

Water Quality Improvement for Pepperell Pond

A Major Qualifying Project



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Submitted by:

Jonathan Carelli

Daniel LaFrance

Christopher Luppino

Kristen Ostermann

Approved by:

Professor Paul P. Mathisen, Advisor

Abstract

This project assesses water quality in the Nashua River mainstem and Pepperell Pond, in Pepperell, Massachusetts. Water quality testing and flow modeling were used to assess various nutrient loadings and explores means of remediation. Through water quality analysis, mass balances, and point and nonpoint loading models, it determines methods for reducing nutrient levels in the pond, as well as developing a management plan to control nuisance plants and improve and maintain water quality in the ensuing years.

Capstone Design Requirement Statement

This project satisfies the capstone design requirement for a Bachelor of Science degree in Civil & Environmental Engineering at Worcester Polytechnic Institute. It satisfies the Accreditation Board of Engineering and Technology (ABET) design requirement for Civil Engineering by including a management plan for the control of nuisance plants and algae in Pepperell Pond, Pepperell, Massachusetts. The Massachusetts Department of Environmental Protection, along with its drafted TMDL report for phosphorus in the Nashua River, recommended “a separate management plan for Pepperell Pond... which would focus on identifying zoned uses of the pond with corresponding structural controls for removal of bottom aquatic vegetation in certain specified recreational use areas.”¹ This project delivers a preliminary management plan for nutrients in the pond, including methods to control all significant phosphorus loads, and physical controls for the removal of nuisance plants. It involves analysis of the nutrients available in the pond, and their forms- soluble, settled, or absorbed in vegetation, and removal methods applicable in the available cases. The project included an evaluation of a series of design alternatives and consideration of a number of constraints to develop a recommended design that was applicable for the specific pond. Constraints on the design included consideration of environmental quality and public health, environmental sustainability, economics, and social and political factors. Since the DEP’s ultimate goal for the pond is recreational use, invasive structural controls were not advised as other techniques proved capable of inexpensive, environmentally low-impact implementation.

This project also includes an analysis of current conditions and the potential impact of increased and decreased discharges from the nearby Wastewater Treatment Facilities (WWTFs) which may require future expansion at this time, as well as various changes to impervious area resulting from local development. It is therefore expected that the management plan will serve as a sufficient guide for the immediate future of Pepperell and Groton.

¹ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester.

Executive Summary

This project investigated water quality and nutrient loadings for Pepperell Pond, an impoundment of the Nashua River main stem in Pepperell Massachusetts. It used land use and weather information to model nonpoint loadings directly to the pond, as well as estimating nutrient flow from septic systems, sediment analysis, water quality measurement, and flow monitoring data. This information was used to create a detailed picture of the factors affecting the health of the pond, and to determine effective methods for nutrient reduction, algae removal, and control of future development to prevent further damage.

The final product of this project is a management plan for the pond, to be used by the Nashua River Watershed Association and other interested parties to restore the health of the pond. This management plan is included in the report. Management recommendations include stormwater management, education of local landowners regarding fertilizer use, vegetative barriers and landscaping, changes to septic system practices, and frequent skimming of the nuisance plants.

On two separate days, October 5 and November 30, 2007, the authors collected water samples from approximately seven locations in Pepperell and surrounding areas, including the Ice House Dam in Shirley, and the pond inlet at route 119 in Groton. On October 5, sediment cores were taken from three locations, near the inlet at the Groton boat launch, at the public canoe launch in Pepperell, at the pond's north end, and in the widest section of the river, about half a mile south of the Pepperell canoe launch. The water samples were tested for pH, alkalinity, nitrogen compounds, phosphorus, and total solids. Phosphorus loads were generally 0.1-0.2 mg/L, and were found to be the governing nutrient. Nitrate and ammonia were generally present in concentrations of 1.5-3 mg/L as nitrogen.

Soil cores were extracted to determine sediment phosphate loading, because the Massachusetts Department of Environmental Protection found that the nearby Assabet River drew approximately 40% of its phosphate loading from the sediments in the riverbed. In the case of Pepperell Pond, the samples were mixed with 40 mL of water and agitated for 24 hours. At the conclusion of the 24 hours, the water was tested for phosphorus, nitrogen, and ammonia concentrations. Results indicated hypoxic conditions at the north end of the pond, as ammonia appeared in much higher concentrations than nitrate, and phosphorus concentrations appeared to

establish equilibrium with the sediments at approximately 0.2 mg/L. To test the phenomenon of equilibrium, standard solutions of known phosphorus concentrations were mixed with sediment samples and the same experiment was re-run. The resulting phosphorus concentrations tended to reflect an equilibrium around 0.2 mg/L as phosphorus. The samples with less phosphorus initially increased in concentration over the 24 hour span, while those with greater than 0.2 mg/L tended to lose phosphorus, which appeared to adsorb to the sediment. The phenomenon became more pronounced at higher initial concentrations. The conclusion drawn from this experiment was that phosphates are bound to the sediments in the pond, but form an equilibrium with the surrounding water, which allows them to either be released when concentrations are low, or move to the sediments when concentrations are high. Therefore, restoring the health of the pond must consider the consequences of high phosphorus concentrations in any conditions, regardless of the presence of aquatic plants capable of reproducing in phosphate-rich water.

Nonpoint loadings directly to the pond were established using event mean runoff nutrient concentrations and the NRCS method for runoff volumes. The design storm approximated a one month return period, because Pepperell's annual rainfall can be approximated as a series of one month, quarterly, and one year return period, 24 hour duration storms. We estimated a curve number of 67 for the entire tributary area around the pond, and 75 for the predominantly agricultural southwest edge of the pond. Peak runoff was estimated to be 72 cubic feet per second for a 24 hour storm duration and 2.1" of precipitation. Using estimates from Marsh² for runoff phosphorus concentration by land use and annual nutrient runoff by land use, the storm loading was estimated at 21-50 kg of phosphate, or 7-18 kg of phosphorus per storm. Septic system loadings were also considered. Approximately 40 homes lie within 100 yards of the river's edge and thus may contribute, collectively, 11.2 kg of phosphorus (34.4 kg as phosphate) per year, approximately equaling an additional one month storm per year.

A series of potential management options was the next step of this project. Many address the presence of certain types of plants- blue-green algae, duckweed, and water chestnut. Methods for physical removal of these plants can restore aesthetic qualities to the pond, but will not necessarily remove all of the nutrients present. Reduction of point loadings upstream has been initiated in the form of the total maximum daily loading passed by the Massachusetts DEP, which will address influent concentrations. Runoff mitigation and stormwater reduction can

² Marsh, William M. Landscape Planning, Fourth Edition. 2005, John Wiley & Sons, New York. 216-217.

address non-point loadings, as will sewer extensions over time. Education regarding proper application of fertilizer can prevent runoff of pure nutrients. Surface agitation and aeration can create conditions that prevent phosphorus from leaching out of sediments, while encouraging the presence of fish and preventing algae from matting together by increasing shear in the direction of flow. Other options, such as dredging and dam removal, would succeed in removing much of the sediment, but were not considered due to the potential for environmental damage, as well as the problems downstream resulting from high solids loading. Benthic barriers, which physically block contact between sediments and plants, were considered, but were ruled out due to sensitive animal species living along the riverbed. A series of inexpensive options, each with the potential to solve a section of the problem, were packaged together to create a plan for overall management of Pepperell Pond, so that over time the pond can be restored for use as a recreational water.

Acknowledgements

The project team would like to thank Ms. Martha Morgan of the Nashua River Watershed Association for agreeing to be the liaison for the sponsor of this project and for the contact information she has provided to us. In addition, Professor Paul P. Mathisen, P.E., PhD, of the Worcester Polytechnic Institute Civil and Environmental Engineering Department is acknowledged for his guidance as an advisor. We would also like to thank Dean Daigneault and Donald Pelligrino of the Civil and Environmental Department for their assistance with sampling and laboratory testing. Finally, we would like to thank our family and friends for the total support they have given through this challenging project.

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Authorship

The members of this group have worked together efficiently, effectively, and with great determination. Each of the group members contributed significantly to the project as a whole. Furthermore, each member put in equal amounts of time in the editing and the revising of the report, as well as providing comments and additions to each other's sections. Nevertheless, the primary authors for each section are outline below.

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1. Introduction

The Nashua River, located in north-central Massachusetts and southern New Hampshire, has a long history of industrial abuse. For over a century, Fitchburg and Leominster, on the north branch of the Nashua, have hosted heavy industries, many of which loaded the river with pollution, killing fish, and making the river unsafe for recreation and unattractive for the passersby. It was at one time, in 1965, listed as unsafe to receive further sewage.³ With the United States Environmental Protection Agency (EPA) promoting clean water after the Federal Water Pollution Control Act of 1972, there has been a surge in pollution abatement efforts nationwide.⁴ The Nashua River has benefited from pollution prevention measures, toxics reduction, and an emphasis on greener industries. With increased attention from the EPA, Massachusetts Department of Environmental Protection (DEP), the New Hampshire Department of Environmental Services, and the Nashua River Watershed Association, the river has witnessed improvement. However, the work is not complete.

Pepperell Pond, located on the Nashua River at the Groton-Pepperell town line near the Massachusetts-New Hampshire border, as indicated by the arrow in Figure 1, illustrates the work remaining ahead for the Nashua River Watershed Association, and for cleanup of the river in general. This section of the river is plagued by eutrophication, or growth of nuisance plants and algae as a result of excessive nutrient loading.⁵ This growth can produce aesthetic concerns with the colors and smells associated with the bloom, and in some cases can produce toxins and make the water unsafe for consumption and recreation.⁶

³“The Past and the Future,” Nashua River Watershed Association. Online at <http://www.nashuariverwatershed.org/> last accessed October 25, 2007.

⁴ “Clean Water Act” Last updated on Friday, September 7th, 2007. <http://www.epa.gov/region5/water/cwa.htm>

⁵ Fetter, C.W. Applied Hydrogeology, Fourth Edition. 2001, Prentice Hall, Upper Saddle River, New Jersey. 386.

⁶ Davis, Mackenzie L, and Masten, Susan J. Principles of Environmental Engineering and Science, Third Edition. 2004, McGraw Hill, Boston. 586.



Figure 1: Massachusetts, with Pepperell indicated by the arrow⁷

Pepperell Pond is listed by the DEP as a “Class D impacted water” for nutrient enrichment and nuisance plant growth.⁸ It has been targeted for cleanup and the development of management practices to reduce nutrient loadings and associated problems. Figure 2 shows a section of Pepperell Pond during an algal bloom. The bloom has been attributed to excessive phosphorus loading of the pond, which encourages rapid growth in warm weather.⁹ A total maximum daily loading has been drafted by the DEP to prevent further nutrient enrichment of this section. While this loading restriction impacts wastewater discharges, it does not affect nonpoint sources, such as surface runoff, or the actual blooms in the pond, further than to recommend a management plan, by which nonpoint sources can be curbed and pond water quality can be restored.¹⁰

⁷ Google Maps 2/20/08

⁸ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 4.

⁹ Ibid

¹⁰ Ibid



Figure 2: An algal bloom covers Pepperell Pond.¹¹

The Nashua River watershed is located in a rapidly urbanizing area, and is threatened by changes to land use and development along its banks.¹² Land development and road building have increased impervious areas contributing to the effects of stormwater on the river. Phosphates, from agricultural and organic sources, are a leading cause of eutrophication. Increased stormwater flows tend to increase the nonpoint loads to the pond, and may diminish the work being done to reduce point loadings. The DEP has recommended that the Nashua River Watershed Association draft a collective management plan for nutrient loadings to Pepperell Pond, which will define actions to reduce algal blooms, dampen dissolved oxygen swings, and restore overall health to the system.¹³

¹¹ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 1.

¹² Ibid

¹³ Ibid

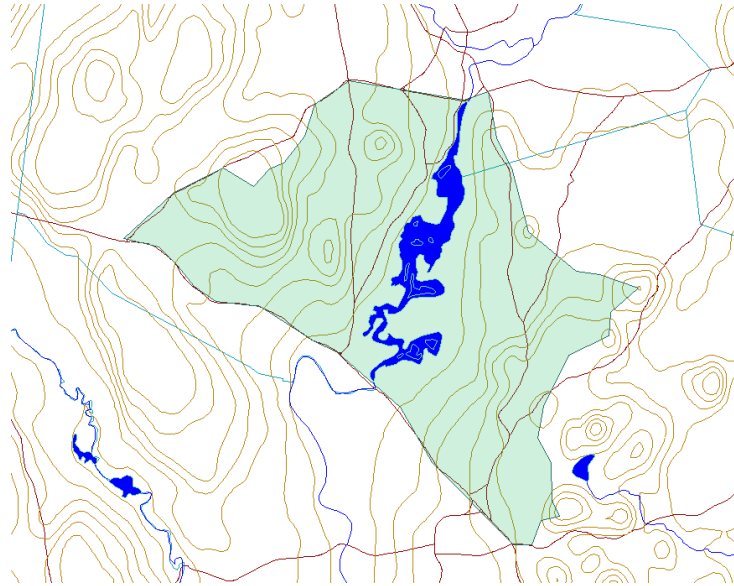


Figure 3: Topography and tributary area of Pepperell Pond¹⁴

The goal of this project was to develop a management plan for reducing nutrients and their effects on the pond. Accomplishing this goal required analysis of existing information about Pepperell Pond and its surrounding, as well as field testing and stormwater modeling. The watershed that contributes to Pepperell Pond, as shown in Figure 3, is the area within which these studies were conducted due to it have the greatest impact on the pond. Water quality, sediment quality, flow conditions, land use, and runoff analyses were chosen as means to model the area directly contributing to nutrient loads in the pond. Such analysis assisted in quantifying the amount of phosphorus entering and exiting the pond. While current conditions were the focus of this work, scenarios involving future development in the area were developed and considered for nonpoint runoff impacts. Remediation measures, targeted at the most significant sources of phosphorus, were proposed and considered with regard to overall effectiveness, cost of implementation, ease of operation, and impact of implementation. The most feasible candidates were chosen for a management plan, addressing point and nonpoint nutrient sources and the methods to implement each option.

In order to eventually create a management plan, a process which begins with investigating various sources of background information on the topic of nutrients and general conditions of the area is initiated. After background information is researched methods are

¹⁴ "Surface Contour Map" Map. MassGIS. 25 Feb. 2008 <<http://www.mass.gov/mgis/mapping.htm>>.

undertaken to develop a model of water quality conditions impacting Pepperell Pond. Analysis of these results leads to the various remedies considered, as well as the final recommendations based on the various modeling efforts. Since this report is focusing on Pepperell Pond as a key area of concern within the Nashua River, these final recommendations as presented in the management plan could be applied, along with the other research associated with this report to the entire Nashua River. The modeling efforts, which are the basis for the recommendations, include analysis of water quality conditions and nutrients throughout the northeastern United States, details sampling, testing and modeling for several point and nonpoint source loadings, as well as the methods employed to derive a phosphate mass balance for the area.

With a management plan in place, the amount of nutrients entering into the pond by various avenues will be reduced. Lowering the amount of nutrients in the pond will serve to diminish the potential for algal growth in the pond. While management practices may not result in a dramatic reduction in algal growth in the short term, continued administration of the practices developed in the following chapters will result in a restoration of Pepperell Pond to a pristine state.

2. Background

The underlying problem this project addresses is the high level of phosphorus in Pepperell Pond, on the mainstem of the Nashua River. This high level is associated with the upstream wastewater discharges, which are designed to be over 30 million gallons per day (MGD).¹⁵ The river has issues associated with algae, nuisance and invasive plant species, and the impacts of historical industrial use. Phosphorus has been targeted for removal because of its role in eutrophication.¹⁶ The history and pollution issues associated with the Nashua River, the Nashua River watershed hydrologic system, aquatic plant and nutrient behavior in natural systems, and recent remediation efforts are presented.

2.1 Hydrology

Hydrology is the study of the circulation, distribution, and quality of water throughout the earth. For many years, people have been studying the movement of water, in order to provide insight into environmental policy, planning, and engineering.¹⁷ The hydrologic cycle is an important aspect of water transport in any natural system.

2.1.1 Hydrologic Cycle

The hydrologic cycle is a complex cycle that distributes water throughout the oceans and lakes, the land, and the air. Water usually first evaporates into the air from water bodies such as lakes, rivers, and streams. Evaporation can also occur through the cell walls of plants, a phenomenon called transpiration.¹⁸ Hydrologists call the combination of evaporation from surface water bodies and transpiration from plants evapotranspiration.

As the evaporated water declines in temperature in the atmosphere, the water vapor forms clouds, which in turn precipitate onto the ground. Vegetation catches much of this precipitation while other amounts are stored back into surface water bodies. In highly developed and urban areas, there is not enough vegetation to catch much of the water that falls as rain. As a result,

¹⁵ Ibid.

¹⁶ Ibid.

¹⁷ Hwang, Ned H., and Robert J. Houghtalen. "Hydrology for Design." Hydraulic Engineering Systems. 3rd ed. Upper Saddle, New Jersey: Prentice-Hall, Inc, 1996. 322.

¹⁸ Ibid.

much of the water becomes runoff and carries pollutants overland into surface water bodies.¹⁹ In addition, much of the water infiltrates the ground where it becomes ground water, which eventually flows throughout the land and into public drinking supplies.

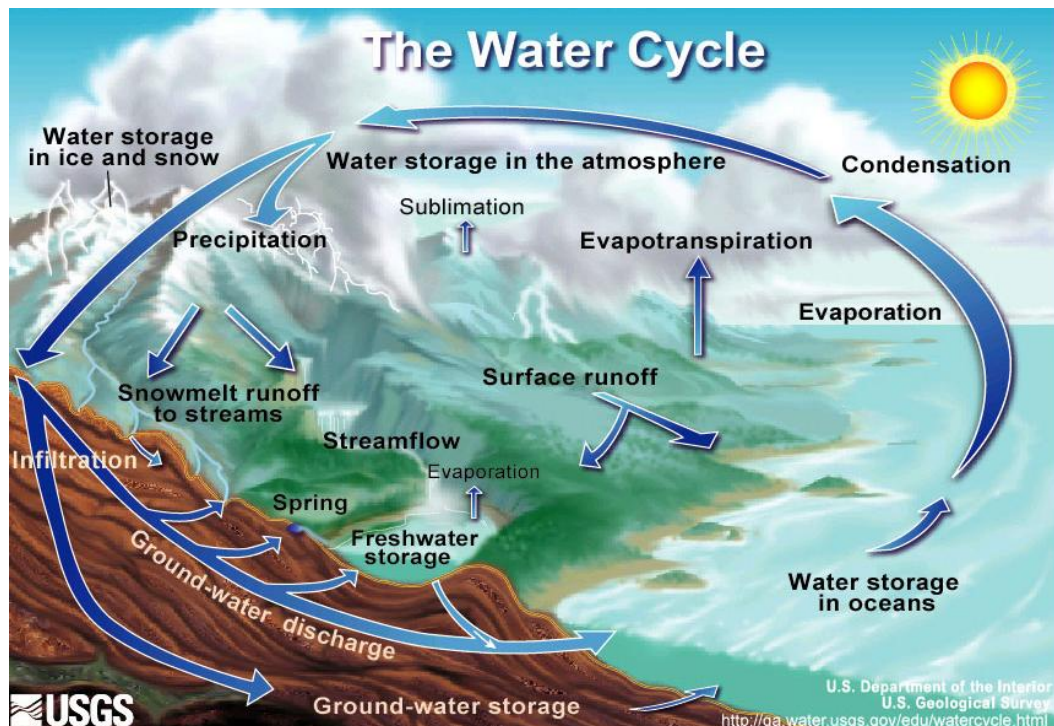


Figure 4: Hydrologic Cycle²⁰

2.1.2 Watershed

A watershed is a tract of land that supplies surface water to a stream or river at a particular point. Water drains throughout a watershed along the steepest topographical slopes. This land may be a few acres or it could be many thousands of acres in area. Many times, a particular watershed may have sub basins in which water flows into smaller streams before entering the larger streams, and then finally to a particular discharge point.²¹

¹⁹ Davis, Mackenzie L, and Masten, Susan J. Principles of Environmental Engineering and Science, Third Edition. 2004, McGraw Hill, Boston. 191.

²⁰ Perlman, Howard. "The Water Cycle- USGS Science for Schools." Online at <http://ga.water.usgs.gov/edu/watercycle.html>. Updated February 15, 2008. Last accessed February 20, 2008.

²¹ Davis, Mackenzie L, and Masten, Susan J. Principles of Environmental Engineering and Science, Third Edition. 2004, McGraw Hill, Boston. 193.

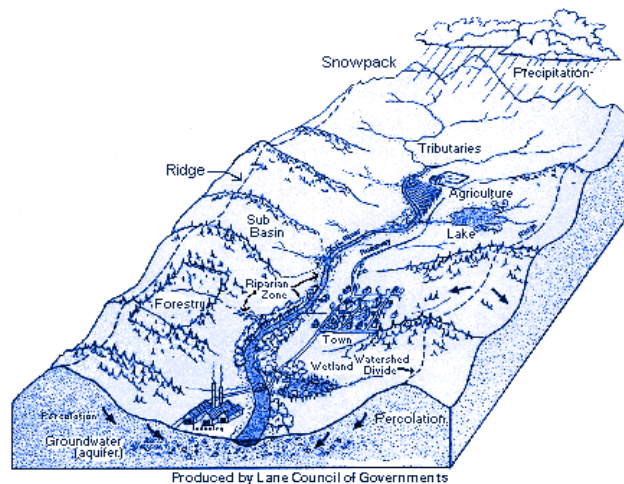


Figure 5: Example Watershed²²

2.2 Surface and Ground Water Flow and Exchanges

Surface water comprises rivers, streams, and other overland flow. This water moves along the contours of the land. Ground water flow is the water that infiltrates into the ground. This flow usually travels through large aquifers, underground layers of porous rock that water saturates, until the ground water flow meets a surface water body.²³ As the demand for clean water is rising, many people are using ground water as their source of water. This demand, along with seasonal variability often affects the water ground water flows throughout the ground.²⁴ Ground water and surface water are often interconnected. They rely on each other and it is important to know how they interact.

Ground water usually interacts with surface water when the ground water is located in unconfined shallow water table aquifers. This interaction comes in the form of receiving water from a lake or stream or discharging water into a lake or stream. Usually, a stream's base flow is defined as the flow from an unconfined aquifer that feeds water to a river or stream.²⁵ The base flow of a stream is the portion of a stream's flow that does not come from surface runoff but rather ground water contributions. Another way in which ground water interacts with surface

²² Doppelt, Bob, Mary Scurlock, Chris Frissell, and James Karr. 1993. *Entering the Watershed: A new approach to save America's River Ecosystems*. Washington, DC: Island Press. Copyright: Pacific Rivers Council

²³ Fetter, C.W. *Applied Hydrogeology, Fourth Edition*. 2001, McGraw Hill, Upper Saddle River, New Jersey. 5.

²⁴ Marsh, William M. *Landscape Planning, Fourth Edition*. 2005, John Wiley & Sons, Boston. 135.

²⁵ Fetter, C.W. *Applied Hydrogeology, Fourth Edition*. 2001, McGraw Hill, Upper Saddle River, New Jersey. 5.

water is when people pump ground water to the surface for use as drinking and irrigation water.²⁶

Surface water interacts with ground water by “recharging” the amount of ground water flow below the surface. The amount of precipitation that does not contribute to rivers or streams percolates downward through the ground surface into aquifers. In most areas, five to fifty percent of annual precipitation contributes to ground water recharge.²⁷

2.3 Total Maximum Daily Loads (TMDLs)

Total maximum daily loads (TMDLs) are average wastewater effluent concentrations for given contaminants. Their levels are determined such that they do not cause damage to the receiving stream, and are legally binding. Under the Clean Water Act, the DEP is required to list streams that are impaired by pollutants, and to require measures that will improve conditions.²⁸ The Nashua River is listed as a “Category 5” river for nutrient enrichment,²⁹ meaning that the river does not meet prescribed water quality standards and can be improved with a loading restriction, or TMDL.³⁰

2.3.1 Phosphorus TMDL for the Nashua River

In 2007, the Massachusetts Department of Environmental Protection drafted a TMDL for phosphorus on the Nashua River. The report identified the Nashua River as a “Class 303(d) listed water,” meaning that it has excessive nutrient levels, low dissolved oxygen, and aquatic nuisance plants.³¹ The main nutrient sources, particularly during low-flow conditions, were identified as point loadings from wastewater treatment facilities, with the most striking difference between point and nonpoint loads being in the North Branch, in Fitchburg. Figure 6 below shows the DEP model’s simulated loadings in low flow conditions, at various locations along the Nashua River. Models used included BASINS, Qual2E, and HSPF, which are now integrated into BASINS 4.0, a free software package which allows a user to build and model an entire watershed using geographical information systems (GIS) software.

²⁶ Phillips, Nancy. "Ground Water & Surface Water: Understanding the Interaction." Conservation Technology Information Center. Online at <http://www.ctic.purdue.edu/KYW/Brochures/GroundSurface.html>. 2008.

²⁷ Ibid.

²⁸ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 5

²⁹ Ibid.

³⁰ NCGA Clean Water Act Primer, page 29

³¹ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 4.

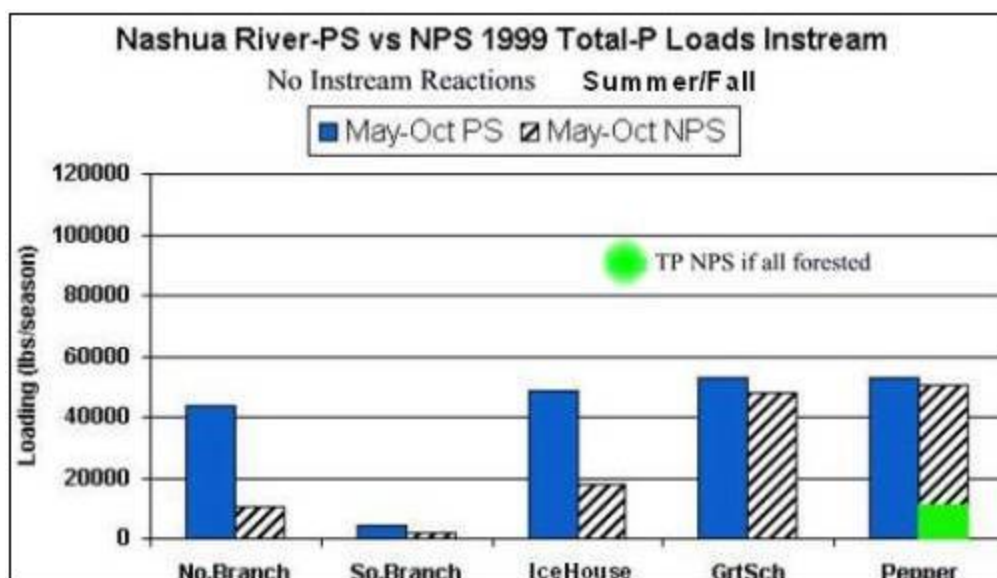


Figure 6: Total Phosphorus Loadings Throughout the Nashua River, May-October 1999.³²

The DEP's assessment is that the point sources are much more significant upstream, and removal of these sources will result in lower loadings for the rest of the river. As the majority of the load enters from the North Branch, traveling through Fitchburg, Leominster and Lancaster, reductions along the North Branch and mainstem are more significant, and a load limit of 0.2 mg/L of total phosphorus is required for any large-scale municipal treatment facilities upstream of the Pepperell Dam. The Groton School has a load limit of 1.0 mg/L due to its comparatively small outflows. The south branch faces a less stringent reduction, due to its generally lower impact, and the effluent limit there is 0.5 mg/L.³³ The expected impacts of compliance are summarized in Table 1. Phosphorus levels immediately downstream of the WWTFs are shown in Figure 7.

Table 1: Design flows and total phosphorus loads in compliance with the TMDL

WWTF Effluent Limits Total Phosphorus, mg/L April 1 – October 31			
WWTF	Design Flow, MGD	mg/L	lbs/day @ design flow
Fitchburg West	10.5	0.2	17.5
Fitchburg East	12.4	0.2	20.7
Leominster	9.3	0.2	15.5
Clinton	3	0.5	12.5
Ayer	1.8	0.2	3
Pepperell	1.1	0.5	4.6
TMDL	38.1		252.8

³² MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 7.

³³ Ibid.

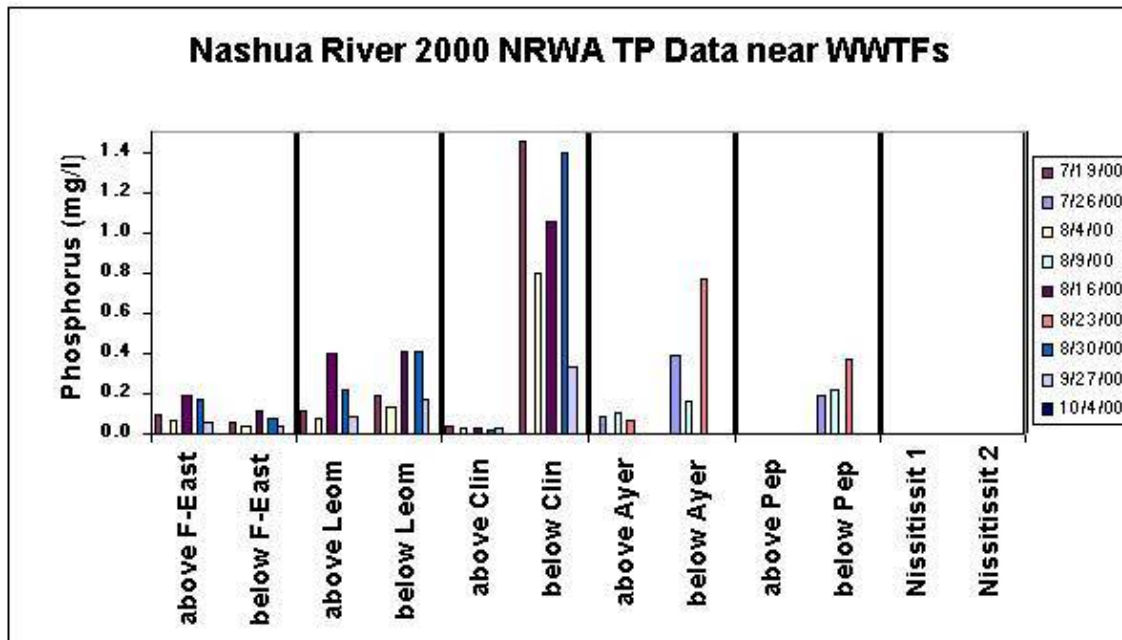


Figure 7: Downstream Phosphorus Levels near WWTFs in 2000

The TMDL also recommends a 20% reduction in nonpoint sources, as nonpoint sources add a significant phosphorus load between the Groton School and Pepperell, as shown in Figure 6. Methods for nonpoint reduction include removal of combined sewer overflows (CSOs) in Fitchburg and Leominster, and best land management practices (BMPs).³⁴

The models the DEP used, as was mentioned, were Qual2E and HSPF. The Qual2E model is for steady-state loading from point sources. This model was developed and run first, in order to prepare the HSPF model. HSPF is a modeling package which handles both point and nonpoint sources, but requires more input information. Once the Qual2E model was run using ten year low flow conditions (7Q10 conditions) the HSPF model was built using the Qual2E results.³⁵ Both packages are now combined into BASINS, (Better Assessment Science Integrating Point and NonPoint Source Pollution) a modeling package which allows an operator to build a watershed system, complete with point and nonpoint sources, and run several models to determine pollution loads under a variety of conditions.

2.3.2 TMDL for Phosphorus on the Assabet River

The Assabet River has a similar history to that of the Nashua River. Both have been historically used for industrialized activities, and are presently being remediated as a result.

³⁴ Ibid, 66.

³⁵ Ibid, 47.

Figure 8 shows the location of the Nashua River Watershed adjacent to the Assabet River Watershed.

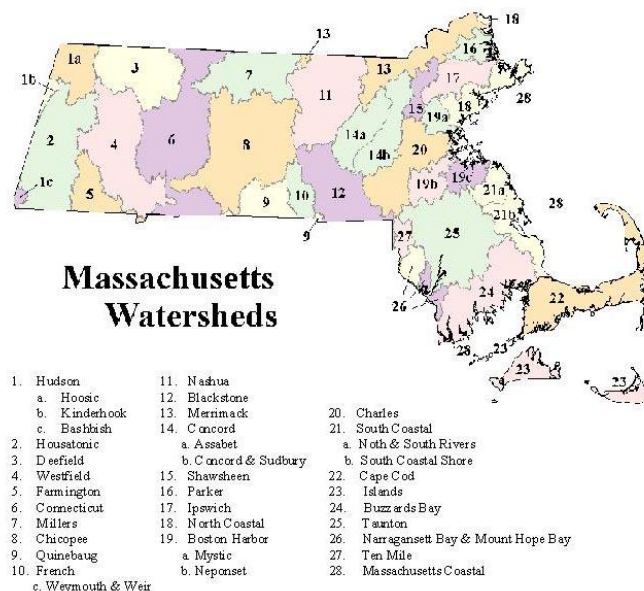


Figure 8: Map of Massachusetts Watersheds³⁶

The Nashua River Watershed is denoted by the number 11 and the Assabet River Watershed is denoted by the number 14a.

The Assabet River has been classified as what was formally known as the “303d list” for impaired waters and is now known as “Category 5 of the Integrated List.”³⁷ A body of water that has been identified as an impaired water is required by the Federal Clean Water Act for the DEP to restore the health of the waterway by creating a pollution budget, or a Total Maximum Daily Load (TMDL) report. Water quality standards that are applicable to the Assabet River are 314 CMR 4.05(3)(b)1(a) pertaining to Dissolved Oxygen, 314 CMR 4.05(5)(a) pertaining to Aesthetics, 314 CMR 4.05(5)(c) pertaining to Nutrients. Flow and nutrient budgets for the Assabet River consider the river to be part of a larger watershed, referenced as SuAsCo, for the Sudbury, Assabet, and Concord rivers. This TMDL was developed in order to establish limits for four major publicly owned treatment works and three smaller treatment plants³⁸, as shown in Table 2.

³⁶ "Massachusetts Watersheds." Map. 26 Feb. 2008 <<http://www.commonwaters.org/mapMa.jpeg>>.

³⁷ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 7.

³⁸ Ibid 4.

Table 2: Load Limits for Nutrients on Assabet River³⁹

TMDL for Total Phosphorus				
(minor POTWs not modeled in italics)				
		POTW Effluent Limits		POTW Effluent Limits
		Total Phosphorus, mg/L		Total Phosphorus, mg/L
		April 1 – October 31 ¹		November 1 – March 31
POTW	Design Flow, MGD	mg/L	lbs/day @ design flow	mg/L and lbs/day
Westborough	7.68	0.1	6.4	Optimize for particulate phosphorus removal and monitor and report for total and dissolved phosphorus concentration
Marlborough West	2.89	0.1	2.4	
Hudson	3	0.1	2.5	
Maynard	1.45	0.1	1.2	
<i>Powdermill Plaza²</i>	---	N/A	N/A	N/A
<i>Middlesex School³</i>	0.052	0.5	0.22	0.50 mg/l / 0.22 lb/day
<i>MCI Concord⁴</i>	0.3	0.5	1.25	0.50 mg/l / 1.25 lb/day
Total	15.37		13.97	
¹ Includes a margin of safety of 6.1 pounds per day				
² connecting to Acton POTW – no TMDL necessary				
³ Spencer Brook is receiving water – tributary to Assabet River and below all impoundments				
⁴ downstream of all impoundments and near confluence with Concord River				

ENSR Inc., a engineering consultant company, conducted a field investigation of the Assabet River to determine historic nutrient loadings and occurrence of eutrophic conditions in order to assist in the compilation of this report. This study found that excessive phosphorus and nitrogen resulted in nutrient saturation and plant growth, causing the dissolved oxygen to frequently be below 5.0 mg/L, the applicable water quality standard.⁴⁰ The field study found that the major nutrient sources were point sources and that the phosphorus released from these sources during the winter months went through the system and did not contribute the to the nutrient load that could be used by plants during the summer months.

