MASSACHUSETTS
watershed·based plans

WATERSHED-BASED PLAN

Stockbridge Bowl

July 27, 2022

Prepared By:

Stockbridge Bowl Stewardship Commission
Town of Stockbridge
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Prepared For:

MassDEP
Commonwealth of Massachusetts
Department of Environmental Protection

Contents

Prior to finalizing your Watershed-based Plan, don't forget to right click on Table of Contents below and select "Update Field" to update the page numbers using the "Update entire table" option

Executive Summary

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Stockbridge Bowl is a robust ecosystem and beautiful natural resource for Stockbridge residents. Since the mid-20th century, the management of Stockbridge Bowl has been a priority for the Town and stakeholders. Management challenges have included nuisance conditions of aquatic plants including the non-native Eurasian watermilfoil (*Myriophyllum spicatum*), high sedimentation rates and infilling in certain areas of the lake and adjacent wetlands, and deep-water anoxia which causes water quality issues including internal nutrient loading, high cyanobacteria densities and infrequent cyanobacteria blooms. To date, many studies and projects have been commissioned and implemented to improve the ecological health of the lake as well as protecting the recreational usage by residents. Stockbridge Bowl is better off for this effort as all the data collected provides valuable information on the characteristics of the lake and watershed and provides data for comparison for future management strategies.

Management of the lake will continue to be a long-term endeavor to maintain and improve lake conditions, as historical issues are still present. For instance, *Myriophyllum spicatum* may occur in nuisance conditions in certain areas of the lake and persistent over-bottom anoxia promotes internal nutrient loading and other associated water quality issues (e.g., high cyanobacteria density). Sedimentation in certain areas of the lake needs to be addressed and maintained on a scheduled basis to control accumulation impacts on lake use and health.

The purpose of this WBP is to provide a cohesive overview of the current management issues that Stockbridge Bowl faces, list the stakeholders and their involvement, and to outline the various priorities, plans and approaches the stakeholders agree to address in a comprehensive manner regarding watershed management, ecological, and lake water quality concerns. Much of the data and plans used to construct this WBP come from the numerous historical reports conducted on Stockbridge Bowl and the current Town and stakeholder information provided at the time of its preparation.

A challenging aspect to compiling and synthesizing the various management recommendations for Stockbridge Bowl is reconciling or otherwise navigating between conflicting opinions offered by different organizations, consultancies, and individuals. A comprehensive WBP (lake management plan) considers the interests and priorities of all parties and forms an agreement so as a stakeholder group the parts can move the lake health management forward together.

The Town conducts annual limnological monitoring of Stockbridge Bowl as a primary component of lake and watershed management. For all the work collected to date, routine annual monitoring of Stockbridge Bowl was not conducted until 2020. It is essential to stay apprised of lake conditions to effectively manage them. Collecting monitoring data for Stockbridge Bowl has the immediate benefit of allowing informed decision-making and reducing uncertainty surrounding the causes of lake issues or outcomes of prospective management practices. For instance, when an event occurs, such as the August 2018 cyanobacteria bloom, having diagnostic information available from lake monitoring can help identify and detect potential blooms and appropriate actions can be taken. Additionally, regular annual monitoring provides the benefit of hindsight as there will certainly be need in the future to analyze particular ecological trends in Stockbridge Bowl, or to judge certain changes against baseline lake conditions. This is doubly true with the types of climate change that the Northeast US is projected to experience through the 21st century. These comparisons and analyses will only be possible with a robust dataset collected by routine annual monitoring.

A summary of specific management efforts or plans by stakeholders will go here.

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In summary, a comprehensive watershed-based lake management plan for Stockbridge Bowl will integrate three critical aspects of lake management:

1. *Watershed management* to control external loading of nutrients and other contaminants. Watershed management promotes long-term protection of the ecosystem resource.
2. *Shoreline and littoral zone management* to control habitat quality of the most important recreational areas of the lake. This includes, for example, identifying aquatic plant management strategies to reduce the abundance of invasive aquatic macrophytes that can pose a nuisance condition for aesthetics, impair recreational use, and reduce habitat, while minimizing the risk of adverse impacts to native vegetation and other biota. This also includes routine monitoring of sediment accumulation for management and removal in the near term and into the future.
3. *Lake management* to maintain quality conditions and habitat within the pelagic (deep water) zone of the lake. For example, managing anoxia to control internal nutrient loading and the abundance of potentially toxic cyanobacteria, ultimately reducing the risk of blooms.

Thus, many aspects of the Stockbridge Bowl ecosystem—watershed, in-lake water quality, phytoplankton, macrophyte community, protected species and habitat, fisheries, and recreational usage—are rightly incorporated into this comprehensive WBP.

Introduction

What is a Watershed-Based Plan?

Purpose & Need

The purpose of a Massachusetts Watershed-Based Plan (WBP) is to organize information about Massachusetts' watersheds and present the information in a format that will enhance the development and implementation of projects that will restore water quality and beneficial uses in the Commonwealth. The Massachusetts WBP follows the United States Environmental Protection Agency's (EPA's) recommended format for "nine-element" watershed plans, as described below.

All states are required to develop WBPs, but not all states have taken the same approach. Most states develop WBPs only for selected watersheds. Massachusetts Department of Environmental Protection's (MassDEP's) approach has been to develop a tool to support statewide development of WBPs so **that good projects in all areas of the state may be eligible for federal watershed implementation grant funds** under Section 319 of the Clean Water Act.

EPA guidelines promote the use of Section 319 funding for developing and implementing WBPs. WBPs are required for all projects implemented with Section 319 funds and are recommended for all watershed projects, whether they are designed to protect unimpaired waters, restore impaired waters, or both.

Watershed-Based Plan Outline

This WBP includes nine elements (a through i) in accordance with EPA Guidelines:

a) An **identification of the causes and sources** or groups of similar sources that will need to be controlled to achieve the load reductions estimated in this WBP and to achieve any other watershed goals identified in the WBP, as discussed in item (b) immediately below.

b) An **estimate of the load reductions** expected for the management measures described under paragraph (c) below, recognizing the natural variability and the difficulty in precisely predicting the performance of management measures over time.

c) A **description of the nonpoint source (NPS) management measures** needed to achieve the load reductions estimated under paragraph (b) above as well as to achieve other watershed goals identified in this WBP and an identification (using a map or a description) of the critical areas in which those measures will be needed to implement this plan.

d) An **estimate of the amounts of technical and financial assistance needed**, associated costs, and/or the sources and authorities that will be relied upon, to implement this plan. As sources of funding, States should consider the use of their Section 319 programs, State Revolving Funds, United States Department of Agriculture's (USDA's) Environmental Quality Incentives Program and Conservation Reserve Program, and other relevant federal, state, local, and private funds that may be available to assist in implementing this plan.

e) An **information/education component** that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the NPS management measures that will be implemented.

f) A **schedule for implementing the NPS management measures** identified in this plan that is reasonably expeditious.

g) A description of **interim, measurable milestones** for determining whether NPS management measures or other control actions are being implemented.

h) A set of **criteria to determine if loading reductions are being achieved** over time and substantial progress is being made toward attaining water quality standards and, if not, the criteria for determining whether this WBP needs to be revised or, if a NPS total maximum daily load (TMDL) has been established, whether the TMDL needs to be revised.

i) A **monitoring component** to evaluate the effectiveness of the implementation efforts over time measured against the criteria established under item (h) immediately above.

Project Partners and Stakeholder Input

Created "*… to conserve and protect Lake Mahkeenac and its watershed, to enhance the water quality, fishery, wildlife habitat and aesthetics of Lake Mahkeenac as a public recreational facility for today and for future generations while respecting the interests of property owners and the public, providing permanent stewardship to the lake ecosystem*," the Town voted to establish the Stockbridge Bowl Stewardship Commission (SBSC) (on xx/xx/xx). This body has been tasked to oversee the preparation of the WBP for Stockbridge Bowl. The SBSC acts as an advisory group to the Stockbridge Board of Selectmen. Its responsibilities include:

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1. Annual evaluation and maintenance of a comprehensive Lake Management Plan in response to changing environmental conditions.
2. Maintaining, sharing, and assimilating all ecosystem data collected from Stockbridge Bowl and its watershed including but not limited to water sampling data and analysis, invasive species data, aquatic plant sampling data, wildlife data including fish, birds, mollusks, crustaceans, and insects.
3. Routinely communicating with expert limnologists, biologists, lake managers and other experts contracted with the Town to determine recommended projects and actions in response to environmental conditions and stakeholder concerns to preserve the health of the lake, watershed and ecosystem.
4. Provide public information and educational resources to the residents of Stockbridge regarding the status of the Stockbridge Bowl and its watershed to promote community responsibility and involvement.
5. Maintain communications with the Town Administrator, all pertinent Boards and Committees such as the Board of Selectmen, Parks and Recreation Commission, Water and Sewer Commission, Conservation Commission, camps, non-profit organizations, boat clubs and community groups as appropriate, etc.
6. The voting body of the SBSC shall elect a Chairperson on an annual basis and determine their meeting schedule which shall be no less than twice a month from March through October and no less than once a month from November through February.

7. Annual budget, subject to approval by the Selectmen. The Selectmen are responsible for presenting the budget to the Finance Committee and for presenting the motion for the budget appropriation to Town Meeting.

The SBSC consists of the following seven voting members (*current members in parenthesis*):

1. Stockbridge Select Board - (*Patrick White*)
2. Board of Health – (*Charles Kenny*)
3. Water and Sewer Department - (*Mike Buffoni*)
4. Conservation Commission – (*Sally Underwood-Miller*)
5. SBA - (*Michael Nathan*)
6. Water and Sewer Commission – (*John Loiodice*)
7. Stockbridge Sportsmen's Club – (*Roxanne McCaffrey*)

And two non-voting members:

8. Stockbridge Harbormaster – (*Gary Kleinerman*)
9. Tri-Town Health Department - (*Jim Wilusz*)

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The SBSC reached out to other stakeholders for information and feedback including:

1. The Highway Department regarding road salts (Hugh Page)
2. Parks and Recreation Commission?
3. Camp Mah-Kee-Nac?
4. Tanglewood?
5. Homeowners and residents?

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Data Sources

This WBP was developed using the framework and data sources provided by MassDEP's WBP Tool. In addition to this resource, Stockbridge has a rich history of monitoring, studies, and projects that collectively characterize the structure, function, ecology, community, and environmental issues of Stockbridge Bowl and its watershed. These historical reports are numerous and in chronological order include:

1. Ludlam, S.D., Hutchison, K.S., and Henderson. G.E. 1971. Water Resources Research Center, University of Massachusetts, Amherst, Massachusetts: "The Limnology of Stockbridge Bowl, Stockbridge, Massachusetts"
2. Department of the Army New England Division, Corps of Engineers, 1981: "Stockbridge Bowl Dam MA 00022 Phase I Inspection Report, National Dam Inspection Program"
3. Lycott Environmental Research, Inc., 1991: "Stockbridge Bowl Diagnostic/Feasibility Study Report"
4. Wetzel, R. G., 1994: "Letter to Stockbridge Bowl Association"
5. Fugro East, Inc., 1996: "Lake and Watershed Management Plan for Stockbridge Bowl, Stockbridge, Massachusetts"
6. ENSR, 1999: "Memorandum: Sediment Analysis"

7. ENSR, 1999: “Stockbridge Bowl Snail Survey”
8. Coote, T. & Roeder, D., 2000: “The Relative Abundance of *Marstonia lustrica* Pilsbry and its Movements in Stockbridge Bowl, Stockbridge Massachusetts, September-December, 1999”
9. BRPC/SBA/Town of Stockbridge, 2012: “Stockbridge Bowl Watershed Survey”
10. GZA GeoEnvironmental, Inc., 2014: “Preliminary Design Report for the Stockbridge Bowl Diversion Pipe Channel Dredging Project”
11. GZA GeoEnvironmental, Inc., 2015 & 2016: “*Marstonia lustrica* Habitat Assessment—Survey Results & Report”
12. Town of Stockbridge & BRPC, 2017: “Stockbridge Bowl Watershed Assessment”
13. Massachusetts Division of Fisheries and Wildlife, 2018: “Response to Notice of Intent for the 2019 application of fluridone”
14. Wagner, K., Water Resource Services, Inc., 2019: “Letter to the Board of Health, Stockbridge, MA”
15. GZA, 2020: “Stockbridge Bowl 2020 Limnology Update”
16. Otter Environmental Services, 2020: “Report on the Distribution of Invasive Plants and *Marstonia lustrica* in Stockbridge Bowl”
17. GZA, 2022: “Stockbridge Bowl 2021 Limnology Update”

Much of this information is useful, but some is priority while other is tangential to the scope of this WBP, outdated, or in disagreement with subsequent empirical data and informed opinion. To assist with the prioritization and interpretation of these documents and the data and information they contain, the Town of Stockbridge commissioned a summary memorandum produced by GZA GeoEnvironmental in 2021 (*Stockbridge Bowl Watershed Management Plan Memorandum*). The purpose of this memorandum was to provide an historical overview of the reports conducted to through 2020 on the Stockbridge Bowl limnology and management of the lake and watershed in preparation for this WBP.

Summary of Completed Work

Out of the studies and projects listed above, the following were found to be most useful for characterizing Stockbridge Bowl and diagnosing its current issues:

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Ludlam, S.D., Hutchison, K.S., and Henderson. G.E. 1971. Water Resources Research Center, University of Massachusetts, Amherst, Massachusetts: “The Limnology of Stockbridge Bowl, Stockbridge, Massachusetts”

As implied by the title, this paper discusses the basic limnology of the lake as well as providing a review of previous work completed on the lake and provides historical insights into the characteristic of the lake and management strategies implemented up to the time of the publication of the document. The paper provides a limnological assessment of data collected from 1971-1972. The lake showed many of the same characteristics that it does today with stratification increasing through the summer, loss of dissolved oxygen in the hypolimnion, hardwater condition of the lake, the presence of cyanobacteria (*Oscillatoria rubescens*), and dense beds of Eurasian watermilfoil and Chara. In addition, the paper discusses how the lake has changed over the previous 25 years shifting to a more eutrophic status due in-part to increased development in the watershed and discusses the use of herbicides to manage aquatic plant growth with limited success, and the significant decrease in the snail *Viviparous georgianus*. The paper does not offer any management strategies / recommendations but does surmise that in-lake conditions may have a delayed response to alterations in the watershed, a shift in the diatom community may indicate significant enrichment of the lake, and the aquatic plant community plays a significant role in the dynamics of the lake ecosystem.

Lycott Environmental Research, Inc., 1991: "Stockbridge Bowl Diagnostic/Feasibility Study Report"

The Lycott study was conducted from 1988-1989. Two major problems were identified: 1) Excessive macrophyte growth present in the lake, and 2) hypolimnetic oxygen depletion. The first issue was due to nuisance densities of *Myriophyllum spicatum*, Eurasian watermilfoil. The densities reported had negative impacts on recreational activities, navigation, and caused habitat loss for fish spawning. The second issue, oxygen depletion—termed anoxia— in the deep-water portions of the lake contributed to cold-water fishery habitat loss and release of the nutrient phosphorus from lake sediments. Bloom conditions of the cyanobacteria *Planktothrix* (*Oscillatoria*) *rubescens* were recorded in November 1988, likely resulting from elevated phosphorus concentrations that accumulated in the hypolimnion through the summer. Lycott management recommendations to control *Myriophyllum spicatum* density included implementing a six-foot winter drawdown (requiring modifications to the outlet channel to allow this) and intensified plant harvesting during the summer months (using the plant cutter that the Town of Stockbridge owned and maintained). Other measures that were considered included the use of benthic barriers, biological control methods (via grass carp or weevil), dredging to remove areas of accumulated sedimentation and to deepen these areas, herbicide treatments (fluridone), hydroraking, and mechanical harvesting. To manage deep water anoxia, hypolimnetic aeration was recommended. Other measures considered included artificial circulation, dredging, hypolimnetic withdrawal, phosphorus inactivation (alum treatment application), and sediment oxidation.

