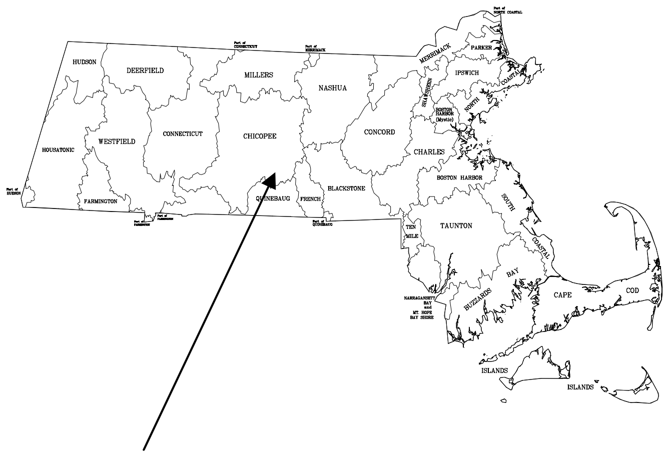
Total Maximum Daily Loads of Total Phosphorus for Quaboag & Quacumquasit Ponds

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
STEPHEN R. PRITCHARD, SECRETARY
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
ROBERT W. GOLLEDGE Jr., COMMISSIONER
BUREAU OF RESOURCE PROTECTION
MARY GRIFFIN, ASSISTANT COMMISSIONER
DIVISION OF WATERSHED MANAGEMENT
GLENN HAAS, DIRECTOR

Total Maximum Daily Loads of Total Phosphorus for Quaboag & Quacumquasit Ponds

DEP, DWM TMDL Final Report MA36130-2005-1 CN 216.1 May 16, 2006



Location of Quaboag & Quacumquasit Pond within Chicopee Basin in Massachusetts.

NOTICE OF AVAILABILITY

Limited copies of this report are available at no cost by written request to:

Massachusetts Department of Environmental Protection
Division of Watershed Management
627 Main Street
Worcester, MA 01608

This report is also available from DEP's home page on the World Wide Web at:
http://www.mass.gov/dep/water/resources/tmdls.htm

A complete list of reports published since 1963 is updated annually and printed in July. This report, entitled, "Publications of the Massachusetts Division of Watershed Management – Watershed Planning Program, 1963-(current year)", is also available by writing to the DWM in Worcester.

DISCLAIMER

References to trade names, commercial products, manufacturers, or distributors in this report constituted neither endorsement nor recommendations by the Division of Watershed Management for use.

Front Cover
Photograph of the flow gate at Quacumquasit Pond, East Brookfield.

Executive Summary

The Massachusetts Department of Environmental Protection (DEP) is responsible for monitoring the waters of the Commonwealth, identifying those waters that are impaired, and developing a plan to bring them back into compliance with the Massachusetts Surface Water Quality Standards. The list of impaired waters or the "303d list" identifies river, lake, and coastal waters, the reason for impairment is also known as category 5 (waters requiring a TMDL report) of the integrated list. The current and proposed integrated list, and further explanation can be found at http://www.mass.gov/dep/water/resources/tmdls.htm.

Once a water body is identified as impaired, DEP is required by the Federal Clean Water Act to essentially develop a "pollution budget" designed to restore the health of the impaired body of water. The process of developing this budget, generally referred to as a Total Maximum Daily Load (TMDL), includes identifying the source(s) of the pollutant from direct discharges (point sources) and indirect discharges (non-point sources), determining the maximum amount of the pollutant that can be discharged to a specific water body to meet water quality standards, and developing a plan to meet that goal.

This report develops total phosphorus TMDLs for Quaboag Pond and for Quacumquasit Pond in the Chicopee Basin Watershed. The lakes are listed on the "Massachusetts Year 2002 Integrated List of Waters" for metal and exotic species and Quaboag Pond has a history of algal blooms that is an indicator of nutrient enriched system, better known as the process of eutrophication. Quaboag Pond was added to the 2004 Integrated list because of excessive nutrients and noxious aquatic plants (following a large noxious cyanobacteria bluegreen bloom in July 2004). In freshwater systems the primary nutrient known to accelerate eutrophication is phosphorus. This report will satisfy the requirement of a TMDL for Quaboag Pond and will serve as a protective TMDL for Quacumquasit Pond. In order to prevent further degradation in water quality and to ensure that each lake meets state water quality standards, the TMDL establishes a phosphorus limit for each lake and outlines actions to achieve that goal. Because of uncertainties in the analysis, this will be considered a Phased TMDL and additional monitoring will be required to determine what additional implementation may be required in the future.

Even when a water body is not listed for nutrients, because of the inter-relationship of the cause and effects of the pollutants and response variables, it is a prudent policy to be conservative when determining loading allocations and planning management strategies. In-lake data used for this analysis were collected by DEP and combined with a group of five empirical lake phosphorus models for Quacumquasit Pond and a simple mass balance model for Quaboag Pond to estimate the reductions in phosphorus loading needed to meet Water Quality Standards. Because Quaboag Pond is a shallow, warmwater fishery and naturally more eutrophic due to the large watershed, the target phosphorus concentration was set higher than in Quacumquasit Pond. The latter pond is a deep coldwater trout lake with a small watershed and requires a lower phosphorus concentration target to maintain clear conditions and to maintain dissolved oxygen in the deep hypolimnetic zone of the lake for the trout fishery.

The following table lists the two lakes, their total phosphorus concentrations and annual phosphorus loads, as well as the selected target phosphorus concentration and loads necessary to achieve surface water quality standards. The target and loads for Quaboag Pond focus on summer conditions due to the quick flow of water through the pond, while the target for Quacumqausit Pond is based on spring concentrations and annual loads that are more appropriate for a lake with a long water residence time.

Total Phosphorus Targets.

WBID	Lake Name	Current Load Year 2003 kg/yr	Surface TP (ppb)	Target Load kg/yr	Target TP (ppb)
MA36130	Quaboag Pond	3710	43 (June-Sept.)	2588	30 (June-Sept.)
MA36131	Quacumquasit Pond	199	15 (spring)	146	12 (spring)

The implementation of the TMDL is comprised of 4 parts: 1) Optimization/Upgrades to the Spencer Wastewater Treatment Plant, to meet 0.2 mg/l (0.79 lb/day) summer limit, 2) Control of nonpoint source pollution targeting Phase II stormwater controls by Town of Spencer and MassHighway for State Route 9, Route 31 and Route 49, by requiring roadway sweeping and catchbasin inspection/cleaning twice a year or other approved BMPs, 3) Modification to increase Quacumquasit flood control gate height by adding 18 inches to height, and 4) Modification to Quaboag Pond macrophyte management plan to target specific recreational zones such as boat channels and swimming areas.

Because of the limited data available on discrete sources of nutrients within a given watershed, a locally organized watershed survey is recommended to identify and target reductions in nonpoint sources of nutrients and sediments. A portion of the phosphorus load can be regulated under existing NPDES permits, however, the majority of the load originates from non-point sources. In most cases, authority to regulate nonpoint source pollution and thus successful implementation of this TMDL is limited to local government entities and will require cooperative support from local volunteers, lake and watershed associations, and local officials in municipal government. Those activities can take the form of expanded education, obtaining and/or providing funding, and possibly local enforcement. Funding support to aid in implementation of this TMDL is available on a competitive basis under various state programs including the Section 319 Grant Program. The Town of Brookfield, working with the Quaboag and Quacumquasit Lake Association have just received a 319 grant of $162,500 which will be increased by matching funds from the Town to implement the nonpoint source controls recommended by this TMDL including parts 2-4, above.

Table 1. Quaboag Pond MA36130 TMDL May-October Load Allocation.

Source	***Current TP Loading (kg/yr)***	***Current TP Loading (kg/day)***	***Target TP Load Allocation (kg/yr)***	***Target TP Load Allocation (kg/day)***
Load Allocation				
Forest	1378	3.77	938	2.57
Wetland	64	0.18	63	0.17
Agriculture	590	1.62	402	1.10
Open Land	163	0.44	111	0.30
Residential (Low den.)	375	1.03	255	0.70
Septic System	48	0.13	33	0.09
Internal recycling	603	1.65	411	1.13
Waste Load Allocation				
Spencer WWTP NPDES(MA0100919) *	131	0.36	131	0.36
Urban & road stormwater.	358	0.99	244	0.67
Total Inputs	3710	10.16	2588	7.09

*The Target load for the Spencer WWTP is set at the current phosphorus load of 0.79 lb/day (0.36 kg/day) or approximately 0.2mg/l at a flow of 0.47 MGD during May-October as shown above. Recommended winter limits of 1.19 lb/day are not reflected in the table. Note for NPDES permits the seasonal values should be used.

Quacumquasit Pond MA36131 TMDL Load Allocation.

Source	*Current TP Loading (kg/yr)*	*Current TP Loading (kg/day)*	*Target TP Load Allocation (kg/yr)*	*Target TP Load Allocation (kg/day)*
Load Allocation				
Local NPS runoff, not including commercial, high density housing	44	0.12	42	0.12
Nonpoint source from backflooding of Quaboag*	54	0.15	13	0.04
Internal Loading	30	0.08	29	0.08
Septic System	42	0.12	40	0.11
Other	0	0	0	0
Waste Load Allocation				
Point source from backflooding of Quaboag*	8	0.02	2	0.01
Point source from local commercial, high density housing runoff (32% of 65)	21	0.06	20	0.06
Total Inputs	199	0.55	146	0.40

*The loading from backflooding is divided in this table to account for both point and nonpoint source contributions. Note that for purposes of NPDES permits the seasonal TMDL values should be used.

Table of Contents

LIST OF TABLES.

LIST OF FIGURES.

Programmatic Background and Rationale

Section 303(d) of the Federal Clean Water Act requires each state to (1) identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. TMDLs may also be applied to waters threatened by excessive pollutant loadings. The TMDL establishes the allowable pollutant loading from all contributing sources at a level necessary to achieve the applicable water quality standards. The TMDLs must account for seasonal variability and include a margin of safety (MOS) to account for uncertainty of how pollutant loadings may impact the receiving water's quality. This report will be submitted to the USEPA as a TMDL under Section 303d of the Federal Clean Water Act, 40 CFR 130.7. After public comment and final approval by the EPA, the TMDL will be used as a basis to develop future NPDES permit requirements for the Spencer wastewater treatment plant (WWTP) and for the Phase II stormwater permits for MassHighways and for the town of Spencer, and serve as a guide for future implementation activities. Information on watershed planning in Massachusetts is available on the web at http://www.mass.gov/dep/water/waterres.htm and further information on lake management is available from the publication "Eutrophication and Aquatic Plant Management In Massachusetts, Final Generic Environmental Impact Report" (Mattson et al., 2003) on the DCR web site http://www.mass.gov/dcr/waterSupply/lakepond/publications.htm

The proposed Total Maximum Daily Loads (TMDLs) for the two lakes are based on a yearlong (December, 2002-November, 2003) study of the lakes and inlet streams and discharges from the Spencer Wastewater treatment plant (WWTP). In addition, the loads are compared to Total Phosphorus loadings estimated from five different published lake models. A target concentration is selected for each pond and a yearly load of phosphorus is calculated for each lake. The phosphorus TMDL is established to control eutrophication and various plant management options are discussed. A total phosphorus TMDL is established to meet Massachusetts Surface Water Quality Standards, and to maintain a minimum of 4-foot visibility in both lakes and to maintain dissolved oxygen in the hypolimnetic bottom waters of Quacumquasit Pond during the summer. In many cases the State has limited authority to regulate nonpoint source pollution and thus successful implementation of this TMDL will require cooperative support from the public including lake and watershed associations, local officials and municipal governments in the form of education, funding and local enforcement. Additional funding support is available under various state programs including the DEP section 319 (nonpoint source grants) and the State Revolving Fund Program (SRF); see watershed grants listed in http://www.mass.gov/dep/water/finance.htm

Nutrient Enrichment: Nutrients are a requirement of life, but in excess can create problems. Lakes are ephemeral features of the landscape and over geological time most tend to fill with sediments and associated nutrients as they make a transition from lake to marsh to dry land. However, this natural successional ("aging") process can be and often is accelerated through the activities of humans—especially through development in the watershed. For highly productive lakes with developed watersheds, it is not easy to separate natural succession from "culturally induced " effects. Nonetheless, all feasible steps should be taken to reduce the impacts from cultural activities. The following discussion summarizes the current understanding of how nutrients influence the growth of algae and macrophytes, the time scale used in the studies, the type of models applied and the data collection methods used to create a nutrient budget. A brief description of the rationale for choosing a target load (the TMDL) as well as a brief discussion of implementation and management options is presented.

A detailed description of the current understanding of limnology (the study of lakes and freshwaters) and management of lakes and reservoirs can be found in Wetzel (1983), Cooke et al., (1993) and Holdren et al., 2001. To prevent cultural enrichment it is important to examine the nutrients required for growth of phytoplankton (algae) and macrophytes. The limiting nutrient is typically the one in shortest supply relative to the nutrient requirements of the plants. The ratio of nitrogen (N) to phosphorus (P) in both algae and macrophyte biomass is typically about 7 by weight or 16 by atomic ratio (Vallentyne, 1974). Examination of relatively high N/P ratios in water suggests P is most often limiting and careful reviews of numerous experimental studies have concluded that phosphorus is a limiting nutrient in most freshwater lakes (Likens, 1972; Schindler and Fee, 1974). Most diagnostic/feasibility studies of Massachusetts lakes also indicate phosphorus as the limiting nutrient. Even in cases where nitrogen may be limiting, previous experience has shown that it is easier, more cost-effective and more ecologically sound to control phosphorus than nitrogen. The reasons include the fact that phosphorus is related to terrestrial sources and does not have a significant atmospheric source as does nitrogen (e.g., nitrates in precipitation). Thus, non-point sources of phosphorus can be managed more effectively by best management practices (BMPs). In addition, phosphorus is relatively easy to control in point source discharges. Finally, phosphorus does not have a gaseous phase, while the atmosphere is a nearly limitless source of nitrogen gas that can be fixed by some blue-green algae, (i.e. cyanobacteria) which may result in toxic blooms. For all of the reasons noted above, phosphorus is chosen as the critical element to control freshwater eutrophication, particularly for algal dominated lakes or in lakes threatened with excessive nutrient loading.

There is a direct link between phosphorus loading and algal biomass (expressed as chlorophyll a) in algae dominated lakes (Vollenweider, 1976). The situation is more complex in macrophyte-dominated lakes where the rooted aquatic macrophytes may obtain most of the required nutrients from the sediments. In organic, nutrient rich sediments, the plants may be limited more by light or physical constraints such as water movement than by nutrients. In such cases, it is difficult to separate the effects of sediment deposition, which reduce depth and extend the littoral zone, from the effects of increased nutrients, especially phosphorus, associated with the sediments. In Massachusetts, high densities of aquatic macrophytes are typically limited to depths less than ten feet and to lakes where organic rich sediments are found (Mattson et al., 1998). Thus, the response of rooted macrophytes to reductions in nutrients in the overlying water will be much weaker and much slower than the response of algae or non-rooted macrophytes, which rely on the water for their nutrients. In algal or non-rooted macrophyte dominated systems nutrient reduction in the water column can be expected to control growth with a lag time related to the hydraulic flushing rate of the system. In lakes dominated by rooted macrophytes, additional, direct control measures such as harvesting, herbicides or drawdowns will be required to realize reductions in plant biomass on a reasonably short time scale. In both cases, however, nutrient control is essential since any reduction in one component (either rooted macrophytes or phytoplankton) may result in a proportionate increase in the other due to the relaxation of competition for light and nutrients. In addition, it is critical to establish a Total Maximum Daily Load so that future development around the lake will not impair water quality. It is far easier to prevent nutrients from causing eutrophication than to attempt to restore a eutrophic lake. The first step in nutrient control is to calculate the current nutrient loading rate or nutrient budget for the lake.

Nutrient budgets: Nutrient budgets and loading rates in lakes are determined on a yearly basis because lakes tend to accumulate nutrients as well as algal and macrophyte biomass over long time periods compared to rivers, which constantly flush components downstream. In cases of short retention time reservoirs (less than 14 days), nutrient budgets may be developed on a shorter time scale (e.g. monthly budgets from waste water treatment plants) but the units are expressed on a per year basis in order to be comparable to nonpoint sources estimated from landuse models. Nutrients in lakes can be released from the sediments into the bottom waters during the winter and summer and circulated to the surface during mixing events (typically fall and spring in deep lakes and also during the summer in shallow lakes). Nutrients stored in shallow lake sediments can also be directly used by rooted macrophytes during the growing season. In Massachusetts lakes, peak algal production, or blooms may begin in the spring and continue during the summer and fall while macrophyte biomass peaks in late summer. The impairment of uses is usually not severe until summer when macrophyte biomass reaches the surface of the water interfering with boating and swimming. Also, at this time of year the high daytime primary production and high nighttime respiration can cause large fluctuations in dissolved oxygen. In addition, oxygen is less soluble in warm water of summer as compared to other times of the year. The combination of these factors can drive oxygen to low levels during the summer and may cause fish kills. For these reasons the critical period for use impairment is during the summer, yet the modeling is done on a yearly basis.