The preliminary loadings allowed for all major publicly owned treatment works was 0.1mg/l by April of 2009, but since this would require some major changes to the treatment plants as well as waiting for this measure to have an effect over time, other options are considered. Other remediation options considered were sediment impoundment and discharge of

³⁹ Ibid 8.

⁴⁰ Ibid 5.

treated effluent to groundwater flows. A more extreme option that was considered is dam removal. Since the discharge of the treatment plants is responsible for 97% of the phosphorus loading of the river, it seems that for long term remediation to be effect the discharges by these plants would have to be limited. The effluent discharges account for 80% of the flow of the river at a USGS gage in Maynard.⁴¹

In order to model the system and determine how suggested remediation would affect water quality in the Assabet River, Mass DEP employed computer-based modeling tools. HSPF v 10, a time variable application that simulates hydrology generated from specified land uses within the watershed as well as precipitation, was used to model the SuAsCo watershed. HSPF is now part of BASINS, a larger, comprehensive modeling software package available from the USEPA.

2.4 History of the Nashua River

Beginning in the 1700s, the Nashua river valley began to see development in the form of mills. The river was used to supply energy to milling operations in Gardner, Fitchburg, Leominster, and Nashua.⁴² Until the 1970s, these industries took water from the river for their use, and very often returned untreated industrial wastewater. The best-known offenders in the area were paper mills, whose inks stained the river with the color of paper being printed that day.⁴³

In the late 1960s, Marion Stoddart began an effort to clean up the industrial pollution, and formed the Nashua River watershed association in 1969 to assist the cleanup.⁴⁴ With help from Clean Water Act funding, many wastewater treatment systems were improved, and much of the pollution has been removed. Today the river is safe for swimming and recreation in several areas, and is home to several fisheries.⁴⁵ Since 1985, the river has improved moderately, though

⁴¹ Ibid 13.

⁴² Nashua River Watershed Association Homepage, <http://www.nashuariverwatershed.org/> last accessed September 26, 2007.

⁴³ NRWA Homepage, "Past and Future"

⁴⁴ Ibid.

⁴⁵ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007,Massachusetts Department of Environmental Protection, Worcester. 41.

it is still considered to be impacted on the south branch and impaired on the north branch as a result of sediment and nutrient loadings, and stormwater runoff.⁴⁶

2.5 Pepperell Pond

Pepperell Pond, located in Pepperell and Groton MA near the New Hampshire border, is a 300 acre area where the Nashua River enters an impoundment just south of downtown Pepperell.⁴⁷ The pond suffers from plant growth problems and is listed by the EPA as an impacted water under the Clean Water Act, for toxics, nuisance plants, turbidity and nutrients.⁴⁸ Nutrient and sediment buildup tend to be higher in the pond than upstream because the pond is much wider, allowing velocities to drop and sediments to fall out.⁴⁹

The slower flow also allows nutrients to build up without being swept away, which allows large mats of algae to grow in the summer. The DEP noted diurnal swings in dissolved oxygen in the water, including supersaturation (roughly 125% of the normal maximum) during some days, while nights dropped to low oxygen levels. These swings can harm fish that arrive in the oxygen-rich water and are threatened at lower oxygen levels during the night.⁵⁰

The DEP has given increased attention to the pond itself, because it is more affected than other sections of the river by the nutrient loadings in the water. Since the TMDL was only recently passed, its impact on the pond and its plant growth remain to be seen. Water samples have been tested at both ends of the river and monitoring should point to the impact of the TMDL, and of the continuing impact of non-point sources on the river. Just upstream of the Pepperell Pond impoundment, the Squannacook River adds a significant flow into the Nashua River. Much of the phosphorus carried from this direction is from non-point sources, which the TMDL report has attempted to reduce by roughly 20%. These sources could be more significant since the point sources have been reduced by the TMDL.⁵¹

⁴⁶ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007,Massachusetts Department of Environmental Protection, Worcester. 24

⁴⁷ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007,Massachusetts Department of Environmental Protection, Worcester. 5.

⁴⁸ Ibid.

⁴⁹ Ibid.

⁵⁰ Ibid.

⁵¹ Ibid

2.6 Current Status of Removal of Dams in Massachusetts

As noted previously, Pepperell Pond is an impoundment that is maintained by a dam in Pepperell, Massachusetts. As the amount of dams and other impoundments in Massachusetts, including those on the Nashua River, continue to deteriorate and become structurally deficient due to their age, a movement has become increasingly popular to replace and or altogether remove these impoundments. However, due to the heavy industrial use throughout the Industrial Revolution in Massachusetts in the early 1800's, the possible health effects may not outweigh the benefits of removing the dams.

Industrial companies, primarily to provide hydropower, have used dams in Massachusetts for hundreds of years. As many of these companies discharged their wastewaters directly into the rivers adjacent to them, many toxic substances were released into the river and eventually made their way into the sediments.⁵²

A study completed by the United States Geological Survey in 2003 examined three impoundments and the surrounding sediment quantity and quality. This study looked at dams on the Connecticut River and the Quinebaug River. In both these cases, the sediments analyzed behind these dams were harmful to the public. Dangerous substances such as Total Petroleum Hydrocarbons (TPH), Polychlorinated Biphenyls (PCBs), and heavy metals were tested positive for in their investigations.⁵³ These substances not only negatively affect surrounding wildlife but also humans as well. Prolonged exposure to these elements may contribute to significant ailments.

As municipalities and other government agencies continue to debate whether or not to replace impoundments, it is in the public's best interest that intensive studies be made to assess the quality of the sediments around the dam in order to not adversely affect the public's welfare. For this report, the removal of the dam impounding Pepperell Pond is considered to be an unlikely option.

⁵² Zimmerman, Marc J., and Robert F. Breault. Sediment Quantity and Quality in Three Impoundments in Massachusetts. United States Geological Survey. Northborough: United States Department of the Interior, 2003. 18-30

⁵³ Ibid.

2.7 Nutrients and Biology

To understand the problems in Pepperell Pond, it is important to understand the relationship between nutrients and aquatic growth. There are two nutrients that are more vital and more limiting than most nutrients in aquatic systems; nitrogen and phosphorus. These two nutrients are essential for all life and more recently, there have been excess loads of these nutrients in freshwater systems due human activity. Agricultural and other land disruptive activity caused these nutrients to overload bodies of water causing aquatic plants life to grow with greatly enhanced boundaries. Excess plant growth eventually results in decreased dissolved oxygen, killing off other aquatic life. Some of the plants that often taken advantage of excess nutrient loads are blue green algae and duckweed.

2.7.1 Nitrogen

Nitrogen, a diatomic gas, is essential to all living things and although it is not one of the ten most abundant elements, it does comprise 78% of the atmosphere. Only a few bacteria, such as cyanobacteria can fix nitrogen, forming nitrate or ammonia compounds, which can be used by other living things.⁵⁴ Nitrogen is an essential part of hereditary material that contains the information to create every cell of everything living. It helps comprise amino acids, which are the building blocks of proteins, important structural components of organs, muscle, tissue, hormones, and enzymes.⁵⁵ The two most significant sources of nitrogen compounds are nitrogen fixing bacteria, which can produce usable nitrates and ammonia, and fertilizer production, which makes more usable nitrogen available to the biosphere than natural nitrogen fixation.⁵⁶

The nitrogen cycle consists of sets of four major processes, which are carried out by different types of bacteria that use the multiple forms of nitrogen for metabolic processes.⁵⁷ Starting from nitrogen gas, bacteria can perform nitrogen fixation to form organic nitrogen. Organic nitrogen is nitrogen that has its origin in living material, and can include proteins, urea,

⁵⁴ Hickman, Cleveland P., Larry S. Roberts, Allan Larson, Helen I'Anson. *Integrated Principles of Zoology*. 13th Ed. McGraw Hill: 2006.

⁵⁵ Ibid.

⁵⁶ Moore, John W., Conrad Stanitski, Peter Jurs. *Chemistry the Molecular Science*, Second Edition. Brooks/Cole 2005. Chapter 4, pages 96-107.

⁵⁷ Notes taken in General Microbiology (BIO 3304) taught by Dr. Donald Downer during the Fall 2006 at Mississippi State University.

food material, and cleaning agents.⁵⁸ Disposal of these compounds releases organic nitrogen to septic tanks and wastewater treatment plants, which eventually release it to the environment. Through ammonification, the decomposition of organic nitrogen by bacteria, ammonium and ammonia are formed. Nitrogen leachate from septic systems is most often in the ammonium form, some of which is adsorbed to soil particles and prevented from further transport.⁵⁹ The next process, nitrification, is aerobic, uses ammonium (often from septic tanks) as it travels through leaching fields, and results in nitrite and nitrate.⁶⁰ The last process is denitrification, which is an anaerobic process, requiring anoxic conditions to occur. This can occur in nitrogen compounds which are no longer in a leaching field and have migrated to unconsolidated soils and groundwater. This process may cause significant amounts of nitrogen that would have been useful to living material in the biosphere to form nitrogen gas.⁶¹

2.7.2 Phosphorus

Phosphorus, like nitrogen, is essential for life because it helps to compose nucleic acids. The nitrogenous bases of nucleic acids extend from structural supports called the phosphate-sugar backbone. Each nucleotide that forms a nucleic acid has three parts: the nitrogenous heterocyclic base, which is either a purine or pyrimidine, pentose sugar, and a phosphate group.⁶² The phosphate bonds hold nucleic acids together. Phosphate is also essential to intracellular energy transfer as part of the adenosine triphosphate molecule (ATP). ATP transports energy throughout a cell by breaking and forming the bond that holds the third phosphate to the molecule. When the bond is broken, adenosine diphosphate is formed and the bond energy is released. The bond is formed during photosynthesis as energy is absorbed from the sun, and broken to complete the cell's metabolic processes. Nitrogen is also a part of this molecule but its role is not as active as that of phosphate.⁶³

Phosphorus is a very common element, but it is highly reactive and not found freely nature. It can be found in cells, since it is a required element for DNA and RNA. Human

⁵⁸ Ibid

⁵⁹ Ibid

⁶⁰ Ibid

⁶¹ Woods Hole

⁶² Hickman, Cleveland P., Larry S. Roberts, Allan Larson, Helen I'Anson. *Integrated Principles of Zoology*. 13th Ed. McGraw Hill: 2006.

⁶³ Schachtamn, Reid, Ayling.

activity can create an increased loading of phosphorus in the surrounding area through the use of fertilizers and other activities.⁶⁴ In water, phosphorus is normally found in the phosphate form. Organic phosphates are those that are the result of biological processes and are bound to plant or animal tissue. These types of phosphates are created by human activity in form of sewage and are also sometimes created as pesticides break down. Inorganic phosphates are used by plants and are also used in detergents.⁶⁵

In fresh water systems, phosphorus is generally the limiting agent for plant growth; an increased load in phosphorus will allow smaller, faster growing plant life to experience rapid growth.⁶⁶ Algae and fairly quick growing aquatic plants can take advantage of brief increases in phosphorus loads. After these plants have used up the excess phosphorus, they die and decompose, depleting the oxygen in the water and resulting in the death of other aquatic species, like fish.⁶⁷

While nitrogen may not be reduced by increased aeration of the pond, phosphorus leaching has been shown to be linked to anoxic conditions. The amount of dissolved oxygen appears to have an effect on phosphorus retention in bodies of fresh water. A study by Gertrud K. Nürnberg found that lakes that have an anoxic bottom most layer of water for a significant period have consistently low retention of phosphorus and sometimes have negative phosphorus retention.⁶⁸ Using mass balances with terms for external loading and predicted retention, Nürnberg showed that phosphorus is not retained under anoxic conditions. Negative phosphorus retention would imply another source of phosphorus, such as phosphorus leaching from the sediment. Aeration may help to bind phosphorus to the sediment, and may help to reduce the overall contribution of the bottom sediments.

2.7.3 Causes of algal blooms

Eutrophication is the pollution of fresh water systems by an overload of a nutrient, like phosphorus, and is classified as either point or nonpoint pollution. Point pollution sources are those such as effluent discharged from a wastewater treatment plant, which are easily measured

⁶⁴ Moore, John W., Conrad Stanitski, Peter Jurs. *Chemistry the Molecular Science*, Second Edition. Brooks/Cole 2005. Chapter 4, pages 96-107.

⁶⁵ Murphy

⁶⁶ Ibid

⁶⁷ Ibid

⁶⁸ Nürnberg, Gertrud K. "The prediction of internal phosphorus load in lakes with anoxic hypolimnia." *American Society of Limnology and Oceanography*, 29(1), 1984, 111-124.

and controlled.⁶⁹ The sources of nonpoint pollution are difficult to measure or control because they often originate from large areas of land and are transported through the air, over or under the ground to the water system.⁷⁰ Table 3 provides a list of point and nonpoint sources of pollution.

Table 3: Characteristics of point and nonpoint sources of chemical inputs to receiving waters recognized by statutes of the United States (modified from Novotny and Olem 1994).

Point sources	Nonpoint sources
Runoff and leachate from waste disposal sites	Runoff from pasture and range
Runoff from mines, oil fields, unsewered industrial sites	Septic tank leachate and runoff from failed septic systems
Overflows of combined storm and sanitary sewers	Runoff from abandoned mines
Runoff from agriculture (including return flow from irrigated agriculture)	Activities on land that generate contaminants, such as logging wetland conversion, construction, and development of land or waterways
Urban runoff from unsewered areas and sewer areas with a population <100 000	
Runoff from construction sites <2 ha	
Atmospheric deposition over a water surface	
Wastewater effluent (municipal and industrial)	
Runoff and infiltration from animal feedlots	
Storm sewer outfalls from cities with a population >100 000	
Runoff from construction sites >2 ha	

The percentage of phosphorus in surface waters caused by point versus nonpoint sources varies depending on land use in the surrounding area. In more urbanized areas, point sources of pollution, such as sewers and effluent from treatment plants, play a more significant role than in rural areas. Nonpoint pollution sources, such as construction, pet waste, and unsewered development, still contribute a significant loading in urban areas. In more rural areas, heavy phosphorus loads can be attributed to nonpoint sources, such as fertilized fields. The amount of a nutrient applied to a field is greater than the amount the nutrient being harvested in crops, and this net gain in nutrients in an area results in nonpoint pollution.⁷¹

The excessive blooms of cyanobacteria observed in many bodies of fresh and salt water are believed to be caused by abnormally large nutrient loads as a result of human activity. This

⁶⁹ Davis, Mackenzie L., and David A. Cornwell. Introduction to Environmental Engineering. 4th ed. New York: McGraw Hill, 2008. 354-356.

⁷⁰ Ibid.

⁷¹ Ibid.

nutrient load can be a result of catchment basins, sewage disposal, and leaching from agricultural land.⁷² Areas of stagnant water in lakes, rivers, and streams are also conducive to algal blooms.⁷³

2.7.4 Pond Algae

Pepperell Pond has three different species of vegetation that are blooming in amounts that result in negative impacts. One type, the Water Chestnut, has received more attention than the other two and as a result, the Nashua River Watershed Association has received a three hundred thousand dollar grant to help remove this species from the pond.⁷⁴ One of the other types of vegetation that is growing in excessive amounts is duckweed, which has not received much notice, possibly due to it being relatively harmless. The last species is blue-green algae, and is responsible for the large algal blooms that cover the pond in large green mats. All three types of vegetation negatively impact the river, for as all these plants grow and die they are decomposed by bacteria, which use up the dissolved oxygen.⁷⁵ Due to these plants' ability to perform oxygenic photosynthesis, the lack of oxygen in the water is not detrimental to the plants. The plants' ability to perform this causes the dissolved oxygen concentration to increase during the day and dramatically decrease at night, when oxygen can no longer be produced due to the lack of sunlight. At night, the bacteria that decompose the dead plant material reduce the dissolved oxygen content of the water. The decreased dissolved oxygen creates an inhospitable environment for many fish and aquatic insects.⁷⁶

Excess vegetation, especially in the form of algal blooms, is usually attributed to high nutrient loads. Serruya and Berman recognized this association in Lake Kinneret, where it was found that high levels of phosphorus indicated a bloom would occur.⁷⁷ Although in this lake the limiting nutrient was phosphorus, nitrogen is also an important nutrient. This study of Lake Kinneret and others have found the atomic ratio of nitrogen to phosphorus in algae to be 16:1, with ratios higher than this as evidence of phosphorus limitation.⁷⁸

⁷² Reynolds

⁷³ Billen, Garnier

⁷⁴ Gunderson, Matt. "Clogged pond to get relief: Grant will help reduce weeds." Boston Globe: 13 September 2007.

⁷⁵ Murphy

⁷⁶ Ibid

⁷⁷ Serruya, Colette and Thomas Berman. "Phosphorus, Nitrogen and the Growth of Algae in Lake Kinneret." *Journal of Phycology* 11. Pages 155-162, 1975.

⁷⁸ Serruya, Colette and Thomas Berman. "Phosphorus, Nitrogen and the Growth of Algae in Lake Kinneret." *Journal of Phycology* 11. Pages 155-162, 1975.

2.7.5 Duckweed

Another aquatic species of plant that is growing in Pepperell Pond that is of interest is duckweed. Duckweed is the common name of a family of small floating plants called *Lemnaceae*, which includes four different genera and at least 37 species.⁷⁹ The different species of duckweed thrive in slightly different environmental conditions including temperature, light intensity, pH and availability of nutrients. This family of plants is eurytopic, meaning that they have ability to survive in a wide range of conditions and therefore this species is found throughout the world.⁸⁰ These plants are small and have simple plant morphology with the structural components consisting of only short roots and a frond that is only a few millimeters for most species. Due to structural simplicity, including the lack of stems and leaves, almost the entire plant is actively involved in photosynthesis. Possibly due to the fact that very little of plant is devoted to structural support, the plant has very low fiber content and high protein content.⁸¹ These qualities make the plant highly nutritious and digestible for a wide range of animals, including farm animals. Not only is duckweed able to absorb nutrients but it can be used as a method of recycling these nutrients from an unwanted location, bodies of water, to a place where nutrients are in high demand, as feed and fertilizer.⁸²

Duckweed could be harvested from Pepperell Pond in order to help remove the excess nutrients that are causing eutrophication. Duckweed is already growing in Pepperell Pond, so it is a known fact that it has the right environmental conditions to thrive. Duckweed is not the only floating family of plants that has been studied for its ability to remove nutrients and contaminants from water, especially wastewater. Macrophytes have been found to be an effective step in the wastewater treatment process; in fact most studies appear to concern these plants application to this process. Fecal coliform and effluent turbidity removal were also measured, which were found to be 95% and 50% respectively. The application of aquatic plants

⁷⁹ Gijzen, Huub J. and Siemen Veenstra. "Chapter 7: Duckweed-Based Wastewater Treatment for Rational Resource Recovery and Reuse." Environmental Biotechnology and Cleaner Bioprocesses. Ed. Eugenia J. Olguin, Gloria Sanchez, and Elizabeth Hernandez. Taylor & Francis CRC Press: 1999 pages 83-94.

⁸⁰ Molles, M.C. Ecology: Concepts and Applications, McGraw-Hill, 2005.

⁸¹ Gijzen, Huub J. and Siemen Veenstra. "Chapter 7: Duckweed-Based Wastewater Treatment for Rational Resource Recovery and Reuse." Environmental Biotechnology and Cleaner Bioprocesses. Ed. Eugenia J. Olguin, Gloria Sanchez, and Elizabeth Hernandez. Taylor & Francis CRC Press: 1999 pages 83-94.

⁸² Ran, Noemi, Moshe Agami, and Gideon Oron. "A pilot study of constructed wetlands using duckweed (*Lemna gibba* L.) for treatment of domestic primary effluent in Israel." *Water Research* Volume 38, Issue 9, May 2004, Pages 2241-2248.

has proven to be highly beneficial because it is a “recycling engine driven by photosynthesis and therefore the process is sustainable, energy efficient, [and] cost efficient.”⁸³ Using duckweed and other plants for wastewater treatment in less developed areas has proven to be one of the most economic ways to treat the water.

Other macrophytes with large leaves have been found to be more productive than small-leaf plants like duckweed.⁸⁴ Water hyacinth, a macrophyte, was found to be quite effective at improving water quality by reducing nutrients, chemical oxygen demand, solids and salinity. This plant was found to reduce the ammonium by 99.6% and total phosphorus by 98.5%, clearly showing that floating flora is an effective option for removing these nutrients.⁸⁵ Table 4 clearly shows that water hyacinth does remove more nitrogen and phosphorus on average than duckweed.

Table 4: Macrophyte Nutrient Uptake⁸⁶

Location	Macrophyte	Daily uptake (g m ⁻² per day)		Reference
		N	P	
Florida, USA	Water hyacinth	1.30 (0.25)*	0.24 (0.05)	Reddy and DeBusk, 1987
Florida, USA	Water lettuce	0.99 (0.26)	0.22 (0.07)	Reddy and DeBusk, 1987
Florida, USA	Pennywort	0.37 (0.37)	0.09 (0.08)	Reddy and DeBusk, 1987
USA	<i>Lemna sp.</i>	1.67	0.22	Zirschky and Reed, 1988
India	<i>Lemna sp.</i>	0.50–0.59	0.14–0.30	Tripathi <i>et al.</i> , 1991
Louisiana, USA	Duckweed	0.47	0.16	Culley and Meyers, 1980
Bangladesh	<i>Spirodela polyrrhiza</i>	0.26	0.05	Alaerts <i>et al.</i> , 1996

* Values in parentheses were obtained during winter season

⁸³ Gijzen, Huub J. and Siemen Veenstra. “Chapter 7: Duckweed-Based Wastewater Treatment for Rational Resource Recovery and Reuse.” *Environmental Biotechnology and Cleaner Bioprocesses*. Ed. Eugenia J. Olguin, Gloria Sanchez, and Elizabeth Hernandez. Taylor & Francis CRC Press: 1999 pages 83-94.

⁸⁴ Sooknah, Reeta D. and Ann C. Wilkie. “Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater.” *Ecological Engineering* Volume 22, Issue 1. 1 February 2004, pages 27-42.

⁸⁵ Ibid.

⁸⁶ Gijzen, Huub J. and Siemen Veenstra. “Chapter 7: Duckweed-Based Wastewater Treatment for Rational Resource Recovery and Reuse.” *Environmental Biotechnology and Cleaner Bioprocesses*. Ed. Eugenia J. Olguin, Gloria Sanchez, and Elizabeth Hernandez. Taylor & Francis CRC Press: 1999 pages 83-94.

A plant's ability to remove nutrients is only one of many factors to be concerned with for the application to Pepperell pond. Economics play a key role in most decisions and the importing of another invasive species to a pond that already has problems with aquatic plants may have unexpected consequences. Duckweed is already growing in Pepperell Pond, so it is a known fact that it has the right environmental conditions to thrive. Also, after water hyacinth has been applied, grown and been harvested, so far no economically beneficial option for the application of the generated biomass has been found. Table 5 shows the protein content of duckweed that has been grown in different sources of wastewater.

Table 5: Nutrient Content of various organisms⁸⁷

Species	Cultivation	Production (DM/ha/year)	Protein (% DM)	References
<i>S. polyrrhiza</i>	Domestic sewage	17–32	–	Alaerts <i>et al.</i> (1996)
<i>L. minor</i>	UASB – effluent	10.7	28.9	Weller and Vroon (1995)
<i>L. gibba</i>	Pretreated sewage	55	30	Oron (1994)
<i>L. gibba</i>	Domestic sewage	10.9–54.8	30–40	Oron <i>et al.</i> (1986)
<i>S. polyrrhiza</i> , <i>L. perpusilla</i> and <i>W. arrhiza</i>	Septage from septic tank	9.2–21.4	24–28	Edwards <i>et al.</i> (1992)
<i>Lemna spp.</i>	Domestic sewage	27	37	Zirschky and Reed (1988)
<i>S. polyrrhiza</i>	Domestic sewage	17.6–31.5	30	Gijzen (1996)

Although the application that we are considering is not to wastewater, it is to a pond with excess nutrient content and therefore the harvested duckweed may be used as feed or fertilizer. Since duckweed is such a small plant that is not interconnected, it is also much easier to harvest than water hyacinth. Duckweed is, therefore an economically viable option for reducing the nutrient load of Pepperell Pond due to its known ability to grow in the pond, easy of harvest, and possible use after harvest.

2.8 Best Management Practices (BMPS)

Management practices and remediation methods for controlling aquatic vegetation and water quality problems in eutrophic lakes almost all recommend reducing the nutrient load into

⁸⁷ Gijzen, Huub J. and Siemen Veenstra. "Chapter 7: Duckweed-Based Wastewater Treatment for Rational Resource Recovery and Reuse." *Environmental Biotechnology and Cleaner Bioprocesses*. Ed. Eugenia J. Olguin, Gloria Sanchez, and Elizabeth Hernandez. Taylor & Francis CRC Press: 1999 pages 83-94.

the body of water if possible. A study of Lake Mendota in Wisconsin found that by reducing the nutrient load by 50% the probability of the occurrence of an algal bloom on any summer day decreased from 60% to 20%.⁸⁸ Reducing the nutrient load can result in a healthier body of water by reducing eutrophication by increasing the dissolved oxygen. Another important aspect, as pointed out in the aforementioned study, is that of public opinion, and how by decreasing algal blooms the public views a body of water in a much more positive light. Some recommended methods of reducing nutrient loads are: reducing surplus nutrient flows from agricultural processes, reducing agricultural and urban runoff, and reducing nitrogen emissions from the burning of fossil fuels.⁸⁹ The surplus nutrient flows from agriculture can be reduced by applying nutrients at rates that match their uptake by crops which is partially implemented by applying fertilizer when crops are growing at rapid rates.

Best management practices for bodies of water included the practices concerning the application of fertilizer as well as many other controls on activities that could negatively impact nearby water, as shown in Table 6.

⁸⁸ Lathrop, Richard C., Stephen R. Carpenter, Craig A. Stow, Patricia A. Soranno, and John C. Panuska. "Phosphorus loading reductions needed to control blue-green algal blooms in Lake Mendota." *Canadian Journal of Fisheries and Aquatic Sciences* 55(5): 1169-1178 (1998).

⁸⁹ Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. "Nonpoint pollution of surface waters with phosphorus and nitrogen." *Ecological Applications* 8(3): 559-568 (1998).

Table 6: Typical Best Management Practices⁹⁰

Agricultural	Forestry	Urban
Nonstructural		
Tillage and cropland erosion control Pesticide and fertilizer application Range and pasture management Contour farming and strip cropping Confined feedlot management Cover cropping Crop residue usage Cropland irrigation management	Forestry preharvest Streamside management areas Forest chemical management Fire management Forest vegetation of disturbed areas	Land use planning and management Public acquisition of watershed land Minimum lot size zoning restrictions Impervious surface restrictions Buffer zones and setbacks Public information and education Citizen advisory committees Watershed sign posting Storm drain stenciling Illegal dumping and illicit connection controls Material exposure controls Material disposal and recycling Household hazardous pickup days Used motor oil collection Wastewater disposal restrictions Septic tank management Community wastewater systems control Sanitary sewer facilities planning and management Catch basin and street cleaning Construction site land stabilization
Structural		
Animal waste management Terrace systems Diversion systems Sediment basins Filter strip and field borders	Erosion and sediment controls Access roads Skid trails Stream crossings Filter strip sediment controls	Detention/retention facilities Wet detention ponds Extended detention ponds Vegetated swales and strips Constructed wetlands Infiltration ponds and trenches Drainage structure controls Inlet floatable controls Oil water separators Media filtration Erosion and sediment control Stream bank stabilization and riparian buffer restoration

Reducing nonpoint nutrient loading by animal waste management and cropland erosion control could help decrease the frequency of algal blooms and growth of other nuisance species. For point sources, such as wastewater treatment plants, management practices include the planning and operation of sanitary sewer facilities, including the use of microorganisms in biological nutrient removal to remove total nitrogen and total phosphorus.⁹¹ The remaining sections of this report address the control of both point and non point sources, and improve water quality in Pepperell Pond.

⁹⁰ Handbook of Public Water Systems, Second Edition. HDR Engineering, Inc. John Wiley & Sons, Inc: Omaha, NE 2001: 211.

⁹¹ Ibid.

3. Methodology

To establish a management plan for the level of phosphorus in Pepperell Pond, it was necessary to obtain information about the relationships between the pond and its surroundings. The pond has many influences that must be characterized and evaluated for their effects. To characterize these influences, background research was conducted to establish the current conditions for the pond. Field research served to supplement this information and to identify areas in need of control. Exploration of options to exert control over the amount of phosphorus in Pepperell pond resulted in the foundation of a management plan. The steps taken to realize a management plan for Pepperell Pond included,

- 1) acquiring background data from outside sources,
- 2) conducting field research,
- 3) analyzing the field data,
- 4) quantifying loads,
- 5) researching alternatives,
- 6) evaluating and adapting alternatives,
- 7) developing a formal management plan, and
- 8) composing a report.

The following sections elaborate upon these eight steps and their contribution towards the final goal of establishing a formal management plan for phosphorus in Pepperell Pond.

3.1 Background Research

The first step necessary towards developing a formal management plan for Pepperell Pond was to research the current conditions of the pond. This included obtaining information about the area surrounding the pond as well as the Nashua River which flows through it. Research into total maximum daily loads for the River introduced the topic of nutrient loading for the Pond. In order to better understand nutrient excess nutrient loadings in Pepperell Pond, a literature review was completed, with regard to nutrient behavior in freshwater bodies, and conditions associated with eutrophic systems. Two particular nutrients, nitrogen and phosphorus, were studied in greater depth to establish their relationship to algal development within the Pond. This background information provided a foundation upon which to construct our field research.

3.2 Field Research

Field research was the most important aspect in identifying the current conditions in the Pond. Field research began by taking water and sediment core samples at many different points along the Nashua River with specific focus placed on Pepperell Pond. The samples were analyzed in the laboratory for their nutrient concentrations, as well as other characteristics such as dissolved oxygen and alkalinity. The core samples were used to determine the maximum amount of nutrients that could be released by sediment within the Pond. The following sections outline the sampling plan utilized as well as the testing methods performed on the samples to obtain the concentration of nutrients and other characteristics of the samples.

3.2.1 Sampling

Sampling from the Nashua River occurred at two different times during the year. The first set of samples, taken on October 5, 2007, consisted of a total of five water samples and three sediment core samples. Water samples were taken from the inlet of the pond, from three points within the pond, and from a covered bridge just downstream of the pond. These locations were chosen to capture every aspect of the pond including what is going into and coming out of the pond. Such information was necessary to quantify the flow of nutrients throughout the system. In addition, three core samples of the Pond's basin were taken at the inlet, at a point towards the middle of the pond, and at a point just before the dam at the downstream end of the pond. These locations were chosen as best to represent a point at the inflow, middle, and outflow of the pond with the resources available. These locations were essential for calculating the relative contribution of nutrients from points upstream and the area surrounding the pond. Table 7 presents the relative location of each of the sampling locations with more detail on each location in Appendix A: Sampling Locations.

Table 7 : Relative Sampling Locations

Sample	Location
<u>10/5/2007</u>	
1	Beginning of Pepperell Pond
2	Middle of Pepperell Pond
3	Downstream of Pepperell Pond
4	Middle of Pepperell Pond
5	Middle of Pepperell Pond
Core 1	Middle of Pepperell Pond
Core 2	Middle of Pepperell Pond
Core 3	Beginning of Pepperell Pond
6	Upstream of Pepperell Pond
<u>11/29/2007</u>	
7	Farthest Upstream of Pepperell Pond
8	Upstream of Pepperell Pond
9	Beginning of Pepperell Pond
10	Middle of Pepperell Pond
11	Downstream of Pepperell Pond

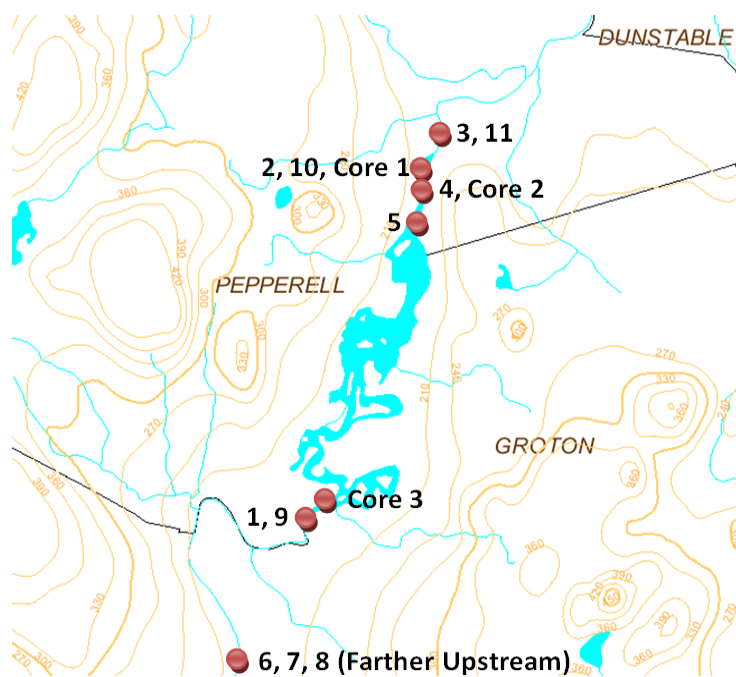


Figure 9: Map of Sampling Locations⁹²

⁹² "Surface Contour Map" Map. MassGIS. 25 Feb. 2008 <<http://www.mass.gov/mgis/mapping.htm>>.

The second round of sampling on November 29, 2007 studied conditions farther upstream in addition to locations throughout the pond. Two samples were taken from the Ice House Dam Impoundment, one from just before the dam and the other from just after the dam. Only three samples were taken from the pond this time with one at the inlet, one just before the dam at the downstream end of the pond, and the last from the covered bridge. These three sampling locations coincided with locations from the first round of sampling. This was of importance because it allowed for a direct comparison with points of the first round of sampling. This identified the negligible effects of the TMDL restriction on phosphorus which had been lifted a week and a half prior to the second round of sampling.⁹³ No core samples were taken during the second round of sampling due to the lack of resources. All samples were taken to WPI for refrigerated storage until evaluation in the laboratory.

3.2.2 Laboratory Analysis

Laboratory analysis of the water samples can be broken down in three distinct groups, each to represent different characteristics of the sample water. First, the solids concentration present in the sample was measured using the procedure outlined by Standard Method 2540.⁹⁴ The second, applying only to the first set of samples, was the measurement of dissolved oxygen using a dissolved oxygen probe and alkalinity of the sample by Gran Titration. All of the water samples were measured for pH. The third and most important analysis group was for nutrients, in the form of ammonia, nitrates, and phosphates using the Hach DR3000 Spectrophotometer. The three sediment cores were only analyzed for nutrients by a similar method as the samples.

