0.032 | 0.044 | 18.3 | 0.19 | 571,858 | 0.039 | 22.3 | 0.23 |
| Long Pond Direct | 165.4 | 759,641 | 0.005 | 3.6 | 0.02 | 755,719 | 0.015 | -- | 11.0 | 0.07 | 753,349 | 0.021 | 15.5 | 0.09 |
| **Kingston Lake** | **958.8** | **10,540,175** | **0.005** | **53.1** | **0.06** | **10,473,179** | **0.027** | **--** | **289.0** | **0.30** | **10,442,565** | **0.034** | **356.1** | **0.37** |
| Greenwood Pond Direct | 153.1 | 513,675 | 0.004 | 2.1 | 0.01 | 508,700 | 0.019 | -- | 9.6 | 0.06 | 506,344 | 0.026 | 13.0 | 0.08 |
| Kingston Lake Direct | 138.5 | 832,787 | 0.004 | 3.7 | 0.03 | 824,307 | 0.037 | -- | 30.4 | 0.22 | 822,816 | 0.043 | 35.1 | 0.25 |
| Northern Tributary* | 58.1 | 294,553 | 0.004 | 1.3 | 0.02 | 289,013 | 0.043** | 0.074 | 12.5 | 0.22 | 287,734 | 0.053 | 15.1 | 0.26 |
| Northwestern Tributary | 181.1 | 1,033,802 | 0.004 | 4.6 | 0.03 | 1,029,111 | 0.016 | 0.054 | 16.7 | 0.09 | 1,027,186 | 0.021 | 21.6 | 0.12 |
| Powwow River South* | 428.0 | 2,164,750 | 0.005 | 10.4 | 0.02 | 2,130,569 | 0.032** | 0.027 | 68.6 | 0.16 | 2,118,096 | 0.042 | 88.7 | 0.21 |

** Table shows water and P loads for the direct sub-watershed area only*

*** Actual predicted P for the outlets of these sub-watersheds (including upstream sub-watersheds) are 0.026 mg/L for the Powwow River North, 0.026 mg/L for the Northern Tributary to Kingston Lake, and 0.020 mg/L for the Powwow River South.*

