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Bantam Lake Nutrient TMDL Model
Modeling Report

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1. Introduction

1.1 Background

Excess nutrients can contribute to eutrophication and potential formation of Harmful Algal Blooms (HABs) in lakes and impoundments. Addressing nutrient impacts to water quality has been identified as a high priority for the state by the Connecticut Department of Energy and Environmental Protection (CT DEEP). In order to address the impact of nutrients on lakes and impoundments in Connecticut and the potential for development of HABs within these waterbodies, CT DEEP and the U.S. Environmental Protection Agency (EPA) are currently developing Connecticut Statewide Lake Nutrient Total Maximum Daily Load (TMDL). This document will address nutrient loading and HAB formation with watershed-specific appendices to address site-specific conditions at Connecticut lakes. Nutrient loads will be evaluated against changes in lake trophic status, as defined in Section 22a-426-6 of Connecticut's Water Quality Standards Regulations. The watershed-specific appendices will provide site-specific information to document existing nutrient loads and conditions contributing to HABs and identify nutrient load reductions needed to eliminate water quality impairments in Connecticut lakes.

CT DEEP has selected Bantam Lake for the first appendix that will accompany the Statewide Lake Nutrient TMDL. Bantam Lake is Connecticut's largest natural lake. Bantam Lake is an important local resource for public recreation, including boating and swimming. Bantam Lake runs along a north-south axis and is comprised of three primary bays (i.e., "North Bay", "Center Lake", and "South Bay"). The primary tributaries of the lake are the Bantam River and Whittlesey Brook. The Bantam River enters the lake in North Bay. Whittlesey Brook enters the lake in South Bay. The outlet of the lake is located along the north shore of the lake directly to the west of North Bay (i.e., "Outlet Cove").

Bantam Lake has a history of frequent blooms of cyanobacteria due to eutrophication of the lake from external and internal loading of nutrients. Bantam Lake was listed on CT DEEP's 2018 Integrated Water Quality Report as impaired for recreation. Impairment causes include chlorophyll-*a*, excess algal growth, and excess nutrients.

1.2 Project Goals and Objectives

Goals and objectives of this project were as follows:

- Setup, calibrate, and validate a water quality model for Bantam Lake.
- Using the calibrated and validated model, calculate nutrient loading capacities and load reductions necessary to meet water quality targets for Bantam Lake.

1.3 Purpose of this Document

The purpose of this document is to describe the modeling process to perform the nutrient load reduction analysis for Bantam Lake. Modeling and analysis were performed in accordance with the approved Quality Assurance Project Plan (QAPP) (**Appendix A**). Sections covered by this document include:

- **Data Collection:** An overview of the data collection process.
- **Model Development:** The approach for calculating model inputs from collected data.
- **Model Evaluation**: Model adjustments and subsequent calibration and validation results.
- **Nutrient Load Reduction Analysis**: Load reductions needed to meet water quality targets.
- **Recommendations**: Recommendations for next steps.

2. Data Collection

Model setup, calibration, validation, and application for this project was accomplished using secondary data from qualified sources. Data quality of secondary sources was assessed prior to use for modeling in accordance with the approved QAPP. The relevant data sources collected for this study are listed in **Table 2-1**.

Table 2-1. List of relevant data sources.

Description	Use	Original File Name	Source
Diagnostic Evaluation Report for Bantam Lake	Misc. background and reference information; water quality data from 2007-2008.	Bantam Lake Diagnostic Report 2008 Final.pdf	Northeast Aquatic Research (2009)
Nutrient Model Assessment and Selection to Support Statewide TMDL	Misc. background and reference information.	Bantam Lake Model Evaluation October 2017.pdf	Tetra Tech (2017)
In-lake water quality monitoring data (2009-2017)	BATHTUB calibration and validation, misc. BATHTUB inputs	bantam data.xlsx	Collected and compiled by Northeast Aquatic Research (unpublished source), CT DEEP (2019a)
In-lake water quality monitoring data (2018)	BATHTUB calibration and validation, misc. BATHTUB inputs	bantam data 2018.xlsx	Collected and compiled by Northeast Aquatic Research (unpublished source), CT DEEP (2019a)
Tributary water quality monitoring data (2006-2013).	LLRM evaluation	Bantam LLRM July 11 2019.xlsx	Compiled by CT DEEP based on Northeast Aquatic Research (2009) and in-house data, CT DEEP (2019b)
Bathymetry data	BATHTUB morphometry inputs	Bantam Bathymetry.shp	Collected in 2-ft intervals via depth finder in 1995, original Source is CT Lake Bathymetry Dataset[1], CT DEEP (2019c)
Hydrography features (waterbodies, rivers, streams, etc.)	BATHTUB morphometry inputs	Bantam Hydro line.shp; Bantam Hydro poly.shp	Derived from 2005 CT DEEP statewide datasets, CT DEEP (2019c)
Subwatersheds	LLRM inputs (e.g., watershed area, routing, attenuation)	Bantam Basins.shp	Subwatersheds delineated by CT DEEP for use in LLRM modeling, CT DEEP (2019c)
Land use	LLRM inputs (e.g., pollutant export)	Bantam Land Use.shp	Original source is 2016 National Land Cover Database (NLCD)[2]. Land use data processed by CT DEEP into LLRM required categories, CT DEEP (2019c)
Hourly precipitation data (2006 through 2018)	BATHTUB / LLRM precipitation input	1852415.csv	NCDC (2019)
Monthly avg. evaporation data (1950-2001)	BATHTUB evaporation input	evap data.xlsx	Hobbins et al (2017)

[1] Bathymetry Data: https://www.ct.gov/deep/cwp/view.asp?a=2698&q=322898&deepNav_GID=1707
[2] 2016 NLCD: https://www.mrlc.gov/data

3. Model Development

3.1 Model Overview

Modeling was performed using the Lake Loading Response Model (LLRM) and BATHTUB in accordance with recommendations from a prior evaluation of modeling alternatives (Tetra Tech, 2017). The Tetra Tech study concluded that this approach strikes a balance between complexity and capability and therefore has the potential to be applied widely to lakes throughout Connecticut.

*Note: All relevant files used to inform the modeling effort were transmitted electronically upon the conclusion of this project. Transmitted files include: 1) Compiled Data; 2) Model Files; 3) Analyzed Results (see **Appendix B** for an index of transmitted files).*

3.1.1 LLRM

LLRM[3] is a spreadsheet-based model used to evaluate nutrient loading to a lake and the consequences of that loading in terms of algal blooms and water clarity. LLRM originated as a teaching tool in a college course on watershed management, where it was called SHEDMOD. Certain functions and variables have been periodically refined as new literature has been published. The LLRM model is configured for a period of interest based on user inputs (e.g., watershed boundaries, land cover, precipitation, point source inputs, etc.). Embedded calculations are then executed based on reference equations and commonly used coefficients from the scientific literature to predict watershed runoff, resulting nutrient loads, and other variables. Inputs to the LLRM can be modified to represent Connecticut-specific or watershed-specific information.

LLRM was used to calculate nutrient loading for input into the BATHTUB model.

3.1.2 BATHTUB

BATHTUB[4] is a steady-state water and nutrient mass balance model developed by Dr. William Walker for the U.S. Army Corps of Engineers (USACOE) Waterways Experimental Station. BATHTUB performs steady-state water and nutrient balance calculations for spatially segmented hydraulic networks in order to simulate eutrophication-related water quality conditions in lakes and reservoirs. BATHTUB predicts eutrophication-related water quality conditions (e.g., total phosphorus, total nitrogen, chlorophyll-*a*, transparency, and hypolimnetic oxygen depletion) using empirical relationships derived from assessments of lake and reservoir data.

BATHTUB was used to simulate in-lake water quality based on nutrient loading estimates from the LLRM model.

3.2 Water Quality Targets

One goal of this project was to establish load reductions needed to meet numeric water quality targets for the "natural" trophic state of Bantam Lake for total phosphorus, total nitrogen, chlorophyll-*a*, transparency, and hypolimnetic oxygen depletion rate. The "natural" trophic status of the lake is an expression of the

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[3] LLRM and accompanying user documentation prepared by AECOM (2009) is available for download at: https://github.com/MattAtMassDEP/LLRM_model. An updated version was obtained from CT DEEP (2019e).

[4] BATHTUB and accompanying user documentation prepared by Walker (2006) is available for download at: http://www.wwwalker.net/bathtub/help/bathtubWebMain.html.

best attainable expected condition for the lake (i.e., management goal). Water quality targets based on trophic state have been established by Section 22a-426-6 of Connecticut's Water Quality Standards for all of these parameters except for the hypolimnetic oxygen depletion rate (See **Table 3-1**). These water quality targets are collectively used to determine the trophic status of a lake (i.e., characterization of biological productivity). Trophic status can range from high productivity ("Highly Eutrophic") to low productivity ("Oligotrophic"). Section 22a-426-6 of Connecticut's Water Quality Standards Regulations include dissolved oxygen criteria for Class AA, A, and B waterbodies. The Standards indicate that dissolved oxygen must always exceed 5 mg/L.

Table 3-1. Parameters and defining ranges for trophic state of lakes in Connecticut[1].

Trophic State Based on Water Column Data	Parameters	Defining Range [Natural State Target Range]
Oligotrophic	Total Phosphorus	0-10 µg/l spring and summer
	Total Nitrogen	0-200 µg/l spring and summer
	Chlorophyll-*a*	0-2 µg/l mid-summer
	Secchi Disk Transparency	6 + meters mid-summer
Mesotrophic	Total Phosphorus	10-30 µg/l spring and summer
	Total Nitrogen	200-600 µg/l spring and summer
	Chlorophyll-*a*	2-15 µg/l mid-summer
	Secchi Disk Transparency	2-6 meters mid-summer
Eutrophic	Total Phosphorus	30-50 µg/l spring and summer
	Total Nitrogen	600-1000 µg/l spring and summer
	Chlorophyll-*a*	15-30- µg/l mid-summer
	Secchi Disk Transparency	1-2 meters mid-summer
Highly Eutrophic	Total Phosphorus	50 + µg/l spring and summer
	Total Nitrogen	1000 + µg/l spring and summer
	Chlorophyll-*a*	30 + µg/l mid-summer
	Secchi Disk Transparency	0-1 meters mid-summer

1. State of Connecticut Department of Environmental Protection Water Quality Standards 2011 (Sec. 22a-426-6).
2. Standards also include additional indicator for aquatic macrophyte distribution and abundance (Eutrophic: extensive and dense growth 75-100% of water body area; Mesotrophic: extensive and dense growth 30-75% of water body area when water column indicators are Oligotrophic.

Bantam Lake's trophic state has been previously assessed by CT DEEP as eutrophic, based on evaluations of water quality data in 2016 and 2018 in comparison to the parameters and trophic class ranges presented in **Table 3-1** (CT DEEP, 2019d). These assessments represent only the conditions observed during the periods of data collection. For the individual parameters listed in **Table 3-1**, the 2016/2018 Bantam Lake data ranged from upper-mesotrophic to eutrophic.

It is CTDEEP's intention to develop an approach to use to identify the natural trophic tendencies for lakes in order to define appropriate water quality-based goals for lake management. A defined procedure has not yet been developed, so water quality targets for this project were set by CTDEEP based on professional judgement. As the process for determining appropriate water quality targets for lakes in Connecticut matures, the water quality targets for Bantam Lake may be revisited. However, for the purposes of the Bantam Lake Nutrient TMDL project, CT DEEP evaluated the data referenced above and established water quality goals for Bantam Lake that are intended to be conservatively protective of the lake's ecology and designated uses. The "natural" trophic status of Bantam Lake will be defined for this project as "upper range mesotrophic" in accordance with the defining ranges for parameters as listed in **Table 3-1**. As listed below, the water quality targets selected for Bantam Lake generally represent the upper third of each parameter's range for the mesotrophic category:

- Total Phosphorous: 23 to 30 µg/L
- Total Nitrogen: 467 to 600 µg/L
- Chlorophyll-*a*: 10.7 to 15.0 µg/L
- Secchi Depth: 2 to 3.3 meters (mid-summer)

The hypolimnetic oxygen depletion rate was estimated and documented during the BATHTUB modeling process and can be used as an additional parameter to qualitatively evaluate lake conditions. However, a specific water quality target for hypolimnetic oxygen depletion rate was not evaluated for the following reasons:

1) Section 22a-426-6 of Connecticut's Water Quality Standards Regulations do not indicate a specific range or rate for hypolimnetic oxygen depletion.
2) Similar lakes with nearly identical hypolimnetic oxygen depletion rates can have very different in-lake dissolved oxygen concentrations due to natural conditions such as lake bathymetry. In order to set a reasonable "reference" hypolimnetic oxygen depletion rate for Bantam Lake, an empirical characterization of natural background levels of depletion would be required for various lake types and classifications across the state.

3.3 Analysis Time Periods

The following sections provide an explanation of various analysis time periods that were used during modeling, including the averaging period, calibration, validation, and the nutrient load reduction analysis.

3.3.1 Averaging Period

All analysis (i.e., LLRM pollutant loading and BATHTUB in-lake water quality) and corresponding inputs were computed during a specified averaging period. The averaging period is defined as the period of time over which water and mass balance calculations are performed. BATHTUB model documentation indicates that the lake turnover ratio should ideally approach or exceed 2.0 during the selected averaging period (Walker, 2006). The lake turnover ratio is defined as the length of the averaging period divided by hydraulic residence time. The appropriate averaging period is typically one year for reservoirs with relatively long nutrient residence times or seasonal (e.g., May-September) for reservoirs with relatively short nutrient residence times.

According to past studies, the hydraulic residence time of Bantam Lake is approximately 115 days (Northeast Aquatic Research, 2009). Water quality data has historically been collected seasonally from April through October (i.e., 7-month period or approximately 215-day period). An assumed averaging period of 215 days and a residence time of 115 days results in a lake turnover ratio of 1.9. An averaging period of 215 days (0.58 years) was selected for this study because (1) this ratio is close to the recommended ratio of 2.0 and (2) using this period has the benefit of aligning model output with historic in-lake water quality data.

3.3.2 Critical Period of Interest

The critical period of interest is the climatic period for which the Bantam Lake nutrient load reduction analysis will be conducted. This period should be representative of critical climatic conditions related to the water quality targets selected for this project and that are likely to lead to excessive algal growth and cyanobacteria blooms in Bantam Lake. As indicated by previous studies, Bantam Lake typically experiences severe algae blooms in July, August, and September (Northeast Aquatic Research, 2009). Recent evidence of this trend is provided by memorandum indicating that the “lake was green throughout” on August 4, 2016 (Northeast Aquatic Research, 2016).

Given the regularity of algae blooms in Bantam Lake, it was determined that the critical period of interest for the nutrient load reduction analysis would ideally span an approximate ten-year period to enable computation of representative long-term average conditions (i.e., typical annual conditions). This long-term time period would also correspond, as feasible, to available tributary and in-lake water quality monitoring data that matches the selected BATHTUB calibration period. Based on review of available data, the ten-year period of 2007 through 2016 was selected as the critical period of interest to perform the nutrient load reduction analysis.

