DRAFT PROJECT REPORT

Diagnostic Report and Management Plan

Bartlett Pond
Plymouth, Massachusetts

February 26, 2020 // ESS Project P320-000

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EXECUTIVE SUMMARY

ESS Group, Inc. (ESS) has prepared this Diagnostic Report and Management Plan for Bartlett Pond on behalf of the Town of Plymouth's Department of Public Health and Division of Marine and Environmental Affairs. The objective of this document is to address the goals of the Town of Plymouth (Town), as they relate to Bartlett Pond and to provide a framework for future management decisions.

The primary goals of the Town were as follows:

- Understand the Bartlett Pond ecosystem and potential pathogen and contaminant exposures that may impact population health
- Address environmental eutrophication and harmful bacteriological concerns in the White Horse Beach/Bartlett Pond area
- Revise policies and procedures, based on key findings, applicable to Board of Health regulations and the White Horse Beach Management Plan.

ESS used historical information and existing data, along with directly collected data and modeling to develop the following elements of this report:

1. Diagnostic Report – A summary of the data collection and analyses used to assess the characteristics and baseline condition of the pond and its watershed, identify deficiencies that may be addressed, and project the pond's future condition under build-out.
2. Management Plan – A review and evaluation of available in-pond, watershed management, and other options to achieve the Town's management goals.

Key findings of the Diagnostic Report include the following:

- Bartlett Pond is currently in a nutrient-enriched state (eutrophic).
    - Under this trophic state, the pond is dominated by algal growth, water transparency is typically low, and cyanobacteria blooms are expected to occur at some point in most years (although rapid flushing of the pond may prevent this from being realized).
    - Modeling of a future watershed development scenario suggests that deterioration of water quality conditions would be expected to continue with increases in nutrient loading. Bartlett Pond would likely become hypereutrophic. Water transparency would be expected to drop further and cyanobacteria blooms would be expected to be a regular occurrence.
    - Although Bartlett Pond appeared to be nitrogen-limited over most of the course of this study, it may become phosphorus- or co-limited under different hydrologic conditions or other environmental sources of seasonal or interannual variability.
- The primary sources of nutrient loading to Bartlett Pond are external.
    - Beaver Dam Brook is the main external source of nutrient loading to Bartlett Pond. The highest loading rates are associated with wet weather discharge. However, when baseflows are high, dry weather nutrient loading rates can also be substantial.

- Direct groundwater loading of nitrogen to Bartlett Pond appears to be lower in magnitude than surface water sources. It may still be a driver of general phytoplankton growth and blooms in Bartlett Pond, particularly when the pond is nitrogen-limited. However, cyanobacteria that are able to fix nitrogen from the atmosphere could still bloom even in the absence of direct groundwater nitrogen loading.

- Phosphorus loading from the sediments occurs and is higher than direct groundwater loading but appears to be low compared to surface water sources.

- Rapid flushing of Bartlett Pond may keep phytoplankton blooms, including cyanobacteria, largely at bay, even when nutrient and environmental conditions are otherwise conducive. However, during extended dry periods, which are likely to coincide with warm, sunny weather, a reduction in flushing rate could allow blooms to develop.

- Bartlett Pond regularly experiences periods when dissolved oxygen concentrations are low (hypoxia) or close to zero (anoxia). These periods were observed in both summer and autumn and tended to occur for a short time during the diel cycle. The presence of macroinvertebrates throughout the pond also suggests that the extent and duration of hypoxic or anoxic conditions is limited.

- Chlorophyll *a* levels (indicators of algal productivity) in the pond were high in the spring with lower concentrations observed over most of the summer, followed by an uptick in autumn.

- Diatoms were the dominant algal group in Bartlett Pond over the course of this study. Cyanobacteria were sometimes also present at low densities, primarily as benthic mats. However, no harmful algal blooms were observed. Additionally, cyanotoxin results were below both the laboratory method reporting limits and the US Environmental Protection Agency's recreational water quality criteria.

- No aquatic invasive plant species were documented in Bartlett Pond. However, water hyacinth and water lettuce were detected in Beaver Dam Brook near Brook Road. Additionally, at least three exotic emergent plants are present at Bartlett Pond, including purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites australis*), and yellow flag iris (*Iris pseudacorus*).

- Resident waterfowl, including Canada Goose, are present at nuisance levels in Bartlett Pond. Nuisance waterfowl increase bacteria and nutrient loading to the pond. Shoreline areas with easy access to the water or plentiful forage of mown grass appear to host the largest congregations of nuisance waterfowl.

The Management Plan assessed a number of management options and found the following to have the highest potential to address the issues at Bartlett Pond:

- Algaecides
- Hand Harvesting
- Herbivores – loosestrife beetles only

- Resident Waterfowl Control
- Nutrient Inactivation – dependent on feasibility study for in-stream dosing
- Septic System Improvements
- Stormwater Controls
- Additionally, monitoring and public education and outreach are recommended for further consideration.

These options would provide a comprehensive suite of short- and long-term approaches to address excessive algae, bacteria, nutrients, and extant invasive species, while also building in flexibility to deal with contingencies like new infestations of aquatic invasive species.

Regarding nutrients, both nitrogen and phosphorus are logical targets for active management at Bartlett Pond, given the nutrient-enriched state of the pond. Nitrogen management is likely to be more difficult to achieve with in-pond or in-stream approaches. Therefore, a watershed focus may be needed to reduce both septic and surface sources of nitrogen. Phosphorus can also be managed in the watershed over the long term. However, in-pond and in-stream approaches, if determined to be feasible, may produce significant reduction of phosphorus concentrations in the short term at a fraction of the cost.

The no-action alternative would entail avoidance of all the management actions. If implemented, this option would allow algae blooms to go unchecked and aquatic invasive species to potentially become established in Bartlett Pond while it fills with fine sediments and water quality continues to degrade. The volume of aquatic habitat would likely see reductions, recreational opportunities would decrease, and the aesthetic value of the pond would decline.

The following next steps are recommended to address the management issues at Bartlett Pond:

1. Develop a long-term (typically five years) implementation plan for Bartlett Pond. This would include prioritization and scheduling of management actions, development of cost estimates, and identification of potential funding mechanisms for the management program.
2. Continue the Bartlett Pond and watershed data collection and analysis program in 2020 to better capture interannual variability and identify potential sources of pollutants. While the 2019 program provided a wealth of useful data, a number of key questions remain. The Town may desire to reduce or eliminate certain elements of the program while expanding others. For example, there may be limited value in continuing to sample for poly- and perfluoroalkyl substances (PFAS), which were widespread but only found at very low concentrations. Similarly, phthalates could probably be eliminated from the sampling program for now, as these substances were not detected in any samples. However, additional investigations upstream/upgradient from Bartlett Pond may be worthwhile in helping to better bracket groundwater and surface water sources of nutrients.
3. Permit and implement the Bartlett Pond long-term management program. Use results from the accompanying monitoring program to adjust or revise the management plan over time.

1.0 INTRODUCTION

ESS Group, Inc. (ESS) has prepared this Diagnostic Report and Management Plan for Bartlett Pond on behalf of the Town of Plymouth's Department of Public Health and Division of Marine and Environmental Affairs. The objective of this document is to address the goals of the Town of Plymouth (Town), as they relate to Bartlett Pond and to provide a framework for future management decisions.

The primary goals of the Town were as follows:

- Understand the Bartlett Pond ecosystem and potential pathogen and contaminant exposures that may impact population health
- Address environmental eutrophication and harmful bacteriological concerns in the White Horse Beach/Bartlett Pond area
- Revise policies and procedures, based on key findings, applicable to Board of Health regulations and the White Horse Beach Management Plan.

Following a brief introduction to Bartlett Pond, this report is divided into two primary sections, as follows:

1. Diagnostic Report – A summary of the data collection and analyses used to assess the characteristics and baseline condition of the pond and its watershed, identify deficiencies that may be addressed, and project the pond's future condition under build-out.
2. Management Plan – A review and evaluation of available in-pond and watershed management options to achieve the Town's management goals.

1.1 Setting

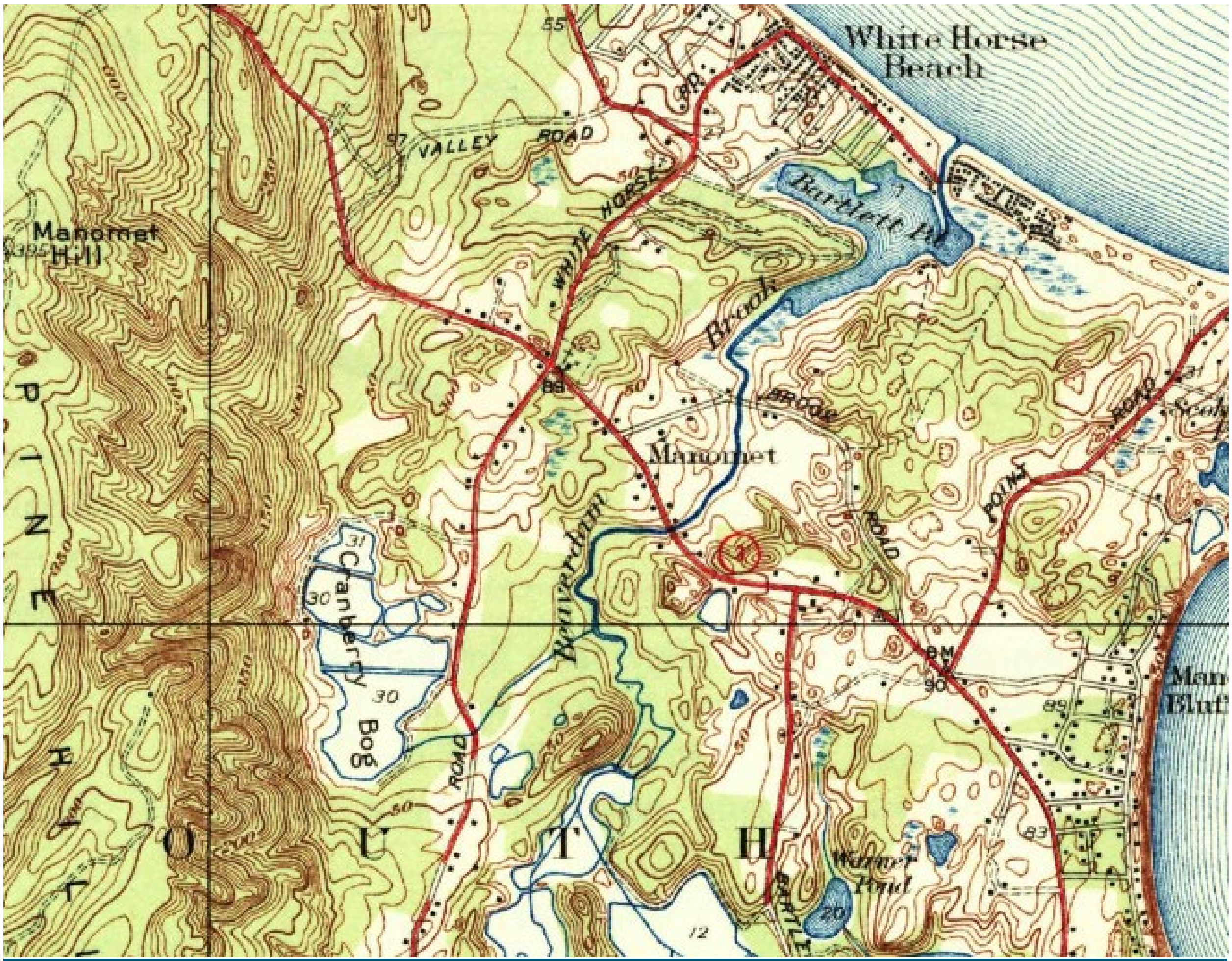
Bartlett Pond is an approximately 30-acre coastal pond located in the Manomet neighborhood of Plymouth, Massachusetts. The pond is a natural water body, although its morphology has been modified to some degree by human activity, including but not limited to the construction of the Taylor Avenue Bridge at its outlet.

The only perennial surface tributary to Bartlett Pond is Beaver Dam Brook, which enters from the southwest. As with most of Plymouth and Cape Cod, the hydrology of Bartlett Pond and Beaver Dam Brook is heavily influenced by groundwater; the pond's 3,524-acre surface watershed is substantially different from the 5,308-acre contributing groundwater area. The combined size of contributing groundwater and surface water areas is approximately 6,365 acres.

Unconsolidated glacial deposits are thick in much of this area and consist primarily of coarse sand and gravel meltwater deposits. However, some portions of the area (e.g., Pine Hills) are characterized by thin till deposits at the surface, underlain by hundreds of feet of glacial outwash. The result is a predominance of highly permeable soils.

Land use in the areas contributing to Bartlett Pond consists of a mix of developed land (primarily residential and commercial), forest, wetlands, and water. Until recently, a substantial portion of Bartlett Pond's surface and groundwater contributing area consisted of cranberry bogs, which had been present for decades, as evidenced from historical maps of the area. However, in the last few years, most of these bogs have been or are being converted from agricultural use to wetlands other less intensive land uses. Conversely, over a similar time period, portions of the western part of Bartlett Pond's groundwater basin have been converted from forest to residential and recreational (golf) land uses.

The shoreline of Bartlett Pond is largely developed, primarily as single- and multi-family residences. The majority of these homes are located along the north, east, and west shorelines of the pond. These homes are serviced by onsite treatment systems (septic systems). Forested shoreline is mainly confined to the southernmost shoreline of Bartlett Pond.



Manomet, Bartlett Pond, Beaver Dam Brook, White Horse Beach and surroundings depicted on 1937 USGS topographic map.

Although areas adjacent to Bartlett Pond have been identified as high-yield aquifers, the pond and its surroundings fall well outside state-designated Groundwater and Surface Water Protection Areas and ESS is not aware of any public potable water intakes in or near the pond. However, it is possible that private wells are operated near the pond, most likely for irrigation, although this has not been confirmed.

Bartlett Pond is listed by the Massachusetts Department of Environmental Protection (MassDEP) as a Category 2 water body in the Final 2016 Integrated List of Waters, which means that it supports some designated uses (in this case, aesthetics) but has not been assessed for others. The pond is an anadromous fish resource and the Bartlett Pond/Beaver Dam Brook system is known to host a herring run.

Despite the importance of groundwater inputs to the system, its waters are not listed as a coldwater fisheries resource. Although Bartlett Pond and areas immediately upstream were previously located within a Priority or Estimated Habitat of Rare Species (as designated by the Massachusetts Natural Heritage and Endangered Species Program [NHESP]), this designation was removed during the last update of the Massachusetts Natural Heritage Atlas (NHESP 2017).

1.2 Summary of Prior Studies

Although this study is believed to be the first comprehensive investigation of the system, Bartlett Pond and its watershed have been previously studied to some degree. Most of the prior studies were limited in focus or duration but provide context and, in some cases, historical data that may help to inform the management of the system going forward.

A listing and brief description of each study is provided in Table A. Note that this table only summarizes the most relevant published or completed studies on Bartlett Pond, its watershed, or White Horse Beach. ESS is aware of other ongoing investigations in the Bartlett Pond watershed, including those associated or coincident with cranberry bog restoration projects (e.g., Tidmarsh) that will likely provide additional information on water quality over time.

Table A. Summary of Prior Studies on Bartlett Pond and its Watershed

Author	Year	Summary Title	Description
CDM	1995	Wastewater Treatment Facilities Plan EIR	Some detail on Manomet area with data on lot size, septic pumping rates, waivers, etc. Also contains background on residential development trends and changes from seasonal to year-round living, extent of sanitary sewer system, soils, and other supplemental information.
ECR	2018	White Horse Beach Management Plan	Description of geology, beach use, protected resource areas, public education efforts, and management recommendations in narrative.
Lyons-Skwarto Associates	1970	Baseline Survey for 41 Ponds in Plymouth	Includes bathymetry, plant, algae, and watershed information for Bartlett Pond.
Metcalf & Eddy	1984	Facilities Plan for Wastewater Management	Similar to CDM 1995 content but more detail with additional focus on Manomet/Bartlett Pond watershed. Good documentation of septic failures and high bacteria levels near Bartlett Pond and WHB.
SMAST	2015	PPALS Atlas	Provides most recent water quality data from Bartlett Pond alongside prior data from 1970 and 2010.
SMAST	2017	PPALS QAPP	Describes methods, QAQC, DQOs used by PPALS for pond monitoring.
SMAST	2016	PPALS 2015 Data Update 1	Contains one profile for Bartlett Pond from September 2015.
Town of Plymouth Public Works	2011	Pond & River Biological Monitoring Program Data Report	Provides water quality, phytoplankton, and aquatic plant information from two surveys in April and June 2010.

1.3 Surface and Groundwater Watersheds

The development of the watershed delineations for Bartlett Pond utilized readily available information from MassGIS (Bureau of Geographic Information), GIS-based information provided by the Town of Plymouth GIS Coordinator, and readily-available hydrologic and hydrogeologic information for the Project area, including two detailed groundwater modeling studies performed by the U.S. Geological Survey (USGS). This GIS-based information was then verified using other available hydrologic and hydrogeologic information and reports as detailed below.

While the project area was known to be dominated by groundwater-driven flows, the developed nature of the Bartlett Pond and Beaver Dam Brook system suggested that human-influenced surface routing of flows to these water bodies might play an important role in water quality. Therefore, both a surface water and groundwater watershed boundary were delineated for this study.

The Bartlett Pond surface water watershed was primarily based on the MassGIS Subbasins datalayer. This delineation of the surface water watershed was verified relative to hydrology information available on USGS topographic maps of the Manomet area and also compared to the delineated watershed for Bartlett Pond using the USGS StreamStats program (https://streamstats.usgs.gov/ss/). The delineated surface water watershed was almost identical to the watershed provided through the USGS StreamStats program and encompasses the various surface water bodies (ponds, streams, etc.) that are hydrologically connected to Beaver Dam Brook and Bartlett Pond.

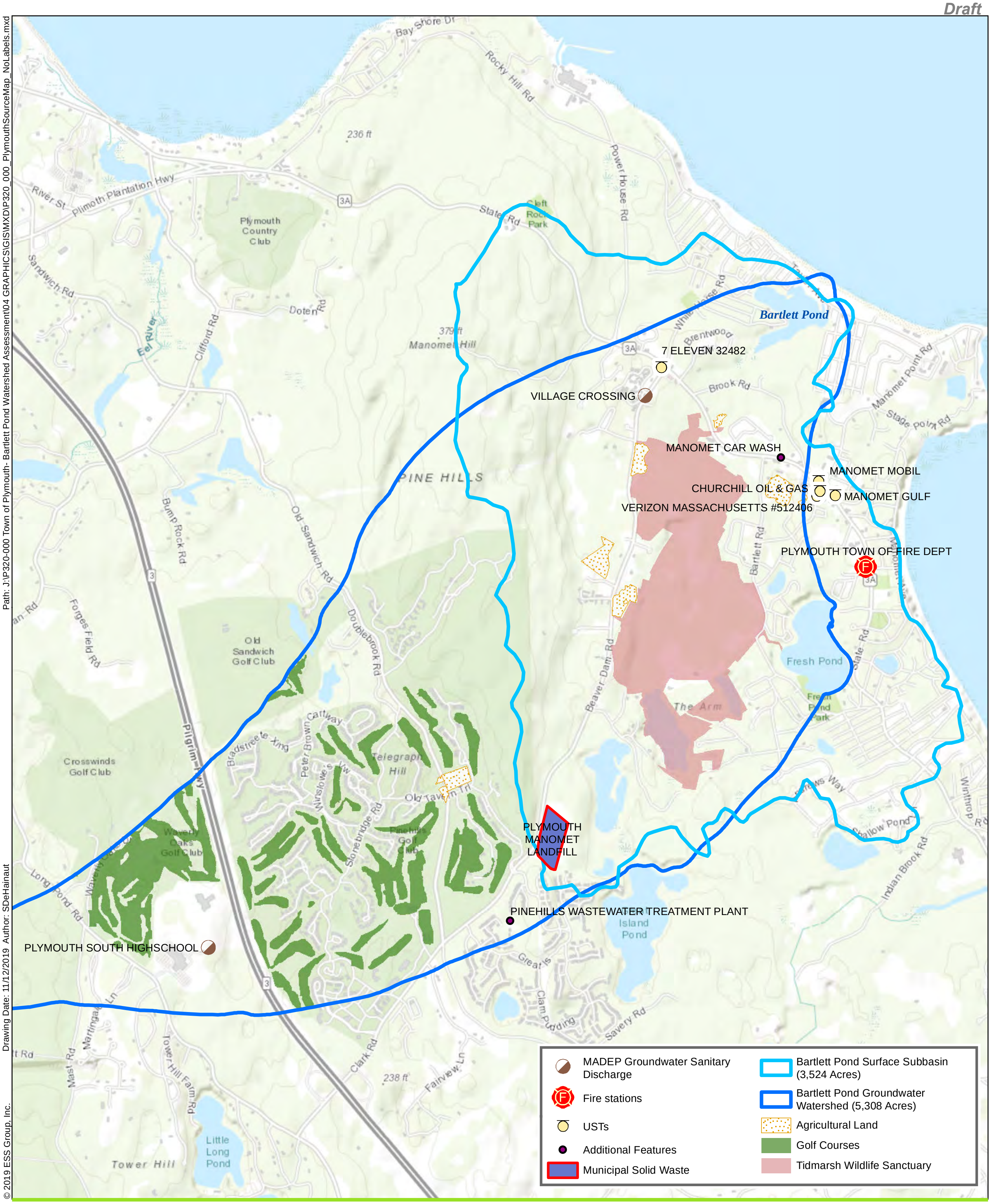
The groundwater watershed was derived from the Aquifer Protection datalayers provided by the Town of Plymouth GIS Coordinator, which are based on the results of the regional modeling of the Plymouth-Carver Aquifer by the USGS (Hansen and Lapham 1992, Masterson et. al. 2009). In particular, the delineation of the groundwater watershed for Bartlett Pond is based on the Area 3 (Contributing Areas to Significant Recreational Water Bodies) datalayer. It should be noted that the groundwater watersheds for Long Island Pond and Fresh Pond were also included in the Bartlett Pond groundwater basin because these two ponds are known to be connected as part of the surface water watershed. This approach ensures that both the delineated watersheds (surface water and groundwater) include all of the land areas contributing water (surface water or groundwater) to the pond. This delineation was reviewed relative to the groundwater elevation contours and flowpaths developed using the USGS groundwater model for the Plymouth-Carver aquifer area (Hansen and Lapham 1992, Masterson et. al. 2009) as presented in these reports. In this type of hydrogeologic setting (areally extensive and thick regional groundwater aquifer), the use of groundwater modeling is the best approach for evaluating groundwater flow paths to Bartlett Pond.

The outcome of this task was a GIS-based mapping of the surface water and groundwater watersheds for the Beaver Dam Brook/Bartlett Pond hydrologic system (Figure 1).

An inventory of land uses that could potentially impact water quality within the Bartlett Pond surface water and groundwater watersheds was also developed to support the evaluation of the water quality data collected during the 2019 field investigation. This inventory used a variety of readily-available data source including:

- Town of Plymouth
    - Septic System Permits
- MassGIS
    - Land Use (e.g., agricultural lands)

Draft



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ESS group environmental consulting & engineering services

Bartlett Pond
Plymouth, MA

Surface and Groundwater Watersheds of Bartlett Pond

Source: 1) Town of Plymouth, Aquifers, 2019
2) MassGIS, Hydrology (2007), Land Use (2005)
3) MassDEP, Groundwater Discharges (2019), Ch. 21e Sites (2019), USTs (2016), Landfills (2016)
4) MEMA, Fire Stations, 2015
5) Town of Plymouth, Septic, 2019

Figure 1

- Massachusetts Department of Environmental Protection (MassDEP)
  - Permitted Groundwater Discharges (e.g., Village Crossing)
  - Chapter 21E Disposal Sites
  - Underground Storage Tanks (USTs)
  - Landfills
- Massachusetts Emergency Management Agency (MEMA)
  - Fire Stations

Further evaluation of land uses within the Bartlett Pond watersheds was performed using readily-available aerial photography (current and historic). This approach, in conjunction with available information regarding the Pine Hills development, was used to identify the locations for The Pinehills Wastewater Treatment Facility, Plymouth Manomet Landfill and the Manomet Car Wash.

Although these sites appear to be located in the Bartlett Pond watersheds, the scope of the current study was not designed to trace the source of water quality issues to specific locations or facilities. Therefore, these areas and facilities are identified for context and cannot be presumed to be actual sources of water quality impairment to Bartlett Pond at this time.