There are three basic approaches to estimating current nutrient loading rates: the measured mass balance approach; the landuse export modeling approach; and modeling based on the observed in-lake concentration. The measured mass balance approach requires frequent measurements of all fluvial inputs to the lake in terms of flow rates and phosphorus concentrations. The yearly loading is the product of flow (liters per year) times concentration (mg/l), summed over all sources (i.e., all streams and other inputs) and expressed as kg/year. The landuse export approach assumes phosphorus is exported from various land areas at a rate dependent on the type of landuse. The yearly loading is the sum of the product of landuse area (Ha) times the export coefficient (in kg/Ha/yr). Using a model of in-lake phosphorus concentrations is an indirect method of estimating loading and does not provide information on the sources of input but can be used in conjunction with other methods to validate results. The mass balance method is generally considered to be more accurate, but also more time consuming and more costly due to the field sampling and analysis. For this reason, the mass balance results are used whenever possible. If a previous diagnostic/ feasibility study or mass balance budget is not available, then a landuse export model, such as Reckhow et al., (1980) or the NPSLAKE model (Mattson and Isaac, 1999) can be used to estimate nutrient loading.

Individual point sources phosphorus loadings are determined from the most recent National Pollutant Discharge Elimination System (NPDES) data reported in the Discharge Monitoring Reports (DMRs) for the site and checked against independently collected data. In many cases the permits are written with seasonal limits and the more stringent permit requirements are established during the non-winter months when both use and impairments are greatest. Generally, the impoundments downstream of NPDES discharges have short residence times and thus May-October data are used to compute total phosphorus loads based on actual measured flow times concentrations. If the discharge is immediately to a lake via a pipe, channel or short stream segment, then no phosphorus uptake is assumed. That is, the lake is assumed to receive 100 percent of the discharge. For lakes or reservoirs located further downstream, retention in each lake is calculated and in some cases, uptake or other retention by plants may be calculated based on best available information from previous research on the pond. Thus, the TMDL reflects the amount of phosphorus that is predicted to actually reach the lake in question.

Target Load: Once the current nutrient loading rate is established, a new, lower rate of nutrient loading must be established which will meet surface water quality standards for the lake. This target load or TMDL can be set in a variety of ways. Usually a target concentration in the lake is established and the new load must be reduced to achieve the lower concentration. This target nutrient concentration may be established by a water quality model that relates phosphorus concentrations to water quality required to maintain designated uses or specific water quality standards, such as the minimum visibility Public Health criterion at Massachusetts swimming beaches (historically set at 4 feet visibility). Alternatively, the target concentration may be set based on concentrations observed in background reference lakes for similar lake types or from concentration ranges found in lakes within the same ecological region (or sub-ecoregion). In cases of impoundments or lakes with rapid flushing times (e.g., less than 14 days), somewhat higher phosphorus targets may be used because the planktonic algae and nutrients are rapidly flushed out of the system and typically do not have time to grow to nuisance conditions in the lake or accumulate in the sediments.

Various models (equations) have been used for predicting productivity or lake total phosphorus concentrations in lakes from analysis of phosphorus loads. These models typically take into consideration the waterbody's hydraulic loading rate and some factor to account for settling and storage of phosphorus in the lake sediments. Among the more well known metrics are those of Vollenweider (1975), Kirchner and Dillon (1975), Chapra (1975), Larsen and Mercier (1975) and Jones and Bachmann (1976). The TMDL must account for the uncertainty in the estimates of the phosphorus loads from the sources identified above by including a "margin of safety". The margin of safety can be specifically included, and/or included in the selection of a conservative phosphorus target, and/or included as part of conservative assumptions used to develop the TMDL.

After the target TMDL has been established, the allowed loading of nutrients is apportioned to various sources that may include point sources as well as private septic systems and various land uses within the watershed. In Massachusetts, few lakes receive direct point source discharges of nutrients. In cases where large point sources exist upstream of a lake or impoundment, the point source will in most cases be required to use the Highest and Best Practical Treatment (HBPT) to reduce total phosphorus loading. The current loads for NPDES point sources are calculated based on current DMR data, not on the permitted discharge loading. New discharge limits at the treatment plant may be computed based on the percent reduction of current loads estimated by DMR reports. The new permitted concentrations of total phosphorus can then calculated based on total mass loading divided by permitted flow rate for the discharge.

The nutrient source analysis generally will be related to landuse that reflects the extent of development in the watershed. This effort can be facilitated by the use of geographic information systems (GIS) digital maps of the area that can summarize landuse categories within the watershed. The targeted reductions must be reasonable given the reductions possible with the best available technology and Best Management Practices (BMPs). The first scenario for allocating loads will be based on what is practicable and feasible for each activity and/or landuse to make the effort as equitable as possible.

Implementation: The implementation plan or watershed management plan to achieve the TMDL will vary from lake to lake depending on the type and degree of development. While the impacts from development cannot be completely eliminated, they can be minimized by prudent "good housekeeping" practices, known more formally as best management practices (BMPs). Among these BMPs are control of runoff and erosion, well-maintained subsurface wastewater disposal systems and reductions in the use of fertilizers. Activities close to the waterbody and its tributaries merit special attention for following good land management practices. In addition, there are some statewide efforts that provide part of an overall framework. These include the legislation that curbed the phosphorus content of many cleaning agents, revisions to regulations that encourage better maintenance of subsurface disposal systems (Title 5 Septic systems), and the Rivers Protection Act that provides for greater protection of land bordering waterbodies. In some cases, structural controls, such as detention ponds, may be used to reduce pollution loads to surface waters.

Although the landuse approach gives an estimate of the magnitude of typical phosphorus export from various landuses, it is important to recognize that nonpoint phosphorus pollution comes from many discrete sources within the watershed. Perhaps the most common phosphorus sources in rural areas are leaching from failed or inadequate septic systems; phosphorus associated with soil erosion and use of phosphorus lawn fertilizers. Soils tend to erode most rapidly following soil disturbances such as construction, gravel pit operations, tilling of agricultural lands, overgrazing, and trampling by animals or vehicles. A common problem with erosion in rural areas is erosion from unpaved roads. Soils may also erode rapidly where runoff water concentrates into channels and erodes the channel bottom. This may occur where impervious surfaces such as parking lots direct large volumes of water into ditches which begin to erode and may also result from excessive water drainage from roadways with poorly designed ditches and culverts. Any unvegetated drainage way is a likely source of soil erosion.

Discrete sources of nonpoint phosphorus in urban, commercial and industrial areas include a variety of sources that are lumped together as 'urban runoff' or 'stormwater' and may be considered as point sources under wasteload allocations in the tables below. As many of these urban sources are difficult to identify the most common methods to control such sources include reduction of impervious surfaces, street sweeping and other best management practices as well as treatment of stormwater runoff in detention ponds or other structural controls.

Other sources of phosphorus include phosphorus based lawn fertilizers used in residential areas, parks, cemeteries and golf courses and fertilizers used by agriculture. Manure from animals, especially dairies and other confined animal feeding areas is high in phosphorus. In some cases the manure is inappropriately spread or piled on frozen ground during winter months and the phosphorus can leach into nearby surface waters. Over a period of repeated applications of manure to local agricultural fields, the phosphorus in the manure can saturate the ability of the soil to bind phosphorus, resulting in phosphorus export to surface waters. In some cases, cows and other animals including wildlife such as flocks of ducks and geese may have access to surface waters and cause both erosion and direct deposition of feces to streams and lakes.

Perhaps the most difficult source of phosphorus to account for is the phosphorus recycled within the lake from the lake sediments. In most north temperate lakes, phosphorus that accumulated in the bottom waters of the lake during stratification is mixed into surface waters during spring and fall turnover when the lake mixes. Phosphorus release from shallow lake sediments may be a significant input for several reasons. These reasons include higher microbial activity in shallow warmer waters that can lead to sediment anoxia and the resultant release of iron and associated phosphorus. Phosphorus release may also occur during temporary mixing events such as wind or powerboat caused turbulence or bottom feeding fish, which can resuspend phosphorus rich sediments. Phosphorus can also be released from nutrient 'pumping' by rooted aquatic macrophytes as they extract phosphorus from the sediments and excrete phosphorus to the water during seasonal growth and senescence (Cooke et al., 1993; Horne and Goldman, 1994). Shallow lakes also have less water to dilute the phosphorus released from sediment sources and thus the impact on lake water concentrations is higher than in deeper lakes.

The most important factor controlling macrophyte growth appears to be light (Cooke et al., 1994). Due to the typically large mass of nutrients stored in lake sediments, reductions in nutrient loadings by themselves are not expected to reduce macrophyte growth in many macrophyte-dominated lakes, at least not in the short-term. In such cases additional in-lake control methods are generally recommended to directly reduce macrophyte biomass. Lake management techniques for both nutrient control and macrophyte control have been reviewed in "Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report" (Mattson et al., 2004, http://www.mass.gov/dcr/waterSupply/lakepond/publications.htm). The Massachusetts Department of Environmental Protection will support in-lake remediation efforts that is cost-effective, long-term and meet all environmental concerns, however, instituting such measures will be aided by continued Federal support via EPA and State support.

Financial support for implementation is potentially available on a competitive basis through both the non-point source (319) grants and the state revolving fund (SRF) loan program. The 319 grants require a 40 percent non-federal match of the total project cost although the local match can be through in-kind services such as volunteer efforts. Other sources of funding include the 604b Water Quality Management Planning Grant Program, the Community Septic Management Loan Program. Information on these programs is available in a pamphlet "Grant and Loan Programs – Opportunities for Watershed Protection, Planning and Implementation" through the Massachusetts Department of Environmental Protection, Bureau of Resource Protection; see also http://www.mass.gov/dep/water/finance.htm

Since the lake restoration and improvements can take a long period of time to be realized, follow-up monitoring is essential. This can be accomplished through a variety of mechanisms including volunteer efforts. Recommended monitoring may include Secchi disk readings, lake total phosphorus, macrophyte mapping of species distribution and density, visual inspection of any structural BMPs, coordination with Conservation Commission and Board of Health activities and continued education efforts for citizens in the watershed.

Waterbody Descriptions and Problem Assessment

Quaboag Pond and Quacumquasit Pond are two adjacent waterbodies in the Chicopee Basin of Massachusetts. Although next to each other, the two ponds are very different, one being nutrient rich, the other nutrient poor. Quaboag is a warmwater fishery with nutrient rich shallow waters fed by a large watershed. In contrast, Quacumquasit is a deep, clear, coldwater fishery with a small watershed and no permanent flowing inlets. More detailed descriptions are given below.

Quaboag Pond

Quaboag Pond in Brookfield/East Brookfield is a large 540-acre natural pond with a maximum depth of only 14 feet and a short annual retention time of about 12 days. The main inlet of the pond is the East Brookfield River and the outlet is the Quaboag River. The watershed is 60 percent forested. Rural landuse accounts for about 25 percent that includes agricultural (14%), low density residential housing (7%) and some open land. About 9 percent of the watershed consists of water and wetlands. The remainder of the watershed is composed of high-density residential housing (4%) and some commercial-industrial land (2.5%). The north and east shorelines are developed with housing (see Figure 1 below). A numbers of cemeteries including Green Hollow Cemetery, Southwest Cemetery and Pine Grove Cemetery, several campgrounds, the Moose Hill Wildlife Management Area, Spencer State Forest as well as some sand pits/sand and gravel pits are within the rather large watershed. Segments of Route 9, Route 31, Route 122 and small section of Route 56 all crosses the watershed. Population in Brookfield ranged between 2,397 and 2,968 from 1980 to the 1990 census. The University of Massachusetts (MISER) predictions on growth are 3,152 for the year 2000 and 3,566 for the year 2010 with an estimated 20-year growth rate of about 20 percent. Population in East Brookfield ranged between 1,955 and 2,033 from 1980 to the 1990 census. MISER predictions on growth are 2,163 for the year 2000 and 2,198 for the year 2010 with an estimated 20-year growth rate of about 8 percent.

Table 2. Quaboag Pond Characteristics.

Quaboag Pond Characteristics		
Lake area	2,200,000 m^2	540 acres
Max. Depth	4.25 m	14 feet
Mean Depth	2.03m	6.6 feet
Volume	4,460,000 m^3	3,590 acre-feet
Retention time	12 days (annual)	19-43 days (summer)
Watershed area (includes pond)	19867 Ha	76.7 sq. mi.

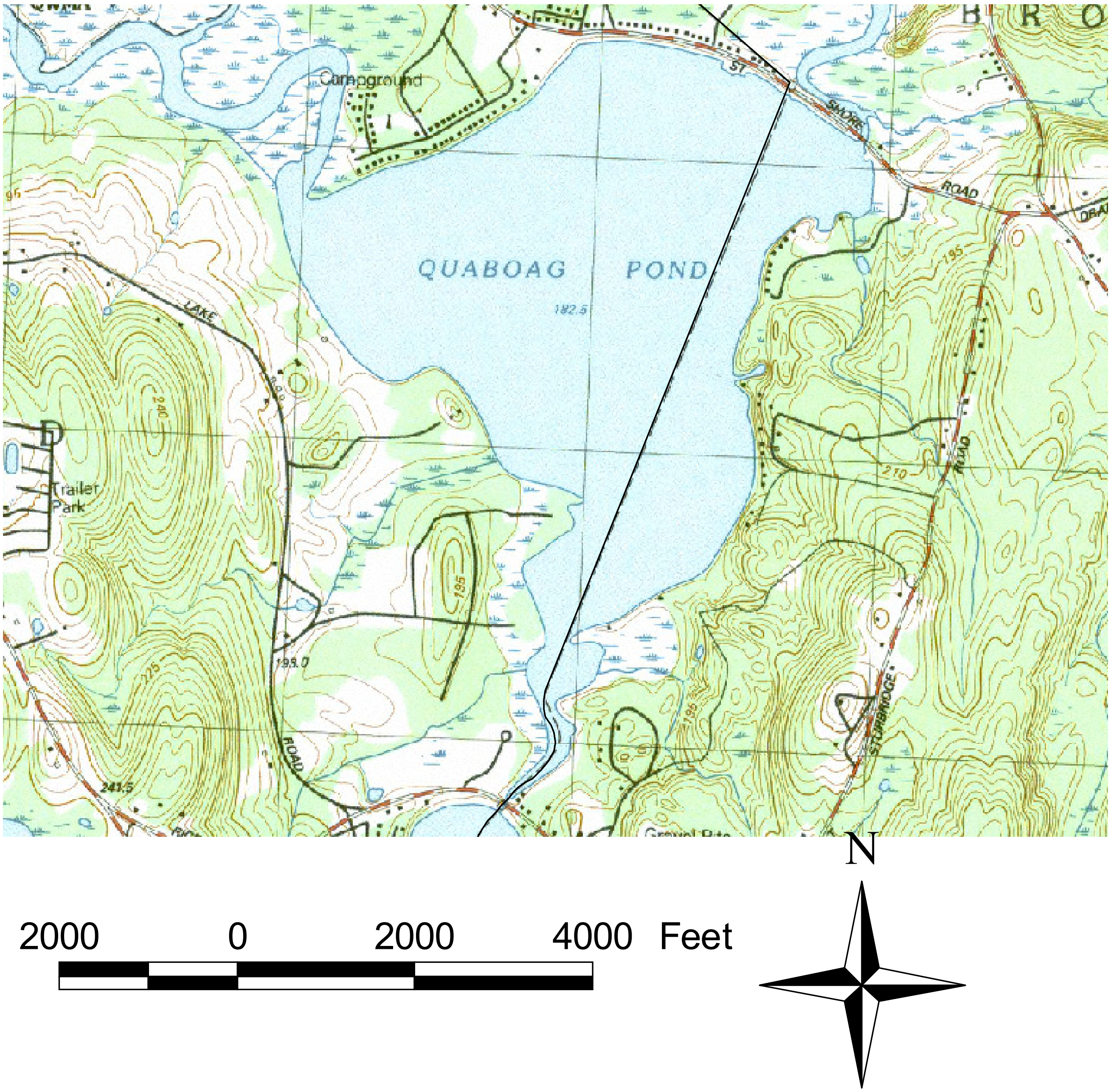


Figure 1. Quaboag Pond Environs.