3.3.3 Calibration and Validation

Model calibration and validation time periods were selected based on review of available monitoring data. Both the LLRM and BATHTUB models would ideally be calibrated and validated during the same time periods with the validation time period being performed independently of the calibration time period. The ideal calibration and validation time periods would also be selected to be representative of long-term annual average conditions (i.e., with outlier years removed).

Data Availability

In-lake water quality data collected during the averaging period were available from 2007-2018. Precipitation data were available from 2006-2018. Limited tributary data were available as follows:

- 2006: Bantam River at West Branch Confluence (“Confluence”) (1 sample);
- 2007: Whittlesey Creek (2 samples), Bantam River Inlet (7 samples);
- 2008: Confluence (1 sample), West Branch Bantam River (“West Branch”) (3 samples);
- 2011: Confluence (1 sample);
- 2013: West Branch (2 samples).

Pollutant loading predictions from the LLRM model were not calibrated to tributary data given its limited availability. To properly calibrate the LLRM model to tributary data, a minimum of three to five years of monthly sampling data during the averaging period would be required at the major tributary input to Bantam Lake (i.e., Bantam River). Additional tributary monitoring locations would also be beneficial based on availability of resources (e.g., Whittlesey Brook inlet to Bantam River, Upper Bantam River, West Branch of Bantam River, etc.). Although the LLRM model was not calibrated to available tributary data, adjustments to its pollutant loading predictions were still made based on calibration of the BATHTUB model to in-lake water quality monitoring data as summarized by **Section 4.1**. This approach is consistent with other comparable TMDL modeling efforts that utilized BATHTUB (e.g., MPCA, 2011).

Outlier Review

Based on review of existing precipitation and in-lake monitoring data from 2006 through 2018, the following outliers were identified: 1) 2011 for abnormally high precipitation; 2) 2016 for abnormally low precipitation. Outliers were identified by assigning a reasonable range to annual precipitation and in-lake monitoring data based on review of confidence intervals, then removing years outside of the range. The calibration period was selected as the ten-year period of 2007 through 2016 with the outlier years removed. The validation period was selected as the two-year period of 2017 and 2018. Refer to **Table 3-2** for a summary of the calibration period and validation period relative to available data and outlier years. The nutrient load reduction analysis was performed during the BATHTUB calibration period.

Table 3-2: Model calibration and validation periods based on available data and outlier years.

Year	Data Availability and Outlier Review			Analysis Time Periods	
	Precipitation	In-Lake Water Quality	Tributary Water Quality	Calibration	Validation
2006	OK	-	LIMITED	-	-
2007	OK	OK	LIMITED	✓	-
2008	OK	OK	LIMITED	✓	-
2009	OK	OK	-	✓	-
2010	OK	OK	-	✓	-
2011	**HIGH**	OK	LIMITED	-	-
2012	OK	OK	-	✓	-
2013	OK	OK	LIMITED	✓	-
2014	OK	OK	-	✓	-
2015	OK	OK	-	✓	-
2016	**LOW**	OK	-	-	-
2017	OK	OK	-	-	✓
2018	OK	OK	-	-	✓

3.4 Calibration and Validation Targets

Model calibration is the systematic changing of initial model parameters to minimize error between observed and simulated values. Calibration begins with the best estimates for model input on the basis of measurements and subsequent data analyses. Results from initial simulations are then used to improve the concepts of the system or to modify the values of the model input parameters. The success of a model calibration is largely dependent on the validity of the underlying model formulation. Model validation is an evaluation of the calibrated model goodness-of-fit using an independent data set.

Model performance criteria used to evaluate predicted in-lake water quality concentrations from the BATHTUB model are listed by **Table 3-3**. Model performance was ideally deemed acceptable where a performance evaluation of “good” or “very good” was attained during evaluation of water quality parameters.

Table 3-3. Model calibration and validation targets (Donigian 2002)

Variable	Percent Difference between Simulated and Observed Values		
	Very Good	**Good**	**Fair**
Water Quality / Nutrients	< 15%	15% – 25%	25% - 35%

3.5 Model Geometry

Bantam Lake runs along a north-south axis and is comprised of three primary bays (i.e., "North Bay", "Center Lake", and "South Bay"). The primary tributaries of the lake are the Bantam River and Whittlesey Brook. The Bantam River enters the lake in North Bay. Whittlesey Brook enters the lake in South Bay. The outlet of the lake is located along the north shore of the lake directly to the west of North Bay (i.e., "Outlet Cove"). Outflow from Outlet Cove discharges to Bantam River (i.e., the Bantam River flows into the lake, enters North Bay, then discharges out of the lake from Outlet Cove) (See **Figure 3-1**). Model geometry was represented by the following primary components: 1) subwatersheds (LLRM); tributaries (BATHTUB); and 3) segments (BATHTUB).

3.5.1 Subwatersheds

LLRM model geometry was represented by a series of subwatersheds that encompass the overall Bantam Lake watershed. LLRM includes a subcatchment load routing schema which takes into account potential attenuation (e.g., ponds, evaporation, etc.). Therefore, it is advantageous to delineate subwatersheds to include major features of interest within the overall watershed (e.g., notable ponds, wetlands, confluence of major channels, etc.). CT DEEP provided preliminary LLRM subcatchment delineations in July 2019 (CT DEEP, 2019c). These delineations were used as a base, then adjusted based on best judgement and output from version 4.3.8 of the United States Geological Survey (USGS) StreamStats application[5]. The following notable adjustments were made:

1) Omitted 3.83 km^2 surface area of Bantam Lake from all subwatershed W1 computations to ensure that land use-based tributary loading statistics were not computed based on Bantam Lake.

2) Refined portions of subwatershed boundaries that appeared to be inconsistent with existing topography as delineated by StreamStats (i.e., straight lines associated with W9, W11, W14). These adjustments were minor and resulted in fractional adjustments to each subwatersheds area.

Subwatersheds delineated for each primary tributary are depicted by **Figure 3-2**. Finally, refer to **Figure 3-3** for delineated subwatersheds and associated land uses from the 2016 National Land Cover Database (NLCD).

[5] USGS StreamStats: https://streamstats.usgs.gov/ss/

Figure 3-1: Overview of Bantam Lake

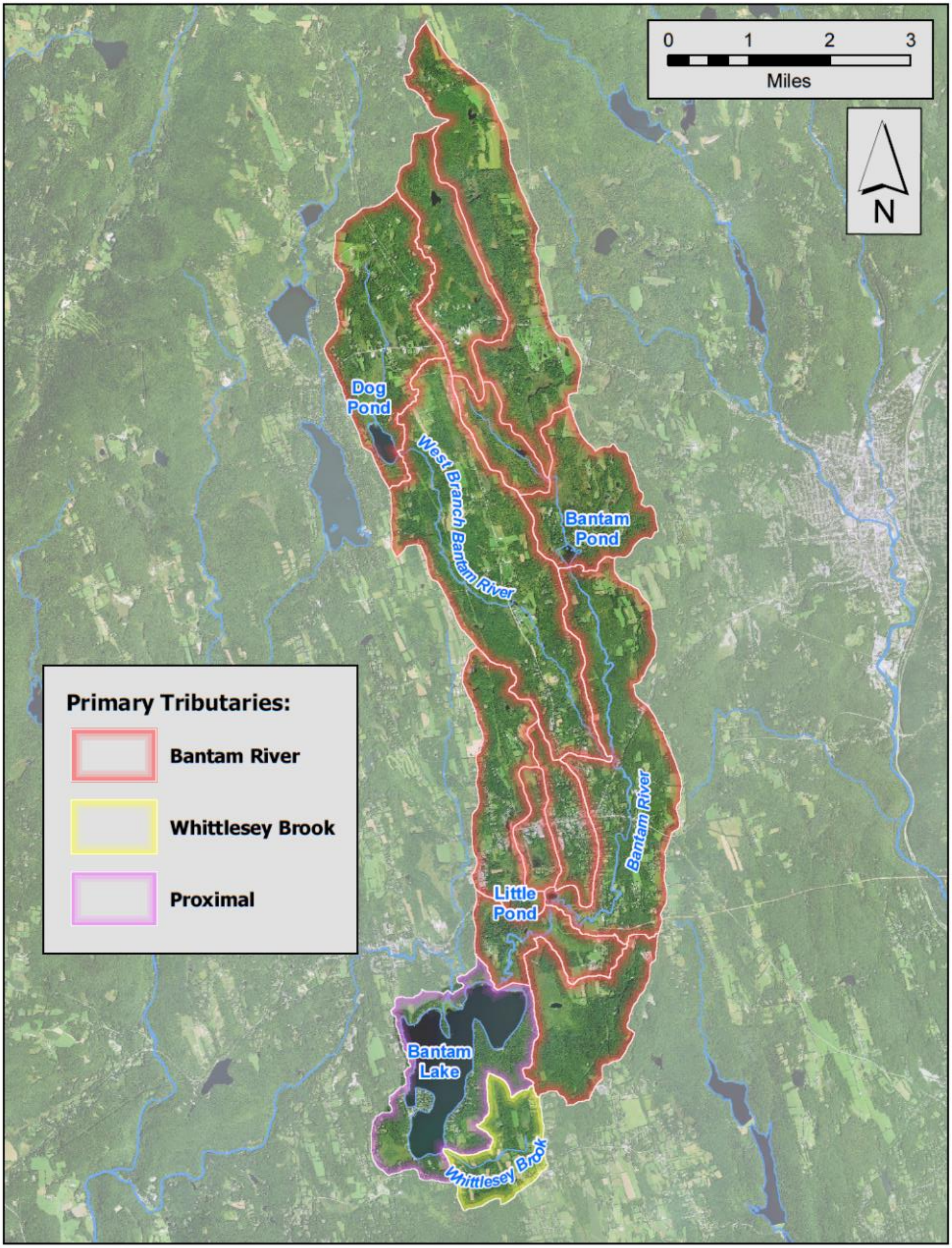


Figure 3-2: Delineated subwatersheds comprising the Bantam Lake watershed

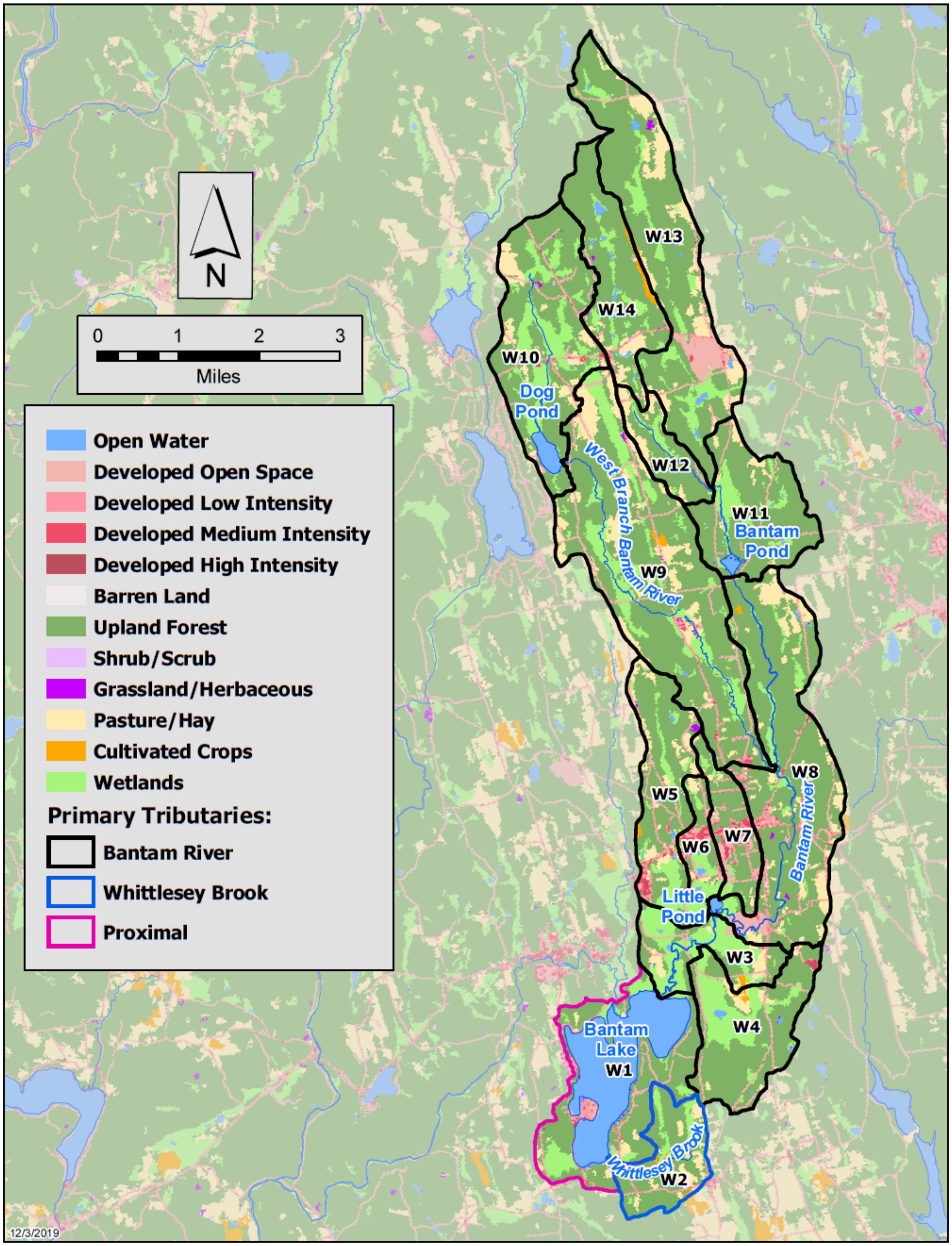


Figure 3-3: Delineated subwatersheds relative to 2016 NLCD land use

3.5.2 Segments

BATHTUB segments refer to geographic regions of the waterbody. Segments can be modeled independently or linked in a network. Each segment is defined in terms of its morphometry (i.e., area, mean depth, length, mixed layer depth, hypolimnetic depth). Morphometric features refer to average conditions during the simulation period. An independent segment (i.e., single segment) assumes minimal spatial (horizontal) variation in nutrient concentrations and trophic state indicators. Water quality predictions are calculated for the entire lake (as one segment).

Bantam Lake was represented by a single segment in the BATHTUB model because water quality sampling data do not indicate that there is a significant difference in water quality between the three bays (North Bay, Center Lake, and South Bay) (See **Section 3.6.5** for discussion).

3.5.3 Tributaries

Tributaries in BATHTUB represent areas where external inflows are routed to model segment(s). The primary modeled tributaries to Bantam Lake were: 1) Bantam River, proximal area to Bantam Lake, and Whittlesey Brook. **Figure 3-4** depicts a schematic of BATHTUB model geometry.