2.0 DIAGNOSTIC SUMMARY

The Bartlett Pond Diagnostic Summary presents a summary of the data collection and analyses used to assess the characteristics and baseline condition of the pond and its watershed, identify deficiencies that may be addressed, and project the pond's future condition under build-out conditions. Each key element of the Diagnostic Summary is presented in the following sections.

2.1 Bathymetry

Approach

The Bartlett Pond bathymetric survey began with review of a prior survey from 1970 (Lyons-Skwarto Associates) to identify any areas of complex bathymetry and plan for sufficient survey coverage to capture major features.

The initial bathymetric survey of Bartlett Pond for this study was conducted on May 22, 2019. A single beam echosounder was used to measure depth near the open waters of the deep hole but, due to the very shallow water present in most portions of the pond, the majority of measurements were collected with a sounding rod or line. A Trimble Geo7X Global Positioning System (DGPS) capable of sub-meter horizontal accuracy was used to measure position and log bathymetric data. Bathymetric data were collected at 75 locations during this initial survey.

The initial bathymetric survey dataset was checked for quality assurance/quality control (QA/QC) purposes, then used as the basis for delineation of one-foot depth contours. This initial contouring process suggested the need for additional bathymetric data to better define areas of more complex bathymetry, such as the area associated with the sandbar at the pond's outlet. Therefore, a second bathymetric survey was conducted on June 18, 2019 to collect additional, focused data in these areas. A total of 89 bathymetric measurements were collected.

Results

Aside from some minor variations, the bathymetric contours of Bartlett Pond are concentric and follow the general shape of the shoreline (Figure 2). The northwestern and southwestern coves of the pond are characterized by substantial areas of very shallow water, located adjacent to large, contiguous beds of emergent vegetation. A sizeable sandbar occupies the area near the outlet of the pond. Although historical aerial photographs suggest that this deposit shifts in size and configuration from year-to-year, it appears to be a perennial feature.

Bartlett Pond has shallowed substantially since the 1970 bathymetric survey completed by Lyons-Skwarto Associates. The pond's average depth was 2.4 feet while the maximum depth, reached near the center of the pond, was 4.1 feet. These represent a decrease of approximately 1.6 feet and 1.9 feet, respectively, from 1970. This is somewhat greater than findings by Stromer et al. (2015), which suggest approximately 0.6 ft to 0.7 ft of sediment accumulation since 1978.

2.2 Hydrology

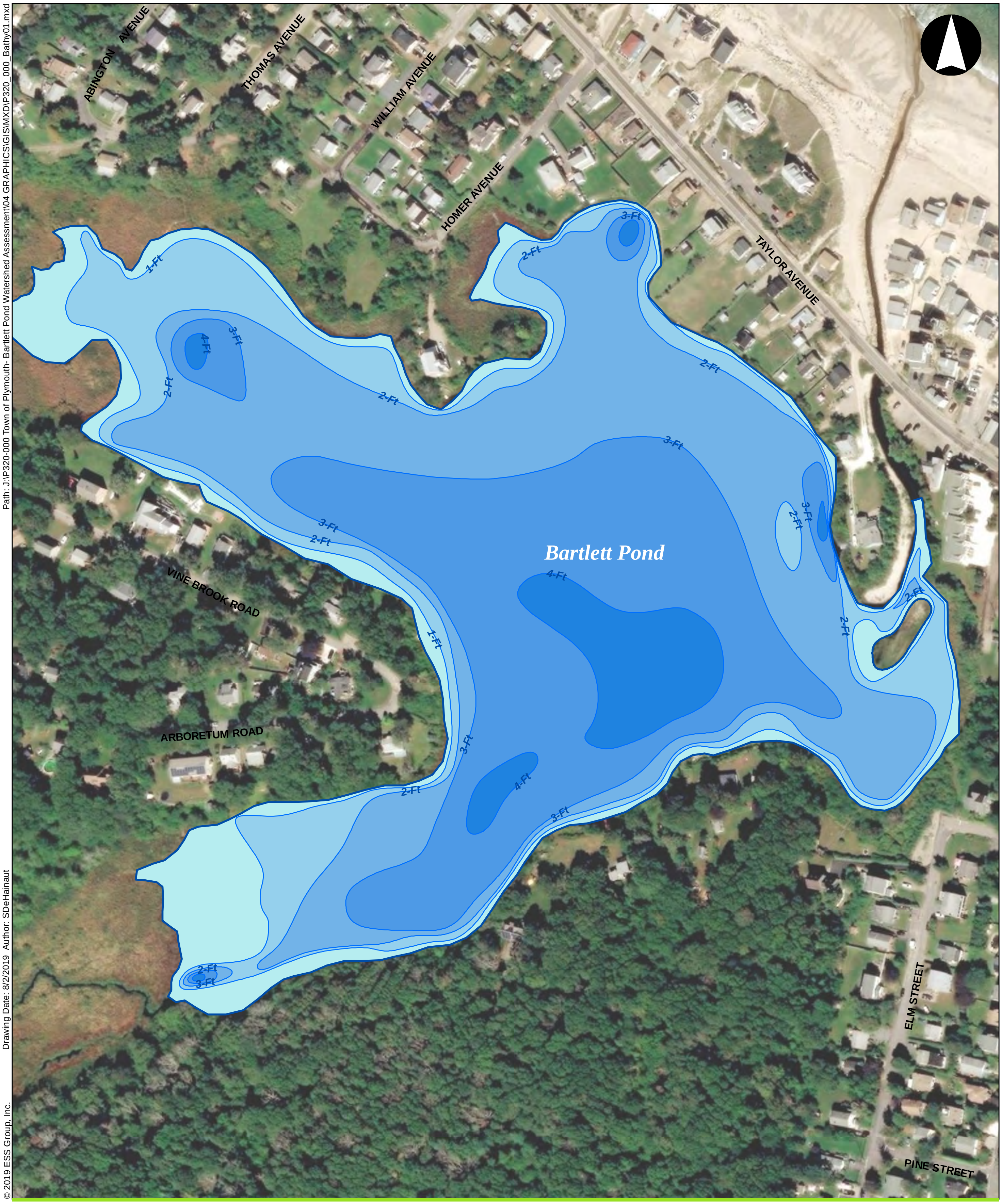
Approach

Surface Discharge Monitoring

To collect continuous water level data, Solinst Leveloggers were deployed in Beaver Dam Brook at Brook Road (designated as "Inlet") and just above the Taylor Avenue Bridge (designated as "Outlet") on April 24, 2019 (Figure 3). The data loggers were attached to cinder blocks or rebar for stability and submerged in a permanently wetted area at each location to record water depth over time. These loggers include non-vented pressure transducers that must be corrected for atmospheric pressure. Therefore, a Solinst Barologger was also deployed in at the Inlet location to provide a record of atmospheric pressure over the course of the monitoring program. Each data logger was set to record readings on an hourly basis over the course of the study.

Leveloggers were installed in protective PVC deployment tubes.

Discharge measurements were collected in the stream channel at each location during surface and stormwater sampling events. Measurement events were staggered from April to December to ensure collection of data over a broad range of flows. Field protocols included the measurement of stream depth and water velocity at multiple points along a perpendicular cross section. This results in multiple subsections for which the respective discharge can be calculated as a function of average velocity, average depth, and width. The sum of all subsection discharges within the measured cross section is equivalent to the discharge of the stream.



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Bartlett Pond Watershed Assessment
Plymouth, MA

Bathymetry

Source: 1) ESRI, World Imagery, 2018
2) ESS, GPS Locations, 5/22/2019 and 6/18/2019

Pond Depth (Ft)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5

Figure 2

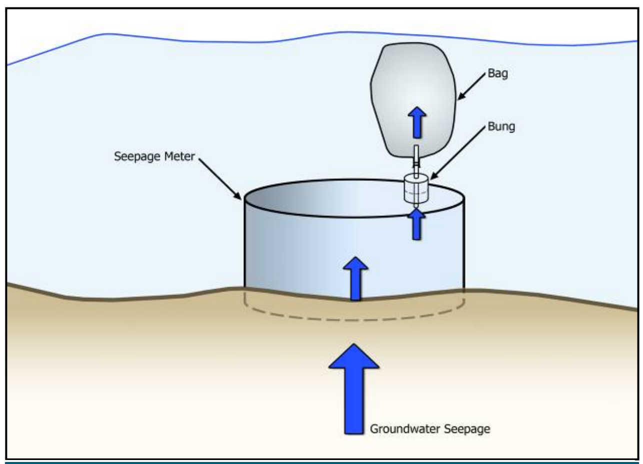
Stream velocity was estimated using a time-of-travel method, which measures surface velocity, rather than depth-averaged velocity. This typically results in a measurement that is biased high. Given the rough channel boundary at each station, the measured velocity was multiplied by a correction coefficient of 0.8.

Water level logger data were downloaded and corrected using measured atmospheric pressure from the barometric logger. Measured stream discharge data were paired with logger-measured depth (stage) data for each sampling event, yielding at least nine stage-discharge data points for each location. These data were plotted and used to develop stage-discharge rating curves describing the relationship between water level and discharge at each location. The equations developed from these rating curves were then used to convert stage data into an estimate of instantaneous discharge over the course of the study.

Shallow Groundwater Seepage Measurements

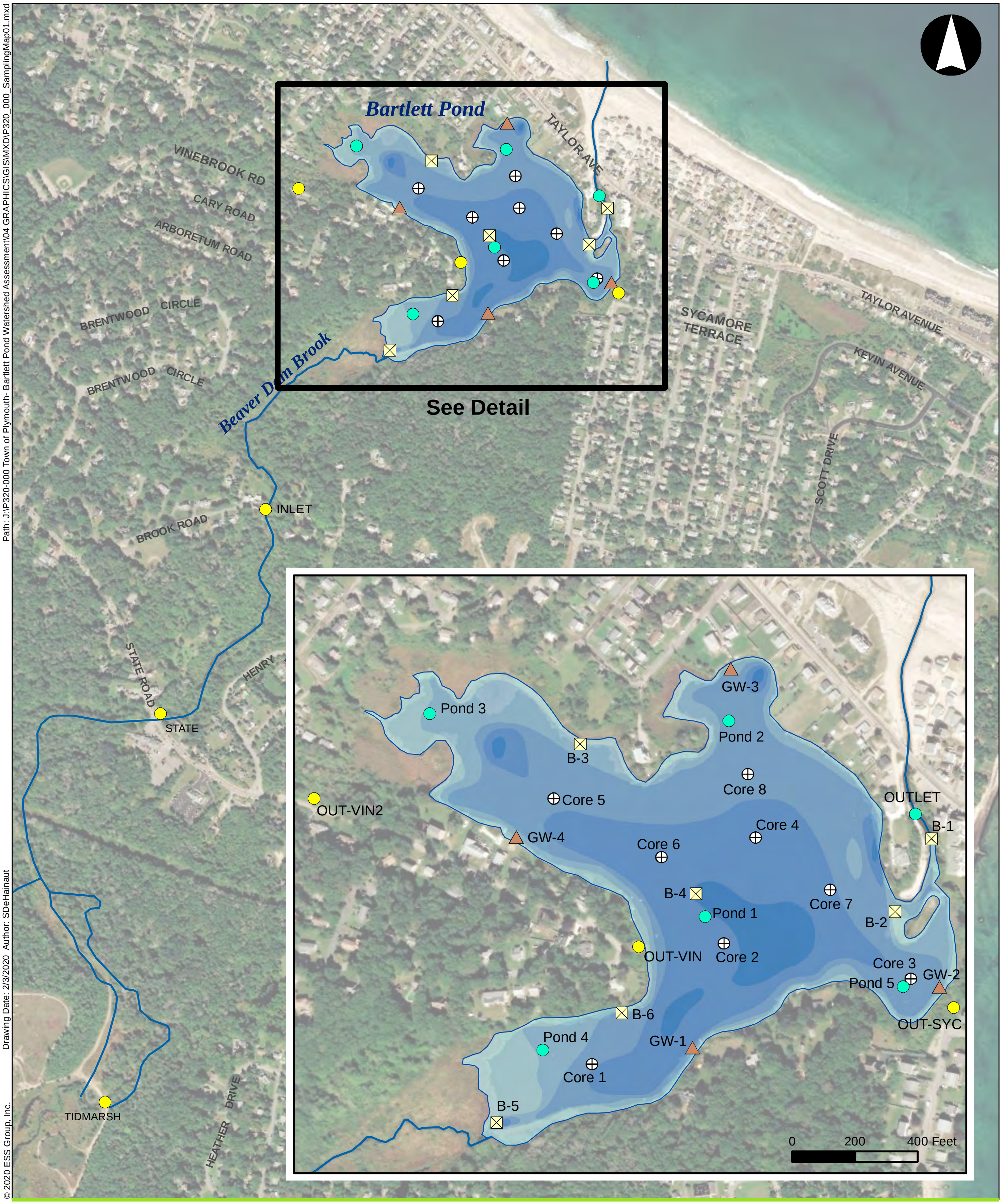
Given the location of Bartlett Pond, groundwater was presumed to have a substantial influence on the hydrology and potentially the water quality of the pond. In order to assess groundwater inputs directly, a groundwater seepage survey was conducted to measure the quantity of groundwater entering or exiting the pond along the immediate shoreline where groundwater inseepage is typically the highest and also most influenced by human behaviors and activities.

A seepage meter is a device that allows the rate of seepage influent to or effluent from the pond to be measured. The device sealed off from surface water influence by advancing the barrel of the meter into pond sediments and then primed with a known volume of water using watertight tubing and receptacles. Seepage meters are usually installed in soft sediments (silt or sand), where they can be deployed deeply enough to prevent lifting of the devices through wave action and ensure that changes in water volume are due to seepage. Once the devices have been installed, they are allowed to sit undisturbed for several hours before measuring seepage rates. Over this time period, inseepage causes the volume of water to increase in the meter while outseepage causes it to decrease.



Conceptual illustration of seepage meter system.

At Bartlett Pond, seepage meters were deployed along four key shorelines (Figure 3) to estimate the rate of in- or out-seepage. These study shorelines were distributed at opposite ends of the pond to ensure characterization of overall seepage conditions. During each seepage survey, two meters were installed along each study shoreline (i.e., total of eight seepage meters) to characterize the local variability in groundwater movement. Additionally, to help account for seasonal variability in seepage rates, one seepage survey was completed in spring (May 8, 2019) and a second was completed in autumn (September 25, 2019).



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Bartlett Pond Watershed Assessment
Plymouth, MA

Bartlett Pond Sampling Locations

- Surface Water Sample Location
- Sediment Sample Location
- Groundwater Sample Location
- Stormwater Sampling Location
- Benthic Sample Locations

Source: 1) ESRI, World Imagery, 2018

Figure 3

Results

Surface Discharge Monitoring

Surface discharge hydrographs developed for Beaver Dam Brook at the Inlet and Outlet locations (Figure 4) demonstrate similar general patterns in discharge over most of the course of this study. Although flow at these locations clearly responds to individual storm events, as evidenced by the alignment between the numerous storm events and discharge peaks in the series, substantial baseflow is also evident. For instance, discharge did not appear to drop much below 10 cfs, even during what is typically the low flow period of the year in late summer/early autumn. Therefore, groundwater flow into Beaver Dam Brook and Bartlett Pond appeared to be adequate to buffer the system from periods of dry weather throughout the course of this study.

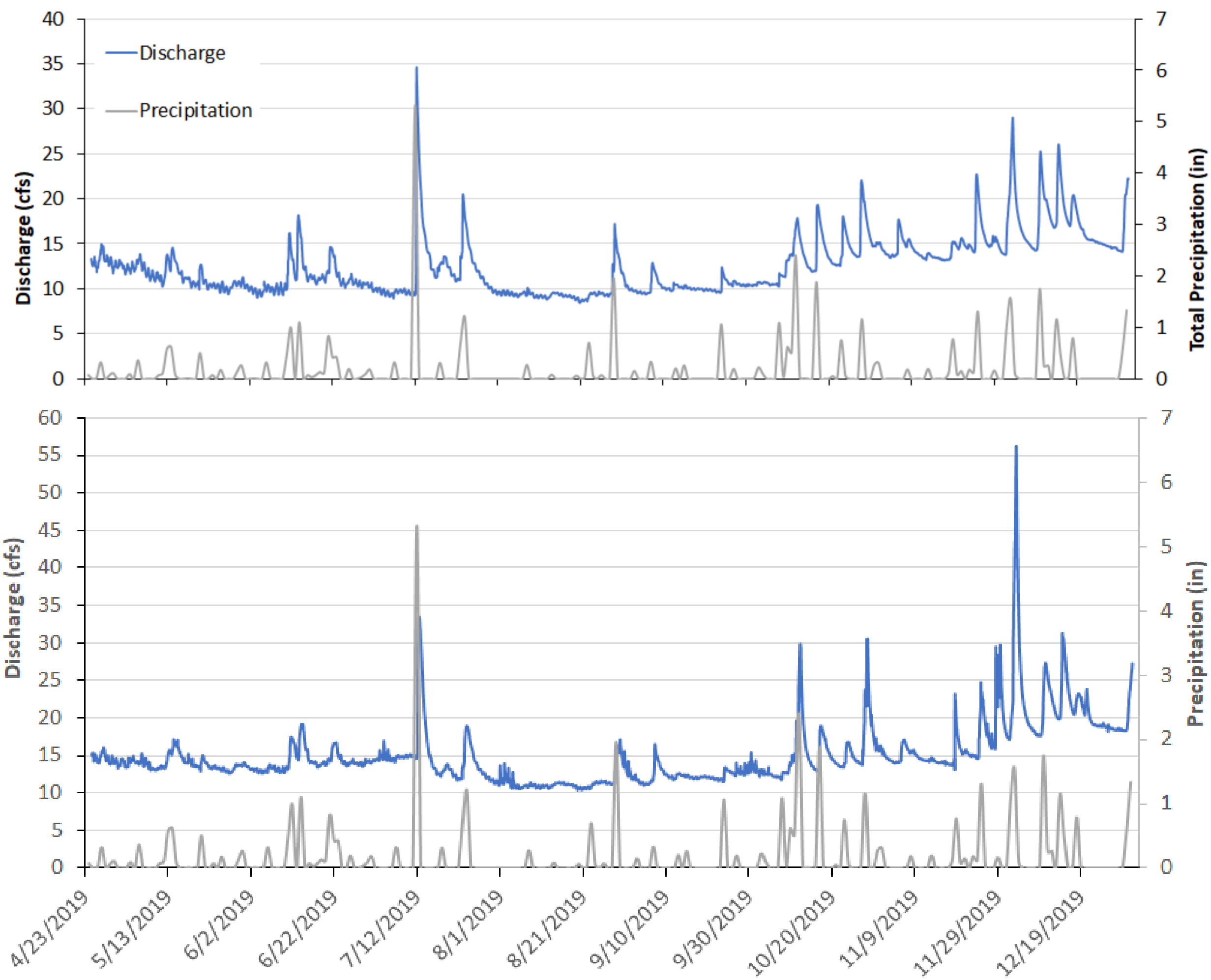


Figure 4. Calculated Continuous Discharge Series for Beaver Dam Brook
Series depict Inlet (above) and Outlet (below). Precipitation totals from Plymouth Municipal Airport are provided for context.

The antecedent weather for this study was particularly wet, with 2018 being the wettest year on record for the Commonwealth (NRCC 2020). Over the period of continuous discharge recorded for this study (April 24 to December 31, 2019), 44.48 inches of precipitation fell at the Plymouth Municipal Airport. This included

66 days with more than 0.1 inch recorded, meaning substantial precipitation fell an average of once every 3.8 days over the course of the study. The longest streak of dry weather was 14 days, starting July 25 and lasting through August 7, 2019. Although 0.27 inches of rain fell on August 8, another 14-day period without a 0.1-inch or greater storm event immediately followed. However, no other substantial dry spells were observed over the course of this study.

Shallow Groundwater Seepage Measurements

During both seepage surveys, seepage of groundwater was predominantly positive, suggesting inseepage to the pond (Table B). The only exception was in the eastern cove near the sandbar (GW-1), where no seepage was detected during the autumn sampling event.

During both surveys, seepage rates were highest on the southern and western shorelines of the pond at GW-1 and GW-4, with decreasing inflows to the north and east (Table B). Measured seepage rates at these two locations were substantially higher during the autumn sampling event than spring, while rates at GW-2 and GW-3 were somewhat lower.

Table B. Summary of Measured Seepage Rates at Bartlett Pond

Sample Location	Description	Average Seepage Rate (L/m2/day)	
		May 8, 2019	Sep 25, 2019
GW-1	Near inlet cove	4.648	11.241
GW-2	Eastern cove near sandbar	0.952	0.000
GW-3	Northern cove near Taylor Ave	0.481	0.156
GW-4	Western cove near Vinebrook Ave	2.169	24.622

2.3 Water Quality

Approach

In-pond Water Quality Monitoring

The in-pond water quality monitoring program for Bartlett Pond included both continuous data logging and collection of discrete water quality samples.

The continuous data logging portion of the field program included deployment of monitoring arrays at the deep location in the pond (Pond 1; Figure 3). Data sensors/loggers deployed as part of this study included the Solinst LTC (water level, temperature, and conductivity), Cyclops-7 (chlorophyll a), and HOBO U26 (dissolved oxygen). PVC tubes with pre-drilled holes were used to protect each logger while allowing for free exchange of water between the water column and the tube. Data loggers were deployed as they became available for use on this study, as follows:

- Solinst LTC – April 24
- Cyclops-7 – May 8
- HOBO-U26 – July 15

Data logging of dissolved oxygen was not originally proposed as part of this study but was added following collection of sediment samples to improve identification of potential periods of phosphorus release from the sediments. Therefore, the dissolved oxygen logger was not acquired until later in the year.

Data loggers were installed 0.5 m to 1.0 m above the pond bottom, except for the HOBO-U26, which was deployed just above the sediment-water interface to detect sags in dissolved oxygen that could impact phosphorus release from the sediments. Each device was programmed to collect and log measurements at four-hour intervals to provide enough detail to capture diel cycles. In-pond data loggers were removed on November 20, 2019.

To complement and supplement the continuous data logging program, multiple rounds of discrete in-pond water quality samples were collected from April to November 2019.

Bacteria samples were collected on a bimonthly basis at the Pond 1 location and were analyzed for the following indicators:

- Fecal coliform
- *E. coli*
- Enterococci

Additionally, nine rounds of in-pond sampling were completed at the Pond 1 location to measure the following parameters:

- Total Phosphorus
- Dissolved Phosphorus
- Total Nitrogen (nitrite-N, nitrate-N, and TKN)
- Chlorophyll a (pheophytin-corrected)
- Alkalinity
- Secchi Disk Transparency
- Apparent Color
- pH
- Turbidity
- Dissolved Oxygen (full vertical profile at 0.5 m increments)
- Salinity (full vertical profile at 0.5 m increments)
- Specific Conductance (full vertical profile at 0.5 m increments)
- Water Temperature (full vertical profile at 0.5 m increments)

Additionally, the following analytes were collected at Pond 1 during two baseline sampling events:

- Per- and Polyfluoroalkyl Substances (PFAS) via EPA Method 537 – 24 target compounds
- Phthalates

Pheophytin-corrected chlorophyll a, bacteria, phthalates, and PFAS samples were sent to Alpha Analytical Laboratories of Mansfield and Westborough, Massachusetts. All other surface water samples were sent to Phoenix Environmental Laboratories of Manchester, Connecticut.

Six rounds of cyanotoxin sampling were also completed at the Pond 1 location during the peak summer season (July to September) to test for microcystins. Cyanotoxin testing was completed by GreenWater Laboratories of Palatka, Florida.

Finally, occasional measurements of selected in situ parameters were also made at the Pond 2 through Pond 5 locations to assess variability in water quality elsewhere in the pond.

Tributary, Stormwater, and Outlet Water Quality Monitoring

To complement and supplement the continuous data logging program, multiple rounds of discrete water quality sampling were completed from April to November 2019. These sampling events were used to assess watershed inputs and resulting outputs from Bartlett Pond toward White Horse Beach.

Nine rounds of baseline water quality sampling were completed at the Inlet and Outlet locations to measure the following parameters:

- Total Phosphorus
- Dissolved Phosphorus
- Total Nitrogen (nitrite-N, nitrate-N, and TKN)
- Apparent Color
- pH
- Turbidity
- Dissolved Oxygen
- Salinity
- Specific Conductance
- Water Temperature

Additionally, the following analytes were collected at the Inlet and Outlet during two baseline sampling events:

- PFAS: Modified Method 537 by Isotope Dilution
- Phthalates: EPA Method 8270D

The analytical method for phthalates included analysis for six common phthalates. The analytical method for PFAS included analysis for 24 PFAS compounds.