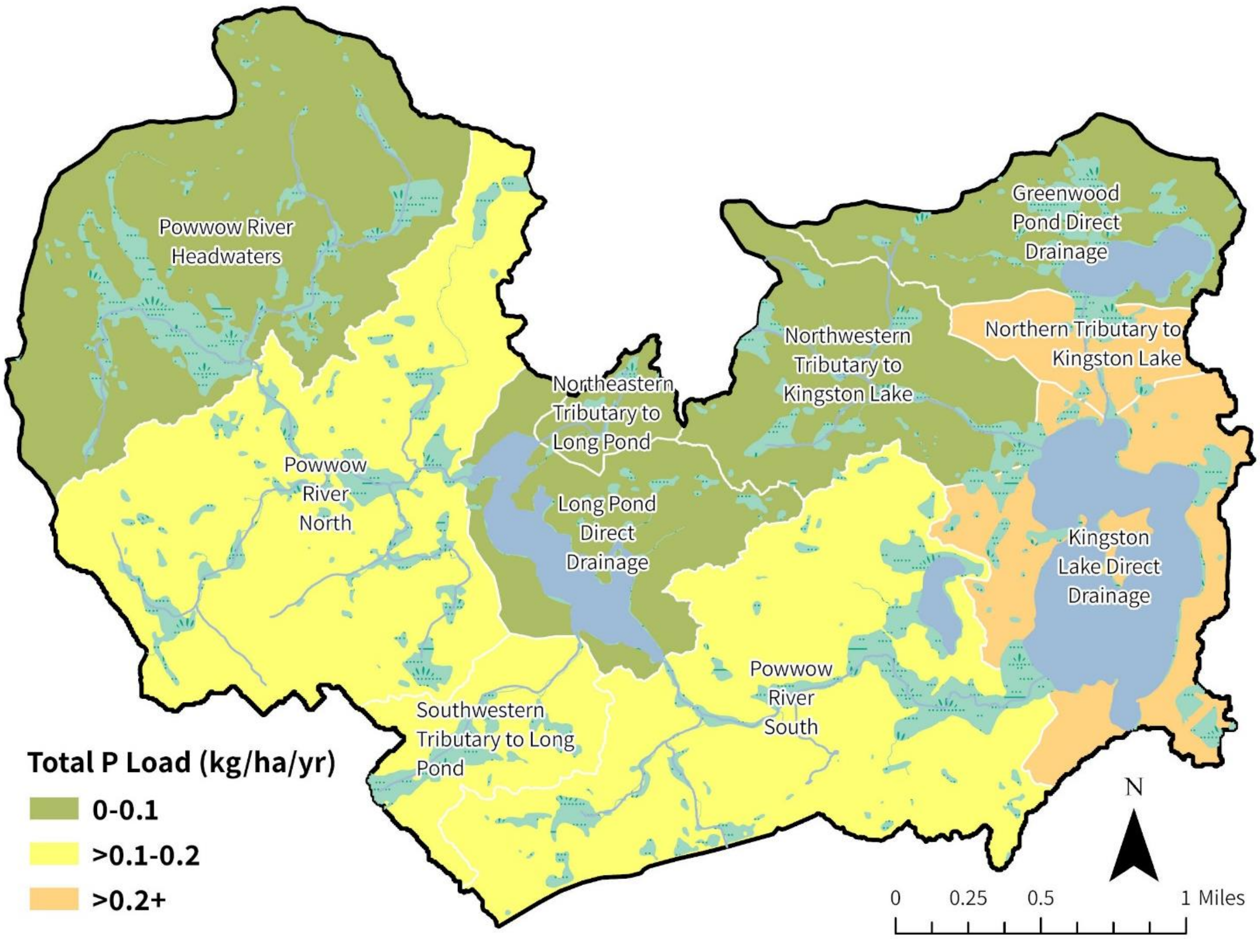


FIGURE 5. Map of current total phosphorus load per unit area (kg/ha/yr) for each sub-watershed in the Kingston Lake watershed. Phosphorus load per unit area only includes the direct area for each sub-watershed (excludes upstream sub-watersheds). Higher phosphorus loads per unit area are concentrated in the more developed areas, including direct shoreline areas.

## CONCLUSION

Kingston Lake's elevated total phosphorus load has resulted in low water clarity, low dissolved oxygen, and cyanobacteria blooms in 2017 and 2021. This degradation in water quality will likely continue in the future with expansion of development in the watershed. Any new increases in phosphorus to a lake can disrupt the ecological balance in favor of increased algal growth, resulting in degraded water quality. The impact from new buildings can be greatly reduced by implementing 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). The impact from existing development and septic systems may be reduced by best management practice (BMP) retrofits and replacing old or failing septic systems with a newer system located as far from the shoreline as possible. The watershed management plan for Kingston Lake will highlight the following actions to improve and protect water quality in the watershed: 1) maximize land conservation of intact forestland, 2) improve and maintain stormwater control practices throughout the watershed, and 3) consider zoning ordinance amendments that encourage LID techniques on existing and new development. We also recommend that enhanced monitoring be completed in the future to further refine the modeling effort and the internal loading estimate. Refer to the Kingston Lake Water Quality Analysis memorandum for further details.