Quaboag Pond has a long history of nutrient related impairment of recreation. The D/F study of 1986 noted a high weighted average total phosphorus concentration at the inlet to Quaboag Pond of 71 ppb. Much of the phosphorus at the time was coming from the Spencer WWTP that at the time was discharging 45% of the total phosphorus loading to the pond. The WWTP had no specific total phosphorus limit in the discharge permit but was estimated to discharge 3.25 mg/l. In the 1980's the pond itself had an average TP concentration of about 45 ppb and a summer Secchi disk transparency of about 1.25 m with some readings below the swimming target of four feet (1.2 m). The study noted some surface scums of bluegreen algae (cyanophytes) at times. The high turbidity was apparently limiting the extent of rooted macrophytes to a depth less than 2m as noted in the BEC (1986) study. The ESS (2000) report notes that after the upgrades to the Spencer WWTP between 1987 and 1990 the concentrations in Quaboag Pond dropped from about 0.045mg/l to 0.020mg/l. The pond also shows signs of high sedimentation, particularly in the area near the East Brookfield River inlet to the pond, were water depths are now so shallow it is difficult to maneuver motor boats in this area. Control of sedimentation (which is often associated with total phosphorus) is called for in this TMDL even though the pond is not currently listed as impaired specifically by sediments.

Quacumquasit Pond

Quacumquasit Pond (also known locally as South Pond) is located just to the south of Quaboag Pond, in the towns of Brookfield, East Brookfield and Sturbridge. Quacumquasit Pond is a large (225 acre) and deep (74 feet) natural pond with essentially no permanent inlets and an outlet to the interbasin connector that is partially regulated by a backflood control gate at the north end of the pond. The watershed is 55 percent forested (Figure 2). Water and wetlands account for about 21 percent of the watershed. Approximately 16 percent is in the rural category most of which consists of low-density residential housing (11%), some open space (about 3%) and little agricultural land (2%). The rest of the watershed consists of urban land that includes mostly high-density residential housing (about 8%) and commercial-industrial landuse (1%). Camp Day and several gravel pits are within the watershed. Populations in the towns of Brookfield and East Brookfield have been stated above. Population in the town of Sturbridge ranged between 5,976 and 7,775 from 1980 to the 1990 census. Miser predictions on growth are 8,133 for the year 2000 and 9,091 for the year 2010 with an estimated 20-year growth rate of about 17 percent.

Table 3. Quacumquasit Pond Characteristics.

Quacumqausit Pond Characteristics		
Lake area	911,000 m^2	225 acres
Max. Depth	22.5 m	74 feet
Mean Depth	9.24m	30.3 feet
Volume	8,330,000 m^3	6,800 acre-feet
Retention time	1.46 years	534 days
Watershed area	454. Ha	1.8 sq. mi.

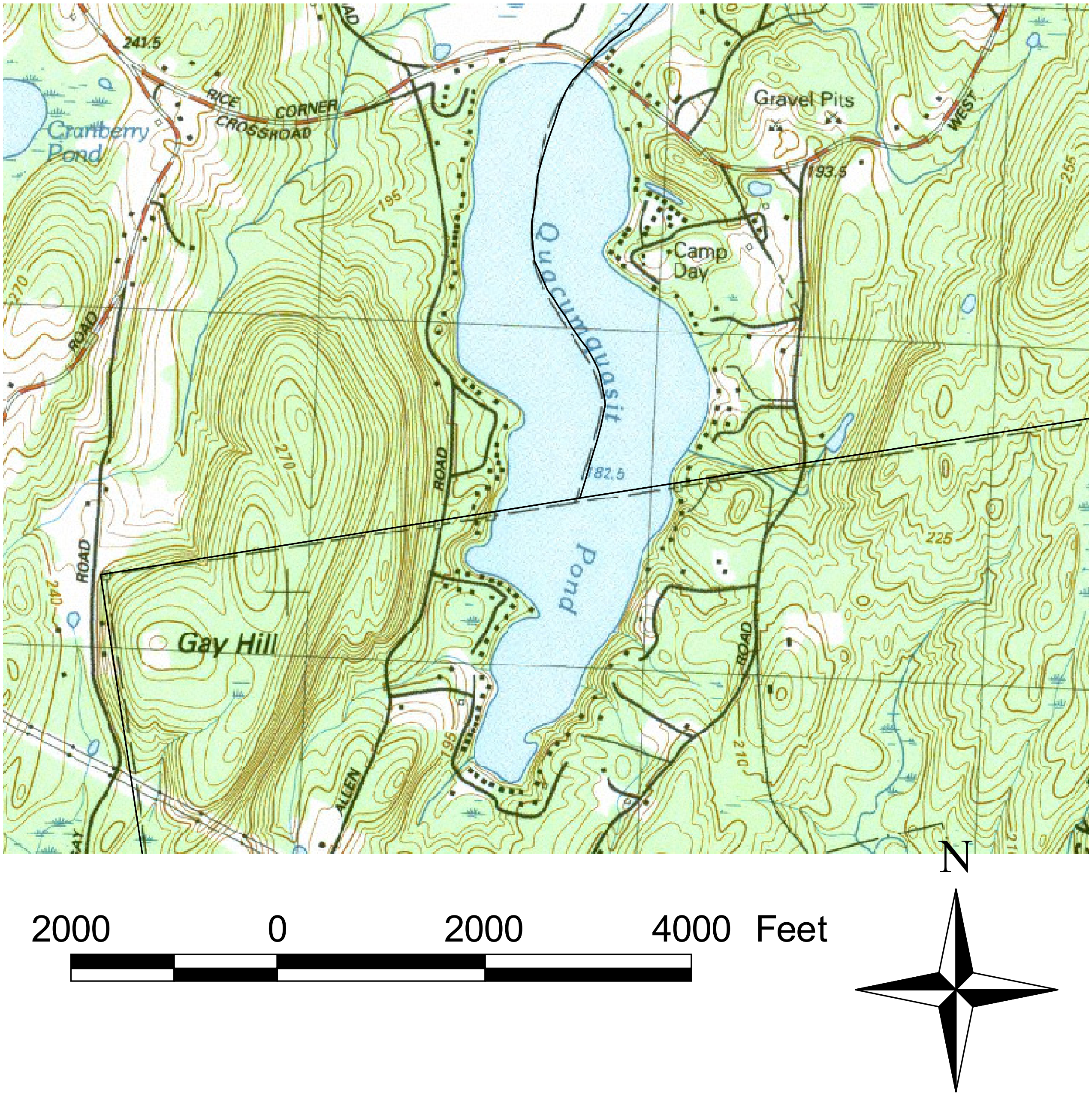


Figure 2. Quacumquasit Pond Environs.

The history of the ponds is detailed in the 1986 Diagnostic/Feasibility (D/F) study of the ponds (BEC, 1986) which notes the interbasin connector was deepened and widened sometime after the mid-1800's and again in the mid-1960's. While this allowed boat traffic between the ponds it also allowed a greater degree of floodwaters from the Quaboag Pond to enter into Quacumquasit Pond in a process known as backflooding as the floodwaters reverse the flow of the outlet of Quacumquasit Pond. Unfortunately, this also allowed nutrients associated with the floodwaters to enter the relatively clear waters of Quacumquasit Pond.

The BEC (1986) reported with no gate backflows occur 17% of the time, which account for 4.56 million m^3 of water enter Quacumquasit from Quaboag backflows annually in the absence of a flow controls (and that was in a relatively dry year). This also accounted for an estimated 205 kg of phosphorus loading from Quaboag to Quacumquasit Pond that at the time accounted for about 53% of the total load.

The 4.5 foot high gate was installed in July of 1991. However, the gate was installed with a maximum elevation at the top of the gates of only 599.5 feet (above sea level) compared to normal water levels of about 598.75 feet from the USGS topographic map. Thus the present gate can normally hold back only 0.75 feet of additional floodwater above median water levels. As noted in the Lycott (1994) report, the gates were successful at reducing late spring, summer and fall flow reversals (with the gate being left open winter and early spring), and in mid-1993 the order was amended to focus on spring flow reversals while attempting to leave the gate open in summer to minimize interference with boat traffic. Lycott (1994) also noted that the gate prevented backflows 22% of the time in 1992 (a wet year) and 6% of 1993 (a dry year) until it was closed in October of 1993. Lycott (1994) concluded the gate prevented 63% of the flow reversals during the post construction monitoring period. However, the largest flows occurred in early spring when the gate was left open, and because the gate was overtopped on several occasions the percentage of water stopped was less than 63%; perhaps roughly half of the back flooding was stopped. This combined with lower concentrations of total phosphorus in Quaboag (due to improvements in the Spencer WWTP and other inputs) resulted in an estimated 41% reduction in phosphorus loading or an estimated load of 84 kg of phosphorus.

In a personal communication of November of 2002 Carl (Skip) Nielsen Sr. said the gate is closed Nov. 15 through ice out in spring (and flows over top during winter) and closed any time there is a backflow but noted the current gatekeeper may decide not to close the gate if a lot of boats are about on a weekend and thus, some backflooding occurs thru the open gates. At other times, particularly in spring the gates may be overtopped and result in a backflood. Mr. Nielsen noted the last couple of years (2001 and 2002) were dry with no overflows over the top of the gate.

Some of the backflooding reported in the BEC (1986) report was due to drawdown of Lake Lashaway and subsequently the operating procedures were changed to regulate the flow out of Lashaway by opening the gates over a seven day period beginning with 4 inches on Nov. 1st and progressively increasing the gate opening daily to reach 22 inches (one half open) by Nov. 7 and 24 inches open after that with a note that in case of rainy weather the gate may have to be closed to 4 inches to avoid impacts on downstream environment. The order of conditions has expired and the Town of East Brookfield should reapply for a new Order of Conditions which should include a slower release of water (initially opening to a maximum of 22 inches over 10 day period) and include a requirement to contact the South Pond gatekeeper prior to starting drawdown and more specific language stating that in the event of rainfall of .2 inch or more the gates should be closed to a maximum of 4 inches and consult with the South Pond gatekeeper to ensure no backflooding to South Pond is occurring before opening further.

It was also noted in the management recommendations of BEC(1995) that the then present operation of the gate 'may be ineffective at addressing the loading of South Pond with nutrients and plant fragments'; and that more frequent monitoring and immediate closing of the gate may reduce nutrient levels (BEC, 1995).

Historically, backflooding contributed to the high phosphorus concentrations in Quacumquasit Pond. Quacumquasit Pond had total phosphorus concentrations, averaging 33ppb over the year and 22 ppb for the mid-summer period (mid-June thru mid-September) of 1984. The Secchi disk transparency averaged 3.5 m in 1984 with some values as high as 4.6 m in mid-summer. The pond had chlorophyll a concentrations that were slightly less than 10 ppb (some higher values may have been lab errors or due to flow reversals (BEC, 1986). The ESS (2000) report notes the after the upgrades to the Spencer WWTP between 1987 and 1990 and following the installation of the flood control gate the TP concentrations fell to 0.012 mg/l in Quacumquasit Pond in 1992.

Spencer Wastewater Treatment Plant

Years ago the Spencer WWTP was a major source of nutrients to both Quaboag and Quacumquasit Ponds but today it is a relatively minor source. The BEC (1986) D/F study recommended a number of actions including an upgrade to the Spencer WWTP and the installation of a flow reversal gate at the outlet of Quacumquasit Pond and these improvements were all implemented. The Spencer treatment plant has a NPDES permit (MA0100919) with a permit final effluent flow rate of 1.08 MGD (million gallon per day) and growing season TP limit of .2 mg/l (1.8 lbs/day) and winter limits of 0.75 mg/l (6.8 lbs/day) with an overall permitted load of 708 kg/yr (1,563 lbs/yr) although they are operating under an interim Total Phosphorus growing season limit of 0.3 mg/l pending results of an optimization study (i.e. optimizing the use of chemicals such as aluminum to remove phosphorus). Figure 3 shows the decline in the concentration of the Spencer WWTP effluent over the years. It should be noted that influent to the plant may be higher (in the study year it was 0.86 MGD). During the study year about 43% of the total flow is lost, presumably to groundwater infiltration in the final constructed wetlands and thus the final effluent flow averaged 0.49 MGD (0.76 cfs) and that is discharged to Cranberry Brook. Recent reports suggest most of the P load to the downstream ponds is not due to the treatment plant, but rather is from nonpoint sources in the watershed. ESS completed a NPS study that sampled and modeled TP and other pollutants in the Quaboag sub-basin (ESS, 2001).

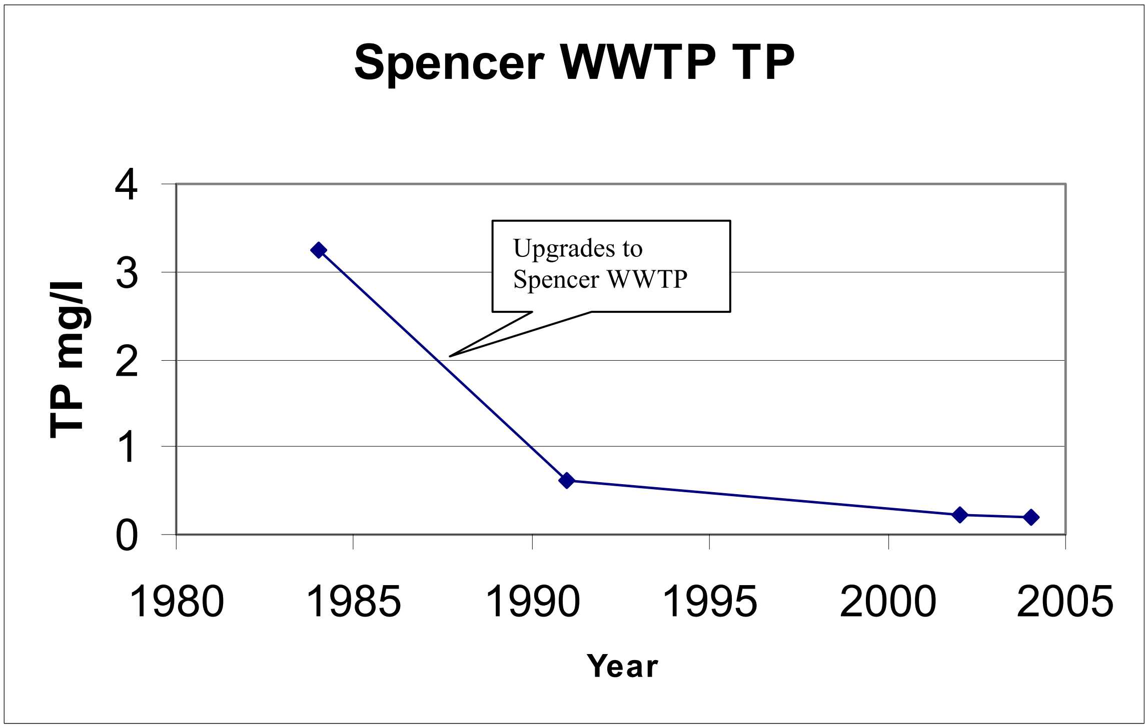


Figure 3. Trend in Total Phosphorus in effluent of Spencer WWTP.

Both lakes have seen deceases in total phosphorus concentrations and increases in transparency, however, bluegreen cyanobacteria blooms have continued to occur on Quaboag Pond (and to a lesser extent on Quacumquasit Pond) and Quaboag has experienced an expansion of submersed rooted plant growth out to a depth of about 9 feet as a result of the improved light penetration. In addition the aluminum flood control gate was installed at the outlet to Quacumquasit Pond, which appeared to further reduce nutrient concentrations in Quacumquasit, but did not eliminate the problem of backflooding entirely (Lycott, 1994).

Although the lakes were not officially listed as impaired by nutrients on the 2002 Integrated List, in 2003 the Department began a 12-month study of the lake in preparation to develop a protective total phosphorus TMDL in response to concerns about continuing nutrient loads from the Spencer WWTP. The focus of the study is to determine how much phosphorus input to the ponds comes from point sources vs. nonpoint sources and how to reduce the sources to meet a target in-lake concentration. The discharge from the Spencer WWTP is complicated by the fact that about half of the discharge is lost to groundwater in the constructed wetlands and further retention of phosphorus might occur in wetlands enroute to the pond. The study was designed to determine total phosphorus loads to the lakes with an emphasis on estimating the proportion of the load to Quaboag that is due to the Spencer WWTP (particularly during the summer period) and what proportion of the load to Quacumquasit is due to the backflooding past the flood control gate either when it is left open or when it is overtopped. The Town of Spencer also has a MS4 NPDES stormwater discharge permit (MAR041162) and has stormwater discharges to streams tributary to Quaboag Pond.