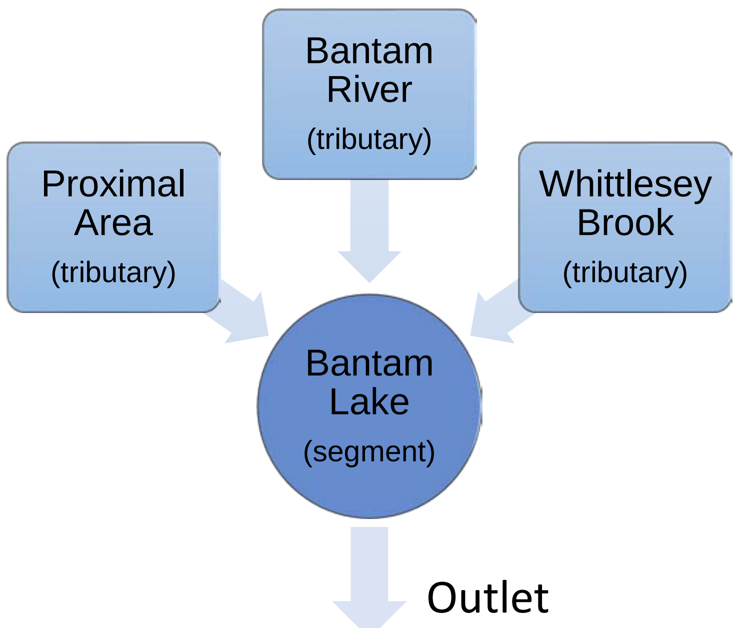


Figure 3-4: BATHTUB model geometry

3.6 Initial Model Inputs

This section provides a summary of the calculation methodology and resulting initial model inputs for the LLRM and BATHTUB models. Select inputs were modified during the calibration process as discussed by **Sections 4.2** and **4.3**. Supplemental model inputs are provided by **Appendix C**.

3.6.1 Watershed Loading

Watershed loading (mass per year) and anticipated tributary inflow (volume per year) for each tributary was calculated using LLRM, then was formatted for input into BATHTUB as a concentration. Compiled initial LLRM inputs are summarized by **Table 3-4**.

Table 3-4: Summary of Initial LLRM model inputs.

Input Variable	Units	Description	Calculation Methodology	Result
Precipitation	m	Annual average precipitation calculated during the averaging period.	Annual average precipitation data from 2007-2016 and selected annual averaging period was compiled and calculated from Global Historical Climatology Network (GHCN) station USC00060227 located in Bakersville, CT, approximately 15 miles northeast of Bantam Lake (NCDC, 2019). This is the closest available station to Bantam Lake with hourly (or daily) precipitation data available from 2006-2018.	**Table C-1**
Subwatersheds	ha	Subwatersheds that comprise the overall Bantam Lake watershed.	Subwatersheds were delineated by using CT DEEP delineations as a base (CT DEEP 2019c), then adjusted based on professional judgement and output from USGS StreamStats. The area of each subwatershed was calculated using GIS tools.	**Table C-2**
Land Use	ha	LLRM includes 14 pre-defined land use categories (e.g., urban, forest, agriculture, etc.). Each land use category is assigned a series of runoff and baseflow export coefficients to enable calculation of nutrient export (i.e., kg/ha/yr).	Land use data were obtained from the 2016 National Land Cover Database (NLCD)[6]. GIS tools were used to apply the land use data to each delineated subwatershed and to calculate the area and percentage comprised by each category. NLCD land use categories were assigned to the 14 pre-defined LLRM categories in accordance with **Table C-3**.	**Table C-4**
Precipitation Coefficients (for Runoff and Baseflow)	Fraction	Runoff and baseflow precipitation coefficients are assigned to each land use to indicate the fraction of overall rainfall that is converted to overland flow ("runoff") or baseflow, respectively (0 = none; 1 = all).	LLRM provides default coefficients for each land use category from the published scientific literature. Default LLRM values were used for initial model inputs (AECOM, 2009).	**Table C-5**
Phosphorus and Nitrogen Export Coefficients (for Runoff and Baseflow)	kg/ha/yr	Phosphorus and nitrogen export coefficients are assigned to each land use category to enable estimation of phosphorus and nitrogen export via runoff and baseflow.	LLRM provides default coefficients for each land use category, including an overall range from the published scientific literature. Default coefficients were used for initial model inputs for both runoff and baseflow based on the median value (AECOM, 2009).	**Table C-5**
Atmospheric Deposition	N/A	N/A	Atmospheric deposition was calculated during the BATHTUB modeling process (See **Table 3-5**).	N/A

[6] National Land Cover Database: https://www.mrlc.gov/national-land-cover-database-nlcd-2016

Input Variable	Units	Description	Calculation Methodology	Result
Internal Loading	N/A	N/A	Internal loading was calculated during the BATHTUB modeling process (See **Section 3.6.6**)	N/A
Waterfowl Loading	kg/yr	Waterfowl can be a direct source of nutrients to lakes. The purpose of this calculation is to estimate the amount of annual average mass contributed by waterfowl.	LLRM provides default estimates of phosphorus and nitrogen loading from waterfowl on a per bird basis from the published scientific literature (AECOM, 2009). CT DEEP provided input data in February 2020, estimating an average of 216 waterfowl on the lake (annual average of weekly data from the eBird database; CT DEEP, 2020a). This number was adjusted to the BATHTUB averaging period (multiplied by 0.583), then multiplied by default LLRM values (0.20 kg/unit/yr P; 0.95 kg/unit/yr N) to determine estimated loading. Waterfowl represent a small fraction of overall nutrient loading to Bantam Lake.	25.2 (TP) 119.7 (TN)
Septic Loading	kg/yr	Septic systems located in close proximity to receiving waters can significantly contribute to nutrient loading. The purpose of this calculation is to estimate the amount of annual nutrient loading from septic systems within approximately 300 feet of Bantam Lake.	LLRM provides default estimates of factors that contribute to septic systems (AECOM, 2009). According to Northeast Aquatic Research (2009), 99 seasonal homes and 50 year-round homes potentially have septic systems with an estimated occupancy of 2.5 people per home. Default LLRM median estimates were used to estimate septic loading from seasonal and year-round homes based on an assumed initial concentration, people per home, occupancy days per year, and attenuation factor (i.e., portion of load that reaches the lake). Septic loading represents a small fraction of nutrient loading to Bantam Lake.	9.7 (TP) 388 (TN)
Subwatershed Routing	-	LLRM includes a subwatershed routing mechanism for nutrients, baseflow, and runoff.	Since attenuation in a downstream subwatershed can affect inputs from an upstream subwatershed that passes through the downstream subwatershed, the model must be directed as to where to apply attenuation factors and additive effects. Subwatershed routing was assigned based on review of delineated subwatersheds.	See **Figure 3-2.** Proximal watershed includes W1; Whittlesey includes W2; and Bantam River includes all other subwatersheds (W3 - W14).
Subwatershed Attenuation	Fraction	Water and nutrient attenuation within a subwatershed can occur from a variety of mechanisms including evapotranspiration, depression storage, wetlands, infiltration, etc. This variable provides an easily adjustable removal mechanism on the subwatershed scale.	Water attenuation (loss) as a fraction of estimated baseflow and runoff can range from a 5% loss in nearly all cases to 15% loss in areas with large ponds or wetlands (AECOM, 2009). Nutrient attenuation can range from 10% to 60% removal (AECOM, 2009). These values may be adjusted during the calibration process.	Initial attenuation set as 1 (i.e., no attenuation) for all subwatersheds

3.6.2 Global Variables

Global variables are applied to the entire BATHTUB model over the selected averaging period regardless of segment. Initial global BATHTUB variable inputs are summarized by **Table 3-5**.

Table 3-5: Summary of global BATHTUB variables.

Input Variable	Units	Description	Calculation Methodology	Result
Averaging Period	fraction	The period of time as a fraction of a year over which water and mass-balance calculations are performed (as a fraction of a year).	A seven-month averaging period from April through October (0.58) was used in accordance with discussion from **Section 3.3.1** of this report.	0.58 yr
Precipitation	m/yr	Annual average precipitation calculated during the averaging period.	Obtained from LLRM model inputs (see **Table 3-4** for station information)	**Table C-1**
Evaporation	m/yr	Annual average evaporation calculated during the averaging period.	Obtained from estimates of monthly pan evaporation data from NOAA COOP Station 65445 in Norfolk, CT between 1950-2001 (Hobbins et al, 2017).	**Table C-6**
Increase in Storage	m/yr	The increase in water level elevation between start and end of the averaging period.	Bantam Lake water level data are unavailable. Therefore, a “no increase” in storage was assumed to be representative of steady-state conditions. According to BATHTUB user documentation (Walker, 2006), this value is only used for completeness in mass balance computations and does not influence predicted nutrient concentrations.	N/A
Atmospheric Loads	mg/m^2-yr	Annual average atmospheric deposition of total phosphorus and total nitrogen to surface of Bantam Lake during the averaging period.	The atmospheric deposition rate was obtained from the published literature for phosphorus (Schloss, et al 2013) and nitrogen (USGS, 2004). Atmospheric deposition represents a small fraction of nutrient loading to Bantam Lake.	42 (TP) 3,945 (TN)

3.6.3 Tributary Inputs

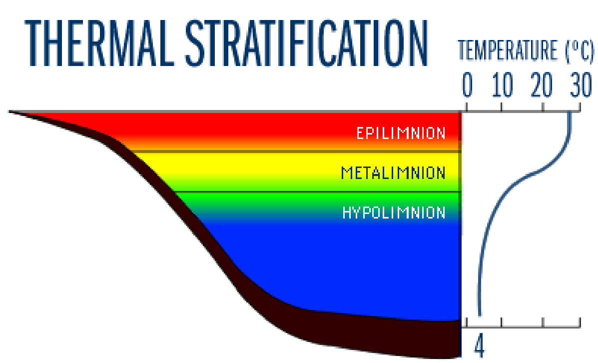
Data compiled from the LLRM watershed loading analysis were used to populate BATHTUB tributary data. Initial BATHTUB tributary inputs are summarized by **Table 3-6**.

Table 3-6: Summary of initial BATHTUB tributary inputs.

Input Variable	Units	Description	Calculation Methodology	Result
Tributary Watershed Area	km^2	Total area of subwatersheds that comprise each tributary into Bantam Lake.	Obtained from results of the LLRM watershed loading analysis as a summation of contributing subwatersheds.	**Table C-2**
Tributary Inflow Rate (i.e., discharge)	hm^3/yr	Annual average inflow rate from each tributary into Bantam Lake during the averaging period.	Obtained from results of the LLRM watershed loading analysis as a summation of contributing subwatershed outflows.	See **Section 4.1** and **Section 4.3** for discussion
Tributary Total Phosphorus Concentration	ppb	Annual average total phosphorus concentration at each tributary's inflow into Bantam Lake during the averaging period.	Obtained from results of the LLRM watershed loading analysis. Estimated waterfowl and septic system loading estimates were added to the "proximal" (direct) tributary to Bantam Lake.	See **Section4.1** and **4.3** for discussion
Tributary Total Nitrogen Concentration	ppb	Annual average total nitrogen concentration at each tributary's inflow into Bantam Lake during the averaging period.	Obtained from results of the LLRM watershed loading analysis. Estimated waterfowl and septic system loading estimates were added to the "proximal" (direct) tributary to Bantam Lake.	See **Section4.1** and **4.3** for discussion

3.6.4 Lake Morphometry

Lake morphometry variables are applied to the selected BATHTUB segmentation scheme. As previously indicated, Bantam Lake was represented by a single segment that "outflows" from Outlet Cove to the Bantam River. Initial BATHTUB lake morphometry inputs are summarized by **Table 3-7**.



For reference, the following are definitions of the layers in a thermally stratified lake:

Epilimnion: The surface layer in a thermally stratified lake. It is warmer and typically has a higher pH and higher dissolved oxygen concentration than the hypolimnion.

Metalimnion: The middle layer of the lake (also known as the thermocline), representing a zone of relatively abrupt change in water temperature, water density, and chemistry. During stratification, this zone can act as a barrier to mixing between the epilimnion and hypolimnion.

Hypolimnion: The bottom layer of the lake, which during summer will have the coldest and densest water. This layer is typically isolated from wind mixing during summer and in deep lakes receives insufficient light for photosynthesis to occur.

Table 3-7: Summary of BATHTUB lake morphometry inputs.

Input Variable	Units	Description	Calculation Methodology	Result
Surface Area	km^2	Overall surface area of Bantam Lake.	Calculated from hydrography shapefiles obtained from CT DEEP on July 2019 that depict the surface of Bantam Lake (CT DEEP, 2019c).	3.83 (**Table C-7**)
Mean Depth	m	Spatially averaged depth of Bantam Lake.	Calculated from bathymetry shapefile obtained from CT DEEP (CT DEEP, 2019c). Bathymetry data were collected using a depth finder in 1995. Depth increments are in 2-foot intervals ranging from 2 feet to 26 feet. Depth increments are in "slices". Each "slice" represents an area. Bathymetry were used to calculate the overall volume of Bantam Lake by multiplying the depth and area of each "slice", then summing the results. The calculated volume was then divided by the overall surface area of Bantam Lake to obtain a mean depth. Calculated values were compared to results from the diagnostic report (Northeast Aquatic Research, 2009).	4.5 (**Table C-7**)
Length	km	Average distance along the major flow axis. Used to estimate diffusive exchange rates (i.e., longitudinal dispersion).	Bantam Lake includes three primary tributaries with flow axes (i.e., Proximal Area, Whittlesey Brook, and Bantam River). Bantam River contributes a majority of flow to Bantam Lake and is therefore the major flow axis. The length of the flow axis from the mouth of the Bantam River to the outlet of Bantam Lake was estimated to be a curved line from the inlet of Bantam River to North Bay, to the mouth of North Bay, and to the terminus of Outlet Cove at the approximate location of North Shore Road.	1.6
Mixed Layer Depth	m	The mixed layer is used by BATHTUB for chlorophyll-*a* computations. This mixed layer is also used for comparison of observed water quality data during the growing season.	Based on review of recent Bantam Lake data, the lake exhibits summer thermal stratification and hypolimnetic oxygen depletion. As an example, 2018 dissolved oxygen (DO) and temperature profiles demonstrate that the lake develops a summer epilimnion between 0-3 m, metalimnion between 3-6 m, and hypolimnion with anoxic conditions during June, July, and August between 6-8 m. During July 2018, the temperature gradient from the lake surface (27.3 C) to bottom (17.4 C) was 9.9 C. Based on this review, a mixed layer depth of 3 m was used.	3
Hypolimnetic Thickness	m	The hypolimnetic depth is used to calculate hypolimnetic and metalimnetic oxygen depletion rates in stratified impoundments.	As indicated by Walker (2006), mean hypolimnetic depth should correspond to late spring or early summer, after onset of stratification. Since the empirical models for predicting oxygen depletion rate have been developed using data from near-dam stations, hypolimnetic depths should be specified only for near-dam (i.e., outlet) segments. The hypolimnetic depth was assigned based on review of temperature and DO profiles in Center Lake, which discharges to the Bantam Lake outlet. As indicated in the "mixed depth" calculation methodology, DO/temperature profiles in 2018 indicate that the Center Lake hypolimnion occurs at a depth of approximately 6-8 m (i.e., 2 m thickness).	2

3.6.5 Observed Water Quality Data

In-lake water quality data was applied to the BATHTUB model for calibration and validation purposes. In-lake water quality data relevant to this study has been routinely collected by Northeast Aquatic Research for the Bantam Lake Association at South Bay, Center Lake, and North Bay at the top, middle, and bottom of the water column from April through October for a 12-year period from 2007 through 2018 (CT DEEP 2019a, CT DEEP 2019b). Collected variables relevant to this study include total phosphorus (TP), total nitrogen (TN), Secchi depth, and chlorophyll-*a*. Based on BATHTUB model documentation (Walker, 2006), observed water quality should reflect the upper mixed layer and growing season. Refer to **Table 3-8** for a summary of data collected at the upper mixed layer of Bantam Lake (i.e., 0-3 m). Key observations include:

- North Bay and Center Lake have more data points than South Bay. TP, TN, and Secchi depth data was collected much more frequently than chlorophyll-*a*.
- Average TP measurements (23.7 µg/L), TN (513.8 µg/L), and Secchi depth (2.1 m) are indicative of upper mesotrophic conditions, while the chlorophyll-*a* average was within the eutrophic range (*Note: For reference to parameter ranges for each lake trophic class per the CT Water Quality Standards, see **Table 3-1***). Measurements of each parameter vary considerably throughout the monitoring period as indicated by lake coefficients of variation (CVs) ranging from 27% to 50%.
- There were only four available chlorophyll-*a* measurements during the calibration period. More measurements are needed to have confidence in chlorophyll-*a* results for model calibration.
- Water quality data for the upper mixed layer at each sampling location is similar and indicative that performing BATHTUB modeling as a single segment is a reasonable approach given similar water quality. “Totals” from **Table 3-8** were input into BATHTUB. An electronic file was transmitted upon conclusion of the project with results of statistical significance testing (see **Appendix B**). Results indicate that there is no statistically significant difference of TP concentrations within the upper mixed layer between the sample means (i.e., average) of each of the three monitoring locations.