Fugro East, Inc., 1996: "Lake and Watershed Management Plan for Stockbridge Bowl, Stockbridge, Massachusetts"

Similar to the Lycott study, Fugro East recognized two challenges for Stockbridge Bowl: nuisance *Myriophyllum* spicatum densities and water quality conditions caused by persistent deep-water anoxia and subsequent phosphorus release from lake sediments. Controlling the *M. spicatum* growth was determined to be the primary management objective and recommendations were made to conduct four to eight feet winter drawdowns, with outlet modifications to make this feasible. It was noted that permitting for such a drawdown would likely be complicated by the presence of two protected snail species (*Valvata sincera and Marstonia* (formerly *Pyrgulopsis*) *lustrica*, both which occupy shallow, *Chara* and *Najas*-dominated areas) as well as amphibian and reptile species that could be adversely affected. It was pointed out that the snails would be as impacted by *Myriophyllum spicatum* expansion as they would be by the potential effects of conducting a drawdown, and short-term losses should be weighed against long-term gains. Continued mechanical harvesting was recommended to remove *M. spicatum* growth beyond the depth of drawdown control (four to eight feet). Other *M. spicatum* management options considered in this report included the use of dyes, biological controls, dredging, benthic barriers, and herbicide use (fluridone). Sedimentation control was recommended by conducting sediment removal (dredging) at the outlet to facilitate aquatic plant control through winter drawdowns, and sediment entrainment via improving retention capacity near the tributaries. Aeration was recommended to improve water quality, increase deep water oxygenation, expand cold-water fish habitat, and reduce the occurrence of algae blooms. Another management option that was considered for improving water quality was phosphorus inactivation (alum treatment application).

ENSR, 1999: "Stockbridge Bowl Snail Survey"

This study served to characterize populations of two protected snail species, *Valvata sincera* and *Marstonia lustrica* in order to assess the potential impact of a deep, five-to-eight-foot winter drawdown necessary for *Myriophyllum spicatum* control. The transect surveys conducted in August and September of 1998 around the perimeter of the lake found only one of the endangered snail species, *Marstonia lustrica*. This led ENSR to believe that *Valvata sincera* are likely now absent from the lake. *Marstonia lustrica* were found in the southwest and northwest corners of the lake. The greatest abundance of *Marstonia lustrica* occurred in the northwest corner (in sum, 38 individuals were collected in the northwest vs. 8 individuals collected in the southwest). Half of the sites that contained *Myriophyllum lustrica* were *Chara* dominated, leading the author of the study to conclude that *Chara* beds are the preferred habitat for this snail. Because *Chara* is a macro-alga that produces 'seed-like structures', it is likely to recover from drawdown exposure. ENSR strongly believed that drawdown impacts on *M. lustrica* would be minimal, and the risks were outweighed by the long-term benefit of increasing the snail habitat (i.e., more extensive *Chara* beds) by controlling the growth of *Myriophyllum spicatum* and the subsequent minimization of muck substrate accumulation.

Coote, T. & Roeder, D., 2000: "The Relative Abundance of Marstonia lustrica Pilsbry and its Movements in Stockbridge Bowl, Stockbridge Massachusetts, September-December, 1999"

The goal of this research effort was to determine locations of ***Marstonia lustrica*** within Stockbridge Bowl and to identify winter migration patterns which would be important for drawdown management purposes. Samples were collected from September to December of 1999 along the transects established by the ENSR 1999 study. *M. lustrica* was found in the northwest corner of the lake, in front of the outlet in the southwest corner, and also in the southeast corner of the lake. Snail counts dropped between October and December. Also, it was noted that snails were not necessarily located in *Chara* beds, but in locations with somewhat sparse *Chara* growth. Collected data did not support the hypothesis that snails migrate into deeper water during seasonal progression from fall to winter, but it was noted that the number of snails collected was related to water temperature.

BRPC/SBA/Town of Stockbridge, 2012: "Stockbridge Bowl Watershed Survey"

The Berkshire Regional Planning Commission (BRPC), the Stockbridge Bowl Association (SBA) and the Town conducted field work from 2010 to 2012 to evaluate land uses within the Stockbridge Bowl watershed that could potentially affect sediment and phosphorus loading of the lake. It provided a brief summary of work conducted under the 2009 s.319 Nonpoint Source Pollution Grant, including:

1. Final design and installation of the outlet diversion pipe
2. Continuation of plant harvesting
3. Identification of nonpoint pollution sources within watershed
4. Design of management practices for a high priority nonpoint source pollution site
5. Public outreach to educate and address potential nonpoint pollution sources

This survey provided a Watershed Action Plan that outlined actionable items to be conducted lake wide as well as at specific shoreline locations:

- Lake wide high priority actions:
  - Inquire whether the Housatonic Valley Association would conduct stormwater monitoring at tributary streams.
  - Work with landowners to minimize runoff from residential properties into the lake by conducting "Rainy Day Survey workshops".
  - Produce a brochure that informs residents of Town policies and regulations regarding lakefront land use (up to 150' from lake shore).
  - Conduct pilot testing of runoff control measures at sand beach sites.
- Northern shore high priority actions:
  - Divert flow from the Kripalu parking lot into tributary #1.
  - Replace the undersized culvert on the Bullards Crossing trail to prevent erosion during peak flows.
- Lily Brook high priority actions:
  - Establish a technical team to conduct a comprehensive Lily Brook watershed study.
  - Secure funding for this study.
- East Shoreline high priority actions:
  - Implement design improvements to the Stockbridge Town Beach.
  - Armor areas of Mahkeenac Road roadbed that are experiencing erosion.
  - Work with landowners along Mahkeenac Road to reduce runoff from their properties.
  - Investigate a white PVC discharge pipe identified during a survey.
- West Shoreline high priority actions:
  - Design and construct stormwater runoff controls at the public boat launch.
  - Work with landowners that have exposed soils adjacent to shoreline to reduce erosion and runoff.
  - Remove a small stand of phragmites.

GZA GeoEnvironmental, Inc., 2014: "Preliminary Design Report for the Stockbridge Bowl Diversion Pipe Channel Dredging Project"

This report outlined the feasibility and approach for dredging the outlet channel in order to allow for deep winter drawdown to a depth of 5.5 feet, as was approved for the Town of Stockbridge by the MassDEP. A secondary purpose for this dredging was to minimize sediment transport into the diversion drain pipes (constructed in 2012) during lake drawdown. Average water depth for the outlet channel was two to three feet, with a maximum of six feet. Measurements indicated that "hard" bottom (either compacted glacial silts, clays, or bedrock) was at least thirteen feet below water surface. The study proposed a dredging depth of seven feet, requiring the removal of an estimated 20,000 cubic yards of sediments by hydraulic dredging. Sediments within the outlet channel were highly organic, and marl deposits were found between organic layers at a few locations. Sediments were analyzed for contaminants such as metals, PAHs, VOCs, PCBs, and EPHs. Concentrations for these contaminants were compared to the most stringent MCP regulations (S-1 soil and GW-1 groundwater). Two out of eleven samples had slightly higher arsenic levels than S-1 soil and GW-1 groundwater MCP values. Whether or not these slight exceedances would have any impact on sediment disposal at the proposed disposal site (the Bullard Woods area owned by the SBA), was not mentioned. The report discussed the importance of detailed planning and evaluation of potential winter drawdown scenarios. Several key findings included:

- Timing drawdown to winter elevation (especially for biota that over-winter relative to lake shoreline).
- Stability of winter water level (especially for biota that over-winter relative to lake shoreline).
- Rate and timing of refill while allowing a downstream passing flow.
- Other potential effects of exposing the shallow lake bottom during winter.

GZA GeoEnvironmental, Inc., 2015 & 2016: "Marstonia lustrica Habitat Assessment—Survey Results & Report"

In 2012, the Town of Stockbridge installed a bypass beneath the gas and sewer lines to allow for increased winter drawdown depth, pending further dredging of the outlet channel. Due to concerns expressed by the Massachusetts Natural Heritage and Endangered Species Program (MA NHESP), the Town was required to complete a monitoring program to determine the potential impacts of a deeper winter drawdown on *Marstonia lustrica*, a state-listed endangered species. GZA completed the first two years of the three-year baseline study, to be followed by a subsequent three-year post-impact study following dredging and 5.5 ft winter drawdown (which was subject to approval). In mid-September of 2015, thirteen snail species were found in the transect surveys conducted around the lake basin and outlet channel, including highly decomposed shells of Valvata sincera. Seventy-eight *Marstonia lustrica* individuals were identified, only 3 of which were living. These were located in the northwest corner of the lake and western shore. The low number of viable *M. lustrica* was noted but was likely due to the timing of the survey, which corresponded to the end of the adult life cycle of this annual species. No living *M. lustrica* were found in the southwestern outlet (where the dredging was being proposed), but forty-four shells were collected close to the mouth of the outlet. The 2016 survey was conducted from August to November and managed to collect more viable specimens of *M. lustrica*. Twenty-nine viable and seventy-eight non-viable individuals were collected in the main basin. Of the twenty-nine viable snails, twenty-two were found at the two-to-four-foot depth range. Eleven viable and one nonviable individual was collected within the outlet. The areas of highest *M. lustrica* density overlapped with those areas identified in the 2015 study, and four populations were identified: three in the lake basin and one in the upper half of the outlet.

Town of Stockbridge & BRPC, 2017: "Stockbridge Bowl Watershed Assessment"

The goal of this project, conducted from 2015 to 2017, was to identify sources in the watershed transporting sediment into Stockbridge Bowl and to recommend best management practices (BMPs) to reduce the accumulation of sediment into the lake. Fieldwork and data analysis was conducted by Inter-Fluve, Inc., though the report was prepared by the Town and the BRPC. The project concentrated specifically on the Lily Brook watershed and sub-watersheds to the south of the lake (e.g., Duck Pond Brook). Though sediment loading from the Marsh Brook sub-watershed was evaluated, it was determined that appreciable loading from this source was unlikely. It was concluded that sediment transport and accumulation into Stockbridge Bowl is a largely natural process due to a combination of steep topography and increased water level from historical damming. BMPs focusing on sites located within the larger watershed, such as those measures outlined in the 2012

BRPC/SBA/Town of Stockbridge Report, were predicted to be mostly ineffectual for sedimentation management, though the SBA chose three high priority sites for BMP designs. It was recommended that the greatest improvement would come from dredging the Lily Brook holding pond area and adjacent shoal within the lake basin to remove accumulated sediment, prevent transport of fines into the lake during storm events, and increase the storage capacity of the holding pond for future sediment flux. This would not be a permanent solution and this sediment removal process would have to be repeated approximately every decade or so. A further recommendation included an evaluation of road sand contributions from the causeway separating the Lily Brook holding pond area from the lake basin, as well as the north shore area.

GZA, 2020: "Stockbridge Bowl 2020 Limnology Update"

GZA conducted a lake and tributary monitoring program for the 2020 spring, summer, and autumn seasons following a single sampling event in 2019 to understand the Stockbridge Bowl limnology, water quality, and ecology following a cyanobacteria bloom that occurred in August 2018 following high rains and windstorm events. The report characterized the seasonal progression of strong thermal stratification, persistent deep-water anoxia, increased deep water phosphorus and iron concentrations resulting from anaerobic respiration processes, followed by the autumn lake turnover. In addition to physical and chemical characterization, the report importantly monitored upper and lower water column phytoplankton data. These data demonstrated that the overall community is dominated by cyanobacteria, and in particular *Planktothrix rubescens*, one of the organisms that caused the 2018 bloom. Due to the seasonal dynamics of *P. rubescens* and robust community of cyanobacteria that sits at the boundary of the nutrient-rich, anoxic hypolimnion, ECS identified the risk of future algae blooms, likely to occur in autumn or following extreme weather events as was the case in 2018. The report recommended further research to determine whether cyanobacteria density could be controlled when the populations are concentrated in the deep strata to reduce the risk of a toxic bloom during Fall turnover. A successful strategy would be focused on cyanobacteria while minimizing the risk of impacts to other biota or ecosystem structure and function.

Otter Environmental Services, 2020: "Report on the Distribution of Invasive Plants and Marstonia lustrica in Stockbridge Bowl"

Otter Environmental conducted a plant and snail survey at the end of July (27th and 28th) 2020. Limited sampling was conducted in the southern end of the lake off the town beach area. Despite limited sampling, the report states that 'significant numbers' of *Marstonia lustrica* were found at an average density of 0.25 individuals per square meter. The plant survey found no extensive beds of invasive plants except for a small patch of *Myriophyllum spicatum* at the northern end of the lake, and occurrence of *Najas minor*. Notably, only a single individual of *Potomageton crispus* (curly-leaf pondweed) was identified.

GZA, 2022: "Stockbridge Bowl 2021 Limnology Update"

Though this was not included in the *Stockbridge Bowl Watershed Management Plan Memorandum* (which included sources prior to 2021), this report summarizes the follow-up monitoring for Stockbridge Bowl and its inlets for the 2021 season. It adds to the dataset established in 2020, confirms many of the observations made in the prior year, and further explores the question of internal vs. external (i.e., via internal loading vs. watershed loading) phosphorus enrichment; suggesting that phosphorus dynamics recorded from spring to autumn may be causing internal loading during persistent anoxia as a likely mechanism.

Element A: Identify Causes of Impairment & Pollution Sources

Element A: Identify the causes and sources or groups of similar sources that need to be controlled to achieve the necessary pollutant load reductions estimated in the watershed based plan (WBP).

General Watershed Information

Table A-1: General Watershed Information

Watershed Name (Assessment Unit ID):	Stockbridge Bowl (MA21105)
Major Basin:	HOUSATONIC
Watershed Area (within MA):	7317.3 (ac)
Water Body Size:	384 (ac)

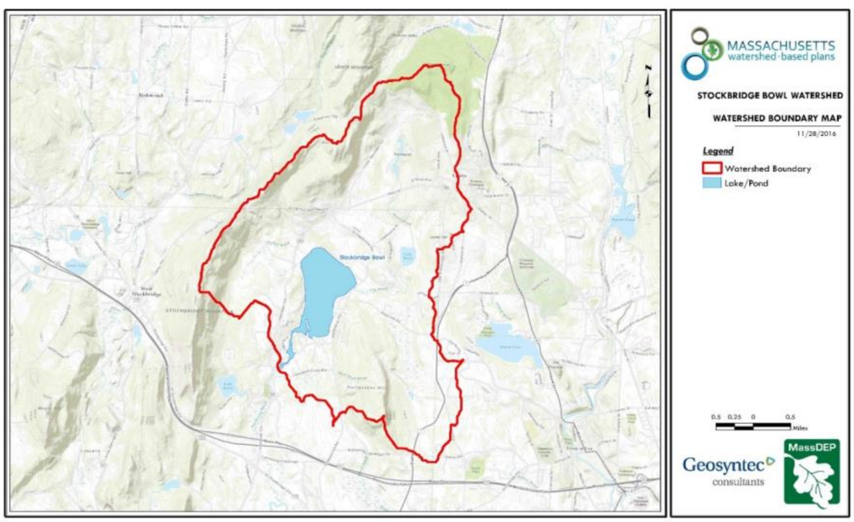


Figure A-1: Watershed Boundary Map (MassGIS, 1999; MassGIS, 2001; USGS, 2016)

Ctrl + Click on the map to view a full sized image in your web browser.