Finally, two wet-weather water quality events were completed at the Inlet, Beaver Dam Brook at State Road (State), Beaver Dam Brook at the Tidmarsh pedestrian bridge (Tidmarsh), and stormwater outfalls discharging to Bartlett Pond (Figure 3). These events included measurement of all the baseline water quality parameters above plus the following:

- Ammonia Nitrogen
- Total Suspended Solids
- Fecal Coliform
- *E. coli*
- Enterococci

A precipitation sample was also collected and analyzed for the following:

- Total Phosphorus
- Total Nitrogen
- Specific Conductance

- Salinity
- pH

Water quality parameters were field-measured or sent to an analytical laboratory for analysis. Bacteria, phthalates, and PFAS samples were sent to Alpha Analytical Laboratories of Mansfield and Westborough, Massachusetts. All other surface water samples were sent to Phoenix Environmental Laboratories of Manchester, Connecticut.

Shallow Groundwater Quality Monitoring

In conjunction with the seepage meters described previously, shallow porewater samples were also obtained from the same shoreline locations (GW-1 through GW-4; Figure 3). Samples were extracted using a stainless steel Littoral Interstitial Porewater (LIP) sampler. The LIP sampler is essentially a mini-well that extracts groundwater from sediments for water quality testing. A minimum of three porewater samples were extracted from representative points along each of the shoreline locations and composited into a single representative sample for analysis.

Two rounds of sampling were completed (one in spring and another in autumn) and samples were analyzed for the following parameters:

- pH
- Specific Conductance
- Water Temperature
- Phosphorus
- Ammonia-nitrogen
- Nitrate-nitrogen

Water quality parameters were field-measured or sent to an analytical laboratory for analysis. Water samples were sent to Phoenix Environmental Laboratories of Manchester, Connecticut.

Results

Results are summarized in the following sections and detailed lab results are presented in Appendix A.

In-pond Water Quality Monitoring

Water Temperature

Water temperature in Bartlett Pond mainly followed the expected seasonal cycle over the course of this study, as indicated by logger data retrieved from the Pond 1 location, just off the bottom of the pond (Figure 5). An upward progression toward warmer water temperatures was evident until July, when temperatures reached a mid-summer plateau. Peak temperature in Bartlett Pond was reached on August 6, when the water temperature reached just beyond 26°C. By September, temperatures began to decline and diel cycles were more likely to be masked by storm events, airmass changes, and occasional incursions of salt water. Water temperatures dropped to their lowest levels over the course of this study (just below 6°C) on November 18.

Field measured data collected as part of the sampling program indicate that slightly higher maximum water temperatures (nearly 28°C) were recorded near the surface of Bartlett Pond at several locations (Table C). Bartlett Pond is too shallow to thermally stratify, so variation in water temperature from the surface to the bottom was minimal in all seasons.

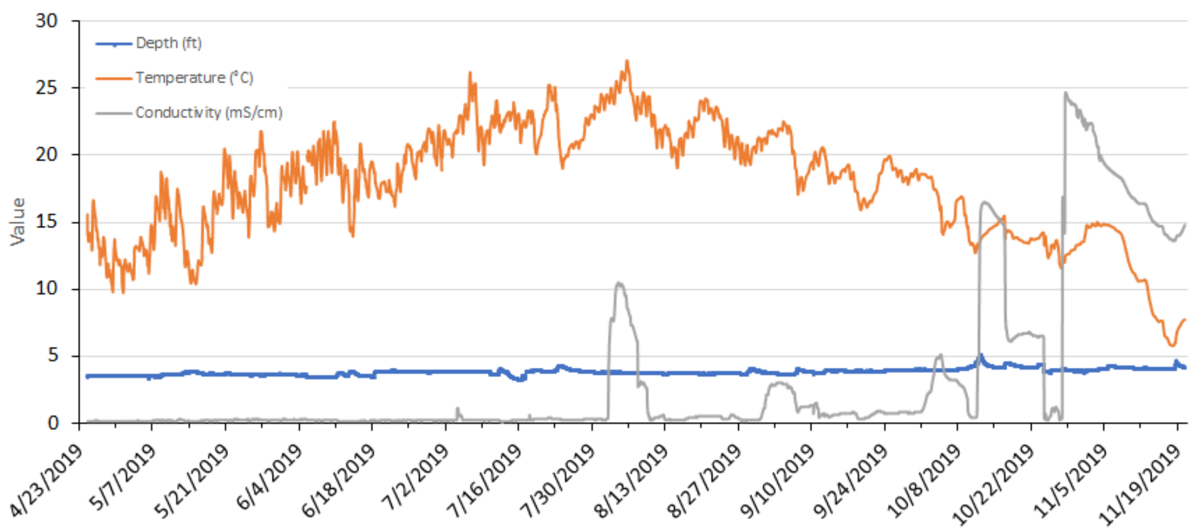


Figure 5. Water Depth, Temperature, and Conductivity in Bartlett Pond
Series depicts conditions at Pond 1 location.

Dissolved Oxygen

Dissolved oxygen is a measure of oxygen gas dissolved in water and is essential for aerobic respiration by aquatic life. The solubility of oxygen in water decreases with increased water temperature and also varies with barometric pressure and salinity. Therefore, dissolved oxygen can be measured both as a raw concentration and as a percentage of saturation.

Dissolved oxygen, as collected by the data logger retrieved from the Pond 1 location, just off the bottom of the pond, demonstrated similar seasonal patterns to water temperature. Although the dissolved oxygen data logger was not deployed until July, it shows strongly diel patterns for most of the summer, as well as hypoxic to near anoxic conditions overnight (Figure 6). However, by October, diel patterns are masked by the impacts of storms and occasional incursions of saltwater. The most substantial incursion of saltwater from late October to early November (Figure 5) was accompanied by depressed concentrations of dissolved oxygen, which where hypoxic to anoxic for several days. This suggests stratification of the pond with a layer of fresh water overlying a denser layer of brackish water near the sediment-water interface. It is possible that strong stratification allowed sediment oxygen demand to deplete dissolved oxygen in the brackish layer over this period. In mid-November, this pattern reversed, with oxygen-rich water again reaching the bottom of Bartlett Pond. By late November, another incursion of saltwater was again associated with a period of anoxia at the bottom of Bartlett Pond.

Field-measured data collected as part of the sampling program indicate minimum dissolved oxygen concentrations that are much higher than the hypoxic and anoxic conditions detected by the data logger (Table C). However, in addition to relying on fewer data points, these measurements were entirely collected during the daytime, which would have allowed photosynthesis to raise dissolved oxygen concentrations from overnight minima. Field-measured data also indicate that dissolved oxygen becomes supersaturated (i.e., greater than 100 percent saturation) at times, especially at the Pond 1 location. Based on the field-measured data alone, it appears that dissolved oxygen is sufficient to support aquatic life (above 5.0 mg/L) in most of Bartlett Pond. However, the data logger series indicates that dissolved oxygen concentrations may at least locally decline below those levels on some nights and following incursions of saltwater.

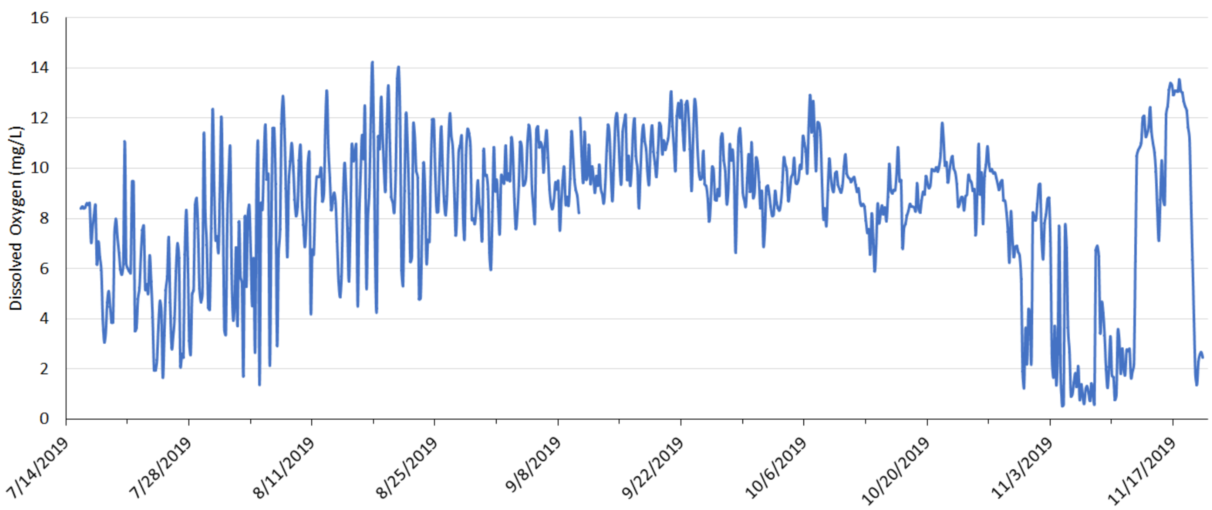


Figure 6. Dissolved Oxygen in Bartlett Pond
Series depicts conditions at Pond 1 location.

Specific Conductance and Salinity

Specific conductance is a measure of electrical conductivity in the water and is standardized to a temperature of 25°C. Although specific conductance can be affected by the presence of any charged materials in the water, it is most responsive to dissolved salts and typically tracks with salinity.

Specific conductance and salinity in Bartlett Pond were typical of a freshwater system (i.e., less than 1 mS/cm or 0.5 ppt) from April through July, as indicated by logger data retrieved from the Pond 1 location, just off the bottom of the pond (Figure 5). Then, in early August, both measures rose substantially and remained brackish for almost a week before returning to freshwater levels. At least four additional spikes in specific conductance and salinity occurred from early September to early November, with each peak higher and lasting longer than the last. Peak conductance in Bartlett Pond was reached on October 29 at 24.2 mS/cm, which is approximately 15 ppt.

Field measured data collected as part of the sampling program indicate a freshwater median specific conductance and salinity at all in-pond locations (Table C). The highest specific conductance and salinity were measured at the Pond 1 location, which is also the deepest location in the pond, on November 6.

Table C. Summary of Field-Measured Water Quality Data at Bartlett Pond

Parameter	Units	Statistic	Inlet	Pond-1	Pond-2	Pond-3	Pond-4	Pond-5	Outlet
Water Temperature	(C)	Max	20.5	27.2	27.9	27.5	26.1	25.9	25.2
		Median	16.2	16.7	17.7	17.8	16.7	17.5	19.6
		Min	7.9	6.5	8.7	9.3	7.5	8.7	6.8
DO	(mg/L)	Max	12.3	12.1	11.5	11.8	10.9	11.8	12.3
		Median	8.0	9.8	8.7	8.6	8.8	9.9	11.3
		Min	5.9	5.8	5.7	5.6	6.0	5.9	6.6
DO	(%)	Max	126	126	101	102	104	100	134
		Median	79	92	83	82	87	95	107
		Min	65	70	71	67	75	71	80
Specific Conductance	(µS/cm)	Max	125	8,635	344	466	135	358	1,603
		Median	107	157	128	273	115	132	159
		Min	88	109	101	144	94	105	125
Salinity	(ppt)	Max	0.1	1.4	0.2	0.3	0.1	0.3	1.3
		Median	0.1	0.1	0.1	0.2	0.1	0.1	0.1
		Min	0.1	0.1	0.1	0.1	0.1	0.1	0.1
pH	(SU)	Max	7.3	7.8	7.9	8.5	7.7	8.0	9.0
		Median	6.5	6.7	6.6	6.9	6.5	6.8	7.0
		Min	5.5	6.0	6.2	6.5	6.0	6.3	6.3
Turbidity	(NTU)	Max	2.54	3.35	3.01	3.05	3.10	2.76	2.97
		Median	1.67	1.65	1.68	1.66	1.55	1.72	2.11
		Min	0.74	0.24	1.25	1.25	0.30	1.25	1.64
Apparent Color	(PCU)	Max	30	75	60	75	65	50	50
		Median	20	20	20	40	30	20	20
		Min	10	10	15	15	10	10	10
Secchi Depth	(m)	Max*	-	1.4	-	-	-	-	-
		Median*	-	1.2	-	-	-	-	-
		Min	-	0.7	-	-	-	-	-

*Measurement was on the pond bottom during maximum and some median measurements. Therefore, this measurement was constrained.

pH

The measurement of pH is used to determine the degree to which water is acidic or basic. The pH scale extends from 0 (strongly acidic) to 14 (strongly basic) with 7 being neutral. The pH of most natural waters in the region falls near the middle of the scale (circumneutral), although it can vary by season or even on a diel basis, especially in poorly buffered waters.

Field measured data collected as part of the sampling program indicate that pH in Bartlett Pond varied from a low of 6.0 SU at Pond 1 and Pond 4 to a maximum of 8.5 SU at Pond 3 (Table C). However, the median pH measurement varied only slightly among in-pond sampling locations (6.5 SU to 6.9 SU). This suggests that water in Bartlett Pond tends to be slightly acidic to circumneutral.

Turbidity, Apparent Color, and Secchi Depth

Turbidity is a measure of water clarity as sensed by the scattering of light through water. Colloidal and suspended materials in the water column raise turbidity. Turbidity is affected by the size, shape, color, and concentration of materials in water and has an inverse relationship with transparency.

Apparent color is related to turbidity and affected by a number of variables, including the presence of dissolved organic carbon (DOC), algae, and other particulates.

Secchi depth is a measure of water transparency, as indicated by a Secchi disk. The value indicates the deepest point at which the Secchi disk is just visible. Although the Secchi depth does not directly represent either the depth limit of light penetration or plant growth, it provides a depth-integrated and easily understood measure of transparency in surface waters.

Field measured data collected as part of the sampling program indicate that turbidity in Bartlett Pond varied from a low of 0.24 NTU at Pond 1 to a maximum of 3.35 NTU, also at Pond 1 (Table C). However, the median turbidity measurement varied only slightly among in-pond sampling locations (1.55 NTU to 1.72 NTU).

Apparent color was highly variable over the course of the field program, ranging from a low of 10 PCU at multiple in-pond locations to a high of 75 PCU at Pond 1 and Pond 3 (Table C). The median color measurement ranged from 20 PCU to 40 PCU at all in-pond stations.

Secchi depth was only measured at the deep hole location (Pond 1) and ranged from a low of 0.7 m to a maximum of 1.4 m (Table C). The median Secchi depth was 1.2 m. However, the maximum and median values for Secchi depth were affected by pond depth. Therefore, the true Secchi transparency may have been greater than measured at those times. The Secchi desk was not visible at the bottom of the pond seven times (41 percent of measurements) over the course of this study.

Taken together, the turbidity, color, and Secchi disk measurements suggest that Bartlett Pond is somewhat turbid with occasional periods of higher turbidity and lower transparency, possibly due to algae, particulate matter, and/or DOC.

Nutrients

High levels of nutrients (e.g., nitrogen and phosphorus) in the water column can lead to undesirable biological consequences. For example, floating plants like duckweed and watermeal may grow to excessive levels when soluble inorganic nitrogen (e.g., nitrate, ammonia) and phosphorus are present at high concentrations. Likewise, high levels of these nutrients may also trigger excessive algal growth, leading to bloom conditions and, under certain conditions, dominance by harmful species of cyanobacteria. Phosphorus tends to be the limiting nutrient in freshwater ponds while nitrogen is more likely to be limiting in brackish or salt ponds, although this can vary between water bodies and over time at the same water body. Co-limitation by phosphorus and nitrogen can also occur.

Total phosphorus concentrations at Bartlett Pond ranged from 0.050 mg/L to 0.176 mg/L, with a median concentration of 0.073 mg/L (Table D). Dissolved phosphorus concentrations ranged from 0.024 mg/L to 0.089 mg/L with a median of 0.039 mg/L. These concentrations suggest that phosphorus is plentiful within Bartlett Pond. The highest concentrations of total and dissolved phosphorus values were observed in the summer with a peak in mid-July, a few days subsequent to a torrential rainfall event (more than 5 inches of precipitation in 24 hours) on July 12.

Total nitrogen concentrations at Bartlett Pond ranged from 0.275 mg/L to 1.075 mg/L, with a median concentration of 0.485 mg/L (Table D). Nitrate-N concentrations ranged from 0.01 mg/L to 0.31 mg/L with a median of 0.08 mg/L. TKN concentrations ranged from 0.19 mg/L to 1.01 mg/L with a median of 0.38 mg/L. Nitrate-N concentrations were highest in early spring and later in autumn, although a secondary peak also occurred in July. TKN concentrations were lowest in spring and autumn, rising to a peak in mid-July, just after the torrential rainfall event of July 12.

The Redfield ratio provides a framework through which to interpret phosphorus and nitrogen relative to each other. It assumes that the 14:1 molar ratio of nitrogen to phosphorus found, on average, in algal cells, is the ideal balance of these nutrients to sustain growth. Above this ratio, nitrogen would be relatively plentiful, making phosphorus the limiting nutrient and vice versa below this ratio. In Bartlett Pond, N:P ratios exceeded the Redfield ratio in spring and November but were close to or below the ratio over most of the summer (Figure 7). This suggests that the growth of algae in Bartlett Pond may lean toward phosphorus limitation early and late in the season, with nitrogen limitation or co-limitation at other times.

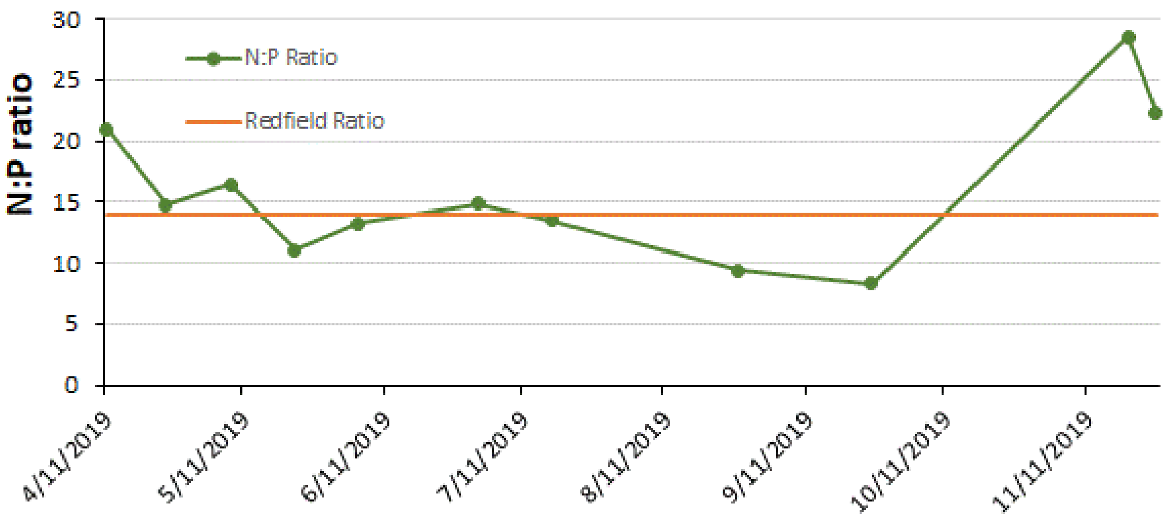


Figure 7. Nitrogen to Phosphorus Ratio in Bartlett Pond
Series depicts conditions at Pond 1 location.

Alkalinity

Alkalinity is the capacity of water to resist changes in pH (also known as acid neutralizing capacity) and is driven largely by the bedrock and soil that water comes into contact with prior to entering a pond. However, anthropogenic sources (e.g., soil liming) may also influence the alkalinity of surface waters. Waters with higher alkalinity are less susceptible to fluctuations in pH from acid deposition or pollutants.

Alkalinity concentrations in Bartlett Pond ranged from 11.0 mg/L to a maximum of 17.4 mg/L, with a median of 15.0 mg/L (Table D). These low concentrations are typical of softwater lakes and ponds in eastern Massachusetts, where limestone bedrock is rare.

Table D. Summary of Laboratory-Analyzed Baseline Water Quality Data

Parameter	Units	Statistic	Inlet	Pond-1	Outlet
Total Phosphorus	mg/L	Max	0.101	0.176	0.156
		Median	0.073	0.073	0.088
		Min	0.039	0.050	0.047
Dissolved Phosphorus	mg/L	Max	0.067	0.089	0.096
		Median	0.042	0.039	0.056
		Min	0.024	0.024	0.024
Nitrate	mg/L	Max	0.30	0.31	0.32
		Median	0.24	0.08	0.07
		Min	0.07	0.01	0.01
Nitrite	mg/L	Max	<0.01	<0.01	<0.01
		Median	<0.01	<0.01	<0.01
		Min	<0.01	<0.01	<0.01
TKN	mg/L	Max	0.43	1.01	0.80
		Median	0.29	0.38	0.38
		Min	0.18	0.19	0.29
Total N	mg/L	Max	0.615	1.075	0.875
		Median	0.515	0.485	0.555
		Min	0.325	0.275	0.305
Alkalinity	(mg/L $CaCO_3$)	Max	-	17.4	-
		Median	-	15.0	-
		Min	-	11.0	-
Corrected Chl-a	(mg/m^3)	Max	-	22.028	-
		Median	-	7.626	-
		Min	-	0.801	-
Cyanotoxins (Microcystins/Nodularins)	(µg/L)	Max	-	<0.3	-
		Median	-	<0.3	-
		Min	-	<0.3	-
Fecal Coliform	(col/100mL)	Max	-	330	-
		Median	-	42	-
		Min	-	3	-
E. coli	(col/100mL)	Max	-	380	-
		Median	-	54	-
		Min	-	<2	-
Enterococci	(col/100mL)	Max	-	5,600	-
		Median	-	74	-
		Min	-	<2	-

Chlorophyll *a*

Algal density is inferred by measuring the fluorescence of chlorophyll a, a pigment found in algal cells. High chlorophyll a levels are associated with elevated algal production. Phaeopigments (collectively called phaeophytin) are degradation products of chlorophyll a, and can account for 16-60% of measured chlorophyll a content (Marker et al. 1980). These can be subtracted from laboratory results to provide a corrected chlorophyll a concentration.

Chlorophyll a, as collected by the data logger retrieved from the water column at Pond 1, exhibited similar a high degree of variability over the course of this study (Figure 8). Concentrations were highest in early May, approaching or exceeding 100 µg/L but quickly dropped to substantially lower levels by mid-May. From late May until the end of August, chlorophyll a concentrations generally trended lower. At the end of August, chlorophyll a concentrations became highly variable, with short periods of elevated levels interspersed with readings near zero.

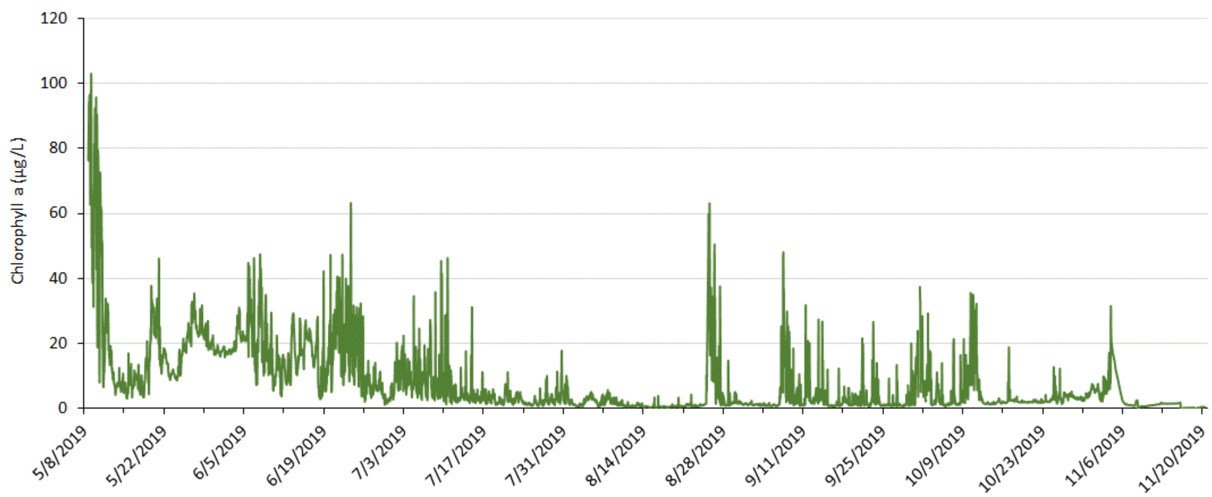


Figure 8. Chlorophyll a in Bartlett Pond
Series depicts conditions at Pond 1 location.

Samples collected and analyzed at the laboratory indicate corrected chlorophyll a concentrations ranging from 0.801 µg/L to 22.028 µg/L (Table D). The median chlorophyll a result obtained from the laboratory was 7.626 µg/L. These results are well within the range detected by the in-pond datalogger.