Table 3-8. Summary of relevant monitoring data (April – October, 2007 – 2018, depth 0 to 3 m)

Parameter	Measure	Station			
		North Bay	Center Lake	South Bay	Totals
Total Phosphorus (µg/L)	Count	92	67	23	**182**
	Average	23.6	24.4	22.0	**23.7**
	Range	9 to 51	8 to 78	12 to 42	**8 to 78**
	CV	0.37	0.48	0.35	**0.42**
Total Nitrogen (µg/L)	Count	71	59	20	**150**
	Average	503.9	543.6	460.9	**513.8**
	Range	199 to 1,490	175 to 1,630	219 to 775	**175 to 1630**
	CV	0.46	0.50	0.36	**0.47**
Secchi Depth (m)	Count	41	52	39	**132**
	Average	2.1	2.1	2.0	**2.1**
	Range	0.85 to 4.15	0.90 to 4.20	0.85 to 4.05	**0.85 to 4.20**
	CV	0.43	0.45	0.42	**0.43**
Chlorophyll-*a* (µg/L)	Count	2	2	0	**4**
	Average	35.0	39.0	-	**37.0**
	Range	27 to 43	30 to 48	-	**27 to 48**
	CV	0.32	0.33	-	**0.27**

Notes:

1. *Data files obtained from CT DEEP in March 2019 ("Bantam.Data.xls" and "Bantam Data 2018.xls") for data collected between 2009 and 2018 (CT DEEP, 2019a). Original data source is Bantam Lake Association collected by Northeast Aquatic Research. Additional data from 2007 and 2008 compiled from Diagnostic Feasibility Study (Northeast Aquatic Research, 2009).*
2. *Includes data collected from April-October in 2007 through 2018 (i.e., the selected averaging period).*
3. *Includes data collected at upper mixing zone of Bantam Lake (i.e., 0 to 3m). Data excluded at depths greater than 3m.*
4. *CV is the coefficient of variation, calculated as the standard deviation divided by the average.*
5. *Performed outlier analysis on monitoring data.*
    a. *Removed chlorophyll-a measurement of 48,500 µg/L taken at the surface of North Bay on 7/27/2017.*
    b. *Removed chlorophyll-a measurement of 5,300 µg/L from surface of Center Lake on 7/27/2017.*

3.6.6 Internal Loading

Internal loading rates reflect nutrient recycling from bottom sediments. As indicated by the BATHTUB model documentation, rates are normally initially set to zero, since the pre-calibrated nutrient retention models already account for nutrient recycling that would normally occur (Walker, 2006). Based on the BATHTUB guidance cited above, internal loading was initially entered into the model as zero. Internal loading was then adjusted as needed during the model calibration process based on the best fit for both external and internal pollutant loads (See **Section 4.2.1**). As noted in the BATHTUB guidance, any overestimation of internal load will result in an associated underestimation of external load.

As a point of reference for calibration, a simple internal load calculation was performed by comparing the difference in hypolimnion phosphorus concentration at the beginning of the season (i.e., pre-stratification, May) and the time of the highest observed hypolimnetic concentrations (August). The hypolimnion is expected to occur from 6 to 8 meters within Center Lake, the deepest part of Bantam Lake. This difference was then multiplied by the estimated volume of the hypolimnion to estimate the mass of phosphorus assumed to be derived from internal loading. This estimate was further adjusted to account for the fraction of total particulate phosphorus assumed to be exchanged with the epilimnion during summer stratification. As indicated by **Table 3-9**, internal phosphorus loading is estimated to be 564 kg/yr (order-of-magnitude estimate). This estimate is in line with the 2009 Diagnostic Feasibility Study, which estimated internal phosphorus loading to range from 500 to 1,000 kg/yr (NAR, 2009).

Table 3-9. Estimated annual average internal total phosphorus loading

Input Variable	Units	Result
Median Hypolimnetic Total Phosphorus Concentration (May)[1]	µg/L	21.0
Median Hypolimnetic Total Phosphorus Concentration (September)[2]	µg/L	173.5
Accumulated Hypolimnetic Total Phosphorus Concentration[3]	µg/L	152.5
Estimated Volume of Hypolimnion[4]	L	$6.60 \cdot 10^9$
Accumulated Hypolimnetic Total Phosphorus Mass[5]	kg/yr	1,006.9
Adjustment Factor[6]	%	0.56
Estimated Internal Load (*Order-of-Magnitude Estimate*)	kg/yr	563.9

Notes:

1. *Based on 8 measurements from depth of 6 to 8 meters within Center Lake.*
2. *Based on 14 measurements from depth of 6 to 8 meters within Center Lake.*
3. *Difference from May to September.*
4. *Based on bathymetry data from 6-8 meters (**Table C-7**).*
5. *Mass calculated as concentration multiplied by volume, then converted to kg.*
6. *Calculated based on Nürnberg Retention Parameter (R) (i.e., fraction of sediment retained by lake) (Nurnberg, 1984)*
   a. *R = 15 / (18+ Hydraulic Overflow Rate)*
   b. *Hydraulic Overflow Rate = Annual Average Discharge / Lake Surface Area*
   c. *Annual Average Discharge (from LLRM) = 33,301,770 m^3/yr; Surface Area = 3,830,000 m^2*
   d. *R = 15 / (18 + 8.7) = 0.56*

4. Model Evaluation

Once model inputs were configured, initial model outputs were evaluated relative to available monitoring data. Inputs were then adjusted as described below to obtain acceptable and reasonable outputs. Model adjustments were first made to the LLRM model which provides tributary loading predictions, then were applied to the BATHTUB model for simulation of in-lake water quality. Calibration and validation were performed once model adjustments were completed.

4.1 LLRM Adjustments

As discussed by **Section 3.3.3**, reliable long-term tributary water quality observations were not available for comparison with LLRM model predictions. In lieu of this data, external watershed loads estimated by LLRM were calibrated based on the following iterative process: 1) internal loading estimates were input into BATHTUB to determine which overall load to the lake resulted in an acceptable in-lake water quality prediction based on **Table 3-3** model evaluation criteria ; 2) a reasonable external load was back-calculated based on the proportion of internal load relative to total acceptable load; 3) LLRM inputs were adjusted accordingly.

4.1.1 Flow Attenuation

Estimates of average annual outflow (runoff plus baseflow) from each tributary were first reviewed to determine if it was necessary to assign water attenuation (i.e., loss) factors to each subwatershed to account for mechanisms such as depression storage, wetlands, infiltration, etc. Predicted annual average outflow of the Bantam River tributary during the seven-month averaging period was approximately 28.8 million m^3/yr from the initial LLRM model. Based on review of the previous diagnostic feasibility report, the observed annual outflow from the Bantam River in 2007 during the averaging period was approximately 30 million m^3/yr (NAR, 2009). As indicated by **Table C-1**, precipitation totals during 2007 are representative of precipitation totals during the overall calibration period. Based on this information, flow attenuation factors were not applied to the LLRM model.

4.1.2 Nutrient Attenuation

Based on LLRM guidance, nutrient attenuation within subwatersheds can vary widely based on removal processes such as infiltration and filtration provided by wetlands, ponds, and other features. Nutrient attenuation within an individual watershed can range from 0.4 (60% removal) to 0.9 (10% removal) (AECOM, 2009). Based on this guidance, attenuation factors were assigned to each subwatershed based on review of the relative extent of major visible attenuation features (i.e., wetlands and ponds) as follows: 1) Minimal: 1; Small: 0.9; Medium: 0.85; Large: 0.80. Attenuation factors for each subwatershed and tributary are summarized by **Table C-8**.

> ***Note on Attenuation**: As indicated by **Table 3-4**, LLRM enables a user to apply attenuation factors to simulate additive attenuation effects from upstream to downstream subwatersheds. The LLRM model double counts these additive effects in "triple" nested subwatersheds and beyond. For example, imagine three (3) "triple nested" subwatersheds (W1, W2, W3) that feed into one another (W3 → W2 → W1). Each subwatershed has an initial load of 5 kg/yr and an attenuation factor of 0.9.*
>
> - *The 0.9 attenuation factor is applied to W3's initial load, resulting in an output load of 4.5 kg/yr.*
> - *The resulting 4.5 kg/yr output load from W3 is routed to W2 and their cumulative load is summed (9.5 kg/yr)*

- *The 0.9 attenuation factor from W2 is then applied to the cumulative load from W3 and W2, resulting in a cumulative output load of 8.6 kg/yr from W3 and W2.*
- *This initial "double" nesting is correct, but the formula breaks down when routing cumulative loads from W3 and W2 to W1 (i.e., "triple nesting").*
- *The cumulative output load of 8.6 kg/yr per year from W3 and W2 is routed to W1, along with an additional (double counted) initial load of 5 kg/yr from W2. This results in a cumulative load of 18.1 (i.e., W3/W2 (8.6 k g/yr), W2 (5 kg/yr) and W1 (5 kg/yr). W1's 0.9 attenuation factor is applied to this cumulative load, resulting in a cumulative output load of 16.2 kg/yr.*
- *As indicated by this example, the cumulative output load predicted by LLRM (16.2 kg/yr) is greater than overall generated initial loads (15 kg/yr).*

*In the case of the Bantam Lake watershed, there are many instances of "triple" nesting and beyond. For example, subwatershed W11 receives inflows from W12, W13 and W14 which are then passed along to W8 which also receives inflows from W10 and W9 (See **Figure 3-3**). Due to the highly nested nature of subwatersheds within the Bantam Lake Watershed, a companion spreadsheet was created to cumulatively route loads and associated attenuation factors to successive nested watersheds without double counting these additive effects. The spreadsheet performs the following functions:*

1. *Initial load for each subwatershed is imported from LLRM, prior to attenuation and routing.*
2. *Attenuation factors are assigned to each subwatershed as described above (see **Table C-8**).*
3. *Subwatershed routing sequence is visually depicted by a Bantam-specific interactive diagram.*
4. *Computations are performed by cumulatively routing loads from each successive nested subwatershed (upstream to downstream) without double counting, then applying the subwatershed specific attenuation factors of the downstream subwatershed.*
5. *Imagine the previous example. Instead of double counting, the cumulative output load of 8.6 kg/yr from W3 and W2 is routed to W1, resulting in a cumulative load of 13.6 kg/yr. The 0.9 attenuation factor is then applied, resulting in a cumulative output load of 12.2 kg/yr from W3, W2, and W1.*

*This spreadsheet is included in the electronic project submittal file (see **Appendix B** for file index).*

4.1.3 Export Coefficients

Nutrient runoff and baseflow export coefficients for various land use classifications were initially input into the LLRM model based on the median LLRM default values (**Table C-5**). In practice, these coefficients can vary widely based on numerous site-specific factors (e.g., septic systems, attenuation features, point source discharges, agricultural operations, etc.) Following nutrient attenuation adjustments, total phosphorus and total nitrogen tributary concentrations were still higher than expected. Therefore, runoff coefficients for each land use classification were decreased by 50% and 10% for total phosphorus and total nitrogen, respectively. Baseflow coefficients were not adjusted given their minor contributions to overall tributary load. All adjusted export values are well within reasonable ranges established by LLRM guidance (AECOM, 2009) (see **Table C-9** for acceptable ranges and selected values).

4.2 BATHTUB Adjustments

Once adjustments to LLRM tributary inputs resulted in reasonable outputs; data were input into BATHTUB for initial evaluation. Based on this initial evaluation, the BATHTUB model was generally underpredicting observed in-lake water quality observations of total nitrogen, total phosphorus, chlorophyll-*a*, and Secchi depth. Model parameters that were adjusted based on this finding are discussed below.

4.2.1 Internal Loading

As discussed in **Section 3.6.6**, internal phosphorus loading was initially set as zero, but is estimated to contribute approximately 564 kg/yr of total loading (as a rough order-of-magnitude estimate). An average internal total phosphorus loading value of 0.4 mg/m^2-day was therefore assigned to the model, resulting in a comparable predicted internal total phosphorus load of 560 kg/yr.

4.2.2 Model Selection

BATHTUB includes multiple model options that can be selected to generate in-lake water quality predictions. For example, total phosphorus can be predicted using a second-order available phosphorus model (default), or a more simplistic model such as the Vollenweider Equation. Simulations were run for all available models for each in-lake water quality parameter, then were evaluated by comparing the goodness of fit of model predictions (i.e., percent difference) to observed water quality monitoring data. The model for each water quality parameter that resulted in the best goodness of fit was selected for further evaluation as summarized by **Table 4-1**.

Table 4-1. Selected in-lake water quality evaluation models

Parameter	Selected Evaluation Method
Total Phosphorus	2^{nd} Order Available Phosphorus (*default*)
Total Nitrogen	Bachman Flushing Rate (*Bachman, 1980*)
Chlorophyll-*a*	Phosphorus, Light, and Flushing (*default*)
Secchi Depth	Carlson Trophic State Index (Carlson, 1977)

Notes:

1. Refer to Walker (2006) for explanation of each evaluation method.

4.2.3 Calibration Factors

According to Walker (2006), the empirical models implemented in BATHTUB are generalizations of lake behavior. When applied to data from a particular lake without site-specific calibration, observations may differ from predictions by a factor of two or more. Such differences reflect data limitations (measurement or estimation errors in the average inflow and outflow concentrations), as well as unique features of the particular reservoir. BATHTUB therefore includes a procedure to calibrate the model to match observed predictions through application of calibration factors. For example, if the BATHTUB model initially predicts a Secchi depth of 2 meters, a calibration factor of 2 will result in a prediction of 4 meters.