Water Quality Standards Violations:

Quaboag Pond and Quacumquasit Pond are both listed on the Massachusetts 2002 Integrated List of waters as category 5, for not meeting uses and requiring a TMDL or Metals (mercury in fish tissue) as well as for Exotic Species. Quaboag Pond will be listed in the 2004 Integrated list for excessive nutrient and noxious aquatic plants. The recent blue-green (cyanobacteria) blooms in both ponds provide ample justification for issuing a protective TMDL for phosphorus. The Water Quality Standards are described in the
Code of Massachusetts Regulations under sections:

314CMR 4.04 subsection 5:
(5) Control of Eutrophication. From and after the date 314 CMR 4.00 become effective there shall be no new or increased point source discharge of nutrients, primarily phosphorus and nitrogen, directly to lakes and ponds. There shall be no new or increased point source discharge to tributaries of lakes or ponds that would encourage cultural eutrophication or the growth of weeds or algae in these lakes or ponds. Any existing point source discharge containing nutrients in concentrations which encourage eutrophication or growth of weeds or algae shall be provided with the highest and best practical treatment to remove such nutrients. Activities which result in the nonpoint source discharge of nutrients to lakes and ponds shall be provided with all reasonable best management practices for nonpoint source control.

and

> 314CMR 4.05 (3) b: "These waters are designated as a habitat for aquatic life, and wildlife, and for primary and secondary contact recreation...These waters shall have consistently good aesthetic value.
>
> 1. Dissolved Oxygen:
>
> a. Shall not be less than 6.0 mg/l in cold water fisheries nor less than 5.0 mg/l in warm water fisheries unless background conditions are lower;
>
> b. natural seasonal and daily variations above this level shall be maintained…

and

> 314CMR 4.05 (5)(a) Aesthetics - All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life.

and 314CMR 4.05 (5)(c) Nutrients - Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication (also, see 314 CMR 4.04(5)).

Section 314 CMR 4.40(3) subsection 6 also states:

> 6. Color and Turbidity - These waters shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this class.

In addition, the Minimum Standards for Bathing Beaches established by the Massachusetts Department of Public Health which state that swimming and bathing are not permitted at public beaches when there is a lack of water clarity.

Lake Water Quality Monitoring Methods

The current conditions of the lakes were monitored for one year beginning December, 2002 as part of a baseline survey to determine how conditions may have changed since the earlier BEC(1986) report. The baseline survey consisted of monthly sampling of the deep station at each pond and the baseline survey was conducted in conjunction with the Quaboag mass balance nutrient budget survey sampling of flow and stream concentrations (see below). The baseline survey included Secchi disk transparency, chlorophyll a as an indicator of planktonic algal biomass, apparent color and total phosphorus. During the summer an aquatic plant survey was conducted as during the late summer a multiprobe profile of dissolved oxygen, temperature, conductivity and pH was determined. Sampling details are available in the Quality Assurance Project Plan (DWM, 2003). Full results will be available in the draft Technical Memo after appropriate data quality review. Additional grab samples were collected in the summers of 2004 during a large blue-green cyanobacterial bloom on Quaboag Pond and during 2005 prior to and after copper treatments to control cyanobacterial blooms.

Results of Monitoring Quaboag Pond

In late summer of 2003 the dissolved oxygen (DO) and temperature profile showed Quaboag Pond was weakly stratified near the bottom. The DO showed minor supersaturation at the surface, but DO was depleted to near zero by 2.5 meters as shown in Figure 4. Thus, it appears there is some potential for anaerobic phosphorus release from the sediment in Quaboag Pond during periods of stratification. In comparison, during the year of the BEC(1986) study the lake was typical unstratified for most of the summer and varied considerably in DO concentration at the bottom, again indicating periods of anoxia followed by mixing are likely. Total phosphorus for surface waters ranged from 0.014 mg/l in April, to 0.029 in June 2003, to 0.060mg/l in September 2003 with a summer (June-September) average of about 0.043 mg/l. These concentrations were somewhat higher than that reported in the 1990's as noted above. The apparent color of Quaboag Pond ranges between 60 and 75 PCU (platinum cobalt units), which is moderately colored and suggests upstream wetlands contribute dissolved organic carbon to the water and may limit light penetration. Chlorophyll a concentrations ranged from 10.2ppb in June to 35.1 and 32.8 in August and September, respectively, with a summer average of 23.7ppb. Such high values are bordering on hypereutrophic conditions. Secchi disk for the year 2003 followed a pattern of fairly clear water (2.9m Secchi) observed during early spring with more turbid conditions (0.8m Secchi) by September. This pattern is also seen in past years data. The overall summer (June-September) trend as shown in Figure 5 suggests a slight improvement in Secchi disk transparency from about 1.25 m in 1984. Secchi disk transparency appears to be fairly stable from 1995 up to the present average of 1.45m.

Quaboag Pond has become invaded by exotic plants and plant density overall has increased dramatically as well as expanded into deeper water since the BEC (1986) report. Back in the 1980's the lake was dominated by a mix of native pondweeds, tapegrass and milfoil species, but these were restricted to depths of less than 2 m and the BEC (1986) report noted there was a probably a shallow compensation point (due to light limitation and reduced transparency). The current plant community is much more dense in both percent coverage (percent of lake bed area covered by plants) and in biovolume (percent of lake volume at sample point filled by plants) and the plant beds now extend out to nearly 3m (10 foot contour) as shown in Figures 6, 7 and 9. The lake also has large populations of exotic Eurasian milfoil (M*yriophyllum. spicatum*) and fanwort (*Cabomba carolinina)*, as shown in Figure 8. During the year of study the milfoil (and Najas in the western part) became dense enough in July that it required frequent cleaning of the outboard motor to traverse the pond although conditions improved by August.

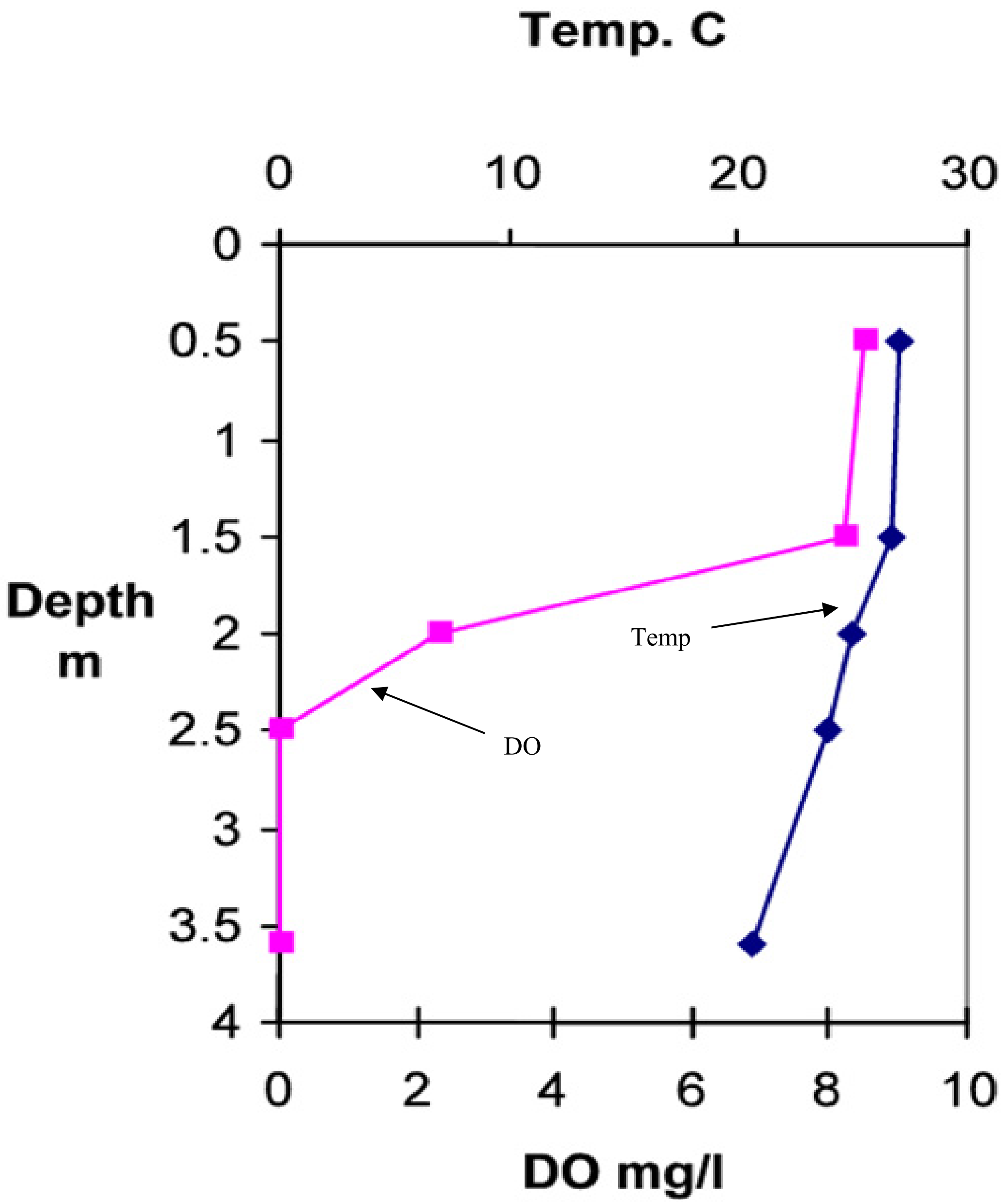


Figure 4. Quaboag Pond DO and Temperature 8/20/03.

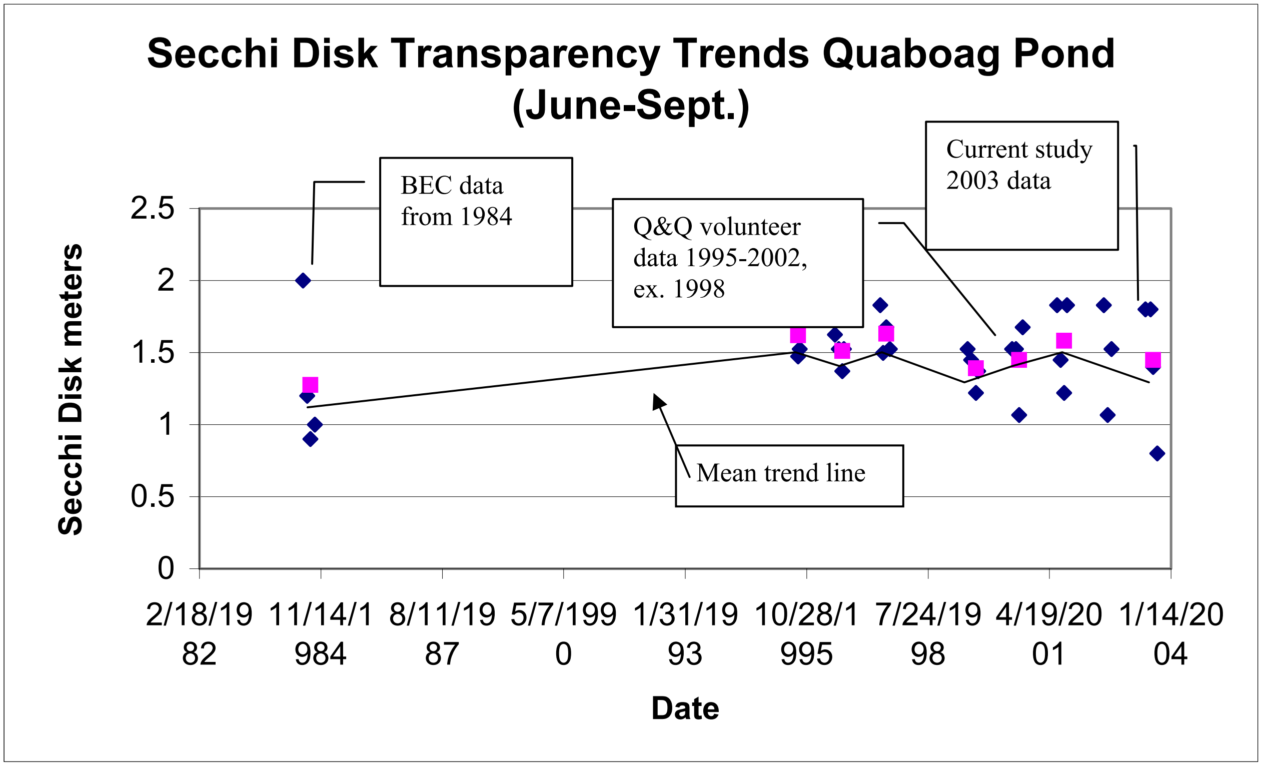


Figure 5. Secchi Disk June-Sept. trends in Quaboag Pond.

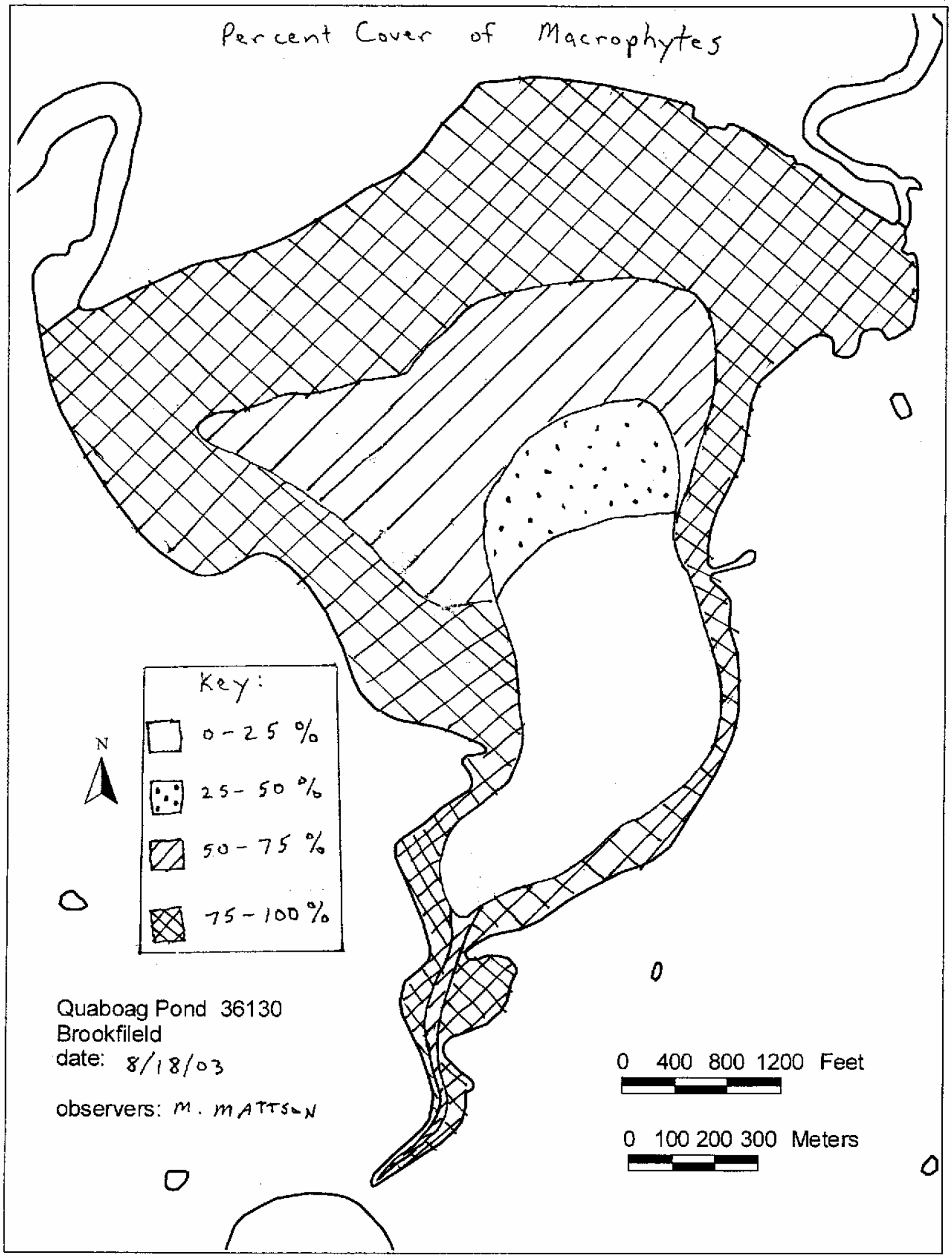


Figure 6. Quaboag Pond Macrophyte distribution (2003).