Cyanotoxins

Cyanotoxins, including anatoxin, microcystin, cylindrospermopsin, and nodularin, are toxins produced by cyanobacteria. These toxins are harmful to humans and other animals; therefore, elevated levels of these compounds are highly undesirable in drinking water reservoirs. US EPA has issued recreational contact criteria for microcystin and cylindrospermopsin.

Samples collected and analyzed at the laboratory indicate cyanotoxin results were below both the laboratory method reporting limits and the US Environmental Protection Agency's recreational water quality criteria of 8 µg/L for microcystin (Table D).

<u>Bacteria</u>

Fecal coliform bacteria, including *E. coli*, and enterococci, occur in the digestive tracts of humans and other animals. Although these bacteria may not always directly cause illness, they serve as indicators of fecal contamination and possible pathogens. Enterococci are salt-tolerant organisms, as compared to the fecal coliforms, and are therefore usually preferred for monitoring bacteria levels in brackish or salt water (Byappanahalli et al. 2012).

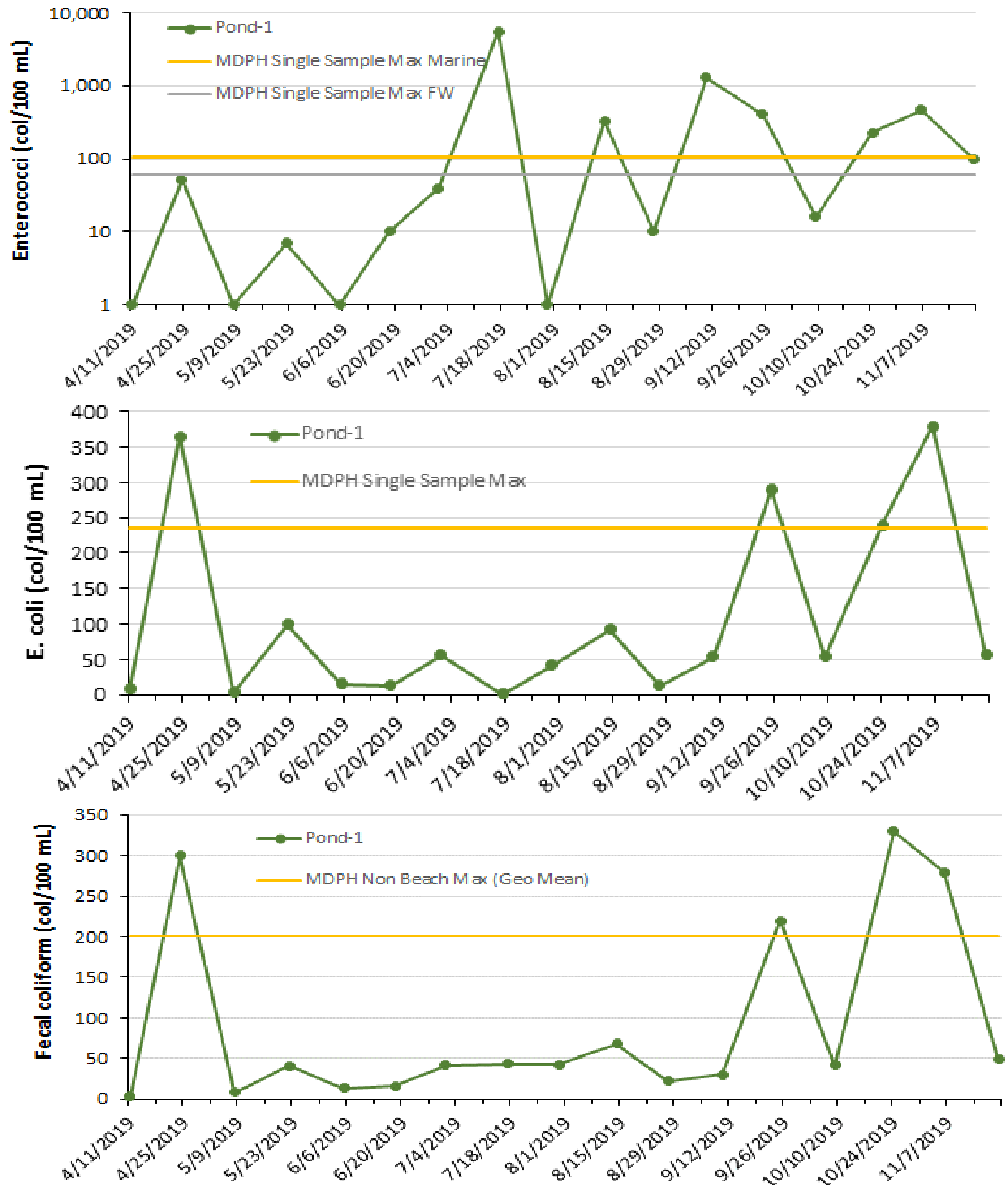


Figure 9. Bacteria in Bartlett Pond
Series depicts conditions at Pond 1 location.

Although Bartlett Pond discharges onto White Horse Beach, it does not host a public swimming beach itself. Therefore, the state enterococci and *E. coli* standards do not strictly apply. However, they do provide a useful means of comparison for this study. Additionally, fecal coliform results can be compared to standards for waters without a public swimming beach.

Samples collected and analyzed at the laboratory indicate that *E. coli* and fecal coliform results exhibited similar trends over time (Figure 9). Peak counts occurred in spring and autumn and exceeded 200 col/100 mL Enterococci results generally aligned with the spring and autumn trends for *E. coli* and fecal coliform. However, they deviated substantially during the summer months and reached counts as high as 5,600 col/100 mL in July (Table D, Figure 9). The July enterococci peak occurred within a week following the passage of two substantial (greater than one inch) precipitation events.

Tributary and Outlet Baseline Water Quality Monitoring

Results are summarized in the following sections and detailed results are presented in Appendix A.

<u>Water Temperature</u>

Field measured water temperature data collected as part of the sampling program suggest that the incoming water from the Beaver Dam Brook Inlet was cooler than water in Bartlett Pond or Outlet during the summer but similar the remainder of the study period (Table C). Given the canopy cover and cooling influence of groundwater inputs during the warm season, this is not unexpected. Water temperatures ranged from 7.9°C to 20.5°C at the Inlet with a median temperature of 16.2°C. Water temperatures ranged from 6.8°C to 25.2°C at the Outlet with a median temperature of 19.6°C.

<u>Dissolved Oxygen</u>

Field-measured data collected as part of the sampling program indicate minimum dissolved oxygen concentrations that are generally sufficient to support aquatic life (above 5.0 mg/L) at the Beaver Dam Brook Inlet and Outlet (Table C). Although these data were all collected during the day, stream dissolved oxygen readings tend to show less diel variability than pond readings because the water is flowing, thereby encouraging mixing of the shallow water column and entrainment of atmospheric oxygen throughout the diel cycle. Field-measured data also indicate that dissolved oxygen becomes supersaturated (i.e., greater than 100 percent saturation) at times, especially at the Outlet location.

<u>Specific Conductance and Salinity</u>

Field measured data collected as part of the sampling program indicate freshwater conditions at the Beaver Dam Brook Inlet with more variable conditions at the Outlet (Table C). Although the median specific conductance and salinity readings at the Outlet were characteristic of freshwater conditions (159 µS/cm; 0.1 ppt), the maximum value represented brackish water conditions (1,603 µS/cm, 1.3 ppt).

<u>pH</u>

Field measured data collected as part of the sampling program indicate somewhat acidic conditions prevailing at the Beaver Dam Brook Inlet while the Outlet tended to be closer to circumneutral (Table C). At the Inlet, pH ranged as low as 5.5 SU with a median value of 6.5 SU and a maximum value of 7.3 SU.

At the Outlet Bartlett Pond varied from a low of 6.3 SU to a maximum of 8.0 SU with a median value of 6.8 SU.

Turbidity and Apparent Color

Field measured data collected as part of the sampling program indicate that turbidity at the Beaver Dam Brook Inlet varied from a low of 0.74 NTU to a maximum of 2.54 NTU, with a median of 1.67 NTU (Table C). The Outlet exhibited somewhat higher turbidity levels.

Apparent color was very similar between the Beaver Dam Inlet and Outlet locations (Table C). The primary difference was a higher maximum color reading (50 PCU) at the Outlet than the Inlet (30 PCU).

Taken together, these measurements suggest that conditions become somewhat more turbid from the Inlet to the Outlet.

Nutrients

Total phosphorus concentrations at the Beaver Dam Brook Inlet ranged from 0.039 mg/L to 0.101 mg/L, with a median concentration of 0.073 mg/L (Table D). These values are somewhat lower than Bartlett Pond at the extremes but the median concentration was similar. The Outlet exhibited a higher median total phosphorus concentration (0.088 mg/L) than either the Inlet or Bartlett Pond, although the maximum and minimum values were between the two. Dissolved phosphorus concentrations at the Beaver Dam Brook Inlet ranged from 0.024 mg/L to 0.067 mg/L with a median of 0.042 mg/L (Table D). The Outlet exhibited a higher median total phosphorus concentration (0.056 mg/L) than either the Inlet or Bartlett Pond.

Taken together these concentrations suggest that phosphorus is already plentiful in Beaver Dam Brook but rise further within Bartlett Pond or at the Outlet. As with Bartlett Pond, the highest concentrations of phosphorus were observed in the summer with a peak in July (Figure 10).

Total nitrogen concentrations at the Beaver Dam Brook Inlet ranged from 0.325 mg/L to 0.615 mg/L, with a median concentration of 0.515 mg/L (Table D). The minimum and median values are higher than Bartlett Pond and similar to the Outlet but the maximum value is lower than both of these locations. As with phosphorus, total nitrogen concentrations peaked in July. However secondary peaks in spring and November were also observed.

Median and minimum nitrate-N concentrations generally decrease from the Inlet to the Outlet, while TKN minimum and median concentrations follow an opposite pattern (increasing from the Inlet to the Outlet; Table D). Nitrate-N concentrations at the Inlet were highest in early spring with a declining trend until November. Concentrations at the Outlet were also highest in early spring and November but also exhibited a smaller peak in July. In contrast, TKN concentrations at both the Inlet and Outlet trended similar to phosphorus, with highest concentrations in July.

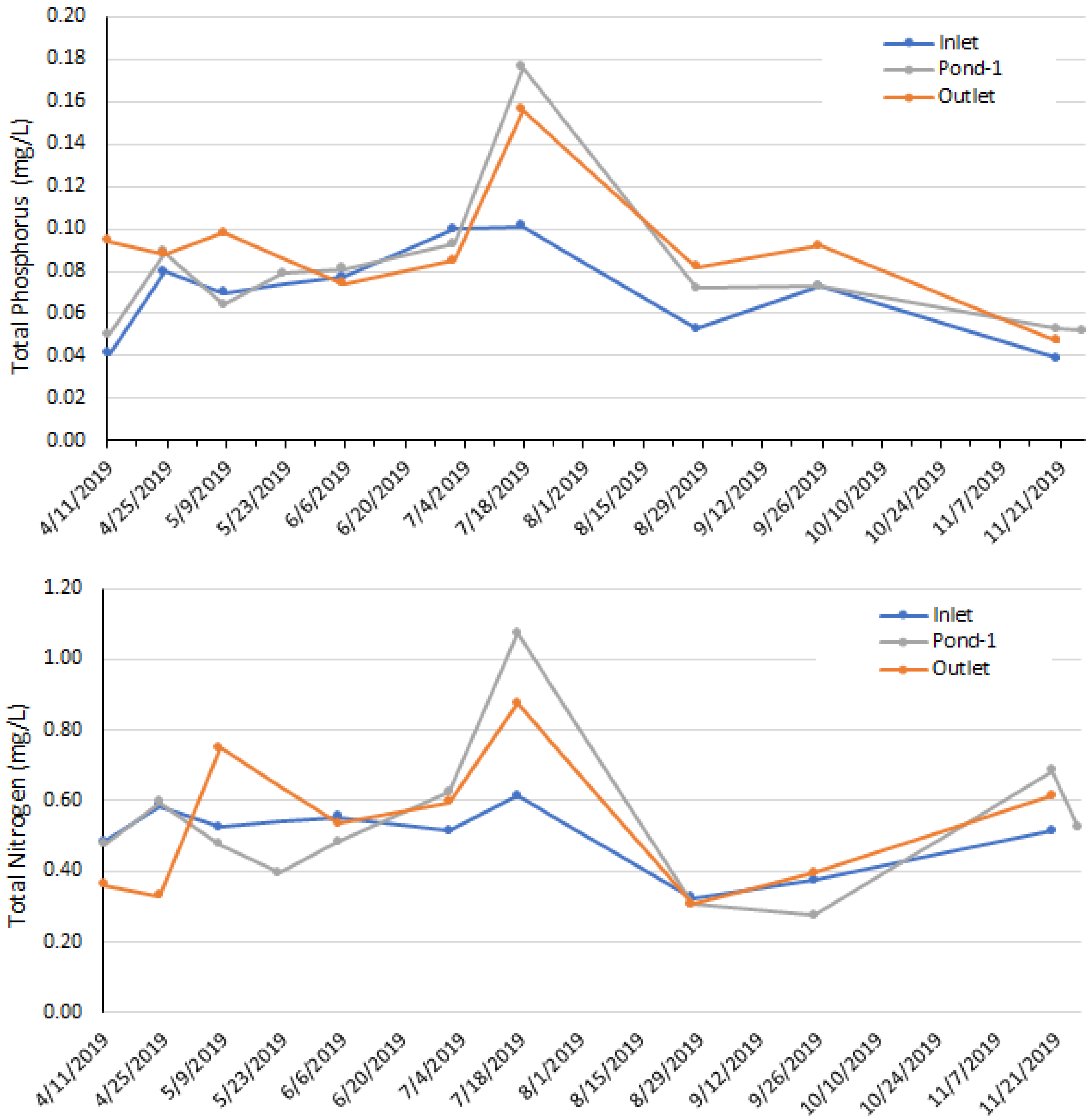


Figure 10. Nutrient Concentrations at Inlet, Pond-1, and Outlet
Total Phosphorus (above) and Total Nitrogen (below)

Wet Weather Water Quality Sampling Results

Nutrients

Phosphorus concentrations (total and dissolved) were elevated at each of the Beaver Dam Brook and stormwater outfall locations on both sampling dates (Table E). However, phosphorus was particularly high at the Beaver Dam Brook locations during the July 23, 2019 storm event.

In Beaver Dam Brook, wet weather total nitrogen concentrations were highest at the State location and lowest at the Tidmarsh location during both sampling events (Table E). TKN contributed the bulk of nitrogen at most locations; of this, ammonia-nitrogen was typically a minor fraction, suggesting that organic nitrogen was the primary form of nitrogen present at most locations. Nitrate-nitrogen was also present at detectable concentrations at most locations during both sampling rounds. It accounted for the largest percentage of total nitrogen at Tidmarsh, particularly in December, when it made up more than half of all nitrogen at that location.

Table E. Wet Weather Laboratory Analytical Data

Analyte	Location								
	Tidmarsh		State		Inlet		Out-Syc	Out-Vin	Out-Vin-2
	7/23/19	12/9/19	7/23/19	12/9/19	7/23/19	12/9/19	7/23/19	7/23/19	12/9/19
Phosphorus (mg/L)	0.166	0.053	0.137	0.048	0.161	0.065	0.089	0.23	0.12
Dissolved Phosphorus (mg/L)	0.083	0.029	0.099	0.028	0.116	0.038	0.043	0.099	0.081
Nitrite-N (mg/L)	<0.010	<0.010	<0.010	0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Nitrate-N (mg/L)	0.110	0.420	0.100	0.370	0.120	0.370	0.040	<0.06	0.240
Ammonia-N (mg/L)	<0.05	0.070	0.050	0.110	0.060	0.110	<0.05	<0.10	0.080
TKN (mg/L)	0.450	0.350	0.850	0.550	0.660	0.430	0.300	1.11	0.560
Total Nitrogen (mg/L)	0.560	0.770	0.950	0.920	0.780	0.800	0.340	1.170	0.800
TSS (mg/L)	<5.0	4	28	4	22	24	20	180	23
Fecal Coliform (col/100 mL)	960	42	3,200	64	3,800	48	17,000	17,000	600
E. Coli (col/100 mL)	1,200	64	4,200	92	3,000	<2	8,200	20,000	550
Enterococci (col/100 mL)	2,400	530	24,000	120	13,000	340	37,000	30,000	21,000

Total Suspended Solids

Among the Beaver Dam Brook wet-weather sampling stations, total suspended solids (TSS) was lowest at the Tidmarsh location during both sampling rounds with increasing concentrations downstream at State and Inlet locations (Table E).

Among the stormwater outfalls into Bartlett Pond, the highest TSS concentration was observed at Out-Vin (Table E). The other two locations also demonstrated elevated TSS levels but were similar in magnitude to the most turbid Beaver Dam Brook locations.

Bacteria

Wet weather bacteria results were substantially higher than most of the baseline dry weather results from Bartlett Pond (Table E). The highest counts of *E. coli*, fecal coliform, and enterococci were found at the stormwater outfall locations (Out-Syc and Out-Vin on July 23, 2019 and Out-Vin-2 on December 9, 2019). However, each of the Beaver Dam Brook locations also exhibited counts in the thousands for at least two of the three bacterial indicators.

Bacterial counts were generally lower in December than July, which would be anticipated given the cooler temperatures and smaller magnitude of the storm. However, counts in December were still above state standards for enterococci across all of the sampled locations.

Precipitation Samples

A precipitation sample collected near the shoreline of Bartlett Pond on July 23, 2019 provided a background water quality condition for comparison to surface and groundwater samples. The precipitation sample results are presented in Table F.

Table F. Precipitation Water Quality Summary

Parameter	July 23, 2019 Result
Temperature (°C)	18.8
Specific Conductance (µS/cm)	24.7
Salinity (ppt)	0.0
pH (SU)	6.7
Total Phosphorus (mg/L)	0.031
Total Nitrogen (mg/L)	0.20

Per- and Polyfluoroalkyl Substances and Phthalates

Phthalates were not detected at concentrations above the laboratory reporting limits in any of the surface water or stormwater samples submitted for analysis. The laboratory reporting limits were adequate for analysis of the results and appropriate given applicable standards and risk thresholds. The results of internal QA/QC performed by the laboratory during the analysis of the samples were all within the applicable acceptance criteria. The results support the conclusions that these compounds are not present at meaningful concentrations in the surface water and stormwater in the lower portion of the Bartlett Pond watershed.

Select PFAS compounds were detected during both stormwater sampling rounds and the second surface water sampling round (Table G).

Table G. PFAS Compounds Detected by Sampling Round

PFAS Compounds Detected by Round			
Surface Water (May 2019)	Stormwater (July 2019)	Surface Water (September 2019)	Stormwater (December 2019)
None	PFBA	PFBA	PFBA
	PFPeA	PFHxA	PFOS
		PFOA	
		PFOS	

The detected concentrations ranged from 1.76 ng/L to 20.8 ng/L and most were not significantly greater than the laboratory reporting limits which ranged from 1.72 to 2.01 ng/L. The only detection that was significantly greater than the laboratory reporting limits was PFBA (20.8 ng/L; Out-Vin-2) during the December 2019 stormwater sampling round.

Two additional totals are provided and include Total PFOA/PFOS, which is the total detected concentrations for these two compounds, and Total PFAS (5) which is the total detected concentrations for five PFAS compounds as shown in Table H. The individual PFAS concentrations detected and the total of the detected concentrations for al PFAS analytes for each sample were significantly less than the current drinking water standards, guidelines and/or risk thresholds listed below.

- EPA lifetime Health Advisory: ***70 ng/L*** (PFOA plus PFOS)
- 2018 Massachusetts Department of Environmental Protection Office of Research and Standards Guideline (MassDEP ORSG) level: ***70 ng/L***
  (total of PFOA, PFOS, PFNA, PFHxS and PFHpA)

The MassDEP Massachusetts Contingency Plan (MCP) Method 1 GW-1 standards, which address existing and potential drinking water source areas, and GW-3 standards, which address groundwater discharges to surface water, are tabulated by compound in Table H.

Table H. Proposed MassDEP MCP Method 1 PFAS Standards (ng/L)

PFAS Compound	MCP Method 1 Standard (GW-1)	MCP Method 1 Standard (GW-3)
PFAS Compounds (sum of 6 compounds shown below)	20	N/A
PFDA	N/A	40,000,000
PFHpA	N/A	40,000,000
PFHxS	N/A	500,000
PFOA	N/A	40,000,000

PFAS Compound	MCP Method 1 Standard (GW-1)	MCP Method 1 Standard (GW-3)
PFOS	N/A	500,000
PFNA	N/A	40,000,000

PFOA and PFOS were the only MCP-regulated PFAS compounds detected during this sampling and only during the September surface water sampling round and the December stormwater sampling round (PFOS only). These detected concentrations were all below the applicable GW-1 standards. The GW-1 standards would be applicable in the Bartlett Pond watershed since this area is mapped as a Potentially Productive Aquifer Area by MassDEP. All of the detected concentrations were also significantly less than the MCP GW-3 standards which, as noted above, are intended to be protective of groundwater discharges to surface water.

Following are key findings of the PFAS sampling program:

- More PFAS compounds were detected during the second surface water sampling event (September 2019) than any other event. However, these were detected at low concentrations.
- PFAS compounds were detected in at least one sample during both stormwater sampling rounds.
- The low concentrations and generally consistent results by sampling round suggest that the presence of the PFAS compounds may be due to widespread atmospheric deposition of these compounds, which has been widely documented to result in similar low-level detections.
- Perfluorobutyrate (PFBA), the one PFAS compound detected at a concentration significantly higher than the laboratory reporting limit (greater than 10 times the RL), is not currently regulated either on the federal or state level.

  PFBA was used in the manufacture of photographic film and is also a breakdown product of other PFAS compounds used in stain-resistant fabrics, paper food packaging, and carpets (Minnesota Department of Health 2017). The manufacture of PFBA and PFBA-containing products was phased out by 3M in 1998.

Shallow Groundwater Quality Monitoring

Phosphorus concentrations in shallow groundwater were higher in autumn than spring at all four sampling locations (Table I). Additionally, all four stations maintained the same order of highest to lowest phosphorus concentration between the two sampling rounds. The highest phosphorus concentrations, by far, were observed at GW-3, followed by GW-2. Concentrations at these two locations were higher than the mean phosphorus concentration in Bartlett Pond over the course of this study. However, these two locations were also characterized by the lowest inseepage rates, which reduces the phosphorus loading rates along these shorelines.

This was not the case for dissolved inorganic nitrogen (DIN) concentration, which can be approximated by adding ammonia-nitrogen to nitrate-nitrogen. DIN concentrations did not show a consistent seasonal pattern, increasing at two locations and decreasing at two from spring to autumn. However, DIN concentrations were much higher at GW-4 than the other three stations during both seasons. Seepage rates at GW-4 were also high relative to other locations, indicating that DIN loading may be elevated in this area.

Table I. Porewater Quality Data, Spring and Autumn 2019

Sample Site	Phosphorus (mg/L)		Ammonia as N (mg/L)		Nitrate as N (mg/L)	
	May 8	Sep 25	May 8	Sep 25	May 8	Sep 25
GW-1	0.02	0.055	0.07	0.75	0.04	0.16
GW-2	0.102	0.182	0.24	1.46	0.01	0.01
GW-3	0.34	0.478	3.08	1.74	0.03	0.04
GW-4	0.013	0.031	2.31	1.56	11	6.8

Septic systems that function correctly should have a minimal phosphorus signature because the fraction of phosphorus leached into the ground readily adsorbs onto particles in the soil matrix, rather than migrating toward the pond. Failing or poorly sited septic systems may result in discharge of phosphorus-rich wastewater into nearby water bodies. Additionally, septic systems that have been in operation for many years may load phosphorus to nearby water bodies at a higher rate, due to the saturation of binding sites for phosphorus in the soil over time.

DIN is typically much more mobile through soil than phosphorus and may generate a plume that reaches the pond quickly. Even septic systems that are regularly pumped and functioning properly typically remove less than half of the nitrogen. Therefore, DIN concentrations in groundwater can be orders of magnitude higher where septic systems are prevalent.