Although the use of calibration factors is coarse and typically not encouraged, it can be warranted where data gaps exist. Calibration factors were not required to adjust water quality parameters for this analysis.

4.3 Watershed Loading Results

A summary of resulting relevant LLRM watershed loading predictions by tributary is provided by **Table 4-3**. A majority of tributary load is expected to be derived from the Bantam River tributary. A summary of nutrient load estimates by source is provided by **Table 4-4**. Total annual phosphorus loading to Bantam Lake is expected to be 1,606 kg/yr with 63% contributed by tributary sources.

Table 4-3. Summary of Annual Average Tributary Predictions (LLRM)

Variable	Units	Tributary			
		Proximal	Whittlesey Brook	Bantam River	Totals
Watershed Area	ha	493.2	304.7	7,302.9	8,100.8
Discharge	hm^3/y	1.9	1.3	28.8	31.9
Total Phosphorus Load	kg/yr	118	51	835	1,004
Total Phosphorus Concentration	µg/L	62	41	29	-
Total Nitrogen Load	kg/yr	2,345	1,130	19,440	22,915
Total Nitrogen Concentration	µg/L	1,234	904	675	-

Notes:

1. *Time period is 2007-2016 with 2011 and 2016 outlier years removed during April-Oct. averaging period.*
2. *Proximal load and concentration predictions include Septic System (9.7 kg/yr TP; 388.2 kg/yr TN) and Waterfowl (25.2 kg/yr TP; 119.7 kg/yr TN) predictions for Total Phosphorus and Total Nitrogen.*
3. *Surface area of Bantam Lake excluded from "Proximal" tributary (a.k.a subwatershed W1).*

Table 4-4. Summary of Annual Average Nutrient Load Estimates by Source

Load Source	Total Phosphorus		Total Nitrogen	
	Load (kg/yr)	**Percent**	**Load** (kg/yr)	**Percent**
Tributary	1,004	62.5%	22,915	85.3%
Internal	560	34.8%	-	0.0%
Atmospheric	42	2.6%	3,945	14.2%
Totals	**1,606**	**100.0%**	**26,860**	**100.0%**

Notes:

1. *Time period is 2007-2016 with 2011 and 2016 outlier years removed for April-Oct. averaging period.*
2. *Tributary, septic, and waterfowl load estimates obtained from LLRM.*
3. *Internal load and atmospheric load estimates obtained from BATHTUB.*

4.4 In-Lake Water Quality Results

Once model inputs were adjusted, BATHTUB was re-run to compare results to the calibration and validation targets in accordance with the time periods identified by **Section 3.3.3**. Results are summarized by **Table 4-2**.

As indicated by **Table 4-2**, the percent difference between in-lake water quality observations and model predictions during the calibration period ranged from -9.5% to 4.2% for the evaluated parameters. This result is indicative of a "very good" calibration according to the metrics established by **Table 3-3**. *Note that observed* chlorophyll-*a data were not included in the calibration and validation evaluation given limited available observations (See **Section 3.6.5** for discussion).*

The BATHTUB model was then validated by re-computing LLRM tributary outflow rates and predicted nutrient concentrations using an independent dataset of 2017-2018 annual average precipitation values and in-lake water quality observations. As indicated by **Table 4-2**, validation results indicate that the percent difference between water quality observations and model predictions slightly increased for each parameter; however, are still indicative of a "very good" validation in accordance with **Table 3-3**. The BATHTUB model generally underpredicted observed conditions during the validation period.

Table 4-2. In-Lake Water Quality Predictions *(BATHTUB Calibration and Validation Results)*

Parameter	Units	Calibration [2007-2016]			Validation [2017-2018]		
		Observed	Predicted	% Difference	Observed	Predicted	% Difference
Total Phosphorus	µg/L	23.7	24.7	**4.2%**	24.1	22.5	**-6.6%**
Total Nitrogen	µg/L	513.8	528.6	**2.9%**	487.9	455.8	**-6.6%**
Chlorophyll-*a*	µg/L	-	12.7	**-**	-	10.6	**-**
Secchi Depth	m	2.1	1.9	**-9.5%**	2.4	2.1	**-12.5%**
Hypolimnetic Oxygen Depletion Rate	mg/m^3-day	-	427.3	**-**	-	391.2	**-**

Notes:

1. *Calibration period excludes 2011 and 2016 outlier years.*
2. *Observed water quality data from validation period:*
    a. *Total Phosphorus: 76 measurements, CV = 0.43*
    b. *Total Nitrogen: 71 measurements, CV = 0.36*
    c. *Chl-a: 1 measurement, CV = N/A (excluded from evaluation)*
    d. *Secchi Depth: 100 measurements, CV = 0.29.*

5. Nutrient Load Reduction Analysis

This section summarizes the approach used to estimate watershed-based annual phosphorus and nitrogen load reductions that are needed to attain the water quality targets during the critical period of interest as discussed in **Section 3.2**. For reference, a summary of annual average nutrient loading estimates and resulting concentrations in Bantam Lake is provided by **Sections 4.3** and **4.4**, respectively.

The first step of the nutrient load reduction analysis was to run BATHTUB iteratively for five hypothetical loading scenarios. Hypothetical loading scenarios were created by sequentially adjusting the tributary input concentrations for total phosphorus and total nitrogen at selected intervals to enable visualization and analysis of a wide range of potential conditions. The lower end of the range was established by inputting tributary concentrations significantly lower than existing conditions (i.e., minimal to no tributary loading). The upper end of the range was established by inputting tributary concentrations significantly higher than existing conditions. The following tributary input concentration scenarios were used:

- Total phosphorus (µg/L): 0, 15, 25, existing conditions (See **Table 4-3**), 60.
- Total nitrogen (µg/L): 250, 500, 600, existing conditions (see **Table 4-3**), 1000.

Results of this exercise are depicted by **Figures 5-1** and **5-2** for total phosphorus and total nitrogen, respectively. The next step of the analysis was to use these results to define a relationship between hypothetical loading and resulting in-lake nutrient concentrations based on best fit trend lines. The resulting relationships are:

$$L_{phosphorus} = 16.7 \cdot C_{phosphorus}^{1.43}$$

$$L_{nitrogen} = 50.81 \cdot C_{nitrogen} + 1.79$$

Where,

L = Predicted annual average loading during the averaging period (includes all potential loading sources: tributary, internal, septic, atmospheric, waterfowl) (kg/yr)

C = Predicted average in-lake concentration in the upper mixed layer (0-3 m) during the averaging period (µg/L).

Finally, these relationships were used to estimate the lake's loading capacity (i.e., the maximum total loads that result in compliance with **Table 3-1** water quality targets) and the resulting required load reductions needed to meet water quality targets. As indicated by **Table 5-1**, an estimated 127 kg/yr reduction (8.6%) in total phosphorus loading to Bantam Lake is expected to be required to achieve an in-lake total phosphorus concentration of 23 ug/L (i.e., the lower end of the water quality target range of 23 to 30 µg/L established for phosphorus in **Section 3.2**). Similarly, a 3,130 kg/yr reduction (13.2%) in total nitrogen loading is expected to be required to meet an in-lake total nitrogen concentration of 467 µg/L (i.e., the lower end of the water quality target range of 467 to 600 µg/L established for nitrogen in **Section 3.2**). If these load reduction targets are met, the model predicts an in-lake chlorophyll-*a* concentration of 11.8 µg/L and Secchi depth of 2.1 m. These values are both within the water quality target ranges established by **Section 3.2** to achieve "upper range mesotrophic" conditions. Phosphorus is the limiting nutrient in Bantam Lake. Therefore, future management measures should focus on reduction of total phosphorus.

Table 5-1. Nutrient Load Reduction Predictions

Model Predictions	**Total Phosphorus**		**Total Nitrogen**	
	Existing Conditions *(Calibration Period)*	*Load Reduction* (WQ Target)	Existing Conditions *(Calibration Period)*	*Load Reduction* (WQ Target)
In-Lake Concentration (µg/L)	24.7	23.0	528.6	467.0
Total Loading (kg/yr)	1,606	1,479	26,860	23,730
Required Reduction (kg/yr)	-	127	-	3,130
Required Reduction (%)	-	**8.6%**	-	**13.2%**

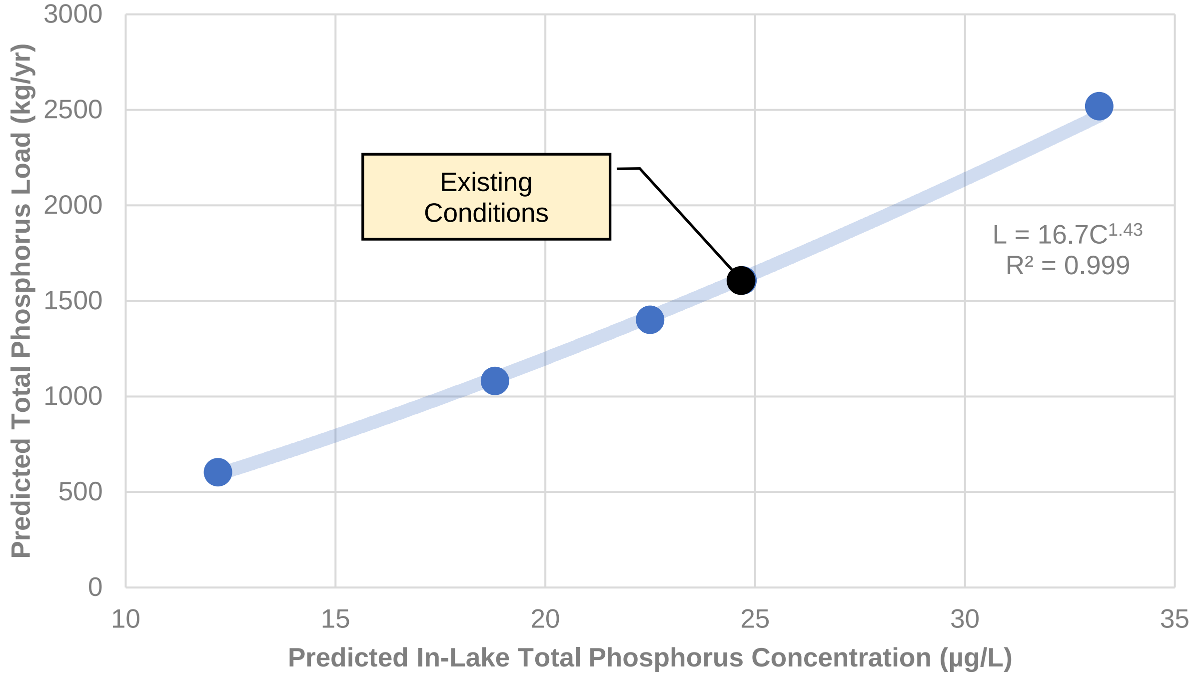


Figure 5-1: Predicted relationship between total phosphorus loading and resulting average in-lake total phosphorus concentration in the upper mixed layer (0-3 m) during the averaging period.

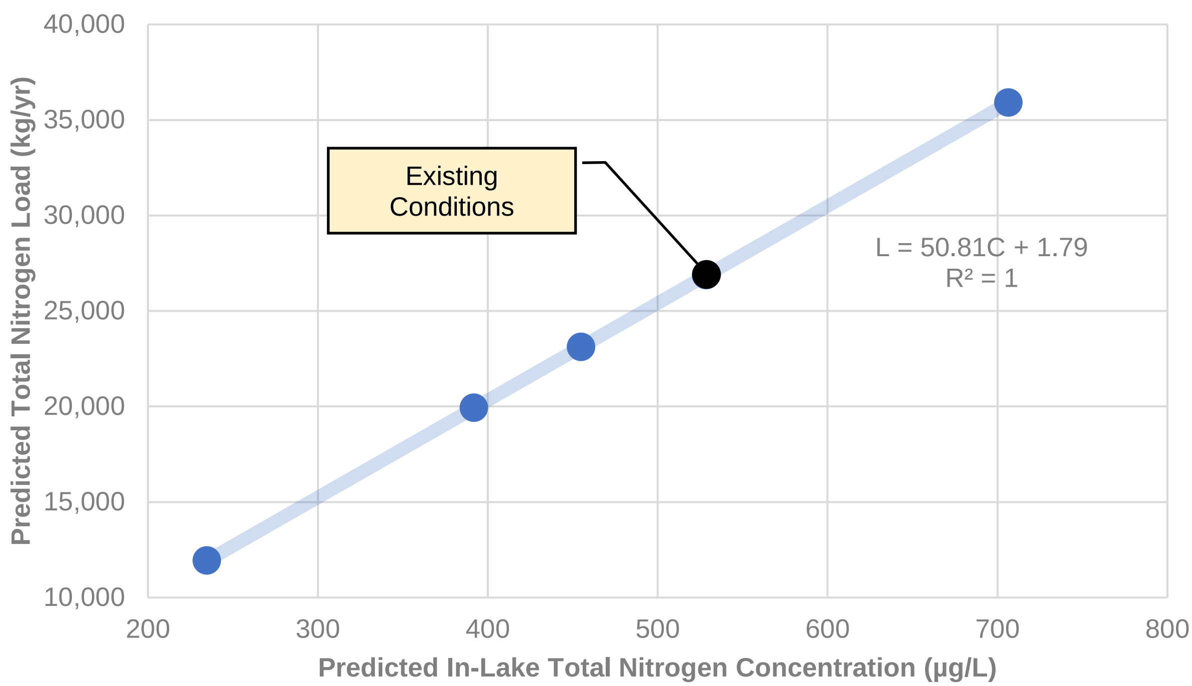


Figure 5-2: Predicted relationship between total nitrogen loading and resulting average in-lake total nitrogen concentration in the upper mixed layer (0-3 m) during the averaging period.

6. Recommendations

The BATHTUB model was calibrated and validated based on a long-term in-lake water quality monitoring dataset. We therefore have confidence that in-lake nutrient water quality predictions are accurately represented by the model. However, the proportion of loading from various sources that contribute to in-lake water quality conditions is less certain (e.g., tributary vs. internal loading). Based on review of available data, future modeling efforts would benefit from some minor adjustments to the monitoring program as summarized below.

- **Tributary monitoring**: Pollutant loading predictions from the LLRM model were not calibrated to tributary data given its very limited availability. Tributary loading predictions were therefore reviewed and adjusted for reasonability based on rule of thumb estimates. To properly calibrate the LLRM model to tributary data, a minimum of three to five years of monthly sampling data during the averaging period would be required at the major tributary input to Bantam Lake (i.e., Bantam River). Additional tributary monitoring locations would also be beneficial based on availability of resources (e.g., Whittlesey Brook inlet to Bantam River, Upper Bantam River, West Branch of Bantam River, etc.).

- **Chlorophyll-*a* monitoring**: Chlorophyll-*a* predictions could not be calibrated or validated given limited data availability. It is recommended that chlorophyll-*a* measurements be included in future water quality sampling efforts at North Bay, South Bay, and Center Lake.

It is expected that these recommendations will enable validation of the predicted proportion between tributary and internal loading (the two primary sources of loading to Bantam Lake) while also enabling validation of in-lake chlorophyll-*a* predictions. Additional data collection or study could also be performed to gain more confidence in other estimates such as septic system and waterfowl loading. These two sources are relatively minor and any adjustments would likely have minimal impact on model results.