3.2.2.1 Group I – Solids Measurement

Total Solids

Total solids measurements were taken for each sample by shaking the sample water to mix it, and then withdrawing 50 mL and adding it to a pre-weighed porcelain dish and evaporated at 104°C for 5 hours to dry. After the samples were removed from heat to cool and

⁹³ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 75.

⁹⁴ Clesceri, Lenore S. et al. Standard Methods for the Examination of Water and Wastewater, 17th Edition. 1989, Port City Press, Baltimore. 2-71.

dry overnight in a desiccator, they were reweighed, with the difference being the total solids weight. While this may have added slight errors from initial moisture in the dishes (which were only heated for a few minutes prior to being cooled, dried and weighed) and in a small amount of splattering from the samples, these errors were expected to be slight when compared to the final mass changes due to the solids. Samples were checked regularly while evaporating, and were not boiling vigorously or actively steaming during the evaporation, making it unlikely that solids were lost. Total solids (TS) results were calculated according to the following equation:

$$TS \left(\frac{mg}{L} \right) = 1000 \frac{mL}{L} * \frac{((Residue\ and\ dish\ weight) - (Dry\ dish\ weight))(mg)}{V_{sample} (mL)}$$

Settleable Solids

Settleable solids are defined as solids capable of settling from the sample to the bottom of an Imhoff cone in one hour. Each cone was filled to either the 0.5 L or 1 L mark on the cone, and allowed to settle for 45 minutes without agitation. After 45 minutes, the sides of the sample were agitated near the surface to free any material collecting on the sides and allowing it to settle for another 15 minutes. The lowest limit available on the Imhoff cones was 0.1 mL/L, and all samples yielded results below that threshold. This test determined that there was a negligible amount of settleable solids present in all of the samples.

Fixed and Volatile Total Solids

Fixed and volatile solids delineated organic matter in the water and inorganic matter. The results of a previous test (it can be either total solids, as was in this case, or suspended solids) were heated at 550°C for 20 minutes in a muffle furnace. After cooling for several hours in the desiccator, they were weighed and compared to the initial total solids weights. In each case, 50-60% of the total solids weight came in the form of inorganic “fixed” solids. The remainder volatilized, and was assumed to be organic material.

Suspended Solids

Suspended solids were those removed by filtration using a small-pore filter. A 1.2 µm, silica fiber filter was used for this process. The procedure was conducted several times, using

varying amounts of well-mixed water from each sampling location. In volumes ranging from 100-500 mL, the sample water was poured onto the filter and drawn through the filter using a vacuum pump. Although the filters became discolored with solid material, their final weights were recorded to be less than their initial weights. A scale that may have not been calibrated properly, or used properly between points of measurement, were likely explanations for this development. As a result, no accurate values for total suspended solids were present.

3.2.2.2 Group II– Alkalinity by Gran Titration Method

Alkalinity is the buffering capacity which prevents a sample of water from changing pH substantially while neutralizing acid. Total alkalinity can be expressed as equivalents or mg/L as CaCO_3 , and is considered to be the total basic equivalent of the acid required to lower pH to 4.5.⁹⁵ In order to measure total alkalinity, titration to the lower limit, indicated by methyl orange or a pH probe must occur. The total volume of acid added during the titration determined the total alkalinity.

The Gran Titration method used 100 mL of each water sample, and small volumes of sulfuric acid. The acid additions were to be small enough as to be insignificant when compared to the volume of the water sample, as the whole test generally required approximately 400 μL of acid, or 0.4% of the total final volume. Each sample had an initial pH of approximately 7, and was titrated to between 4 and 4.5. A spreadsheet was employed to perform the calculations. Once the pH is below 4.5, there was no remaining alkalinity in the water, which yielded a direct correlation between acid addition and pH (assuming minimal acid additions).⁹⁶ The point at which linearity was achieved indicated the total alkalinity. All samples had total alkalinity between 33 and 42 mg/L as CaCO_3 . Appendix B: Alkalinity Results contains the spreadsheets for this experiment.

3.2.2.3 Group III – Nutrient Analysis

Phosphorus

To test for phosphorus in the collected samples, our team first created a set of standards. From a known standard solution at 10 mg/mL as phosphorus, five standards were created at

⁹⁵ HDR Engineering Inc. Handbook of Public Water Systems, Second Edition. 2001, John Wiley & Sons, New York. Pages 106-108.

⁹⁶ Ibid.

concentrations of 0.1, 0.2, 0.5, 1.0, and 2.0 mg/L as phosphorus. Five values were chosen to achieve greater precision in determining the concentration of phosphorus within each of the samples. This range of concentrations was based on preliminary total phosphorus testing of the samples that yielded concentrations well below 2.0 mg/L as phosphorus. As a result of these low values, the standards and samples were measured only for reactive phosphorus using this procedure. Twenty-five (25) milliliters of the standard solution was poured into its own clean glass sample cell. To the cell, 1 mL of molybdovanadate was added, marking the beginning of the 3 minute reaction period. After the three minutes, the cell was then inserted into the Hach DR3000 Spectrophotometer, set to a wavelength of 400 nm, and its absorbance (1/cm) recorded. To zero the instrument, the same procedure was completed for a sample cell containing deionized water and the “Zero” button pressed⁹⁷. Measurements of each of the standards using this procedure, presented in Table 8, produced a linear relationship between the concentration of the standard and its absorbance as displayed in Figure 10. This calibration curve was used through interpolation of the water samples to determine the concentration of reactive phosphorus in each of the samples.

Table 8: Absorbance Measurements for Phosphorus Standard Solutions

Standard (mg/L)	Absorbance (1/cm)
0.1	0.062
0.2	0.091
0.5	0.157
1	0.271
2	0.498

⁹⁷ Hach. Hach DR3000 Spectrophotometer Manual

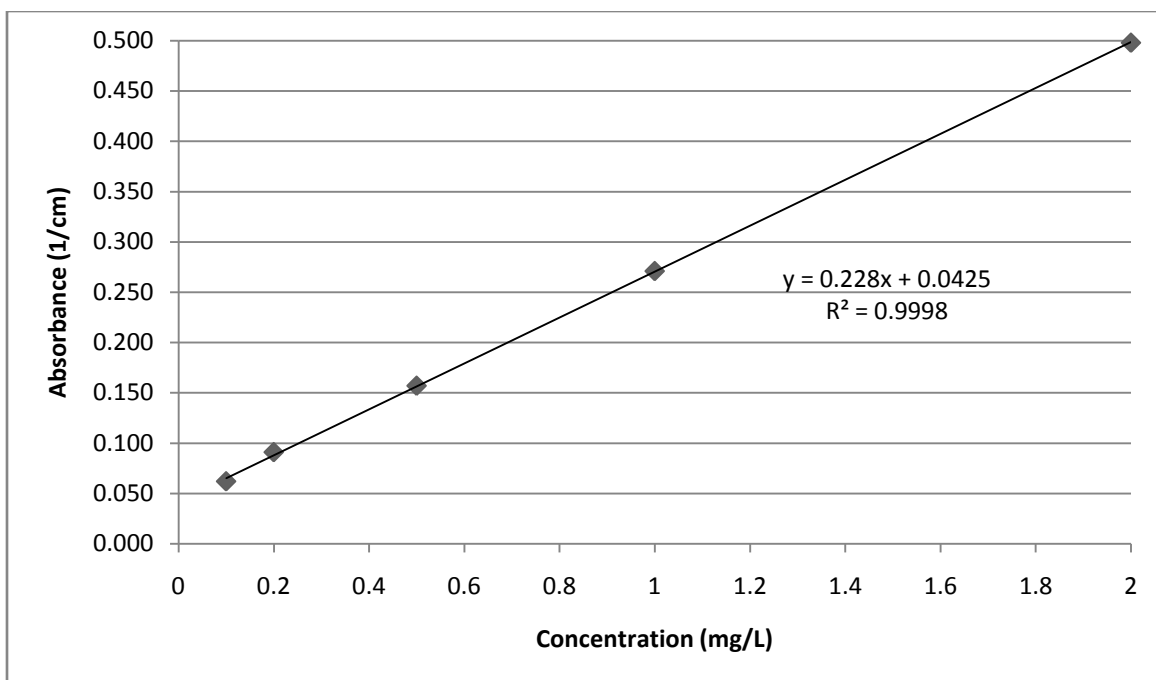


Figure 10: Phosphorus calibration curve from standard solutions

Nitrates

Nitrogen as nitrate ($\text{NO}_3\text{-N}$) present in the samples was measured in a manner similar to the phosphorus measurements. Standards of concentrations of 0.0, 0.5, 1.0, 2.0, 5.0, 10.0 mg/L nitrate-nitrogen ($\text{NO}_3\text{-N}$) from a standard solution of 100 mg/L nitrogen as nitrate were created for this experiment. Approximately 40 mL of each standard solution was poured into its own clean glass beaker. A NitraVer 5 Nitrate Reagent AccuVac Ampuls was then inserted upside down such that the score mark was well below the surface of the solutions. Pushed up against the side of the beaker, the ampul broke along the score mark withdrawing the solution from the beaker and into the ampul. The ampul was then inverted and swirled for a period of 1 minute to ensure complete mixture. After an additional reaction period of 5 minutes, the ampul was then inserted into the Hach DR3000 Spectrophotometer, also set to a wavelength of 400 nm and its absorbance (1/cm) recorded. To zero the instrument for this procedure, a vial filled with deionized water was inserted into the spectrophotometer and the “Zero” button pressed⁹⁸. For every successive standard solution however, the spectrophotometer had to be zeroed with a vial containing solution of the same concentration. For the samples, this meant zeroing the spectrophotometer using the sample water and then taking a reading of the ampul. Table 9

⁹⁸ Ibid.

contains the absorbance measurements obtained from each of the standard solutions. These measurements established a linear relationship, seen in Figure 11, between the nitrate concentration of the standard solution and its absorbance. This calibration curve through interpolation of the water samples was used to determine the concentration of nitrogen as nitrate in each of the samples.

Table 9: Absorbance measurements for nitrogen standard solutions

Standard (mg/L)	Absorbance (1/cm)
0	0.014
0.5	0.029
1	0.048
2	0.074
5	0.161
10	0.275

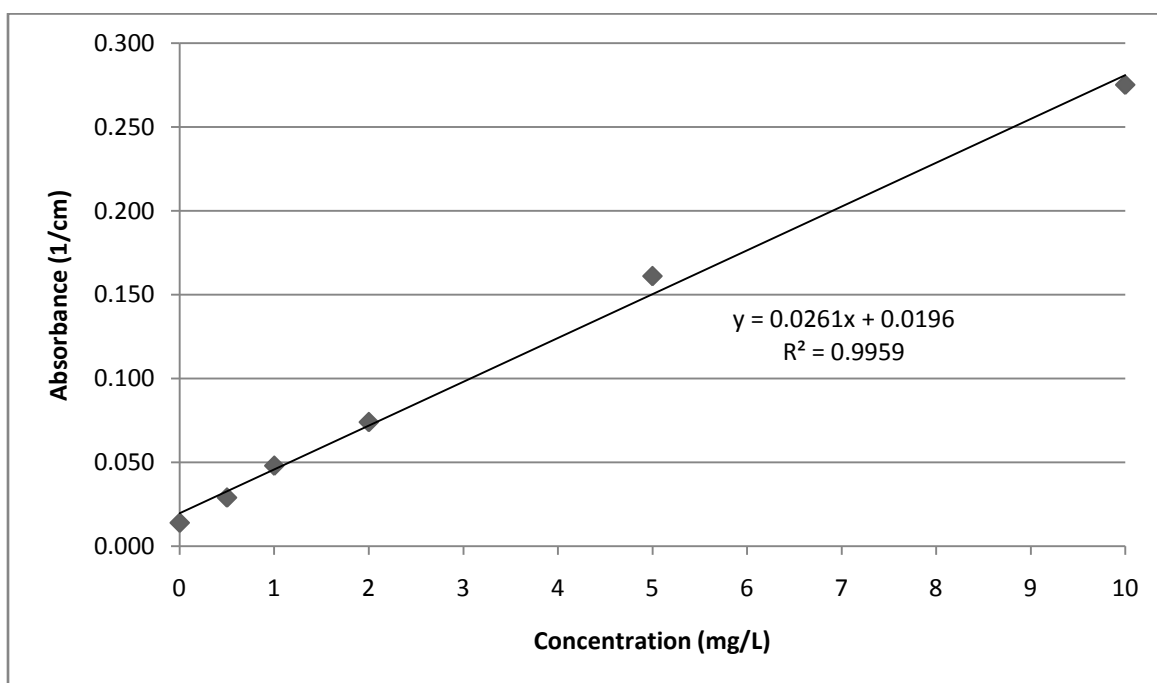


Figure 11: Nitrogen calibration curve from standard solutions

Ammonia

The last procedure utilizing the Hach DR3000 Spectrophotometer measured the concentration of ammonia present in the samples. A set of standards were created at concentrations of 0.2, 0.5, 1.0, and 3.0 mg/L of ammonia using an ampul containing a standard

solution 50 mg/L of ammonia. Twenty-five (25) milliliters of the standard solution was poured into a clean glass sample cell. To the cell, 3 drops of mineral stabilizer and polyvinyl dispersing agent were added with inversion of the cell taking place after each addition. Next, 1 mL of Nessler Reagent was to the cell beginning a one minute reaction period. It was important that the sample be analyzed soon after the reaction period terminated as the results obtained 15 minutes later on the sample would not be valid. The sample cell was then inserted into the Hach DR3000 Spectrophotometer, set to a wavelength of 425 nm, and its absorbance (1/cm) recorded. To zero the instrument, the same procedure was completed for a sample cell containing deionized water, pressing the “Zero” button after insertion⁹⁹. Similar to the other two tests, the measurements, presented in Table 10, prescribe a linear relationship between the concentration of the standard and its absorbance. The resulting calibration curve illustrated by Figure 12 was used to determine through interpolation of the water samples the ammonia concentration present in the samples.

Table 10: Absorbance measurements for ammonia standard solutions

Standard (mg/L)	Absorbance (1/cm)
0.2	0.019
0.5	0.110
1	0.318
3	1.292

⁹⁹ Ibid.

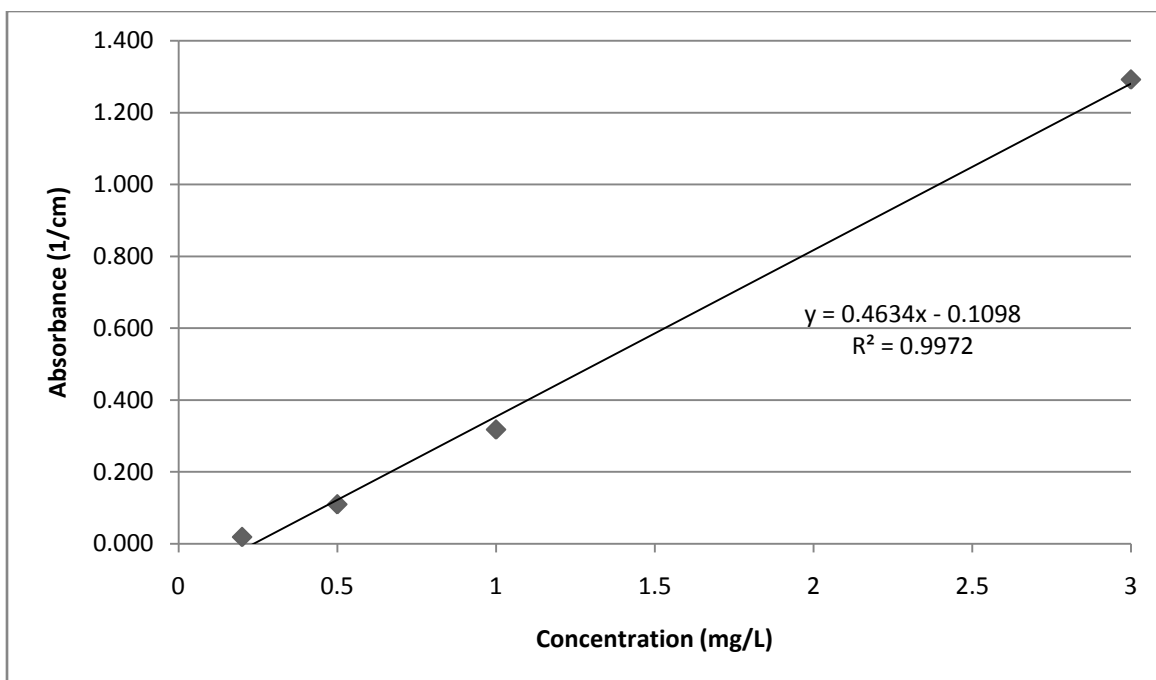


Figure 12: Ammonia calibration curve from standard solutions

3.2.3 Sediment Core Analysis

To determine the contribution of the sediment in the Pond to the total nutrient loading, each of the cores were analyzed to assess the potential for desorption of ammonia, nitrates, and phosphorus. Since the sediment is in solid form, a different method of analysis had to be developed to accommodate this source. Once the core was extracted from its tube, it was allowed to dry for four days after which the top inch of each was removed and placed into a separate ceramic dish. This dish was heated for an hour at 67 °C to remove and additional moisture present in the sample and then allowed to cool to room temperature. Approximately 1.5 grams of sediment was placed into a vial to which 40 mL of pond water was added. The pond water was obtained during field sampling. The combination was then inverted repeatedly for approximately 20 hours. In order to reduce the turbidity of the samples and allow for analysis, the solid sediment was filtered out with the aid of a vacuum pump. The appropriate laboratory procedure for testing each nutrient was applied to the remaining water as outlined in this section. Three vials of the sediment and Pond water were prepared to provide one complete vial for each procedure. For quality control, an additional test was prepared using the sediment and deionized water. Although the concentration of nutrients present in the sample water had

been measured previously, another series of the tests were conducted on the Pond water alone as well as on a set containing only deionized water.

3.3 Runoff and Nutrient Loading Determination

Nutrient loadings from runoff in the tributary area of Pepperell Pond were another possible source of excessive phosphorus, which could contribute to the eutrophication of the Nashua River. It was necessary to quantify the amount of runoff which could be expected to contribute nutrients, and then to assess the nutrient load as a result of this runoff quantity. In order to assure accuracy of results, runoff results were generated using the National Resource Conservation Services (NRCS) Method, and BASINS, an EPA assessment software package. Their results were assessed and compared for nonpoint loading by runoff.

3.3.1 Runoff– NRCS Method

Analysis of the water samples obtained along the Nashua River identified the level of nutrients present at points along the river as well as entering and exiting the Pond. While the Nashua River was a major source for the level of nutrients in the pond, it was not the only source of nutrients to enter the system. To gauge the contribution of phosphorus due to runoff from the sub basin surrounding the Pepperell Pond, the National Resource Conservation Service (NRCS) method was used to calculate the rainfall excess. By calculating these values, it allowed the overall nutrient loadings to be calculated for the entire sub basin due to storm runoff.

The first step was to determine the area surrounding the pond itself. The sub basin was delineated using a topography contour map. After the area of the watershed was delineated by using the contours of the map, estimates of the overall width and the length of the area were made. By using this geometry of the region a general area of the tributary area of Pepperell Pond was estimated.. This area is represented in the green area of Figure 13.

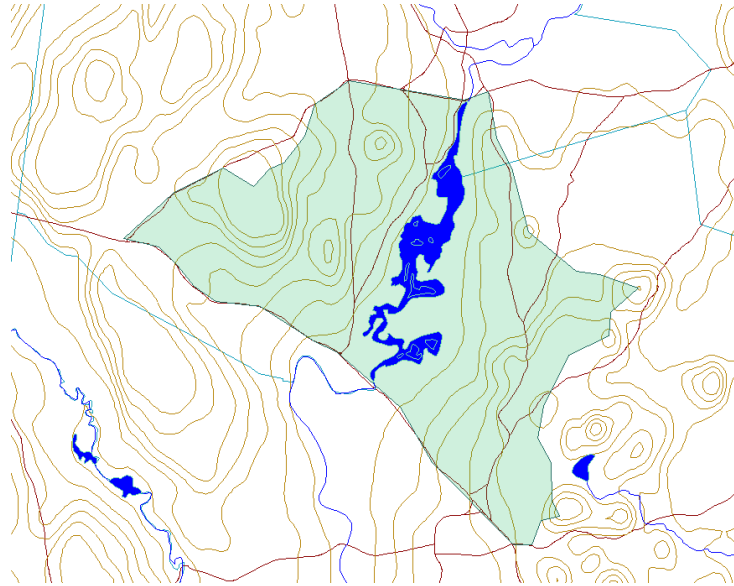


Figure 13: Topography and Tributary Area near Pepperell Pond¹⁰⁰

The next step in using the NRCS method was to approximate the Curve Number (CN) for the area. In this case, a Composite Curve Number (CCN) was established by adding the sum of the specific areas and their respective curve numbers and dividing this value by the sum of the entire area of the sub watershed basin. A table of curve numbers used for this analysis is contained in Appendix G: Curve Numbers for NRCS Analysis.

$$CCN = \frac{\sum A_i CN_i}{\sum A_{total}}$$

To determine the land use and soil type in the area surrounding the pond, two separate GIS maps were surveyed to determine the land use in particular areas as well as the soil types in these same areas. A map of the area around Pepperell Pond with soil types can be seen in Figure 14. A map with land use can be seen in Figure 15.

¹⁰⁰ "Surface Contour Map" Map. MassGIS. 25 Feb. 2008 <<http://www.mass.gov/mgis/mapping.htm>>.

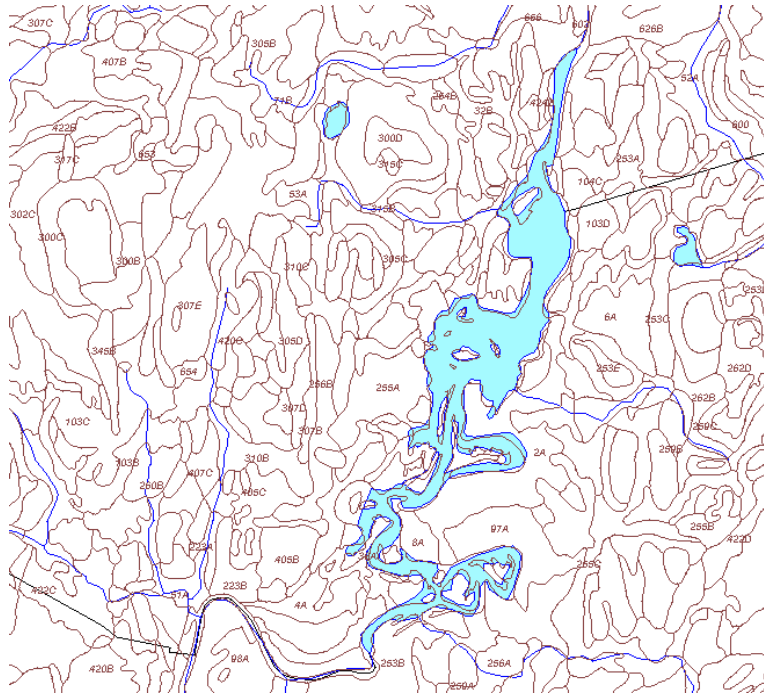


Figure 14: Soil Polygons with Map Unit Names¹⁰¹

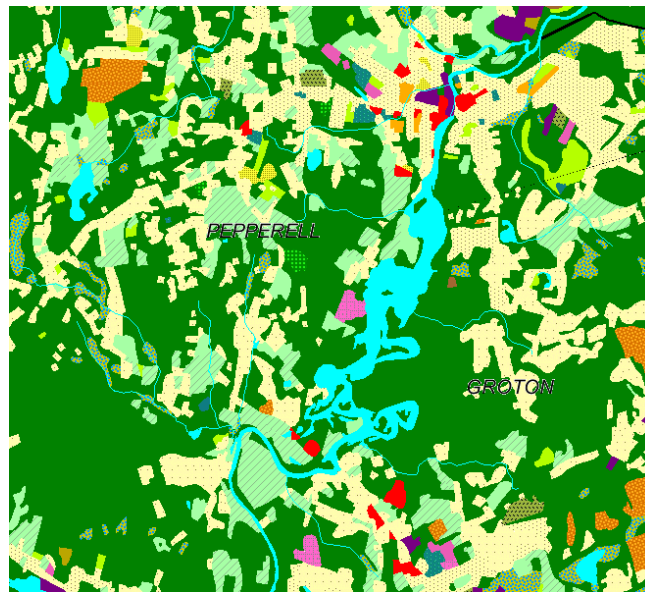


Figure 15: Land Use Surrounding Pepperell Pond¹⁰²

Here, half of the entire area, east of the pond, was state forest and protected land reserves. Since this land was undeveloped, the category of Woods with Good Hydrologic Condition was chosen using the table “Runoff Curve Numbers for Hydrologic Soil Cover

¹⁰¹ "Soil Polygons with Map Unit Names." Map. MassGIS. 25 Feb. 2008
<<http://www.mass.gov/mgis/mapping.htm>>.

¹⁰² "Land Use Surrounding Pepperell Pond." Map. MassGIS. 25 Feb. 2008
<<http://www.mass.gov/mgis/mapping.htm>>.

Complexes.” For the entire area, Hydrologic Soil Group B was chosen, because as Figure 14 shows, while soils vary widely in the area, type B soils are both common, and an adequate average of the other types of soil in the vicinity.¹⁰³ Soil Group B is defined as having moderately low runoff potential.¹⁰⁴

West of the pond possesses more developed area. More specifically, one quarter of the overall area west of the pond was mainly residential with spacious land plots. As a result, the “2-acre residential district” category was chosen for “Curve Numbers for Urban Land Uses.”¹⁰⁵ The final quarter of the sub basin surrounding the Pepperell Pond was more developed with some light industry and commercial development. As a result, using the aforementioned table, the “Commercial and Business” category was selected. After these curve numbers were multiplied with their respective areas, the value was divided by entire area of the sub basin. A summary of the composite curve numbers used for the various calculations is found in Table 11.

Table 11: Composite Curve Numbers for Runoff Calculations

Condition	Composite Curve Number
Present Day	67
10% More Impervious	70
20% More Impervious	72
10% More Impervious, 50% Protected Land	69
20% More Impervious, 50% Protected Land	72
Present Day, Smaller Residential Plots	68
10% More Impervious, Smaller Residential Plots	71
20% More Impervious, Smaller Residential Plots	73
10% More Impervious, Smaller Residential Plots, 50% Protected Land	70
20% More Impervious, Smaller Residential Plots, 50% Protected Land	72

To determine the correct rainfall data for calculating the runoff of the area, several steps were taken. First, US Geological Survey Rainfall Data Maps for the state of Massachusetts were analyzed and precipitations were interpolated on the map for the Pepperell Massachusetts area. The lowest available rainfall data was for a 2-Year, 24 Hour Rainfall. However, this was too intense as this type of storm only occurs every two years on average. Therefore, using data from the United States Geological Service (USGS) was used to determine how frequently a significant storm occurred. In addition, a spreadsheet was created using the years of the storms and the

¹⁰³ Wanielista, Martin, Robert Kersten, and Ron Eaglin. "Infiltration." Watershed Characteristics and Infiltration. New York: John Wiley and Sons, Inc., 1997. 157.

¹⁰⁴ Wanielista, Martin, Robert Kersten, and Ron Eaglin. "Infiltration." Watershed Characteristics and Infiltration. New York: John Wiley and Sons, Inc., 1997. 150.

¹⁰⁵ Wanielista, Martin, Robert Kersten, and Ron Eaglin. "Infiltration." Watershed Characteristics and Infiltration. New York: John Wiley and Sons, Inc., 1997. 156.

precipitation amounts. A trend line was created and from this an estimation could be made for the precipitation for a more common storm. In this case, the design storm occurs once each month. The summary of results and an associated trend line are shown in Table 12 and Figure 16.

Table 12: Pepperell Storm Total Precipitation by return period

Frequency (years)	Precipitation (Inches)
0.083	2.1
0.25	2.3
1	2.5
2	2.9
5	3.85
10	4.4
25	5.15
50	5.8
100	6.2

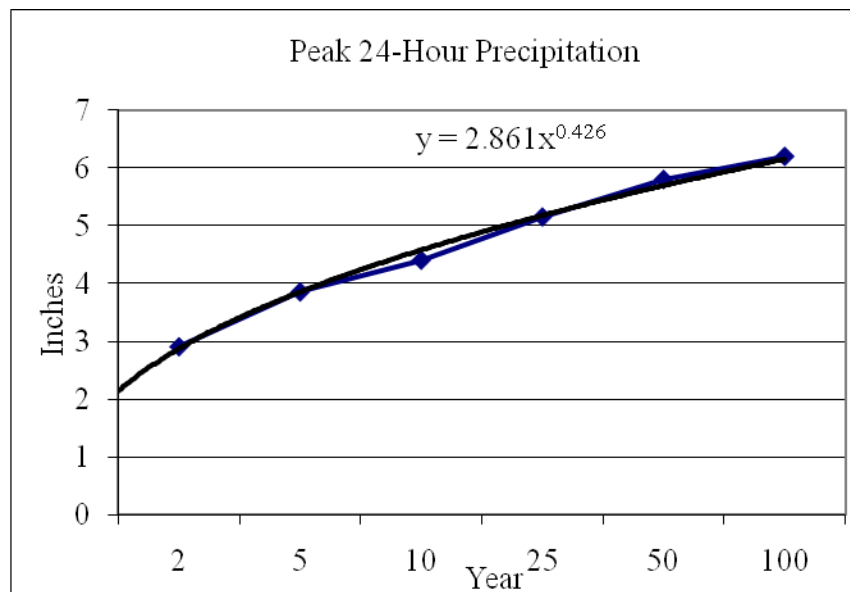


Figure 16: Precipitation by storm return period.

Using the data that was gathered, the abstraction number was determined through the equation.¹⁰⁶

$$S' = \frac{1000}{CN} - 10$$

After finding this value, it was then plugged into an equation that determined the runoff over the entire area.

$$R = \frac{(P - 0.2S')^2}{(P + 0.8S')} \quad \text{For } P > 0.2S'$$

This model assumes an initial abstraction of 20%, meaning that the soil was incapable of absorbing any more moisture. Pepperell receives approximately 45 inches of rain per year,¹⁰⁷ and 80% of the precipitation can be modeled as a combination of one month, quarterly, and one year storms for runoff concerns. This model assumes that lighter rains will not produce a large amount of runoff, and any precipitation from storms with a return period less than one month will infiltrate into the ground instead of running off.

The value that was computed was converted from inches over the watershed to cubic feet of total runoff for a 24 hour storm and entered into a Microsoft Excel Spreadsheet. This value was determined for rainfall of one month, three months, one year, five years, ten years, twenty five years, fifty years, and one hundred years.

3.3.2 Development and Expected Future Stormwater Conditions

The same methodology used to develop expected stormwater under existing conditions was repeated for a number of potential land development scenarios. The first considered 50% constant protected land and future values of 10% and 20% more impervious area. After this the same calculations were made with varying constant land values and future values of 10% and 20% more impervious area. Finally, calculations were made with smaller residential plots for all of these cases to determine the runoff for a future time in which the area around the pond would be more developed.

¹⁰⁶ Wanielista, Martin, Robert Kersten, and Ron Eaglin. "Infiltration." Watershed Characteristics and Infiltration. New York: John Wiley and Sons, Inc., 1997. 148-164.

¹⁰⁷ Taken from The Weather Channel online: <http://www.weather.com/weather/wxclimatology/monthly/USMA0327> Accessed February 21, 2008

3.3.3 Event Mean Concentration Determination

Once total stormwater loads were developed, it became necessary to relate them to nonpoint nutrient loadings. One method for this analysis is the event mean concentration, an expected average concentration for a contaminant of concern during a storm event.¹⁰⁸ Using land use information, zoning considerations, and land-based loadings from Marsh (2005), a stormwater event mean concentration of phosphorus was developed.¹⁰⁹ Using the event mean concentration, as well as stormwater flows established with the NRCS method, nonpoint loads were developed for annual runoff phosphorus totals.

3.3.4 BASINS and PLoad Analysis

Where possible the results for this project were verified with other models. The US Environmental Protection Agency (EPA) has a number of techniques for stormwater loading and modeling, including an integrated unit called “Better Assessment Science Integrating point and Nonpoint Sources” (BASINS.) BASINS allows the user to build a model of a system using geographical information systems (GIS) information on the land use, watershed area, and climate of a system, and then can use several methods to model the system for nutrients, toxics, and pathogen loading.

The first step involved in this model is the deliniation of a watershed area. While it would be possible to create a model for the entire Nashua River watershed, this approach was not considered to be essential for the scope of this project. The inlet of the pond is considered a point loading for the purposes of this project, because the DEP considered upstream point loads and their impacts. The focus of this project is Pepperell Pond, so the subwatershed of interest was the tributary area around the pond. This area was obtained by connecting hills and peaks within the surrounding major roads, and determining an area around the pond where water could feasibly flow toward the pond. The roads on the river’s edge were not considered to be barriers, because they are fairly flat, and the terrain around them has a steep enough slope to force a large

¹⁰⁸ Wanielista, Martin, et al. Hydrology, Second Addition. 1997, John Wiley & Sons, New York. 170.

¹⁰⁹ Marsh, William M. Landscape Planning: Environmental Applications, Fourth Edition. New York: John Wiley and Sons, Inc., 2005. 215-217.

volume of water over the road. The resulting tributary area is shown as the green shaded area in

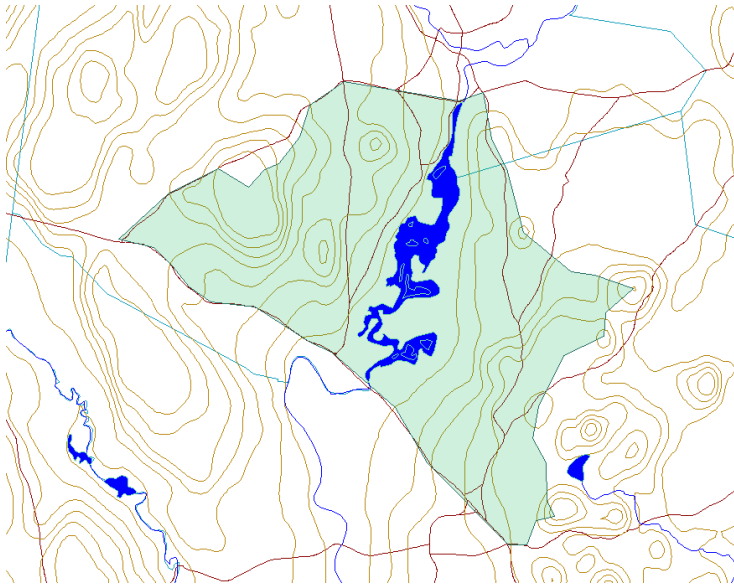


Figure 17.