2.4 Sediment Sampling

Approach

Eight cores were collected on May 2, 2019 using a handheld corer. The cores were manually advanced into the sediments from eight locations distributed across the major coves of the pond (Figure 3). Undisturbed and uncontaminated cores were capped from below, then extruded upward and cleanly sliced into 2-cm sections (ranging from 1 to 7 per core for a total of 41 sections). Core samples were sent to Barr Engineering in Edina, Minnesota and analyzed for the following parameters:

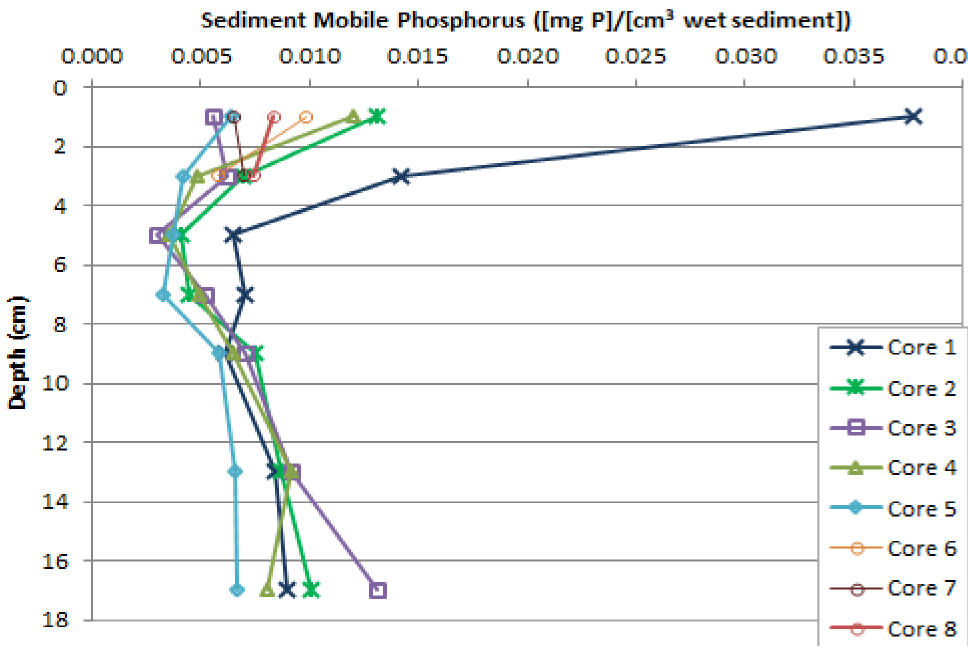
Sediment corer used at Bartlett Pond

- iron-bound phosphorus
- aluminum-bound phosphorus
- calcium-bound phosphorus
- organically-bound phosphorus
- percent water
- loss on ignition-organic carbon content
- density

These data were used in tandem with water quality, biological, and hydrologic data to model the sediment phosphorus release rate (internal loading) for the pond.

Results

Sediment core analysis indicated that mobile (iron-bound) phosphorous was present in the Bartlett Pond sediments, with highest levels typically found in the upper two to four cm (0.06 ft to 0.13 ft) of sediment



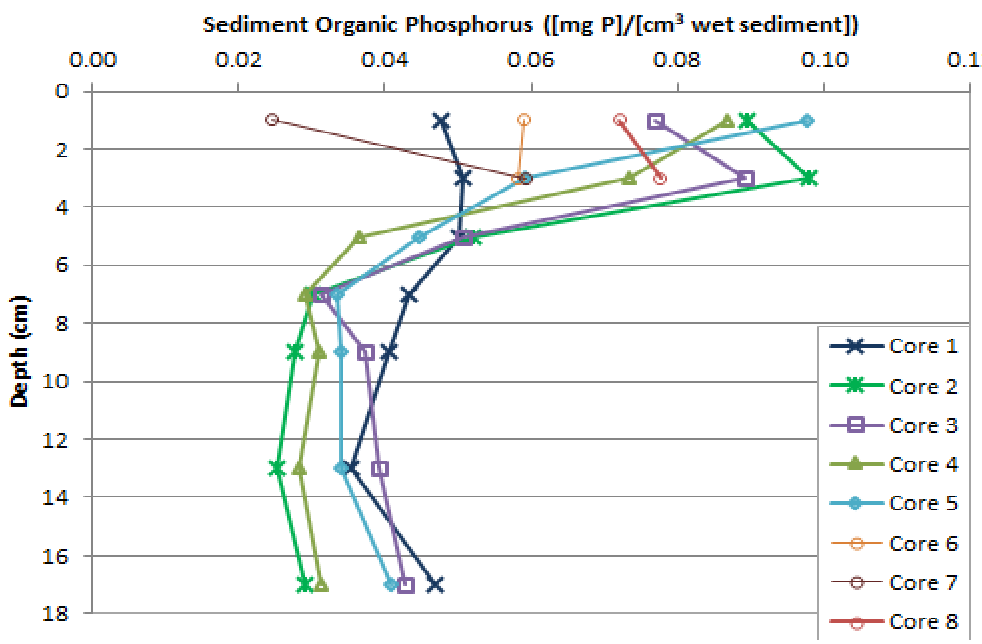


Figure 11. Sediment Phosphorus in Bartlett Pond Cores
Mobile Phosphorus (above) and Organic Phosphorus (below)

(Figure 11). Additionally, cores from the southwestern and central portions of the pond tended to have the highest levels of mobile phosphorus. Mobile phosphorus is the most readily released under low dissolved oxygen conditions.

Organic phosphorus constituted a greater proportion of the total phosphorus measured in Bartlett Pond sediments (Figure 11). As with mobile phosphorus, this tended to be highest in the uppermost sediments. However, unlike mobile phosphorus, organic phosphorus was more prevalent in cores from the northern and eastern portions of the pond. Organic phosphorus also provides a source of internal phosphorus loading, as decay processes result in release from the sediments.

Aluminum-bound phosphorus was also present but this is generally considered to be permanently bound and therefore not subject to release.

Full results of the sediment phosphorus fractionation analysis can be found in Appendix A

2.5 Aquatic Macrophytes

Approach

ESS mapped the locations of all native and non-native aquatic plant species observed at more than 70 sampling points throughout Bartlett Pond on June 18, 2019. Observations of species composition, plant cover, and biovolume were collected, with special attention paid to documenting the presence of exotic invasive plants. All vascular aquatic plants were identified to genus or species level in the field by qualified staff. Areas of filamentous algal growth were also noted.

Direct visual observations were made in shallow waters, and a throw rake was used to collect samples in deeper waters. Percent cover and biovolume were visually ranked using the following scale; 0, 1-25%, 26-50%, 51-75% and greater than 75%. All observed species, percent cover, and biovolume were recorded at each point and positions were collected with a sub-meter accurate Trimble Geo7X GPS receiver.

Results

Overall, 13 species of aquatic plants were observed in Bartlett Pond or just upstream at the Inlet location (Table J). This is similar to the number of aquatic species previously reported in 2011 (Plymouth DPW) and 1970 (Lyons-Skwarto Associates).

*Bartlett Pond was hosted few large aquatic plants. However, small beds of minute native species, such as this slender milfoil (*Myriophyllum tenellum*) were present in multiple locations.*

Of the thirteen aquatic species observed, two were exotic (Table J), including water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*). Although neither species was observed in Bartlett Pond proper, they were observed just upstream and may be able to spread into the pond in the near future.

Both water hyacinth and water lettuce are popular water garden plants and it is likely that these species escaped from an ornamental pond in the watershed. In addition to being exotic, these plants have invasive tendencies, rapidly expanding into available habitats and forming near-monocultures of very dense growth at the water surface during the growing season. Monocultures of these plants can lead to reduction in dissolved oxygen levels and shading of native plants growing below the surface. This is primarily a problem in warmer climates, where the growing season is long and plants are able to flower and set viable seed. However, the ability of these plants to establish overwintering infestations in New England may be enhanced by climate change.

*One of the smaller emergent plants at Bartlett Pond was slender milfoil (*Myriophyllum tenellum*) were present in multiple locations.*

Native plants were represented by 11 aquatic species at Bartlett Pond (Table J), most of which were low-growing and found in sparse patches along the shoreline of the pond. The most widespread native plant species were slender milfoil (*Myriophyllum tenellum*), duckweed (*Lemna* sp.), and waterwort (*Elatine* sp.). One species that appeared to have returned to Bartlett Pond after being absent in prior recent surveys was Canadian waterweed (*Elodea canadensis*).

Although emergent plants were not the primary target of this study, several species were readily observed at Bartlett Pond (Table J). Of these, three exotic species were observed, including yellow flag iris (*Iris pseudacorus*), purple loosestrife (*Lythrum salicaria*), and common reed (*Phragmites australis*). The dominant emergent plant was water willow (*Decadon verticillata*), which is a native species but has formed extensive and dense beds along the aquatic fringe of the pond, particularly in the northern coves.

As part of this project, ESS developed a field guide to the plants of Bartlett Pond, which includes these native species, as well as exotic invasives observed in the pond or known to be nearby (Appendix B). Distribution maps for each species observed at Bartlett Pond are also presented in the field guide.

Table J. Aquatic and Emergent Plants Observed at Bartlett Pond

Scientific Name	Common Name	Growth Habit	Status
Aquatic Species			
Ceratophyllum demersum	Coontail	Submerged-floating	Native
Callitriche heterophylla	Water Starwort	Submerged	Native
Eichhornia crassipes	Water Hyacinth	Floating	Exotic*
Elatine sp.	Waterwort	Submerged	Native
Eleocharis sp.	Spikerush	Submerged/emergent	Native
Elodea canadensis	Canadian Waterweed	Submerged	Native
Eriocaulon aquaticum	Pipewort	Submerged	Native
Lemna sp.	Duckweed	Floating	Native
Myriophyllum tenellum	Slender Water-Milfoil	Submerged	Native
Nymphaea odorata	White Water Lily	Floating-leaved	Native
Pistia stratiotes	Water Lettuce	Floating	Exotic*

Scientific Name	Common Name	Growth Habit	Status
Pontederia cordata	Pickerelweed	Submerge/emergent	Native
Potamogeton perfoliatus	Clasping-leaf Pondweed	Submerged	Native
Potamogeton pusillus	Thinleaf Pondweed	Submerged	Native
Emergent Species			
Decadon verticillata	Water Willow	Emergent	Native
Hydrocotyle umbellata	Water Pennywort	Emergent	Native
Iris pseudacorus	Yellow Flag Iris	Emergent	Exotic
Lythrum salicaria	Purple Loosestrife	Emergent	Exotic
Phragmites australis	Common Reed	Emergent	Exotic
Typha latifolia	Cattail	Emergent	Native

*Not observed in Bartlett Pond but present upstream

Aquatic Plant Cover

Aquatic plant cover was generally low throughout Bartlett Pond, with plants observed at fewer than 32 percent of the sample locations (Figure 12). Aquatic plant growth was most abundant in the southwestern cove of the pond, near the mouth of Beaver Dam Brook but, even here, large areas of open water were observed. Where aquatic plant growth was observed, it was typically sparse. Cover exceeding 25 percent of the pond bottom was limited to just five locations.

Aquatic Plant Biovolume

Aquatic plant biovolume followed a pattern similar to plant cover; plant growth exceeded 25 percent of the water column at just three locations (Figure 13). Higher biovolume areas were occupied by water starwort (*Callitriche heterophylla*), white water lily (*Nymphaea odorata*), and/or slender milfoil. Areas with low aquatic plant biovolume frequently hosted growths of filamentous green algae.

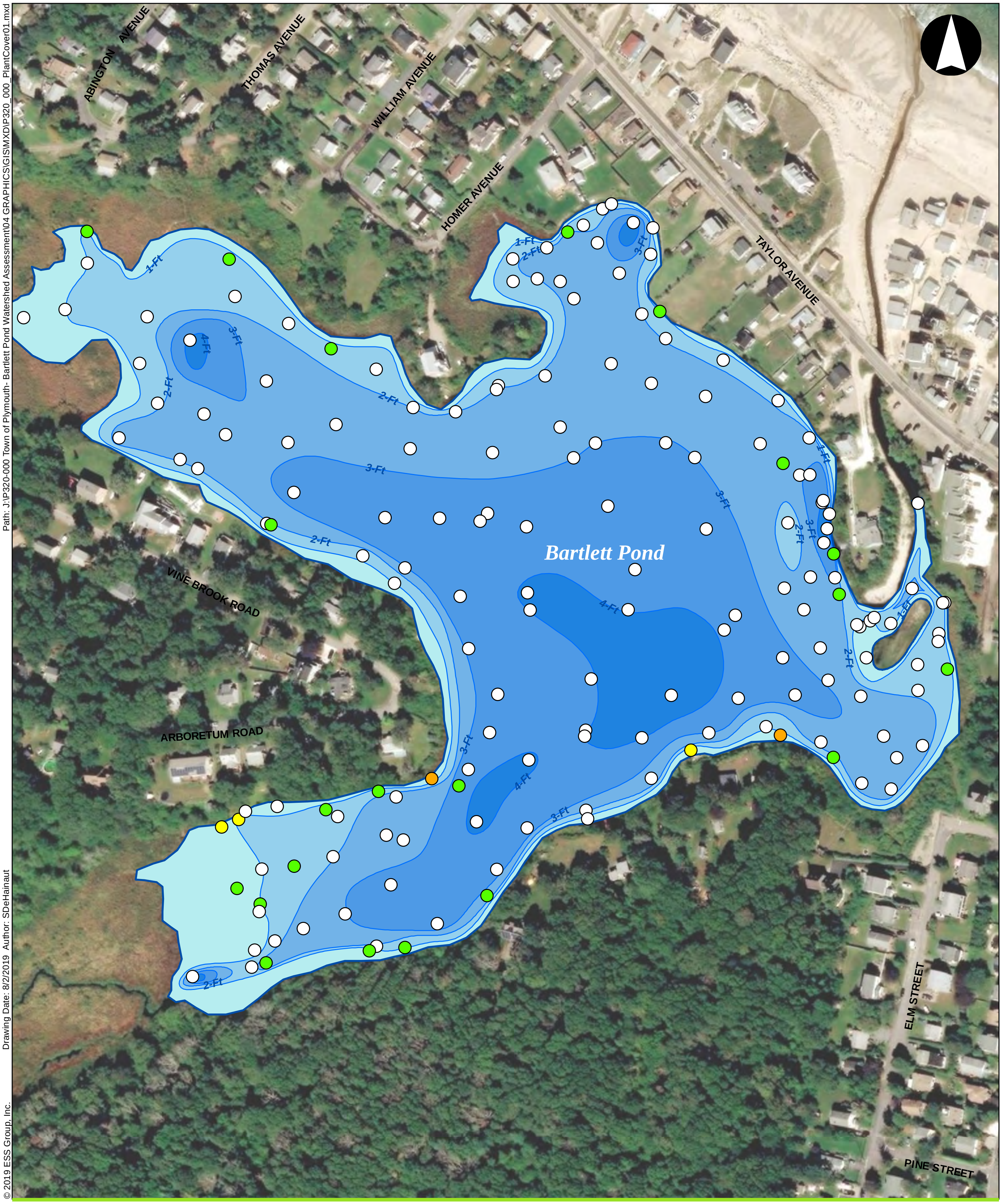
Due to the low biovolume observed at Bartlett Pond, aquatic plants do not appear to impede recreational passage of boats, kayaks, canoes or other small watercraft anywhere in the pond. While emergent plant beds (not included in the biovolume measurement) do grow thickly enough to restrict navigation of vessels along multiple shoreline areas, they do not appear to close off passage or pose a substantial obstacle to water circulation between the existing open water areas of the pond.

2.6 Aquatic Macroinvertebrates

Approach

Due to their relatively long lifespan (months to years), benthic macroinvertebrates are one of the most useful organisms for inferring longer term water quality conditions in surface waters. In particular, benthic macroinvertebrates provide data useful for improving the understanding of dissolved oxygen, salinity, and vegetation gradients in Bartlett Pond.

Draft



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Drawing Date: 8/2/2019 Author: SDeHainaut

ESS group environmental consulting & engineering services

0 125 250 Feet

Bartlett Pond Watershed Assessment

Plymouth, MA

Source: 1) ESRI, World Imagery, 2018
2) ESS, GPS Locations, 5/22/2019 and 6/18/2019

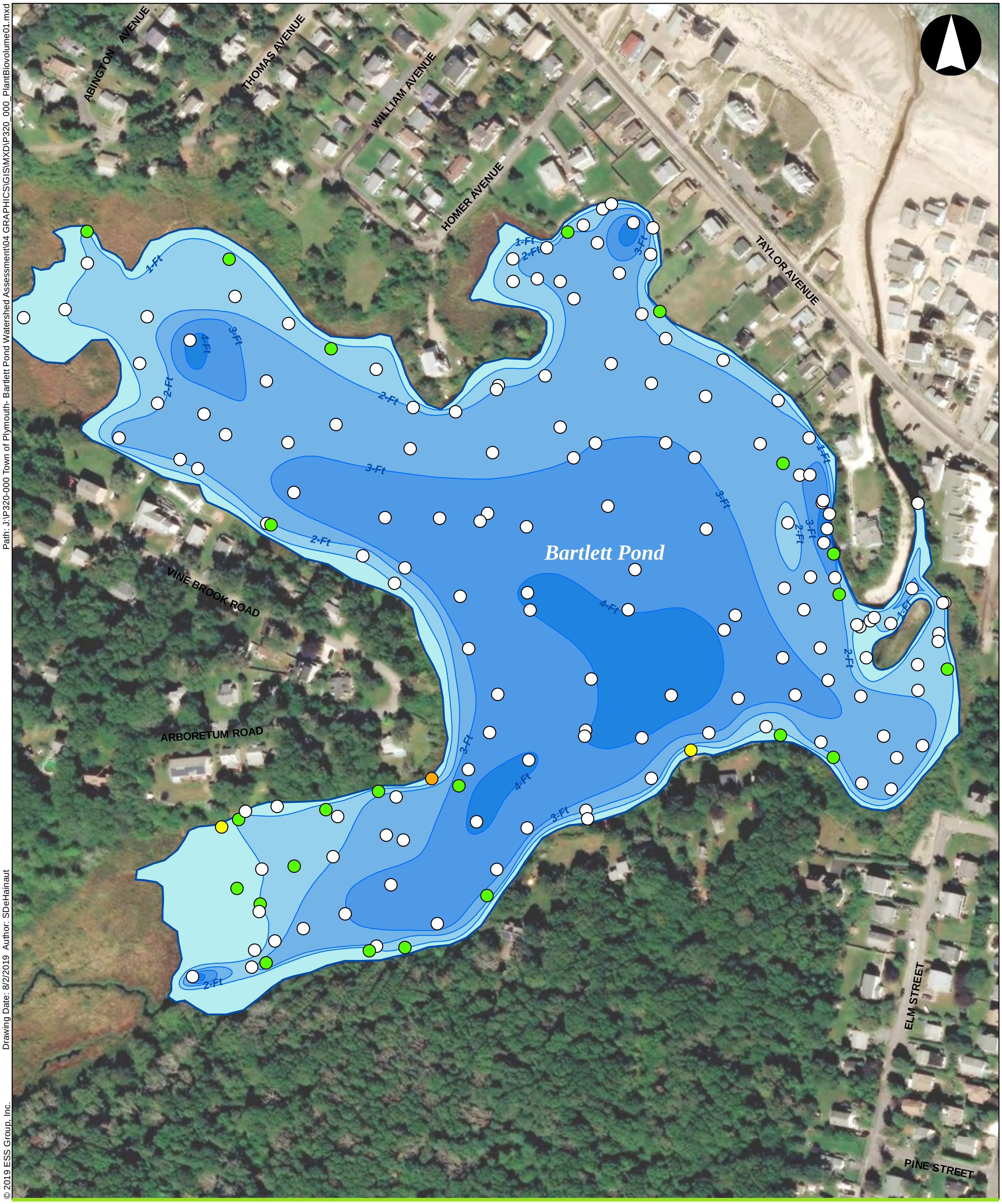
Aquatic Plant Cover

- 0% (49 Points)
- 1% - 25% (18 Points)
- 26% - 50% (3 Points)
- 51% - 75% (2 Points)

Bartlett Pond Plant Cover

Figure 12

Draft



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Drawing Date: 8/2/2019 Author: SDeHainaut

ess group
environmental consulting & engineering services

0 125 250
Feet

Bartlett Pond Watershed Assessment

Plymouth, MA

Source: 1) ESRI, World Imagery, 2018
2) ESS, GPS Locations, 5/22/2019 and 6/18/2019

Aquatic Plant Cover

- 0% (49 Points)
- 1% - 25% (20 Points)
- 26% - 50% (2 Points)
- 51% - 75% (1 Point)

Bartlett Pond Plant Biovolume

Figure 13

ESS collected six benthic macroinvertebrate samples representative of different habitats in the pond (Figure 3) on June 18, 2019, including the following:

- The outlet of the pond near Taylor Ave (B-1)
- Littoral area of open mineral substrate (B-2)
- Littoral area of shallow water and emergent plant growth (B-3)
- The deep location in the pond (B-4)
- Mouth of Beaver Dam Brook inlet to the pond (B-5)
- Littoral area of shallow water and submerged plant growth (B-6)

A six-inch by six-inch Ekman grab sampler was used to collect samples at the four locations where plant growth was minimal, including the Inlet, Deep Hole, Sandbar, and Outlet locations. A dip net was used to collect sweep samples where vegetation was dense, including the Emergent and Submerged locations.

Samples were field-preserved in 75% denatured ethanol and returned to ESS's offices for sorting, identification, and enumeration by an SFS-certified taxonomist under a microscope.

Results

Analysis of the macroinvertebrate samples collected from Bartlett Pond resulted in a total of 46 taxa with a mean of 14.5 taxa/sample and 7,580 organisms/m^2 (Table K).

*This small squaregilled mayfly nymph (*Caenis *sp) was found in water willow (*Decadon verticillata*) beds. Water willow hosted the greatest taxa richness of any habitat sampled in the pond.*

The highest taxa richness and lowest abundance was found in the samples collected at vegetated locations (Table L). In contrast, the lowest taxa richness and highest abundance was found in the samples collected in the deep hole (Table L). Although the sampling design and effort for this study was not sufficient for determination of cause and effect, low taxa richness and high abundance may result in areas with low habitat complexity and greater exposure to ecological stressors, such as the recurring hypoxic/anoxic conditions observed in the deep hole of Bartlett Pond.

Table K. Summary of Aquatic Macroinvertebrate Samples at Bartlett Pond

Statistic	Value
Number of Samples	6
Mean Density per Square Meter (±1 SD)	7,580 ± 11,201
Mean Taxa Richness (±1 SD)	14.5 ± 7.0
Total Number of Taxa	46
Number of Taxa Observed by Taxonomic Group	
Annelida	5
Arthropoda (non-crustacean)	28
Crustacea	5
Mollusca	7
Nematoda	1
Percent of Total Abundance by Taxonomic Group	
Annelida	13.7%
Arthropoda (non-crustacean)	60.7%
Crustacea	21.7%
Mollusca	2.9%
Nematoda	1.0%

The macroinvertebrate community encountered in the samples includes snails, mussels, nematodes, oligochaete worms, leeches, and a number of arthropods, such as crustaceans, arachnids, springtails, dragonflies, damselflies, mayflies, true bugs, caddisflies, beetles, and true flies.

Table L. Aquatic Macroinvertebrate Density and Taxa Richness by Location

Statistic	B-1	B-2	B-3	B-4	B-5	B-6
	Outlet	Sandbar	Decadon Bed	Deep Hole	Inlet	Submerged Vegetation Bed
Annelida Density (#/m^2)	1,602	1,148	57	3,100	323	17
Arthropoda Density (#/m^2)	3,307	2,469	121	21,011	517	178
Crustacea Density (#/m^2)	155	0	135	5,511	3,810	264
Mollusca Density (#/m^2)	0	57	29	0	1,163	92
Nematoda Density (#/m^2)	0	0	0	344	65	0
Total Density (#/m^2)	**5,063**	**3,674**	**347**	**29,967**	**5,877**	**551**
Annelida Taxa Richness	2	1	2	1	3	2
Arthropoda Taxa Richness	5	9	11	5	3	11
Crustacea Taxa Richness	2	0	5	2	1	5
Mollusca Taxa Richness	0	1	5	0	3	5
Nematoda Taxa Richness	0	0	0	1	1	0
Total Taxa Richness	**10**	**11**	**23**	**9**	**11**	**24**

Although many of the taxa found at Bartlett Pond are considered to be tolerant of organic pollution and low dissolved oxygen concentrations, all are freshwater taxa. This suggests that incursions of saltwater at Bartlett Pond are likely to be short-lived, spatially limited, and/or low magnitude.

2.7 Algae

Approach

Nine rounds of in-pond phytoplankton samples were collected to monitor the algal community in Bartlett Pond over the course of this study. Phytoplankton samples were collected as a grab composite from the top 1.5 feet of the water column. All phytoplankton samples were preserved in Lugol's solution and sent to Aquatic Analysts of Friday Harbor, Washington for identification, enumeration, and estimation of biovolume.