7. References

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Appendix A

QAPP for Bantam Lake Nutrient TMDL Model

Quality Assurance Project Plan for Bantam Lake Nutrient TMDL Model

Prepared for

United States Environmental Protection Agency Region 1 – New England
5 Post Office Square
Boston, MA 02109

Prepared by

Comprehensive Environmental, Inc.
21 Depot Street
Merrimack, NH 03054

and

HydroAnalysis, Inc.
481 Great Road, Suite 3
Acton, MA 01720

EPA Contract No. 68HE0118A0001
Order Number 68HE0118F0009

November 28, 2018
Revision No. 2

A. Project Management

A.1. Title and Approval Sheet

Quality Assurance Project Plan for Bantam Lake Nutrient TMDL Model

12/13/18

Steven Winnett (EPA), Task Order Contracting Officer Representative — Date

12/11/18

Robert Reinhart (EPA), Quality Assurance Officer — Date

12/7/2018

Bob Hartzel (Comprehensive Environmental), Task Order Manager — Date

12/7/18

Ken Hickey (HydroAnalysis), Quality Assurance Coordinator — Date

A.2. Table of Contents

List of Figures

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A.3. Distribution List

This Quality Assurance Project Plan (QAPP) will be distributed to the key project personnel listed in Table 1, and to all contractor and subcontractor personnel involved in the project, including those who may join the project after approval of the QAPP.

Table 1. QAPP Distribution

Name, Agency, Role	Contact Information	Mailing Address
Steven Winnett U.S. Environmental Protection Agency Task Order Contracting Officer Representative	617-918-1687 winnett.steven@epa.gov	5 Post Office Square, Suite 100 (OEP06-2) Boston, MA 02109
Mary Garren U.S. Environmental Protection Agency Project Team Leader	617-918-1322 garren.mary@epa.gov	5 Post Office Square, Suite 100 (OEP06-2) Boston, MA 02109
Toby Stover U.S. Environmental Protection Agency Project Technical Advisor	617-918-1604 stover.toby@epa.gov	5 Post Office Square, Suite 100 (OEP06-2) Boston, MA 02109
Robert Reinhart U.S. Environmental Protection Agency Quality Assurance Coordinator	617-918-8633 reinhart.robert@epa.gov	EPA New England Regional Laboratory 11 Technology Drive (EQA) North Chelmsford, MA 01863-2431
Bob Hartzel Comprehensive Environmental, Inc. Task Order Manager	508-281-5201 rhartzel@ceiengineers.com	225 Cedar Hill Street, Marlborough, MA 01752
Laura Blake HydroAnalysis, Inc. Technical Lead	lblake@hydroanalysisinc.com 617-320-6000	481 Great Road, Suite 3 Acton, MA 01720
Ken Hickey HydroAnalysis, Inc. Quality Assurance Coordinator	khickey@hydroanalysisinc.com 978-501-5111	481 Great Road, Suite 3 Acton, MA 01720

A.4. Project Organization

Comprehensive Environmental, Inc. (CEI) and HydroAnalysis, Inc. have been contracted by the U.S. Environmental Protection Agency (EPA) Region 1 (through a task order under EPA Contract No. 68HE0118A0001 with PARS Environmental) to provide support in developing the modeling capacity of staff at Connecticut Department of Energy and Environmental Protection (CT DEEP) to support nutrient total maximum daily load (TMDL) development for lakes and impoundments. An organization chart for the project team is depicted in Figure 1, and includes the relationships and lines of communication among all key project personnel. The roles and responsibilities of key project personnel are summarized below.

Steve Winnett (EPA) is the Task Order Contracting Officer Representative (TOCOR), and will provide overall project and budget oversight for the task order, including tasking contractors with work required to complete the project. Mr. Winnett will review and approve the QAPP and ensure that all contractual issues are addressed as work is performed on this project.

Mary Garren (EPA) is the Project Team Leader, and will coordinate with contractors to ensure that project objectives are attained. Ms. Garren will also review project deliverables developed by the contractors to ensure technical quality and contract adherence.

Toby Stover (EPA) is the Technical Advisor, will assist with the review of project deliverables developed by the contractors to ensure technical quality and contract adherence.

Robert Reinhart (EPA) is the QA Officer, and will be responsible for reviewing and approving this QAPP. In addition, Mr. Reinhart will conduct external performance and system audits, as needed, and participate in any EPA reviews of work performed. Mr. Reinhart will remain independent from the project.

Bob Hartzel (CEI) is the Task Order Manager, and is responsible for overall management of the contract team, including overseeing CEI staff and subcontractor staff and coordinating with the EPA TOCOR. Mr. Hartzel will review project deliverables (including model setup), assist with model training, and ensure the completion of high quality work within the established budget and schedule.

Laura Blake (HydroAnalysis) is the Technical Lead, and will develop model input data sets, calibrate and validate the model, apply the model, conduct the model training, and prepare project deliverables. Ms. Blake will implement the QA/QC program, complete assigned work on schedule and with strict adherence to the established procedures, and complete required documentation.

Ken Hickey (HydroAnalysis) is the Quality Assurance Coordinator, and will support the preparation of the QAPP, review and approve the QAPP, and perform monitoring of quality control (QC) activities to determine conformance with quality assurance and quality control (QA/QC) requirements.

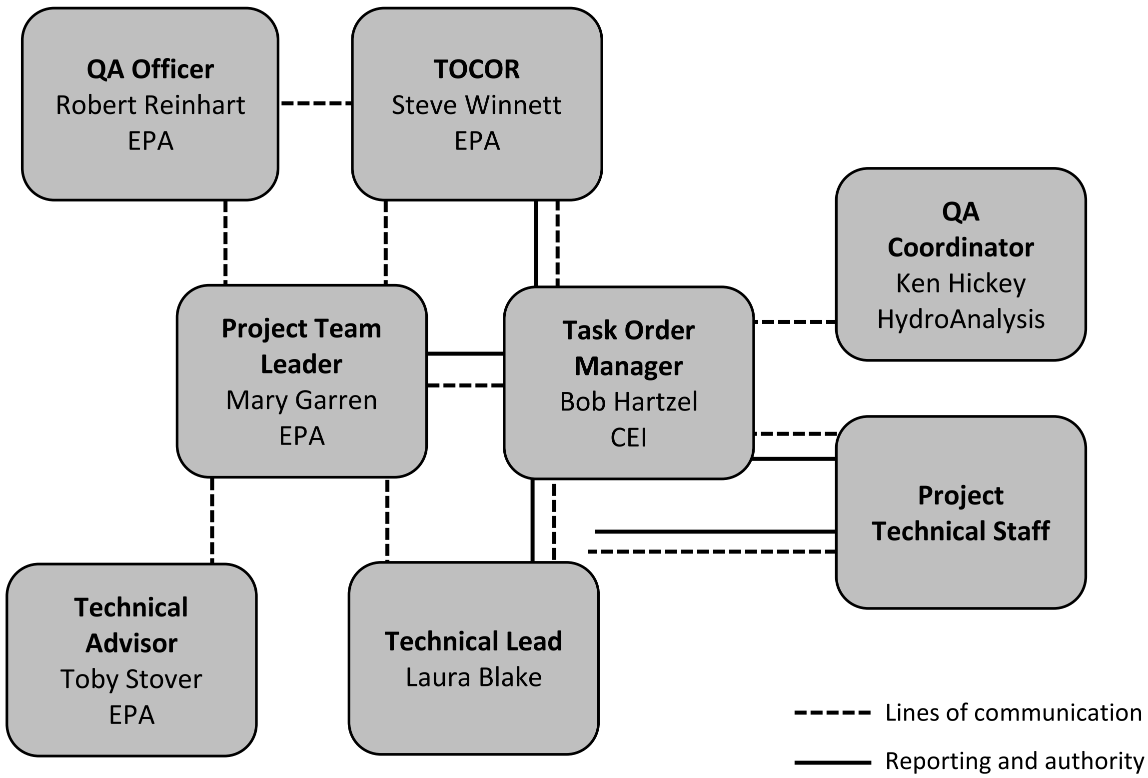

Figure 1. Project Organizational Chart

A.5. Problem Definition and Background

Excess nutrients can lead to eutrophication and potential formation of Harmful Algal Blooms (HABs) in lakes and impoundments. Addressing nutrient impacts to water quality has been identified as a high priority for the state by the CT DEEP. In order to address the impact of nutrients on lakes and impoundments in Connecticut and the potential for development of HABs within these waterbodies, CT DEEP is proposing to develop a statewide TMDL to address nutrient loading and HAB formation with watershed specific appendices to address site-specific conditions. The statewide TMDL will include a core document and watershed specific appendices. The core document will provide background information on the water quality impacts associated with nutrients and HABs and include a general TMDL and discussion of implementation resources. Nutrient loads will be evaluated against changes in lake trophic status, as defined in Section 22a-426-6 of Connecticut's Water Quality Standards Regulations. The watershed specific appendices will provide site-specific information to document existing nutrient loads and conditions contributing to HABs as well as identify necessary nutrient load reductions and other actions to prevent HABs formation in the future.

CT DEEP has selected Bantam Lake for the first appendix that will accompany a future statewide HAB Nutrient TMDL. With surface area of 947 acres, Bantam Lake is Connecticut's largest natural lake. Bantam Lake is an important local resource for public recreation, including boating and swimming. Bantam Lake has a history of frequent blooms of cyanobacteria due to eutrophication of the lake from external and internal loading of nutrients. Bantam Lake was listed on CT DEEP's 2016 Integrated Water Quality Report as impaired for recreation with chlorophyll a, excess algal growth, and nutrient/eutrophication biological indicators identified as the causes of impairment. CT DEEP selected the BATHTUB model (Walker, 1999, 1987, 1985) to support the evaluation of nutrient loading and estimation of watershed based annual load reductions needed to attain the natural trophic status of Bantam Lake.

CEI and HydroAnalysis have been contracted by EPA Region 1 (through a task order under EPA Contract No. 68HE0118A0001 with PARS Environmental) to provide support in developing the modeling capacity of staff at CT DEEP to support nutrient TMDL development for lakes and impoundments. The specific project objectives are as follows:

1) Setup, calibrate, and validate the BATHTUB model for Bantam Lake.

2) Using the calibrated and validated BATHTUB model, calculate nutrient loading capacities and load reductions necessary to meet water quality targets for Bantam Lake, including total phosphorus (TP), total nitrogen (TN), chlorophyll-a concentrations, transparency, and hypolimnetic oxygen depletion rate.

3) Provide CT DEEP staff with model training such that they are able to independently replicate the analysis for Bantam Lake and apply the modeling analysis to support the development of TMDLs for nutrients in other lakes and impoundments in Connecticut.

This QAPP describes the quality system that will be implemented for this project. This QAPP presents the data quality objectives for the BATHTUB model and describes the quality control steps and techniques to be followed to achieve the QA/QC criteria established for the project. This QAPP also addresses the use of secondary data (i.e., data collected for another purpose or collected by an organization not under the scope of this QAPP) to support model development and TMDL calculations. This QAPP was developed in accordance with EPA guidance documents for QAPPs, including *EPA Guidance for Quality Assurance Project Plans* (EPA QA/G-5) (EPA, 2002), *EPA New England Environmental Data Review Program Guidance* (EPA, 2018), EP*A New England Quality Assurance Project Plan Guidance for Environmental Projects Using Only Existing (Secondary) Data* (EPA 2009), and the EPA New England templates and checklist for modeling QAPPs.

A.6. Project and Task Description

A.6.1. Project Tasks

CEI and HydroAnalysis have been contracted by EPA Region 1 (through a task order under EPA Contract No. 68HE0118A0001 with PARS Environmental) to provide support in developing the modeling capacity of staff at CT DEEP to support nutrient TMDL development for lakes and impoundments. The specific tasks to be completed under this project are as follows:

- Develop a Quality Assurance Project Plan.
- Assemble, review, and format secondary data for the BATHTUB model input for Bantam Lake.
- Prepare a technical memorandum to summarize the modeling methodology and BATHTUB model input data.
- Setup, calibrate, and validate the BATHTUB model for Bantam Lake.
- Use the calibrated BATHTUB model to calculate nutrient loading capacities and load reductions necessary to meet water quality targets for Bantam Lake, including TP, TN, chlorophyll a, transparency, and hypolimnetic oxygen depletion rate.
- Develop and conduct model training for CT DEEP staff, such that CT DEEP staff are able to independently replicate the analysis for Bantam Lake, and apply the modeling analysis to other lakes.
- Prepare a final report that summarizes the model setup, calibration, validation, and application to calculate nutrient load reductions needed to meet the water quality targets for Bantam Lake.
- Provide all data and related files used in the modeling of Bantam Lake.

A.6.2. Project Schedule

The project schedule for deliverables and other key milestones is provided below.

Milestone	Date
Notice to Proceed	September 19, 2018
Technical Progress Reports & Invoices (Task 1)	Monthly
Kickoff Call (Task 1A)	October 2018
Kickoff Call Summary (Task 1A)	Within 7 days of call
Conference Calls (Task 1B)	To be scheduled as needed
Conference Call Summaries (Task 1B)	Within 7 days of each call
QAPP – draft (Task 2)	October 9, 2018
QAPP – EPA comments (Task 2)	October 30, 2018
QAPP – final (Task 2)	November 13, 2018
QAPP – EPA approval (Task 2)	November 27, 2018
Technical Memo & Model Input Files – draft (Task 3)	January 22, 2019
Technical Memo – EPA comments (Task 3)	February 5, 2019
Technical Memo – final (Task 3)	February 19, 2019
Complete Model Files (Task 4)	April 30, 2019
Onsite Model Training (Task 5)	Week of May 20, 2019 (tentative)
Final Report – draft (Task 6)	June 28, 2019
Final Report - EPA comments (Task 6)	July 26, 2019
Final Report – final (Task 6)	August 23, 2019

A.7. Quality Objectives and Criteria for Measurement Data

This section describes the quality objectives for the project, including the performance and acceptance criteria to achieve the objectives. The QA process for this project consists of using data of acceptable quality, data analysis procedures, modeling methodology and tools, administrative procedures, and technical reviews. Project quality objectives and criteria for data will be addressed by: (1) evaluating the quality of the data used, and (2) assessing the results of the model application.

A.7.1. Measurement Data Acceptance Criteria

Model setup, calibration, validation, and application for this project will be accomplished using secondary data from qualified sources, including governmental agencies. Data of known and documented quality are essential components of the success of the water quality modeling analysis to be conducted under this project because the model will generate data to be used to support the TMDL decision-making process. Table 2 summarizes the acceptance criteria for secondary data that will be used in the setup and calibration of the model.

The organizations generating the secondary data that may be used in this project typically apply their own review and verification procedures to evaluate a dataset's integrity and conformance to QA/QC requirements. The quality of the data will be judged using information in source documents, from websites of origin, or directly from the authors. If the quality of the data can be adequately determined, the data will be used. If it is determined that no quality requirements exist or can be established for a dataset that must be used for this task, a case-by-case basis determination will be made regarding the use of the data. Data of unknown quality will not be used if the use of such data is believed to have a significant or disproportionate impact on the TMDL results.