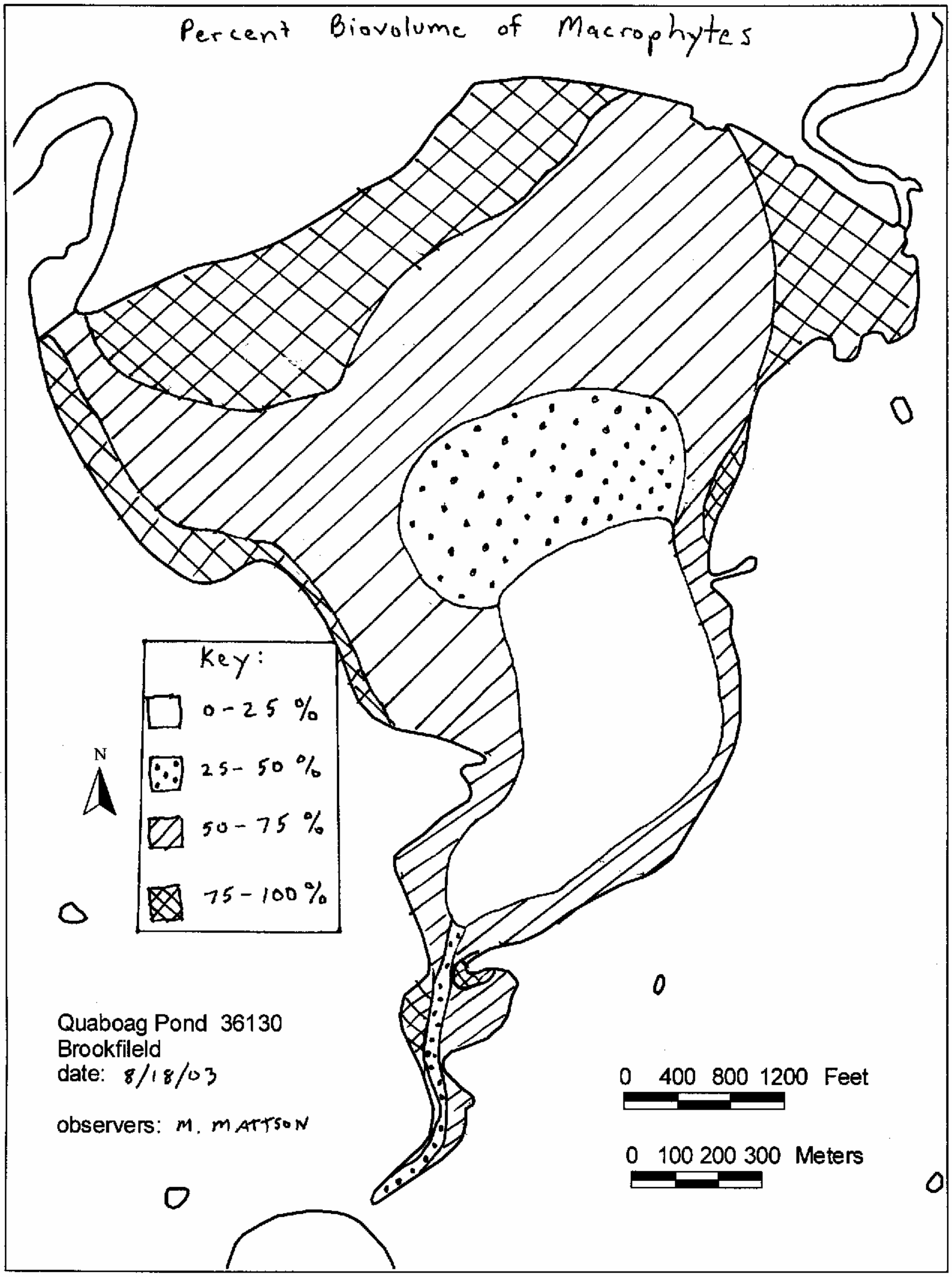


Figure 7. Quaboag Pond Percent Biovolume Map.

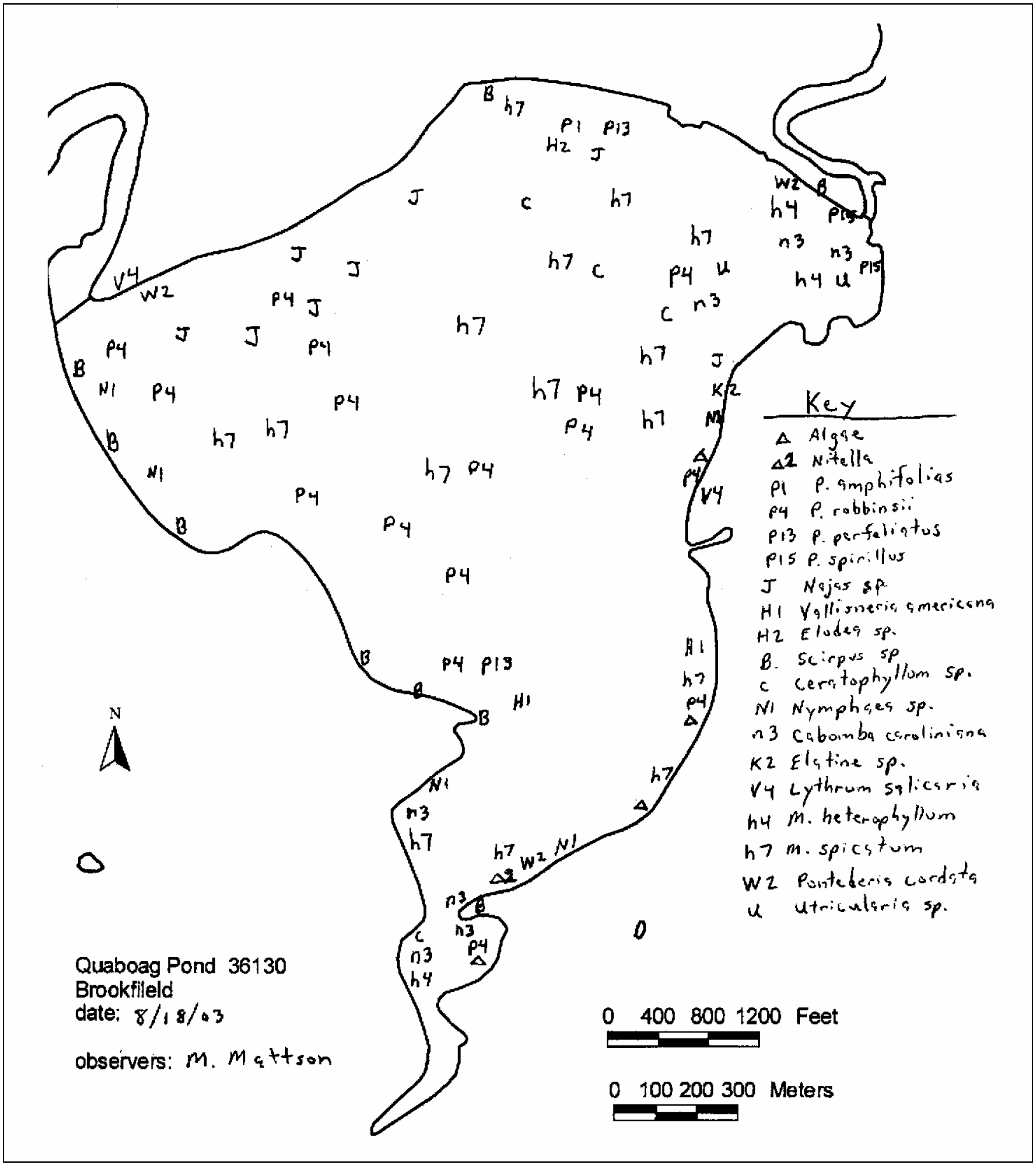


Figure 8. Quaboag Pond Macrophyte Species distribution (2003).

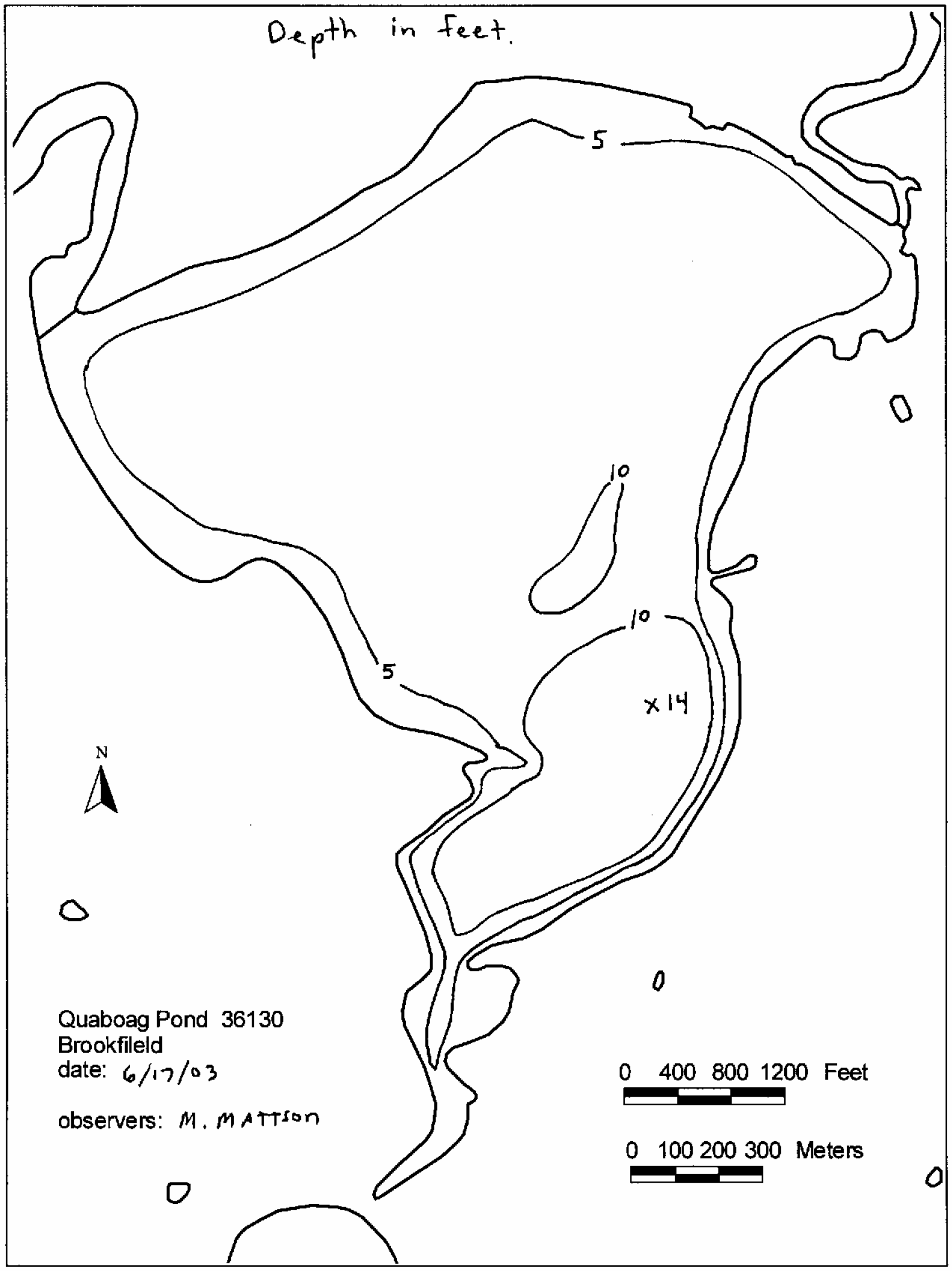


Figure 9. Quaboag Pond Depth map (2003).

Results of Monitoring Quacumquasit Pond

In late summer of 2003 the dissolved oxygen (DO) and temperature profile showed Quacumquasit Pond was thermally stratified with the epilimnion extending to just below 4 meters and the DO profile showed a slight supersaturation in the thermocline but then quickly dropped to near zero at 18 meters as shown in Figure 10. It was estimated by interpolation that the trout space (waters less than 20C and greater than 6mg/l DO) was approximately 3.0 meters between 8.1 and 5.1 meters depth. This is an improvement from the 1.5m of trout space estimated from historic profiles in BEC(1986) on the same day of the year. Total phosphorus ranged between 0.007 and 0.018 mg/l with an average of 0.012 mg/l and no clear seasonal pattern. While current oxygen concentrations are satisfactory to maintain a trout population, there have been reports of minor surface blue-green (cyanobacterial) blooms on occasion and there is a desire to further reduce the total phosphorus concentrations in the pond. Chlorophyll a concentrations ranged from 5.1 to 10.6 ug/l that are more typical of a mesotrophic lake and these high levels are difficult to explain given the transparent waters and low total phosphorus concentrations. Apparent color in Quacumquasit Pond is very low during summer months, typically ranging from not detectible (<15) to 19 PCU. This is typical for seepage lakes with few wetlands in the watershed. Plant surveys were not conducted on Quacumquasit Pond as part of this study because macrophytes were not believed to be impairing any uses on the pond. The pond has been treated with herbicides in the past to control patches of Eurasian milfoil.

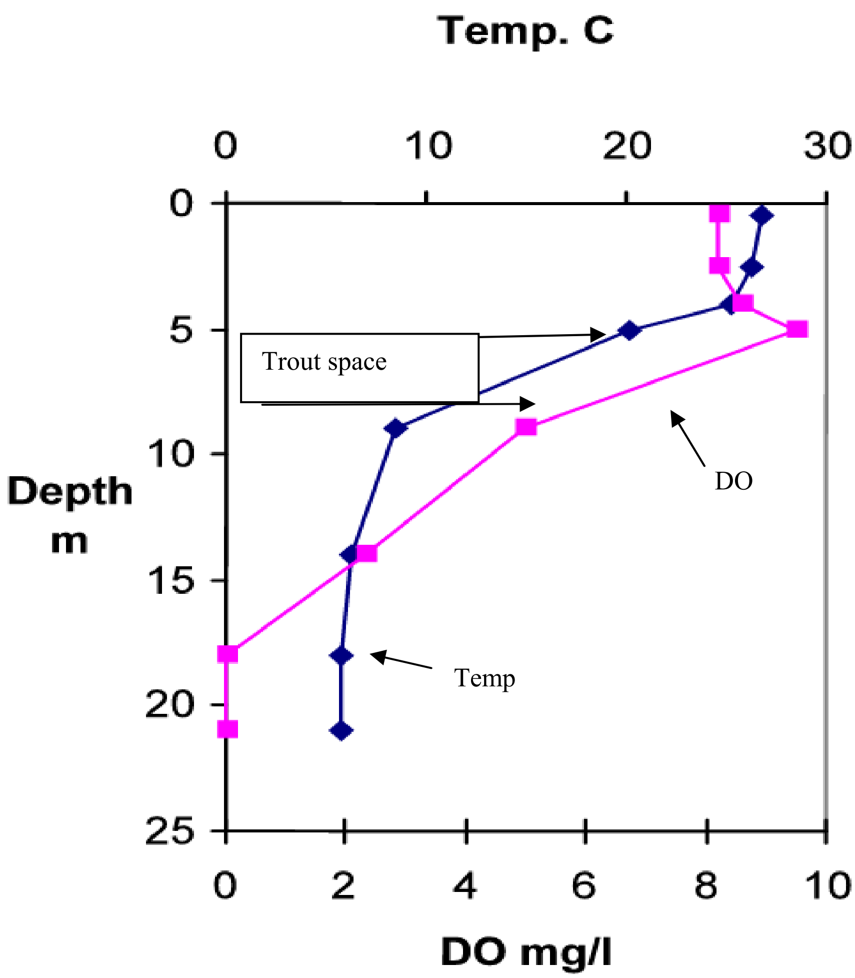


Figure 10. Quacucmquasit Pond DO and Temperature 8/20/03.

Nutrient Budget Methods

The estimation of nutrient budgets for the ponds involves a comparison of several approaches including: 1) landuse modeling of nutrient loads for both ponds, 2) lake modeling of nutrient loads for both ponds, and 3)a phosphorus mass balance/flow study of Quaboag Pond by measuring both flow and TP at a variety of tributary sites and at the Spencer WWTP discharge, 4) a mass loading calculation for Quacumquasit Pond was based on a combination of landuse modeling, estimation of backflooding mass inputs, and best professional judgment based on literature values for other septic systems and internal source. Each of these approaches is discussed below.

Landuse Modeling

The NPSLAKE model of Mattson and Isaac (1999) was designed to estimate rates of phosphorus loading from the watershed to lakes. The phosphorus loading estimates from the model are used with estimates of water runoff and these are used as inputs into a water quality model of Reckhow (1979). A brief description of the NPSLAKE model and data inputs is given here. MassGIS digital maps of 1999 land use within the watershed were used to calculate areas of landuse within three major types: Forest, rural and urban landuse. This model takes the area in hectares of land use within each of three categories and applies an export coefficient to each to predict the annual external loading of phosphorus to the lake from the watershed.

Other phosphorus sources, such as septic system inputs of phosphorus, are estimated from an export coefficient multiplied by the number of homes within 100 meters of the lake. The Spencer WWTP effluent is not part of the landuse modeling but is manually added to the model as shown for Quaboag Pond in Table 3 below.