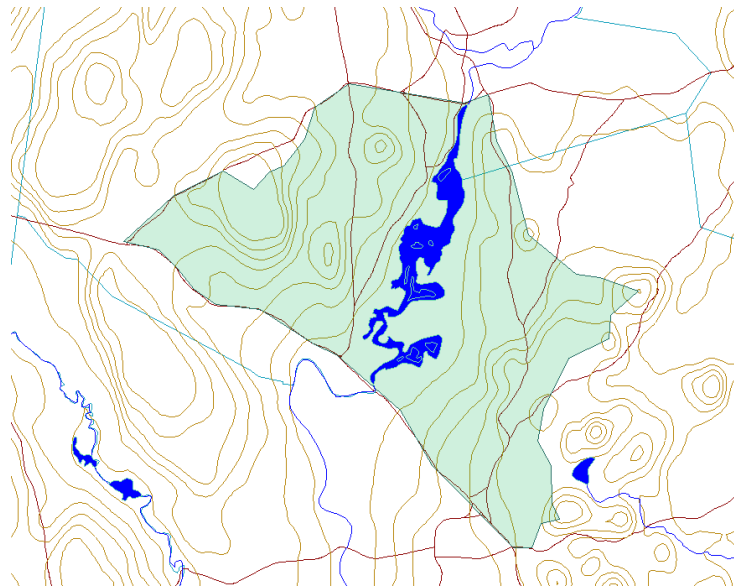


Figure 17: Pepperell Pond Tributary Area¹¹⁰

Massachusetts has a wide range of information available in a system called MassGIS. Data layers on land use and zoning are updated approximately annually, and information regarding water bodies, surface contours, surficial geology, and other layers of interest are available to the public. BASINS includes a free, open source GIS system, but it is not as

¹¹⁰ "Surface Contour Map" Map. MassGIS. 25 Feb. 2008 <<http://www.mass.gov/mgis/mapping.htm>>.

powerful as ArcGIS 9.0, which was available, so this was the system used to create the subwatershed. The required layers for a BASINS model are surface contours, water bodies, a subwatershed delineation (such as the one shown in Figure 17) and land use within the watershed. Each of these layers was available for the entire state of Massachusetts, and land use was available by county, but these layers contained a great deal of information not necessary for this analysis. Therefore, these layers were imported into ArcGIS 9.0 and the excess area was trimmed out of them, so that only immediate surrounding towns remained in the model. This allowed BASINS to run much more quickly, because it only had to load a small fraction of the information it otherwise would.

Once these layers were trimmed, they were loaded into BASINS, and arranged so that the land use and surficial geology layers were underneath the surface water and land contours, so that the map would be easier to use. This model had to first have the default BASINS layer set removed, because the projection of the model layers relative to the US datum resulted in large discrepancies. The default layers were removed, and all layers in this model were shown without reprojection, so that the model would be based on the Massachusetts datum, rather than the US datum.

The final result of this model is the image shown in Figure 18. The blue layer is land use, which is not transparent, and all layers below it are obscured. Land contours, major streams and ponds, the subbasin and major roads in the area are also shown.

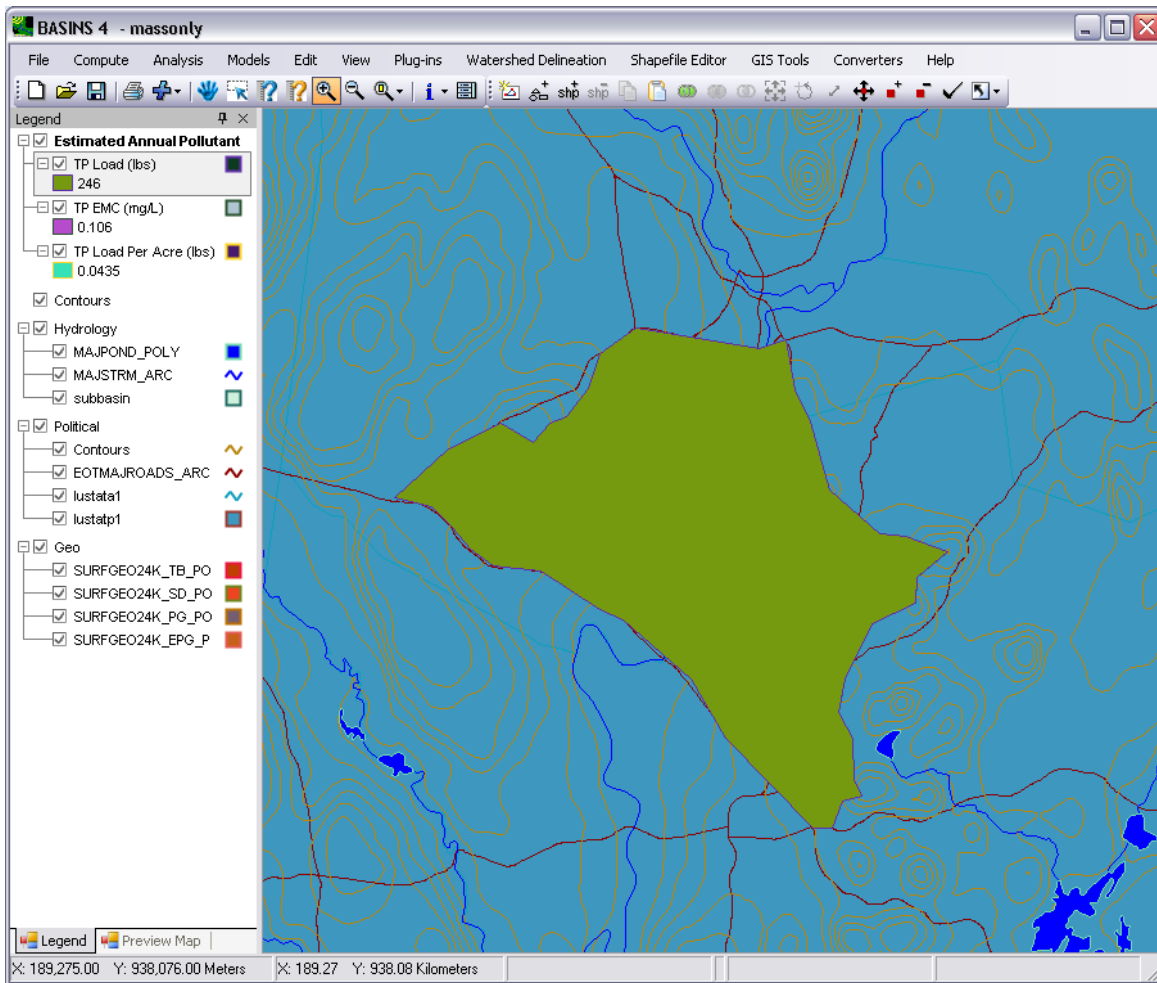


Figure 18: Full BASINS Model, as used

The next step involved developing pollutant loads from this model. There are several models which can run in BASINS. One called PLoad is designed to determine various loadings as a result of land use and area, and produces similar results to the NRCS analysis presented earlier. PLoad was selected to simulate this watershed. To run the PLoad simulation, the user must designate a layer for land use (as well as which section of the layer designates its land use) total precipitation, runoff-causing fraction, subwatershed, and surface contour layers. It then has a default setting for various impervious areas, but allows the user to change them. For example, if residential area is divided into very large or very small lots, the impervious area will be greatly affected, and can be changed to reflect these factors. Once all of these settings are correct, PLoad will generate annual loads (total nitrogen, phosphorus, etc.) event mean concentrations, the expected runoff concentration, and average loading per acre, per year.

3.4 Mass Balance for Phosphorus on days of sample collection

A flow and mass balance for phosphorus yielded approximate groundwater flow and sink strength (ability to bind phosphorus to sediments and plants) values for Pepperell Pond. This analysis assumed steady state conditions and since the weather was cold and overcast, which would inhibit biological growth, it can be assumed that very little biological activity occurred on November 30, 2007. Another critical assumption is the relatively small input of phosphorus from groundwater and septic systems around the pond. This assumption is reasonable, because Marsh (2005) recommends loadings of 0.28kg of phosphorus per home contributing septic loads (within 100 yards of the river's edge) annually.¹¹¹ Assuming, therefore, that the only flows were groundwater, inflow, and outflow, that groundwater flow contained negligible nutrients, and there was no biological activity or sediment nutrient contribution, groundwater flow can be estimated from the following system of equations:

$$Q_{out} = Q_{in} + Q_{GW}$$

And:

$$Q_{out} * C_{out} = Q_{in} * C_{inflow}$$

Outflow is measured at a downstream gage, so data points are available for these flows. Phosphate concentrations were determined for both the inlet and outlet of the pond, so flow at the inlet can be approximated from its relative dilution. Groundwater flow can be estimated as the difference between this value and the measured outflow.

Using the acquired groundwater flow rate and gage data for outflows, it is possible to estimate river flows and mass flow rates for the October sample collection date. From this information, a total mass change in phosphorus can be estimated for biological and sorption activity on the October collection date, using the following equation:

$$\Delta m = Q_{in} * C_{in} - Q_{out} * C_{out}$$

From these results, it was possible to determine the sum of all sinks for phosphorus on the date of sampling in October, as well as the groundwater flow rate.

¹¹¹ Marsh, William M. Landscape Planning: Environmental Applications, Fourth Edition. New York: John Wiley and Sons, Inc., 2005. 218.

3.5 Discovery and Analysis of Remediation Methods

With the analysis of loadings complete, critical areas of control were identified. These areas served as the target of remediation methods. Remediation methods were compiled from EPA methods, treatment techniques used and recommended for other sections of Massachusetts rivers, and research of treatment techniques for nutrient reduction. Any method was considered, provided it had either been implemented elsewhere or was considered for use, or if there was valid scientific evidence to prove its effectiveness. The goal of this process was to identify as many options as possible, such that any or all could be implemented, and then to choose the most applicable and effective means.

Once loadings had been determined, it became possible to point to more significant sources of nutrients, and focus on those for elimination. Knowing that one major target would be the reduction of runoff-driven nutrient loads, it became necessary to research both runoff control techniques (such as infiltration beds) and filtering mechanisms (for instance, riparian buffers) to remove nutrients from the runoff before stormwater could reach the Nashua River.

3.6 Evaluating and adapting alternatives.

Research into remediation methods yielded a variety of different ways to suppress or eliminate algal growth within the pond. Many that would be most effective were either cost prohibitive, need to be implemented at too large of a scale to be feasible, or would cause other problems downstream. While many different options are presented, analysis of these options resulted in a select few that are practical for this scenario. This phase required careful consideration of the costs of any construction required, as well as impacts to the surrounding ecosystem, and potential effects on downstream water quality. The most innocuous systems were selected as the first criterion- any system which could negatively affect downstream water quality or damage sensitive habitats would not be considered except as a last resort. The next criterion was efficiency- cost of implementation, as compared to removal efficiency for the nutrients. This process was largely subjective, as cost estimates would be subject to a number of factors: whether the project was independent, or part of another project, market prices for various construction projects, and funding sources (a project paid with state and federal money creates much less of a burden on the group undertaking it, so it can pass without cost restrictions.) A largely effective project was likely to be considered as a long term option, even if price would

create a short-term restriction. This led to a short list of reasonable methods for plant and nutrient removal techniques.

3.7 Developing a formal management plan and composing the report

Once a list of possible methods was established, they were divided amongst the nutrient sources they would address. These sources were point, nonpoint, residual (sediment) and groundwater sources. The best candidate for each source was recommended for implementation over a series of years. An analysis and recommendation for the DEP, regarding the TMDL for phosphorus removal, was also included, as changes to the point source at the pond's inlet would largely be affected by the TMDL's implementation. A report was compiled to reflect the final management options, as well as the path to development and the research to justify each choice.

4. Results and Analysis

Laboratory analysis, hydrology analysis, and other methods were used to determine nutrient loads into Pepperell Pond. Results were generated for existing conditions within the pond itself, and for several scenarios involving different styles of development in South Pepperell and Groton. From these scenarios and loads, it was possible to determine the most significant phosphorus contributions, and to consider possible methods of mitigation of phosphorus loads.

4.1 Basin Characterization

Land use often contributes to nutrient pollution. Water inputs may include surface runoff from agricultural use, wastewater inputs from septic system use, storm water contributions from sewers, or a host of other inputs. These can be quantified via the use of the rational method, an analysis which allows a user to consider a contributing area, average runoff coefficient, and storm intensity.¹¹² For this analysis, nutrient inputs from the various land uses (such as fertilizer applications) can be used in addition to impervious area to determine the approximate nonpoint nutrient loadings applied around the pond.

The area in and around Pepperell Pond is used in several different ways, ranging from industrial to farmland and protected forests. Several factors contribute to the hydrology of the area. From satellite imagery, several geographic features and land uses in the area are apparent. GIS maps and United States Geological Survey (USGS) data can be used to assess tributary areas and nutrient loads entering Pepperell Pond. Figure 19 is a satellite image of Pepperell Pond, with Pepperell Village to the north and west, and Groton to the east.

¹¹² Wanielista, Martin, et al. Hydrology, Second Addition. 1997, John Wiley & Sons, New York. 208.



Figure 19. Pepperell Pond, Satellite View¹¹³

Using the GIS system OLIVER, it is possible to examine important hydrological aspects of the area. The first important hydrological aspect is the surface contour of the surrounding areas. A map providing the surficial topography is shown in Figure 20. Generally, the immediate area surrounding the pond is flat. However, to the east of the pond, this area becomes steeper. Surface water from this area can flow directly into the tributaries adjacent and then make their way into Pepperell Pond. It may also be possible, since the immediate area is flat and somewhat forested, for storm runoff to infiltrate into the soil, and only reach the pond as a result of groundwater flow.

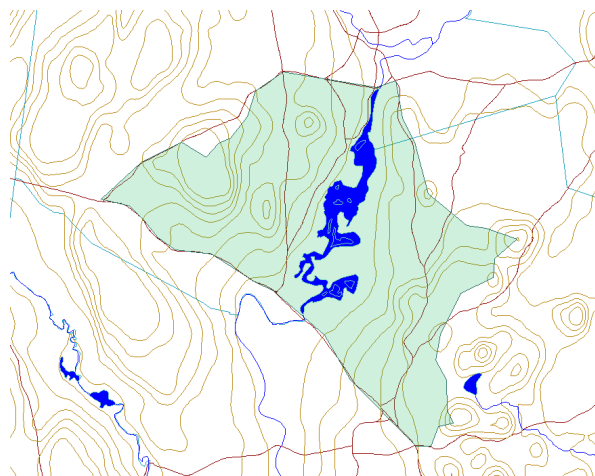


Figure 20. Surface Contour Map.¹¹⁴

¹¹³ "Pepperell Pond, Satellite View" Map. MassGIS. 25 Feb. 2008 <<http://www.mass.gov/mgis/mapping.htm>>.

¹¹⁴ "Surface Contour Map" Map. MassGIS. 25 Feb. 2008 <<http://www.mass.gov/mgis/mapping.htm>>.

A second area of information that is necessary for an analysis is the land use in the immediate vicinity of Pepperell Pond. The most recent available information on land use in this area is available for 1997, through MassGIS. The land use can be seen in Figure 21 and the subwatershed is delineated by the thick black line.

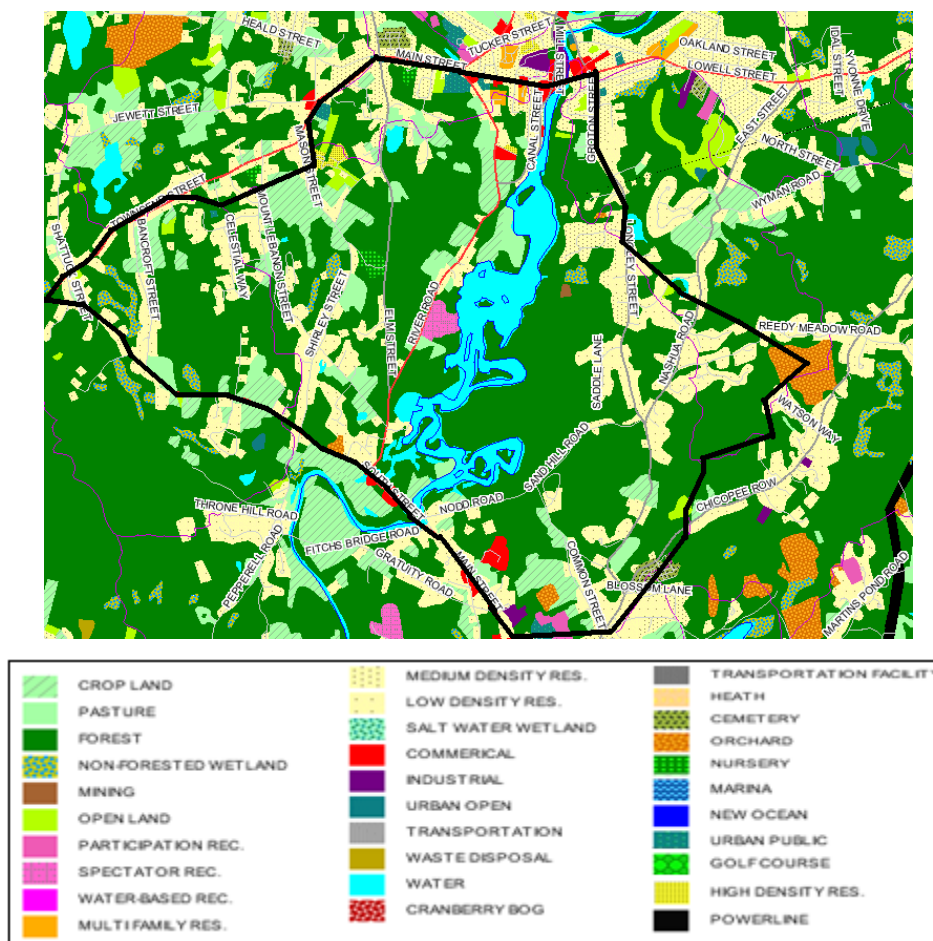


Figure 21. Land Use Surrounding Pepperell Pond¹¹⁵

For the most part, the area directly surrounding the banks of the pond is classified as forest area. However, there are important parcels of land that are not classified as forested land, which include agricultural land and some commerce and industry along the south end of the pond. The east side of the pond, specifically where the pond becomes steep, is classified as crop land and pasture.

¹¹⁵ "Land Use Surrounding Pepperell Pond." Map. MassGIS. 25 Feb. 2008
<<http://www.mass.gov/mgis/mapping.htm>>.

Given both the land use and steepness of this area, nutrients may travel along the surface water contours and directly into the pond. To the north of the pond, the land use is classified as industrial and commercial. This area was the location of the most persistent algal blooms.

4.2 Flow Estimate

Using data from the USGS, flows out of the pond can be estimated. Currently, the USGS maintains a gage station 200 feet downstream from the power plant of the James River-Pepperell Co. at East Pepperell. This location is situated just beyond the north end of Pepperell Pond, and is represented by the red dot in the map in Figure 22.

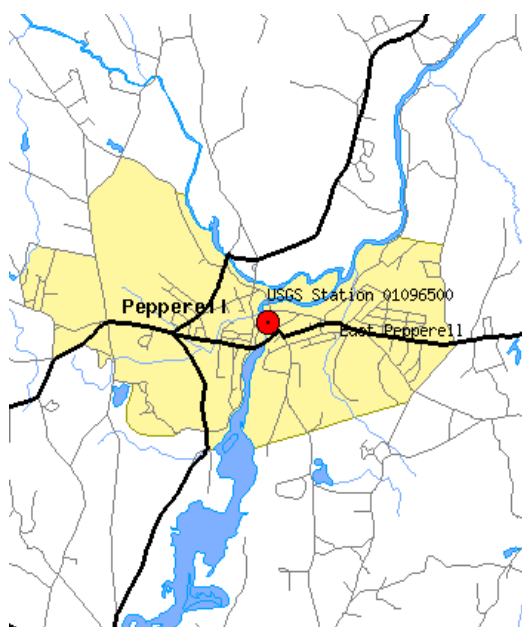


Figure 22. USGS Gage Station.¹¹⁶

4.2.1 Current Flow Analysis

The USGS gauging station records daily discharge data, and has done so from 1935 to the present day. However, the USGS has only made monthly data available for the 1935 to 2006 span. Using the recent years of 1997 to 2006, these values were looked at to determine the flow through this area.

The monthly mean flow through the gage varied through the different months. April had a high monthly mean of 1,040 cubic feet per second of discharge while the September passed only 226 cubic feet per second of water. A complete table of these values can be seen in Table

¹¹⁶ "USGS Gage Station." Map. United States Geological Survey. 25 Feb. 2008
<http://waterdata.usgs.gov/ma/nwis/uv?site_no=01096500&format=gif&period=31>.

13. Considerations of flows for this project tended to reflect average flow conditions. Flows are generally 500 cubic feet per second. Low flow conditions were not considered here because low flows were addressed by the Massachusetts DEP in the TMDL report for phosphorus.¹¹⁷ Higher flows were not considered because sampling was not done in wet weather, so there was no reference data available to model these conditions.

Table 13: Mean, high and low Monthly Discharge from 1997 to 2006¹¹⁸

Month	Mean Monthly Discharge (cfs)	High (cfs)	Low (cfs)
January	668	1,028	141.3
February	680	1,146	264.9
March	1040	1,931	452.5
April	1310	2,071	471.2
May	856	1,217	270.2
June	733	1,488	106.7
July	325	433.6	109.9
August	243	512.3	69.6
September	226	434.4	72.9
October	497	1,570	116.9
November	434	937.3	94.7
December	587	1,026	171.4

Table 14 displays the seasonal mean, peak, and minimum values for the flow through Pepperell Pond for 10 years from 1997 to 2006. Seasonally, the peak flows for this area occur in the spring between the months of March and May. Here, the seasonal mean is 1,069 cubic feet per second. This period produces the greatest amount of water flowing through the pond. On the other hand, autumn provides the least amount of flow throughout the pond. Between the months of September through November, the mean discharge was 386 cubic feet per second.

Table 14: Seasonal Mean, Peak, and Minimum

Period	Mean (cfs)	Peak (cfs)	Minimum (cfs)
Spring (Mar-May)	1,069	2071	270
Summer (June-Aug)	434	1448	69.6
Autumn (Sept-Nov)	386	1570	72.9
Winter (Dec-Feb)	645	1146	141.3

The flows that were recorded when sampling differed in value. On October 5, 2007 the mean flow was 93 cubic feet per second while the flow on November 29, 2007 was 244 cubic feet per second. These values can be seen in the Table 15. Both of these flows are unusually low

¹¹⁷ MassDEP DWM. Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 47.

¹¹⁸ "USGS Realtime Water Data." United States Geological Survey. Department of the Interior. 26 Feb. 2008 <http://waterdata.usgs.gov/ma/nwis/uv?site_no=01096500&format=gif&period=31>.

for their respective time periods during the year. Specifically, the flow recorded during the October visit was 404 cubic feet per second below the average time for October. Similarly, the flow on November was 190 cubic feet per second below normal.

Table 15: Flow Values for Sampling Dates

Date	Mean Discharge Rate (cfs)	Yearly average (cfs)
5-Oct-07	93	497
29-Nov-07	244	434

Based on these observations, both these times during the year were experiencing very low flow conditions. This implies that there has been very low runoff over a long period of time in the watershed. In addition, with the low flows occurring, the effect of the flows from waste water treatment facilities may pose a greater impact than of periods with average and high flow conditions. Therefore, the nutrients entering the pond from these point sources are likely contributing to the detrimental effects on the pond.

Using the land use data that was gathered, the abstraction number was determined through the equation presented in the section of the methodology entitled “Runoff-NRCS Method.”¹¹⁹ A comprehensive curve number of 72 was determined for the area as a whole. With this value, the runoff over the entire area was determined using the runoff equation offered in the section of the methodology stated above. The value that was computed was converted from inches over the watershed to total runoff, cubic feet per day. The final resulting runoff values are presented in Table 16. The design storm had a total 24-hour precipitation of 2.1 inches.

Table 16: Runoff rates for various return periods

Frequency of Storm (Yr.)	Runoff (inches per day)	Volume (acre-feet per day)	Total runoff (cubic feet per day)
0.0833 (1 Month)	0.21	96.3	4,200,000
0.25 (3 Month)	0.28	129.6	5,650,000
1	0.36	166.6	7,260,000
2	0.54	250.6	10,900,000
5	1.06	492.3	21,400,000
10	1.40	653.3	28,500,000
25	1.91	891.3	38,800,000
50	2.38	1110.7	48,400,000
100	2.69	1250.7	54,500,000

Total runoff averages approximately 166 million cubic feet per year, assuming a series of 12 one-month storms, four quarterly storms, and one annual storm as a typical annual storm

¹¹⁹ Wanielista, Martin, Robert Kersten, and Ron Eaglin. "Infiltration." Watershed Characteristics and Infiltration. New York: John Wiley and Sons, Inc., 1997. 148-164.

distribution. These series can be used to estimate yearly runoff volumes flowing into Pepperell Pond.

4.2.2 Direct Precipitation and Evaporation

Additional flow includes 45.4 inches per year of direct rainfall on a 300 acre water surface. However, evaporation from a water surface in northern Massachusetts is approximately 28 inches per year.¹²⁰ Therefore, the net precipitation would be 17.4 inches, and 435 acre-feet per year. This would be a total flow of 18.9 million cubic feet per year.

4.2.3 Estimating Event Mean Concentrations (EMC)

Marsh (2005) presents estimates for runoff nutrient concentrations in various locations and land cover. For the northeast, forested land (approximately 50% of the pond's tributary area) averages 0.022 mg/L phosphorus. Mixed use agriculture (50% agricultural land, which accounts for 25% of the watershed) averages 0.123 mg/L phosphorus. The remaining tributary area is residential and commercial, with about 50% forested area, which averages 0.028 mg/L phosphorus.¹²¹ Since the tributary area is a combination of these areas, it became necessary to use an area-based weighted average approach to determine the average concentration of all runoff from the area. This concentration is 0.049 mg/L phosphorus in the runoff, which, at average runoff in a one-month storm (144 cfs or 4100 L/s) yields a phosphorus influx of 200 mg/s, or 17.2 kg/day. Considering the yearly runoff volume and average event mean concentration, this yields a total load of 430 kg/year.

Since the forested and mixed use areas have similar loadings, and the agricultural area has a much higher loading, it is important to also consider that as an entirely independent area. The curve number for that area alone is 75, as estimated from ¼ acre house lots and small grain cropland.¹²² The area is estimated at 1420 acres, or 25% of the watershed, yielding an abstraction of 3.33" and runoff of 0.432" per day, or 25.8 cubic feet per second. This area, with

¹²⁰ Friesz, Paul J., and John A. Colman. United States. US Geological Survey. Department of the Interior. Hydrology and Trophic Ecology of Walden Pond, Concord, Massachusetts.

¹²¹ Marsh, William M. Landscape Planning: Environmental Applications, Fourth Edition. New York: John Wiley and Sons, Inc., 2005. 215-217.

¹²² Wanielista, Martin, Robert Kersten, and Ron Eaglin. "Infiltration." Watershed Characteristics and Infiltration. New York: John Wiley and Sons, Inc., 1997. 148-164.

its 0.123mg/L phosphorus loading, yields 91mg/s of phosphorus into the pond over the course of a single day storm, or 15.5 kg of total phosphorus.

Another way to convert this to a nutrient load is to apply a number of nutrient loading approximations from Marsh (2005) to the overall area. Yearly estimates for nutrient loading by land use were given, and are presented in Table 17. Nutrient loading is shown to increase as areas go from forested to agricultural or other deforested uses such as golf courses.

Table 17: Nutrient Loading Estimates for Various Land Uses¹²³

<i>Use/Cover</i>	<i>Nitrogen (kg/km²/yr)</i>	<i>Phosphorus (kg/km²/yr)</i>
Forest	440	8.5
Mostly forest	450	17.5
Mostly urban	788	30.0
Mostly agriculture	631	28.0
Agriculture	982	31.0
Mixed	552	18.5
Golf Course	1500	41.0

At this time, the western portion of the pond is evenly divided between loadings from agricultural and residential runoff, with regard to both nitrogen and phosphorus, and the most significant source of nitrogen is the protected forest land on the eastern portion of the tributary area. The current conditions, and resultant nutrient loads, are shown in Table 18. Phosphorus loadings correlate closely with the event mean concentration-based estimate.

Table 18: Specific nutrient results for current conditions

			Loading rate kg/yr-km ²		Total loading, kg	
Location	Description	Area (km ²)	N	P	N	P
West	Mixed res / agriculture	5.74	1262	56	3620	160
East	Forest	11.4	880	17	5000	96
Northwest	Urban	5.74	1576	60	4520	172
				Annual	13140	430
				Monthly Mean	1100	36

4.2.4 Future Flow Analysis

Increasing the impervious area with time, according to this land use estimate, may not have a significant impact on the phosphorus loadings, except in the case of 20% impervious area increase. There are, however, many inherent assumptions in this estimate. While the EPA presented the land use based loadings, they do not necessarily fit cleanly into the same

¹²³ Marsh, William M. Landscape Planning: Environmental Applications, Fourth Edition. New York: John Wiley and Sons, Inc., 2005. 216.

delineations present in Pepperell and Groton. Agricultural loadings vary by crop, time of year, and proximity to receiving water, as vegetation along the land's edge may absorb the nutrients before runoff occurs. However, this estimate provides a beginning point from which assessments can be made of nutrient impacts.

The northwest area is mixed, but predominantly urban land use. The southwest is mostly agricultural, with some houses, and the east is forest. Applying annual loading estimates from Table 17 to the watershed yielded approximate annual loadings. Averaging these annual loading over a year, as twelve one month loadings corresponding to a one-month storm event yields the loadings presented in

Table 19.

As this area becomes more developed, the potential for nutrients entering the pond at this location and along other sections of the Nashua River becomes greater. Development of commercial and industrial land is also occurring to the south of the pond. Here is the greatest chance in which nutrients and other substances can enter the river and eventually into the pond through surface water runoff and ground water seepage. The area to the east of the pond is conservation land classified as forest area, which is less likely to add nutrients, and likely serves as a buffer against the residential areas on the other side of it.

Table 19: Nutrient Loadings over various land use conditions

Condition	Impervious area, % ¹²⁴		N (kg)	P (kg)
Present	9.1	Annual	6581	215
		1 month	548	18
10% More Impervious	19.1	Annual	6840	227
		1 month	570	19
20% More Impervious	29	Annual	7147	251
		1 month	596	21
10% More impervious, 50% protected	19	Annual	6731	216
		1 month	561	18
20% More Impervious, 50% protected	29	Annual	6910	218
		1 month	576	18

¹²⁴ "Nashua River Watershed Association: Five Year Plan." Nashua River Watershed Association. 2007. Nashua River Watershed Association. 26 Sept. 2007 <<http://www.nashuariverwatershed.org/>>.

Since nearly 80% of the phosphorus is expected to enter from the west side, policies can be written to prevent runoff from the West side of the Nashua River, without impacting the Groton side, which is largely protected forest and has a much less significant impact on the total phosphorus load.

4.3 BASINS and PLOAD Results

The results generated by BASINS generally align themselves with the results generated by the NRCS method. The NRCS method relied on a general assumption that the mean concentration of the runoff would be 0.123 mg/L as phosphorus. The BASINS results, summarized in the following table, were similar for mean concentration, but varied widely in total loading. It can be expected, however, that BASINS will yield lower numbers, because many areas, including agricultural land expected to contribute the vast majority of the loadings, had no impervious area in the model. This assumption generally means that there will be no runoff from these areas, and thus no loading. It can, therefore, be used to establish the potential effect of stormwater mitigation measures from this area. Under the NRCS modeling, 40% of the phosphorus contribution came from the northwestern area, in Pepperell center. Given BASINS' assumption that no runoff is generated by forests or agriculture, this could result in approximately the same result as the PLOAD simulation.

Table 20: Stormwater loading by model

	PLOAD	NRCS	Difference / mean (%)
EMC	0.106	0.123	15
Lbs/year	245	473	64

The NRCS method yielded a higher phosphorus load than PLOAD, which was largely due to the assumption that all runoff occurs during storms with at least 2 inches of rainfall per day. If smaller storms were considered instead of a single large storm, there would be more time with slightly less runoff, which would likely yield higher overall nutrient loadings. PLOAD has a preloaded climate setting to approximate a rainfall distribution, which considers storms with low return rates.

4.4 Nutrient Analysis in Nashua River Water Samples

For nutrient analysis of the water along the Nashua River, two sets of samples were taken. The first sampling on October 5, 2007 represented dry weather low flow conditions where there had been no significant rain for weeks. The second sampling, on November 30, 2007, occurred in contrasting conditions where it had rained recently during the week with precipitation experienced at the time of sampling. Figure 23 displays all of the sampling locations. In the first round of sampling, water samples were collected at locations 1, 2, 3, 4, 5, 6. Table 21 contains the results of both field and laboratory analysis of the first set of samples.

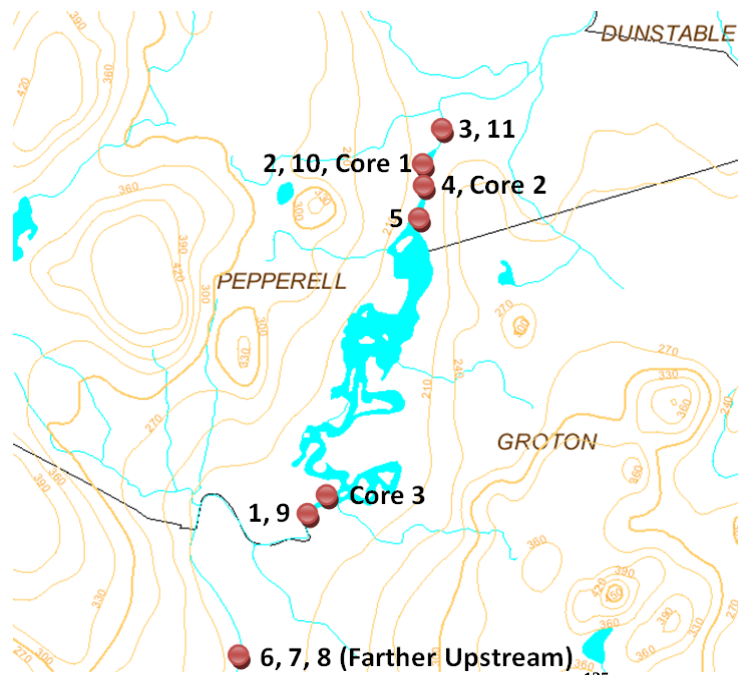


Figure 23. Map of Sampling Locations¹²⁵

Table 21: Laboratory Analysis of October 5, 2007 Samples

October 5, 2007	6	1	5	4	2	3
pH	-	7.13	7.43	6.91	6.85	7.27
Temperature (°C)	20.0	20.0	20.0	20.0	20.0	20.0
Dissolved Oxygen (mg/L)	-	6.72	8.02	5.38	6.38	8.04
Alkalinity (mg/L as CaCO ₃)	42.0	35.5	35.5	35.5	33.3	35.3
Ammonia (mg/L)	-	0.33	0.31	0.39	0.31	0.35
Nitrates (mg/L)	-	2.00	1.20	3.60	1.70	1.60
Sum of Ammonia and Nitrates (mg/L)	-	2.33	1.51	3.99	2.01	1.95
Phosphate (mg/L)	0.16	0.12	0.13	0.09	0.06	0.09

¹²⁵"Surface Contour Map" Map. MassGIS. 25 Feb. 2008 <<http://www.mass.gov/mgis/mapping.htm>>.