Additionally, qualitative samples of benthic algae were collected in spring and summer when visual observations suggested potential development of cyanobacteria mats. These samples were examined for cyanobacteria under the microscope by ESS.

Results

No cyanobacteria blooms were observed in Bartlett Pond during any of the field visits conducted in 2019. However, patches of various filamentous green algae taxa (Chlorophyceae) and diatoms mixed with occasional filaments of cyanobacteria were observed growing in mats on the pond bottom. Benthic cyanobacteria primarily consisted of *Oscillatoria* sp.

Mixed benthic mats of algae were common in Bartlett Pond, seen here as dark patches on a light substrate. Oscillatoria *(a cyanobacterium) filaments were sometimes found in these mats along with diatoms and filamentous green algae.*

Seventy-two algal taxa were detected in the quantitative phytoplankton samples and included chrysophytes, cryptophytes, cyanobacteria, diatoms, dinoflagellates, and green algae. Peak phytoplankton abundance and biovolume occurred in early May during a diatom bloom. Both measures declined substantially in June, remaining fairly stable in samples collected over the summer and autumn. These results generally echoed the seasonal trends in chlorophyll a concentrations, with the exception of a longer duration of the late spring bloom (extending well into June) a few short-lived blooms observed by the in-pond chlorophyll a sensor in late summer.

Aside from the predominance of the diatom *Stephanodiscus hantzschii* in May, the phytoplankton community was typically not dominated by any one taxon. A number of benthic algal taxa – particularly diatoms – were noted in the samples and this likely reflects the shallow morphology of the pond; benthic algae can more easily be mobilized into the water column by wind and hydrologic events. Quantitative phytoplankton results are summarized in Table M and lab reports are provided in Appendix A.

Table M. Phytoplankton Summary for Bartlett Pond*

Taxon	Density (#/mL)								
	4/11/19	4/24/19	5/8/19	5/22/19	6/5/19	7/1/19	7/17/19	8/27/19	11/20/19
Chrysophytes	187	15	0	33	134	76	21	0	0
Cryptophytes	50	222	173	392	802	682	1,762	40	34
Cyanobacteria	0	8	0	0	0	0	0	0	0
Diatoms	835	560	74,970	29,413	1,904	311	1,057	584	598
Dinoflagellates	0	0	0	0	0	0	0	6	0
Green Algae	12	92	35	261	367	278	249	51	9
	1,084	897	75,178	30,099	3,207	1,346	3,088	681	641

*All samples collected at Pond-1 location

2.8 Other Biology

Approach

Although not a target of quantitative surveys, opportunistic observations of fish, birds, and wildlife were made over the course of the 2019 field program at Bartlett Pond.

Results

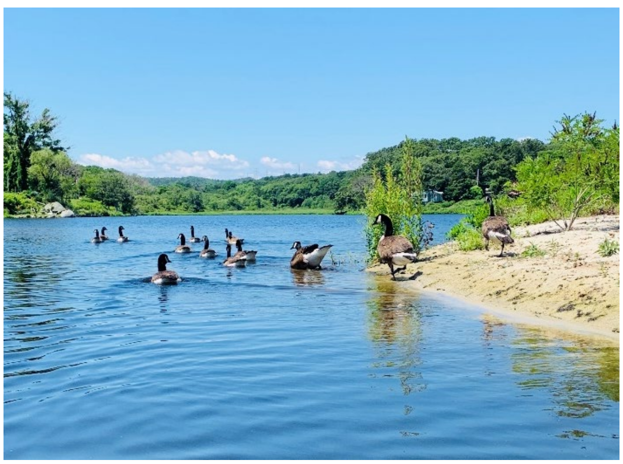
The incidental fish, bird, and wildlife species observations for Bartlett Pond are summarized in Table N. This list is not intended to be exhaustive but provides documentation of readily visible water-dependent species.

Table N. Other Biological Observations at Bartlett Pond

Scientific Name	Common Name
Birds	
Actitis macularius	Spotted Sandpiper
Anas platyrhynchos	Mallard
Ardea herodias	Great Blue Heron
Branta canadensis	Canada Goose
Butorides virescens	Green Heron
Cygnus olor	Mute Swan
Larus delawarensis	Ring-billed Gull
Larus marinus	Great Black-backed Gull
Larus smithsonianus	Herring Gull
Leucophaeus atricilla	Laughing Gull
Pandion haliaetus	Osprey
Phalacrocorax auritus	Double-crested Cormorant
Sternula antillarum	Least Tern
Herpetofauna	

Scientific Name	Common Name
Chelydra serpentina	Snapping Turtle
Chrysemys picta	Painted Turtle
Lithobates catesbeianus	Bullfrog
Fish	
Fundulus diaphanus	Banded Killifish
Lepomis macrochirus	Bluegill

Large numbers of resident waterfowl were observed over the course of the study, either directly or indirectly (i.e., deposits of feathers and feces). The primary species observed was Canada Goose (*Branta canadensis*), which was frequently seen in groups of 20 or more birds, although Mute Swan (*Cygnus olor*) was also common.




Canada Goose (left) was the most commonly observed waterfowl species at Bartlett Pond. Mute Swan (right) was also common.

Resident waterfowl can be a significant source of phosphorus and bacteria loading to surface waters. Canada Goose is particularly problematic because of its foraging habits, which involve frequent grazing of upland vegetation, where most phosphorus was bound in organic compounds, and subsequent conversion to more biologically available forms of phosphorus, which are then released to the reservoir through defecation near or directly in the water. A single resident goose may contribute 83 g of total phosphorus and 523 g of TKN to a waterbody in a single year (Bowen and Valiela 2004, Unckless and Mararewicz 2007, French and Parkhurst 2009).

2.9 Trophic State

Approach

The trophic state of a pond is a measure of its productivity. Nutrient-poor waterbodies are classified as oligotrophic and tend to support little primary production (plants or algae). The low respiration rates in oligotrophic waterbodies generally support adequate levels of dissolved oxygen for aquatic life use throughout most or all of the water column. As nutrient levels increase, a waterbody may move into higher (more productive) trophic states, sequentially mesotrophic, eutrophic, and hypereutrophic. These states are accompanied by increasing rooted plant and/or algae growth and sedimentation rates. Eutrophication can be greatly accelerated through human-induced sediment and nutrient loading from the watershed (cultural eutrophication).

Carlson (1977) developed a Trophic State Index (TSI) to standardize and facilitate communication with the public regarding the trophic status of lakes and ponds. The TSI scale was first derived for Secchi disk transparency but additional parameters, such as total phosphorus and chlorophyll *a* were also incorporated. In practice, the TSI scale extends from 0 (nutrient-poor) to 100 (extremely fertile) and corresponds to the traditional trophic state categories, as follows: oligotrophic ponds less than 40, mesotrophic ponds between 40 and 50, eutrophic ponds between 50 and 70, and hypereutrophic ponds above 70.

The measured values for chlorophyll a and total phosphorus at Bartlett Pond were transformed into TSI scores to facilitate discussion of its trophic state. Although Secchi disk transparency could also be used for this analysis, it was not incorporated, due to the shallow depth of the pond, which truncated this measure.

It should be noted that single measurements or even multiple measurements from a single season are unlikely to sufficiently account for the expected natural variation of the TSI. Nor can limited data be used to infer trends in the trophic state of a water body. That said, the TSI does provide a useful tool for describing the likely current trophic state, especially when interpreted in the context of additional data pertaining to the aquatic vegetation and algal communities.

Results

Based on chlorophyll *a* levels from this study, the median TSI for Bartlett Pond was 50.5, which suggests that the current trophic state of the pond is likely to be eutrophic. However, individual measurements of chlorophyll a over the course of this study would result in TSI values as high as 76.1 (hypereutrophic) and as low as 28.4 (oligotrophic).

When the TSI is calculated for phosphorus, the median value is 66.0, which supports a classification of Bartlett Pond as eutrophic. The TSI value for phosphorus was much less variable than chlorophyll a, ranging from a minimum value of 60.6 (eutrophic) to a maximum value of 78.7 (hypereutrophic).

In the context of the TSI analysis and supporting information, a eutrophic classification would appear to be appropriate, as Bartlett Pond is affected by occasional anoxia and is an algae-dominated system. The higher TSI values for phosphorus also suggest that Bartlett Pond has potential for algae blooms that may not have been realized in 2019 due to some other limiting factor, such as flushing rate, zooplankton grazing, or plant competition. Of these, flushing rate would appear to be the most likely factor, given the wet conditions and high flow rates relative to the volume of Bartlett Pond.

2.10 Water Quality Modeling

Approach

The model used for Bartlett Pond is a mass balance and ecological model that was designed specifically for shallow lakes. The model's ecological components include phytoplankton and freshwater aquatic plants. Phytoplankton growth is a function of nutrients (nitrogen and phosphorus), water temperature, and sunlight availability. The model is designed for completely mixed systems, meaning it is assumed that flows into Bartlett Pond rapidly mix with the entire pond volume. This is a reasonable assumption for small waterbodies such as Bartlett Pond.

A detailed list of the model components is provided below:

- Water balance (hydrologic budget)
    - Surface water flow inflows and outflows
    - Direct precipitation and evaporation
    - Groundwater inflows and outflows
    - Water level and volume
- Nutrients
    - Phosphorus
        - Ortho-phosphate
        - Dissolved organic phosphorus
        - Particulate organic phosphorus
        - Particulate inorganic phosphorus
    - Nitrogen
        - Nitrate + ammonia (modeled together)
        - Particulate organic nitrogen
        - Dissolved organic nitrogen
- Climatic and In-Lake Inputs
    - Air temperature
    - Wind
    - Sunlight
    - Humidity
    - In-lake water temperature
    - In-lake dissolved oxygen
- Lake bottom sediment processes
    - Phosphorus release from iron-bound phosphorus as a function of dissolved oxygen in the lake water column
    - Phosphorus release from organically-bound phosphorus as function of lake water temperature
- Groundwater
    - Phosphate loading from groundwater inputs
    - Nitrogen loading (nitrate plus ammonia) from groundwater inputs
- Phytoplankton processes
    - Dissolved phosphorus and nitrogen uptake with growth
    - Phytoplankton settling
    - Particulate phosphorus and nitrogen release with mortality
    - Growth can be nitrogen or phosphorus limited.

    - Daily growth cycles also a function of sunlight and water temperature
- Aquatic plant process (not currently included in the Bartlett Pond model, due to limited growth)
    - Aquatic plant growth and mortality as a function of lake depth
    - Nutrient uptake from the water column and sediment
    - Nutrient release from dead plants
- Surface water loading
    - Inputs from surface waters for the following constituents are included in the model:
        - All phosphorus forms
        - All nitrogen forms
        - Phytoplankton
        - Inorganic and organic suspended solids

The model is Python programming language-based but can be run using inputs from an Excel spreadsheet. Once all the required inputs are assembled, the model is run and the outputs are assessed. The outputs include in-lake phytoplankton (represented as chlorophyll a), in-lake phosphorus (dissolved, particulate, and total), in-lake nitrogen (dissolved, particulate, and total), as well as mass balances for phosphorus and nitrogen for all inputs and sinks (e.g., settling to the pond bottom).

The ultimate goal of the calibration process and this study was to develop an improved understanding of the factors that determined the observed changes in phytoplankton populations over the monitoring period. When a model accurately simulates changes in phytoplankton (as chlorophyll a) throughout the monitoring season, then there is confidence that that the model can be used to assess what is driving algal growth and ultimately which management actions may be most appropriate to avoid or control phytoplankton blooms.

With this calibration, the model can also be used as a tool to explore how changes in hydrology, weather, nutrients, and plant growth would impact phytoplankton populations in Bartlett Pond.

Results

The model calibration process resulted in several key observations regarding the function of the Bartlett Pond system and algal response, as follows:

- Phytoplankton growth was mainly limited by nitrogen availability during this study (Figure 14)

- Under the right environmental conditions, this may favor nitrogen-fixing cyanobacteria, such as *Dolichospermum* spp.

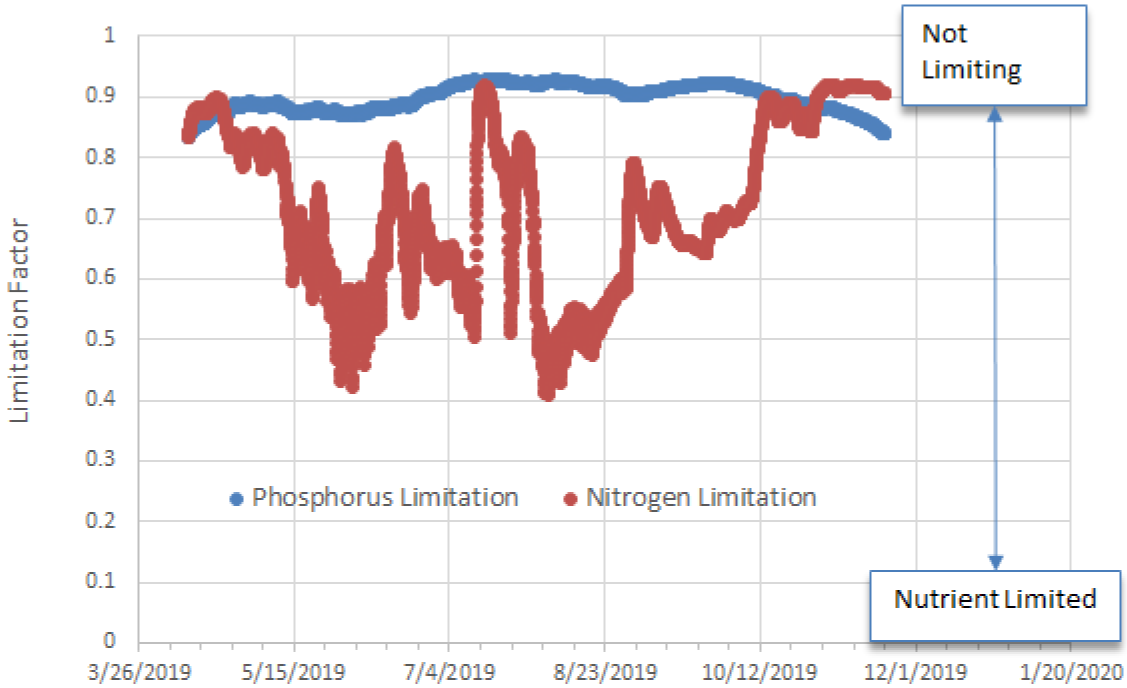


Figure 14. Nutrient Limitation in Bartlett Pond
Lower values indicate limitation. Nitrogen appeared to be the limiting nutrient at Bartlett for much of the study period.

- Direct groundwater inputs of nitrogen appeared to have a role in phytoplankton growth in Bartlett Pond.
  - Even though there are significant nitrogen inputs from the upstream watershed, nitrogen from groundwater is a significant source of nitrogen and the form of nitrogen in the groundwater is more available for phytoplankton growth.

Table O. Annualized Nutrient Loading Summary

Phosphorus Source	Load (kg/yr)	Nitrogen Source	Load (kg/yr)
Surface Inflows	716	Surface Inflows	4,982
Groundwater	12	Groundwater	1240
Internal Loading	59	-	-
Total	**786**	**Total**	**6,222**

- Phosphorus was released from Bartlett Pond bottom sediments throughout the period of this study with a peak rate of release occurring in mid- to late July (Figure 15).

- Although internal phosphorus loading was present, it appeared to be a minor source of phosphorus compared to watershed loads delivered by surface water inflows (Table O). However, it was a large source relative to groundwater.

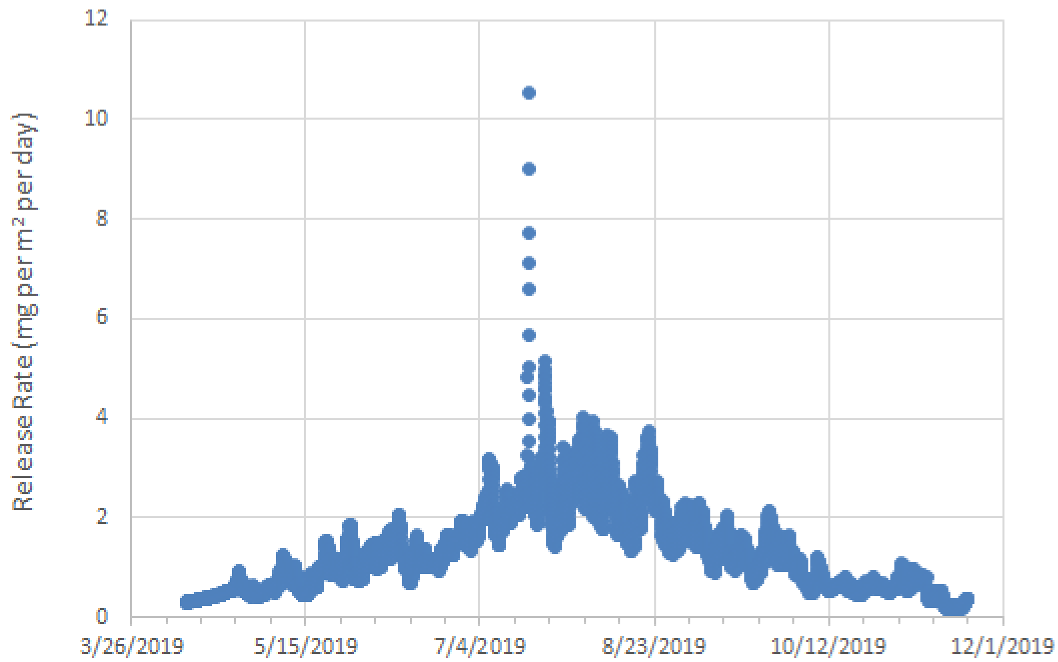


Figure 15. Internal Phosphorus Loading from Bartlett Pond Sediments

- Phytoplankton inputs from upstream watersheds appear to act as a seed for phytoplankton blooms in Bartlett Pond.

- Due to Bartlett Pond's rapid flushing rate (Table P), phytoplankton blooms appear to be precluded unless conditions are conducive to rapid growth. These conditions would include available nitrogen and phosphorus (even though nitrogen is limited, phosphorus is needed) and suitable water temperature and light. In the absence of these conditions, phytoplankton populations in Bartlett Pond appear to be a function of the density of phytoplankton populations that flow into the pond.

Table P. Bartlett Pond Hydrologic Summary

Element	Value
Watershed Area (surface) Watershed Area (groundwater) Watershed Area (combined)	3,524 acres 5,308 acres 6,365 acres
Pond Area	30 acres
Pond Circumference	8,750 feet
Pond Volume	3,158,000 cubic feet
Annualized Direct Groundwater Seepage Inputs	0.459 cfs (3%)

Element	Value
Annual Direct Precipitation	0.091 cfs (1%)
Annualized Surface Water Inputs	15.162 cfs (96%)
Flushing Rate	156.9 flushes/yr
Average Detention Time	2.33 days

The nitrogen-limited conditions observed at Bartlett Pond for much of the study period initially suggest that additional algal growth would be stimulated with increased nitrogen loading, while additional phosphorus loading would have reduced impact. However, this does not necessarily imply that phosphorus should not be managed, as the concept of limitation is related to the ratio of nutrients rather than the actual concentrations. In a system where phosphorus concentrations are very high, as is the case with Bartlett Pond, the potential for algal blooms remains elevated over much of the year and may be quickly realized with an influx of nitrogen from septic loading or stormwater. However, severe algal blooms could also potentially develop in the absence of human-generated nitrogen sources. Such a scenario would most likely involve the growth of nitrogen-fixing cyanobacteria, which can obtain nitrogen directly from atmospheric sources and thrive when available phosphorus is plentiful. Therefore, if the phosphorus concentration in Bartlett Pond can be lowered, the potential for explosive algae growth will also be reduced, regardless of which nutrient tends to be the limiting one.

Detailed outputs of the model calibration process are provided in Appendix C.

2.11 Watershed Buildout

Approach

The most recent MassGIS land use, open space, wetlands data layers were used to determine existing land use in the Bartlett Pond watershed and to identify areas that may be protected from future development (undevelopable). Existing land use classifications were simplified into developed and undeveloped categories for the purpose of this analysis. Residential, industrial, and commercial land uses were considered to be developed. Cranberry bogs were considered to be developed as intensive agriculture, unless they were part of the Tidmarsh restoration project or upcoming restoration to the west of Beaver Dam Road; those areas were classified as undeveloped. Other adjustments to classifications were also made where available evidence (aerial orthophotography, street photography, or knowledge of the watershed) suggested a more appropriate alternative classification.

To estimate the extent of watershed buildout, protected open space, conservation land, and wildlife sanctuaries were classified as undevelopable. Additionally, water bodies and other wetlands were buffered and considered to be undevelopable (except where evidence suggested that these areas were already developed). All other land was assumed to be developable in some form.

The watershed buildout analysis for this project focused on the surface watershed of Bartlett Pond because impacts from development would be expected to be both broader and more immediate. Buildout impacts from the groundwater watershed are also considered on a qualitative basis.

A land use export coefficient approach (based on Reckhow et al. 1980) was then used to estimate loading rates from developed and undeveloped/undevelopable land in each scenario. The potential impacts to water quality in Bartlett Pond associated with future development in the watershed were then predicted using equations developed by Vollenweider (1975) and others.

Results

Buildout Analysis

Under the long-term (full buildout) scenario, developed land would become the primary watershed land use, with forested conservation lands, open space, and wetlands reduced from 53 percent of the surface watershed (1,859 acres; Figure 16) to approximately 31 percent of the surface watershed (1,105 acres; Figure 17). This major shift in land use would be expected to generate substantially higher surface loads of nutrients to Bartlett Pond.

In addition to generation of additional nutrient loading through surface flows, watershed development could potentially also result in increased groundwater sources of nutrients through a rise in the number of septic systems or other wastewater discharges. Most of the land adjacent to Bartlett Pond is either currently developed or protected from future development. Therefore, little additional loading through septic discharges would be expected, unless conversion of smaller homes and seasonal cottages to larger, year-round dwellings occurs. In more distant portions of the groundwater watershed where new development occurs, groundwater phosphorus will likely be subject to substantial attenuation, given the distance from Bartlett Pond.

In the long term, eventual buildout of all available land in the Bartlett Pond watershed would be predicted to result in a substantial increase in annual nutrient loading. In particular, external phosphorus loading would be expected to increase by more than 248 kg/yr (Table Q). Under this scenario, the total annual phosphorus load would exceed 1,000 kg/yr. Nitrogen loading would also increase by nearly 2,000 kg/yr to approximately 8,200 kg/yr.

These models predict a substantial rise in in-pond phosphorus concentrations would likely trigger substantially higher chlorophyll *a* levels and, therefore, algal growth (Table Q). Re-examining the TSI under these conditions, Bartlett Pond would likely be on edge of becoming a hypereutrophic pond. This would be expected to further exacerbate the current management issues at Bartlett Pond, leading to more frequent and persistent algae blooms and further reducing water clarity.