## ATTACHMENT 1: Land Cover

**Land cover water (precip) and phosphorus (P) export coefficients and land cover areas for sub-watersheds in the Kingston Lake watershed. Excludes lake surface area.**

| LAND COVER | RUNOFF EXPORT COEFF. | | BASEFLOW EXPORT COEF | | KINGSTON LAKE SUB-WATERSHEDS | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Precip (Fraction) | P Export (kg/ha/yr) | Precip (Fraction) | P Export (kg/ha/yr) | Greenwood Pond Direct Area (ha) | Kingston Lake Direct Area (ha) | Northern Tributary Area (ha) | Northwestern Tributary Area (ha) | Powwow River South Area (ha) |
| Urban 1 (Low Den Res.) | 0.30 | 0.79 | 0.25 | 0.01 | 10.72 | 18.79 | 10.16 | 8.63 | 44.92 |
| Urban 2 (Med Den Res./Comm.) | 0.50 | 0.82 | 0.05 | 0.01 | 0.63 | 0.72 | 0.00 | 0.00 | 4.97 |
| Urban 3 (Roads) | 0.50 | 1.16 | 0.05 | 0.01 | 4.03 | 7.49 | 4.72 | 4.21 | 25.39 |
| Urban 4 (Industrial) | 0.50 | 1.42 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Urban 5 (Open Space/Mowed) | 0.30 | 0.51 | 0.25 | 0.01 | 1.56 | 1.48 | 0.00 | 0.00 | 6.29 |
| Agric 2 (Row Crop/Hayfield) | 0.30 | 0.37 | 0.30 | 0.01 | 0.50 | 0.00 | 0.00 | 0.00 | 5.88 |
| Agric 3 (Grazing) | 0.30 | 1.50 | 0.30 | 0.01 | 0.35 | 0.00 | 0.00 | 0.00 | 1.48 |
| Forest 1 (Upland) | 0.20 | 0.03 | 0.40 | 0.00 | 88.00 | 79.72 | 31.46 | 135.23 | 254.39 |
| Forest 2 (Wetland) | 0.05 | 0.00 | 0.40 | 0.00 | 24.10 | 23.17 | 8.52 | 24.54 | 57.58 |
| Open 1 (Open Water) | 0.05 | 0.01 | 0.40 | 0.00 | 22.70 | 0.03 | 0.94 | 4.10 | 15.88 |
| Open 2 (Meadow) | 0.30 | 0.20 | 0.30 | 0.00 | 0.00 | 0.27 | 0.00 | 0.24 | 6.95 |
| Open 3 (Excavation) | 0.80 | 0.80 | 0.10 | 0.01 | 0.00 | 1.09 | 0.00 | 0.00 | 0.00 |
| Other 1: Logging | 0.30 | 0.06 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.73 | 0.36 |
| Other 2: Unpaved Road | 0.60 | 0.83 | 0.05 | 0.01 | 0.51 | 5.74 | 2.30 | 3.38 | 3.94 |
| | | | | | **153.1** | **138.5** | **58.1** | **181.1** | **428.0** |

| LAND COVER | LONG POND SUB-WATERSHEDS | | | | | TOTAL AREA (HA) |
|---|---|---|---|---|---|---|
| | Powwow R Headwaters AREA (HA) | Powwow River North AREA (HA) | Northeastern Tributary AREA (HA) | Southwestern Tributary AREA (HA) | Long Pond Direct AREA (HA) | |
| Urban 1 (Low Density Res.) | 23.68 | 47.46 | 0.91 | 9.63 | 5.59 | 180.50 |
| Urban 2 (Medium Density Res./Comm.) | 0.00 | 3.65 | 0.00 | 1.04 | 0.00 | 11.01 |
| Urban 3 (High Density Res./Comm./Roads) | 10.00 | 21.70 | 0.71 | 4.35 | 2.60 | 85.19 |
| Urban 4 (Industrial) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Urban 5 (Open Space/Mowed) | 2.60 | 3.41 | 0.00 | 1.58 | 0.00 | 16.92 |
| Agric 2 (Row Crop/Hayfield/Orchard) | 2.61 | 0.56 | 0.00 | 0.00 | 0.00 | 9.55 |
| Agric 3 (Grazing) | 1.95 | 1.58 | 0.00 | 1.18 | 0.00 | 6.54 |
| Forest 1 (Upland) | 271.81 | 274.98 | 14.45 | 50.76 | 91.27 | 1292.08 |
| Forest 2 (Wetland) | 49.87 | 48.33 | 3.49 | 14.74 | 4.36 | 258.71 |
| Open 1 (Emergent Wetland/Lake) | 8.93 | 9.05 | 0.46 | 1.62 | 0.62 | 64.33 |
| Open 2 (Meadow) | 11.80 | 20.53 | 0.00 | 6.08 | 0.00 | 45.88 |
| Open 3 (Excavation) | 0.00 | 5.49 | 0.00 | 0.00 | 0.02 | 6.60 |
| Other 1: Logging | 0.00 | 1.65 | 10.33 | 5.19 | 17.29 | 35.55 |
| Other 2: Unpaved Road | 4.34 | 3.41 | 0.96 | 0.78 | 0.55 | 25.91 |
| | **387.6** | **441.8** | **31.3** | **96.9** | **122.3** | **2038.76** |