General watershed information:

Stockbridge Bowl is a great pond located in Berkshire County of Western Massachusetts. The lake is a highly valued resource that provides recreation to both full time and part time residents as well as to the numerous visitors who come for the local summer camps and day schools, Tanglewood musical events, fishing and boating events, and other special events such as the Great Josh Billings Triathlon.

Stockbridge Bowl is located in the Town of Stockbridge, Massachusetts and is situated between mountains to the east (West Stockbridge and Lenox) and to the southwest (Rattlesnake Hill) of the lake. Stockbridge Bowl has a surface area of 398 acres which includes the long (approximate 4,000 foot) and narrow outlet channel (Pagenstecher Reach) at the southwestern end of the lake. According to Ludlam et al., the lake level has been controlled by dams since the early 1800's, and currently the lake level is controlled by a spillway. An additional weir (Barker Dam) is present further south of the spillway that releases water by manually turning a gate valve. The valve is opened when water levels drop below the spillway elevation and allows water to leave the lake and continue to feed the outlet stream, Larrywaug Brook. This outlet structure is used for lake drawdown during the winter. Pagenstecher Reach is shallow and macrophytes cover its entire stretch. A utility transmission lines run perpendicular (west to east) through the channel. A submerged earthen berm was built to protect the utility lines which limits the depth of winter drawdown to 1.9 feet. Winter drawdown has been used as a management technique for decades to control macrophyte growth in the main body of the lake. The earthen berm may promote sedimentation on the lake side (north side) of the dam and restrict water movement to some degree through the channel.

The Stockbridge Bowl watershed is located in the Housatonic watershed basin and is approximately 28.2 square kilometers (7,068 acres), not including the Stockbridge Bowl surface area as estimated from the MA GIS 2005 land use data (BRPC Stockbridge Bowl Watershed Assessment dated June 2012). The watershed includes the towns of Stockbridge, Lee, Lenox, and Richmond. The watershed drains into the lake through a variety of streams and groundwater sources.

The watershed can be broken down into nine primary sub basins (Stockbridge Bowl Watershed Assessment, 2014-04/604, dated August 2017). Of primary importance are the Lily Brook and Marsh Brook subbasins. These watersheds account for approximately 58% of the lake's watershed. Lily Brook enters the lake on the northeastern shoreline and feeds water from both the northeast (Marsh Brook) and southeast (Lily Brook) portions of the watershed. According to the BRPC 604(b) watershed report dated August 2017, Marsh Brook and Lily Brook were named the main potential sources of sediment loading to the lake.

Lily Brook enters the lake through two culvert pipes that direct water under Mahkeenac Road. Before entering the lake, Lily Brook widens into a holding pond. This area captures sediments from the brook before entering the lake. In the past the holding area has been routinely dredged to remove accumulating sediments from the holding area. However, the holding area has not been recently dredged and the accumulating sediments have been transported from the brook into the lake (BRPC, Stockbridge Bowl Watershed Assessment, 2014-04/604, dated August 2017).

Shadow Brook (northwest watershed) and Duck Pond Brook (south / southeast watershed, Beachwood area) are also important streams in the watershed. However, these streams are prone to drying up during the summer months and then only run during storm events while Lily Brook runs all year.

The watershed is characterized by light to medium density residential housing present along the western, southern, and southeastern portions of the lake shoreline. According to the 2020 MA GIS data, there are approximately 1,300 properties in the Stockbridge Bowl watershed. The northern portion of the immediate lake shoreline is occupied by large tracts of land including the lake boat launch and parking area, the Kripalu Center for Yoga and Health, the Berkshire County Day School, Camp Mahkeenac, and Tanglewood. The majority of the eastern shoreline, southern shoreline, and a portion of the western shorelines are connected to sewer. We assume the remaining properties use septic systems.

The geology in the watershed is very influential on the processes that occur within the lake and has been well documented in prior reports (Lycott 1991, BRPC 2012 and 2017). The watershed bedrock is comprised of calcareous rock consisting of calcitic limestones, quartz, dolomites, and marble derived from old sedimentary rocks from Lower Cambrian metamorphosed sandstones (Dale, N. The Lime Belt of Massachusetts and Parts of Eastern New York and Western Connecticut, 1923). The overlying surficial geology is primarily comprised of glacial till and are classified as loamy soils. The topography of the watershed promotes runoff as the lake is nestled between mountains on either side of the lake which presents steep slope gradients in many areas. The weathering of the surrounding calcareous and magnesium bedrock, infiltration of groundwater, and runoff potential supplies Stockbridge Bowl with high concentrations of calcium and magnesium creating a 'hard water' lake system.

MassDEP Water Quality Assessment Report and TMDL Review

The following reports are available:

- Housatonic River Watershed 2002 Water Quality Assessment Report
- STOCKBRIDGE BOWL DIAGNOSTIC FEASIBILITY STUDY REPORT

The section below summarizes the findings of any available Water Quality Assessment Report and/or TMDL that relate to water quality and water quality impairments. Select excerpts from these documents relating to the water quality in the watershed are included below (note: relevant information is included directly from these documents for informational purposes and has not been modified).

Housatonic River Watershed 2002 Water Quality Assessment Report (MA21105 - Stockbridge Bowl)
The non-native aquatic macrophytes Myriophyllum spicatum was documented in Stockbridge Bowl during the 1997 DWM synoptic survey (Kennedy and Weinstein 2000). The Aquatic Life Use is assessed as impaired because of the presence of the non-native aquatic macrophyte. The Town of Stockbridge has been trying to draw down water levels in the Bowl for five years for management of aquatic plant species. In one year, leaves clogged the outlet allowing on a tiny trickle to Larrywaug Brook. In October 2005, heavy rains resulted in high water levels, so the lake could not be drawn down. Fish from Stockbridge Bowl were collected by DWM in 1983 and fish tissue samples were analyzed for dioxins (Maietta

undated). No site-specific fish consumption advisory was issued for this water body, so the Fish Consumption Use is not assessed.

There are nine bathing beaches on the shores of Stockbridge Bowl. The water at the beaches was tested weekly for E. coli bacteria in 2001, 2002, 2003, and 2004 (MA DPH 2002, 2003, 2004, 2005a).
Beachwood Association (n=53) no postings
Berkshire Country Day School (n=76) no postings
Camp Mahkeenac (n=82) no postings
Kripalu (n=48) three exceedances, no postings
Sports Day camp (n=35) two exceedances, no postings
Tanglewood (n=42) no postings
Town Beach (n=48) one exceedance, no postings
White Pines (n=38) no postings
Mah-Kee-Nac Shores (n=35) no postings
Currently, there is uncertainty associated with the accurate reporting of freshwater beach closure information to the Massachusetts DPH, which is required as part of the Beaches Bill. Therefore, no Primary Contact Recreational Use assessments (either support or impairment) decisions are being made using Beaches Bill data for this waterbody.

Report Recommendations:
NA

Historical and current Technical Memoranda (TM) produced by the MassDEP Watershed Planning Program are available here: Water Quality Technical Memoranda | Mass.gov and are organized by major watersheds in Massachusetts. Most of these TMs present the water chemistry and biological sampling results of WPP monitoring surveys. The TMs pertaining primarily to biological information (e.g., benthic macroinvertebrates, periphyton, fish populations) contain biological data and metrics that are currently not reported elsewhere. The data contained in the water quality TMs are also provided on the "Data" page (Water Quality Monitoring Program Data | Mass.gov). Many of these TMs have helped inform Clean Water Act 305(b) assessment and 303(d) listing decisions.

The Mass DEP Division of Watershed Management (DWM) produced three technical memoranda regarding water quality, fish population, and benthic macroinvertebrate bioassessment for the Housatonic River Watershed using 2007 survey data (CN 289.1 2013; CN 289.3 2013; CN 289.4 2014). While these data were not specific to Stockbridge Bowl, water quality and biomonitoring assessment was conducted on the outlet stream, Larrywaug Brook. From a bioassessment standpoint, Larrywaug Brook's degree of impact was "slightly impaired". Various physical and chemical parameters collected in the water quality survey were all within normal range and did not indicate problematic conditions. Mean 2007 *E. coli* in Larrywaug Brook was 24 CFU/100 mL (n= 5).

Literature review information:
In addition to the 2014 reports, Mass DEP has conducted several site inspections of Stockbridge Bowl to monitor the lake for several variables including nutrients, dissolved oxygen, aquatic plants, and zebra mussels. Two main reports available from the MassDEP are:

1. Housatonic River Watershed 2002 Water Quality Assessment Report (MA21105 – Stockbridge Bowl)

2. Zebra Mussel Phase I Assessment: Physical, Chemical, and Biological Evaluation of 20 Lakes and the Housatonic River in Berkshire County, Massachusetts. 2009.

The 2002 Housatonic River Watershed Water Quality Assessment Report formed the basis for the decisions made as to whether a waterbody was considered impaired for the 2004 Integrated List of Waters report for the State. At that time, Stockbridge Bowl was listed as impaired for Aquatic Life due to the presence of non-native aquatic plant life, specifically *Myriophyllum spicatum*. The lake was a given a designation of 4c in the 2004 Integrated Report, meaning the lake was impaired by a pollutant not requiring a TMDL. The other four categories of impairment were not assessed at the time of the report for Stockbridge Bowl. Subsequent evaluations have required a TMDL for mercury found in fish tissue and low dissolved oxygen concentrations as described in the section below. Currently, the 2018/2020 draft of the integrated List of Waters report describes the lake as a category 5 due to the low dissolved oxygen concentrations requiring a TMDL.

The Phase I Zebra Mussel study conducted in 2009 sought to identify those lakes that posed a higher risk of zebra mussel infestation in Berkshire County. The study included measurements for chemistry and dissolved oxygen concentrations as well as biological information including the presence or absence of zebra mussels. At the time of the 2009 study, dissolved concentrations in the lake fell below 1.0 mg/l at 7.5 meters depth on September 18, 2009. The report discussion on Stockbridge Bowl provides a description of low water clarity due to the presence of high algal counts and a Secchi disk depth of 3.4 m or 11 ft. Dominant aquatic plan species were *Chara*, *Vallisneria americana*, *Najas* spp., *Potamogeton amplifolius*, *Myriophyllum spicatum*, and *Ærataphyllum demersum*. It was also noted that the outlet channel was heavily overgrown with aquatic plants especially with *Nuphar* and *Nymphaea* species. The chemistry collected at that time measured calcium (32-34 mg/l), pH (8.35-8.45 S. U.), and alkalinity (122.0 mg/l). The lake was and still is considered a high risk for attracting and supporting zebra mussel populations.

Additional water quality assessments of the lake and watershed have been conducted by consultants hired by the BRPC, the Town, or the SBA. Several of the main studies are listed below.

- Ludlam, S.D., Hutchison, K.S., and Henderson. G.E. 1971. The Limnology of Stockbridge Bowl, Stockbridge, Massachusetts.
- Lycott Environmental Research, Inc., 1991: “Stockbridge Bowl Diagnostic/Feasibility Study Report
- Fugro East, Inc., 1996: “Lake and Watershed Management Plan for Stockbridge Bowl, Stockbridge, Massachusetts”
- BRPC/SBA/Town of Stockbridge, 2012: “Stockbridge Bowl Watershed Survey”
- Town of Stockbridge & BRPC, 2017: “Stockbridge Bowl Watershed Assessment”
- Massachusetts Division of Fisheries and Wildlife, 2018: “Response to Notice of Intent for the 2019 Application of Fluridone”
- GZA, 2020: “Stockbridge 2020 Monitoring Report”
- GZA, 2022: “Stockbridge 2021 Monitoring Report”

Most of these reports indicate similar trends of depleted dissolved oxygen conditions below the thermocline, moderate-high total phosphorus levels due to internal nutrient loading, a presence of cyanobacteria in the water column, and a littoral zone covered by aquatic macrophytes that include *Chara* and *Myriophyllum spicatum*. The hardwater characteristic of the lake is a primary factor in the lake dynamics. To generalize these studies, the primary areas of concern with Stockbridge Bowl are from issues within the lake such as internal nutrient loading and littoral zone coverage by aquatic plants. While watershed management is an important element of the lake management plan, the steps to address the in-lake issues are key to maintaining and improving the quality of the lake.

Biological Components of the Lake Ecosystem:

Macrophytes. Stockbridge Bowl has struggled with nuisance macrophyte management since the 1960s when herbicide application was implemented. Mechanical harvesting began in the 1970s, which is when Eurasian watermilfoil (*Myriophyllum spicatum*) was identified as a dominant and problematic plant species in the lake. *M. spicatum* dominance has persisted, though its noticeable reduction (particularly in 2020) has called into question its priority as a management target. Other plant species occur in nuisance conditions, notably curly-leaf pondweed (*Potamogeton crispus*). Such nuisance conditions hinder navigation and recreational use of the outlet channel.

Chara beds are a common feature in Stockbridge Bowl, particularly between Kwuniikwat Island and the outlet channel. These beds were thought to be vital for endangered snail habitat (*Marstonia lustrica*), but *M. lustrica* occurrence and abundance is more likely a function of plant density and substrate type (Coote & Roeder 2000; GZA 2015 & 2016). Nonetheless, *Chara* is a low-growing, beneficial native macro-algae that provides valuable habitat and likely performs important ecosystem functions such as calcite formation and phosphorus sequestration.

Vertebrates. Stockbridge provides warm- and cold-water fisheries. Yellow perch, largemouth bass, and pickerel dominate the warm-water fishery, and brown and brook trout are stocked twice per year and constitute the cold-water fishery (Fugro 1996).

Suitable summer habitat for trout consists of water below 21 °C with dissolved oxygen concentration above 5 mg/l. The summer volume of water that matched these conditions was 20% in 1947, 8% in 1974, and 16% in 1991. Suitable volume could actually be smaller than these estimates, as ammonia and sulfides generated during summer anoxia would shrink habitat due to toxicity. The desired volume for a healthy cold-water fishery in Stockbridge Bowl would be 25%. Thus, cold-water fisheries management in Stockbridge Bowl is directly linked to water column management.

The warm-water fishery is linked to Stockbridge Bowl macrophyte management, as nuisance conditions shrink suitable spawning habitat. In 1991, for instance, the MA DFW issued a letter to Lycott that stated Stockbridge Bowl macrophyte density was adversely affecting gamefish production. The current status of warm-water fishery spawning habitat could very well be improved compared to 1991 conditions, but updated surveys would be needed to confirm this.

Macroinvertebrates. The endangered snail species, *Marstonia lustrica*, has four populations within Stockbridge Bowl: one in the upper portion of the outlet channel, one in the west littoral zone, one in the north littoral area, and another in the southeast littoral area. Though *M. lustrica* is never a dominant species, these four populations have been monitored and identified in Stockbridge Bowl since at least 1999. *M. lustrica* is thought to be an annual species (with reproduction and growth occurring over the spring and summer season, followed by an autumn and winter die off), and though there is uncertainty surrounding habitat association, gravelly substrate with moderate plant cover appears to be the preferred niche.