The NPSLAKE model assumes the MassGIS digital maps accurately represent land uses and that land use has not changed appreciably since the maps were compiled in 1999. The predicted loading is based on the equation:

$$\text{P Loading (kg/yr)} = 0.5 * \text{septics} + 0.13 * \text{forest ha} + 0.3 * \text{rural ha} + 14 * (\text{urban ha})^{0.5}$$

The coefficients of the model are based on a combination of values estimated with the aid of multiple regression on a Massachusetts data set and of typical values reported in previous diagnostic/feasibility studies in Massachusetts. All coefficients fall within the range of values reported in other studies such as Reckhow et al., (1980). Further details on the methods, assumptions, calibration and validation of the NPSLAKE model can be found in Mattson and Isaac (1999). The overall standard error of the model is approximately 172 kg/yr.

Some of the simplifying assumptions used in the NPSLAKE model may not apply to Quaboag and Quacumquasit Pond and the estimates are not as reliable as direct mass balance measurements discussed above, but do provide a reasonable means to allocate sources to landuses within the watershed. The model assumes wetlands do not contribute any phosphorus loading, yet high phosphorus concentrations are noted in areas of the state that have extensive wetland influence. The model was modified slightly for Quaboag Pond to include wetlands as a source (wetland are not considered a source in the original model) with export rate similar to forests. Also, the model assumes that atmospheric inputs to lakes is negligible, yet this may not be true for Quacumquasit Pond, which has a relatively large surface area in relation to a small watershed area. Internal sources (recycling) of phosphorus are also not included but can be estimated from data (see below) or literature sources and added to the budget as shown for both ponds in Table 3 and Table 4.

The NPSLAKE model also generates predictions of estimated yearly average water runoff to the lake based on total watershed area and runoff maps of Massachusetts (see Mattson and Isaac, 1999). Because of the general nature of the landuse loading approach, natural background is included in land use based export coefficients. Natural background can be estimated based on the forest export coefficient of 0.13 kg/ha/yr multiplied by the hectares of the watershed assuming the watershed to be entirely forested. Without site specific information regarding soil phosphorus and natural erosion rates the accuracy of this estimate would be uncertain and would add little value to the analysis.

Table 4. NPSLAKE Landuse Results for Quaboag watershed.

Total Annual Estimated Pollution loads based on GIS Landuse

Watershed Area=	19866.8 Ha (76.7 mi2)
Average Annual Water Load =	121108372.4 m3/yr (137.2 cfs)
Average Runoff=	61.0 cm/yr (24.0 in/yr)
Lake area=	220.0 Ha. (543.4ac)
Areal water loading to lake: q=	55.0 m/yr.
Homes with septic systems within 100m of lake.=	97.0
Other P inputs =	131.0 kg/yr

Estimate of annual Nonpoint Source Pollution Loads by land use

Land use	Area Ha (%)	P Load kg/yr (%)
Forest category		
Forest:	12824 (64.5)	1667. (38.5)
Rural category		
Agriculture:	2379 (12.0)	714 (16.5)
Open land:	657 (3.3)	197 (4.6)
Residential Low:	1514 (7.6)	454 (10.5)
Other Landuses		
Water:	945 (4.8)	0.0 (0.0)
Wetlands:	590 (3.0)	77 (1.8)
Other P inputs:		
Spencer WWTP	NA	131 (3.0)
97.0 Septics:	NA	48 (1.1)
Internal sources	NA	603. (13.9)
Urban category		
Residential High:	632 (3.2)	286. (6.6)
Comm - Ind:	327 (1.6)	148. (3.4)
Total	19868 (100.0)	4325. (100)

Table 5. NPSLAKE Landuse Results for Quacumquasit watershed.

Total Annual Estimated Pollution loads based on GIS Landuse

Watershed Area=	454.1 Ha (1.8 mi2)
Average Annual Water Load =	2,768,466. m3/yr (3.1 cfs)*
Average Runoff=	61.0 cm/yr (24.0 in/yr)
Lake area=	91.1 Ha. (225.0ac)
Areal water loading to lake: q=	3.0 m/yr.*
Homes with septic systems within 100m of lake.=	118.0
Other P inputs=	30 kg internal + 48kg Quaboag =78.0 kg/yr

Estimate of annual Nonpoint Source Pollution Loads by land use

Land use	Area Ha (%)	P Load kg/yr (%)
Forest category		
Forest:	247.1 (54.4)	32.1 (11.5)
Rural category		
Agriculture:	9.4 (2.1)	2.8 (1.0)
Open land:	11.8 (2.6)	3.5 (1.3)
Residential Low:	51.1 (11.3)	15.3 (5.5)
Other Landuses		
Water:	91.4 (20.1)	0.0 (0.0)
Wetlands:	2.5 (0.6)	0.0 (0.0)
Other P inputs:		
Internal P		30. (10.6)
Backflood from Quaboag		48. (17.1)
118.0 Septics:	NA	59.0 (21.0)
Urban category		
Residential High:	34.7 (7.7)	76.1 (27.1)
Comm - Ind:	6.2 (1.4)	13.5 (4.8)
Total	454.1 (100.0)	280.4(100)

Mass Balance Estimates of Nutrient Loads to Quaboag Pond.

This method is considered the most accurate but does require a large dataset of both flowrates and nutrient concentrations collected over a long time period. A number of sites within the Quaboag watershed were sampled in an effort to identify subwatersheds with high loadings and to allow for comparisons of upstream sources to downstream delivery and thus identify unknown sources or sinks within the watershed. The study was conducted for one year beginning in December of 2002. There are seven flow + chemistry sites with measured data used in the study and are shown in Figure 11:

1) Site SM01: Sevenmile R. at Rt. 9;
2) Site CR01: Cranberry Brook at S. Spencer Rd.;
3) Site SM02: Sevenmile at Rt. 49;
4) Site EB04: Outlet of Lashaway at Rt. 9;
5) Site EB04a: Inlet to Quaboag Pond
6) Site QP011:Flood gate at Quacumquasit Pond outlet (flow estimated indirectly from rise in lake stage)
7) Site SPEFF: The final effluent of the Spencer WWTP (flow data provided by the plant).

In addition, continuous daily runoff data was obtained from the USGS site 01175670 and was used to predict runoff from the other sites as well as from extrapolated subwatersheds (direct drainage).

8) Site SMG: Upstream USGS Sevenmile gage at Cooney Rd 01175670

In addition, the ponds themselves were monitored for phosphorus concentration at the surface (over the deepest site) and this data was also used for nutrient budget calculations (see Monitoring above). The subwatersheds for the sampling locations are shown in Figure 12.

Stage discharge relationships were developed from a set of three flow and three staff gage readings at each site. Stage discharge relationships could not be established at the flood control gate due to water movement in both directions. The measured discharges were compared to discharges estimated from daily flow factors based on the daily discharge at the USGS SMG site, multiplied by appropriate watershed areas (see Appendix D for details). Because of the good agreement between measured and flow calculated from the USGS gage, the USGS gage data was used for all flow estimates except for backflooding at the Quacumquasit gate. Daily estimated flow at each site was multiplied by the average concentration of total phosphorus samples take prior to and after that day. Daily flow and weekly composite TP concentrations for the Spencer WWTP were taken from the Discharge Monitoring Reports (DMRs) provided by the facility. Composite concentrations reported in summer (May-August) were slightly lower than monthly grab samples taken by DEP (0.20 mg/l vs. 0.25 mg/l), but it was assumed this was due to differences in sampling and no changes were made in the calculations of mass flux.

Flows and total phosphorus export (mass phosphorus per day) were summed for the year and recalculated for the summer months (June-September) to check for seasonal differences, but no significant differences were found so the discussion will focus on the yearly budget. In areas of direct drainage, daily phosphorus loads were instead extrapolated from land area and export rates (mass of phosphorus per acre per day) based on the Cranberry Brook site CR01. The Cranberry River subwatershed was chosen as the basis for calculation of indirect total phosphorus export because it appeared to be the most similar in terms of landuse and topography to other ungauged subwatersheds in the study area.

At three sampling stations (SM02, EB04a and the outlet of Quaboag Pond), hereafter referred to as summary stations, yearly subtotals of upstream phosphorus sources were calculated and loadings from areas of indirect drainage runoff added. The resulting subtotal of measured and estimated upstream sources was compared to the total export measured at the summary station itself, and this was used to estimate any unknown source or sink of phosphorus in that subwatershed, by difference. The same procedure is repeated at the remaining downstream summary points.

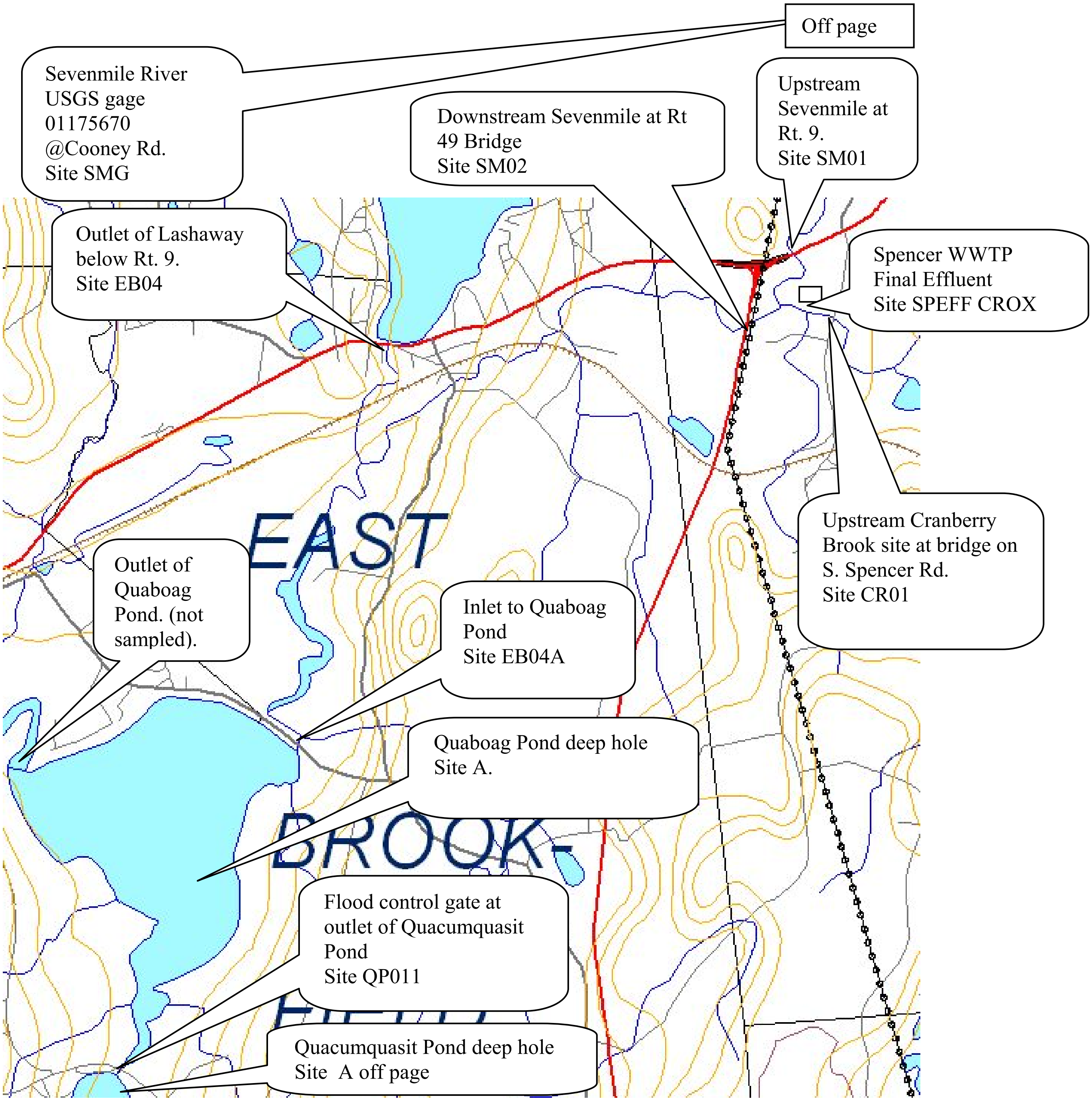


Figure 11. Sampling locations near Quaboag Pond.

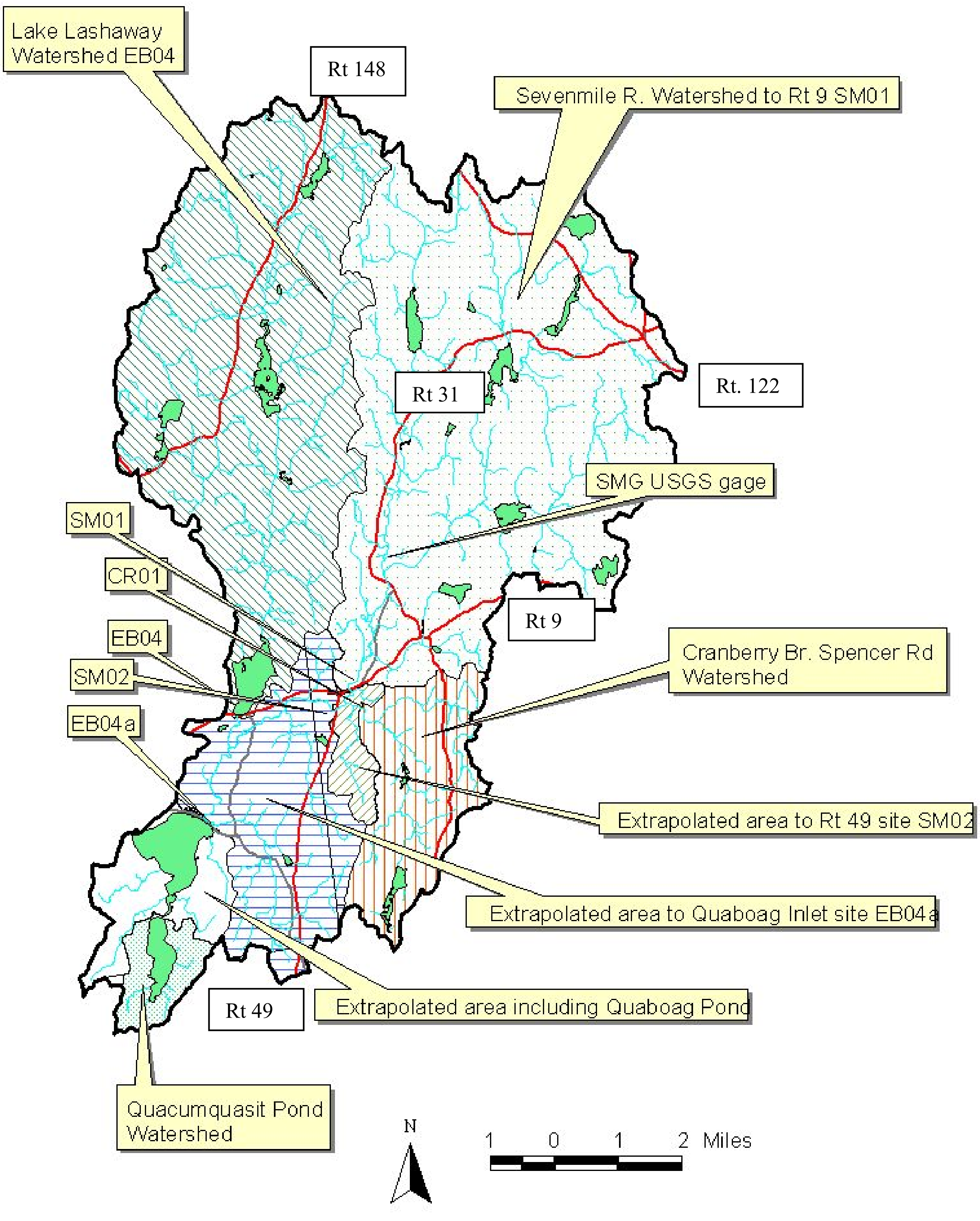


Figure 12. Quaboag Pond subwatersheds used in the nutrient budget (see text).

Results of Flow and Mass Loadings to Quaboag Pond

As discussed in Appendix D, the flows estimated by the USGS gage based flowfactor predicted measured flows very well and therefore daily flows were based on the flowfactor method. The water flows were 22 percent higher than average during the study year (Dec. 2002-Nov. 2003) and it is presumed that the measured phosphorus loadings may be somewhat higher than normal as well. The results of measured phosphorus mass loads for the subwatersheds, the loads estimated for extrapolated areas and unknown loads estimated by difference are all presented for the study year in Table 5 below. The loadings were recalculated to include only the summer months (June-September), but the results were very similar in both loading rates (when annualized) and in proportions coming from each source with the exception that the internal Quaboag source was essentially calculated by difference to be negative in the summer, so only the annual budget will be discussed. It is possible that during an extended period of exceptionally dry weather the Spencer WWTP could become a relatively large source of phosphorus to the pond and this will require further monitoring (see below).