## ATTACHMENT 2: Estimating Pre-Development Phosphorus Load

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

## ATTACHMENT 3: Estimating Future Phosphorus Load at Full Build-Out

1. Estimated number of new buildings at full buildout by sub-watershed. CommunityViz software uses model inputs such as population growth rates, zoning, wetlands, conservation lands, and other constraints to construction, and generates a projected number of new buildings in the future. The new building count was generated for each sub-watershed at full buildout. Refer to the 2024 Kingston Lake Watershed Build-out Analysis Report.
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, Open 3, and Other 1-2 per new building (based on current land cover areas and number of existing buildings) were multiplied by the number of new buildings in each sub-watershed.
3. Incorporated land use changes to LLRM for P loading predictions. Added the new developed land use figures to the LLRM. Within each sub-watershed, existing undeveloped land uses (Forest 1) were replaced with areas equal to added developed land.
4. Incorporated septic system loading to LLRM for P loading predictions. The number of new buildings within 250 feet of water was estimated from the CommunityViz output shapefile of projected new buildings. All other assumptions were kept the same.
5. Increased atmospheric loading coefficient to 0.25 kg/ha/yr.
6. Calculated potential increase in internal loading. Assumed a similar magnitude increase in future internal loading as compared to the increase in future total load to the lake.
7. Roughly matched outflow TP to predicted in-lake TP.
8. Kept all else the same.

# ATTACHMENT 4: Watershed Delineation

To complete modeling for Kingston Lake, accurate delineation of the watershed and sub-watershed boundaries was required. We extracted the watershed boundary from the USGS National Watershed Boundary Dataset (WBD) (HUC12-010700020105) for the Powwow River drainage. FBE derived an initial version of the Kingston Lake watershed from StreamStats, an online watershed modeling tool developed by the USGS. This online tool integrates data collected through the National Hydrography Dataset (NHD). The output of this model is represented by the thick black outlines in Figure A-1. Then, FBE completed sub-watershed delineations according to an ArcGIS Pro workflow that uses a digital elevation model from the USGS to determine flow direction and accumulations. This analysis provided higher resolution flow paths and identified several flow paths that appeared to discharge to points outside of the watershed rather than into the watershed (refer to the red flow paths highlighted in Figure A-1).