Zooplankton. Stockbridge Bowl contains a robust zooplankton community, quantified in the GZA 2020 report. Density of total animals ranged from 16 organisms/l in November to 175 organisms/l in May, with a mean of 98 organism/l. Small rotifers were the most abundant group, followed by copepods at various life stages (from nauplii to large adult). Large-bodied zooplankton (copepods and daphnia >1 mm) are important algae grazers and mostly maintained a density above 10 organisms/l, indicating a healthy grazer community.

Phytoplankton. The most notable and managerially important feature of the Stockbridge Bowl phytoplankton community is the deep layer of cyanobacteria that forms around 10-meter depth, just within the euphotic zone (where light penetration still allows for photosynthesis) and at the top of the anoxic zone, where nutrients (notably phosphorus and iron) are in abundant concentrations. For most of the summer, this assemblage is dominated by the *Planktothrix* (*Oscillatoria*) genera. This cyanobacterium is known to float to the surface when the water cools in autumn, which can cause bloom events or red scums on lake ice in winter. *Planktothrix* reaches high densities at depth in Stockbridge Bowl (above 50,000 cells/ml) but is only problematic when it is brought to the surface via lake cooling or mixing events due to storms (such as in August 2018). In autumn, when *Planktothrix* ascends to the surface of the lake, other cyanobacteria genera then dominate the deep-water assemblage, such as *Microcystis*, *Lyngbya*, and *Agmenellum*. Similar to *Planktothrix*, these cyanobacteria occur in high densities (nearly 300,000 cells/ml) but are contained to the deep-water layer.

Water Quality Impairments

Known water quality impairments, as documented in the Massachusetts Department of Environmental Protection (MassDEP) 2016 Massachusetts Integrated List of Waters (MassDEP, 2019), are listed below. Impairment categories from the Integrated List are as follows:

Table A-2: 2016 MA Integrated List of Waters Categories

Integrated List Category	Description
1	Unimpaired and not threatened for all designated uses.
2	Unimpaired for some uses and not assessed for others.
3	Insufficient information to make assessments for any uses.
4	Impaired or threatened for one or more uses, but not requiring calculation of a Total Maximum Daily Load (TMDL), including: 4a: TMDL is completed 4b: Impairment controlled by alternative pollution control requirements 4c: Impairment not caused by a pollutant - TMDL not required
5	Impaired or threatened for one or more uses and requiring preparation of a TMDL.

Table A-3: Water Quality Impairments (MassDEP 2019)

Assessment Unit ID	Waterbody	Integrated List Category	Designated Use	Impairment Cause	Impairment Source
MA21105	**Stockbridge Bowl**	**4A**	Fish Consumption	Mercury in Fish Tissue	Atmospheric Deposition - Toxics
MA21105	**Stockbridge Bowl**	**4A**	Fish Consumption	Mercury in Fish Tissue	Source Unknown
MA21105	**Stockbridge Bowl**	**4A**	Fish, other Aquatic Life and Wildlife	Eurasian Water Milfoil, Myriophyllum spicatum	Introduction of Non-native Organisms (Accidental or Intentional)

In watershed assessments conducted in 2014 and 2016, Stockbridge Bowl was identified as not supporting Fish Consumption due to the presence of Mercury in fish tissue. The primary cause of mercury contamination is due to regional air emissions and the resulting atmospheric deposition of mercury. Other sources that can contribute mercury to waterbodies include municipal wastewater treatment plants, non-municipal wastewater discharges, and stormwater discharges. To address the issue of mercury, the northeast states (NY, CT, RI, MA, VT, NH, and ME) developed a Northeast Mercury TMDL. The resulting TMDL for Massachusetts waterbodies is 0.3 ppm methylmercury in fish tissues. The Northeast Mercury TMDL was approved by the EPA and the lake was categorized as a 4a waterbody, having a completed TMDL.

The lake was also listed as impaired for Fish, Other Aquatic Life and Wildlife due to the presence of Eurasian watermilfoil, *Myriophyllum Spicatum*. No TMDL is designated for this impairment. While the 2018/2020 Integrated Report has not been finalized, a draft copy of the report is available for public comment. In addition to the mercury and nuisance aquatic plant impairments, Stockbridge Bowl was also listed as impaired for depleted dissolved oxygen concentrations and the lake will be categorized as a Category 5 waterbody. A threshold for the dissolved oxygen concentrations will need to be established by the State of Massachusetts and approved by the EPA.

Information collected from:
Appendix 16: Housatonic River Watershed Assessment and Listing Decision Summary
Massachusetts Integrated List of Waters for the Clean Water Act 2018/20 Reporting Cycle
Draft for Public Comment

Stockbridge Bowl (MA21105)

Location	Stockbridge
AU Type	Freshwater Lake
AU Size	384 Acres
Classification / Qualifier	B

AU = Assessment Unit

2016 AU Category	2018/20 AU Category	Impairment:	ATTAINS Action ID	Impairment Change Summary
4a	5	Dissolved Oxygen		Added

Category change from 4a to 5, added DO as an impairment. Category 5 means water requiring a TMDL. Impaired by one or more pollutants requiring restorative action, i.e., the 303d List.

Category 5 waters listed alphabetically by major watershed
The 303(d) List – "Waters requiring a TMDL"

Waterbody	***AU ID***	***Description***	***Size***	***Units***	***Pollutants Addressed by TMDL***	***ATTAINS Action ID***
Stockbridge Bowl	*MA21105*	*Stockbridge*	*384.00*	*Acres*	*Eurasian watermilfoil, Myriophyllum Spicatum*	
					Dissolved Oxygen	
					Mercury in Fish Tissue	*33880*

ATTAINS ID 33880 = Northeast Regional Mercury Total Maximum Daily Load (MassDEP CN 376.0). Mercury impairment is from atmospheric deposition.
Fish, other Aquatic Life and Wildlife Use: Not Supporting

The summary of Appendix 16, page 110, of the draft 2018/2020 Integrated Report is provided below:

"Water quality sampling was conducted in Stockbridge Bowl by MassDEP on 24 August 2005. The lake was well oxygenated to a depth of 8.5m (DO ≥7.6 mg/L) but dropped below 5.0 mg/L at 8.7m. The lake was anoxic at depth > 9m (194 of the 384 acres) representing ~51% of the lake surface area. The integrated depth chlorophyll a sample was low (2.8 mg/m^3) as was total phosphorus (0.008 mg/L) near the surface. The total phosphorus concentration near the anoxic bottom was higher (0.14 mg/L). Infestation of *M. spicatum* was originally identified by DWM biologists in Stockbridge Bowl during the summer of 1997 during a synoptic field survey and again in 2009 as part of the zebra mussel Phase I Assessment in Berkshire County. *N. minor* was also reported in the 2009 survey. Additionally, there is a report of *P. crispus* in the USGS Non-Indigenous Aquatic Species database, but this needs confirmation. The Aquatic Life Use for Stockbridge Bowl is assessed as Not Supporting. The *M. spicatum* impairment is being carried forward and because of the oxygen depletion at depth comprising more than 10% of the lake surface area a dissolved oxygen impairment is being added. An Alert is being identified due to a potential new infestation of *P. crispus*."

Water Quality Goals

Water quality goals may be established for a variety of purposes, including the following:

a.) For **water bodies with known impairments**, a Total Maximum Daily Load (TMDL) is established by MassDEP and the United States Environmental Protection Agency (USEPA) as the maximum amount of the target pollutant that the waterbody can receive and still safely meet water quality standards. If the waterbody has a TMDL for total phosphorus (TP) or total nitrogen (TN), or total suspended solids (TSS), that information is provided below and included as a water quality goal.

b.) For **water bodies without a TMDL for total phosphorus** (TP), a default water quality goal for TP is based on target concentrations established in the Quality Criteria for Water (USEPA, 1986) (also known as the "Gold Book"). The Gold Book states that TP should not exceed 50 ug/L in any stream at the point where it enters any lake or reservoir, nor 25 ug/L within a lake or reservoir. For the purposes of developing WBPs, MassDEP has adopted 50 ug/L as the TP target for all streams at their downstream discharge point, regardless of which type of water body the stream discharges to.

c.) Massachusetts Surface Water Quality Standards (314 CMR 4.00, 2013) prescribe the minimum water quality criteria required to sustain a waterbody's designated uses. Stockbridge Bowl is a Class 'B' waterbody. The water quality goal for fecal coliform bacteria is based on the Massachusetts Surface Water Quality Standards.

Table A-4: Surface Water Quality Classification by Assessment Unit

Assessment Unit ID	Waterbody	Class
MA21105	Stockbridge Bowl	B

d.) **Other water quality goals set by the community** (e.g., protection of high quality waters, in-lake phosphorus concentration goal to reduce recurrence of cyanobacteria blooms, etc.).

Water Quality Goals Discussed and Identified in Prior Studies

The management issues identified and discussed in historical studies can be organized into three categories, or management areas: Stockbridge Bowl watershed, littoral zone and water column.

1. Watershed

The two main issues of concern stemming from the Stockbridge Bowl watershed are phosphorus (P) loading and sedimentation. P loading was of high concern in the Wetzel 1994 memo due to speculated high inputs of P from septic tanks. This assertion was contrary to Lycott's 1991 findings, which conservatively estimated an annual P load from septic tanks to be 42 kg/year (3% of the total load). Fugro 1996 agreed with Lycott's assessment, adding that Wetzel's claims for septic P loading were unsubstantiated. Further the Fugro and Lycott reports both stressed that internal loading, rather than external P loading from the watershed, is an important determinant of in-lake P concentration and should be the logical target for reduction (as opposed to watershed management).

Lake infilling of certain areas due to sediment transport was identified as a concern by Fugro 1996 and was addressed more fully by the Town of Stockbridge and BRPC 2017 report. The problem areas associated with sedimentation include the Lily Pond inlet area and outlet channel. In both areas, nuisance macrophyte densities have been recorded, possibly as a consequence of easily colonizable substrates. The sediment transport to the lake from the watershed was determined to be a natural occurrence due to steep topography of the area. Further, the sedimentation at the Lily Brook inlet is largely due to the infilling of the sedimentation pond basin which was allowed to infill in the 1990s and is now considered wetland. There is a current plan for the dredging of the outlet channel.

2. Littoral Zone

The main issue of concern within the littoral zone of Stockbridge Bowl (and extending to about 20' depth) is the infestation and nuisance conditions of *Myriophyllum spicatum*. In the past, since at least the 1970s, *M. spicatum* density hindered recreational use, navigation, and reduced habitat for fish spawning. Nearly all ecological reports for Stockbridge Bowl mention this problem. Summer 2020 was noted for a reduction in *M. spicatum* abundance. Thus, the current status of *M. spicatum* as a management priority for Stockbridge Bowl is unclear. It should be noted that nuisance macrophyte conditions also result from diverse assemblages of macrophytes that are not dominated by M. spicatum but instead consist of native and non-native species. This condition occurs in the outlet channel.

3. Water Column

Water quality issues that arise within the deep-water column of Stockbridge Bowl - P enrichment, high Magnesium (Mn) and Iron (Fe) concentrations, and cyanobacteria can all be attributed directly or indirectly to oxygen depletion in the hypolimnion due to high oxygen demand coupled with strong summer stratification that inhibits oxygen diffusion from the top of the lake. Internal P loading that results from this persistent anoxic condition is substantial: Lycott 1991 estimated 555 kg/year, about 40-50% of total loading. P and Fe enrichment from internal loading supports a robust cyanobacteria community that remains above the hypolimnetic water boundary. The GZA 2020 monitoring characterized this community through the summer and identified it as the source for blooms that can occur late in the autumn season following lake turnover, or sooner following storm events (as occurred in August of 2018).

Out of the potential management targets outlined, the SBSC are currently prioritizing the following water quality goals: (Town to provide agreed upon goals and reference stakeholders involved. Examples below)

Commented [SR8]: SBSC needs to discuss and agree on these or similar target goals by priority – dredging has already been selected as the #1 priority with plants next. Please list these in priority, we have selected dredging first, plants (second and third), and anoxia fourth as the 3 main items needed from a water quality heath and use perspective.

1. Control of nuisance plant density in outlet channel via dredging (Town, SBA?)
2. Reduction of *Myriophyllum spicatum* via regular mechanical harvesting (Town, SBA?)
3. Reduction of *Trapa natans* via hand pulling (Town, SBA?)
4. Targeted herbicide treatments (ProcellaCOR) for Eurasian Watermilfoil (Town, SBA?)
5. Reduce anoxia at depth during the summer to minimize internal P loading.
6. TP not to exceed 25 ug/L within Stockbridge Bowl, or 50 ug/L in its inlets (according to Quality Criteria for Water, USEPA, 1986).
7. At public beaches, average E. coli below 126 colonies/100 mL (5 most recent samples), or below 235 colonies/100 mL for any one sample (according to Massachusetts Surface Water Quality Standards, 314 CMR 4.00, 2013).
8. At public beaches, average enterococci below 33 colonies/100 mL (5 most recent samples), or below 61 colonies/100 mL for any one sample (according to Massachusetts Surface Water Quality Standards, 314 CMR 4.00, 2013).
9. At other water areas, or public beaches during non-swimming months, average E. coli below 126 colonies/100 mL (past 6 months), or below 235 colonies/100 mL for any one sample (according to Massachusetts Surface Water Quality Standards, 314 CMR 4.00, 2013).

10. At other water areas, or public beaches during non-swimming months, average enterococci below 33 colonies/100 mL (past 6 months), or below 61 colonies/100 mL for any one sample (according to Massachusetts Surface Water Quality Standards, 314 CMR 4.00, 2013).
11. Bullard Woods old growth tree protection and invasive plant removal (SBA?)
12. Reduction of any residual septic tank nutrient loading via sewering (Town?)

Table A-5: Water Quality Goals

Pollutant	Goal	Source
Total Phosphorus (TP)	Total phosphorus should not exceed: --50 ug/L in any stream --25 ug/L within any lake or reservoir	Quality Criteria for Water (USEPA, 1986)
Bacteria	**Class B Standards** • Public Bathing Beaches: For E. coli, geometric mean of 5 most recent samples shall not exceed 126 colonies/ 100 ml and no single sample during the bathing season shall exceed 235 colonies/100 ml. For enterococci, geometric mean of 5 most recent samples shall not exceed 33 colonies/100 ml and no single sample during bathing season shall exceed 61 colonies/100 ml; • Other Waters and Non-bathing Season at Bathing Beaches: For E. coli, geometric mean of samples from most recent 6 months shall not exceed 126 colonies/100 ml (typically based on min. 5 samples) and no single sample shall exceed 235 colonies/100 ml. For enterococci, geometric mean of samples from most recent 6 months shall not exceed 33 colonies/100 ml, and no single sample shall exceed 61 colonies/100 ml.	Massachusetts Surface Water Quality Standards (314 CMR 4.00, 2013)
Other goals	**See list provided above**	Stakeholders involved

Note: *There may be more than one water quality goal for bacteria due to different Massachusetts Surface Water Quality Standards Classes for different Assessment Units within the watershed.*

Land Use and Impervious Cover Information

Land use information and impervious cover is presented in the tables and figures below. Land use source data is from 2005 and was obtained from MassGIS (2009b).