Secondary data will be assembled, reviewed, and formatted in an Excel spreadsheet format ready for input into BATHTUB. Data that are outside of typical ranges for a given parameter will be flagged for exclusion during model setup, calibration, and validation. Flagged data will only be excluded if they are determined to be erroneous (e.g., pH >14). The final data used in the model, the period of record of the data, and the source of the data will be documented in the final report. Any use of secondary data of unknown quality and any data gaps and the assumptions used in filling such gaps will also be documented in the final report.

Table 2. Data Acceptance Criteria for Secondary Data

Quality Criterion	Description
Reasonableness	Datasets will be reviewed to identify anomalous values that may represent data entry or analytical errors. Such values will not be used without clarification from the agency providing the data.
Completeness	Datasets will be reviewed to determine the extent of gaps in space and time. It is likely that some data gaps will be evident. These gaps and the methods used to fill the gaps will be discussed in project deliverables.
Comparability	Datasets from different sources will be compared by checking the methods used to collect the data and that the units of reporting are standardized.
Representativeness	Datasets will be evaluated to ensure that the reported variable and its spatial and temporal resolution are appropriate for the project. For example, datasets must be able to be reasonably aggregated (or disaggregated) to represent conditions in the model and must be representative of conditions during the simulation periods. The goal is for data and information to reflect present day conditions. Where possible, data from the past 10 years will be used.
Relevance	Data specific to the study site will be used. If needed, regional data and information that most closely represent the study site will be used.
Reliability	Sources of data and information will be considered reliable if they meet at least one of the following acceptance criteria: • The information or data are from a peer-reviewed, government, industry-specific source. • The source is published. • The author is engaged in a relevant field such that competent knowledge is expected (i.e., the author writes for an industry trade association publication versus a general newspaper). • The information was presented in a technical conference where it is subject to review by other industry experts. • The information or data are from a lake association / watershed group, deemed credible by CT DEEP. Sources of data that use unknown collection and data review procedures are considered less reliable, and will be used only if necessary to fill data gaps and following discussion with and approval by EPA.

A.7.2. Model Performance and Acceptance Criteria

EPA's *Guidance for Quality Assurance Project Plans for Modeling* (EPA QA/G-5M) discusses the importance of using performance criteria as the basis by which judgments are made on whether the model results are adequate to support the decisions required to address the study objectives. The focus of this section is to specify model performance criteria for the BATHTUB model to be developed for Bantam Lake.

A 'weight of evidence' approach that embodies the following principles will be adopted for model calibration in this project (Donigian 2002):

- Given that models are approximations of natural systems, exact duplication of observed data is not a performance criterion. The model calibration process will measure, through comparability goals, the ability of the model to simulate observed data.
- No single procedure or statistic is widely accepted as measuring, nor capable of establishing, acceptable model performance. Thus, both quantitative (error statistics) and qualitative (graphical) comparisons of observed data and model results will be used to provide sufficient evidence to weight the decision of model acceptance or rejection.
- All model and observed data comparisons must recognize, either qualitatively or quantitatively, the inherent errors and uncertainty in both the model and the measurements of the observed data sets. These errors and uncertainties will be documented, where possible, in the final report.

The BATHTUB model will be deemed acceptable when it is able to simulate observed data within predetermined statistical measures. Table 3 lists the model performance criteria, sometimes referred to as calibration criteria, that will be used to compare and evaluate the percent mean errors between model predictions and observed data. The ranges in Table 3 are intended to be applied to mean values; individual observations may show larger differences and still be deemed calibrated and validated for application so long as such excursions are limited (Donigian 2000). Model performance will be deemed acceptable where a performance evaluation of "good" or "very good" is attained. While the ranges in Table 3 will be used as targets for model calibration and validation, they cannot be guaranteed to be met as they may not be achievable. The model will be considered calibrated when it reproduces data within an acceptable level of accuracy determined in consultation with EPA, which will be documented in project deliverables.

Table 3. Model Calibration / Validation Targets (Donigian 2002)

Variable	Percent Difference between Simulated and Observed Values		
	Very Good	***Good***	***Fair***
Water Quality / Nutrients	< 15	15 – 25	25 - 35

A.8. Special Training and Certification

Contractor personnel working on this project hold advanced degrees from universities that are well known for excellence in surface water modeling. Further, the contractor personnel all have more than 20 years of experience calibrating, validating, and applying hydrologic and water quality models to support TMDL development in numerous types of water bodies. This experience includes the application of the BATHTUB model to support the development of nutrient TMDLs for lakes.

No special training or certification is required for personnel working on this project beyond the already high degree of academic training and professional experience that they have obtained in order to fulfill job requirements commensurate with their current assignments.

A.9. Documentation and Records

All data and information collected and generated during this project will be stored in a project folder area on HydroAnalysis' network. At project completion, HydroAnalysis will transmit a copy of all project files to EPA and CT DEEP through use of a Microsoft OneDrive folder created for this project. HydroAnalysis will also maintain a copy of all project files on HydroAnalysis' network for a minimum of five years following completion of the project.

The following deliverables will be prepared under this project:

- Quality Assurance Project Plan
- Monthly technical progress reports
- Teleconference summaries
- BATHTUB model
- Modeling methodology technical memorandum
- Model input data tables
- Model execution files
- Model output files

- Excel spreadsheet tools
- Final report

The final report will provide a complete and clear summary of the modeling methodology and all data and assumptions used in the model for Bantam Lake such that the analysis can be easily reproduced by CT DEEP staff.

B. DATA GENERATION AND ACQUISITION

B.1. Data Acquisition Requirements (Non-Direct Measurements)

This project will require the use of secondary data, also referred to as non-direct measurements. Secondary data are data that were collected under a different effort outside of this project. Secondary data to be used in this project will be collected from government publications and databases, scientific literature, industry published studies, lake associations / watershed groups, and other organizations. Table 2 summarizes the acceptance criteria for use of secondary data in the setup and calibration of the model.

The proposed data (including sources) to be used in the model setup and calibration will be submitted to EPA for review and approval prior to model setup. The final report will include a summary of all final data (including complete citations) used in the setup, calibration, and validation of the model.

B.2. Data Management

Consistent data management procedures will be used during pre-processing, model calibration, and post-processing stages of the project. All data and information collected and generated during this project will be stored in a project folder area on HydroAnalysis' network. Original data sources will be documented to identify the website or contact person that provided the data, data query parameters, and data request correspondence. Original (unaltered) copies of all sources of data used in the project will be retained in the project folder on HydroAnalysis' network.

At project completion, HydroAnalysis will transmit a copy of all of the project files to EPA. HydroAnalysis will maintain a copy of the project files on HydroAnalysis' network for a minimum of five years following completion of the project.

C. Assessment and Oversight

C.1. Assessments and Response Actions

The QA program under which this project will operate includes surveillance, with independent checks of the data obtained from data-gathering and analysis activities. The essential steps in the QA program are as follows:

- Identify and define the problem;
- Assign responsibility for investigating the problem;
- Investigate and determine the cause of the problem;
- Assign and accept responsibility for implementing appropriate corrective action;
- Establish the effectiveness of and implement the corrective action; and
- Verify that the corrective action has eliminated the problem.

If quality problems that require attention are identified, the Technical Lead will determine whether attaining acceptable quality requires either short- or long-term corrective actions. Many of the technical problems that might occur can be solved on the spot by the staff members involved, for example, by modifying the technical approach or correcting errors or deficiencies in documentation. Immediate corrective actions form part of normal operating procedures and are noted in records for the project (e.g., monthly progress reports). Problems that cannot be resolved in this manner require more formalized, long-term corrective action. Examples of major corrective actions may include the following:

- Reemphasizing to staff the project objectives, the limitations in scope, the need to adhere to the agreed upon schedule and procedures, and the need to document QC and QA activities.
- Securing additional commitment of staff time to devote to the project.
- Retaining outside consultants to review problems in specialized technical areas.
- Changing procedures (for example, replacing a staff member, if it is the best interest of the project to do so).

The Technical Lead has primary responsibility for monitoring the activities of this project and identifying or confirming any quality problems. These problems will also be brought to the attention of the Task Order Manager and Quality Assurance Coordinator, who will initiate corrective actions described above, document the nature of the problem, and ensure that the recommended corrective action is carried out. The Task Order Manager and Quality Assurance Coordinator have the authority to stop work on the project if problems affecting data quality that will require extensive effort to resolve are identified. The TOCOR and Project Team Leader will be notified of major corrective actions and stop work orders. The TOCOR and Project Team Leader have the authority to stop work on the project if there are QA concerns.

The Task Order Manager and Technical Lead will each perform surveillance activities throughout the duration of the project to ensure that management and technical aspects are being properly implemented according to the schedule and quality requirements specified in this QAPP. These surveillance activities will include assessing how project milestones are achieved and documented, corrective actions are implemented, budgets are adhered to, technical reviews are performed, and data are managed. QA surveillance activities will be documented in monthly progress reports.

D. Model Application

D.1. Model Parameterization (Calibration)

Model calibration is the systematic changing of initial model parameters to minimize error between observed and simulated values. The calibration begins with the best estimates for model input on the basis of measurements and subsequent data analyses. Results from initial simulations are then used to improve the concepts of the system or to modify the values of the model input parameters. The success of a model calibration is largely dependent on the validity of the underlying model formulation.

Models are often calibrated through a subjective trial-and-error adjustment of model input data because a large number of interrelated factors influence model output. The model calibration *goodness of fit* measures can be either qualitative or quantitative. Qualitative measures of calibration progress are commonly based on the following:

- Graphical time-series plots of observed and predicted data.
- Graphical transect plots of observed and predicted data at a given time interval.
- Comparison between contour maps of observed and predicted data, providing information on the spatial distribution of the error.
- Scatter plots of observed versus predicted values in which the deviation of points from a 45 degree straight line gives a sense of fit.
- Tabulation of measured and predicted values and their deviations.

The BATHTUB model will be calibrated to the best available data, including literature values and interpolated or extrapolated existing field data. If multiple datasets are available, an appropriate period and corresponding dataset will be chosen on the basis of factors characterizing the dataset, such as corresponding weather conditions, amount of data, and temporal and spatial variability of data.

The model will be considered calibrated when it reproduces data within an acceptable level of accuracy (see Table 3). Calibration and validation activities and procedures, along with goodness-of-fit validation targets for specific parameters will be documented in the technical memorandum and final report.

D.2. Model Corroboration (Validation and Simulation)

Data review and validation processes provide a method for determining the usability and limitations of data and provide a standardized data quality assessment. HydroAnalysis staff will be responsible for reviewing data entries, transmittals, and analyses for completeness and adherence to QA requirements. The HydroAnalysis Technical Reviewer will perform evaluations to ensure that QC is maintained throughout project. QC evaluations will include reviewing model setup and double-checking work, and other review to ensure that the standards set forth in the QAPP are met or exceeded.

Raw (original) data will be entered into a standard database. All entries will be compared to the original data files to ensure no transcription errors. A screening process will be used to scan through the database and flag data that are outside typical ranges for a given parameter. Values outside typical ranges will not be used to develop model calibration data sets or model kinetic parameters.

Some data may be manipulated using Microsoft Excel (e.g., if lake data for total phosphorus data are reported in mg/L will, minor calculations will be performed to convert the values to ug/L for input into the model). Ten percent of the calculations will be recalculated to ensure that correct formula commands were entered into the program. If five percent of the data calculations are incorrect, all calculations will be rechecked after the correction is made to the database.

Model validation is an evaluation of the model goodness-of-fit using an independent data set. The model will be considered validated if its accuracy and predictive capability have been proven to be within acceptable limits of error independently of the calibration data. Model validation will be performed using a dataset that differs from the calibration dataset. Acceptable limits are those defined by the combined process of quantitative and qualitative examination of the model versus the data. The limits used will be documented in the final report.

Data quality will be assessed by comparing entered data to original data, performing the data and model evaluations described in this QAPP, and comparing results with the measurement performance or acceptance criteria summarized in this QAPP. Results of the review and performance processes and results will be documented in the final report.

D.3. Reconciliation with User Requirements

The value of the information generated by this project will be determined by evaluating data quality and by comparing methods and results with published data and scientific literature and the data quality objectives identified in this QAPP. Confidence in model predictions can be limited by a number of factors including representativeness of calibration data, knowledge of actual nutrient inputs (external loading and internal loading), and the inherent ability of the model to simulate the conditions in the lake.

Data quality indicators will be calculated during model setup, calibration, and validation. Measurement quality requirements will be compared with the data quality objectives to confirm that the correct type, quality, and quantity of data are being used for the model setup and calibration. Computation and post-simulation analysis results will be reviewed for reasonableness.

To ensure reproducibility of the work by CT DEEP, the final report will identify sources of data, assumptions made during model setup, and calculations performed as part of input data pre- and post-processing.

D.4. Reports to Management

The following reports will be prepared under this project and submitted to EPA for review and approval:

- Quality Assurance Project Plan (draft and final)
- Monthly technical progress reports
- Teleconference summaries
- Modeling methodology technical memorandum (draft and final)
- Final report (draft and final)

The final report will provide a complete and clear summary of the modeling methodology and all data and assumptions used in the model for Bantam Lake such that the analysis can be easily reproduced by CT DEEP staff.

E. REFERENCES

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Walker, William W. 1985. Empirical Methods for Predicting Eutrophication in Impoundments - Report 3: Model Refinements. Prepared for Office, Chief of Engineers, U.S. Army, Washington, D.C., Technical Report E-81-9, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. March 1985.

Appendix B

Electronic File Index

Table B-1. Index of Files used for Bantam Lake TMDL Modeling Effort

Data Type	Folder	File Name(s)	Description	Source
Compiled Data	GIS Data	Bantam Lake Modeling.mdx; Bantam_Lake.gdb	Includes compiled .mxd (map file) and .gdb (geodatabase) of GIS based files used for the modeling effort. Geodatabase includes the following feature classes: - Hydrography Features - Delineated subwatersheds - 2016 NLCD Land Cover Data - Bathymetry Data - Calculated land use statistics by subwatershed	CT DEEP (2019c); This Report
	Bathymetry	Bathymetry.xls	Includes raw and compiled bathymetry data, including calculation of lake volume.	CT DEEP (2019c)
	Evaporation	Evap Data.xls	Includes raw and compiled evaporation data.	Hobbins et al (2017)
	Precipitation	1852415.xls	Includes raw and compiled precipitation data.	NCDC (2019)
	Water Quality	InLake_WQData	Includes raw and compiled water quality data.	CT DEEP (2019a); CT DEEP (2019b); NAR (2009)
Model Files	LLRM	LLRM_Bantam_Cal and Val_2019 02 21	Includes LLRM reference values, LLRM inputs, initial results, calibration results, and validation results. Also includes supplemental routing spreadsheets.	This Report
	BATHTUB	Bantam Lake_INITIAL.btb; Bantam Lake_CAL.btb; Bantam Lake_VAL.btb	Includes Bantam Lake BATHTUB model files used to generate inputs and outputs. Scenarios include: 1) initial, 2) calibration, 3) validation.	This Report
Analyzed Data	Analysis	Compiled Model Inputs_2019 12 12	Includes summary of compiled Appendix C supplemental model inputs obtained from Compiled Data	This Report
	Analysis	Analysis_Results_2019 12 12	Includes analysis of model results, including internal load calculations, compiled loading results, compiled calibration and validation results, and load reduction analysis results.	This Report
	Analysis	In_LakeWQ_StatSignificance	Includes testing of statistical significance of total phosphorus measurements at each sampling location within the upper mixed layer.	This Report

Notes:

1. Files transmitted as .zip package entitled "Bantam Lake TMDL Modeling Files" on February 2020 during transmission of final report.