For the first set of samples, the temperature of the water was assumed to be equal to ambient temperature of 20° C on that day for all samples since it was not measured in the field. When the samples were analyzed in the laboratory with the samples, the pH was found to increase from 7.13 at the entrance of the pond to 7.43 downstream of the entrance to the pond. It then dropped down to a minimum of 6.85 just before the impoundment at the downstream end of the pond. The water downstream of the impoundment had a pH of 7.27 which was greater than all other points aside from the middle of the pond. Dissolved oxygen followed a similar pattern to pH where peaks of 8 mg/L occur at the middle and at the downstream end of the pond. In the rest of the pond it was significantly less ranging from a minimum of 5.38 mg/L to 6.72 mg/L. Alkalinity for this set of samples peaked upstream of the pond at 42.0 mg/L but remained constant throughout the pond at 35.4 mg/L.

For nutrients, at the entrance of the pond, marked by sample 1, there was a dip in phosphorus from 0.16 to 0.12 mg/L, followed by a slight rise in to 0.13 mg/L. Phosphorus reached a minimum of 0.06 approaching the dam at the downstream end of the pond. This decrease in phosphorus may have been due to its utilization by the algae it supports or through settlement into pond sediment. If the phosphorus at this point in the pond were making its way into the sediment, a significant drop in concentration present in the water may cause a release of phosphorus from the sediment to maintain the established equilibrium of approximately 0.2 mg/L.

The sum of nitrate and ammonia, the two nitrogen species measured during water quality analysis, peaked at 4mg/L just upstream of the dam at sample location 4. This coincided with a point where phosphorus was near its minimum measured amount of 0.09 mg/L, suggesting that all the phosphorus had been utilized to produce algae and thus the limiting reactant in algal formation. This excessive amount of nitrogen was present in both species as ammonia and nitrate. Throughout the first series of samples, the atomic ratio of phosphorus to nitrogen ranged from 5 to 19 times the 16:1 ratio necessary to support algal growth confirming that phosphorus is the limiting reactant.

For the second set of samples, samples 7, 8, 9, 10, and 11 presented in Table 22, the same pattern was true for phosphorus. In the pond, the peak of 0.19 mg/L occurred at the inlet, with the minimum of 0.14 mg/L occurring before the impoundment at the downstream end of the pond. The spread of 0.048 mg/L was greater than realized in the first set of samples whose

spread was 0.03 mg/L. Although nitrate concentration was greater upstream of the pond at around 3.3 mg/L, nitrate concentration followed the same trend as phosphorus in the pond for this set of samples with the peak of 2.72 mg/L occurring at the inlet the pond. Ammonia, however, had a unique progression whereby the concentration rose to peaks of 0.51 mg/L upstream of the pond and 0.45mg/L downstream of the pond. The nitrogen to phosphorus ratio was much more stable across the spread of pond samples ranging only 6 to 8 times the 16:1 ration necessary to support algal growth.

Table 22: Laboratory Analysis of November 30, 2007 Samples

November 30, 2007	7	8	9	10	11
pH	7.25	7.26	6.85	6.78	6.73
Temperature (°C)	-	7.4	4.7	5.8	4.2
Total Solids (mg/L)	-	214	158	162	166
Ammonia (mg/L)	0.44	0.51	0.41	0.42	0.45
Nitrates (mg/L)	2.81	2.81	2.31	1.97	2.01
Sum of Ammonia and Nitrates(mg/L)	3.25	3.32	2.72	2.39	2.45
Phosphate (mg/L)	0.19	0.19	0.19	0.14	0.16

The temperature for this second set of samples was measured in the field and varied between 7.4 °C upstream of the pond where the water was highly agitated to 4.2 °C just downstream of the pond. The pH of samples from the pond are lower ranging from 6.73 downstream of the pond to 6.85 at the entrance of the pond. Total solids peaked upstream of the pond at 214 mg/L but dropped at the entrance of the pond to 158 mg/L. After that point there was a slight rise in total solids to a final value of 166 mg/L downstream of the pond.

Of importance in the second set of samples was the consistent rise of concentrations of all three species of nutrients which may be the contribution of several factors. First, the second set of samples were taken later in the season where the ambient temperature was less hospitable to biological development. This was also witnessed by the diminished algal growth on the surface of the pond at the time of sampling. Reduced potential for biological growth results in less utilization of the nutrients. Second, as of October 31, 2007 the TMDL for phosphorus along the Nashua River was suspended for the winter months allowing for an uncontrolled amount of phosphorus from wastewater treatment plant point sources. Additional release of solely phosphorus would serve to reduce the nitrogen to phosphorus ratio as more of it is available to react with the total nitrogen. This explained the reduction in the ratio from 5 to 19 times the

atomic ratio down to 6 to 8. Lastly, runoff may have occurred just prior to sampling during the wet weather conditions also contributing to a rise in all three species of nutrients.

4.5 Sediment Core Nutrient Analysis

In order to access the possible impact of the sediments of Pepperell Pond on the nutrient loading of the water, three cores of sediments were analyzed. The ability of nutrients to leach from the sediment into the water was determined. The methods of analysis employed were level of agitation, contact time, and nutrient content before and after contact with the sediment. These experiments were performed in order to achieve a better understanding of the role of nutrient loading from the sediment on the dissolved nutrients in the water, which are of greatest concern since they are used by the plants that cause eutrophication.

4.5.1 Laboratory Results for Sediment Cores

Sediment within the pond may serve as another potential source of nutrients within the pond. Three sediment cores were taken during the first round of sampling on October 5, 2007 to determine the contribution of the sediments to the total nutrients in the pond. Testing of the cores according to the procedures outlined in Section 3.2.3 yielded the concentrations presented in Table 23. The core samples, as seen in Figure 23, are arranged in the order they are encountered going downstream through the pond, starting with core 3 at the upstream end of the pond. The concentrations represent final concentrations measured after the water was mixed with sediment. Table 23 also includes the results of nutrient testing on the sample 9 water used in the experiment as well as an experiment of core 3 sediment mixed with deionized water. To compare the results of nutrient testing on the sediment cores, the results had to be normalized to account for the sample 9 river water used in the experiment as well as the mass of sediment used for each sample. To obtain the normalized data, the nutrient concentrations determined for the sample 9 river water determined at the time of testing through the procedures outlined in Section 3.2.2.3 were subtracted from the sediment sample concentration and then divided by the mass of sediment that had been added to that sample. The resulting normalized values have units of milligrams per liter per gram of sediment.

Table 23: Nutrient Concentrations Determined in Sediment Core Laboratory Experiments

Nutrient	Sample 9 River Water	Core			
		3	3 (w/ Deionized Water)	2	1
Ammonia (mg/L)	0.34	1.65	1.72	7.90	3.40
Nitrates (mg/L)	2.31	13.03	4.61	13.34	6.41
Sum of Ammonia and Nitrates (mg/L)	2.65	14.68	6.33	21.24	9.81
Phosphate (mg/L)	0.20	0.19	0.24	0.16	0.41

The results showed that the level of nitrates in the pond sediments increased from 6.73 mg/L to 13.34 after which there was a sharp drop to 6.41 mg/L at the downstream end of the pond. Ammonia in the sediments followed a similar trend starting at a concentration of 0.83 mg/L, increasing sharply to 5.02 mg/L which was outside the range of the test, and then back down to a concentration of 2.35 mg/L. The sharp spike in ammonia may have been due to dead plant matter lying along the bottom of the pond. High sums of ammonia and nitrogen concentrations relative to phosphorus concentrations released from the sediments corresponded to high sums of ammonia and nitrogen concentrations relative to phosphorus concentrations present in the sample water presenting a comparable relationships between the solid and liquid mediums.

As shown in Table 23, Sample 9 water, used in this experiment, had a concentration of 0.2 mg/L as phosphorus. The first two cores showed a negligible absorption of phosphorus consistent with the established equilibrium at the 0.2 mg/L concentration; however, the last core at the downstream end of the pond presented a significant contribution to the sample water of 0.14 mg/L per gram of sediment. At this location, the sediments contained a higher concentration of phosphorus, which may have been the result of settling due to the presence of the impoundment at the end of the pond. A higher concentration of phosphorus at this location was also consistent with the nitrogen/phosphorus relationship. The increased availability of phosphorus supported increased algal growth and thus, greater depletion of local total nitrogen, the other nutrient source for growth. Although the sediment at this location may have contained more phosphorus, it was still the limiting reactant as there is not enough to completely react with the amount of nitrogen that the sediments also contribute to the water. The result was increased algal growth through immediate consumption of the phosphorus as it is released into the water of containing excess nitrogen. This phosphorus release only occurred once the concentration of phosphorus in the water dropped below the established equilibrium value of 0.2 mg/L as was

witnessed by a greater phosphorus release of 0.14 mg/L in the core 3 deionized water control sample.

4.5.2 Loading Analysis for Sediments

Further analysis of sediment-water equilibrium provided a method to calculate nutrient loading with the sediment as the source. In the experiment, a standard phosphorus solution of known concentration was added to a known mass of sediment and agitated for 24 hours. The sample was then filtered and measured for phosphorus content. It was determined that equilibrium existed at a concentration of just over 0.2 mg/L. For the loading determination, the resulting concentration of the sample was subtracted from the concentration of the known standard it contains. This yielded a total change in concentration which was multiplied by the volume of standard used to obtain the total mass of phosphorus contributed to the solution by the sediment. Division by the mass of sediment used in the sample normalized the contribution of the sediment accounting for the slightly varying masses of sediment used during the experiment. The resulting number represented the total mass of phosphorus contributed per gram of sediment as follows.

$$M_{unit} = \frac{(C_{experimental} - C_{standard}) \times V_{standard}}{m_{sediment}}$$

The second parameter necessary for the determination of sediment nutrient contribution is the total volume of sediment in the pond. The total area of the Pepperell Pond is approximately 400 acres. Through water displacement, the density of its sediment was measured to be 1362 kg/m³ by adding sediment of known mass to a graduated cylinder containing and recording the change in volume. In the core analysis, sediment from the top inch of the core sample was utilized and as such it was assumed that the greatest interaction between the water and the sediments would occur within this one inch depth. The area of the pond multiplied by the assumed depth of one inch and the density of the sediments at 1362 kg/m³ yields a total mass of sediment of 42,000,000 kilograms. To obtain the potential contribution of phosphorus from sediments within the entire pond, the total sediment mass was multiplied by the mass of phosphorus contributed per mass of sediment as follows.

$$V_{sediment} = A_{pond} \times D_{sediment} \times \rho_{sediment}$$

$$M_{phosphorus} = M_{unit} \times V_{sediment}$$

This analysis technique was performed for two distinct scenarios based on the data obtained through sediment-water equilibrium analysis in Appendix I: Sediment-Water Equilibrium. The first was for a theoretical scenario where all of the water in the pond was assumed to be deionized water containing no nutrients. In this analysis the result obtained from the 0.0 mg/L phosphorus solution was utilized to determine a total mass contribution of 3.4 g of phosphorus per kilogram of sediment. When the total area of the pond and a one inch depth of sediment were considered, the total phosphorus contributed by sediment in the pond was calculated to be 473 pounds per day per inch depth of sediment. This results in a total yearly contribution of 172,500 pounds per year per inch depth of sediment. If a greater depth of sediment influence of 2 inches were considered, this contribution would double to 345,000 pounds per year.

A second scenario, considering sediment-water equilibrium, obtained a loading more representative of the actual conditions in the pond. In previous analysis, it was determined that concentration of the water at the point where core 3 was extracted was 0.2 mg/L as phosphorus. The 0.2 mg/L standard solution, combined with the sediments in the equilibrium experiment, resulted in a concentration of 0.228 mg/L. The two concentrations were subtracted and normalized for the mass of sediment used in the sample by division of the total mass of sediment used in the sample, resulting in a mass contribution of 0.7 g of phosphorus per kilogram of sediment. When the entire area of the pond at a one inch depth was considered, the total contribution was 66.5 pounds per day per inch. In a similar manner if a greater depth of 2 inches were considered then this contribution would double to 133 pounds per day. The total contributions for the year would be 24,000 and 48,500 pounds per year respectively.

Table 24: Sediment Loading Analysis Summary

Scenario	Loading (lb/day x inch)	Total Yearly Contribution (lb/inch)
Theoretical (Deionized Water)	473	172,500
Equilibrium (Sample 9 Water)	66.5	245,000

Both the theoretical and equilibrium loading scenarios summarized by Table 24 demonstrate pond sediment as a significant contributor of phosphorus to Pepperell Pond. This contribution is much greater in comparison to other sources such as runoff. While the sediments have the potential to contribute the estimated total, it is unlikely that this total contribution would be reached. In the sediment-water equilibrium analysis, the samples were agitated continuously for a period of 24 hours. This broke down the sediment and maximized exposure to water.

Agitation resulted in a higher contact surface area than the sediment would experience under natural conditions. This resulted in a greater release than would be realized in the pond even under high flow, turbulent conditions.

A leaching experiment was conducted to confirm the concentration of phosphorus in the water at set elevations above the sediment after 24 hours of non-agitated contact with sediment. This experiment confirmed this minimal release, but it was limited by the stillness of the water. Diffusion kinetics and sediment agitation can greatly increase the rate of release in natural conditions.¹²⁶ As such, the estimated contribution from the sediments in this analysis was conservative.

4.6 Aquatic Algae and Plant Analysis of Pepperell Pond

Aquatic growth problems in Pepperell Pond include algae, water chestnut, and duckweed. All three of these plant classifications are present during a significant portion of the year. The Pepperell Pond algal bloom is caused by blue-green algae, a misnamed bacterium more accurately described as cyanobacteria. This type of bacteria is thought to be responsible for dramatically changing the early atmosphere from a reducing one, very little oxygen, to an oxidizing one due to its ability to perform oxygenic photosynthesis.¹²⁷ Cyanobacteria is one of the few types of bacteria that can fix nitrogen. This process is carried out by the enzyme nitrogenase which is found in the thick walled heterocysts. While heterocysts are able to form whenever is necessary, such as under anoxic conditions, cyanobacteria are the only group able to reduce nitrogen and carbon in an aerobic environment.¹²⁸

The two aquatic plants that are the most apparent and are the cause of the greatest annoyance are water chestnut and duckweed. To help with the water chestnut problem the Nashua River Watershed Association has received a three hundred thousand dollar grant to help remove this species from the pond.¹²⁹ Water chestnut is especially difficult to remove since the seeds of the plants can remain dormant for 12 years. Duckweed is less of a nuisance plant due to it's lack of a root system and is actually often used as a method of remediation to help remove

¹²⁶ Fechner-Levy, Elizabeth, Hemond, Harold F. Chemical Fate and Transport in the Environment (2nd Edition). Boston: Academic Press. 2000. Page 15

¹²⁷ Hickman, Cleveland P., Larry S. Roberts, Allan Larson, Helen I'Anson. *Integrated Principles of Zoology*. 13th Ed. McGraw Hill: 2006.

¹²⁸ Ibid.

¹²⁹ Gunderson, Matt. "Clogged pond to get relief: Grant will help reduce weeds." Boston Globe: 13 September 2007.

nutrients from bodies of freshwater. Nonetheless, both of these plants, along with blue-green algae have negative impacts on the aesthetics and recreational use of Pepperell Pond and by reducing nutrient loading all three types of vegetation's growth rates could be reduced.

4.7 Mass Balance and Groundwater Flow Estimates

A mass balance and groundwater flow estimate were constructed using the method and equations presented for mass balances, as well as the data in Table 25.

Table 25: Known Conditions Relating to Flow

Date	Outflow, cfs¹³⁰	C_{in} (mg P/L)	C_{out} (mg P/L)
5-Oct-07	92	0.12	0.09
30-Nov-07	325	0.186	0.164

Using the November data first, groundwater flow is estimated at 38 cfs, or 25 million gallons per day (MGD). Inflow in the river is estimated at 287 cfs, or 190 MGD. Using the mass flux equation, as follows, yields the sediment and biological contribution to the river:

$$\Delta m = Q_{in} * C_{in} - Q_{out} * C_{out}$$

Between sediment and biological uptake, total phosphorus loading is approximately 15 lbs/day, meaning that 15 lbs/day were contributed by some combination of these sources on the late November sampling date. This creates some uncertainty in all values presented, since the total biological activity was assumed to be negligible, and may be substantial. However, it is still a relatively small value compared to the expected inflow of phosphorus from upstream, so it should have a relatively small effect.

On October 5th, the weather was sunnier and warmer, which would encourage biological growth. Since the biological inactivity assumption is invalid, groundwater flow was considered to be 25 MGD, the same rate as estimated for late November. Since flows generally increased from October to November, this assumption may overstate the role of groundwater in October, but it still yielded reasonable results. Using the same analysis as before, flows were estimated at 60 MGD total, with an inflow of 35 lb/day of phosphorus, and an outflow of 45 lb/day, implying a leaching rate of 10 lb/day. Results for both analyses are presented in Table 26 below:

¹³⁰ "USGS Realtime Water Data." United States Geological Survey. Department of the Interior. 26 Feb. 2008
<http://waterdata.usgs.gov/ma/nwis/uv?site_no=01096500&format=gif&period=31>.

Table 26: Mass Balance Phosphorus Load Results

Date	GW flow, MGD	Surface inflow, MGD	TP in (lb/day)	TP out (lb/day)	Flux out of sediment (lb/day)
5-Oct-07	25	35	35	45	10
30-Nov-07	25	190	285	300	15

In both cases, phosphorus is likely to be leaching into the river from sediments or decaying plant matter. Loads are lower than other expected sources, but may be fairly significant in very low loading conditions, such as those experienced in October, where the contribution is nearly 25% of the total load for the day.

4.8 Final Nutrient Mass Balance

Modeling and water quality analysis have confirmed the presence of high levels of nitrogen compounds and phosphorus in Pepperell Pond. Given the biological uptake ratio of approximately 7 parts nitrogen by mass to one part phosphorus, phosphorus governs biological growth in this system. The various analyses have established the following mass loadings, under current conditions. From these loadings, it is possible to determine which management options will directly address the various eutrophication concerns, including nuisance plant growth, water quality concerns, and high dissolved phosphorus, which can be detrimental to downstream water quality. Figure 24 shows the relative phosphorus loads from each source modeled. The blue bars on the left show current conditions, and the red bars show future conditions, provided there are both TMDL point source compliance and 10% impervious area increase. The point sources themselves are not shown because their effects can vary. Input loads for the two sampling dates varied eightfold, and seem to be largely dependent on the river flow rates. Therefore, it is impossible to quantify exact loads from upstream point sources.

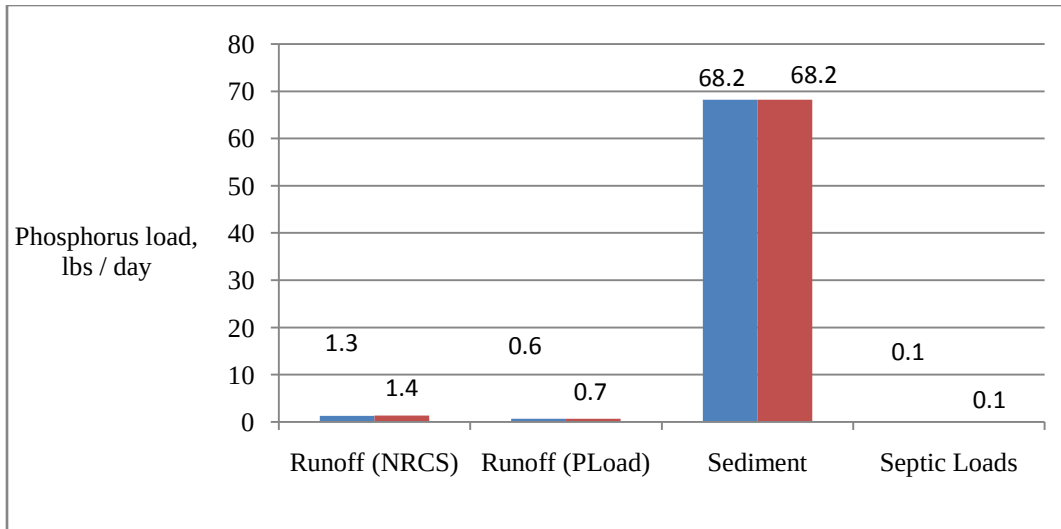


Figure 24: Relative Loads of Phosphorus, for Current and Future Conditions

Future conditions will affect the water quality by reducing input loadings from upstream sources, while land use and development increase nonpoint loadings in the Pepperell and Groton areas. As no measure has been drafted to address sediment and septic loadings, these loads are not expected to change. Given these loads, runoff is expected to be as significant as upstream point loading after the TMDL has taken full effect.

5. Options for Remediation

The nutrient analyses and various methods to quantify loadings yielded relative contributions from several major nutrient sources. It was then possible to determine methods applicable to each source, which could curb the nutrient loads, or prevent the contribution from many different sources. At this stage, no option was immediately rejected for cost or environmental impact. However, later analysis and consideration of those factors made some options far more attractive than others. Options considered for use in Pepperell Pond included removal of aquatic plants, riparian buffers, benthic barriers, a TMDL for nitrogen, environmental legislation, dredging, removal of dams, aeration, and algae removal.

5.1 Removal of Duckweed

Duckweed has many different species each of which thrive in slightly different environmental conditions including temperature, light intensity, pH and availability of nutrients. This family of plants is eurytopic, meaning that they have ability to survive in a wide range of conditions and therefore this species is found throughout the world¹³¹. These plants are small and have simple plant morphology with the structural components consisting of only short roots and a frond that is only a few millimeters for most species. Due to structural simplicity, including the lack of stems and leaves, almost the entire plant is actively involved in photosynthesis. Possibly due to the fact that very little of plant is devoted to structural support, the plant has very low fiber content and high protein content.¹³² These qualities make the plant highly nutritious and digestible for a wide range of animals, including farm animals. Not only is duckweed able to absorb nutrients but it can be used as a method of recycling these nutrients from an unwanted location, bodies of water, to a place where nutrients are in high demand, as feed and fertilizer.¹³³

The application of duckweed that we are interested in is not the end use of the plant, but the manner in which the plant can be applied to Pepperell Pond to help reduce the excess nutrient

¹³¹ Molles, M.C. Ecology: Concepts and Applications, McGraw-Hill, 2005.

¹³² Gijzen, Huub J. and Siemen Veenstra. "Chapter 7: Duckweed-Based Wastewater Treatment for Rational Resource Recovery and Reuse." Environmental Biotechnology and Cleaner Bioprocesses. Ed. Eugenia J. Olguin, Gloria Sanchez, and Elizabeth Hernandez. Taylor & Francis CRC Press: 1999 pages 83-94.

¹³³ Ran, Noemi, Moshe Agami, and Gideon Oron. "A pilot study of constructed wetlands using duckweed (*Lemna gibba* L.) for treatment of domestic primary effluent in Israel." *Water Research* Volume 38, Issue 9, May 2004, Pages 2241-2248.

loads that are causing algal blooms. Duckweed is not the only floating family of plants that has been studied for its ability to remove nutrients and contaminants from water, especially wastewater. Macrophytes have been found to be an effective step in the wastewater treatment process, in fact most studies appear to concern these plants application to this process. The application of aquatic plants has proven to be highly beneficial because it is a “recycling engine driven by photosynthesis and therefore the process is sustainable, energy efficient, [and] cost efficient.”¹³⁴ Using duckweed and other plants for wastewater treatment in less developed areas has proven to be one of the most economic ways to treat the water.

Other macrophytes with large leaves have been found to be more productive than small-leaf plants like duckweed.¹³⁵ Water hyacinth, a macrophyte, was found to be quite effective at improving water quality by reducing nutrients, chemical oxygen demand, solids and salinity. This plant was found to reduce the ammonium by 99.6% and total phosphorus by 98.5%, clearly showing that floating flora is an effective option for removing these nutrients.¹³⁶ Although water hyacinth maybe more effective at removing phosphorus, a plant’s ability to remove nutrients is only one of many factors to be concerned with for the application to Pepperell pond. Economics play a key role in most decisions and the importing of another invasive species to a pond that already has problems with aquatic plants may have unexpected consequences. Also, after water hyacinth has been applied, grown and harvested, so far no economically beneficial option for the application of the generated biomass has been found, unlike duckweed which may be used as feed or fertilizer. Since duckweed is such a small plant that is not interconnected, it is also much easier to harvest than water hyacinth. Duckweed, unlike water hyacinth is also already growing in Pepperell Pond, so it is a known fact that it has the right environmental conditions to thrive. Duckweed is, therefore an economically viable option for reducing the nutrient load of Pepperell Pond due to its known ability to grow in the pond, ease of harvest, and possible use after harvest.

¹³⁴ Gijzen, Huub J. and Siemen Veenstra. “Chapter 7: Duckweed-Based Wastewater Treatment for Rational Resource Recovery and Reuse.” Environmental Biotechnology and Cleaner Bioprocesses. Ed. Eugenia J. Olguin, Gloria Sanchez, and Elizabeth Hernandez. Taylor & Francis CRC Press: 1999 pages 83-94.

¹³⁵ Sooknah, Reeta D. and Ann C. Wilkie. “Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater.” *Ecological Engineering* Volume 22, Issue 1. 1 February 2004, pages 27-42.

¹³⁶ Ibid.

5.2 Riparian Buffer

Creating a buffer between sources of nutrients, such as agricultural lands, and bodies of water has been shown to contribute to healthier waterways. These zones of vegetation separating land and a flowing body of water are called riparian buffers. This zone of vegetation acts as a filter, slowing down nutrient travel from a source, including fertilizers, animal wastes, leaking sewer lines, atmospheric deposition, and runoff from highways, into the body of water.¹³⁷

Vegetation next to moving water bodies also reduces sediment loading by stabilizing stream banks and keeps the temperature of the body of water significantly lower.¹³⁸ No doubt due to the findings of many different researchers a vegetative riparian buffer zone represents a best management practice, as determined by the Environmental Protection Agency. The numerous studies have resulted in many different and often conflicting conclusions, but nearly all of these studies have concluded that this best management practice has a positive effect. The conclusions of these studies have varied in the recommended width of the buffers, anywhere from 7 to 100 meters, as well as their ability to remove nutrients.¹³⁹ However, sources vary on the recommended length of buffer strips. The MassDEP recommends 50-100 feet as shown in figure.

¹³⁷ Mayer, Paul M. and Marshall D. McCutchen. "Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: Review of Current Science and Regulations." Environmental Protection Agency/600/R-05/118. October 2005.

¹³⁸ Osborne, Lewis L. and David A. Kovacic. "Riparian vegetated buffer strips in water-quality restoration and stream management." *Freshwater Biology* 29, pages 243-258, 1993.

¹³⁹ Mayer, Paul M. and Marshall D. McCutchen. "Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: Review of Current Science and Regulations." Environmental Protection Agency/600/R-05/118. October 2005.

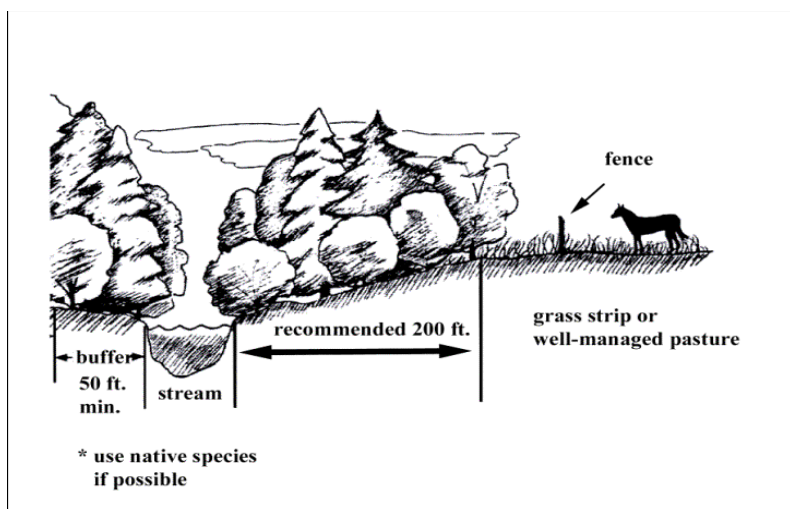


Figure 25: Buffer Zone Recommended Layout¹⁴⁰

Furthermore, correct slopes should be created to ensure that the buffer has been installed correctly and will have the maximized effectiveness. Table 27 displays the recommended buffer strip slopes corresponding to the respective buffer strip length.

Table 27: Buffer Widths for Slope Values¹⁴¹

Slope of Land (%)	Minimum Buffer Strip Width (ft)
0	50
5	70
10	90
15	110
20	130
25	150

Most studies have concluded that riparian buffers are quite effective at removing nitrogen, but the data on phosphorus removal is less conclusive. Some researchers have found that during the growing season forested and grass vegetative buffers acted as sinks, yet during the dormant season released phosphorus into the groundwater.¹⁴²

There are some discrepancies about the management and effectiveness about riparian buffers, but the use of vegetative riparian buffers is recommended. Buffers are found to be especially useful for nonpoint sources of nutrient pollution, since in general they act as a

¹⁴⁰ Vegetated Buffer Strips: Slow the Flow to Protect Water Quality. Boston: Massachusetts Department of Environmental Protection, 2007.

¹⁴¹ Ibid.

¹⁴² Osborne, Lewis L. and David A. Kovacic. "Riparian vegetated buffer strips in water-quality restoration and stream management." *Freshwater Biology* 29, pages 243-258, 1993.

protective shield for waterways.¹⁴³ This fact makes this best management practice is especially attractive for decreasing the nutrient load of Pepperell Pond, since most of the excess nutrients are, after research, thought to come from nonpoint sources. Table 28 shows the wide ranging results of research on phosphorus and nitrogen removal by these buffers but also shows that overall buffers have positive effects on waterways. In general it was found that the greater the width of the buffer was better, but considering that the area around Pepperell Pond is already somewhat commercially and residentially developed, any amount of buffer that could be put in would be beneficial. The effectiveness of the buffer not only depends on its width, but the soil conductivity and the current nutrient loading, which helps to explain the wide range of results.¹⁴⁴ Although, the research on vegetative riparian buffers has resulted in different conclusions on the effectiveness of the method, all data supports that nutrients are removed and the waterway is benefited.

Installation of a riparian buffer would involve the loss of a strip of agricultural and commercial land around the southern edge of the pond. This could result in a high cost to the towns involved, both for the purchase of the land and lost property taxes from fallow, otherwise valuable land. It could also cause financial hardship for the farmers, whose land would be taken for the buffer. The associated costs of this method should be heavily weighed before its implementation.

¹⁴³ Mayer, Paul M. and Marshall D. McCutchen. "Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: Review of Current Science and Regulations." Environmental Protection Agency/600/R-05/118. October 2005.

¹⁴⁴ Ibid.

Table 28: Table of Efficiency of Removal of Nutrients from Surface and Subsurface Waters¹⁴⁵

Width (m)	Parameter	% Reduction	VBS type	Reference
Subsurface				
10	N	60–98	Forest	James, Bagley & Gallagher, in press
16	N	93	Forest	Jacobs & Gilliam, 1985
19	N	93	Forest	Peterjohn & Correll, 1984
19	N	40–90	Forest	Schnabel, 1986
25	N	68	Forest	Lowrance, Todd & Asmussen, 1984
30	N	100	Forest	Pinay & Decamps, 1988
50	N	99	Forest	Peterjohn & Correll, 1984
27	N	10–60	Grass	Schnabel, 1986
19	P	33	Forest	Peterjohn & Correll, 1984
50	P	–114	Forest	Peterjohn & Correll, 1984
Surface				
30	N	98	Forest	Doyle, Stanton & Wolf, 1977
50	N	79	Forest	Peterjohn & Correll, 1984
9	N	73	Grass	Dillaha <i>et al.</i> , 1989
5	N	54	Grass	Dillaha <i>et al.</i> , 1989
27	N	84	Grass	Young, Huntrods & Asmussen, 1980
16	P	50	Forest	Cooper & Gilliam, 1987
19	P	74	Forest	Peterjohn & Correll, 1984
50	P	85	Forest	Peterjohn & Correll, 1984
9	P	79	Grass	Dillaha <i>et al.</i> , 1989
5	P	61	Grass	Dillaha <i>et al.</i> , 1989
27	P	83	Grass	Young, Huntrods & Asmussen, 1980

5.3 Benthic Barrier

A management technique that has been applied to some bodies of water that have experienced unwanted plant growth is the application of a benthic barrier. Benthic barriers are used as local control technique which is used to target specific areas. A benthic zone is the lowest level of a body of water; hence a benthic barrier is a synthetic or organic sheet that is placed on the bottom of a water body.¹⁴⁶ This sheet prevents plant growth in two ways by blocking sunlight and creating a physical barrier that reduces the space available for growth.¹⁴⁷ Due to the way that benthic barriers work, they are most effective for plants that grow from the benthic zone. After this type of treatment has been applied for 30 days, most plants will be controlled. Benthic barriers are difficult to install and rather expensive and therefore should be limited to an area of special concern.¹⁴⁸

¹⁴⁵ Osborne, Lewis L. and David A. Kovacic. "Riparian vegetated buffer strips in water-quality restoration and stream management." *Freshwater Biology* 29, pages 243-258, 1993.

¹⁴⁶ "2005 Aquatic Plant Management Plan Truesdale Lake." Prepared by Allied Biological, Inc. Hackettstown, NJ.

¹⁴⁷ "A Primer on Aquatic Plant Management in NYS." Prepared by the New York State Department of Environmental Conservation. 23 January 2008

¹⁴⁸ Ibid.

5.4 Total Maximum Daily Loading for Nitrogen (various forms)

Nitrogen removal may be capable of providing the same effect as phosphorus, but whereas the phosphate TMDL will only cut phosphates to one third of their original level (approximately 0.4mg/L before and 0.13 after) and establish a lower nitrogen demand for biological growth (6.4 mg/L originally will eventually be only 2.2 mg/L as nitrate) the nitrogen level, unchecked, will contribute to the problem. At this time, there is not enough nitrate to use more than approximately 0.15mg/L total phosphorus. Therefore, phosphate reduction to this level will not change anything. Meanwhile, nitrate and ammonia reductions will reduce available nitrogen and limit algal growth in the river further.

Discharge limits for wastewater nitrogen compounds could become extremely expensive. The cost to retrofit the Nashua River's entire 38 MGD wastewater flow capacity with nitrogen removal systems could be in the millions of dollars. This method also does not address the natural sources of nitrogen compounds, generated by blue-green algae. Since the cost could be astronomical, and the effectiveness will be limited by other nitrogen sources, this method is not advisable without further study into the implications of nitrogen reduction.

5.5 Environmental Legislation

A possible solution to the problem of stormwater runoff affecting the phosphorus loads in the area is to enact legislation that will limit the amount of illicit discharge and lowering the amount of development that can be created directly around the pond in the future, as well as legislation implementing mandatory mitigation measures to reduce runoff.

Currently, the city of Worcester has enacted an additional method of stormwater quality control, which may help both with education and water quality in Pepperell Pond. Storm drains in Worcester are marked with white writing, reading "Don't dump: Drains to..." and the name of a nearby surface water body. The use of this practice can help prevent people from adding chemicals to stormwater loads, which may assist in the reduction of nutrient additions to Pepperell Pond. This method is easily implemented, as it requires only spray paint, stencils, and a team of volunteers to go around to nearby storm drains and mark them appropriately.