Watershed Land Uses

Table A-6: Watershed Land Uses

Land Use	Area (acres)	% of Watershed
Agriculture	328.25	4.5
Commercial	267.03	3.6
Forest	5271.08	72
High Density Residential	52	0.7
Highway	0	0
Industrial	7.49	0.1
Low Density Residential	363.23	5
Medium Density Residential	112.31	1.5
Open Land	476.91	6.5
Water	439.04	6

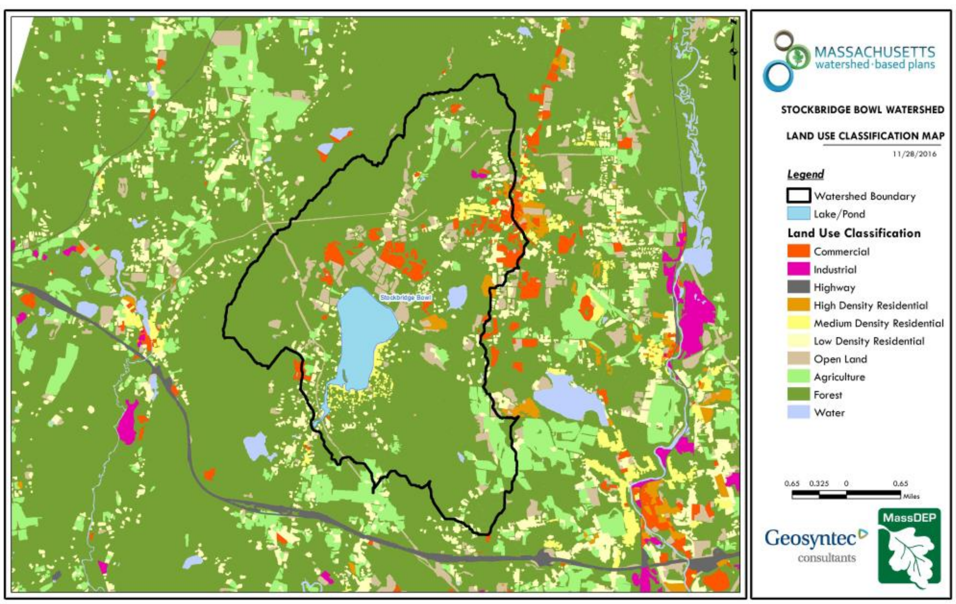


Figure A-2: Watershed Land Use Map (MassGIS, 2009b; MassGIS, 1999; MassGIS, 2001; USGS, 2016)

Ctrl + Click on the map to view a full sized image in your web browser.

Watershed Impervious Cover

There is a strong link between impervious land cover and stream water quality. Impervious cover includes land surfaces that prevent the infiltration of water into the ground, such as paved roads and parking lots, roofs, basketball courts, etc.

Impervious areas that are directly connected (DCIA) to receiving waters (via storm sewers, gutters, or other impervious drainage pathways) produce higher runoff volumes and transport stormwater pollutants with greater efficiency than disconnected impervious cover areas which are surrounded by vegetated, pervious land. Runoff volumes from disconnected impervious cover areas are reduced as stormwater infiltrates when it flows across adjacent pervious surfaces.

An estimate of DCIA for the watershed was calculated based on the Sutherland equations. USEPA provides guidance (USEPA, 2010) on the use of the Sutherland equations to predict relative levels of connection and disconnection based on the type of stormwater infrastructure within the **total impervious area (TIA)** of a watershed. Within each sub-watershed, the total area of each land use were summed and used to calculate the percent TIA.

Table A-7: TIA and DCIA Values for the Watershed

	Estimated TIA (%)	Estimated DCIA (%)
Stockbridge Bowl	4.5	3.3

The relationship between TIA and water quality can generally be categorized as shown in **Table A-8** (Schueler et al. 2009):

Table A-8: Relationship between Total Impervious Area (TIA) and water quality (Schueler et al. 2009)

% Watershed Impervious Cover	Stream Water Quality
0-10%	Typically high quality, and typified by stable channels, excellent habitat structure, good to excellent water quality, and diverse communities of both fish and aquatic insects.
11-25%	These streams show clear signs of degradation. Elevated storm flows begin to alter stream geometry, with evident erosion and channel widening. Streams banks become unstable, and physical stream habitat is degraded. Stream water quality shifts into the fair/good category during both storms and dry weather periods. Stream biodiversity declines to fair levels, with most sensitive fish and aquatic insects disappearing from the stream.

26-60%	These streams typically no longer support a diverse stream community. The stream channel becomes highly unstable, and many stream reaches experience severe widening, downcutting, and streambank erosion. Pool and riffle structure needed to sustain fish is diminished or eliminated and the substrate can no longer provide habitat for aquatic insects, or spawning areas for fish. Biological quality is typically poor, dominated by pollution tolerant insects and fish. Water quality is consistently rated as fair to poor, and water recreation is often no longer possible due to the presence of high bacteria levels.
>60%	These streams are typical of "urban drainage", with most ecological functions greatly impaired or absent, and the stream channel primarily functioning as a conveyance for stormwater flows.

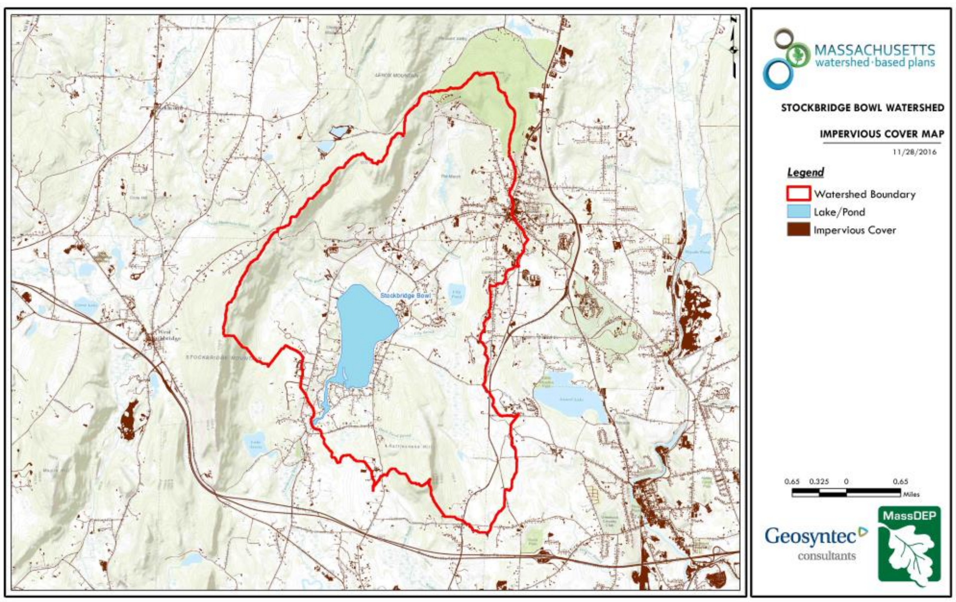


Figure A-3: Watershed Impervious Surface Map (MassGIS, 2009b; MassGIS, 1999; MassGIS, 2001; USGS, 2016)

Ctrl + Click on the map to view a full sized image in your web browser.

Land use information:

Stockbridge Bowl watershed encompasses 7,068 acres, or 11 square miles. Stockbridge Bowl (385 acres) represents 5% of the total watershed area. The land use types of Stockbridge watershed include wooded, residential, open (brushland, cemeteries, powerlines, etc.), and agricultural lands, wetlands, and open water. These are summarized in the following table reproduced from Lycott 1991:

Land use type	Total acreage	% of watershed area
Woodland	4,477	64
Residential	1,080	16
Open Land	788	11
Agricultural	350	5
Wetlands	246	4

An updated land use survey was conducted by the BRPC, SBA, and Town of Stockbridge (2012) using 2005 data that provided slightly different figures. The differences in land use between the two reports are not necessarily reflective of change that occurred within the watershed, but are more likely due to differences in methodological advances between 1991 and 2005:

Land use type	Total acreage	% of watershed area
Woodland	4,954	70
Residential	880	13
Open Land	435	6
Agricultural	336	5
Wetlands	462	6

Pollutant Loading

Geographic Information Systems (GIS) was used for the pollutant loading analysis. The land use data (MassGIS, 2009b) was intersected with impervious cover data (MassGIS, 2009a) and United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) soils data (USDA NRCS and MassGIS, 2012) to create a combined land use/land cover grid. The grid was used to sum the total area of each unique land use/land cover type.

The amount of DCIA was estimated using the Sutherland equations as described above and any reduction in impervious area due to disconnection (i.e., the area difference between TIA and DCIA) was assigned to the pervious D soil category for that land use to simulate that some infiltration will likely occur after runoff from disconnected impervious surfaces passes over pervious surfaces.

Pollutant loading for key nonpoint source pollutants in the watershed was estimated by multiplying each land use/cover type area by its pollutant load export rate (PLER) as follows:

$$L_n = A_n * P_n$$

Where L_n = Loading of land use/cover type n (lb/yr); A_n = area of land use/cover type n (acres);

P_n = pollutant load export rate of land use/cover type n (lb/acre/yr)

The PLERs are an estimate of the annual total pollutant load exported via stormwater from a given unit area of a particular land cover type. The PLER values for TN, TP and TSS were obtained from USEPA (USEPA, 2020; UNHSC, 2018, Tetra Tech, 2015) (see values provided in Appendix A). **Table A-9** presents the estimated land-use based TN, TP and TSS pollutant loading in the watershed.

Table A-9: Estimated Pollutant Loading for Key Nonpoint Source Pollutants

Land Use Type	Pollutant Loading[1]		
	Total Phosphorus (TP) (lbs/yr)	Total Nitrogen (TN) (lbs/yr)	Total Suspended Solids (TSS) (tons/yr)
Agriculture	159	954	9.71
Commercial	136	1,225	15.33
Forest	738	3,801	180.98
High Density Residential	30	213	3.09
Highway	0	0	0.00
Industrial	3	24	0.30
Low Density Residential	97	964	13.05
Medium Density Residential	33	285	3.94
Open Land	112	1,064	17.81
TOTAL LAND USE LOADING:	**1,308** *(593 kg/yr)*	**8,529** *(3869 kg/yr)*	**244.23** *(222 mt)*

[1]These estimates do not consider loads from point sources or septic systems.

Pollutant loading information:

Lycott 1991 estimated total annual P loading with two different methods that yielded consistent results: a 'short-term' method, which was extrapolated from empirical field data, and 'long-term' method which relies on modeling P loading based on average land use values from published sources. The two P loading estimates are summarized below. ***Please note that in the long-term estimate method, land use (which is also estimated above in Table A-9) is a component of the total annual load.***

Long-term estimate			**Short-term estimate**		
Source	P load (kg/year)	% of total	Source	P load (kg/year)	% of total
Land use	715.9	52.5	Tributary base flow	160.4	14.3
Septic tanks	42.2	3.1	Storm flow	343.6	30.7
Anoxic sediments -summer -winter	 438.0 117.2	 32.1 8.6	Anoxic sediments -summer -winter	 438.0 117.2	 39.1 10.5
Atmospherically deposited	50.4	3.7	Atmospherically deposited	50.4	4.5
			Groundwater	10.5	0.9
Total	**1,363.7**	**100.0**	**Total**	**1,120.1**	**100.0**

It is useful to further break down the inputs of these models into constituent parts to understand the sources and pathways of external P loading in finer detail. The long-term model calculated P loading to Stockbridge Bowl based on published values of P export for each land use category:

Long-term estimate model inputs: Nutrient loading for Stockbridge Bowl by land use				
Category	Area		P export	P Loading
	Acres	Hectares	kg/ha/year	kg/year
Forested	4,447.7	1,801	0.20	363.9
Open	1,120.8	454	0.31	142.6
Wetland	244.0	99	0.00	0.0
Residential:				
-Forested Residents	332.4	135	0.22	30.2
-Medium density	11.2	5	0.65	3.0
-Light density	265.2	107	0.34	36.2
-Garden Apt./Hwy/Commercial	66.0	27	1.30	34.8
-Public land/estates	387.2	157	0.65	102.1
-Recreational land	10.0	4	0.79	3.2
Total				**715.9**

The short-term model measured P concentration at different inlets into Stockbridge Bowl, and extrapolated P loading based on measured and estimated rates of discharge for each source:

Short-term estimate model inputs: Nutrient loading for Stockbridge Bowl from extrapolation					
Sampling Station	P conc. mg/l	Total discharge		P loading	
		Measured m^3/year	Estimated m^3/year	Measured kg/year	Estimated kg/year
Mahican Brook	0.002	152,657	157,800	0.3	0.3
Shadow Brook	0.051	1,569,306	1,657,000	79.8	84.5
Kripalu Beach inlet	0.044	152,209	473,400	6.7	20.8
Lily Brook	0.010	1,772,675	5,365,300	18.1	53.6
Duck Pond Brook	0.006	23,044	236,700	0.1	1.4
Total				**105.0**	**160.6**

While quantitative estimates of sediment loading were not available to GZA, Inter-Fluve, Inc. identified the Lily Pond and North subbasin watersheds as important contributors to sediment loading in Stockbridge Bowl. The holding pond basin at the Lily Brook inlet to Stockbridge Bowl was identified as a critical site for the management of sediments and fines washed into the lake during high discharge and storm events.

In-lake dynamics and internal pollutant loading:

GZA conducted seasonal monitoring of Stockbridge Bowl from spring to autumn of 2020 and 201. Several physical, chemical, and biological parameters were monitored and quantified. Based on this comprehensive monitoring, GZA identified two key, possibly coupled, processes that are important in determining water quality in the lake.

The first process involved calcium carbonate precipitation and potential deposition. Calcium carbonate, (or calcite) is abundant in dissolved form in Stockbridge Bowl. This is typical for a hardwater lake. In the littoral zone, significant and widespread calcite precipitate was observed on the leaves of macrophytes and the macroalgae *Chara*. Calcite crystal formation on leaves is due to micro-scale pH changes along the plant cell walls that occur during photosynthesis. Phosphorous can become incorporated into calcite as it precipitates, and this mechanism can sequester phosphorous from the water column that would otherwise be available as a biological resource. Subsequent to calcium carbonate precipitation is its deposition, whereby calcium carbonate settles to lake sediments in deeper areas of the lake. In addition to macrophyte- and macroalgae-driven calcite precipitation, GZA also speculated there may be a potential for calcite precipitation (and subsequent deposition) due to phytoplankton photosynthesis that occurs in the deeper, open water areas of Stockbridge Bowl. This warrants more investigation, however, and may be the focus of a small-scale, future study.

The second process that determines water quality in the lake involves the chemical reduction-oxidation reactions that occur in the anoxic deep waters of Stockbridge Bowl during peak summer months. Anoxia in the deep, over-bottom water results from increased stratification and oxygen demand. Stratification limits the diffusion of oxygen from the surface of the lake to deeper water, and microbial respiration of organic material on the bottom of the lake quickly depletes whatever oxygen was available. When deep water oxygen is depleted, organisms capable of anaerobic respiration then utilize alternative electron acceptors, such as the metals Mn and Fe. The use of Mn and Fe as electron acceptors is the process by which they are reduced from a more oxidized state. When these metals are reduced, they are highly soluble and mobilized from lake sediments into the water column. In their oxidized state, Fe adsorbs and sequesters phosphorus from the water column but when Fe is reduced, it dissociates from phosphorus, releasing it into the water column—known as internal phosphorus loading. This process of phosphorus liberation from lake sediments is biologically driven. A second, chemically driven process of phosphorus liberation is likely present in Stockbridge bowl during lake anoxia. This occurs due to respiration on the bottom of the lake increases amounts of dissolved CO_2, which decreases the over bottom pH (i.e., it becomes more acidic). In low pH water, deposited calcium carbonate (from the first outlined process, above) readily dissolves and releases any phosphorus that it had been sequestering.