The annual flowrate estimated for the major inlet (East Brookfield River) to Quaboag Pond was 147 cfs in the study year and the average flowrate to the pond was 158 cfs or 141,000,000 m^3/yr. The annual load of phosphorus from the major inlet to Quaboag Pond is estimated to be 3107 kg/yr. The flow weighted yearly average concentration would be 0.022 mg/l, which is lower than expected due to the large dilution of relatively pure snowmelt in the winter and spring. The major sources of total phosphorus to Quaboag Pond are nonpoint source runoff and stormwater runoff from the watershed that account for 96% of the total inputs. Less than 4 percent of the load (131 kg/yr) can be attributed to the Spencer Wastewater Treatment Plant (MA0100919). The discharge rate during the summer months was not markedly different from the rate during the winter months in terms of contribution to the nutrient budget of the pond. A possible unknown source in the vicinity of the treatment plant (unknown source to SM02) is estimated to be 167 kg/yr, which may be due to groundwater contributions from the treatment plants wetland treatment ponds, raising the possibility that the total phosphorus load from the Spencer WWTP is higher than the 131 kg/yr noted above. However, because the additional 167 kg/yr is less than the 15% estimated error of the budget, it is uncertain if a significant groundwater source from the treatment plant exists without further study. Similarly, the budget indicates an additional unknown source to the major inlet site at EB04a of 120 kg/yr. Again, this is within the estimated error of the annual budget, but looking at the summer budget and adding this source to the upstream unknown source at SM02, suggests there may be additional nutrient sources in this watershed. The unknown source, if present, is likely to be due to loading from the developed areas along Route 9 in East Brookfield and Spencer that are in excess of the total phosphorus export coefficient estimated for the area based on the Cranberry Brook watershed. At least the available evidence suggests there is not a loss or uptake of phosphorus in this stretch of river and at this point one should not assume that any significant amount of the phosphorus discharged from the Spencer WWTP is taken up by the wetlands along the Sevenmile and East Brookfield Rivers.

The outlet of Lake Lashaway (EB04) appears to be a watershed with relatively low phosphorus export per area, perhaps due to trapping of phosphorus within Lake Lashaway itself. Quacumquasit (South) Pond is also an area of low total phosphorus export. The net phosphorus exported from Quacumquasit Pond is based on measured, in-lake TP and flows estimated from watershed area and the daily flowfactors and does not include volumes of water added to South Pond from backflooding from Quaboag Pond.

Using the concentrations in the surface waters and the estimated flow from the pond based on the flowfactor method above we estimate the discharge of phosphorus from Quaboag Pond to be 3710kg/yr (see Table 5 below). By difference of inputs and outputs the mass balance results in Table 5 suggest an unknown source to Quaboag Pond of 603 kg/yr. This internal source may be phosphorus release from sediments or macrophytes or resuspension of particulate phosphorus from the sediments and some (about 48 kg/yr) may be due to septic system inputs that were not included in the fluvial mass balance study. Most of the internal loading is likely to be transient and may occur when wind events mix the lake following a calm periods when weak stratification results in anoxia near the sediment surface. Measurements have shown very low levels of dissolved oxygen at the deepest depths in Quaboag at times and this may result in dissolution of iron-phosphorus complexes and result in periodic phosphorus release as summer storms re-mix the water column. For example, the mid-June sample showed TP concentrations twice as high at depth as they were at the surface, yet this difference disappeared in the late September sample. There is a large uncertainty associated with the accuracy of this internal loading estimate due to the estimation by difference in the budget for Quaboag Pond in Table 5 and as noted above the source becomes a small sink during the summer but still within the errors of the budget method.   The landuse NPSLAKE modeled estimates of overall loading are in reasonable agreement (within 15 percent) with the inputs observed during the year long study as shown below.

Table 6. Quaboag Pond Annual TP budget.

Subwatershed	Area Ha	TP export kg/yr	TP Percent	Export rate kg/ha/yr
Sevenmile Rt 9 SM01*	8083	1147	31	0.14
Cranberry Br Rd CR01*	1461	203	5	0.14
Spencer WWTP SPEFF*	0	131	4	
Extrapolated area to SM02**	295	41	1	0.14
Unknown Source SM02***	0	167	5	
Subtotal to SM02*	9839	1690		0.17
Lashaway Rt 9 EB04*	6390	815	22	0.13
Extrapolated area to Inlet EB04a**	2248	313	8	0.14
Unknown Source EB04a***	0	120	3	
Subtotal to Inlet EB04a*	18477	2937		0.16
Net export of South Pond*	466	42	1	0.09
Extrapolated area to Quaboag**	925	129	3	0.14
Total fluvial input to Quaboag	19868	**3107**		0.16
Unknown internal source***		603	16	
Annual Total*		**3710**	**100**	

* Measured TP and flow
** TP estimated from Cranberry Br. Export rate x area
***TP estimated by difference between upstream sources and TP measured at site.

Mass Loadings to Quacumquasit Pond

Because much of the water and associated nutrient loading to Quacumquasit Pond is via groundwater seepage, a complete mass balance nutrient load was not calculated. Instead a combined approach of mass balance of nutrient inputs from backflooding was added to landuse inputs calculated from export coefficients and literature estimates of septic and internal sources as described below. The mass of phosphorus loading due to backflooding was calculated based on the product from estimated volumes of floodwater and concentration of TP in the floodwater from Quaboag Pond. Landuse export of water (based on the USGS gage) and total phosphorus loading (based on areal export from the Cranberry Brook subwatershed) were used to estimate watershed loading to Quacumquasit Pond. Additional sources of internal (sediment) sources and backflooding of water and TP from Quaboag Pond were added to these estimates. Sampling of the Quacumquasit flood gate was done in cooperation with Donna Grehl of the Quaboag and Quacumquasit Lake Association (QQLA) who volunteered to collect samples during backflooding events. Prelabeled sample bottles were provided to QQLA and the total phosphorus samples were stored frozen until analysis (see DWM, 2003 CN 128.0 Baseline Lakes QAPP for details). Monthly chemistry for TP was collected at other sites by DWM staff including a baseline lake survey data at the deep station on Quaboag and the deep station at Quacumquasit Pond. The discussion below will focus on the mass loading of phosphorus due to backflooding events.

Backflooding from Quaboag to Quacumquasit Pond

The mass phosphorus loading from backflooding of Quaboag Pond into Quacumquasit Pond depends on the frequency of back flooding, the amount of water involved and the concentration of Phosphorus in the floodwater from Quaboag. The current study began in December of 2002 and numerous backflooding events were recorded during sampling trips over the following twelve months. The first occurred in the days around December 23, 2002 that overtopped the gate. Relative water depths in relation to the gate were recorded and translated to water elevations based on the top of the gate being at 599.5 feet (sheet 3 of License plan, Appendix A of Lycott, 1994). These elevations were compared to elevations recorded during sampling at the inlet to Quaboag Pond and to elevations predicted from estimated daily flows and flow factors described above.

Because detailed flow information on each backflood event is not available, other estimates of backflood volumes based on change in lake stage in Quacumquasit pond from Figure 13 were used in the nutrient budget. A linear model related the stage height at the pond (measured at site EB04a) on the left side Y-axis of Figure 13 to flow at the Sevenmile USGS gage shown on the right hand Y-axis shown as the USGS trace line on the graph, which also can be extrapolated to the stage axis on the left side. The measured Quaboag Pond stage at the inlet site EB04a and at the Quacumquasit flow gate QP011 are also shown in Figure 13 as points on the day of the measurements. The simple model predicts Quaboag will rise to 599.5 feet (the top of the gate) when baseflows increase to a sustained (e.g. 2 day) flow of about 20 cfs at the Sevenmile gage and the pond will overtop the gate by 18 inches at a sustained flow of about 53 cfs. The instantaneous flow at the gage is available on the USGS website:

http://waterdata.usgs.gov/ma/nwis/uv?format=gif&period=31&site_no=01175670

Given an area of 218 acres, each foot of floodwater added to Quacumquasit Pond adds 218 acre-feet or about 270 million liters and the 9 feet of backflood amount to a volume of 2.43 million m^3 in 2003 or 42 percent of the total water budget for the pond. Each ppb of total phosphorus in the floodwater adds 0.270 kg of phosphorus to the lake during a 1-foot backflood event. The mass loading of phosphorus from each of the backflood events during the year is summarized in Table 6.

Table 7. Summary of Backflooding events.

Dates	Notes	Quacumqausit Pd. Flood height feet	TP mg/l in Flood	TP in Pond	Gross TP kg added.
12/23/02	Over gate	3	0.030	0.013	24.3
3/23/03	Over gate	3	0.020	.014*	16.2
4/2/03	Over gate	1	0.018	.014	4.8
4/15/03	Over gate	1	0.018*	.014*	4.8
6/1/03-7/1/03	Open gate	Not recorded	Not recorded	Not recorded	Not recorded
9/24/03	Open gate	1	0.043	.011	11.6
Total					61.7

*Estimated concentration from closest sample date.

Prediction of Lake Stage from USGS Sevenmile flow

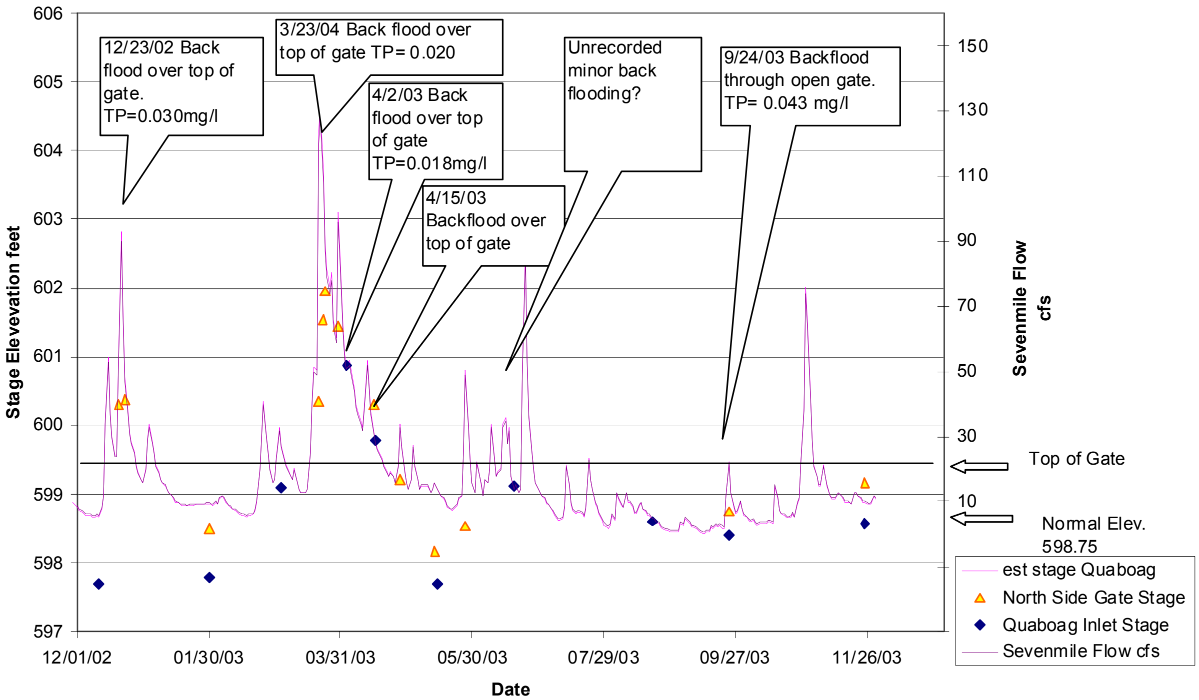


Figure 13. Water Stage at Quaboag Pond and at Quacumquasit gate. Water stage level shown as points. The line represents the instantaneous flow rate at the USGS gage on the Sevenmile River at Cooney Road.

The simple method of concentration multiplied by backflood volume gives a gross estimated input of about 62 kg of phosphorus. This does not include large particulate material such as bits of macrophytes that are commonly observed in the floodwater entering Quacumquasit Pond from Quaboag Pond that would increase the loading estimated here. This estimate is much less than the 205 kg contributed by back flooding prior to the gate being installed as reported in BEC (1986) and slightly less than the 84 kg estimated from calculations in Lycott (1994) after the gate was in use. Given that the study year was relatively wet (Sevenmile gage runoff was 18.1 cfs (2.05 cfsm) compared to long-term average of 14.8 cfs, or 22 percent higher), the backflooding contribution of TP in a normal water year is probably closer to 48 kg/yr.

About half of this phosphorus leaves the lake within weeks as the now mixed flood+lake water levels recede back through the gate. It is important to note that although the largest amounts of water back flooded in the spring, because TP concentrations were relatively low and similar to the lake concentration, the impact was probably less in those months and conversely highlights the importance of closing the gates during summer and fall storms as well as spring floods.

Septic System Loading

The BEC(1986) study estimated septic systems contributed 110 kg/yr of phosphorus to Quacumquasit. This is comparable to the estimate of 118 kg/yr from the NPSLAKE model above. A more detailed report on seepage around the lakes (Fugro East, 1994) estimated the loading to be about 42 kg/yr and this was considered the best estimate for this nutrient budget.

Internal Loading

Internal loads of phosphorus can be calculated from the difference between surface and bottom total phosphorus concentrations during periods of stratification. In the BEC (1986) study such calculations estimated internal inputs at 30 kg/yr for Quacumquasit Pond. Using the same hypolimnetic volume (1.66 million m^3) the surface (0.011mg/l) and hypolimnetic (21m) TP concentrations (0.055 mg/l) taken on September 24, 2003, an estimated an internal load of 73 kg is calculated. This is probably an overestimate as the entire hypolimnion is unlikely to have this much phosphorus. If only the hypolimnetic volume below 18 meters (0.27 million m^3) where the dissolved oxygen is not present is considered, the estimated phosphorus release is about 12 kg, but this is probably an underestimate for the lake as a whole. Based on all available data the best estimate is about 30 kg, the same as estimated by BEC(1986).

Summary Budget for Quacumquasit Pond

The annual total phosphorus budget estimated for each of the sources described above is summarized in Table 7 below. Our best estimate of loading during the study year is 199 kg/yr. Most of the loading is due to landuse export within the local watershed that accounts for 33 percent of the loading. Backflooding was the second highest source and accounted for 62 kg/yr. Septic systems (42 kg) and internal loading (30 kg) accounted for the remainder. The net output from Quacumquasit Pond based on estimated flow rates (daily flowfactors from Sevenmile gage multiplied by in lake concentrations of TP) are estimated to be 42 kg/yr (this method does not include return flows from backfloods). Thus, it appears Quacumquasit Pond acts like a nutrient sink and retains about 95 kg/yr (excluding backflooding contributions).

Table 8. Annual TP Budget for Quacumquasit Pond.

Subwatershed	TP export kg/yr	TP Percent	Export rate kg/ha/yr
Extrapolated Export of 466 ha watershed**	65	33	0.14
Backflooding from Quaboag.*	62	31	
Septic Systems	42	21	
Internal (sediment) recycling summer***	30	15	
Total	199	100	
Unknown source (sink)	-95		
Net Export from South (excluding backflooding)	42		

* Measured TP and extrapolated flow
** TP estimated from Cranberry Br. Export rate x watershed area (includes deposition to pond surface).
***TP estimated by difference between surface and bottom TP concentrations and volumes (see text).

Lake Model Estimates of Nutrient Loads

Although direct mass loading estimates are the most accurate method of constructing nutrient budgets, lake modeling can be used to compare how well the loads agree with the observed concentrations in the lake and to determine if there are missing sources or overestimated sources in the budget. Lake models can be used to predict total phosphorus from annual phosphorus loads as well as to reverse calculate predicted loads from lake total phosphorus concentrations. The same five lake water quality models (Vollenweider (1975), Kirchner and Dillon (1975), Chapra (1975), Larsen and Mercier (1975) and Jones and Bachmann (1976)) used in the original BEC(1986) D/F report, along with a simple mass balance approach, were recalculated using the recently collected data for Quaboag Pond and Quacumquasit Pond to predict annual loads and lake concentrations of TP.

Quaboag Lake Modeling Results.

Using the five established models, the various combinations of predicted annual loads did not agree well with observed spring concentrations or loads measured by mass balance in Quaboag Pond. Using the observed spring concentration of 0.014 mg/l the predicted annual load was only 2062 kg/yr compared to the observed load of 3710 kg/yr. These models as they may not be appropriate for this quick flow-through lake that does not appear to retain phosphorus inputs. In Quaboag Pond, spring nutrient concentrations may be depressed due to dilution by snowmelt yet concentrations tend to increase in both the river and in the pond during summer. A simple mass balance model based on the summer period with no phosphorus retention is more appropriate for this lake. The mass balance model for the summer period (see Appendix A) provided the most accurate estimate of summer TP concentration (0.042 mg/l or 42 ppb) which agrees with the observed summer concentration (43 ppb) and thus the mass balance model will be used as a basis for calculating loading reductions in Quaboag Pond.