2. File index is for all compiled and analyzed data. Refer to Table 2-1 of the report for a list of relevant source data sources.

Appendix C

Supplemental Model Input Information

Table C-1. Annual Precipitation Totals

Year	Precipitation (in)	Precipitation (m)
2007	32.5	0.83
2008	38.6	0.98
2009	39.2	0.99
2010	27.5	0.70
2011	**53.8**	**1.37**
2012	29.2	0.74
2013	35.8	0.91
2014	28.7	0.73
2015	28.0	0.71
2016	**21.5**	**0.55**
2017	34.1	0.87
2018	41.3	1.05
Overall Average:	**34.2**	**0.87**
Overall CV:	*0.25*	*0.25*
Calibration Average:	**32.4**	**0.82**
Calibration CV:	*0.15*	*0.15*
Validation Average:	**37.7**	**0.96**
Validation CV:	*0.13*	*0.13*

Notes:

1. Precipitation data compiled from Bakersville, CT Station (GHCN USC0060227), located appx. 15 miles northeast of Bantam Lake.

2. Includes data from selected averaging period (April through October)

3. Calibration average indicates average annual precipitation during the calibration period of 2007-2016 with outlier years removed (2011, 2016).

4. Validation average indicates average annual precipitation during the validation period of 2017 and 2018.

5. CV is the coefficient of variation, calculated as the standard deviation divided by the average.

Table C-2. Calculated Subwatershed Area

Subwatershed	Tributary	Name	Subwatershed Area (ha)	Tributary Area (km^2)
W1	Proximal	Bantam Lake Proximal Area	493.2	4.9
W2	Whittlesey Brook	Whittlesey Brook	304.7	3.0
W3	Bantam River	Lower Bantam River	305.8	73.0
W4		Miry Brook	531.5	
W5		Moulthrop Brook	507.2	
W6		Unnamed Tributary	138.2	
W7		Tannery Brook	225.5	
W8		Mid. Bantam River	1,148.5	
W9		Lower W. Branch, Bantam River	1,399.3	
W10		Upper W. Branch, Bantam River	811.8	
W11		Mid. Bantam River	507.0	
W12		Upper Bantam River	192.9	
W13		Ivy Mtn. Brook	1,047.2	
W14		Fox Brook	487.9	
		Totals:	**8,100.8**	**81.0**

Notes:

1. Subcatchment base shapefile from CT DEEP (2019c)

2. Professional judgement and USGS StreamStats used to adjust boundaries.

3. Areas calculated using GIS tools.

4. Subwatershed area for W1 excludes Bantam Lake.

Table C-3. Lookup Table to related NLCD Land Use Categories to Pre-Defined LLRM Categories

NLCD Code	NLCD Name	NLCD Definition	LLRM Name	LLRM Definition
11	OPEN WATER	Open Water- areas of open water, generally with less than 25% cover of vegetation or soil.	Open 1 (Wetland/Lake)	Open wetland or lake area (no substantial canopy)
21	DEVELOPED OPEN SPACE	Developed, Open Space- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	Urban 5 (P/I/R/C)	Park, Institutional, Recreational or Cemetery
22	DEVELOPED LOW_INTENSITY	Developed, Low Intensity- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.	Urban 1 (LDR)	Low density residential (>1 ac lots)
23	DEVELOPED MEDIUM INTENSITY	Developed, Medium Intensity -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	Urban 2 (MDR/Hwy)	Medium density residential (0.3-0.9 ac lots) + highway corridors
24	DEVELOPED HIGH INTENSITY	Developed High Intensity-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.	Urban 3 (HDR/Com)	High density residential (<0.3 ac lots) + commercial
31	BARREN LAND	Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.	Open 3 (Barren)	Mining or construction areas, largely bare soils
41	DECIDUOUS FOREST	Deciduous Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	Forest 1 (Upland)	Land with tree canopy over upland soils and vegetation
42	EVERGREEN FOREST	Evergreen Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.	Forest 1 (Upland)	Land with tree canopy over upland soils and vegetation
43	MIXED FOREST	Mixed Forest- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.	Forest 1 (Upland)	Land with tree canopy over upland soils and vegetation
52	SHRUB SCRUB	Shrub/Scrub- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.	Open 2 (Meadow)	Open meadow area (no clearly wetland, but no canopy)
71	GRASSLAND HERBACEOUS	Grassland/Herbaceous- areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	Open 2 (Meadow)	Open meadow area (no clearly wetland, but no canopy)
81	PASTURE HAY	Pasture/Hay-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	Agric 3 (Grazing)	Agricultural pasture with livestock
82	CULTIVATED CROPS	Cultivated Crops -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	Agric 2 (Row Crop)	Agricultural with row crops (some bare soil)
90	WOODY WETLANDS	Woody Wetlands- areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	Forest 2 (Wetland)	Land with tree canopy over wetland soils and vegetation
95	EMERGENT HERBACEOUS WETLANDS	Emergent Herbaceous Wetlands- Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	Open 1 (Wetland/Lake)	Open wetland or lake area (no substantial canopy)

Table C-4. Subwatershed Area Based on LLRM Land Use Classification (ha)

LLRM LU Classification	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	Total	Percent
Urban 1 (LDR)	20.7	5.8	4.2	3.3	20.3	14.5	26.2	38.1	23.9	15.1	1.7	2.3	11.3	10.1	197.5	2.4%
Urban 2 (MDR/Hwy)	3.3	0.5	0.2	2.0	9.0	11.1	15.0	7.7	4.3	2.8	0.1	0.1	1.5	1.6	59.3	0.7%
Urban 3 (HDR/Com)	0.2	0.0	0.1	1.6	1.9	1.4	2.5	0.5	0.4	0.8	0.0	0.0	0.5	0.0	9.9	0.1%
Urban 4 (Ind)															0.0	0.0%
Urban 5 (P/I/R/C)	44.9	8.0	18.0	31.2	28.7	15.8	33.9	75.3	77.4	41.9	24.8	4.2	76.1	8.0	488.3	6.0%
Agric 1 (Cvr Crop)															0.0	0.0%
Agric 2 (Row Crop)	0.1	6.9	4.2	3.3	3.1	0.0	0.0	1.9	5.0	0.2	0.0	0.0	3.8	14.4	42.8	0.5%
Agric 3 (Grazing)	19.4	49.2	27.3	25.5	63.9	12.6	9.2	136.1	200.6	70.0	20.9	41.7	142.6	36.8	855.7	10.6%
Agric 4 (Feedlot)															0.0	0.0%
Forest 1 (Upland)	325.0	189.3	86.0	329.3	285.1	42.9	123.8	802.4	852.3	465.6	377.9	117.8	682.0	350.9	5030.4	62.1%
Forest 2 (Wetland)	65.6	43.3	150.8	128.4	85.5	33.4	14.0	70.8	216.8	179.1	65.4	23.0	111.2	49.7	1237.2	15.3%
Open 1 (Wetland/Lake)	11.1	1.4	14.1	6.2	7.0	6.3	0.9	12.9	15.8	33.6	15.5	3.6	15.9	14.1	158.4	2.0%
Open 2 (Meadow)	2.6	0.2	0.1	0.4	2.3	0.4	0.0	2.3	2.9	2.0	0.6	0.1	2.3	1.7	17.7	0.2%
Open 3 (Barren)	0.3	0.1	0.7	0.3	0.4	0.0	0.0	0.5	0.1	0.7	0.0	0.0	0.0	0.5	3.5	0.0%
Totals	**493.2**	**304.7**	**305.8**	**531.5**	**507.2**	**138.2**	**225.5**	**1148.5**	**1399.3**	**811.8**	**507.0**	**192.9**	**1047.2**	**487.9**	**8100.8**	**100%**

Notes:

1. Subwatershed area for W1 excludes "Open 1" area associated with Bantam Lake.

Table C-5. Initial LLRM Export Coefficients

LLRM LU Classification	Runoff Export Coefficients			Baseflow Export Coefficients		
	Precip. Coefficient (fraction)	P Export Coefficient (kg/ha/yr)	N Export Coefficicent (kg/ha/yr)	Precip Coefficient (fraction)	P Export Coefficient (kg/ha/yr)	N Export Coefficient (kg/ha/yr)
Urban 1 (LDR)	0.30	0.44	3.30	0.15	0.01	5.00
Urban 2 (MDR/Hwy)	0.40	0.44	3.30	0.10	0.01	10.00
Urban 3 (HDR/Com)	0.60	0.44	3.30	0.05	0.01	20.00
Urban 4 (Ind)	0.50	0.44	3.30	0.05	0.01	5.00
Urban 5 (P/I/R/C)	0.10	0.44	3.30	0.05	0.01	5.00
Agric 1 (Cvr Crop)	0.15	0.32	3.65	0.30	0.01	2.50
Agric 2 (Row Crop)	0.30	0.88	5.40	0.30	0.01	2.50
Agric 3 (Grazing)	0.30	0.32	3.11	0.30	0.01	5.00
Agric 4 (Feedlot)	0.45	89.60	1753.92	0.30	0.03	25.00
Forest 1 (Upland)	0.10	0.08	1.48	0.40	0.00	0.50
Forest 2 (Wetland)	0.05	0.08	1.48	0.40	0.00	0.50
Open 1 (Wetland/Lake)	0.05	0.08	1.48	0.40	0.00	0.50
Open 2 (Meadow)	0.05	0.08	1.48	0.30	0.00	0.50
Open 3 (Barren)	0.40	0.32	3.11	0.20	0.00	0.50

Notes:

1. Precipitation coefficients represent the fraction of overall rainfall that is converted to overland flow or baseflow (0 = none, 1 = all)
2. Precipitaion coefficients are LLRM defaults.
3. Nutrient export coefficients (P and N) and LLRM defaults (median value).

Table C-6. Average Monthly Evaporation

Month	Evaporation (m)
Apr	0.06
May	0.10
Jun	0.11
Jul	0.12
Aug	0.10
Sep	0.06
Oct	0.03
Total:	**0.57**
Average:	**0.08**
CV:	**0.38**

Notes:

1. Data compiled from monthly pan evaporation data from NOAA COOP station 65445 in Norfolk, CT from 1950-2001.

2. Includes data from selected averaging period (April through October).

3. CV is the coefficient of variation, calculated as the standard deviation divided by the average.

C-7. Calculated Volume, Surface Area, and Average Depth of Bantam Lake

Depth (ft)	Depth (m)	Area (ac)	Area (km^2)	Vol (ac-ft)
2	0.6	113.3	0.46	226.6
2	0.6	0.7	0.00	1.4
6	1.8	96.9	0.39	581.4
6	1.8	0.1	0.00	0.9
6	1.8	4.6	0.02	27.5
6	1.8	0.8	0.00	4.8
10	3.0	94.1	0.38	941.4
10	3.0	0.6	0.00	5.7
10	3.0	0.5	0.00	5.1
14	4.3	92.6	0.37	1295.9
14	4.3	1.1	0.00	14.8
18	5.5	279.4	1.13	5030.0
18	5.5	23.5	0.10	423.3
22	6.7	217.4	0.88	4781.9
26	7.9	0.8	0.00	19.7
26	7.9	21.2	0.09	552.0
	Totals	**947.6**	**3.83**	**13912.3**

Average Depth (ft):	**14.7**
Average Depth (m):	**4.5**

Notes:

1. Source: "Bantam_Bathymetry" Shapefile (CT DEEP, 2019c).

2. Average depth calculated as total volume divided by surface area.

C-8. Subwatershed Nutrient Attenuation Factors

Subwatershed	Tributary	Name	Potential Attenuation	Assigned Attenuation Factor
W1	Proximal	Bantam Lake Proximal Area	Small	0.90
W2	Whittlesey Brook	Whittlesey Brook	Medium	0.85
W3	Bantam River	Lower Bantam River	Large	0.80
W4		Miry Brook	Medium	0.85
W5		Moulthrop Brook	Medium	0.85
W6		Unnamed Tributary	Medium	0.85
W7		Tannery Brook	N/A	1.00
W8		Mid. Bantam River	Medium	0.90
W9		Lower W. Branch	Small	0.90
W10		Upper W. Branch	Large	0.80
W11		Mid. Bantam River	Medium	0.85
W12		Upper Bantam River	Medium	0.85
W13		Ivy Mtn. Brook	Medium	0.85
W14		Fox Brook	Small	0.90

Notes:

1. Potential attenuation assigned based oin review of relative extent of major visible attenuation features (i.e., wetlands / ponds)

2. Attenuation factor indicates % of nutrients that pass through each subwatershed

Table C-9. Adjusted LLRM Runoff Export Coefficients

LLRM LU Classification	P Runoff Export Coefficient (kg/ha/yr)				N Runoff Export Coefficient (kg/ha/yr)			
	LLRM Minimum	LLRM Median	LLRM Maximum	**Selected Value**	LLRM Minimum	LLRM Median	LLRM Maximum	**Selected Value**
Urban 1 (LDR)	0.2	1.1	6.2	**0.6**	1.5	5.5	38.5	**5.0**
Urban 2 (MDR/Hwy)	0.2	1.1	6.2	**0.6**	1.5	5.5	38.5	**5.0**
Urban 3 (HDR/Com)	0.2	1.1	6.2	**0.6**	1.5	5.5	38.5	**5.0**
Urban 4 (Ind)	0.2	1.1	6.2	**0.6**	1.5	5.5	38.5	**5.0**
Urban 5 (P/I/R/C)	0.2	1.1	6.2	**0.6**	1.5	5.5	38.5	**5.0**
Agric 1 (Cvr Crop)	0.1	0.8	2.9	**0.4**	1.0	6.1	7.8	**5.5**
Agric 2 (Row Crop)	0.3	2.2	18.6	**1.1**	2.1	9.0	79.6	**8.1**
Agric 3 (Grazing)	0.1	0.8	4.9	**0.4**	1.5	5.2	30.9	**4.7**
Agric 4 (Feedlot)	21.3	224.0	795.2	**112.0**	680.5	2923.2	7979.9	**2630.9**
Forest 1 (Upland)	0.0	0.2	0.8	**0.1**	1.4	2.5	6.3	**2.2**
Forest 2 (Wetland)	-	-	-	**-**	-	-	-	**-**
Open 1 (Wetland/Lake)	0.0	0.2	0.8	**0.1**	1.4	2.5	6.3	**2.2**
Open 2 (Meadow)	0.0	0.2	0.8	**0.1**	1.4	2.5	6.3	**2.2**
Open 3 (Barren)	0.1	0.8	4.9	**0.4**	1.5	5.2	30.9	**4.7**

Notes:

*1. Refer to **Table A-5** for additional basefow and precipitation export coefficients.*