The following figures demonstrate the persistent anoxia in the Stockbridge Bowl hypolimnion, as well as concurrent P concentrations throughout the season of 2020:

Dissolved Oxygen, mg/l

Depth (m)	4/29	5/19	6/18	7/27	8/28	9/17	10/15	11/10
0.5	11.2	10.3	8.7		8.2			8.9
1	11.2	10.2	8.8	8.8	8.2	9.2	8.1	8.9
2	11.3	10.3	9.2	8.8	8.2	9.0	8.1	8.8
3	11.2	10.3	9.2	8.8	8.2	9.0	8.1	8.9
4	11.2	10.5	9.1	8.6	8.2	9.0	8.1	8.6
5	11.1	10.3	12.4	8.8	8.2	9.0	8.1	8.4
6	11.1	10.1	12.3	12.4	8.2	9.0	8.1	8.2
7	11.1	9.7	11.0	11.6	10.3	8.9	8.1	7.9
8	11.1	9.5	8.6	9.6	6.1	8.4	8.1	7.5
9	11.0	9.2	4.1	7.4	4.3	5.6	8.0	7.5
10	10.9	8.8	0.3	0.3	0.1	0.1	8.0	7.5
11	10.9	8.4	0.0	0.0	0.0	0.0	0.0	7.1
12	10.5	8.0	0.0	0.0	0.0	0.0	0.0	6.7
13	10.3	7.1	0.0	0.0	0.0	0.0	0.0	5.9
14	10.2	6.6	0.0		0.0	0.0	0.0	4.8
15	9.2	6.1				0.0	0.0	3.2

Total Phosphorus, mg/l

Depth	4/29	5/19	6/18	7/27	8/28	9/17	10/15	11/10
1 m	0.04	0.02	0.02	0.02	0.01	0.02	0.02	0.03
5m	0.03	0.02	0.02	0.02	0.01	0.01	0.03	0.02
7m	0.02	0.04	0.02	0.03	0.02	0.02	0.03	0.03
10 m	0.03	0.02	0.03	0.07	0.09	0.04	0.04	0.03
14 m	0.02	0.03	0.07	0.12	0.32	0.40	0.46	0.04

Element B: Determine Pollutant Load Reductions Needed to Achieve Water Quality Goals

Element B of your WBP should:

Determine the pollutant load reductions needed to achieve the water quality goals established in Element A. The water quality goals should incorporate Total Maximum Daily Load (TMDL) goals, when applicable. For impaired water bodies, a TMDL establishes pollutant loading limits as needed to attain water quality standards.

Estimated Pollutant Loads

Table B-1 lists estimated pollutant loads for the following primary nonpoint source (NPS) pollutants: total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS). These estimated loads are based on the pollutant loading analysis presented in Section 4 of Element A.

Water Quality Goals

Water quality goals for primary NPS pollutants are listed in **Table B-1** based on the following:

- TMDL water quality goals (if a TMDL exists for the water body);
- For all water bodies, including impaired waters that have a pathogen TMDL, the water quality goal for bacteria is based on the Massachusetts Surface Water Quality Standards (314 CMR 4.00, 2013) that apply to the Water Class of the selected water body.
- If the water body does not have a TMDL for TP, a default target TP concentrations is provided which is based on guidance provided by the USEPA in Quality Criteria for Water (1986), also known as the "Gold Book". Because there are no similar default water quality goals for TN and TSS, goals for these pollutants are provided in **Table B-1** only if a TMDL exists or alternate goal(s) have been optionally established by the WBP author.
- According to the USEPA Gold Book, total phosphorus should not exceed 50 ug/L in any stream at the point where it enters any lake or reservoir. The water quality loading goal was estimated by multiplying this target maximum phosphorus concentration (50 ug/L) by the estimated annual watershed discharge for the selected water body. To estimate the annual watershed discharge, the mean flow was used, which was estimated based on United States Geological Survey (USGS) "Runoff Depth" estimates for Massachusetts (Cohen and Randall, 1998). Cohen and Randall (1998) provide statewide estimates of annual Precipitation (P), Evapotranspiration (ET), and Runoff (R) depths for the

northeastern U.S. According to their method, Runoff Depth (R) is defined as all water reaching a discharge point (including surface and groundwater), and is calculated by:

$$P - ET = R$$

A mean Runoff Depth R was determined for the watershed by calculating the average value of R within the watershed boundary. This method includes the following assumptions/limitations:

a. For lakes and ponds, the estimate of annual TP loading is averaged across the entire watershed. However, a given lake or reservoir may have multiple tributary streams, and each stream may drain land with vastly different characteristics. For example, one tributary may drain a highly developed residential area, while a second tributary may drain primarily forested and undeveloped land. In this case, one tributary may exhibit much higher phosphorus concentrations than the average of all streams in the selected watershed.

b. The estimated existing loading value only accounts for phosphorus due to stormwater runoff. Other sources of phosphorus may be relevant, particularly phosphorus from on-site wastewater treatment (septic systems) within close proximity to receiving waters. Phosphorus does not typically travel far within an aquifer, but in watersheds that are primarily unsewered, septic systems and other similar groundwater-related sources may contribute a significant load of phosphorus that is not captured in this analysis. As such, it is important to consider the estimated TP loading as "the expected TP loading from stormwater sources."

c. If the calculated water quality goal is higher than the existing estimated total load; the water quality goal is automatically set equal to the existing estimated total load.

Table B-1: Pollutant Load Reductions Needed

Pollutant	Existing Estimated Total Load	Water Quality Goal	Required Load Reduction
Total Phosphorus	1,308 lbs./yr (593 kg/yr)	1,308 lbs./yr (absent other data, this Goal is set equal to the Total Load. Note the current load is not considered problematic to lake quality heath)	0 lbs./yr
Total Nitrogen	8,529 lbs./yr (3869 kg/yr)	8,529 lbs./yr	0 lbs./yr
Total Suspended Solids	244 ton/yr (221 mt/yr)	244 ton/yr	0 tons/yr
Bacteria	*MSWQS for bacteria are concentration standards (e.g., colonies of fecal coliform bacteria per 100 ml), which are difficult to*	Class B. **Class B Standards** • Public Bathing Beaches: For E. coli, geometric mean of 5 most recent samples shall not exceed	

	predict based on estimated annual loading.	126 colonies/ 100 ml and no single sample during the bathing season shall exceed 235 colonies/100 ml. For enterococci, geometric mean of 5 most recent samples shall not exceed 33 colonies/100 ml and no single sample during bathing season shall exceed 61 colonies/100 ml; • Other Waters and Non-bathing Season at Bathing Beaches: For E. coli, geometric mean of samples from most recent 6 months shall not exceed 126 colonies/100 ml (typically based on min. 5 samples) and no single sample shall exceed 235 colonies/100 ml. For enterococci, geometric mean of samples from most recent 6 months shall not exceed 33 colonies/100 ml, and no single sample shall exceed 61 colonies/100 ml.	

TMDL Pollutant Load Criteria

No TMDL pollutant load criteria data were found based on the Mass DEP estimates and standards.

Pollutant load reduction information:

Pollutant load reductions from the watershed are not indicated at this time. However, monitoring and historical reports suggest the largest source of P loading in Stockbridge Bowl is internal, from lake sediments, rather than external watershed. Though a feasibility study for management of internal P loading has not been conducted to date, several reports have suggested and considered pros/cons for various implementations, such as oxygenation, aeration, and 'sediment capping' or 'phosphorus inactivation' via alum treatment.

Additionally, watershed loading of sediments remains problematic in the Northeast Lily Brook corner of the lake, (as indicated by BRPC/SBA/Town of Stockbridge, 2012: "Stockbridge Bowl Watershed Survey" and Town of Stockbridge & BRPC, 2017: "Stockbridge Bowl Watershed Assessment"), but this sedimentation and impact on *Myriophyllum spicatum* infestation is not indicated by TSS estimates and standards. Thus, sediment transport from the watershed in this area is a potential management target despite the above Mass DEP indications.

Element C: Describe management measures that will be implemented to achieve water quality goals

Element C: A description of the nonpoint source management measures needed to achieve the pollutant load reductions presented in Element B, and a description of the critical areas where those measures will be needed to implement this plan.

BMP Hotspot Map:

The following GIS-based analysis was performed within the watershed to identify high priority parcels for best management practice (BMP) (also referred to as management measure) implementation:

- Each parcel within the watershed was evaluated based on ten different criteria accounting for the parcel ownership, social value, and implementation feasibility (See **Table C-1** for more detail below);
- Each criterion was then given a score from 0 to 5 to represent the priority for BMP implementation based on a metric corresponding to the criterion (e.g., a score of 0 would represent lowest priority for BMP implementation whereas a score of 5 would represent highest priority for BMP implementation);
- A multiplier was also assigned to each criterion, which reflected the weighted importance of the criterion (e.g., a criterion with a multiplier of 3 had greater weight on the overall prioritization of the parcel than a criterion with a multiplier of 1); and
- The weighted scores for all the criteria were then summed for each parcel to calculate a total BMP priority score.

Table C-1 presents the criteria, indicator type, metrics, scores, and multipliers that were used for this analysis. Parcels with total scores above 60 are recommended for further investigation for BMP implementation suitability. **Figure C-1** presents the resulting BMP Hotspot Map for the watershed. The following link includes a Microsoft Excel file with information for all parcels that have a score above 60: hotspot spreadsheet.

This analysis solely evaluated individual parcels for BMP implementation suitability and likelihood for the measures to perform effectively within the parcel's features. This analysis does not quantify the pollutant loading to these parcels from the parcel's upstream catchment. When further evaluating a parcel's BMP implementation suitability and cost-effectiveness of BMP implementation, the existing pollutant loading from the parcel's upstream catchment and potential pollutant load reduction from BMP implementation should be evaluated.

GIS data used for the BMP Hotspot Map analysis included:

- MassGIS (2015a);
- MassGIS (2015b);
- MassGIS (2017a);
- MassGIS (2017b);
- MassGIS (2020);

- MA Department of Revenue Division of Local Services (2016);
- MassGIS (2005);
- ArcGIS (2020);
- MassGIS (2009b);
- MassGIS (2012); and
- ArcGIS (2020b).

Table C-1: Matrix for BMP Hotspot Map GIS-based Analysis

Criteria	Indicator Type	METRICS																											Multiplier	Maximum Potential Score
		Yes or No?		Hydrologic Soil Group				Land Use Type									Water Table Depth				Parcel Area			Parcel Average Slope						
		Yes	No	A or A/D	B or B/D	C or C/D	D	Low and Medium Density Residential	High Density Residential	Commercial	Industrial	Highway	Agriculture	Forest	Open Land	Water	101-200 cm	62-100 cm	31-61 cm	0-30 cm	Greater than 2 acres	Between 1-2 acres	Less than 1 acre	Less than 2%	Between 2% and 15%	Greater than 15%	Less than 50%	Between 51% and 100%		
Is the parcel a school, fire station, police station, town hall or library?	Ownership	5	0																										2	10
Is the parcel's use code in the 900 series (i.e. public property or university)?	Ownership	5	0																										2	10
Is parcel fully or partially in an Environmental Justice Area?	Social	5	0																										2	10
Most favorable Hydrologic Soil Group within Parcel	Implementation Feasibility			5	3	0	0																						2	10
Most favorable Land Use in Parcel	Implementation Feasibility							1	2	4	2	4	5	1	4	X[1]													3	15
Most favorable Water Table Depth (deepest in Parcel)	Implementation Feasibility																5	4	3	0									2	10
Parcel Area	Implementation Feasibility																				5	4	1						3	15
Parcel Average Slope	Implementation Feasibility																							3	5	1			1	5
Percent Impervious Area in Parcel	Implementation Feasibility																										5	2.5	1	5
Within 100 ft buffer of receiving water (stream or lake/pond)?	Implementation Feasibility	5	2																										2	10

Note 1: **X** denotes that parcel is excluded

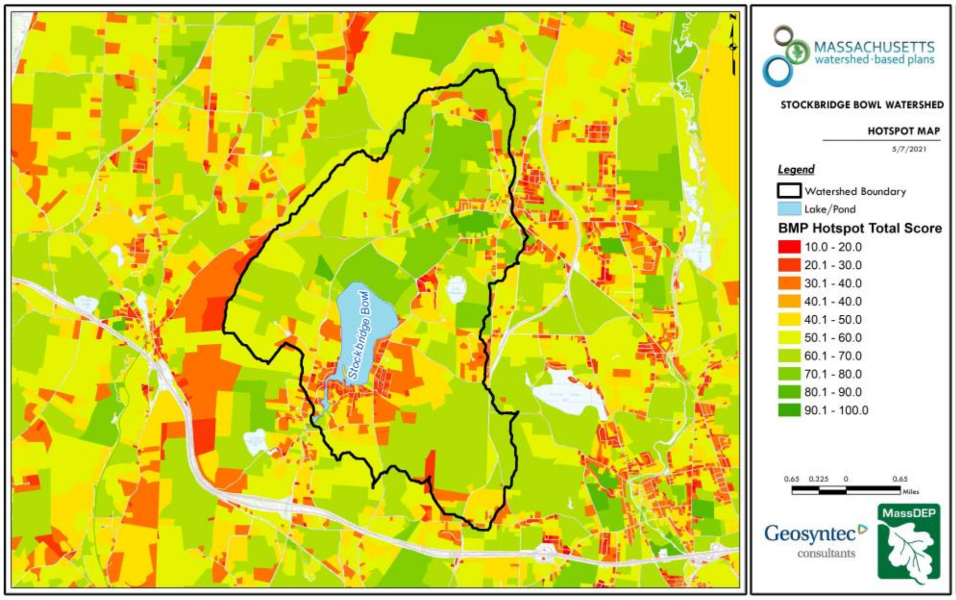


Figure C-1: BMP Hotspot Map (MassGIS (2015a), MassGIS (2015b), MassGIS (2017a), MassGIS (2017b), MassGIS (2020), MA Department of Revenue Division of Local Services (2016), MassGIS (2005), ArcGIS (2020), MassGIS (2009b), MassGIS (2012), ArcGIS (2020b))

Ctrl + Click on the map to view a full sized image in your web browser.