Future development is expected to increase impervious area to the south and west of Pepperell Pond. With increased impervious area occurs increased runoff, so management practices can be undertaken to prevent stormwater problems in the future. Zoning practices

preventing dense residential or commercial use for this section of Pepperell can help to prevent the most widespread stormwater effects. Any residential project to develop this area should take stormwater into consideration, and attempt to mitigate stormwater effects via a retention pond, land contouring, infiltration basins, riparian buffers or other assorted measures. Prevention of runoff will prevent stormwater effects from increasing and creating nutrient problems in the future. Since these methods would be built into the costs of future development, rather than retrofitted to a system, it is assumed that the total costs will be fairly low relative to the cost of the entire project.

5.6 Dredging

It has been shown that settled nutrients are a significant source of phosphorus at the Pepperell Impoundment. These nutrients can be expected to leach into the river over time if the point discharges are reduced enough to keep the river unsaturated into Pepperell Pond. The purpose of dredging would be to force these nutrients into the moving water, allowing them to move out of the impoundment and preventing their future effects. However, this method would also resuspend the sediments, which are likely to contain hazardous chemicals. Therefore, a risk assessment would be necessary before this method can be considered.

5.7 Removal of dams

The Assabet River, which is in many ways analogous to the Nashua River, contains several impoundments which allow phosphorus to build up in their backwater sections. One solution which has been offered is to remove the dams, allowing water to flow more quickly through the river and preventing the settling of phosphorus. This is not recommended except as a last resort, given the amount of damage that will be done to an otherwise stable ecosystem, as well as the removal of approximately 1MW of electrical generating capacity in the town of Pepperell if that approach is implemented.

5.8 Aeration of the pond impoundment

Many of the nutrient-based algal problems impact dissolved oxygen. Some strains of nitrogen-fixing bacteria can only operate in anoxic conditions, and the lessened dissolved oxygen can allow the introduction of nitrogen in usable forms, increasing biological activity in sections

of the river where phosphorus is plentiful. Aeration can help with this problem, as it can stabilize dissolved oxygen in the pond and limit these algal activities. This activity is dependent on the specific forms of algae present in the pond, as some are unaffected by DO, and such an approach will accomplish nothing.

While nitrogen may not be reduced by increased aeration of the pond, phosphorus leaching has been shown to be linked to anoxic conditions. The amount of dissolved oxygen appears to have an effect on phosphorus retention in bodies of fresh water. A study by Gertrud K. Nürnberg found that lakes that have an anoxic bottom most layer of water for a significant period of time have consistently low retention of phosphorus and sometimes have negative phosphorus retention.¹⁴⁹ Using mass balances with terms for external loading and predicted retention, Nürnberg showed that phosphorus is not retained under anoxic conditions. Negative phosphorus retention would imply another source of phosphorus, such as phosphorus leaching from the sediment. Aeration may help to bind phosphorus to the sediment, and may help to reduce the overall contribution of the bottom sediments.

The cost of aeration is generally low, relative to the other options that have been considered. Installation involves a compressor and a series of diffusers on the river bottom, and maintenance costs are generally limited to the operation of the compressor. Therefore, this method is inexpensive relative to other treatment options addressing water chemistry.

5.9 Plant removal after next major algal bloom

Since nutrients build up in the water and are used by the algae, one solution is to harvest the algae after major blooms. The algae will serve as a sink capable of removing large amounts of the nutrients, and if the blooms are then skimmed out and removed, those nutrients disappear as well. It is possible for this solution to be implemented via a boom near the dam, or by any number of other, more portable devices. There is an effort planned for next year to harvest water chestnut and remove it from the river, so the equipment may be available through next year to use this approach.

¹⁴⁹ Nürnberg, Gertrud K. "The prediction of internal phosphorus load in lakes with anoxic hypolimnia." American Society of Limnology and Oceanography, 29(1), 1984, 111-124.

5.10 Advantages and Disadvantages of Remediation Options

There are several advantages and disadvantages to choosing a specific or multiple numbers of remediation options. In order to select the most beneficial options for reducing the phosphorus loading and removal the nuisance plant life, all of the remediation options have been looked at for their individual advantages and their disadvantages as well. Table 29 summarizes the various advantages and disadvantages of implementation.

Table 29: Advantages and Disadvantages to Remediation Options

Option	Advantages	Disadvantages
Environmental Legislation	Reduces Nonpoint Source Runoff	May take time to pass through government and implement
Algae Removal	- Will remove large amounts of nutrients from the pond. - Equipment is inexpensive	Need volunteers to remove.
Aeration of Pond	Stabilizes Dissolved Oxygen, decreases retention of phosphorus.	Nitrogen is not reduced
Removal of Dams	Allows water to flow more quickly through pond	- Will release toxic sediments to environment. - Will reduce electrical generation capability. Expensive
Dredging	Will release and remove nutrients from water	Releases toxic substances into Pond. Expensive
TMDL for Nitrogen	- Will reduce available nitrogen. - Will establish lower nitrogen demand	Not effective in phosphorus removal
Benthic Barrier	Reduces Plant Growth	- Difficult to install. - May be Expensive in some cases. - Targets only specific areas.
Riparian Buffer	- Reduces runoff from farms. - Improves aesthetics surrounding pond.	- Farmers/Residents may not comply. - Can be expensive
Duckweed Removal	- Will Reduce nutrients. - Can be sold as fertilizer. - Inexpensive to remove.	Need volunteers to remove.

5.11 Evaluation of Options

The remediation options in this chapter have been evaluated for impact, cost and effectiveness. Each option was given a qualitative scoring of low, medium or high for each of these criteria, and scored from zero to nine. A higher score indicates a more applicable, safer, or cost-effective method. The results are summarized in Table 30. A red highlight of the total score indicates an ineffective, expensive, or otherwise unfavorable option, with yellow indicating imperfect methods, and green indicating favorable options.

Table 30: Ranking of remediation approaches.

Considerations		Environmental Legislation	Algae Removal	Aeration of Pond	Removal of Dams	Dredging	TMDL for Nitrogen	Benthic Barrier	Riparian Buffer	Duckweed Removal
Cost	Low,3		😊	😊						😊
	Med,2	😊					😊	😊	😊	
	High,1				😞	😞				
Environmental Impact	Low,3		😊						😊	😊
	Med,2	😊		😊			😊	😊		
	High,1				😞	😞				
Effectiveness in Removing Plant Matter	Low,1	😞			😞	😞	😞			
	Med,2			😊				😊	😊	
	High,3		😊							😊
Effectiveness in Removing Phosphorus	Low,1				😞		😞	😞	😞	
	Med,2	😊		😊						
	High,3		😊			😊				😊
Difficulty of implementation	Low,3		😊							😊
	Med,2	😊		😊			😊	😊	😊	
	High,1				😞	😞				
Stakeholders Affected Negatively	Low,3	😊	😊	😊						😊
	Med,2						😊	😊	😊	
	High,1				😞	😞				
	Total	12	18	14	6	8	10	11	12	18

Looking at the chart mentioned above, environmental legislation, algae removal, aeration of the pond, installation of a riparian buffer, and duckweed removal are the most effective means to remediate the pond and reduce future loadings. The TMDL for nitrogen and the installation of a benthic barrier are also possible solutions but may contain negative drawbacks because a combination of sources such as cost, effectiveness, and difficulty to implement. Finally, removal of dams and dredging are not recommended to be used. These two options have the greatest number of drawbacks and are not worth the effort for what would be the final outcome. As such, environmental legislation, algae removal, pond aeration, riparian buffer, and duckweed removal are recommended as potential options for improving water quality and reducing aquatic growth in the pond.

6. Conclusions and Recommendations

6.1 General Conclusions

This project has established the various sources of phosphorus in Pepperell Pond, and has determined their approximate relative values. It has also investigated various methods of remediation for the excessive algal growth on the pond's surface. The sources of phosphorus include nonpoint stormwater runoff, sediment leaching, point sources upstream of the river, and septic system leaching. One of the major sources of phosphorus, which had been previously overlooked was the impact of the sediment on the pond's total nutrient loadings. Runoff conditions were added to the general mass balance, and high and low flow conditions were modeled for expected impacts of various phosphorus loadings.

Flow conditions and approximate mass balances are listed in Appendix G. In low flow conditions, wastewater is expected to account for nearly 40% of the flow in the river, although the total phosphorus level reaching the pond does not support the assumption that extreme reductions in upstream phosphorus loadings will necessarily reduce the phosphorus loading entering the pond. The total contribution of phosphorus entering the pond in low flow conditions is low enough to indicate significant upstream biological uptake. Septic systems contribute a consistent flow, but it is low enough, relative to other inputs, to be considered minimal. Expected runoff conditions contribute 7-15 kg of total phosphorus monthly to the pond, which is only approximately 3-5% of the total daily loading in average flow conditions of 300 cfs, but can be as much as 30% of a daily loading in low flow summer conditions. Sediments can contribute, in low flow conditions, 25-30% of the phosphorus released in the pond, including enough phosphorus to sustain algal growth. Therefore, reduction of nonpoint loadings and sediment loads can play a significant role in the reduction of biological activity in the summer months. From these general conclusions, specific recommendations can be made with regard to land use and nutrient control in Pepperell and Groton to improve water quality in Pepperell Pond.

6.2 Recommendations Based on Conclusions

Based on the conclusions made from analyzing the relevant data and investigating the pertinent background information, there are several recommendations that can help the Nashua River Watershed Association manage and reduce the presence of nuisance plants on Pepperell

Pond. There is no one method that is recommended by itself, instead a combination of many different prevention and remediation methods are recommended. The most effective methods for remediation of Pepperell Pond include point source controls, nonpoint source controls, sediment and aquatic vegetation control.

Point source controls include considerations addressing WWTP discharges in the Nashua River. Currently, there is no phosphorus release limit between November 1st and March 31st. Therefore, the amount of phosphorus release from WWTFs is not fully controlled. Given the established equilibrium phosphate concentration, these amounts could cause influent phosphorus to adsorb into sediments, which can contribute significantly to the total overall amount of phosphorus throughout the pond, damaging any other efforts throughout other parts of the year. As a result, the State of Massachusetts should consider implementing effluent limits of phosphates for the aforementioned dates.

Non point source controls involve addressing runoff, and other inputs from land areas adjacent to the pond. To combat the nutrients released from point loadings, the state of Massachusetts should consider updating the current TMDL to include the restriction of phosphate release throughout the entire year. Currently WWTFs are limited in their phosphate releases for a half of year. With the implementation of a full year system, the amounts of nutrients from point sources will decrease drastically. Since the DEP's model predicted that the vast majority of the phosphorus arrives from point sources, this will have a tremendous impact in reduction of phosphorus arriving in the pond.

To combat non point loadings in areas with the highest storm runoff, several methods should be implemented. Currently, south and west of the pond are the areas with the most development and planned development for the future. To combat this, buffer zones for proposed septic systems should be increased to more than 100 yards from the pond's edge. Development along the pond's bank should be decreased. Legislation should be enacted that will limit the development of the area for the future. As this area around the pond contributes to the greatest amount of runoff and non point nutrient loads, and has the highest expected growth rate in the near future, it is important that these steps be implemented in a timely manner.

As the area directly surrounding the pond becomes more developed specific measures need to be addressed that will limit the impact the nonpoint pollution runoff into the pond. One such area is around the southwestern portion of the pond. Since this area currently contributes a

significant amount of runoff to the pond, the impact of further development should be reviewed and made on a case-by-case basis. Realistically, there should be limits to the amount of land development in the area. The town should not allow the land in this area to be zoned as commercial or dense residential as these two types of zones would have the greatest possibility of increased runoff. Without limits, the degree of runoff impact will continue to grow in the future. Runoff reduction measures, such as retention ponds, should also be considered for any new residential development that results in a significant stormwater impact, or an increased impervious surface which contributes to runoff.

To counter the contribution that surrounding farms have to the nutrient loadings on the pond, a riparian buffer should be grown. This product is a passively grown buffer that should be installed to mitigate the impacts of manure and applied fertilizer of surrounding farms. Although the owners of local farms may be hostile to this idea, it is important that a buffer system be installed to protect the pond. However, if this is opposed for reasons of financial hardship, then those areas that can be buffered should be buffered with native bushes, small shrubs, or trees. This effort requires a minor initial investment in labor and startup costs, and additional cost to control weeds and other harmful species. However, the reduction of nutrient loadings is significant.

To reduce the amount of excessive fertilizer runoff from the area's farms, an educational measure should address both agricultural and residential fertilizer applications, and deal with the proper timing, application, and methods to ensure greatest efficiency. This program will save money for the farmer and cause less nutrient runoff to the pond. If the farmer applies the proper amount of fertilizer for the soil to handle, there will be minimized amounts of phosphates and other nutrients running off into the pond. Also by doing this, the farmer will reduce his fertilizer costs.

A remediation measure should also address the phosphate in the sediments. The phosphate in the sediments should be incorporated as negative feedback into the pond water quality. By identifying this area as negative (self-stabilizing) feedback, and addressing it as a potential barrier to lowering total phosphorus levels in the pond, the corrective steps can be implemented into resolving the overgrowth of algae and other plant species.

"Duckweed farming" is a method that could be used to remove nutrients from the water. Duckweed can be passively grown in the water, and absorbs large quantities of both phosphorus

and nitrogen compounds. Once a bloom grows large enough, the user can skim the duckweed off the pond, and collect nutrients in the form of organic material. The duckweed be grown and then harvested to remove nutrients from the water and then the nutrient-rich material can be sold as “green fertilizer.” A skimming operation should be performed as needed to remove the blooming nuisance vegetation, and until it regrows to the extent that skimming is necessary again, the area can be used recreationally.

A system of skimmers should be utilized to “duckweed farm” the plant growth off the surface of the pond. Several volunteers should travel throughout the pond during the spring and summer months and use a skimmer to remove the plant growth from the top of the surface. From this, the removed plant growth should be utilized as a green fertilizer, and sold to local businesses in order to recoup operating expenses. Skimming should occur as needed, when the plant growth becomes excessive, or on a regular schedule.

Through literature reviews and research the best option for the removal of excess nutrients from Pepperell Pond is a combination of prevention and remediation methods. Enacting legislation that would protect the pond, such as protecting the area around the pond from future development as well as proposing new discharge limits on phosphorus, are part of the overall plan of remediation. More physical measures would include the addition of a riparian buffer around the pond and the use of duckweed as a method to remove nutrients from the pond. Lastly there should be public education to encourage protection of the pond encouraging farmers and other citizens to prevent nutrients from entering the pond in any manner that is under their control. A combination of these aforementioned methods is recommended to reduce the nutrient load to Pepperell Pond and therefore reduced the nuisance plants growing within the pond.

6.3 Limitations of Research and Future Recommendations

In this project a management plan of remediation options was established based on background and field research into the nutrient loading of Pepperell Pond and remediation techniques to reduce such loading. Further research is necessary to improve the effectiveness of the remediation options presented as well as to discover new techniques to reduce nutrient loading of Pepperell Pond. Complete analysis of pond sediment at more points along the length of the pond may help to develop sediment-water equilibrium as well as identify areas of higher

concern within the pond. Points at the midpoint of the pond along its length were inaccessible with the resources available to our team and thus could not be incorporated in analyses. Water samples also taken from these points would achieve finer resolution in the changes in nutrient levels along the length of the pond.

A complete analysis also requires samples during different conditions. In the first round of sampling, the water samples and sediment cores were obtained during dry weather, low flow conditions. The second set of samples, although obtained during wet weather conditions, were also during a period of low flow despite recent precipitation. Sampling occurred during the fall season and thus only represented one season of the year. A sampling scheme representative of all conditions would include dry and wet weather samples from all four seasons of the year, accounting for low and high flow conditions.

Further research can also be aided by real-time data that addresses the flows from wastewater treatment plant upstream as well as their nutrient release rates. This would more accurately define the relative nutrient contribution of point sources upstream. Gathering field data on groundwater flows and monitoring of groundwater would help to identify the inflow of groundwater into the pond. This factor may also impact nutrient leaching from sediment. Considering a larger area for runoff analysis as well as the associated land uses of the area will more accurately depict the magnitude of nonpoint source loadings on the pond.

Addressing these issues would more accurately identify the contribution of each of the various sources. In doing so, the remediation options identified in this report may be tailored to better address these sources. Further research would be beneficial to restoring Pepperell Pond to a pristine state by having more accurate analysis and therefore recommendations for remediation that may be more effective.

Appendix A: Sampling Locations

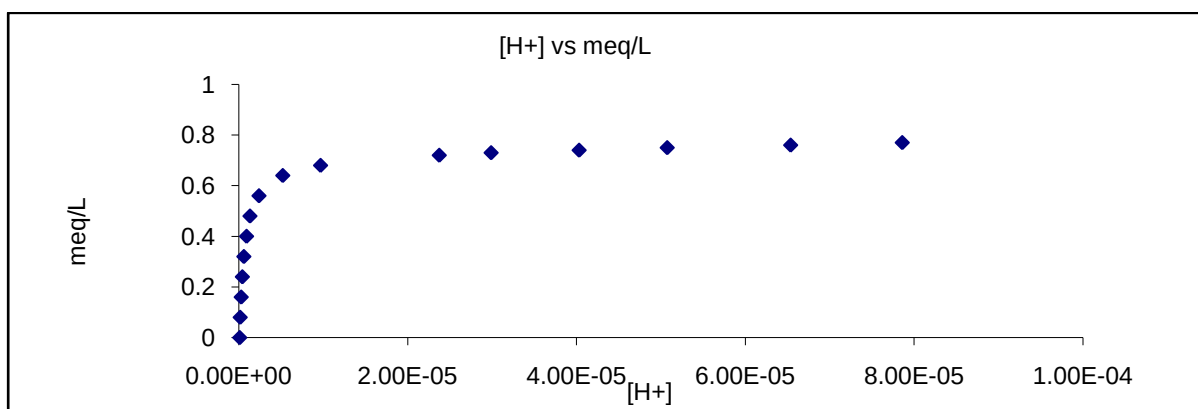
Sample	Description	
<u>10/5/2007</u>		
1	Label:	Up
	Time:	10:50
	Location:	Route 119 Pepperell-Groton bridge
	Lat./Long.:	45° 37' 35" 71° 35' 35"
2	Label:	Pond A
	Time:	8:30
	Location:	75 feet downstream of Pepperell boat ramp
		50 feet away from boat ramp shore
	Depth:	5 feet
Lat./Long.:	45° 39' 50" 71° 34' 39"	
3	Label:	Down
	Time:	10:13
	Location:	Covered bridge in Pepperell
	Lat./Long.:	45° 40' 11" 71° 34' 30"
4	Label:	Pond B
	Time:	9:30
	Location:	30 feet upstream of a house at a point
		10 feet offshore
	Depth:	Surface
Lat./Long.:	45° 39' 42" 71° 34' 42"	
5	Label:	Pond C
	Time:	9:30
	Location:	Middle of pond
	Depth:	Surface
	Lat./Long.:	45° 37' 41" 71° 35' 37"
Core 1	Time:	8:35
	Location:	30 feet upstream of Pepperell boat ramp
		20 feet away from boat ramp shore
	Lat./Long.:	45° 39' 50" 71° 34' 39"
Core 2	Time:	9:30
	Location:	30 feet upstream of a house at a point
		10 feet offshore
	Lat./Long.:	45° 39' 42" 71° 34' 42"
Core 3	Time:	10:27
	Location:	40 feet upstream of Groton boat ramp
		20 feet offshore
	Lat./Long.:	45° 37' 41" 71° 35' 37"
6	Description:	Ice House
	Location:	Ice House Dam Impoundment
<u>11/29/2007</u>		
7	Label:	Ice House Up (IHU)
	Time:	13:30
	Location:	5 feet upstream of Ice House Dam impoundment
		20 feet offshore

	Lat./Long.:	45° 33' 10"	71° 37' 9"
8	Label:	Ice House Down (IHD)	
	Time:	13:30	
	Location:	100 feet downstream of Ice House Dam Impoundment	
		15 feet offshore	
	Lat./Long.:	45° 33' 11"	71° 37' 5"
9	Label:	9	
	Time:	14:00	
	Location:	Route 119 Pepperell-Groton bridge	
	Lat./Long.:	45° 37' 35"	71° 35' 35"
10	Label:	10	
	Time:	14:15	
	Location:	Canoe Launch Ramp for Pepperell Pond	
		Pepperell, MA	
	Lat./Long.:	45° 39' 48"	71° 34' 40"
11	Label:	11	
	Time:	14:45	
	Location:	Covered bridge in Pepperell	
	Lat./Long.:	45° 40' 11"	71° 34' 30"

Appendix B: Alkalinity Results

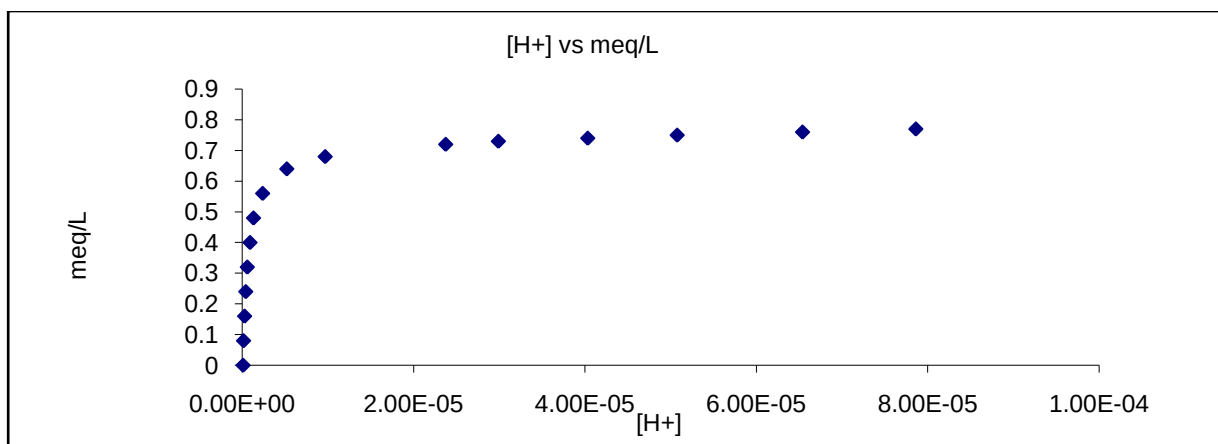
Sample 1:

V _{initial} (L):	0.100	Alkalinity (meq/L)=		0.7098	Alk (mg/L CaCO3)=	36
volume added	pH	Volume, uL	meq/L	[H+]	R ²	Alkalinity (meq/L)
0	7.05	0	0	9.24E-08	#DIV/0!	
240	5.9	300	0.48	1.30E-06	0.9733	0.1545
280	5.64	350	0.56	2.37E-06	0.9137	0.2766
320	5.3	400	0.64	5.19E-06	0.8648	0.3987
340	5.03	425	0.68	9.67E-06	0.8478	0.4887
360	4.64	450	0.72	2.37E-05	0.7526	0.5860
365	4.54	456	0.73	2.99E-05	0.9277	0.6341
370	4.41	463	0.74	4.03E-05	0.9362	0.6660
375	4.31	469	0.75	5.08E-05	0.9870	0.6960
380	4.2	475	0.76	6.54E-05	0.9923	0.7055
385	4.12	481	0.77	7.86E-05	0.9958	0.7098



Sample 2:

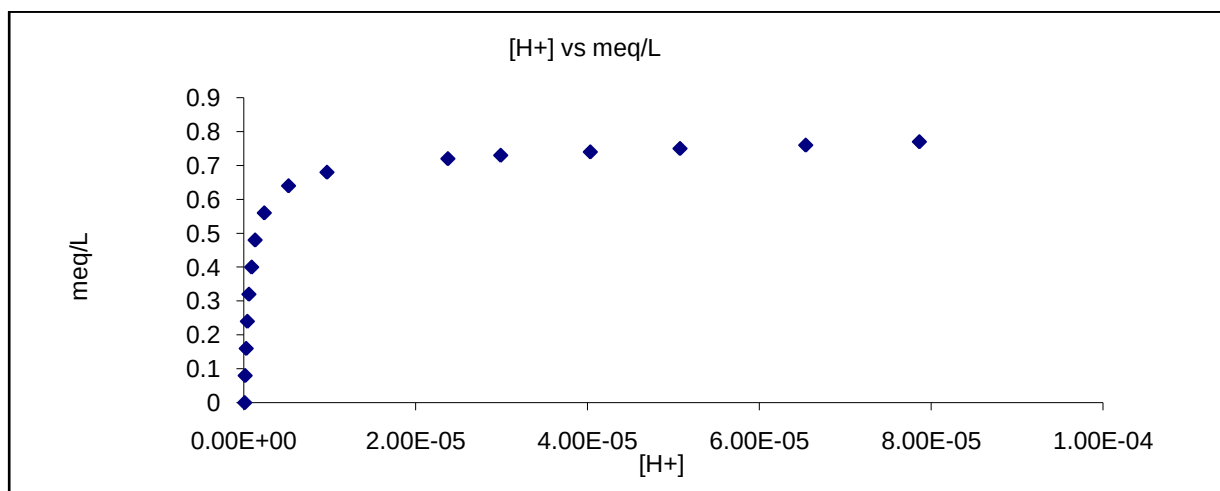
V _{initial} (L):	0.100	Alkalinity (meq/L)=		0.6647	Alk (mg/L CaCO3)=		33
volume added	pH	Volume, uL	meq/L	[H+]	R ²	Alkalinity (meq/L)	
0	7	0	0	1.04E-07	#DIV/0!		
240	5.9	300	0.48	1.30E-06	0.9401	0.1719	
280	5.65	350	0.56	2.32E-06	0.9116	0.2826	
320	5.25	400	0.64	5.83E-06	0.8426	0.4131	
340	4.86	425	0.68	1.43E-05	0.7557	0.5124	
360	4.4	450	0.72	4.13E-05	0.7134	0.5978	
365	4.3	456	0.73	5.19E-05	0.9313	0.6409	
370	4.21	463	0.74	6.39E-05	0.9813	0.6647	



Sample 3:

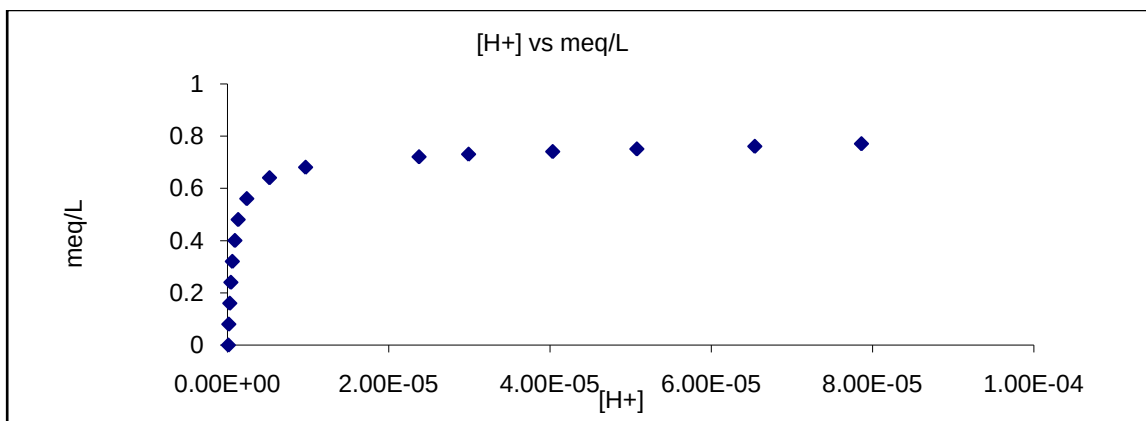
Sample 3:

Volume(L):	0.100	Alkalinity (meq/L)=	0.7047	Alk (mg/L CaCO3)=	35	
volume added	pH	Volume, uL	meq/L	[H+]	R ²	Alkalinity (meq/L)
0	7.01	0	0	1.01E-07	#DIV/0!	
280	5.68	350	0.56	2.17E-06	0.9294	0.2685
320	5.33	400	0.64	4.85E-06	0.8629	0.3987
340	5.04	425	0.68	9.45E-06	0.8252	0.4927
360	4.61	450	0.72	2.54E-05	0.7272	0.5914
365	4.49	456	0.73	3.35E-05	0.9122	0.6390
370	4.37	463	0.74	4.42E-05	0.9440	0.6684
375	4.26	469	0.75	5.69E-05	0.9903	0.6973
380	4.16	475	0.76	7.17E-05	0.9949	0.7047



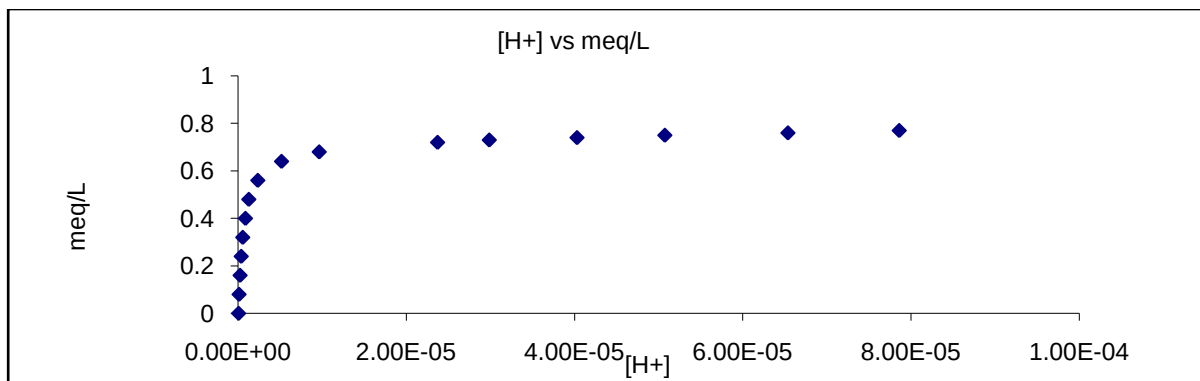
Sample 4:

Volume(L):	0.100	Alkalinity(meq/L)=		0.7091	Alk (mg/L CaCO3)=	35
volume added	pH	Volume, uL	meq/L	[H+]	R ²	Alkalinity (meq/L)
0	6.9	0	0	1.30E-07	#DIV/0!	
240	5.93	300	0.48	1.22E-06	0.9603	0.1318
280	5.74	350	0.56	1.89E-06	0.9486	0.2387
320	5.46	400	0.64	3.59E-06	0.8975	0.3697
340	5.26	425	0.68	5.69E-06	0.8892	0.4604
360	4.91	450	0.72	1.27E-05	0.7685	0.5750
365	4.81	456	0.73	1.60E-05	0.9193	0.6284
370	4.68	463	0.74	2.17E-05	0.9262	0.6642
375	4.55	469	0.75	2.92E-05	0.9709	0.6998
380	4.44	475	0.76	3.76E-05	0.9922	0.7091



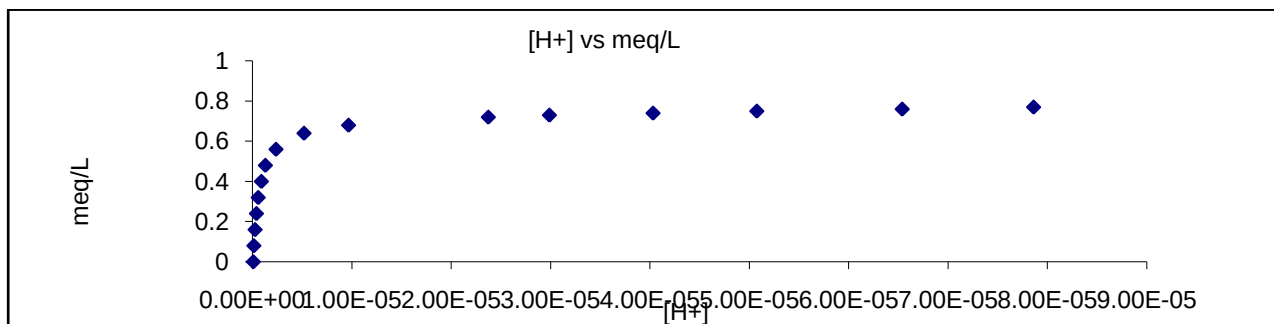
Sample 5:

Volume(L):	0.100	Alkalinity(meq/L)=	0.7101	Alk (mg/L CaCO3)=	36	
volume added	pH	Volume, uL	meq/L	[H+]	R ²	Alkalinity (meq/L)
0	6.79	0	0	1.68E-07	#DIV/0!	
240	5.91	300	0.48	1.27E-06	0.9532	0.1632
280	5.7	350	0.56	2.07E-06	0.9404	0.2613
320	5.33	400	0.64	4.85E-06	0.8502	0.4016
340	5.11	425	0.68	8.04E-06	0.8766	0.4801
360	4.74	450	0.72	1.89E-05	0.7752	0.5808
365	4.6	456	0.73	2.60E-05	0.8925	0.6351
370	4.48	463	0.74	3.43E-05	0.9196	0.6681
375	4.36	469	0.75	4.52E-05	0.9906	0.6997
380	4.26	475	0.76	5.69E-05	0.9942	0.7060
385	4.18	481	0.77	6.85E-05	0.9998	0.7101



Sample 6:

Volume(L):	0.100	Alkalinity(meq/L)=	0.8390	Alk (mg/L CaCO3)=	42	
volume added	pH	Volume, uL	meq/L	[H+]	R ²	Alkalinity (meq/L)
0	7.29	0	0	5.31E-08	#DIV/0!	
240	6.24	300	0.48	5.96E-07	0.9864	0.1067
280	36.07	350	0.56	8.82E-37	0.1765	0.4985
320	5.88	400	0.64	1.37E-06	0.2495	0.4658
360	5.64	450	0.72	2.37E-06	0.7109	0.5080
400	5.2	500	0.8	6.54E-06	0.8920	0.5911
420	4.81	525	0.84	1.60E-05	0.7565	0.6742
430	4.59	538	0.86	2.66E-05	0.7984	0.7389
435	4.47	544	0.87	3.51E-05	0.9287	0.7920
440	4.36	550	0.88	4.52E-05	0.9735	0.8207
445	4.26	556	0.89	5.69E-05	0.9949	0.8347
450	4.18	563	0.9	6.85E-05	0.9990	0.8390



Appendix C: All Sample Results

October 5, 2007		6	1	5	4	2	3
pH		-	7.13	7.43	6.91	6.85	7.27
Dissolved Oxygen (mg/L)		-	6.72	8.02	5.38	6.38	8.04
Alkalinity (mg/L as CaCO ₃)		42.0	35.5	35.5	35.5	33.3	35.3
Total Solids		-	-	-	-	-	-
Nitrates (mg/L)		-	2	1.2	3.6	1.7	1.6
Phosphorus(mg/L)		0.164	0.12	0.129	0.089	0.063	0.09
Ammonia (mg/L)		-	0.328	0.315	0.386	0.306	0.347

November 30, 2007	7	8	9		10	11
pH	7.25	7.26	6.85		6.78	6.73
Dissolved Oxygen (mg/L)	-	-	-		-	-
Alkalinity (mg/L as CaCO ₃)	-	-	-		-	-
Total Solids	-	214	158		162	166
Nitrates (mg/L)	2.81	2.81	2.31		1.97	2.01
Phosphorus(mg/L)	0.190	0.195	0.186		0.138	0.164
Ammonia (mg/L)	0.442	0.509	0.410		0.425	0.448
Temperature (°C)	-	7.4	4.7		5.8	4.2
Conductivity (µs/cm)	-	298	258		312	278

Cores		3		2	1	
Nitrates (mg/L)		13.03		13.34	6.41	
Phosphorus(mg/L)		0.19		0.16	0.41	
Ammonia (mg/L)		1.65		7.90	3.40	

Appendix D: Monthly and Seasonal Flows at the Pepperell Pond Impoundment, 2000-2005

YEAR	Monthly mean in cfs (Calculation Period: 1997-01-01 -> 2006-09-30)											
	Period-of-record for statistical calculation restricted by user											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	923.5	784	1,004	1,956	844	259	179	157	118	137	441	358
1998	1,028	1,146	1,931	874	1,091	1,488	427	171	122	303	225	210
1999	558.1	853	1,175	471	270	107	110	76.1	306	293	341	381
2000	428.7	527	1,168	1,514	858	930	301	355	205	233	398	534
2001	314.6	405	1,331	2,071	358	516	272	131	101	117	94.7	171
2002	141.3	265	453	572	820	491	126	69.6	72.9	156	464	758
2003	530.5	464	1,318	1,414	808	901	401	512	357	1,313	620	945
2004	517.1	282	608	1,986	860	447	320	372	434	356	387	905
2005	881.6	783	958	1,745	1,217	729	434	215	131	1,570	937	1,026
2006	1,354	1,290	500	473	1,435	1,465	684	376	410			
Mean of monthly Discharge	668	680	1,040	1,310	856	733	325	243	226	497	434	587

Peak Flow, 1997-2006 cfs

1999	Mar. 05, 1999	5.69	2,340
2002	15-May-02	6.01	2,560
2003	Mar. 24, 2003	6.68	3,020
2000	Apr. 24, 2000	8.95	4,660
2005	Jan. 05, 2005	9.06	4,740
2006	16-May-06	9.38	4,980
2001	Mar. 24, 2001	9.51	5,080
1998	Mar. 12, 1998	9.76	5,270
1997	Oct. 22, 1996	10.16	5,790
2004	Apr. 03, 2004	10.81	6,140

Average Flow, 1997-2006 cfs

1997	594.1
1998	748.7
1999	409.4
2000	619.8
2001	488.7
2002	366.1
2003	801.1
2004	622.6
2005	886.5

	Seasonal mean in cfs (Calculation Period: 1997-01-01 -> 2006-09-30)											
	Period-of-record for statistical calculation restricted by user											
	Spring (March-May)			Summer (June-Aug)			Autumn (Sept-Nov)			Winter (Dec-Feb)		
	1,931	2,071	1,435	1,488	683.6	512.3	434.4	1,570	937.3	1,026	1,028	1,146
	1,331	1,986	1,217	1,465	433.6	375.8	410.1	1,313	620.3	944.7	1,354	1,290
	1,318	1,745	1,091	929.9	426.6	371.6	357.2	355.7	464.3	904.5	923.5	853.2
	1,175	1,514	859.7	900.9	400.7	354.6	306	302.8	440.8	757.5	881.6	784
	1,168	1,414	857.9	729.3	320.3	215.2	204.6	293.1	397.6	533.9	558.1	782.7
	1,004	1,956	844.1	516.1	300.9	170.5	131.3	233.3	386.7	381.3	530.5	526.8
	957.9	874	820.3	490.5	272.4	156.7	122.4	155.8	340.6	358.1	517.1	463.5
	608.2	572.1	807.5	447.2	178.8	131.4	117.5	136.5	224.5	209.5	428.7	405.3
	499.9	472.8	357.5	259.3	125.9	76.1	100.6	116.9	94.7	171.4	314.6	282.4
	452.5	471.2	270.2	106.7	109.9	69.6	72.9				141.3	264.9
Seasonal Mean	1,069			434			386			645		
Peak	2071			1448			1570			1146		
Minimum	270			69.6			72.9			141.3		

Appendix E: Project Proposal

Project Number MQP-PPM-WQ01

Water Quality Improvement on the Nashua River

A Major Qualifying Project Proposal



Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the Requirements for the
Degree of Bachelor of Science

In Partnership with The Nashua River Watershed Association

Date: February 26, 2008

Submitted by:

Jonathan Carelli

Daniel LaFrance

Christopher Luppino

Kristen Ostermann

Approved by:

Professor Paul P. Mathisen, Advisor

Abstract

This project will assess water quality in the Nashua River main stem approaching and within Pepperell Pond, in Pepperell, Massachusetts. It will assess the effectiveness of various recent efforts to remove nutrients from wastewater discharges, and project future water quality as a result of existing regulation. It will combine and analyze data collected from monitoring stations throughout the watershed, and attempt to develop a specific plan to remediate Pepperell Pond. Additional consideration will be given to projected future development along the river, and any physical controls that can be added to remove sediment phosphorus along the bed of the pond in recreational areas.