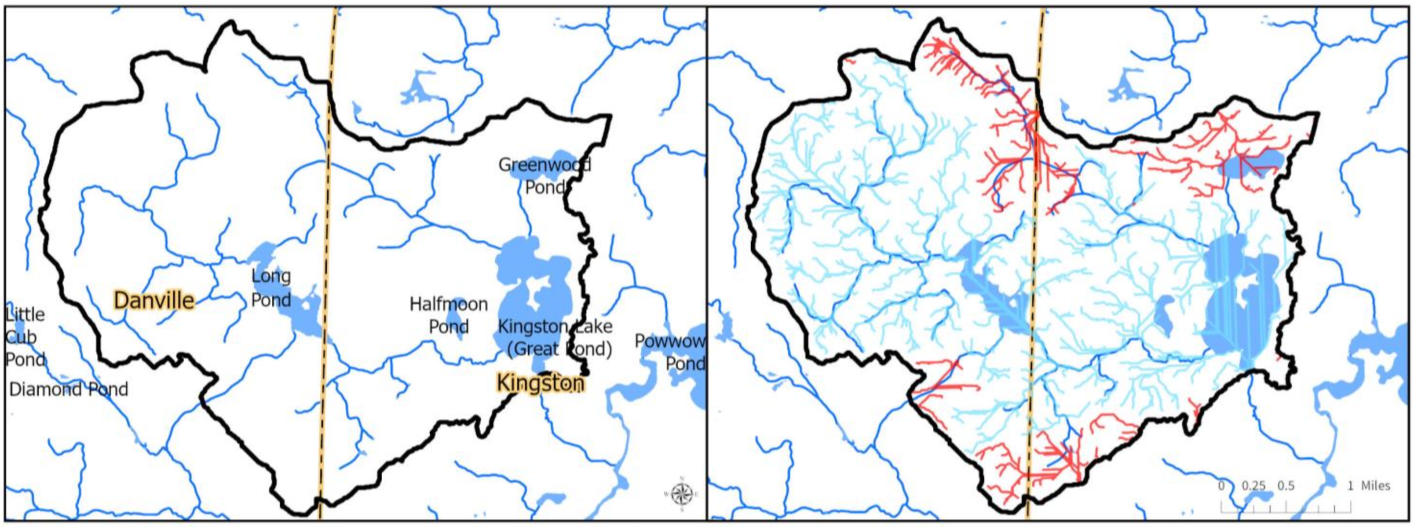


**Figure A-1.** The initial Kingston Lake watershed with NHD flowlines and waterbodies (LEFT). Flow paths delineated from a digital elevation model (light blue) and flow paths identified to not be within the Kingston Lake watershed (red) (RIGHT).

Because of these discrepancies between the original Kingston Lake watershed and the flow paths from the digital elevation model, FBE staff visited the watershed three times to verify flow directions of streams and road and trail crossings. These visits followed periods of wet weather, which allowed for better determination of flow directions. Field checks confirmed whether the digital elevation model or the NHD was correct for different locations near the watershed and sub-watershed boundaries (Figure A-1). The final watershed boundary excludes one area to the north and one area to the south that were included in the preliminary watershed boundary.

The northern flow paths in question were checked for direction of flow and photographed as shown in Figure A-2. Field staff identified the direction of flow and noted the relative volume of water discharged at each point. The primary question was whether the area highlighted in orange was leaving the initial version of the Kingston Lake watershed and not returning. This was difficult to discern at first due to the expansive wetland complexes within the watershed but was determined based on the volume of flow discharging at the area highlighted in orange compared to the volume of flow discharging at the area highlighted in red. Additionally, no flow was identified at the area highlighted in yellow. Due to the large wetlands in the watershed and adjacent area, it is possible that under high flow storm conditions flow direction may shift. However, for baseline conditions, field checks confirmed flow paths created from the digital elevation model workflow were correct for the locations highlighted in orange and red, but the NHD was correct for the location highlighted in yellow (Figure A-2).

The southern tip of the watershed was also eliminated following field verification. A culvert exists at the location identified in pink Figure A-3, but it is impounded, and no flow was present. A stream was identified as leaving the initial Kingston Lake watershed boundary at the location identified in yellow. Field checks confirmed flow paths created from the digital elevation model workflow were correct in this location (Figure A-3).

The final watershed boundary and sub-watershed delineations are shown in Figure A-4.