Proposed Management Measures:

Table C-2 presents the proposed management measures as well as the estimated pollutant load reductions and costs. The planning level cost estimates and pollutant load reduction estimates and estimates of BMP footprint were based off information obtained in the following sources and were also adjusted to 2016 values using the Consumer Price Index (CPI) (United States Bureau of Labor Statistics, 2016):

- Geosyntec Consultants, Inc. (2014);
- Geosyntec Consultants, Inc. (2015);
- King and Hagen (2011);
- Leisenring, et al. (2014);
- King and Hagen (2011);
- MassDEP (2016a);
- MassDEP (2016b);
- University of Massachusetts, Amherst (2004);
- USEPA (2020);
- UNHSC (2018);

- Tetra Tech, Inc. (2015);

Table C-2: Proposed Management Measures, Estimated Pollutant Load Reductions and Costs

Structural BMPs
Sewer Expansion Plan (if any) Septic Replacement Plan (if any) Stormwater Improvement Plan (if any) Highway/Road Improvement Plan (if any) Significant Land Use Changes Planned (if any)
Additional BMPs
Dredging Project Plan Deicing Strategy Plan (if any)

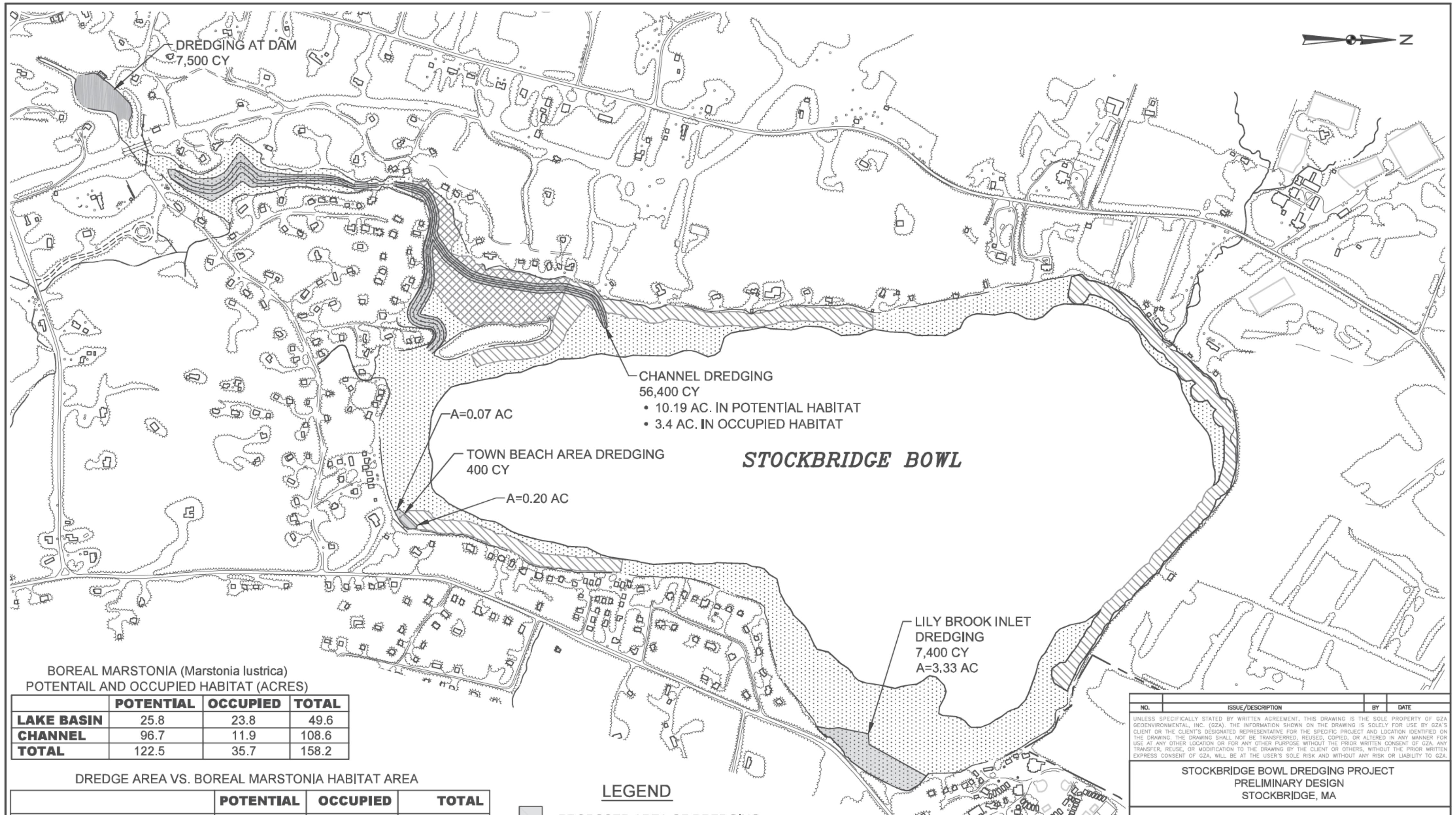
Commented [SR9]: As discussed in our 7/15 meeting as additional info needed

Commented [SR10]: Same as above

Proposed Dredging:

The Town of Stockbridge is planning to hydraulically dredge limited areas within the Stockbridge Bowl. Approximately, 76,000 cubic yards of sediment are to be dredged from the select areas of the lake, a combined total area of approximately 18 acres. The primary focus of dredging will be in the within the "outlet channel" area of the lake where sedimentation and thick aquatic vegetation growth limits navigation and recreational use of the water. Other areas, including the Town Beach, the inlet area of Lily Brook, and the Beechwood shoreline, are also included in the proposed dredging plan. The plan has been strategically developed to minimize impact the occupied and potential habitat to the *Boreal Marstonia* snail, an endangered species in Massachusetts as determined by the Massachusetts Natural Heritage and Endangered Species Program. Hydraulic dredging will not require a drawdown of the lake or any part of it, which will contribute to minimizing impact to the rare snail and its habitat in the lake. The dredge will pump a slurry of sediment and water to a sediment dewatering operation to be established in the fields of Bullard Woods, a public open space recreational area located at the north end of the lake. Sediments are to be dewatered using geotextile tubes with the clarified water to be returned to the lake. The geotextile tubes and sediment are to be buried and remain in place and the fields will be restored following completion of dredging.

Conceptual Plans for the Dredging work are shown below:



BOREAL MARSTONIA (Marstonia lustrica)
POTENTAIL AND OCCUPIED HABITAT (ACRES)

	POTENTIAL	OCCUPIED	TOTAL
LAKE BASIN	25.8	23.8	49.6
CHANNEL	96.7	11.9	108.6
TOTAL	122.5	35.7	158.2

DREDGE AREA VS. BOREAL MARSTONIA HABITAT AREA

	POTENTIAL	OCCUPIED	TOTAL
HABITAT AREA (AC)	122.5	35.7	158.2
DREDGE AREA (AC)	14.6 ~~13.6~~	3.6	18.2 ~~17.2~~
IMPACT TO TOTAL HABITAT AREA (%)	9.2 ~~8.6~~	2.3	11.5 ~~10.9~~
IMPACT TO HABITAT AREA TYPE (%)	11.9 ~~11.1~~	10.1	—

NO.	ISSUE/DESCRIPTION	BY	DATE

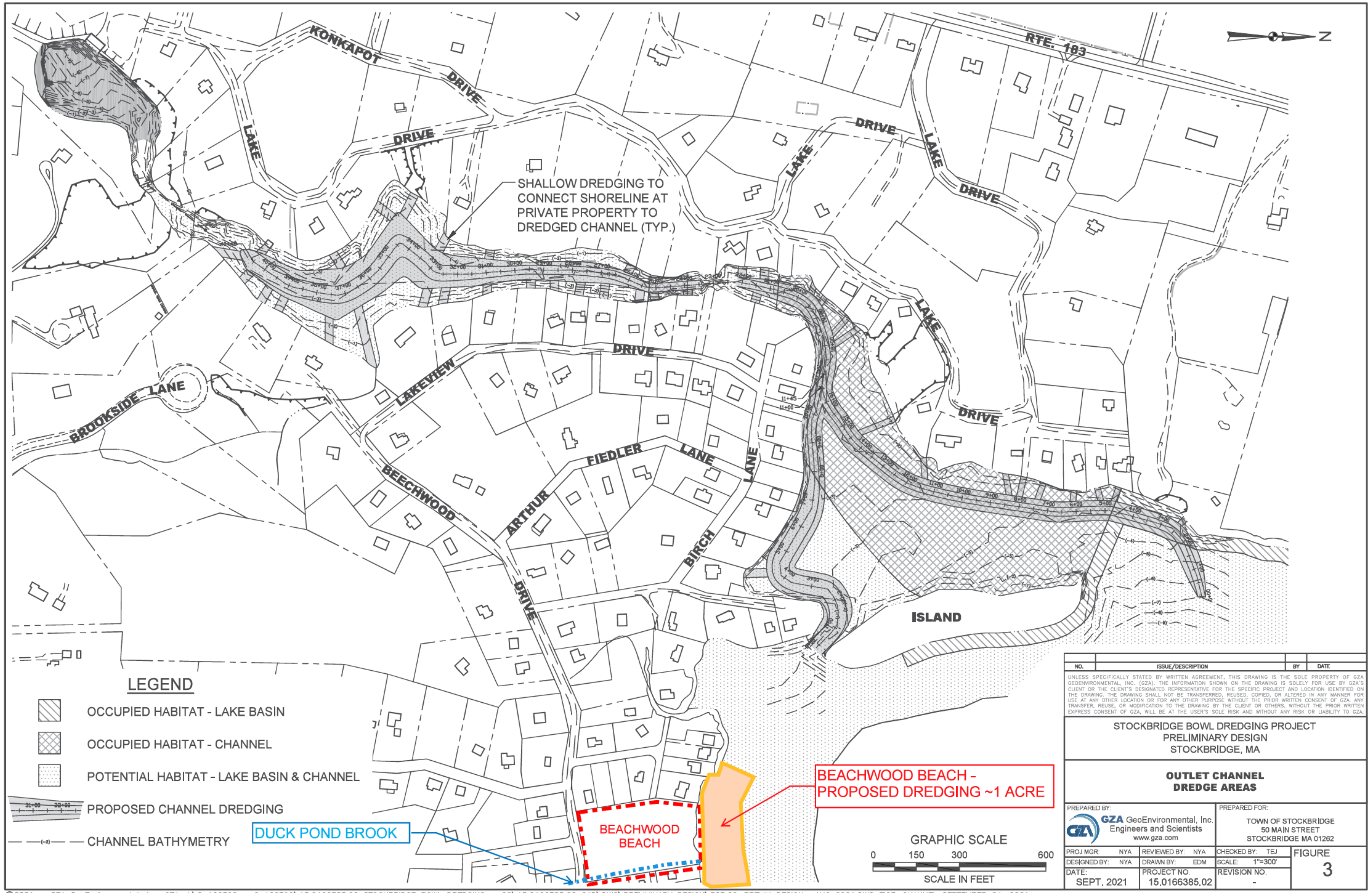
STOCKBRIDGE BOWL DREDGING PROJECT
PRELIMINARY DESIGN
STOCKBRIDGE, MA

POTENTIAL DREDGE AREAS AND BOREAL MARSTONIA HABITAT

PREPARED BY: GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com

PREPARED FOR: TOWN OF STOCKBRIDGE, 50 MAIN STREET, STOCKBRIDGE MA 01262

PROJ MGR: NYA	REVIEWED BY: NYA	CHECKED BY: TEJ	FIGURE 2
DESIGNED BY: NYA	DRAWN BY: EDM	SCALE: 1"=700'	
DATE: SEPT. 2021	PROJECT NO. 15.0166385.02	REVISION NO. -	



©2021 – GZA GeoEnvironmental, Inc. GZA-J:\0 166300 – 0 166399\15.0166385.02 STOCKBRIDGE BOWL DREDGING – 02\15.0166385.02 CAD\DWG\PRELIMINARY DESIGN\385.02-PRELIM DESIGN –AUG 2021.DWG FIG3-CHANNEL SEPTEMBER 24, 2021

Other Observations:

The studies conducted on Stockbridge Bowl to date have focused on a variety of management targets that can broadly be classified as belonging to the watershed, littoral zone, or water column. The Management Strategy Summary Table (below) identifies these three management areas, the targets of concern within them, and the management strategies discussed in historical reports and studies. This table is not comprehensive in its treatment of each management strategy but summarizes the main discussion points and references the original sources where the reader may find more detailed summary. Further, the Town and stakeholders are not committed to any one of these management strategies. Rather, this is considered a list of options that may be currently under discussion or can be considered in the future as goals are achieved and priorities shift.

Table C-3: Stockbridge Bowl Strategy Summary BY MANAGEMENT AREA

Management Area	Target	Method	Source	Advantages	Drawbacks
Watershed	Phosphorus Loading	On-site wastewater systems, community systems, sewers	Wetzel 1994	Preventative; eliminates contamination load from septic systems; community health benefit	Loading from septic systems is likely small effect; capital and operational costs; has substantial sewer upgrades already been completed? Future plans?
		Site-specific projects, improvements, community involvement, and best practice implementation	Wetzel 1994; Fugro 1996; BRPC, SBA & Town of Stockbridge 2012	Proactive; public benefit; enhancement of wetland habitats; elimination of phosphorus detergents and fertilizers; enhancement of vegetation buffering; improvement of specific problematic areas	Limited impact: some regulations may be difficult to implement and enforce; some implementation may be expensive
	Sediment Loading	Dredging	Fugro 1996; Town of Stockbridge & BRPC 2017	Targeted at the holding pond and lakeside area along Mahkeenac Lake Road would provide immediate benefit (removal and storage capacity); restores detention basin function	Expensive; permitting issues for wetland area and endangered species; would require future upkeep; manages sedimentation but does not prevent it
		Road sand study	Town of Stockbridge & BRPC 2017	Proactive; could potentially address sediment accumulation along the Mahkeenac Lake Road and north shore area	Primarily diagnostic; would need to be followed up with feasibility studies and management efforts
		Site-specific projects, improvements, community involvement and best practice implementation	Fugro 1996; BRPC, SBA & Town of Stockbridge 2012; Town of Stockbridge & BRPC 2017	Proactive; public benefit due to outreach, education, and involvement; improvement of specific problematic areas	Likely not to have substantial impact on sedimentation within the lake; no acute erosion sites exist that explain sedimentation rates in lake

Management Area	Target	Method	Source	Advantages	Drawbacks
Lake Littoral Zone	Milfoil	Lake level drawdown (5 to 8 feet)	Lycott 1991; Wetzel 1994; Fugro 1996	Oxidizes organic and nutrient-rich sediments; highly effective for shallow depths; can promote growth of tolerant native species; allows for littoral zone access and maintenance; can export nutrients from lake system; benefits fisheries; cost effective	Outlet channel must be deepened; Potential impact on *Marstonia lustricus* and other hibernating organisms; limited area of impact; requires substantial and consistent annual recharge rates; permitting issues; user dissatisfaction; can exacerbate phytoplankton blooms; potential impact on nearby wells; wetland impacts
		Biological controls (aquatic weevil or triploid carp)	Lycott 1991; Fugro 1996	Avoids chemical treatment; does not interfere with other lake uses; can be highly selective (weevil)	Mixed success; permitting issues; deleterious ecological effects; introduction of nonnative species; removal of desirable plant species (by carp)
		Herbicide (Sonar treatment)	Lycott 1991; Fugro 1996	Selective for nuisance plant species; can be spatially specific; minimal lake use disruption; does not impact fauna; systemic nature minimizes impact on lake oxygen demand	Complex permitting process; negative public perception and user dissatisfaction; potential impact on detrital load and oxygen demand; difficult and costly to do area selective treatments; requires extended contact time
		Hydroraking	Lycott 1991;	Provides better control vs harvesting; removes plants and roots; area selective	Expensive; disruptive of benthos; can kill fish; labor intensive; produces plant fragments
		Mechanical harvesting	Lycott 1991; Wetzel 1994; Fugro 1996	Manages plant density to 6 ft depth; can be highly selective; can avoid detrital load if plants are collected; does not interfere with other lake uses	Impermanent; rapid regrowth requires upkeep; does not remove plants, only manages; labor-intensive and costly; weather and season-dependent; can kill fish; produces plant fragments
		Dyes	ENSR 1999; Fugro 1996	Limits light to plants as well as algae	Will not control shallow plants; non-selective; user dissatisfaction; negative public perception; causes shallow stratification and deep anoxia
	Nuisance Plant Density	Benthic barriers	Lycott 1991; Fugro 1996; ENSR 1999	Provides effective localized plant control; reduces turbidity	Expensive; requires maintenance; can cause anoxia at sediment interface; plants overgrow porous barriers; solid barriers cause gas-buildup and billowing
		Dredging	Lycott 1991; Fugro 1996; ENSR 1999	Removes plants, nutrients, and sediments; area selective; can provide long-term benefits; increases depth; exposes beneficial carbonate marl sediments	Expensive; labor intensive; disruptive to benthos; requires sediment disposal; permitting issues