Introduction

Ground water and surface water comprise much of the water we use in our everyday lives. Much of this water flows into surface waters such as rivers and streams and eventually into larger surface water bodies. By not protecting it, people can abuse and pollute this vital resource.

Many communities use surface water bodies to provide a recreation for their population. Boating, swimming, and fishing are all common practices shared by many. Some communities also use these sources of water for drinking. It is important to maintain these precious resources as they play a vital role to many communities across the United States.

One such area in which heavy pollution has affected water quality is the Nashua River Watershed and in particular, Peperell Pond. The Nashua River is located in North-central Massachusetts and in Southern New Hampshire. For much of the last century, this area has been highly industrialized. In particular, the cities of Fitchburg and Leominster have been the site of heavy industrial companies. These companies routinely dumped the byproducts of their manufacturing processes into the Nashua River, which polluted the river and killed much of the vegetation and fish. This also prevented people from using much of the river for recreation.

Throughout the years, society has become more aware of the effects of pollution on many of the nation's surface water bodies. The Environmental Protection Agency (EPA) and the institution of the Clean Water Acts have created much of this pressure to clean up the nation's water bodies.¹⁵⁰ Through the assistance of the Massachusetts Department of Environmental Protection (MassDEP), the New Hampshire Department of Environmental Services, and the Nashua River Watershed Association, the Nashua River has become less polluted. However, this work is not complete.

¹⁵⁰ "Clean Water Act" Last updated on Friday, September 7th, 2007. <http://www.epa.gov/region5/water/cwa.htm>



Figure 1: An Algal Bloom Covers Pepperrell Pond on the Nashua River

Green algae covers much of Pepperrell Pond throughout the year that is the result of pollution in the area. This Pond is located in the Nashua River Watershed. Within this watershed is a rapidly urbanizing area. Changes in land use and development along the river's banks threaten the river's health. Algae and other nutrient-based growth problems, collectively known as eutrophication, have occurred where the river is otherwise restored. This creates aesthetic problems, and lowering dissolved oxygen concentrations to levels that threaten fish when plant life dies, while creating wide oxygen level swings over the course of the day during an algal bloom.¹⁵¹ Land and road building have increased impervious areas increasing the effects of storm water on the river. It is important to know how this affects the surface and groundwater as it flows directly into the pond itself.

Pepperrell Pond is an illustrative case for the problems remaining on the Nashua River. Plagued by problems with phosphorus and nitrogen loads, it has attracted the attention of the MassDEP. The pond is within ten river miles of two municipal wastewater treatment stations, a wastewater discharge from a local school, and of downtowns Pepperrell, Devens, Shirley, and Ayer that can be seen in Figure 2. Residential developments close to the pond and other human involvement contribute to high phosphate, sediment, and nitrate loads. It is important to know the land use and the hydrology of the area to be able to gauge and measure the surface and ground water contributions to the Pepperrell Pond.

¹⁵¹ Davis, Mackenzie L, and Masten, Susan J. Principles of Environmental Engineering and Science, Third Edition. 2004, McGraw Hill, Boston. 586.

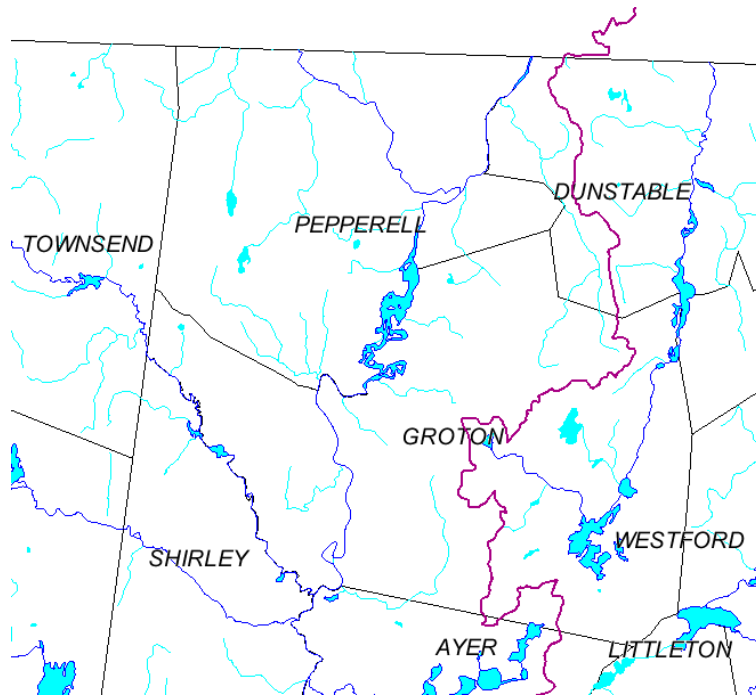


Figure 2: Map of Pepperell Pond and Surrounding Communities

While the initial work to establish a total maximum daily loading (TMDL) is complete, the work on the river is far from over. The next stage, currently in progress, is to monitor the river for the impact of phosphorus load reductions, and determine the effectiveness of the current TMDL. Initially, the DEP determined these to have minimal effects much of the time, but with increased development and storm water effects, there is concern that non-point sources may become significant. Local officials have specifically identified Pepperell Pond as needing additional attention, and a management plan, with physical controls to remove underwater plant growth and a land-use plan that will prevent additional non-point loadings from merely erasing work to remove wastewater-borne phosphorus.

The goal of this project is to assist in analysis of the current source data, taken from dozens of locations in the Nashua River watershed, and attempt to project the future phosphate levels in the river because of the existing restrictions. It will use available data to better assess the effects of surface and ground water flows in the area. These contributions may account for a large portion of the flow into Pepperell Pond. Additionally, it will develop the previously mentioned management plan for Pepperell Pond, assess the pond's health as impacted by the

changes to phosphate levels in the main river, as well as assess the potential impacts from sediment in the pond.

This project will fulfill the Capstone Design Requirement for ABET-approved civil engineering programs. The Massachusetts Department of Environmental Protection, along with its TMDL report, recommended “a separate management plan for Pepperell Pond... which would focus on identifying zoned uses of the pond with corresponding structural controls for removal of bottom aquatic vegetation in certain specified recreational use areas.”¹⁵² This project will deliver a management plan for nutrients in the pond, and design any applicable structural controls or other management techniques for vegetation removal. It will involve analysis of the nutrients available in the pond, and their forms- soluble, settled, or absorbed in vegetation, and removal methods applicable in the available cases. As the DEP’s ultimate goal for the pond is recreational use, invasive structural controls will be considered a last resort, used only if other techniques prove damaging to the environment or overly difficult and expensive for their implementation.

This project will also include an analysis of current conditions and the potential impact of up scaled discharges from the nearby Wastewater Treatment Facilities (WWTFs) which are considering expansion at this time. This will factor into the management plan in terms of expected design parameters- future expected loadings given growth and development in the Pepperell area.

¹⁵²Total Maximum Daily Load for the Nutrient Phosphorus. 2007,Massachusetts Department of Environmental Protection, Worcester. 4.

Literature Review

To understand better the effects of pollution on Pepperell Pond and throughout the Nashua River Watershed, various topics need to be investigated. These topics include the types of nutrients that can pollute a water body, the history of the Nashua River, Pepperell Pond, and the overall watershed. Furthermore, such factors such as pollution sources and water flows will be discussed below.

Phosphorus

Phosphorus is a very common element, but it is highly reactive so it is not found freely in nature. It can be found in every living cell since it is a required element for DNA and RNA. Human activity can create an increased loading of phosphorus in the surrounding area using fertilizers and other activities.¹⁵³ In water, phosphorus is normally found in the form of organic or inorganic phosphates. Organic phosphates are those that are the result of biological processes and are bound to plant or animal tissue. These types of phosphates are created by human activity in form of sewage and are sometimes created as pesticides break down. Plants use inorganic phosphates and are used in detergents.

In fresh water systems, phosphorus is the limiting condition for plant growth; therefore, an increased load in phosphorus will allow smaller, faster growing plant life to experience rapid growth. Algae and quick growing aquatic plants can take advantage of brief increases in phosphorus loads. After these plants have used up the excess phosphorus, they die and decompose which depletes the oxygen in the water, resulting in the death of other aquatic life, like fish. This process is known as eutrophication.¹⁵⁴

Eutrophication is the result of pollution of fresh water systems by an overload in nutrients, like phosphorus, and is classified as point or nonpoint pollution.¹⁵⁵ Point pollution sources are those such as effluent discharged from a wastewater treatment plant, which are easily measured and controlled. The sources of nonpoint pollution are difficult to measure or control because they often originate from large areas of land and are transported through the air, over or under

¹⁵³ Moore, John W., Conrad Stanitski, Peter Jurs. *Chemistry the Molecular Science*, Second Edition. Brooks/Cole 2005. Chapter 4, pages 96-107.

¹⁵⁴ Fetter, C.W. Applied Hydrogeology, Fourth Edition. 2001, Prentice Hall, Upper Saddle River, New Jersey. 386.

¹⁵⁵ Ibid

the ground to the water system. Table 1 provides a list of point and nonpoint sources of pollution.

Point sources

- Wastewater effluent (municipal and industrial)
- Runoff and leachate from waste disposal sites
- Runoff and infiltration from animal feedlots
- Runoff from mines, oil fields, unsewered industrial sites
- Storm sewer outfalls from cities with a population >100 000
- Overflows of combined storm and sanitary sewers
- Runoff from construction sites >2 ha

Table 1: Characteristics of point and nonpoint sources of chemical inputs to receiving waters recognized by statutes of the United States (modified from Novotny and Olem 1994)

Nonpoint sources

- Runoff from agriculture (including return flow from irrigated agriculture)
- Runoff from pasture and range
- Urban runoff from unsewered areas and sewer areas with a population <100 000
- Septic tank leachate and runoff from failed septic systems
- Runoff from construction sites <2 ha
- Runoff from abandoned mines
- Atmospheric deposition over a water surface
- Activities on land that generate contaminants, such as logging wetland conversion, construction, and development of land or waterways

The percentage of phosphorus coming into surface waters due to point or nonpoint sources vary depending on the settlement of the surrounding area. In more urbanized areas point sources of pollution, such as sewers and effluent from treatment plants play a more significant role than in rural areas in phosphorus loading. Nonpoint pollution sources, such construction, pet waste, and developments that do not possess sewer systems in urban areas still contribute a significant amount of pollution. In areas that are more rural the heavy loads of phosphorus can be attributed to nonpoint sources such as fertilized fields. The amount of nutrients coming into a field is greater than the amount of nutrients being harvested as crops, this net gain in nutrients in an area results in nonpoint pollution.

Hydrology

Hydrology is the study of the circulation, distribution, and quality of water throughout the earth. For many years, people have been studying the movement of water. Those who do are able to provide insight into environmental policy, planning, and engineering.¹⁵⁶ Those who study hydrology are familiar with the hydrologic cycle.

Hydrological Cycle

The hydrological cycle is a complex cycle that distributes water throughout the oceans and lakes, the land, and the air. Water usually first evaporates into the air from water bodies

¹⁵⁶ Hwang, Ned H., and Robert J. Houghtalen. "Hydrology for Design." Hydraulic Engineering Systems. 3rd ed. Upper Saddle, New Jersey: Prentice-Hall, Inc, 1996. 322.

such as lakes, rivers, and streams. Evaporation can also occur through the cell walls of plants. Scientists call this phenomenon transpiration.¹⁵⁷ Scientists also call the combination of evaporation from surface water bodies and transpiration from plants evapotranspiration.

As the evaporated water declines in temperature in the atmosphere, the water vapor forms clouds, which in turn precipitate onto the ground. Vegetation catches much of this precipitation while other amounts are stored back into surface water bodies. In highly developed and urban areas, there is not enough vegetation to catch much of the water that falls as rain. As a result, much of the water becomes runoff and carries pollutants overland into surface water bodies.¹⁵⁸ In addition, much of the water infiltrates the ground where it becomes ground water, which eventually flows throughout the land and into public drinking supplies.

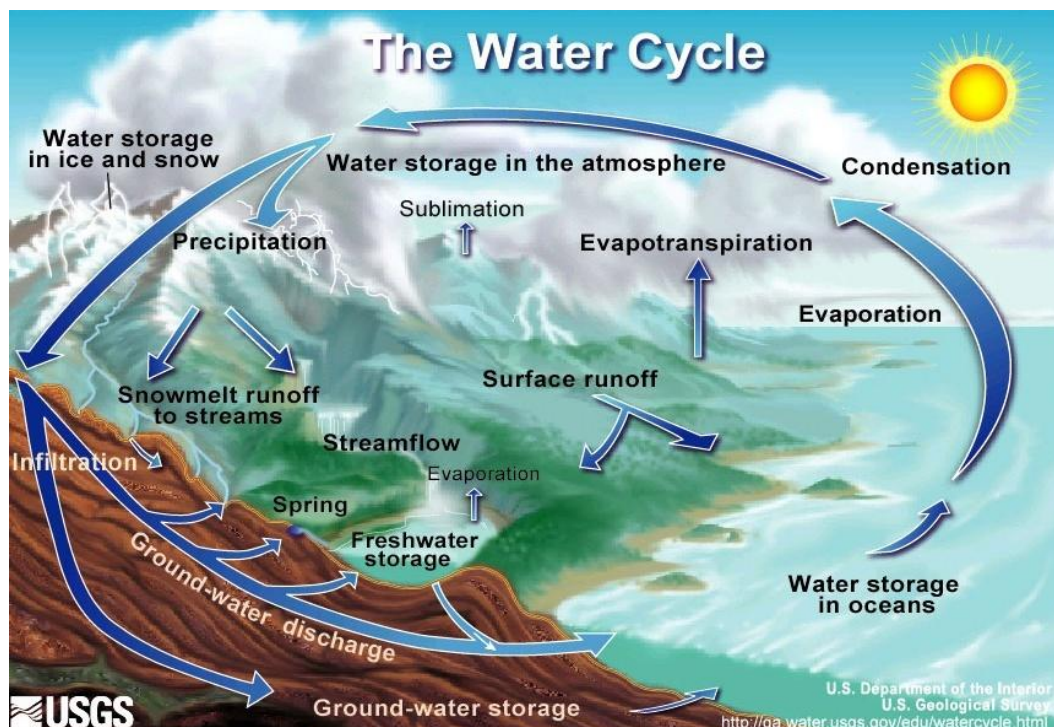


Figure 3: Hydrologic Cycle

Watershed

A watershed is a tract of land that supplies surface water to a stream or river at a particular point. Water drains throughout a watershed along the steepest topographical slopes.

¹⁵⁷ Ibid.

¹⁵⁸ Davis, Mackenzie L, and Masten, Susan J. Principles of Environmental Engineering and Science, Third Edition. 2004, McGraw Hill, Boston. 191.

This land may be a few acres or it could be many thousands of acres in area. Many times, a particular watershed may have sub basins in which water flows into smaller streams before entering the larger streams, and then finally to a particular discharge point.¹⁵⁹

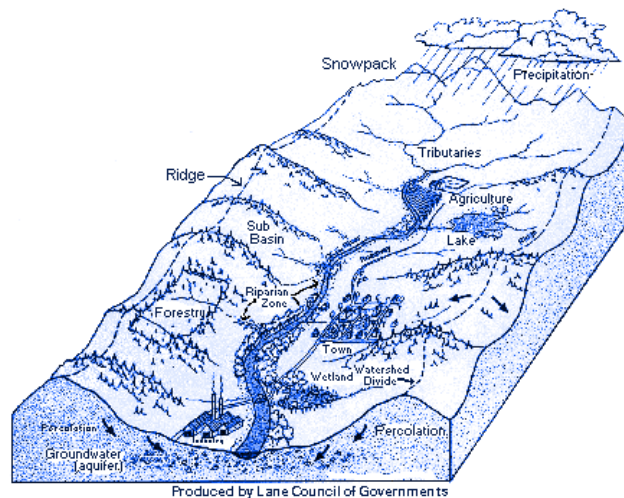


Figure 4: Example Watershed

Surface and Ground Water Flow

Surface water comprises rivers, streams, and other overland flow. This water moves along the contours of the land. Ground water flow is the water that infiltrates into the ground. This flow usually travels through large aquifers, underground layers of porous rock that water saturates, until the ground water flow meets a surface water body. As the demand for clean water is rising, many people are using ground water as their source of water. This demand, along with seasonal variability often affects the water ground water flows throughout the ground.¹⁶⁰

Ground Water Surface Water Exchanges

Both ground water and surface water are often interconnected. They rely on each other and it is important to know how they interact.

Ground water usually interacts with surface water when the ground water is located in unconfined shallow water table aquifers. This interaction comes in the form of receiving water

¹⁵⁹ Davis, Mackenzie L, and Masten, Susan J. Principles of Environmental Engineering and Science, Third Edition. 2004, McGraw Hill, Boston. 193.

¹⁶⁰ Marsh, William M. Landscape Planning, Fourth Edition. 2005, John Wiley & Sons, Boston. 135.

from a lake or stream or discharging water into a lake or stream. Usually, a stream's base flow can be defined as the flow from an unconfined aquifer that feeds water to a river or stream.¹⁶¹

The base flow of a stream is the portion of a stream's flow that does not come from surface runoff but rather ground water contributions. Another way in which ground water interacts with surface water is when people pump ground water to the surface for use as drinking and irrigation water.

Surface water interacts with ground water by "recharging" the amount of ground water flow below the surface. The amount of precipitation that does not contribute to rivers or streams percolates downward through the ground surface into aquifers. In most areas, five to fifty percent of annual precipitation contributes to ground water recharge.¹⁶²

Background

The underlying problem this project will address is the high level of phosphorus in Pepperell Pond, on the main stem of the Nashua River. This high level is associated with the upstream wastewater discharges, which are designed to be over 30 million gallons per day (MGD).¹⁶³ The river has a number of issues associated with it, and phosphorus has been targeted for removal because it causes eutrophication.¹⁶⁴ The general issues associated with the Nashua River and the recent remediation effort are presented below.

Total Maximum Daily Loads (TMDLs)

Total maximum daily loads (TMDLs) are average wastewater effluent concentrations for given contaminants. Their levels are determined such that they do not cause damage to the receiving stream, and are legally binding. Under the Clean Water Act, the DEP is required to list streams that are impaired by pollutants, and to require measures that will improve conditions. The Nashua River is listed as a "Category 5" river for nutrient enrichment,¹⁶⁵ meaning that the

¹⁶¹ Fetter, C.W. Applied Hydrogeology, Fourth Edition. 2001, McGraw Hill, Upper Saddle River, New Jersey. 5.

¹⁶² Phillips, Nancy. "Ground Water & Surface Water: Understanding the Interaction." Conservation Technology Information Center. Online at <http://www.ctic.purdue.edu/KYW/Brochures/GroundSurface.html>. 2008.

¹⁶³ Total Maximum Daily Load for the Nutrient Phosphorus. 2007, Massachusetts Department of Environmental Protection, Worcester. 4.

¹⁶⁴ Ibid.

¹⁶⁵ Ibid. 5

river does not meet prescribed water quality standards and can be improved with a loading restriction, or TMDL.¹⁶⁶

In 2006, the TMDL was assigned for various nitrogen and phosphate compounds. The total phosphate TMDL was 0.2 mg/L for the larger WWTFs in Fitchburg, Leominster, and Ayer, 0.5 mg/L for the smaller treatment facilities, and 1 mg/L for the Groton School. This TMDL is effective from April through October, but since cold weather inhibits plant growth regardless of phosphates, dissolved phosphorus is not regulated during the winter months. However, treatment facilities are required to precipitate as much phosphorus as possible at all times, in order to prevent the phosphates from collecting in sediment, which can then leach into the water later and contribute to eutrophication.

History of the Nashua River

Beginning in the 1700s, the Nashua river valley began to see development in the form of mills. The river was used to supply energy to milling operations in Gardner, Fitchburg, Leominster, and Nashua.¹⁶⁷ Until the 1970s, these industries took water from the river for their use, and very often returned untreated industrial wastewater. The best-known offenders in the area were paper mills, whose inks stained the river with the color of paper being printed that day.

In the late 1960s, Marion Stoddart began an effort to clean up the industrial pollution, and formed the Nashua River watershed association in 1969 to assist the cleanup. With help from Clean Water Act funding, many wastewater treatment systems were improved, and has removed much of the pollution. Today the river is safe for swimming and recreation in several areas, and is home to several fisheries. Since 1985, the river has improved moderately, though it is still considered to be impacted on the south branch and impaired on the north branch because of sediment and nutrient loadings, and storm water runoff.¹⁶⁸

Pepperell Pond

Pepperell Pond, located in Pepperell and Groton MA near the New Hampshire border, is a 300-acre area where the Nashua River enters an impoundment just south of downtown Pepperell.

¹⁶⁶ NCGA Clean Water Act Primer, page 29

¹⁶⁷ Nashua River Watershed Association Homepage, <http://www.nashuariverwatershed.org/> last accessed September 26, 2007.

¹⁶⁸ TMDL Report, page 24

The pond suffers from plant growth problems and is listed by the EPA as impacted water under the Clean Water Act, for toxics, nuisance plants, turbidity, and nutrients. Nutrient and sediment buildup tend to be higher in the pond than upstream because the pond is much wider, allowing velocities to drop and sediments to fall out.

The slower flow also allows nutrients to build up without being swept away, which allows large mats of algae to grow in the summer. The DEP noted diurnal swings in dissolved oxygen in the water, including super saturation (roughly 125% of the normal maximum) during some days, while nights dropped to low oxygen levels. These swings can harm fish that arrive in the oxygen-rich water and are threatened at lower oxygen levels during the night.

The DEP has given increased attention to the pond itself, because it is more affected than other sections of the river by the nutrient loadings in the water. Since the TMDL was only recently passed, its impact on the pond and its plant growth remain to be seen. Water samples have been tested at both ends of the river and monitoring should point to the impact of the TMDL, and of the continuing impact of non-point sources on the river. Just upstream of the Pepperell Pond impoundment, the Squannacook River adds a significant flow into the Nashua River. Much of the phosphorus carried from this direction is from non-point sources, which the TMDL report has attempted to reduce by roughly 20%. These sources could be more significant since the point sources have been reduced by the TMDL.

Methodology

To establish a management plan for the level of phosphorus in Pepperell Pond, it is necessary to obtain information about the relationships between the pond and its surroundings. The pond has many influences that must be characterized and evaluated for their effects. Some of these influences may be controllable while others may be natural circumstances or variations. Those that can be controlled must be further evaluated to see how their changing may affect the conditions in the pond. The following tasks are important to create a management plan for Pepperell Pond:

- Perform literature and background research
- Research and analyze relevant data concerning phosphorus, nitrogen, sediments, and other important parameters.
- Identify the hydrology of the area

- Investigate remediation plans
- Create a management plan for Pepperell Pond
- Produce a report and present recommendations

TASK	WEEK							
	B TERM	2	4	6	C TERM	2	4	6
Literature and Background Research								
Researching Relevant Data								
Identify Hydrology								
Research and Design Remediation Plan								
Create Management Plan								
Produce Report and Recommendations								

Figure 5: Methodology Timeline

Background Research

The relevant information concerning the Nashua River Watershed, the hydrologic cycle, TMDLs, algae, and other important information concerning the history of the watershed will be researched thoroughly. Articles, reports, and other projects will be researched in order to get a better understanding.

Researching Relevant Data

It is necessary to determine all of the sources of phosphorus that contribute to the total phosphorus in Pepperell Pond so that the conditions in the pond may be accurately modeled. These input data will come from water quality reports from likely source points such as

wastewater treatment plants as well as other testing points along the Nashua River. Data obtained from non-point source locations will aid in determining the severity of the impact of other sources such as storm water inflow. In organizing all of the input data, key contributors of phosphorus will be identified and studied in greater depth. Samples from these sources will be gathered and analyzed for phosphorus content to validate its influence on the pond. Another potential source of phosphorus that may pose as a significant contributor is that contained within sediments. Core samples will be taken to identify the extent to which phosphorus has settled to the bottom of the pond and identify its potential to enter back into the water.

Other factors may also control the level of phosphorus, such as temperature, depth, and water velocity; therefore, samples will be taken from areas throughout the pond representative of each of these different conditions. In doing so, the affects of each and any other factors discovered through sampling may be determined and incorporated into the model of the phosphorus levels in the pond. Further analysis of these factors will determine whether or not the factor is one which humans can control and if so then also the extent of that control. One example, within human control, is the output of a single wastewater treatment plant. All of the plants in the area are subject to a specific TMDL as identified in the Background Section of this report. By lowering the TMDL, a reduction in the output level of phosphorus would be forced upon the plants. The mere existence of a TMDL for the Nashua River is an example of an action taken to reduce the amount of phosphorus entering Pepperell Pond. Research into other similar actions is will serve as a baseline for recommendations contained in the management plan. The result of this research will be a complete analysis of the causes and the factors affecting the levels of phosphorus in Pepperell Pond, and of what has been done thus far to lower the present level.

Identifying the Hydrology of the Area

A GIS model will be created for the Nashua river watershed. This will allow direct tracking of levels throughout the watershed, and includes layers for zoning and impervious cover in Pepperell and Groton. Increased development and an increase in impervious area has been identified by the DEP as a possible continued stressor on the area, and by comparing the model under current conditions and future plans for the area, as they impact wastewater, storm water, and recreational use of the pond, the best management practices for the pond can be established.

This model will be created in ArcMap, using data layers provided by the Nashua River Watershed Association and MassGIS. It will display, in addition to zoning and impervious area, the major roads, wetlands, sub-watersheds, and other physical characteristics useful to the analysis. Roads will indicate the locations of future development, and wetland destruction and restoration can drastically affect the chemical composition of the pond- wetlands upstream serve to filter the incoming water, and often provide lush habitats for vegetation to flourish, relocating the nutrient issue entirely. Sub-watersheds provide the locations of the individual inputs to the pond, so that if necessary, major sources can be identified for further study.

Investigating Remediation Options

After analyzing the appropriate nutrient data and the hydrology of the area, as well as other data from various sources, several remediation options will be closely compared and analyzed. Other similar projects in local ponds will be research as well as any new emerging technology that may be of assistance. A close comparison will be made between all of the practical options and the most effective plan will be chosen.

Design a Management Plan for Pepperell Pond

After investigating these choices, the most effective option will be chosen and a remediation plan will be designed that will remove the most significant amounts of the algae from the pond. It will consist of possible future locations of samplings and future remediation actions to enhance the quality of Pepperell Pond. This design will also include preventive measures in assurance that this nuisance will not occur once again.

Produce a Report and Present Recommendations

The report will present the applicable background information, data, analysis, and management plan for the Pepperell Pond. This report will also present recommendations for the Nashua River Watershed Association to enhance the quality of the water in Pepperell Pond in the end to serve the communities that use this important natural resource.

Conclusion

In response to an overactive growth of algae throughout the Pepperrell Pond, this project will attempt to study the effects of phosphorus and land use around the pond in Pepperrell Massachusetts. This pond is a part of the Nashua River and its watershed, which many companies have been polluting since the rise of industrialization in the United States.

Background concepts will be research to understand better the nature of the hydrology and pollution levels in the area. Relevant reports and data will be researched throughout the term of the project.

Data from both samples of the pond itself and GIS programs will be analyzed. A design of a remediation plan will be created, as a tool to implement for the Nashua River Watershed Association. From this, recommendations to the Nashua River Watershed Association will be made in expectations that they will be able to understand the relationship between the pond and the area surrounding it.

End of Proposal.