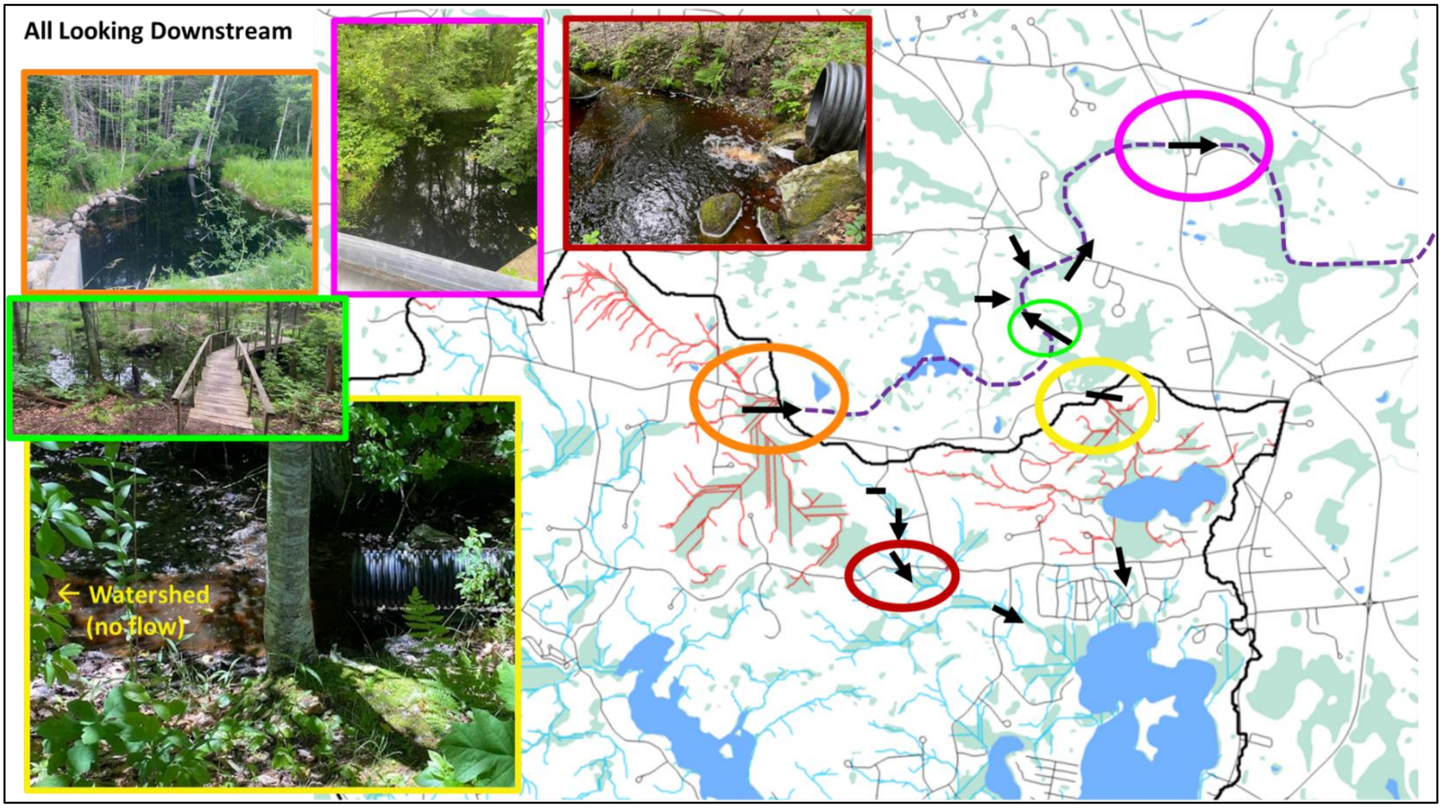


**Figure A-2.** Field verification of flow path direction.

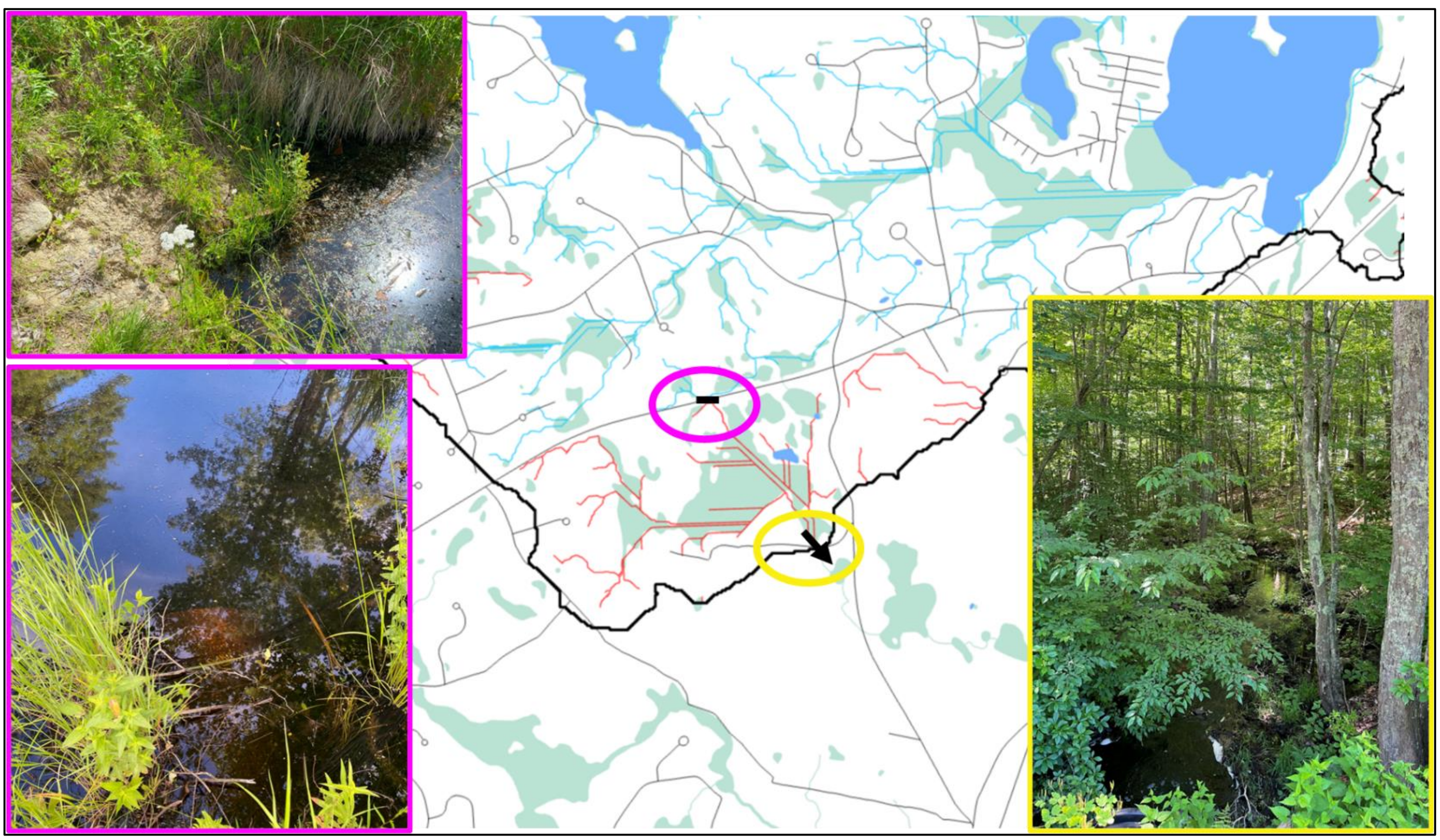

**Figure A-3.** No flow was detected at the culvert along Route 111 (pink), but flow was detected leaving the initial watershed boundary (yellow).