Draft

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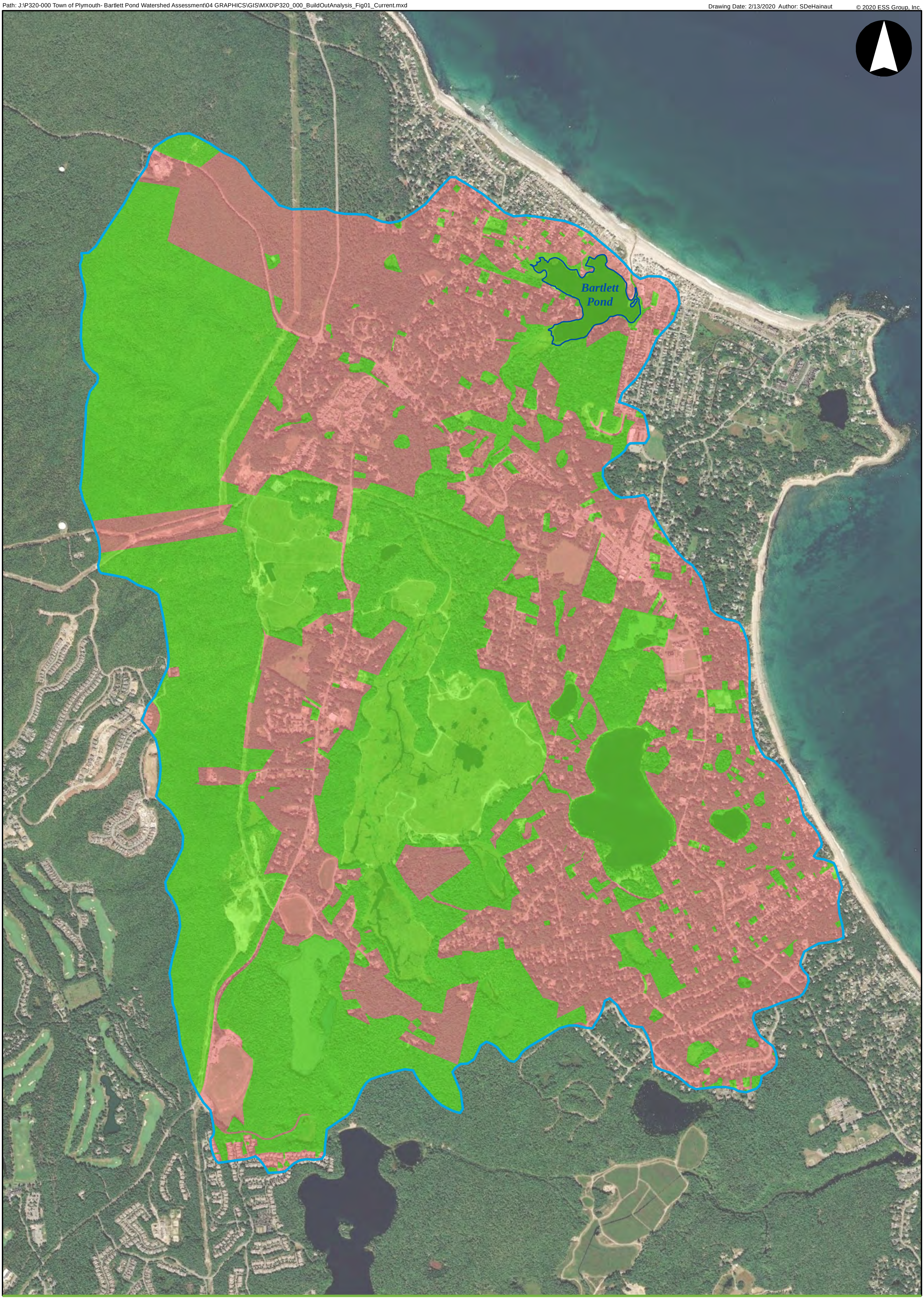
Drawing Date: 2/13/2020 Author: SDeHainaut



ess group
environmental consulting & engineering services

Bartlett Pond Watershed Assessment

Plymouth, MA

Source: 1) MassGIS, Open Space (2019), Land Use (2016)
2) MA DEP, Wetlands, 2009

0 770 1,540 Feet

Pond Shoreline

Bartlett Pond Subbasin

Development Category

Currently Developed

Not Developed

Build-Out Analysis
Current Conditions - Land Use

Figure 16

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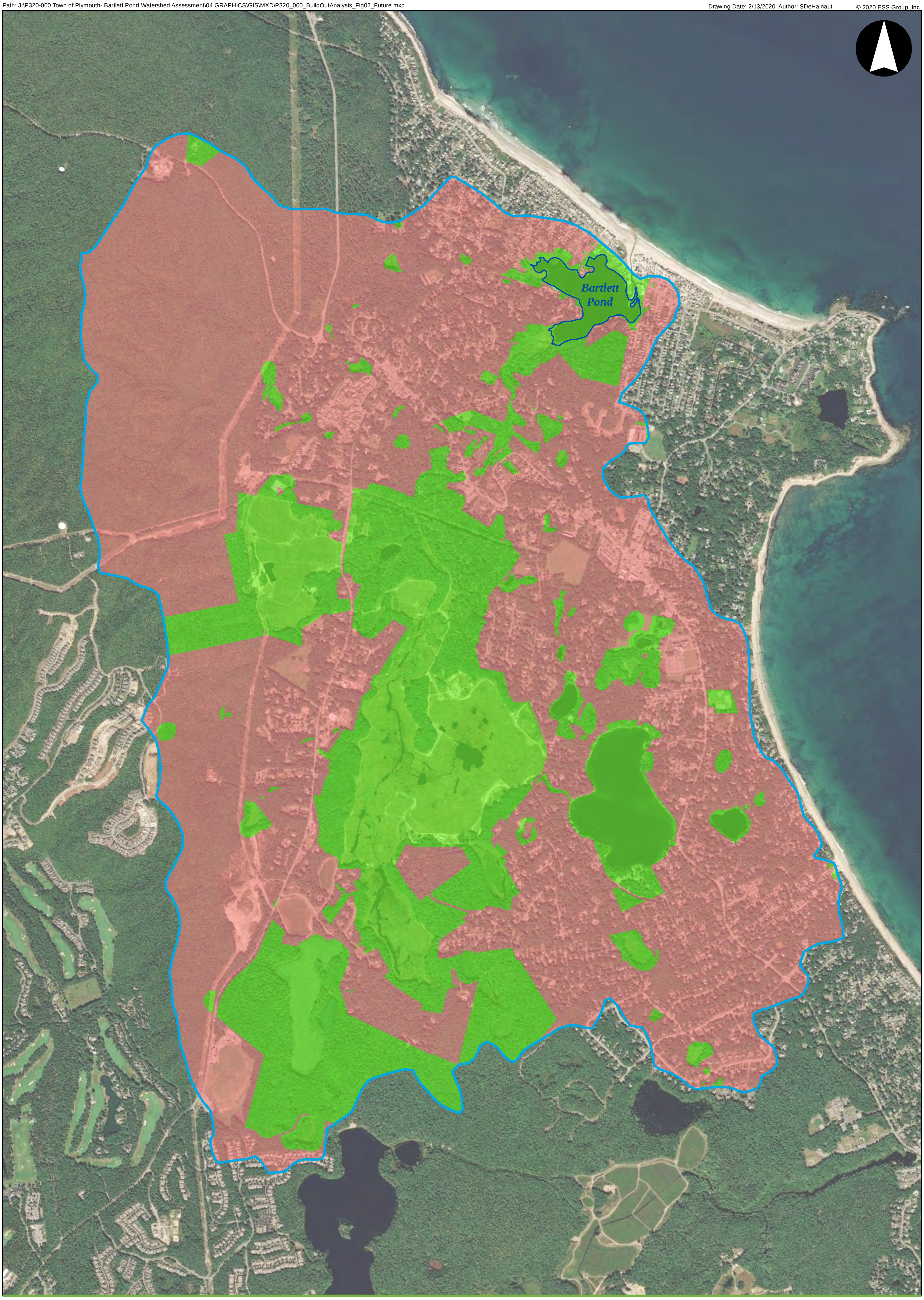

ess group environmental consulting & engineering services

Bartlett Pond Watershed Assessment

Plymouth, MA

Pond Shoreline

Bartlett Pond Subbasin

Developed

Not Developable

Source: 1) MassGIS, Open Space (2019), Streams (2010), Land Use (2016)
2) MA DEP, Wetlands, 2009

0 770 1,540 Feet

Build-Out Analysis
Fully Built

Figure 17

Table Q. Summary of Current and Modeled Future Trophic State Indicators at Bartlett Pond

Scenario	Median Total Phosphorus (mg/L)	Median Chlorophyll *a* (ug/L)	Maximum Chlorophyll *a* (ug/L)	TSI (low)	TSI (high)	Trophic State
Current	0.073	7.63	102.85	50.5	66.0	Eutrophic
Buildout	0.096	48.3	154.6	68.6	70.0	Eutrophic/ Hypereutrophic

In summary, Bartlett Pond has already experienced substantial cultural eutrophication, and is currently estimated to be in a eutrophic state. However, should the Bartlett Pond watershed experience substantial further development, the pond will likely enter a more advanced state of eutrophication, which may be characterized by recurring algae blooms.

2.12 Quality Assurance/Quality Control

To ensure collection of high quality data that met the data quality objectives of this study, Quality Assurance/Quality Control (QA/QC) measures and checks were integrated into the execution of field, laboratory, and desktop analytical portions of this project, as follows:

- Duplicate field and laboratory water quality and discharge measurements were conducted to assess the relative percent difference (RPD) between two measurements at the same location. Laboratory duplicate samples were submitted as blind duplicates to prevent bias.
- Laboratory detection limits and regulatory guidance concentrations for PFAS are extremely low. Given this and the presence of PFAS in numerous everyday products, field blank samples were collected to document that the sampling process did not introduce detectable levels of contamination.
- Contract laboratories also completed internal QA/QC measures to assess precision and accuracy of laboratory results.

Water quality and discharge data collected as part of this project generally met QA/QC criteria with regard to precision, accuracy and completeness of the data collected. In cases of deviation from QA/QC criteria, the reason for and nature of the deviation were assessed to determine whether the data would still be able to meet project data quality objectives. Data not meeting data quality objectives were retained as provisional but excluded from quantitative analyses. Therefore, the dataset used to develop this report is believed to be of sufficient quality to achieve project goals.

3.0 MANAGEMENT OPTIONS SUMMARY

This section identifies the management goals for Bartlett Pond and provides an initial assessment of the applicability of multiple in-pond and watershed management options to support these goals.

3.1 Management Goals

The management goals for Bartlett Pond include the following:

- Improve overall water quality
- Prevent or address harmful algal blooms
- Avoid negative impacts to recreational opportunities at White Horse Beach
- Maintain or improve ecological value
- Prevent the establishment of new invasive species

Additionally, as requested at the initiation of this project, the management goals for Bartlett Pond should complement the White Horse Beach Management Plan (Environmental Consulting & Restoration 2018).

3.2 Management Recommendations

This section presents the range of options for the management of Bartlett Pond, based on the goals stated in Section 3.1. Given the number of issues currently impacting Bartlett Pond, including water quality, sedimentation, and general eutrophication, as well as an upstream infestation of aquatic invasive species, a wide range of management options were assessed for the pond and its watershed.

With respect to nutrients, both nitrogen and phosphorus are logical targets for active management at Bartlett Pond, given the nutrient-enriched state of the pond.

Nitrogen management is likely to be more difficult to achieve with in-pond or in-stream approaches. Therefore, a watershed focus may be needed to reduce both septic and surface sources of nitrogen.

Phosphorus can also be managed in the watershed over the long term. However, in-pond and in-stream approaches, if determined to be feasible, may produce significant reduction of phosphorus in the short term at a fraction of the cost.

This section provides a basic description of recommended management options, a list of key advantages and limitations, a statement regarding possible permits, and a general assessment of cost. Most options can be permitted without substantial additional study or design; a basic permitting cost of $7,000 to $10,000 should be assumed. Options requiring advanced study or design to evaluate feasibility or permit should be expected to have higher permitting costs; further information on these additional costs is provided in the descriptions for those options.

Summaries of each recommended option are presented in Table R.

Table R. Management Options Recommended for Bartlett Pond

Approach	Issue(s) Addressed					Primary Pros	Primary Cons	Applicable/ Feasible
	Algae	Bacteria	Nutrients	Plants	Other			
In-pond Options								
Algaecides	✓					Cost-effective over short term	Does not address root cause Possible water use restrictions	Yes/ Yes
Harvesting – Hand				✓		Allows for precision removal of target species with negligible impact to other resources Simplicity of approach	Only cost-effective for modestly size beds Insufficient for control of most established infestations Can spread plant fragments	Yes/ Yes
Herbivores				✓		Species-specific herbivores are a highly selective method	Relatively few plant species are effectively controlled this way Many herbivores cannot be imported/stocked	Yes/ Yes (loosestrife beetles only)
Resident Waterfowl Control		✓	✓		✓	Addresses one source of nutrients and bacteria Passive measures can provide secondary ecological, water quality, or aesthetic benefits	May reduce or restrict access where passive measures are used	Yes/ Yes
Watershed Options								
Nutrient Inactivation (Dosing Station)	✓		✓			Most cost-effective method of reducing external nutrient loading	Addresses proximal cause but not root cause of watershed nutrient loading	Yes/ Need feasibility study

Approach	Issue(s) Addressed: Algae	Bacteria	Nutrients	Plants	Other	Primary Pros	Primary Cons	Applicable/ Feasible
Septic System Improvements		✓	✓			Addresses source of nutrients and bacteria	Improved systems may reduce septic loading but will not eliminate it Overall costs could be high, although costs may vary substantially by residence/lot requirements	Yes/ Varies
Stormwater Controls		✓	✓		✓	Addresses source of wide range of pollutants	Maintenance costs are high, which may lead to failure Cost-effectiveness reduced for retrofits	Yes/ Yes, with additional study
Other Options								
Monitoring					✓	Early detection of new management issues Improves management approach over time Allows community to stay informed	Does not result in management progress on its own	Yes/ Yes
Public Education and Outreach	✓	✓	✓	✓	✓	Cost-effective Allows community to stay informed May lead to improvements in water quality or biological condition	Improvements are likely to be marginal. Must be paired with other management activities to achieve substantial improvements.	Yes/ Yes

Together, these options provide a comprehensive suite of short- and long-term approaches to address excessive algae, bacteria, nutrients, and extant invasive species, while also building in flexibility to deal with contingencies like new infestations of aquatic invasive species.

Other management options assessed but determined not to be advantageous at this time include the following:

- Aeration or Circulation
- Barley Straw
- Benthic Barriers
- Bioaugmentation
- Biomanipulation
- Dilution or Flushing
- Drawdown
- Dredging
- Harvesting – DASH
- Harvesting – Mechanical
- Herbicides
- Herbivores – Except for loosestrife beetles
- Hydroraking
- Plant Competition
- Shading (Dye)
- Sonication

3.2.1 In-Pond Options

Algaecides

Algaecides are analogous to herbicides in many ways but primarily target algae and cyanobacteria. Application of algaecides results in almost immediate control of a broad spectrum of planktonic and filamentous algae. A variety of different algaecide formulations are available for use, including copper sulfate and chelated copper-based formulations (e.g., Captain and K-Tea), which will generally control most nuisance green algae and cyanobacteria species. Peroxide-based formulations (e.g., PAK 27) are also available for control of nuisance algae, although these tend to be more expensive. Water use restrictions associated with most algaecides are minimal and temporary. Some labels do not carry any restrictions.

Algaecides may be useful for short-term control of algal blooms or patches of filamentous algae on an as-needed basis. Although effective, algaecides treat only the symptom (i.e., excessive algae) and do not address the cause of algae blooms (i.e., excessive nutrients). Therefore, long-term improvements should not be anticipated from the use of algaecides alone.

Applicability to Bartlett Pond

- Algaecides target excessive algal growth. Therefore, this option is applicable to management issues at Bartlett Pond.

Advantages

- Provides rapid control of algae, which can be critical during a developing algae bloom.
- Some selectivity is possible, depending on the formulation used.
- Cost-effective in the short term.

Limitations

- Impacts to non-target species are possible but can be minimized through selection of an appropriate formulation and dose.
- Usually not applied to more than half the pond at a time to reduce the chance of causing dissolved oxygen sags from decomposing algal cells.
- Use of algaecides during a harmful algal bloom may lyse cells and cause the release of cyanotoxins into the water column. However, not treating may allow the bloom to worsen. Therefore, testing is advised prior to initiating treatment.
- Algaecides are not cost-effective in the long term and do not provide lasting water quality benefits.
- Label restrictions apply to most algaecides.

Permitting

- Algaecide use would require obtaining an Order of Conditions from the Plymouth Conservation Commission.
- Additionally, each year's algaecide application would require a License to Apply Chemicals from the MassDEP Bureau of Resource Protection –Watershed Management. The treatment contractor is typically able to obtain the License to Apply Chemicals in about two weeks at a nominal cost. Only applicators certified to apply herbicides in the Commonwealth of Massachusetts may apply aquatic algaecides to Bartlett Pond.

Costs

- Costs for treatment vary by product but are likely to range from $250 to $500 per acre, although some specialty formulations may exceed this cost.

Harvesting

Macrophyte harvesting covers a wide range of techniques, including hand harvesting, diver assisted suction harvesting (DASH), and mechanical harvesting. Hand harvesting is the only techniques that is currently recommended.

The simplest form of harvesting is hand pulling of selected plants. Depending on the depth of the water at the targeted site, hand harvesting may involve wading, snorkeling, or SCUBA diving. Pulled plants and fragments are placed in a mesh bag or container that allows for transport and disposal of the vegetation. Hand harvesting of submerged vegetation aims to remove entire plants, including the roots, thereby preventing re-growth in subsequent seasons. In practice, it is difficult to achieve 100 percent removal, except where beds are isolated or represent pioneer infestations. Where hand harvesting is used to control established weed beds, some re-growth should be expected in subsequent seasons. With diligence, control may be achieved after a few consecutive seasons of hand harvesting.

At Bartlett Pond, hand harvesting could be used to provide precision control of target species around docks, beaches, and shallow shorelines or coves, or to control pioneer infestations of new invasive species. This technique is also an excellent means of controlling small (generally less than one acre) beds of water hyacinth and water lettuce, which were observed upstream of the pond.

Hand harvesting can be conducted on smaller scales by trained homeowners and volunteers. Larger scale work is a major effort that may span weeks or even months and is usually conducted by professionals.

At this time, it appears that the water hyacinth and water lettuce populations in Beaver Dam Brook could potentially be controlled through hand harvesting, although the full upstream extent of these populations has not been surveyed. Therefore, the effort and access required to control the population are uncertain. To improve planning and avoid redundancy in hand harvesting effort, this upstream extent should be delineated prior to implementation of a hand harvesting program.

Applicability to Bartlett Pond

- Harvesting targets excessive or exotic plant growth. Growth of *aquatic plants* at Bartlett Pond is not currently excessive. However, the exotic species identified in upstream waters may be controlled by harvesting. Hand harvesting would be appropriate to the observed size of the current infestation.
- Hand harvesting could be useful for rapid response to pioneer infestations, should they occur in the future.

Advantages

- Allows for highly selective management of target species with negligible impacts to non-target species
- Approach is conceptually simple and can be implemented by volunteers on smaller scales

Limitations

- Plant fragments may be generated from the activity, leading to further spread of the target species. This is less of a concern where the infestation is already established.

- Not cost-effective for large areas.

Permitting

- Harvesting may require filing a Request for Determination of Applicability or obtaining an Order of Conditions from the Plymouth Conservation Commission, depending on the proposed action(s).

Costs

- Hand harvesting costs depend on bed density but may be expected to range from $3,000/acre to $8,000/acre.

- Additional disposal costs may also apply.

Herbivores

Herbivores include a wide variety of biological organisms known to directly control plant growth by ingestion of plant tissues. These primarily include fish and insects when used for lake management purposes. Although excessive aquatic plant growth does not currently appear to be a management issue at Bartlett Pond, exotic species were identified in upstream waters during this survey. Additionally, several exotic emergent plants grow at nuisance levels along the shoreline of Bartlett Pond. Therefore, the use of herbivores as a potential vegetation management option is briefly considered in this section.

One of the best-known herbivores used for aquatic vegetation management is triploid grass carp (*Ctenopharyngodon idella*), which has been used for general macrophyte control on an experimental basis in Connecticut, New York, and Virginia. This species is a generalist herbivore and, although it may prefer certain plants, will eat most once the preferred species are eliminated. This can lead to large areas devoid of aquatic plants and facilitate the switch of some ponds from plant-dominated to algae-dominated systems. If understocked, grass carp may not ingest enough plant material to result in noticeable control of target weed beds. However, these issues are currently moot in Massachusetts as stocking of grass carp is illegal in the Commonwealth.

Among insect herbivores, the milfoil weevil (*Euhrychiopsis lecontei*) is probably the most widely used for aquatic plant management. This species is a specialist, originally requiring indigenous northern milfoil (*Myriophyllum sibiricum)* as its primary food source. However, exotic Eurasian milfoil (*Myriophyllum spicatum*) also serves as an acceptable host for milfoil beetles. Therefore, this species may be used to help control infestations of Eurasian milfoil or hybrids between northern and Eurasian milfoil. The larvae of this beetle burrow into the stems of the Eurasian milfoil plant, consuming the plant tissue within the stem and ultimately causing the plant to collapse. The best results are usually achieved in ponds with dense, monotypic stands of Eurasian milfoil and several years are typically required to measure a positive effect. Bartlett Pond is not currently known to host Eurasian milfoil. Therefore, the milfoil beetle approach would not be applicable at this time.

Water hyacinth weevils (*Neochetina bruchi* and *N. eichhorniae*) have been used to control water hyacinth in warmer climates. However, it is uncertain whether these would be effective in New England, where water hyacinth does not appear to successfully overwinter.

Common reed and yellow flag iris are not typically controlled through the use of herbivores. However, purple loosestrife may be controlled through the culture and targeted release of loosestrife beetles (*Galerucella* spp.). Although the adults are the most visible life stage, it is actually the larvae that play the biggest role in control of purple loosestrife plants. Damage from adults is mostly limited to superficial leaf damage, which is unlikely to weaken the plant substantially. However, larvae burrow deep into stems and can therefore kill back entire shoots. Therefore, it may take several years for loosestrife beetle populations to sufficiently reproduce and grow to a density that makes a measurable difference in purple loosestrife cover.

Purple loosestrife-infested wetland before (left) and one year after (right) release of loosestrife beetles. Brown foliage in the photograph on the right is damage due primarily to stem boring of beetle larvae.

Loosestrife beetles tend to disperse slowly, which makes them most effective where contiguous stands of purple loosestrife occur. Loosestrife beetles are also a highly selective control method because they are specialized herbivores on purple loosestrife. Therefore, the impact to non-target organisms is usually anticipated to be negligible. However, there is some concern within the Commonwealth that loosestrife beetles may also feed on closely related rare species, such as annual toothcup (*Rotala ramosior*). Therefore, loosestrife beetles should be used with caution and not released near rare plant populations without approval from NHESP.

Applicability to Bartlett Pond

- Herbivores target excessive plant growth. Growth of *aquatic plants* at Bartlett Pond is not currently excessive. Although one of the exotic species identified in upstream waters has been managed by herbivory in warmer climates, the viability of this control method in temperate climates is not fully understood. Therefore, this option is not currently considered to be applicable to aquatic plant management issues at Bartlett Pond.

- However, purple loosestrife (an *emergent plant*) does present a potential management issue at Bartlett Pond. Loosestrife beetles specifically target this species. Therefore, this option is applicable to purple loosestrife management at Bartlett Pond.

Advantages

- The cost of loosestrife beetles is relatively low. Other herbivores, such as milfoil weevils, are harder to rear and therefore incur greater costs.
- Plant-specific herbivores, such as loosestrife beetles, pose low risk to non-target species.

Limitations

- The success of herbivores is subject to a number of uncontrollable environmental factors. Therefore, predictability of outcome is generally low.
- Most herbivores are unable to sustain their populations without additional stocking in future years.
- Herbivore generalists may result in deleterious damage to the aquatic plant community if overstocked.
- Grass carp (and many other species) cannot legally be stocked in Massachusetts.

Permitting

- Release of herbivores may require filing a Request for Determination of Applicability or Notice of Intent with the Plymouth Conservation Commission. Exotic species, such as loosestrife beetles, are also regulated by the US Department of Agriculture – Animal and Plant Health Inspection Service (USDA APHIS) at the federal level. Therefore, insects should be obtained from reputable sources that are permitted to distribute and release the desired species.

Costs

- Adult loosestrife beetles can be obtained at a cost of a few hundred dollars for 1,000 beetles. An initial release of up to a few thousand adults in a handful of select locations is recommended. Additional beetles may either be purchased in future years or reared by volunteers on container-grown purple loosestrife plants. Monitoring of purple loosestrife damage and the loosestrife beetle population are the best way to determine whether additional beetles need to be released in subsequent years. However, as a general guideline, repeated releases of adult loosestrife beetles should be planned for the first two to three years of the control program.

<u>Resident Waterfowl Control</u>

Large resident Canada Goose populations have become established in eastern Massachusetts over the last 60 years, where hunting restrictions, shoreline development, and feeding by the public have allowed resident geese to thrive. High densities of resident geese can result in measurable nutrient and bacteria loading to surface waters. Additionally, resident goose flocks can become aggressive toward people and obstructive to vehicular traffic on nearby roads.

Management of the resident Canada Goose population is most likely to be accomplished if multiple active and passive control options are implemented as part of a comprehensive effort. A few examples of active and passive control options are described in this section. However, this list is not exhaustive.

Egg addling or oiling is an active measure that seeks to reduce the viability of goose eggs without destroying the nest. When successful, geese will continue to incubate the non-viable eggs long enough that that they do not attempt to nest again that year. Over time, this reduces the locally grown population of geese. This activity can be implemented by trained volunteers but requires effort to locate nests each year.

Goose harassment is another active measure that involves the generation of loud noises or canine patrolling of favored areas to disturb geese and discourage them from persisting in these areas. Over time, the frequency of harassment may be decreased as geese learn to avoid these areas.