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Appendix F: NRCS Runoff Calculations

Composite Curve Number Present Day

$$CCN = (\sum CN_i * A_i) / \sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

$$25\% \text{ of Entire Area} \quad A = (0.25) * (2816) = 708 \text{ Acres}$$

$$CN = 65$$

(2 Acres Residential Districts by Average Lot Size, Soil Group B)

(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

$$50\% \text{ of Entire Area} \quad A = (0.50) * (2816) = 1408 \text{ Acres}$$

$$CN = 55$$

(Woods, Good Hydrologic Condition, Soil Group B)

(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

$$25\% \text{ of Entire Area} \quad A = (0.25) * (2816) = 708 \text{ Acres}$$

$$CN: 92$$

(Commercial and Business, Soil Type B)

(Table 5.7 p. 156)

$$(65 * 708 + 55 * 1408 + 92 * 708) / 2816 = 67$$

$$CN = 67$$

Composite Curve Number Future 10% More Impervious

$$CCN = (\sum CN_i * A_i) / \sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

$$20\% \text{ of Entire Area} \quad A = (0.20) * (2816) = 563.2 \text{ Acres}$$

$$CN = 65$$

(2 Acres Residential Districts by Average Lot Size, Soil Group B)

(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

$$45\% \text{ of Entire Area} \quad A = (0.45) * (2816) = 1267.2 \text{ Acres}$$

$$CN = 55$$

(Woods, Good Hydrologic Condition, Soil Group B)

(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

$$35\% \text{ of Entire Area} \quad A = (0.35) * (2816) = 985.6 \text{ Acres}$$

$$CN: 92$$

(Commercial and Business, Soil Type B)

(Table 5.7 p. 156)

$$(65 * 563.2 + 55 * 1267.2 + 92 * 985.6) / 2816 = 70$$

$$CN = 70$$

Composite Curve Number Future 20% More Impervious

$$CCN=(\sum CN_i * A_i) / \sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

25% of Entire Area $A=(0.25)*(2816)= 704$ Acres

CN= 65

(2 Acres Residential Districts by Average Lot Size, Soil Group B)
(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

35% of Entire Area $A=(0.35)*(2816)= 985.6$ Acres

CN= 55

(Woods, Good Hydrologic Condition, Soil Group B)
(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

40% of Entire Area $A=(0.40)*(2816)= 1126.4$ Acres

CN: 92

(Commercial and Business, Soil Type B)
(Table 5.7 p. 156)

$$(65*704+55*985.6+92*1126.4)/2816= 72$$

CN=72

Composite Curve Number 10% More Impervious

$$CCN=(\sum CN_i * A_i) / \sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

15% of Entire Area $A=(0.15)*(2816)= 422.4$ Acres

CN= 65

(2 Acres Residential Districts by Average Lot Size, Soil Group B)
(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

50% of Entire Area $A=(0.50)*(2816)= 1408$ Acres

CN= 55

(Woods, Good Hydrologic Condition, Soil Group B)
(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

35% of Entire Area $A=(0.35)*(2816)= 985.6$ Acres

CN: 92

(Commercial and Business, Soil Type B)
(Table 5.7 p. 156)

$$(65*422.4+55*1408+92*985.6)/2816= 69$$

CN=69

Composite Curve Number 20% More Impervious

$$CCN = (\sum CN_i * A_i) / \sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

5% of Entire Area $A = (0.05) * (2816) = 140.8$ Acres

CN= 65

(2 Acres Residential Districts by Average Lot Size, Soil Group B)
(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

50% of Entire Area $A = (0.50) * (2816) = 1408$ Acres

CN= 55

(Woods, Good Hydrologic Condition, Soil Group B)
(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

45% of Entire Area $A = (0.45) * (2816) = 1267.2$ Acres

CN: 92

(Commercial and Business, Soil Type B)
(Table 5.7 p. 156)

$$(65 * 140.8 + 55 * 1408 + 92 * 1267.2) / 2816 = 72$$

CN=72

SMALLER RESIDENTIAL PLOTS

Composite Curve Number Present Day

$$CCN=(\sum CN_i \cdot A_i)/\sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

25% of Entire Area $A=(0.25)*(2816)= 708$ Acres

CN= 68

(1 Acre Residential Districts by Average Lot Size, Soil Group B)
(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

50% of Entire Area $A=(0.50)*(2816)= 1408$ Acres

CN= 55

(Woods, Good Hydrologic Condition, Soil Group B)
(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

25% of Entire Area $A=(0.25)*(2816)= 708$ Acres

CN: 92

(Commercial and Business, Soil Type B)
(Table 5.7 p. 156)

$$(68*708+55*1408+92*708)/2816= 68$$

CN=68

Composite Curve Number 10% More Impervious

$$CCN=(\sum CN_i \cdot A_i)/\sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

20% of Entire Area $A=(0.20)*(2816)= 563.2$ Acres

CN= 68

(1 Acre Residential Districts by Average Lot Size, Soil Group B)
(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

45% of Entire Area $A=(0.45)*(2816)= 1267.2$ Acres

CN= 55

(Woods, Good Hydrologic Condition, Soil Group B)
(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

35% of Entire Area $A=(0.35)*(2816)= 985.6$ Acres

CN: 92

(Commercial and Business, Soil Type B)
(Table 5.7 p. 156)

$$(68*563.2+55*1267.2+92*985.6)/2816= 71$$

CN=71

Composite Curve Number 20% More Impervious

$$CCN=(\sum CN_i \cdot A_i)/\sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

25% of Entire Area $A=(0.25)*(2816)= 704$ Acres

CN= 68

(1 Acre Residential Districts by Average Lot Size, Soil Group B)
(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

35% of Entire Area $A=(0.35)*(2816)= 985.6$ Acres

CN= 55

(Woods, Good Hydrologic Condition, Soil Group B)
(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

40% of Entire Area $A=(0.40)*(2816)= 1126.4$ Acres

CN: 92

(Commercial and Business, Soil Type B)
(Table 5.7 p. 156)

$$(68*704+55*985.6+92*1126.4)/2816= 73$$

CN=73

Composite Curve Number 10% More Imp. Protected Land

$$CCN=(\sum CN_i \cdot A_i)/\sum A_i$$

Area 1 (West of Pond): Residential Use and More Developed

15% of Entire Area $A=(0.15)*(2816)= 422.4$ Acres

CN= 68

(1 Acre Residential Districts by Average Lot Size, Soil Group B)
(Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest

50% of Entire Area $A=(0.50)*(2816)= 1408$ Acres

CN= 55

(Woods, Good Hydrologic Condition, Soil Group B)
(Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development

35% of Entire Area $A=(0.35)*(2816)= 985.6$ Acres

CN: 92

(Commercial and Business, Soil Type B)
(Table 5.7 p. 156)

$$(68*422.4+55*1408+92*985.6)/2816= 69$$

CN=70

Composite Curve Number 20% More Imp. Constant Protected Land
 $CCN = (\sum CN_i * A_i) / \sum A_i$

Area 1 (West of Pond): Residential Use and More Developed
 5% of Entire Area $A = (0.05) * (2816) = 140.8$ Acres

CN= 68
 (1 Acre Residential Districts by Average Lot Size, Soil Group B)
 (Table 5.7 p.156)

Area 2 (East of Pond): Protected Reserve Land and State Forest
 50% of Entire Area $A = (0.50) * (2816) = 1408$ Acres

CN= 55
 (Woods, Good Hydrologic Condition, Soil Group B)
 (Table 5.8 p. 157)

Area 3 (Northwest of Pond): Some Commercial and Development
 45% of Entire Area $A = (0.45) * (2816) = 1267.2$ Acres

CN: 92
 (Commercial and Business, Soil Type B)
 (Table 5.7 p. 156)

$$(68 * 140.8 + 55 * 1408 + 92 * 1267.2) / 2816 = 72$$

CN=72

<u>10% More Impervious</u>	
Precipitation (Inches)	Runoff (Inches/day)
2.1	0.28
2.3	0.36
2.5	0.45
2.9	0.66
3.85	1.23
4.4	1.6
5.15	2.15
5.8	2.65
6.2	2.96

<u>10% More Impervious, Smaller Residential Plots, 50% Protected Land</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.28	
2.3	0.36	
2.5	0.45	
2.9	0.66	
3.85	1.23	
4.4	1.6	
5.15	2.15	
5.8	2.65	
6.2	2.96	

<u>10% More Impervious, 50% Protected Land</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.253	
2.3	0.33	
2.5	0.42	
2.9	0.62	
3.85	1.17	
4.4	1.53	
5.15	2.07	
5.8	2.56	
6.2	2.87	

<u>20% More Impervious</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.34	
2.3	0.43	
2.5	0.53	
2.9	0.75	
3.85	1.36	
4.4	1.75	
5.15	2.31	
5.8	2.83	
6.2	3.16	

<u>20% More Impervious, 50% Protected</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.34	
2.3	0.43	
2.5	0.53	
2.9	0.75	
3.85	1.36	
4.4	1.75	
5.15	2.31	
5.8	2.83	
6.2	3.16	

<u>20% More Impervious, Smaller Residential Plots, 50% Protected Land</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.34	
2.3	0.43	
2.5	0.53	
2.9	0.75	
3.85	1.36	
4.4	1.75	
5.15	2.31	
5.8	2.83	
6.2	3.16	

<u>Present, Smaller Residential Plots</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.23	
2.3	0.3	
2.5	0.39	
2.9	0.51	
3.85	1.11	
4.4	1.46	
5.15	1.99	
5.8	2.47	
6.2	2.77	

<u>10% More Impervious, Smaller Residential Plots</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.31	
2.3	0.4	
2.5	0.49	
2.9	0.7	
3.85	1.29	
4.4	1.68	
5.15	2.23	
5.8	2.74	
6.2	3.06	

<u>20% More Impervious, Smaller Residential Plots, 50% Protected Land</u>		
Precipitation (Inches)	Runoff (Inches/day)	
2.1	0.34	
2.3	0.43	
2.5	0.53	
2.9	0.75	
3.85	1.36	
4.4	1.75	
5.15	2.31	
5.8	2.83	
6.2	3.2	

Appendix G: Curve Numbers for NRCS Analysis

COVER DESCRIPTION		CURVE NUMBERS FOR HYDROLOGIC SOIL GROUP			
		A	B	C	D
COVER TYPE AND HYDROLOGIC CONDITION	AVERAGE % IMPERVIOUS AREA ^b				
<i>Fully developed urban areas (vegetation established)</i>					
Open space (lawns, parks, golf courses, cemeteries, etc.) ^c					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50 to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roof, driveways, etc. (excluding right-of-way) ^d		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved: open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1–2-in. sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
$\frac{1}{8}$ acre or less (town houses)	65	77	85	90	92
$\frac{1}{4}$ acre	38	61	75	83	87
$\frac{1}{3}$ acre	30	57	72	81	86
$\frac{1}{2}$ acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
<i>Developing urban areas</i>					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94
Idle lands (CNs are determined using cover types similar to those in Table 5.8).					

COVER		HYDROLOGIC CONDITION	HYDROLOGIC SOIL GROUP			
LAND USE	TREATMENT OR PRACTICE		A	B	C	D
Fallow	Straight row	—	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes ^a or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		—	59	74	82	86
Roads (dirt) ^b		—	72	82	87	89
(hard surface) ^b		—	74	84	90	92

Appendix H: Mass Balance for Phosphorus on days of sample collection

For November 30, 2007:

$$Q_{\text{out}} * C_{\text{out}} = [325 \text{ cfs}] * [0.164 \text{ mg/L}] = 300 \text{ lbs/day}$$

Let Q_1 = inflow through the river, $C_1 = 0.186 \text{ mg/L}$

Q_2 = groundwater inflow, assumed to have negligible phosphorus¹⁶⁹

No biological activity (cloudy, cold day) or runoff (rain was minimal and sporadic during sampling, so it would not have contributed significant runoff).

$$\text{Massflow}_{\text{out}} = \text{Massflow}_{\text{in}} = [Q * C]_{\text{out}} = [Q * C]_{\text{in}}$$

$$325 * 0.164 = 0.186 Q_1 \Rightarrow Q_1 = 287 \text{ cfs}$$

$$Q_{\text{in}} = Q_{\text{out}} = Q_1 + Q_2 \Rightarrow Q_2 = 38 \text{ cfs} = 25 \text{ MGD}$$

Inlet conditions = 287 cfs @ 0.195 mg/L = 285 lbs/day

Sorption activity = Outflow – inflow (inlet, groundwater, runoff, biological)

Sorption activity is expected to contribute 15 lbs/day

For October 5, 2007:

Biological activity, no runoff, very low flow (outflow of 92 cfs)

Groundwater flow = 25 MGD, 0.05 lb/day, negligible nutrient contribution. Groundwater flow is assumed constant, as recharge points are far from the river's edge.

Outlet flow = 92 cfs (60 MGD) at 0.09 mg/L = 45 lb/day

Inlet flow = 35 MGD at 0.12 mg/L = 35 lb/day

Phosphorus leached = 10 lb/day, as well as the amount necessary to maintain biological growth.

Conditions were sunny and warm, so it is assumed some amount of biological uptake was occurring.

Conclusion: Sediment loads contribute approximately 15 lbs/day to total phosphorus loading.

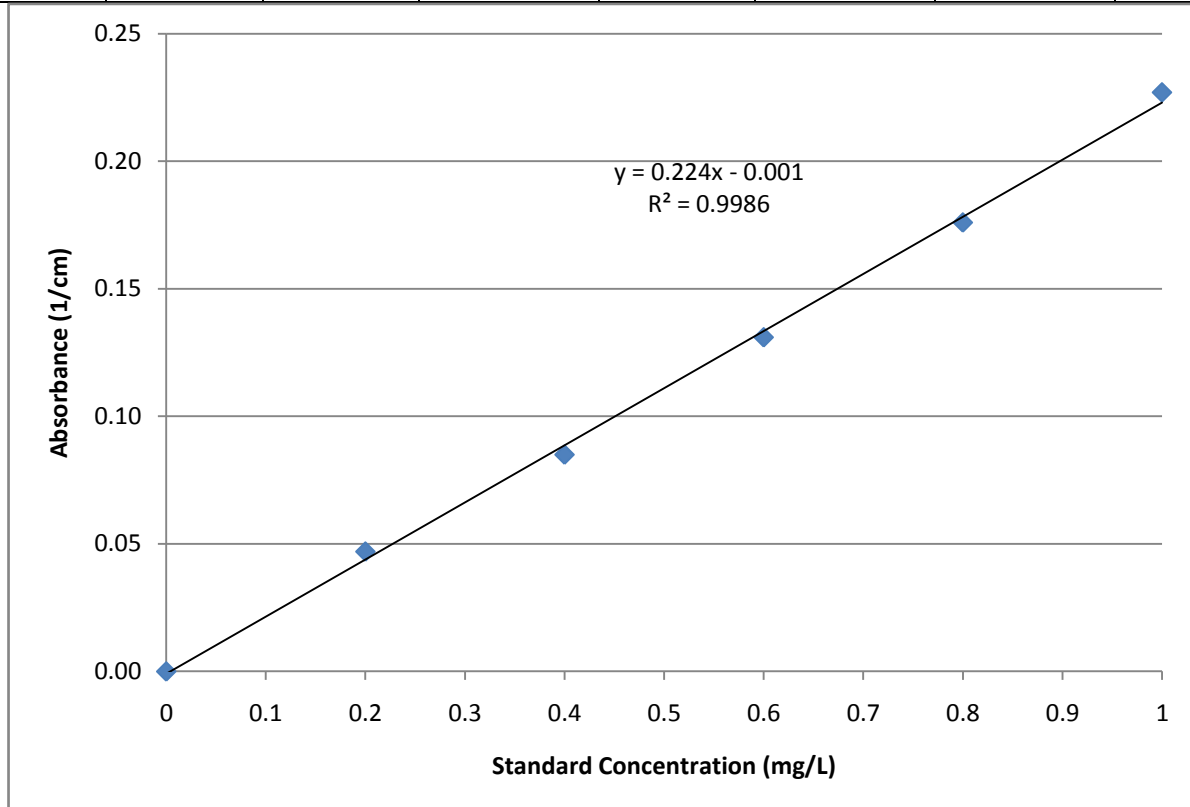
¹⁶⁹ According to Marsh, only homes within 100 yards contribute septic loads, for 0.28 kg/year*home, total of ~0.023 kg/day = 0.05 lbs/day

Appendix I: Sediment-Water Equilibrium

Standards	
Standard (mg/L)	Absorbance (1/cm)
0	0.000
0.2	0.047
0.4	0.085
0.6	0.131
0.8	0.176
1	0.227
25	3.110

Leaching Experiment		
Elevation	Absorbance (1/cm)	Concentration (mg/L)
0	-0.006	-0.02
1	-0.005	-0.02
2	-0.001	0.00
3	-0.006	-0.02
4	-0.003	-0.01
5	-0.005	-0.02
@ sediment	0.008	0.04

Equilibrium Experiment							
Sample	Mass of Sediment (g)	Absorbance (1/cm)	Concentration (mg/L)	Absorbance minus standard (1/cm)	Concentration Change (mg/L)	Normalized Concentration Change (mg/L)	Equilibrium (mg/L)
0	1.5125	0.028	0.13	0.028	0.13	0.13	0.13
0.2	1.5147	0.050	0.23	0.003	0.02	0.02	0.22
0.4	1.5726	0.049	0.22	-0.036	-0.16	-0.15	0.25
0.6	1.5134	0.035	0.16	-0.096	-0.42	-0.42	0.18
0.8	1.5167	0.046	0.21	-0.130	-0.58	-0.57	0.23
1	1.5202	0.065	0.29	-0.162	-0.72	-0.71	0.29
25	1.5190	0.395	2.82	-2.715	-22.56	-22.27	2.73
Pond B	1.5153	0.185	0.83	-0.042	-0.18	-0.18	0.82
Other	1.5182	0.187	0.84	-0.040	-0.17	-0.17	0.83



Appendix J: Management Plan for Phosphorus in Pepperell Pond

Water Quality Improvement for Pepperell Pond on the Nashua River

A Preliminary Management Plan

Submitted to the
NASHUA RIVER WATERSHED ASSOCIATION
In Conjunction with the MQP
Water Quality Improvement on the Nashua River

Date: February 26, 2008



Prepared by:

Jonathan Carelli

Daniel LaFrance

Christopher Luppino

Kristen Ostermann

Advised by:

Paul P. Mathisen

Introduction

Pepperell Pond, located south of downtown Pepperell on the mainstem of the Nashua River, suffers from excessive nutrient enrichment, which has caused excessive growth of algae and duckweed, restricting the pond's use as a recreational water. Many sources contribute nutrients to the pond, including treated wastewater discharges, septic system flows, stormwater flows, and sediments in the bed of the pond itself. Loads are summarized in Figure 27, and are delineated by their particular sources. Upstream point loads are currently nearly 500 lbs per day, dwarfing other loadings to the pond. The NRCS and PLoad methods are two separate ways to quantify agricultural runoff. The other contributors are summarized separately, to show their relative strengths in Figure 28. The tributary area around the pond is shown in Figure 26.

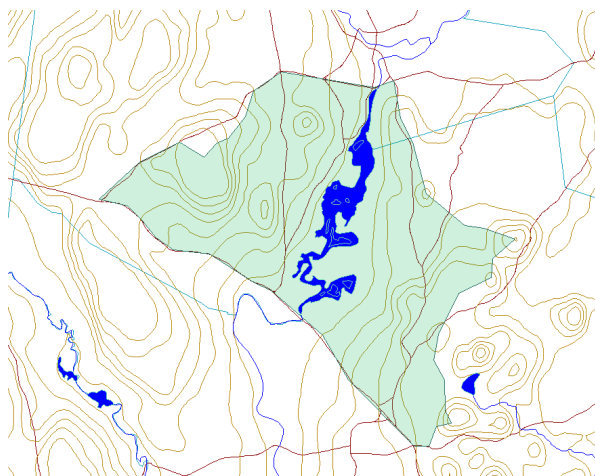


Figure 26: Tributary Area Around Pepperell Pond

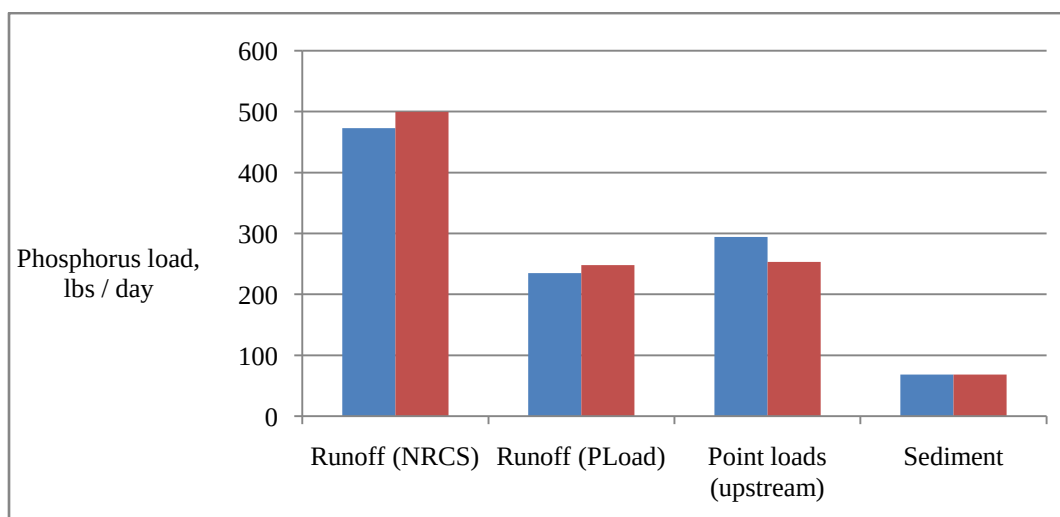


Figure 27: Loadings of Phosphorus at the Pepperell Pond Inlet

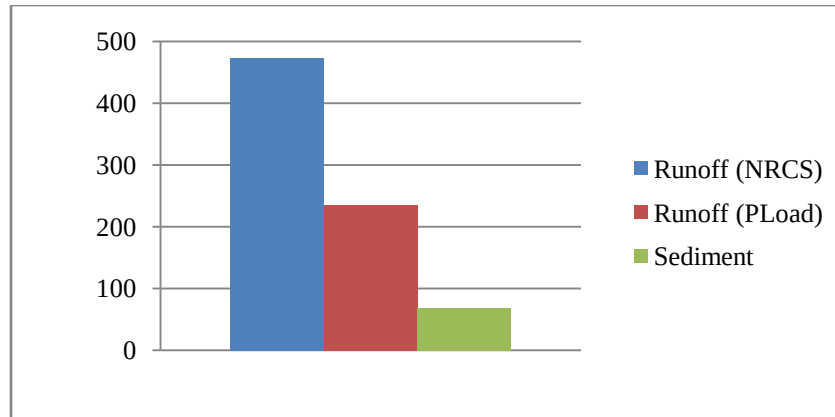


Figure 28: Various Nonpoint Loadings , lbs/day

The purpose of this plan is to present several recommendations for the removal and control of algae, as well as limiting nonpoint phosphorus loads to the pond, which will limit future growth of algae and duckweed on the pond.

The Massachusetts Department of Environmental Protection issued a loading restriction regarding treated wastewater phosphate loads in 2007. Most plant discharges are limited to either 0.2 mg/L along the mainstem or 0.5 mg/L along the upstream branches. These restrictions are proposed to lower point sources, the largest contributor to the pond. There is also a provision for a 20% reduction in nonpoint loads, but no strict legal requirement that this be done, or prescription for reducing this load. The purpose of this plan is to address nonpoint loadings, sediment nutrient concentrations, and other management practices in the immediate area of the pond, as well as the immediate impact of the surface algae and duckweed which are the physical manifestation of the pond's nutrient overloading.

Point Loadings

Input loadings for Pepperell Pond have indicated approximately 0.14 mg/L phosphate, which is enough to introduce eutrophication. Therefore reduction of point loadings, especially during low flows in the summer (100-200 cfs or 147-298 MGD) can significantly reduce nutrient loads on the river and reduce algal blooms and other forms of plant growth. Compliance with the proposed TMDL for phosphorus should reduce phosphorus loading from 0.36 mg/L to 0.13 mg/L according to DEP modeling.¹⁷⁰ In the location of Pepperell Pond, before the TMDL has taken force, the phosphorus load is 0.06-0.195 mg/L as phosphorus at various locations

¹⁷⁰ Total Maximum Daily Load for the Nutrient Phosphorus, 2007, Massachusetts Department of Environmental Protection, Worcester. 8.

throughout the year. Therefore, compliance with this regulation should only reduce the maximum phosphorus level, and still not reduce the lower level. This is still considered “eutrophic to advanced eutrophic,” which will not reduce the level of algae and invasive plant growth.¹⁷¹ Therefore, further action is necessary.

Point loadings are only restricted from April 1st to November 1st each year under the proposed TMDL limits. While the justification for this decision is that biological activity is unlikely to absorb the nutrients in the winter months, this project investigated sediment-phosphorus interactions and found an equilibrium state of approximately 0.2 mg/L as phosphorus between the sediments in the riverbed and the river water. Therefore, it is recommended that the state reconsider its allowance for the winter months until it is further studied and shown that the level of phosphorus discharged in the winter months holds the concentration below this equilibrium point. Otherwise, it is expected that the phosphorus inflow in the winter months will bind to the sediments, and be released in warmer weather to facilitate more biological activity.

¹⁷¹ Marsh, William M. Landscape Planning: Environmental Applications, Fourth Edition. New York: John Wiley and Sons, Inc., 2005. 215.

Nonpoint Loadings from Septic System Leaching

On the west side of Pepperell Pond, there are several homes and businesses located in close proximity to the water's edge. Homes located near the river's edge may contribute nutrient loadings, if they rely on septic systems, and not discharging their wastewater to sewers. The Pepperell Sewer System does not extend in all directions, as Figure 29 shows.

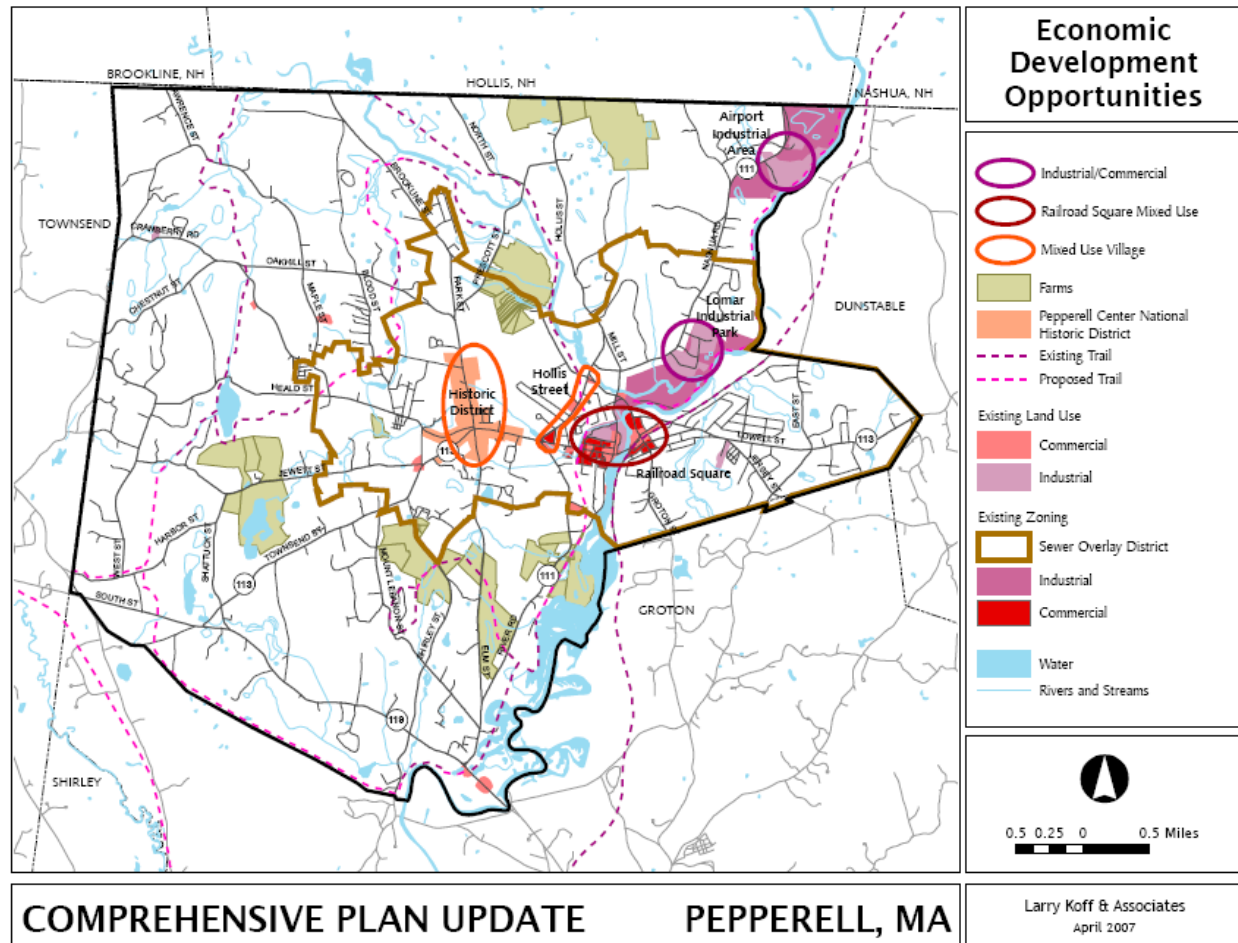


Figure 29: Sewer Overlay for Pepperell MA

The entirety of the Groton sewer district lies to the south and east of Pepperell Pond. Therefore, at least 16 homes on the Groton side of the pond and 24 on the Pepperell side within 100 yards of the river's edge which have no sewer connections, and most likely rely on septic systems. Homes within 100 yards of the river's edge contribute approximately 0.28 kg/year of phosphorus and 10.66 kg/year of nitrogen.¹⁷² This implies an annual loading of 11.2 kg/year of phosphorus,

¹⁷² Marsh, William M. Landscape Planning: Environmental Applications, Fourth Edition. New York: John Wiley and Sons, Inc., 2005. 218.

or 34.3 kg/year as total phosphate. This addition is enough to add 0.2 mg/L to 44.5 million gallons of water. A sewer line along MA 111 and improvements to Groton sewers are estimated at 3-4 miles (15,000-20,000 feet) of sewer lines, at an estimated installation cost of \$75-100 per foot. The exorbitant cost of implementation, in addition to the relatively minimal impact of septic system loads, make sewer lines impractical. Instead, a management practice is advised, requiring any new septic system, or any system which requires extractive maintenance, to be located at least 100 yards from the river's edge. This distance is enough to prevent septic loads from reaching the river, and does not require large-scale construction to implement.

Nonpoint Loading from Runoff

Stormwater is expected to load approximately the same nutrient loadings in one month as the septic systems contribute annually. A one-month storm return period is estimated to contribute 20-50 kg of total phosphate, with the most significant contributions coming from the south and west. Stormwater control measures, and nutrient control measures for land applications are important to the successful management of nutrients.

The majority of the nutrient loading from nonpoint sources is expected to originate at the agricultural land on the southwestern portion of the pond. Agricultural nutrient contributions can be minimized by effective timing of fertilizer applications. Timing applications correctly can ensure that more of the nutrients absorb into the soil and less runoff occurs. An educational measure should address both agricultural and residential fertilizer applications, and deal with the proper timing, application, and methods for ensuring greatest efficiency. Nutrient loadings can be further reduced by land contouring, which should be addressed as a method of nutrient capture.

Infiltration beds offer a means to capture and mitigate stormwater, curbing both storm flows and the associated loadings. These beds could be areas with a trench containing sand, which allows water to flow fairly quickly through it, and below it rock to a depth of several feet. Rainwater can infiltrate into the ground slowly percolate into the river, rather than adding millions of gallons of flow, and loads of up to 100 lbs of phosphorus per day, for a very short duration. Infiltration beds are fairly easy to install, as they are generally large pits filled with sand and rock. The primary concern with this method is the use of groundwater wells in the area, which may be impacted by the discharges, but by law there is a requirement that groundwater wells be a given distance from septic systems, and since most of Pepperell and Groton use septic systems, it is unlikely that there are groundwater wells in the area.

The city of Worcester has enacted an additional method of stormwater quality control, which may help both with education and water quality in Pepperell Pond. Storm drains in Worcester are marked with white writing, reading “Don’t dump: Drains to” and the name of a nearby surface water body. The use of this practice can help prevent people from adding chemicals to stormwater loads, which may assist in the reduction of nutrient additions to Pepperell Pond. This method is easily implemented, as it requires only spray paint, stencils, and a team of volunteers to go around to nearby storm drains and mark them appropriately.

Future development is expected to increase impervious area to the south and west of Pepperell Pond. With increased impervious area occurs increased runoff, so management practices should be undertaken to prevent stormwater problems in the future. Zoning practices preventing dense residential or commercial use are recommended for this section of Pepperell, in order to prevent the most widespread stormwater effects. Any residential project to develop this area should take stormwater into consideration, and attempt to mitigate stormwater effects via a retention pond, land contouring, infiltration basins, riparian buffers or other assorted measures. Prevention of runoff will prevent stormwater effects from increasing and creating nutrient problems in the future.

Sediment Nutrient Loadings

Sediment nutrient loads are the second highest loading problem in Pepperell Pond. Depending on water chemistry conditions, sediments can both adsorb and desorb nutrients, such that they approach an equilibrium water concentration of approximately 0.20 mg/L as phosphorus. Therefore, sediment exerts a nutrient load on the water in the pond in low load conditions, and serves as a nutrient sink in high load conditions.

Given the Nashua River's history of heavy industrial use, there may be hazardous material in the sediments. Any dredging activities are likely to churn up sediment, which may mobilize hazardous materials in the sediments. Therefore, any method to physically extract sediment must be approached with caution, and analyses must be performed to verify low risk before mobilizing sediment. Extractive methods are therefore less advisable than methods allowing sediment to leach phosphates surface water, or physical barriers which stabilize sediment and prevent leachate migration. It is most advisable to either attempt to prevent phosphate leaching, or to encourage leaching for a short term, which would remove the sediment phosphate, while enacting policies to prevent future phosphate collection in the sediment.

One attractive option is "duckweed farming." Duckweed can be passively grown in the water, and absorbs large quantities of both phosphorus and nitrogen compounds. Once a bloom grows large enough, the user can skim the duckweed off the pond, and collect nutrients in the form of organic material. The organic material can become a commercial product in the form of organic fertilizer. This product is passively grown, allowing the user to grow the organic material, and then harvest it, removing the nutrient-rich material and creating what is known as "green fertilizer." A skimming operation can be performed as needed to remove the blooming nuisance vegetation, and until it regrows to the extent that skimming is necessary again, the area can be used recreationally.

Another option involves the isolation of phosphorus in the sediment, and prevention of leaching entirely. For this purpose, there are both physical and chemical means to prevent leaching. Phosphorus is more likely to leach in anoxic conditions, which occur predominantly in the deeper portions of the downstream end of the pond. Implementing aeration at selected points throughout the river would both handle the leaching and create a friendlier habitat for fish, which cannot thrive in sections of the pond with wide dissolved oxygen swings. The fish would both

eat some of the algae and encourage fishing, which would agitate the pond surface, making it more difficult for algae to grow during the day, when sunlight would otherwise encourage growth.

Surface Nuisance Plant Removal

Skimming has been recommended as a preferred method for removal of phosphorus-rich algae, and thus a means to lower the total nutrient loading in Pepperell Pond. In the case of duckweed, the dominant plant in this system, a skimmer must remain near, but slightly below, the water surface. A design for a general skimmer is available online from Duckweed Dave's Guide to Surface Skimmers,¹⁷³ which details the method for building a low-cost, effective skimmer for either duckweed or algae. Since both are present on the pond during the summer months, removal of one may lead to the other's emergence. It is therefore recommended that the Nashua River Watershed Association use both as needed to remove surface nuisance plants, and thus the nutrients supplying them, from the river in the summer months.

Implementation of this method is fairly simple, and extremely cost-effective. The skimmer designs allow for up to several hundred feet of skimming line, which can be anchored to a tree and dragged from one end, or anchored to two canoes and dragged through the water. Using the skimmer would involve a small team of volunteers, on an as-needed basis, to drag the lines across the pond and scoop up the plants captured in the skimmer. Assuming that the volunteers are available, this project requires a capital investment of a few hundred dollars at most, using materials one can obtain from any hardware store.

Removal of surface nuisance plants by means of a skimmer is a relatively inexpensive, simple method. The use of a line that is held afloat with simple foam devices will allow for an efficient capture of the duckweed and algae floating on the pond. The duckweed and algae that are swept up by this line can then be collected and disposed of or in the case of duckweed possibly sold as feed. The dragging of a semi-buoyant line across the water, which collects the floating plant matter in front of the motion of this line, is a task that can easily be explained and accomplished by volunteers. Considering that the funding that has been received to help clean up Pepperell Pond has been designated for use for water chestnut, it is imperative that the recommended remediation options for other nuisance plant and nutrient removal be as cost effective as possible.

¹⁷³ Baggaley, Dave. "Duckweed Dave's Guide to Surface Skimmers." The Native Fish Conservatory. 26 Feb. 2008 <<http://www.nativefish.org/articles/duckweed.php>>.

Conclusions

The most effective single measure which will remove the nutrients from Pepperell Pond is the total maximum daily loading issued by the DEP. This source reduction will eliminate approximately 20% of the nutrients entering the pond. Other measures will have varying effects in the short term, but will contribute to the DEP's larger goal of a 20% nonpoint source reduction. Sediments have been found to be another major contributor, and will increase in primacy as the point loads are cut in the future. Stabilizing the sediments should be the second biggest concern with regard to nutrient control in the pond. Skimming and harvesting aquatic plants is seen as the best method for doing so, as it requires relatively little input from the surrounding community, is relatively inexpensive, and can result in the production of a useful product, organic fertilizer.

Nuisance plant control will be partially addressed by the reduction in phosphorus, as it is the limiting nutrient in the pond. Physical controls, including skimming, and the Nashua River Watershed Association's work on water chestnut control, will also help to address this problem. It will take years before Pepperell Pond's nutrients are entirely exhausted, but these methods provide a step toward pristine water quality, and the pond's eventual restoration as a healthy and vibrant recreational water.

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