Management Area	Target	Method	Source	Advantages	Drawbacks
Lake Water Column	**Over-Bottom Anoxia**	Hypolimnetic withdrawal	Lycott 1991;	Removes oxygen-depleted water; removes nutrient-rich water; can reduce sediment phosphorus content over time	Expensive to implement; can impact thermal stratification; does not improve trout habitat; discharge rates insufficient to keep up with oxygen demand; requires 1.5 miles of pipe from deep hole to outlet
		Hypolimnetic aeration	Lycott 1991; Wetzel 1994; Fugro 1996	Increases deep oxygen concentrations; decreases internal phosphorus loading; preserves thermal stratification; increases trout habitat; provides refuge for zooplankton; can be used for delivery of isolated cyanobacteria treatment;	High initial capital expenditure; requires maintenance costs and annual startups; on-shore air compressor or oxygen tanks needed for operation
		Artificial circulation (aeration or mechanical)	Lycott 1991; Wetzel 1994; Fugro 1996	Decreases anoxia; decreases internal phosphorus loading	Mixes water column; eliminates trout habitat; mixed success rates; can increase nutrients in shallow water
	Internal Phosphorus Loading	Dredging	Lycott 1991;	Source of nutrient loading is completely removed	Only suitable for shallow lakes; may be prohibitively expensive
		Phosphorus inactivation via alum	Lycott 1991; Wetzel 1994; Fugro 1996	Prevents internal phosphorus loading; nutrient reduction limits cyanobacteria growth; could reduce oxygen demand by reducing phytoplankton biomass/decomposition; lasts years before need for further application (5-12 years)	Chemical treatment undesirable to public; decreases pH; requires maintenance of pH to avoid toxicity
		Sediment oxidation via nitrate	Lycott 1991	Prevents release of phosphorus from lake sediments	Maintains anoxia; limited effect; theoretical method with limited data; permitting requirements; public perception
	Cyanobacteria	Copper treatment	Fugro 1996; ENSR 1999	Effective algae control	Toxic to aquatic fauna; temperature dependence; persistent and accumulative in sediments; public perception
		Percarbonate oxidative algaecide treatment	GZA 2020	Effective algae control; potential for chemical oxidation of anaerobic respiration byproducts	New management technology; more expensive than copper-based treatments; oxidation effects on anaerobic respiration byproducts are unknown

Element D: Identify Technical and Financial Assistance Needed to Implement Plan

Element D: Estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan.

Table D-1 presents the funding needed to implement the management measures presented in this watershed plan. The table includes costs for structural and non-structural BMPs, operation and maintenance activities, information/education measures, and monitoring/evaluation activities.

Table D-1: Summary of Funding Needed to Implement the Watershed Plan.

Management Measures	Location	Capital Costs	Operation & Maintenance Costs	Relevant Authorities	Technical Assistance Needed	Funding Needed
Structural and Non-Structural BMPs (from Element C)						
Dredging Project Plan Sewer Expansion Plan (if any) Septic Replacement Plan (if any) Stormwater Improvement Plan (if any) Highway/Road Improvement Plan (if any) Significant Land Use Changes Planned (if any) Deicing Strategy Plan (if any)						
Information/Education (see Element E)						
Pamphlets, flyers, posting, Town-wide communications, community feedback meetings, etc.						
Monitoring and Evaluation (see Element H/I)						
Annual water quality and tributary monitoring in collaboration with GZA, approximately $40,000/yr Other studies and monitoring as requested on 7/15						
					Total Funding Needed:	
Funding Sources:						
Local and potential Grant support						

Commented [SR11]: Info needed from Town and Stakeholders, as discussed in 7/15 meeting. These are the management measures, info for other COLUMN HEADINGS need to be provided by SBSC members or other sources

Commented [SR12]: Same as above

Commented [SR13R12]:

Commented [SR14]: Same as above

Commented [SR15]: Anything that the SBSC would like to mention here?

For each priority, describe the above and estimate funding where you know, or say ‘to be determined’.

Element E: Public Information and Education

Commented [SR16]: Info needed from our 7/15 discussion for all of Element E

Element E: Information and Education (I/E) component of the watershed plan used to:

1. Enhance public understanding of the project; and
2. Encourage early and continued public participation in selecting, designing, and implementing the NPS management measures that will be implemented.

Step 1: Goals and Objectives

The goals and objectives for the watershed information and education program.

Referencing the BRPC/SBA/Town of Stockbridge, 2012: "Stockbridge Bowl Watershed Survey" may be useful for this section.

Step 2: Target Audience

Target audiences that need to be reached to meet the goals and objectives identified above.

Step 3: Outreach Products and Distribution

The outreach product(s) and distribution form(s) that will be used for each.

Step 4: Evaluate Information/Education Program

Information and education efforts and how they will be evaluated.

Other Information

Elements F & G: Implementation Schedule and Measurable Milestones

Element F: Schedule for implementing the nonpoint source management measures identified in this plan that is reasonably expeditious.

Element G: A description of interim measurable milestones for determining whether nonpoint source management measures or other control actions are being implemented.

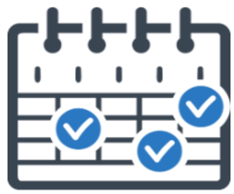


Table FG-1: Implementation Schedule and Interim Measurable Milestones

Structural & Non-Structural BMPs
Dredging Project Plan Sewer Expansion Plan (if any) Septic Replacement Plan (if any) Stormwater Improvement Plan (if any) Highway/Road Improvement Plan (if any) Significant Land Use Changes Planned (if any) Deicing Strategy Plan (if any)

Commented [SR17]: Estimated schedule and measurable milestones for each estimated by SBSC, need SBSC and others to provide SCHEDULE and INTERIM MEASURABLE MILESTONES

Public Education & Outreach
SBSC SCHEDULE and MEASURABLE MILESTONES from Element E above.

Monitoring
Since 2020, ongoing annual monitoring is conducted collaboratively by the SBSC and GZA. Sampling occurs monthly during the heavy-use recreational season (April – November, 9 rounds total). Other STUDIES and MONITORING as requested on 7/15

Commented [SR18]: Same as above

Scheduling and milestone information:

This is where schedule and milestones are described in further detail, according to your agreed upon process.

Elements H & I: Progress Evaluation Criteria and Monitoring

Element H: A set of criteria used to determine (1) if loading reductions are being achieved over time and (2) if progress is being made toward attaining water quality goals. Element H asks "**how will you know if you are making progress towards water quality goals?**" The criteria established to track progress can be direct measurements (e.g., E. coli bacteria concentrations) or indirect indicators of load reduction (e.g., number of beach closings related to bacteria).

Element I: A monitoring component to evaluate the effectiveness of implementation efforts over time, as measured against the Element H criteria. Element I asks "**how, when, and where will you conduct monitoring?**"

The water quality target concentration(s) is presented under Element A of this plan. To achieve this target concentration, the annual loading must be reduced to the amount described in Element B. Element C of this plan describes the various management measures that will be implemented to achieve this targeted load reduction. The evaluation criteria and monitoring program described below will be used to measure the effectiveness of the proposed management measures (described in Element C) in improving the water quality of Stockbridge Bowl.

Indirect Indicators of Load Reduction

Lake water chemistry collected at regular depths down a vertical water column during the early spring months through summer and autumn can provide much insight into watershed loading dynamics. For instance, if phosphorus is sourced from watershed sources, we would expect to observe moderately high to high phosphorus concentrations through the seasons where watershed transport is highest (spring and autumn). We would also expect high P concentrations following large storm events that drop significant amounts of precipitation. Instead, Stockbridge water column P is moderate through the spring season (20 – 40 ug/L), quickly exhausted in the upper portion of the water column as stratification develops and becomes very concentrated over bottom at the deepest depths (to 460 ug/L) as stratification persists through summer. Following autumn turnover, water column P concentrations again become moderate as the over bottom, accumulated P is mixed through the water column. This annual dynamic suggests internal loading, not watershed loading, is the main source of P. If it were to change such that spring and autumn water conditions became enriched, or surface waters became P enriched even during stratification, that would be an indirect indicator of externally sourced P.

Another indicator of where P enrichment is occurring comes from the location and spatial distribution of the organisms that track it most closely, cyanobacteria. Following stratification from spring through autumn, cyanobacteria grow densely only at deep depths where P is most concentrated. Cyanobacteria are typically sparse in the upper water column (0-5 m) until cyanobacteria become entrained due to a water column mixing storm event or autumn turnover. Thus, cyanobacteria concentrated in the upper water column during stratified conditions or growing benthically proximal to the inlet locations could indirectly indicate watershed loading sources.

Project-Specific Indicators

Dredging Project Plan

Sewer Expansion Plan (if any)

Septic Replacement Plan (if any)

Stormwater Improvement Plan (if any)

Highway/Road Improvement Plan (if any)

Significant Land Use Changes Planned (if any)

Deicing Strategy Plan (if any)

Commented [SR19]: SBSC and other sources please provide feedback on how these efforts can be observed to improve water quality – describe plans you may have for on-going monitoring of plants, snails, bacteria, etc.

TMDL Criteria

No TMDL exceedances were recorded for Stockbridge Bowl.

Direct Measurements

Current monitoring includes direct measurements of total phosphorus (TP) which is measured down the water column as well as inlet stream locations. Stream flow is measured in addition to water chemistry. Thus, spatial resolution and potential sources of P enrichment are well-characterized. Other nutrients are monitored directly as well (nitrogen species, silica, and iron) but are not as high concern as phosphorus.

The following table summarizes the parameters collected monthly, from April-October:

Table H-1: Routine monitoring data collected from Stockbridge Bowl

Type of Sample	Individual Parameters	Significance

Field measurements	Lake water level, water clarity (Secchi disk depth), general observations	These basic field observations are important for monitoring the aesthetic qualities of the lake that would be noticed by the general public. Water clarity has ecological implications also.
Water column profiles	Temperature, stratification, dissolved oxygen, transmissivity, pH, turbidity, specific conductivity, total dissolved solids	These measurements provide a snapshot of monthly lake conditions from top to bottom. These various physical and chemical parameters are all collected quickly and in tandem by a submersible instrument deployed over the side of the boat. Together, these data provide insight into water quality and ecological conditions.
Chemistry samples	total phosphorus, ammonia, nitrite, nitrate, total Kjeldahl nitrogen, silica oxide, iron, manganese, calcium, and alkalinity	These chemistry samples are collected from five depths in the water column (1m, 5m, 7m, 10m, and 14m) as well as stream locations and delivered to Phoenix Environmental Lab. They provide information on nutrient concentrations (which is important for anticipating cyanobacteria), and other water quality parameters.
Biological samples	phytoplankton samples for counting, pigment analysis, and zooplankton samples	Phytoplankton samples are preserved and counted to track the general community through the summer, which specific attention given to cyanobacteria. The pigment analyses allow us to rapidly identify how much cyanobacteria are occurring, and where in the water column they are located. Zooplankton are an important part of the larger ecosystem, and also provide insight into overall lake health and phytoplankton changes.

Dredging Project Plan

Sewer Expansion Plan (if any)

Septic Replacement Plan (if any)

Stormwater Improvement Plan (if any)

Highway/Road Improvement Plan (if any)

Significant Land Use Changes Planned (if any)

Deicing Strategy Plan (if any)

Commented [SR20]: SBSC and other sources please provide feedback on any direct measures you intent to do on these topics, if any.

Adaptive Management

Stockbridge Bowl has a comprehensive list of management strategies that have been recommended or discussed since the mid-20th century (see Table C-3). While not all strategies are feasible due to expense or environmental impact, The Town and SBA are afforded the luxury of knowing what options remain available for each management target as priorities shift over time.

Stockbridge Bowl is also closely monitored for physical, chemical, and biological parameters that are important for water quality and public health. Thus, there is a fast feedback loop between the time that a management issue arises, is characterized, and is made apparent to the Town and SBSC. The SBSC's explicit duty is to review lake conditions, maintain a watershed management plan, and maintain regular contact with all stakeholders and technical advisors.

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TMDL

No TMDL Found

Appendices

Appendix A – Pollutant Load Export Rates (PLERs)

Land Use & Cover[1]	PLERs (lb/acre/year)		
	(TP)	(TSS)	(TN)
AGRICULTURE, HSG A	0.45	7.14	2.6
AGRICULTURE, HSG B	0.45	29.4	2.6
AGRICULTURE, HSG C	0.45	59.8	2.6
AGRICULTURE, HSG D	0.45	91	2.6
AGRICULTURE, IMPERVIOUS	1.52	650	11.3
COMMERCIAL, HSG A	0.03	7.14	0.3
COMMERCIAL, HSG B	0.12	29.4	1.2
COMMERCIAL, HSG C	0.21	59.8	2.4
COMMERCIAL, HSG D	0.37	91	3.7
COMMERCIAL, IMPERVIOUS	1.78	377	15.1
FOREST, HSG A	0.12	7.14	0.5
FOREST, HSG B	0.12	29.4	0.5
FOREST, HSG C	0.12	59.8	0.5
FOREST, HSG D	0.12	91	0.5
FOREST, HSG IMPERVIOUS	1.52	650	11.3
HIGH DENSITY RESIDENTIAL, HSG A	0.03	7.14	0.3
HIGH DENSITY RESIDENTIAL, HSG B	0.12	29.4	1.2
HIGH DENSITY RESIDENTIAL, HSG C	0.21	59.8	2.4
HIGH DENSITY RESIDENTIAL, HSG D	0.37	91	3.7
HIGH DENSITY RESIDENTIAL, IMPERVIOUS	2.32	439	14.1
HIGHWAY, HSG A	0.03	7.14	0.3
HIGHWAY, HSG B	0.12	29.4	1.2
HIGHWAY, HSG C	0.21	59.8	2.4
HIGHWAY, HSG D	0.37	91	3.7
HIGHWAY, IMPERVIOUS	1.34	1,480	10.5
INDUSTRIAL, HSG A	0.03	7.14	0.3

INDUSTRIAL, HSG B	0.12	29.4	1.2
INDUSTRIAL, HSG C	0.21	59.8	2.4
INDUSTRIAL, HSG D	0.37	91	3.7
INDUSTRIAL, IMPERVIOUS	1.78	377	15.1
LOW DENSITY RESIDENTIAL, HSG A	0.03	7.14	0.3
LOW DENSITY RESIDENTIAL, HSG B	0.12	29.4	1.2
LOW DENSITY RESIDENTIAL, HSG C	0.21	59.8	2.4
LOW DENSITY RESIDENTIAL, HSG D	0.37	91	3.7
LOW DENSITY RESIDENTIAL, IMPERVIOUS	1.52	439	14.1
MEDIUM DENSITY RESIDENTIAL, HSG A	0.03	7.14	0.3
MEDIUM DENSITY RESIDENTIAL, HSG B	0.12	29.4	1.2
MEDIUM DENSITY RESIDENTIAL, HSG C	0.21	59.8	2.4
MEDIUM DENSITY RESIDENTIAL, HSG D	0.37	91	3.7
MEDIUM DENSITY RESIDENTIAL, IMPERVIOUS	1.96	439	14.1
OPEN LAND, HSG A	0.03	7.14	0.3
OPEN LAND, HSG B	0.12	29.4	1.2
OPEN LAND, HSG C	0.21	59.8	2.4
OPEN LAND, HSG D	0.37	91	3.7
OPEN LAND, IMPERVIOUS	1.52	650	11.3
[1]HSG = Hydrologic Soil Group			