Raising the cutting height on lawnmowers and/or reducing mowing frequency is the simplest passive measure to discourage goose grazing. Geese find taller grass to be less palatable and gravitate to closely cropped lawn areas instead. This method would also have the added benefit of reducing the time and money spent on landscape maintenance by shoreline residents. It would also help to attenuate direct runoff and pollutant loading from adjacent properties into the pond.

Chemical repellents are another passive measure that makes grass less palatable to geese. However, these need to be reapplied frequently over a long period of time to be effective.

Decoys, often in the form of owls, coyotes, or other shapes/patterns that simulate predators are a popular passive measure that typically achieves little success in managing resident waterfowl populations. Although geese may initially avoid areas near decoys, they quickly learn that the simulated predators are not a real threat. Moving or switching decoys every few days may improve effectiveness.

Goose fencing is not always successful on its own, especially if geese are able to reach desirable foraging grounds through adjacent properties, as demonstrated here. However, when used appropriately and/or combined with other nuisance waterfowl control measures, such as vegetative buffers and reduced mowing, it can be very effective.

The most effective passive measure involves creating a barrier to goose movement during the vulnerable summer molting season. This can be accomplished through installation of fencing or re-landscaping the immediate shoreline to incorporate a buffer of shrubs and larger herbaceous plants. When geese molt, they are unable to fly over barriers and avoid passing between obstacles that obscure their vision of potential predators. Fencing can be an excellent goose barrier. If fencing is used, it must extend the entire perimeter of the open shoreline transition area (and extend up along property boundaries, if the neighboring property is unfenced). Fencing must be at least 30 inches tall with the first rail no more than 12 inches above the ground to be effective. Benches, stones, or other objects that form a similar barrier may also be added to break up the fenceline and provide greater visual interest or enhance passive recreational opportunities, although these must be flush with fenceposts and meet the required height specifications to avoid creating potential points of entry for geese to cross through the barrier. Gates may also be installed to allow human access while preventing goose passage. If vegetation is used to form the barrier, it must also be at least 30 inches tall and form a strip at least 6 feet wide, although narrow footpaths between vegetated areas may be maintained to allow people to access the pond. Vegetation may be selected to enhance both aesthetic interest and wildlife value. Vegetative barriers are a particularly attractive option because the also provide nutrient uptake and attenuate direct runoff from adjacent parcels into the pond.

Applicability to Bartlett Pond

- Resident waterfowl control targets excessive nutrients and bacteria. Therefore, this option is applicable to management issues at Bartlett Pond.

Advantages

- Addresses an easily observable source of nutrients and bacteria.
- Passive control measures can provide secondary benefits, including ecological, water quality, and aesthetic improvements.
- Some passive control measures (e.g., reduced mowing) can actually lower costs to homeowners and other shoreline vegetation managers.

Limitations

- Active control measures may be disturbing to pond residents, visitors, and desirable wildlife.
- Active control measures must be persistently implemented to remain effective. Resident waterfowl abound in the region and will quickly return once the perceived threat has ceased.
- Passive control measures, such as fencing and revegetation, must form effective exclosures or nuisance waterfowl will find another path to reach attractive foraging and loafing areas. This may result in reduced access or visibility to the water for people.
- Decoys may be ineffective, especially if they are not frequently moved or exchanged.

Permitting

- Resident waterfowl control may require filing a Request for Determination of Applicability or obtaining an Order of Conditions from the Plymouth Conservation Commission, depending on the proposed action(s). Some actions, such as reduced mowing, require no permits.

Costs

- Costs to implement resident waterfowl control are typically negligible to low, although fencing can become expensive when implemented over large distances.

3.2.2 Watershed Options

Nutrient Inactivation (Dosing Station)

Ideally, external loading of nutrients to Bartlett Pond would be reduced through watershed controls, including stormwater BMPs. However, in practice, this is likely to require many years to achieve given the large (~210:1) watershed to pond ratio large amount of developed land. A tributary dosing station would allow for immediate improvements in nutrient loading by directly injecting a flocculant and binding agent (typically alum [aluminum sulfate] or polyaluminum chloride) into a known major nutrient source, such as Beaver Dam Brook. The aluminum in these chemicals would precipitate out of solution and bind to phosphorus in a way that remains stable under a wide variety of naturally occurring conditions. A dosing station would target phosphorus before it were to reach the pond.

Alum dosing stations may be housed in something as simple as a CONEX box or a more substantial facility like this, depending on dosing needs, site constraints, and available funding.

Alum and polyaluminum chloride (PAC) have a long track record of successful use and are generally more economical to apply than other materials, although aluminum chlorohydrate (ACH), zeolite formulations (e.g., Aqual P), and rare earth/bentonite clay formulations (e.g., Phoslock) are also available and becoming more competitive with alum. Aqual P has also demonstrated some potential to be used for capture of nitrogen, although additional peer-reviewed published results would be needed to confirm this

Alum is acidic and, if applied at high doses without sufficient buffering, can result in a temporary but significant drop in pH that may negatively impact aquatic life. Sodium aluminate is basic and can be injected with alum to prevent pH falls during treatment, while also adding further capacity for inactivation of phosphorus. Therefore, in most cases, alum and sodium aluminate are used together to deliver a pH-balanced treatment and avoid negative impacts to aquatic life.

The two primary advantages of a tributary dosing station are that it would immediately reduce external loading of phosphorus to the downstream pond and cost far less per kilogram of phosphorus removed than other watershed approaches. Since a dosing station would be able to inject alum or polyaluminum chloride as it is needed over a long period of time, it has potential be effective in managing persistent excessive nutrient issues.

Prior to undertaking any nutrient inactivation program, additional investigation would be required to determine the feasibility of implementation and develop a conceptual design at one or more proposed sites. This investigation would consist of the following, at a minimum:

- Evaluation of potential sites for the alum dosing station.
- Additional sampling to determine most cost-effective dosing schedule in response to storm events.
- Conceptual design of the alum dosing station.
- Description of the permitting pathway for the project, given nature of the project and environmental resources at or near the proposed location.
- Opinion of cost for next steps.

Applicability to Bartlett Pond

- Nutrient inactivation targets excessive nutrients and algal growth. Therefore, this option is applicable to management issues at Bartlett Pond.

Advantages

- Provides rapid reduction of nutrient loading into the pond.
- Dosing program can be fine-tuned to target phosphorus removal when it is most important.
- Cost-effective over the long term.

Limitations

- Does not eliminate phosphorus at the source.
- Requires available land and utilities adjacent to Beaver Dam Brook.

Permitting

- A dosing station would require obtaining an Order of Conditions from the Plymouth Conservation Commission. Other permits may also be necessary, depending on the site location and final design.

Costs

- An initial investigation and feasibility study could be completed for approximately $25,000 to $30,000.
- If determined to be feasible, additional costs should be anticipated for design, permitting, installation, and operation and maintenance to refill the dosing tank and service the equipment.
- Costs vary with commodity prices and required dosage but should be anticipated to run in the tens of thousands of dollars per year.

Septic System Improvements

Septic systems provide on-site treatment of sewage for homes and businesses that are not connected to a sanitary sewer. Septic failures may result in ponded or flowing wastewater at the ground surface or into surface waters, which presents a potential public health issue. Additionally, failed, inappropriately sited, or inadequately designed systems may also contribute nutrients to surface waters, which can fuel excessive algal growth.

The Bartlett Pond watershed currently does not have sanitary sewer service. Given the sprawling nature of this watershed, developing a sanitary sewer system for the entire watershed would be extremely costly. Encouraging the upgrade or repair of onsite septic systems may be a less costly and reasonably effective alternative. A survey of septic systems in the Bartlett Pond area could provide information on the types of systems proximal to the pond and help ensure compliance with state Title 5 requirements.

Septic system repairs, improvements, and more frequent maintenance could help reduce the nutrient load associated with these systems in the watershed. Where setbacks or site conditions are insufficient to ensure the proper functioning of traditional septic systems, alternative innovative designs may be appropriate. A wide variety of approaches and designs exist. Some examples include aerobic treatment units, recirculating sand filters, and composting toilets. However, one drawback of non-traditional septic systems is that these systems do not have as long a record of performance and the guidelines for proper operation may not be as well-established, especially for those that rely on proprietary technologies. This may result in confusion on the part of residents and/or regulators with regard to ensuring proper operation and maintenance of the systems.

Applicability to Bartlett Pond

- Septic system improvements target pollutant loading, including nutrients and bacteria. Therefore, this option is applicable to management issues at Bartlett Pond.

Advantages

- Addresses sources of nutrient and bacteria.
- Except for tight tanks, does not divert water away from Bartlett Pond (provides recharge).

Limitations

- Improved systems may reduce septic loading to Bartlett Pond but will not eliminate it, especially with regard to nitrogen.
- Unless failing, the upgrade of an individual septic system is unlikely to have a measurable impact on water quality in Bartlett Pond. The success of this method depends on larger scale adoption, which may require legislative or regulatory updates.

Permitting

- Permitting for new or upgraded septic systems is primarily handled through the Board of Health. However, additional permits or approvals may be required depending on location of and features at the site.

Costs

- Costs to upgrade or otherwise improve septic systems vary substantially by size, location, and design, as well as required maintenance/pump-out frequency. The costs are typically borne by homeowners, although tax credits and/or low-interest financing may be available for some upgrades.

- Additional costs to the Town may result from changes to requirements that create additional review and enforcement responsibilities.

Stormwater Improvements

External sources contribute the most substantial portion of the annual phosphorus and nitrogen loads to Bartlett Pond. Even incremental development can take a significant toll on water quality if not effectively managed as the watershed is further developed. As such, stormwater Best Management Practices (BMPs) may be helpful in minimizing future increases in external pollutant loading.

Rain gardens are small bioretention features that can fit on very small parcels.

External nutrient loading can be mitigated to some degree through watershed controls, especially when enforced and implemented as a condition for new or re-development. However, once watershed land is developed, watershed controls become increasingly difficult to implement and typically require large-scale disconnection of impervious surfaces or retrofits to achieve even small reductions in nutrient, sediment, or bacteria loading. Retrofits can be effective but typically cost many times more to construct and maintain than other means of addressing pollutants.

Other watershed measures, including agricultural and forestry BMPs, can also reduce the amount of nutrient loading from non-urbanized land. Because the Town only controls a small portion of the land in the watershed, work toward BMP implementation is most likely to take the form of coordination with state agencies, non-governmental organizations, and private individuals.

Development and re-development within the watershed should incorporate low impact development (LID) stormwater techniques or green infrastructure in line with the latest version of the Massachusetts Stormwater Handbook and applicable regulations to prevent further deterioration of influent water quality. Small municipal separate storm sewer system (MS4) operators in Massachusetts are required to adopt or update municipal stormwater by-laws to comply with the Small MS4 General Permit. Encouraging stricter municipal stormwater regulations and LID standards can also help control watershed pollutant sources.

Green infrastructure and LID include features as diverse as permeable pavers, sand filters, and bioretention.

Applicability to Bartlett Pond

- Stormwater improvements target pollutant loading, including nutrients, bacteria, and sediment. Therefore, this option is applicable to management issues at Bartlett Pond.

Advantages

- Addresses source of a wide variety of pollutants.
- Can be designed to reduce or attenuate stormwater discharge volumes, thereby also potentially addressing flooding issues.

Limitations

- Require substantial effort, cost, and coordination with a large number of entities to implement and make a noticeable impact on water quality.
- Require substantial effort, cost, and coordination with a large number of entities to operate and maintain so that the positive impact on water quality continues over the long term.
- The lag time between implementation and improvement in water quality of a receiving water may be years.

Permitting

- Depending on approach and siting, some stormwater BMPs may not require a permit at all. Others may require more extensive permitting and approvals.

Costs

- Costs to implement BMPs vary widely, depending on the type, size, site constraints, need for professional services (e.g., engineering), and amount of pollutant removal desired. However, costs per unit weight of pollutant removed are often among the highest of any management approach. For example, a cost of several thousand dollars per kilogram removed would not be unusual for phosphorus.

3.2.3 Other Options

Monitoring

A cost-effective monitoring program could provide continuous background data for the purpose of tracking the effectiveness of any future management practices at Bartlett Pond.

Water quality and algae monitoring would be useful to track in-pond conditions during the growing season each year. This could be used to identify any emerging negative trends in water quality before they become problematic as well as to document any improvements in water quality that may be realized through pond management actions or improvements in watershed management. Phosphorus, nitrogen, and chlorophyll-a levels would be important in this regard, along with easily measured field parameters (pH, dissolved oxygen, temperature, specific conductance/salinity, and clarity [Secchi depth]). Additionally, water quality monitoring of some sort would likely be required as a permit condition for implementation of management actions.

Additional monitoring of vegetation would also be of use for Bartlett Pond and should include the mapping of aquatic plant species distribution, cover, and biovolume. If emergent invasive species are to be managed, then vegetation monitoring should also include mapping of those areas.

Evaluating water quality, algae, plant and other biological trends requires continued data collection over the long term. Frequent sampling of water quality and algae are beneficial, as these may change rapidly over the course of the year. Remote data logger deployment can improve the continuity of the data record but useful datasets can also be achieved with periodic but thorough field visits to directly measure or collect samples. Vegetation surveys could be conducted on a less frequent basis than water quality but should be completed at least once a year to monitor for the introduction of exotic or nuisance species. This would allow the Town the opportunity to implement rapid response actions before the infestations become established.

Applicability to Bartlett Pond

- This approach can provide general benefits to Bartlett Pond by identifying new problems early on (early detection) and gathering information needed to make adjustments to the management program. Therefore, it is applicable to management issues at Bartlett Pond.

Advantages

- Allows the community to stay informed on progress in achieving management goals.
- Provides necessary feedback for making adjustments to management program.
- Enables early detection of new management issues and subsequent rapid response.

Limitations

- In and of itself, monitoring does not resolve any management issues.

Permitting

- Most monitoring activities are exempt from permit requirements.

Costs

- Monitoring costs vary by the scope and frequency of the program, as well as the nature of the instrumentation used. Most monitoring programs require some cost for analytical services and professional interpretation of results.

Public Education and Outreach

Public education and outreach are will raise awareness of issues at Bartlett Pond and encourage public involvement in its protection and management as a community resource, particularly with regard to prevention of future problems as well as extension of benefits from other management actions that may be implemented. In particular, development of a public education program about good housekeeping measures (proper maintenance) could help prevent septic system failure and degradation of water quality at Bartlett Pond and other receiving waters.

Education and outreach may take many forms. These may include content on hosted on the Town website, social media postings, targeted mailings, incorporation into school programs, community events, installation of informational signs or kiosks at public access locations, or other approaches.

Organized public participation programs may provide an enhanced opportunity for members of the public to take a more active role in supporting Bartlett Pond. Examples may include labeling of storm drains, replanting of native plants on public lands or rights-of-way, or development of a citizen water quality monitoring program. Additionally, the Massachusetts Weed Watchers program, sponsored by the Department of Conservation and Recreation Lakes and Ponds Program, provides training and technical assistance to public groups interested in monitoring their ponds for exotic species of aquatic plants.

Applicability to Bartlett Pond

- This approach can provide general benefits to Bartlett Pond by improving community awareness and involvement. Therefore, it is applicable to management issues at Bartlett Pond.

Advantages

- Allows the community to stay informed on key management issues and solutions. Provides practical measures that individuals can take.
- Education and outreach programs are typically cost-effective and can be implemented at some level at nominal cost.

Limitations

- Actual improvements in water quality or biological condition are likely to be marginal. Must pair with other management activities to achieve substantial improvements.

Permitting

- Typically, there is no permitting involved in public education. However, actions that require fill, excavation, or structural components may require permits, particularly if they occur near a wetland resource area or other protected resource.

Costs

- Costs to implement public education and outreach programs vary, depending on the approach and number of people or households targeted. However, they tend to be low compared to the costs of other management approaches.

3.2.4 No-Action Alternative

The no-action alternative at Bartlett Pond would entail avoidance of all the management actions presented in the previous sections. If implemented, this option would allow algae blooms to go unchecked and aquatic invasive species to potentially become established in Bartlett Pond while it fills with fine sediments and water quality continues to degrade. The volume of aquatic habitat would likely see reductions, recreational opportunities would decrease, and the aesthetic value of the pond would decline. The sheltered coves of Bartlett Pond would be at highest risk for significant decline in pond services provided because of the shallow water depths and adjacent beds of aggressive or invasive emergent vegetation.

These declines may be offset somewhat by conversion of land under water to other wetland types, which have ecological value and can provide some level of benefit to the quality of water entering Bartlett Pond from the surrounding shoreline and aquifer.

Applicability to Bartlett Pond

- This option targets minimization of monetary costs in the short term and does not address any management issues at Bartlett Pond.

Advantages

- No immediate monetary costs are associated with this option.

Limitations

- Does not improve any of the current or foreseeable future management challenges at Bartlett Pond.

Permitting

- No permitting is associated with this option.

Costs

- Although this option does have the advantage of requiring no direct monetary costs, it would likely lead to reduced aesthetic, recreational, water quality, water quantity, and ecological value.

- These, in turn, could result in economic costs related to reduced tourism and lowered waterfront property values, among other things.

- This option could also lead to increased future costs to remediate or rehabilitate the area, once conditions have further deteriorated.

4.0 NEXT STEPS

The following steps are recommended to address the management issues at Bartlett Pond:

1. Develop a long-term (typically five years) implementation plan for Bartlett Pond. This would include prioritization and scheduling of management actions, development of cost estimates, and identification of potential funding mechanisms for the management program.

2. Continue the Bartlett Pond and watershed data collection and analysis program in 2020 to better capture interannual variability and identify potential sources of pollutants. While the 2019 program provided a wealth of useful data, a number of key questions remain. The Town may desire to reduce or eliminate certain elements of the program while expanding others. For example, there may be limited value in continuing to sample for poly- and perfluoroalkyl substances (PFAS), which were widespread but only found at very low concentrations. Similarly, phthalates could probably be eliminated from the sampling program for now, as these substances were not detected in any samples. However, additional investigations upstream/upgradient from Bartlett Pond may be worthwhile in helping to better bracket groundwater and surface water sources of nutrients.

3. Permit and implement the Bartlett Pond long-term management program. Use results from the accompanying monitoring program to adjust or revise the management plan over time.

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6.0 GLOSSARY OF BASIC LIMNOLOGICAL TERMS

Abiotic: A term that refers to the nonliving components of an ecosystem (e.g., sunlight, physical and chemical characteristics).

Algae: Typically microscopic plants that may occur as single-celled organisms, colonies or filaments.

Anoxic: Greatly deficient in oxygen and unable to support most aquatic life forms.

Aquifer: A water-bearing layer of rock (including gravel and sand) that will yield water in usable quantity to a well or spring.

Aquatic plants: A term used to describe a broad group of plants typically found growing in water bodies. Most often applied to submerged, floating, and floating-leaved plants.

Bacteria: Typically single celled microorganisms multiply by simple division and occur in various forms. Cyanobacteria are a photosynthetic type of bacteria. Some bacteria may cause disease, but many do not and are necessary for fermentation, nitrogen fixation, and decomposition of organic matter.

Bathymetric Map: A map illustrating the bottom contours (topography) and depth of a lake or pond.

Best Management Practices: Any of a number of practices or treatment devices that reduce pollution in runoff via runoff treatment or source control.

Biomass: A term that refers to the weight of biological matter. Standing crop is the amount of biomass (e.g., fish or algae) in a body of water at a given time. Biomass is often measured in grams per square meter of surface.

Biovolume: Analogous to biomass but expressed in terms of volume rather than mass.

Biota: All living organisms in a given area.

Chlorophyll a: A pigment used by higher plants and certain algae for photosynthesis. Measuring the level of this pigment in surface water is one way of describing the productivity of a pond and determining its trophic state (see Eutrophic).

Cultural Eutrophication: The acceleration of the natural eutrophication process caused by human activities, occurring over decades as opposed to thousands of years.

Ecosystem: An interactive community of living organisms, together with the physical and chemical environment they inhabit.

Epilimnion: In a thermally stratified lake, refers to the warmer, well-mixed upper layer of water.

Erosion: A process of breakdown and movement of land surface that is often intensified by human disturbances.

Eutrophic: A trophic state (degree of eutrophication) in which a lake or pond is nutrient rich and sustains high levels of biological productivity. Dense macrophyte growth, fast sediment accumulation, frequent algae blooms, poor water transparency and periodic oxygen depletion in the hypolimnion are common characteristics of eutrophic lakes and ponds.

Eutrophication: The process, or set of processes, driven by nutrient, organic matter, and sediment addition to a pond that leads to increased biological production and decreased volume. The process occurs naturally in all lakes and ponds over thousands of years.

Exotic Species: Species of plants or animals that occur outside of their normal, indigenous ranges and environments. Populations of exotic species may expand rapidly and displace native populations if natural predators, herbivores, or parasites are absent or if conditions are more favorable for the growth of the exotic species than for native species.

Filamentous: A term used to refer to a type of algae that forms long filaments composed of individual cells.

Groundwater: Water found beneath the soil surface and saturating the layer at which it is located.

Habitat: The natural dwelling place of an animal or plant; the type of environment where a particular species is likely to be found.

Herbicide: Any of a class of chemical compounds that produce mortality in plants when applied in sufficient concentrations.

Hypolimnion: In a thermally stratified lake, refers to the cooler, poorly-mixed lower layer of water.

Hypoxic: Lacking sufficient dissolved oxygen to support all but the most tolerant species.

Infiltration Structures: Any of a number of structures used to treat runoff quality or control runoff quantity by infiltrating runoff into the ground. Includes infiltration trenches, dry wells, infiltration basins, and leaching catch basins.

Invasive: Spreading aggressively from the original site of introduction.

Limnology: The study of lakes.

Littoral Zone: The shallow, highly productive area along the shoreline of a lake or pond where rooted aquatic plants grow.

Macroinvertebrates: Aquatic insects, worms, clams, snails and other animals visible without aid of a microscope. They supply a major portion of fish diets and are important consumers of detritus and algae.

Macrophytes: Macroscopic vascular plants present in the littoral zone of lakes and ponds.

Morphology: A term that refers to the depth contours and dimensions (topographic features) of a lake or pond.

Nutrient Limitation: The limitation of growth imposed by the depletion of an essential nutrient.

Nutrients: Elements or chemicals required to sustain life, including nitrogen and phosphorus.

pH: An index derived from the inverse log of the hydrogen ion concentration that ranges from 0 to 14 indicating the relative acidity or alkalinity of a liquid.

Photosynthesis: The process by which plants use chlorophyll to convert carbon dioxide, water and sunlight to oxygen and cellular products (carbohydrates).

Phytoplankton: Algae that are buoyant and freely suspended in the water.

Pollutants: Elements and compounds occurring naturally or man-made introduced into the environment at levels in excess of the concentration of chemicals naturally occurring.

Secchi disk: A black and white or all white 20 cm disk attached to a cord used to measure water transparency. The disk is lowered into the water until it is no longer visible (Secchi depth). Secchi depth is generally proportional to the depth of light penetration sufficient to sustain algae growth.

Sediment: Topsoil, sand, minerals, and organic matter washed from the land into water, usually after rain or snowmelt. May also be generated by in-water production of organic matter (algae, plants, etc.).

Septic system: An individual wastewater treatment system that traditionally includes a septic tank for removing solids, and a leachfield for discharging the clarified wastewater to the ground.

Siltation: The process in which inorganic silt settles and accumulates at the bottom of a lake or pond.

Stormwater Runoff: Runoff generated as a result of precipitation or snowmelt.

Temperature Profile: A series of temperature measurements collected at incremental water depths from surface to bottom at a given location.

Thermal Stratification: The process by which a lake or pond forms several distinct thermal layers. The layers include a warmer well-mixed upper layer (epilimnion), a cooler, poorly mixed layer at the bottom (hypolimnion), and a middle layer (metalimnion) that separates the two.

TKN: Total Kjeldahl nitrogen, essentially the sum of ammonia nitrogen and organic forms of nitrogen.

TSS: Total suspended solids, a direct measure of all suspended solid materials in the water.

Turbidity: A measure of the light scattering properties of water; often used more generally to describe water clarity or the relative presence or absence of suspended materials in the water.

Vegetated Buffer: An undisturbed vegetated land area that separates an area of human activity from the adjacent water body; can be effective in reducing runoff velocities and volumes and the removal of sediment and pollutant from runoff.

Water Column: Water in a lake or pond between the interface with the atmosphere at the surface and the interface with the sediment at the bottom.

Water Quality: A term used to reference the general chemical and physical properties of water relative to the requirements of living organisms that depend upon that water.

Watershed: The surrounding land area that drains into a water body via surface runoff or groundwater recharge and discharge.

Zooplankton: Microscopic animals that float or are freely suspended in the water.

Appendix A

Laboratory Reports

Appendix B

Field Guide to Plants of Bartlett Pond

Appendix C

Bartlett Pond Modeling