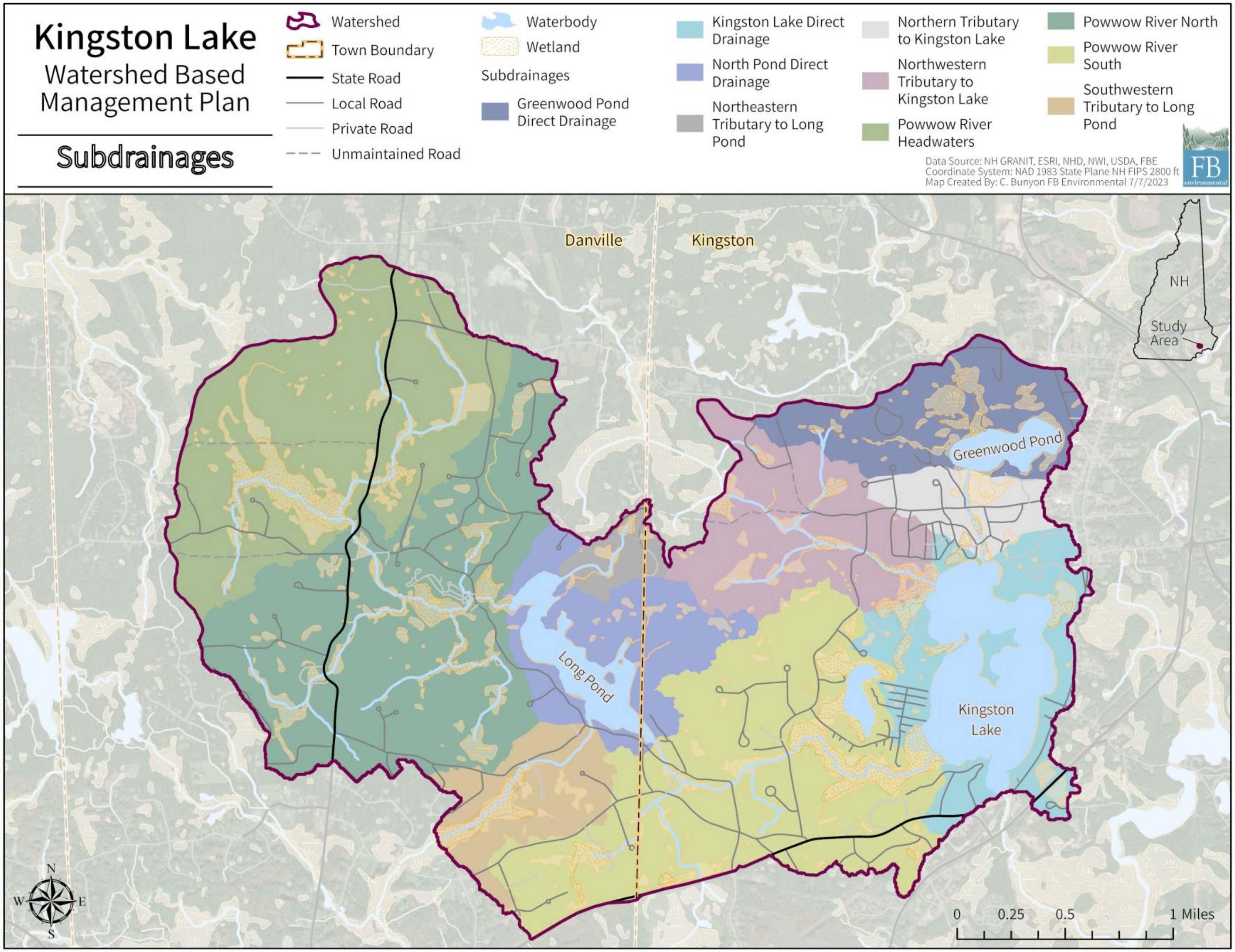


**Figure A-4.** Final watershed boundary and sub-watershed delineations for the Kingston Lake watershed.