Quacumquasit Lake Modeling Results.

As shown in Appendix B, the five models were much better at predicting the loads and concentrations in Quacumquasit Pond, probably due to the fact that Quacumquasit Pond is similar to the lakes on which the models were developed, namely, large deep lakes with long residence times. Using the spring concentration of 0.015 mg/l (15 ppb) the models predicted annual loads of 171-207 kg/yr with an average of 182 kg/yr which agrees very well with the mass loading estimated above of 199 kg/yr. Similarly, the load of 199 kg/yr yielded model spring phosphorus predictions of 14-20 with an average of 0.017 mg/l that agrees well with the observed spring concentration of 0.015 mg/l. Because of the good agreement between observed results and the five models one can be fairly confident that no large sources of phosphorus are missing from the budget.

TMDL Total Phosphorus Targets.

There is no loading capacity *per se* for nuisance aquatic plants. As the term implies, TMDLs are often expressed as maximum daily loads. However, as specified in 40 CFR 130.2(I), TMDLs may be expressed in other terms when appropriate. For these cases, the TMDLs are expressed in terms of allowable annual loadings of phosphorus because the growth of phytoplankton and macrophytes responds to changes in annual rather than daily loadings of nutrients. One approach to setting total phosphorus targets is based on typical concentrations of phosphorus in lakes within uniform ecological regions (the ecoregion approach). The lake phosphorus concentrations predicted from the Griffith et al. (1994) and Rohm et al., (1995) range between 10 and 19 ppb for typical summer to fall conditions. However, these may not be appropriate for the quick flushing Quaboag Pond, and may not be appropriate for the very slow flushing Quacumquasit Pond. The Department must also consider seasonality in setting the targets. In a shallow, quick flushing pond such as Quaboag, the spring conditions are often characterized by high water but relatively dilute snowmelt. As summer proceeds Quaboag tends to have higher TP concentrations. Conversely, in Quacumquasit the spring season coincides with water column turnover and total phosphorus may be high as nutrient rich deeper water is mixed to the surface after winter ice cover breaks up. In Quacumquasit Pond, concentrations tend to decline as summer progresses due to lack of inputs and sedimentation of algae and associated phosphorus. Most lake water quality models are developed for large stratified lakes such as Quacumquasit and these models rely on spring (isothermal) TP concentrations when surface samples also are representative of the entire lake volume.

Instead of using the ecoregional targets from the literature, the proposed targets are based on support of the uses of each pond. The target for Quaboag will be set for summer conditions and the target for Quacumquasit will be set for spring conditions. Both ponds must meet the visibility required to maintain swimming (typically about 40 ppb to maintain 4 feet of visibility). In addition, both lakes must maintain their respective uses (warmwater fishery in Quaboag at 43ppb summer TP and coldwater fishery in Quacumquasit Pond at spring concentrations of 12 ppb). However, lower targets will be chosen to ensure a margin of safety and to further protect other uses such as aesthetics. Given that current conditions occasionally result in algal blooms, and in 2004 a fish kill was observed in Quaboag Pond, the Department has proposed a summer target TP concentration of 30 ppb to further protect the warmwater fishery and to provide a margin of safety. Quacumquasit Pond must also meet aesthetics and aquatic life but in this pond there is a need to support a coldwater fishery by maintaining the 3 meters of late summer trout space observed in the study year (see above) and thus the target is set at a spring concentration of 12 ppb to protect uses and to provide a margin of safety. Note that the summer surface concentrations in Quacumquasit Pond will likely be less than the target (perhaps 6 to 8 ppb). The targets require a reduction of 30 percent in summer TP concentrations in Quaboag and a 33 percent reduction in Quacumquasit Pond. The target for Quaboag Pond is above the range suggested by the ecoregion studies noted above, but Quaboag is unusual in several respects. First, it is a pond with a quick flushing rate, which reduces the frequency of algal blooms and can allow somewhat higher TP concentrations. Second, the pond has a large watershed, which delivers large amounts of phosphorus to the pond, and thus higher TP concentrations are expected as a natural condition in such ponds. The NPSLAKE model estimates a forested condition loading of 2583 kg/ha, which is similar to the TMDL target. Third, the pond is shallow with a long fetch that allows wind to naturally resuspend nutrients from the bottom and the shallow waters also allow macrophytes to recycle nutrients to the water column, naturally raising TP concentrations during the summer period. Fourth the concentrations in the various tributaries within the watershed tend to naturally increase in TP concentration during low flow of the summer and the concentrations of total phosphorus in the Sevenmile River, the main tributary upstream of the town of Spencer is often higher than our target 30 ppb during the summer, despite being largely forested with no major sources noted. Thus a higher target is justified in Quaboag Pond. On the other hand, the target for Quacumquasit Pond is set at the lower end of the TP range suggested by the ecoregion studies. In this case the pond has a small watershed area in comparison to the lake area and the pond is very deep. Lower TP concentrations are expected for such ponds because few nutrients are transported to the lake and in the case of Quacumquasit Pond, much lower TP concentrations are expected due to the lack of a permanent flowing tributary (the pond is largely a groundwater seepage pond). Last, the presence of a coldwater fishery with 3 meters of trout space requires more protection than the more common warmwater lakes in the region. Such conditions favor setting a lower TP target than suggested by the ecoregion analysis.

The lower phosphorus concentrations will lessen the chance of nuisance algal blooms and should further improve dissolved oxygen levels in the hypolimnion of the ponds. Rooted aquatic plants are not likely to be controlled by reducing ambient nutrient concentrations in the water. Thus, reducing the supply of external phosphorus may not meet the goals of the TMDL in Quaboag Pond without additional management in the lake as discussed below.

Loading Capacity

For Quacumquasit Pond the five published models and the target spring concentration of 12 ppb from above, the average target load is calculated to be 146 kg/yr as shown in Table 8. For Quaboag Pond a simple conservative mass balance model allows target loads to be estimated based on the ratio of target concentration to current summer concentration in Quaboag Pond. The ratio of 30/43 implies a target load of 70 percent of the current load or 2588 kg/yr (annualized) as shown in Table 8. For purposes of this TMDL the annualized load will apply only during the months of May-October, which should provide protection during the growing season and allow the lake to reach the target concentration during the critical portion of the summer months (June-September).

Table 9. Total Phosphorus Targets and TMDL Loads.

WBID	Lake Name	Current Load Year 2003 kg/yr	Surface TP (ppb)	Target Load kg/yr	Target TP (ppb)
MA36130	Quaboag Pond	3710	43 (June-Sept.)	2588	30 (June-Sept.)
MA36131	Quacumquasit Pond	199	15 (spring)	146	12 (spring)

Modeling Assumptions, Key Input, Calibration and Validation:
The five lake models used were developed and validated on north temperate lakes with relatively long retention times and are similar to Quacumquasit Pond. Quaboag Pond is not well predicted by the typical lake models and is best modeled by a conservative (no phosphorus retention) mass balance model. The reader is referred to original papers for additional details on the models assumptions, and details of calibration and validation. There are no numeric models available to predict the growth of rooted aquatic macrophytes as a function of nutrient loading estimates, therefore the control of nuisance aquatic macrophytes is based on best professional judgment.

Seasonality

As the term implies, TMDLs are often expressed as maximum daily loads. However, as specified in 40 CFR 130.2(I), TMDLs may be expressed in other terms when appropriate. For most lakes, it is appropriate and justifiable to express a nutrient TMDL in terms of allowable annual loadings. The annual load should inherently account for seasonal variation if it is protective of the most sensitive time of year. The most sensitive time of year in most lakes occurs during summer, when the frequency and occurrence of nuisance algal blooms and macrophyte growth are usually greatest. Therefore, because the phosphorus TMDL was established to be protective of the most environmentally sensitive period (i.e., the summer season), it will also be protective of water quality during all other seasons. Additionally, the targeted reduction in the annual phosphorus load to lakes will result in the application of phosphorus controls that also address seasonal variation. For example, certain control practices such as stabilizing eroding drainage ways or maintaining septic systems will be in place throughout the year while others will be in effect during the times the sources are active (e.g., application of lawn fertilizer). In cases of rapidly flushing (less than 14 days) lakes or impoundments downstream of point sources it may be appropriate to set seasonal limits on phosphorus inputs based on the growing season (May-October). In such cases permit limits in the winter months could be relaxed.

Because the two ponds have very different hydraulic retention times the TMDLs will be written for different critical time periods. The retention time for Quaboag Pond is about 12 days averaged over the study year, but increases to 19 days during the summer and as much as 43 days during the driest month of September. The TMDL for Quaboag Pond is written specifically for the summer with slightly relaxed limits for the winter months. In quick flushing ponds the critical period is based on the response time (time to actually replace water in the pond) and is three times the retention time. Thus four months appears to be an appropriate period. The impact of droughts is still an uncertainty in the TMDL analysis and thus additional monitoring will be required and this will be considered a phased TMDL subject to future revision.

The TMDL for the slow flushing Quacumquasit Pond is expressed in terms of allowable annual loadings of phosphorus. Although critical conditions occur during the summer season when both macrophyte and algal growth is more likely to interfere with uses and when hypolimnetic dissolved oxygen depletion occurs, water quality in Quacumquasit Pond is generally not sensitive to daily or short term loading, but is more a function of loadings that occur over longer periods of time (e.g. annually). Therefore, seasonal variation is taken into account with the estimation of annual loads for Quacumquasit Pond. In both ponds, evaluating the effectiveness of nonpoint source controls can be more easily accomplished on an annual basis rather than a daily basis and for this reason, the TMDL for both ponds will also be expressed as an 'annualized' budget.

Wasteload Allocations, Load Allocations and Margin of Safety:

The TMDL is the sum of the wasteload allocations (WLA) from point sources (e.g., sewage treatment plants and urban stormwater) plus load allocations (LA) from nonpoint sources (e.g., landuse sources) plus a margin of safety (MOS). Thus, the TMDL can be written as:

TMDL = WLA + LA + MOS

The margin of safety is set by establishing a target that is below that expected to meet the visibility target of 4-feet for swimming (about 40 ppb TP) and below the concentration levels needed to maintain current uses, particularly warmwater fisheries in Quaboag Pond and the trout space for the coldwater fishery in Quacumquasit Pond. Both uses are currently being supported and the reduction from the current concentration represents an additional margin of safety. There is some uncertainty concerning how the streams and Quaboag Pond will respond under drought conditions. Because droughts may cause stream TP concentrations to naturally rise and low flows will also result in a higher proportion of TP loading from the Spencer WWTP the Department is requiring additional monitoring to target this issue. As such the TMDL will be considered a phased TMDL and subject to modification based on additional data collection.

Allocation for Quaboag Pond

Rather than using Table 5 to allocate loads to Quaboag Pond subwatersheds, the TMDL process requires that loads be allocated to point and non-point sources. The total loads from Table 5 were taken and reallocated based the known point source contribution and on the remaining proportion of nonpoint loads estimated from the modified NPSLAKE model in Table 3. The resulting allocation tables are shown below in Table 9 with the best estimate of current loading shown in the left column.

Wasteload allocations include all point sources. In this case point sources include the loading from the Spencer wastewater treatment plant (NPDES permit MA0100919) and loading from urban stormwater runoff that may or may not be specifically included in stormwater Phase II permits. The only area included within a Phase II permit is the urbanized area of parts of downtown Spencer, which has submitted a Notice of Intent (NOI transmittal number W039544) for a NPDES Phase II permit (MAR041162). The map of urbanized area and the Spencer Notice of Intent are available on the web at http://www.epa.gov/region01/npdes/stormwater/ma.html.

The current loading from the Spencer WWTP is based on flow and concentrations reported in the DMR reports by the facility. Because the plant contributes a minor portion of the nutrient load to either pond during the summer the allocation for the WWTP for May-October will remain at current loading levels (131 kg/yr or 0.79 lb/day) which can be achieved at the 0.2mg/l as long as discharge flow rates are 0.47 MGD or less. This represents a significant reduction compared to the current permit with the interim limit of 0.3 mg/l and permit flow rate of 1.08 MGD. This will require any future increases in flow at the plant during May-October to be compensated by proportional decreases in effluent TP concentrations. Because Quaboag Pond has a short retention time and winter loadings are not expected to directly impact the pond during the critical summer period, the Spencer WWTP may be allowed to operate with somewhat relaxed winter limits. There is no specific information concerning the possible effect of winter adsorption or storage of phosphorus with subsequent release and so it is prudent to continue to reduce winter phosphorus concentrations and loads somewhat. Because winter stream flows are typically 50 percent higher the winter limits (November-April) can be set 50% higher (1.19 lb/day). This is considered is also considered protective to limit winter loading to both the groundwater and soils between the constructed wetlands and nearby surface waters and to winter limit loading to wetlands boarding the East Brookfield river which may release phosphorus at other times of the year. More strict treatment limits above and beyond this TMDL, may be required in the future at the Spencer WWTP to comply with 314CMR4.04(5) regarding the requirement for highest and best practical treatment.

The stormwater point sources and all other nonpoint sources that constitute the majority of the loading to Quaboag Pond will have to be reduced by approximately 32 percent except for wetlands which have no BMPs to improve phosphorus retention. Effective BMPs exist for urban stormwater, highway runoff, septic systems and residential housing and it is expected that these proposed nutrient reductions are possible and should be targeted first. The targeted reductions for forest lands, agricultural and open lands will be more difficult to attain given that most forests are not being harvested, and much of the intensive farming such as dairy farming is no longer present in the watershed. DEP is currently examining the effect of wetland types to determine the amounts of phosphorus exported by different types of wetlands and it remains a possibility that natural wetlands may be a significant source of loading in the watershed.

Table 10. Quaboag Pond MA36130 TMDL May-October Load Allocation.

Source	*Current TP Loading (kg/yr)*	*Current TP Loading (kg/day)*	*Target TP Load Allocation (kg/yr)*	*Target TP Load Allocation (kg/day)*
Load Allocation				
Forest	1378	3.77	938	2.57
Wetland	64	0.18	63	0.17
Agriculture	590	1.62	402	1.10
Open Land	163	0.44	111	0.30
Residential (Low den.)	375	1.03	255	0.70
Septic System	48	0.13	33	0.09
Internal recycling	603	1.65	411	1.13
Waste Load Allocation				
Spencer WWTP NPDES(MA0100919) *	131	0.36	131	0.36
Urban & road stormwater.	358	0.99	244	0.67
Total Inputs	3710	10.16	2588	7.09

*The Target load for the Spencer WWTP is set at the current phosphorus load of 0.79 lb/day (0.36 kg/day) or approximately 0.2mg/l at a flow of 0.47 MGD during May-October as shown above. Recommended winter limits of 1.19 lb/day are not reflected in the table. Note for NPDES permits the seasonal values should be used.

Allocation for Quacumquasit Pond

As discussed above, TMDL process requires nutrients to be allocated between point and nonpoint sources. This was accomplished for Quacumqausit Pond by taking the phosphorus load of 62 kg/yr for backflooding in Table 7 and dividing it by assuming 13 percent of the backflooding load from Quaboag is due to point sources (Wasteload allocation) and 87 percent is due to nonpoint sources as indicated in Table 9. The resulting 8 kg/yr and 54 kg/yr are shown in Table 10 below. Similarly, the load of 65 kg/yr attributed to the local Quacumquasit watershed in Table 7 is allocated by assuming the division of point and nonpoint sources of 32 and 68 percent shown for Quacumquasit Pond in Table 4 results in loads of 21 kg/yr for local point sources (high density housing but not Phase II) and 44k g/yr for local nonpoint sources as indicated in the left column of Table 10.

The target allocation, shown in the right column of Table 10 is based on meeting the target load of 146 kg/yr by modifying the flood gate height and thus reducing backflooding loads by 75 percent and reducing local watershed loading by about 5 percent. Thus the nonpoint backflooding from Quaboag is targeted to be reduced to 13 kg/yr and the point source loading from Quaboag is targeted to be reduced to 2 kg/yr (a negligible amount). If the modifications to the flood control gate cannot be made, the allocation of reductions can be shifted to other local sources (internal and septic systems) as needed to meet the TMDL of 146 kg/yr. While Quacumquasit Pond is potentially sensitive to winter as well as summer loading the Quacumquasit nutrient budget indicates that the implementation of the improvements to the backflooding gate will eliminate nearly all loading from Quaboag Pond including the small amount of point source loading contained in the Quaboag water. Therefore extending the summer loading limits at the Spencer WWTP into the winter period are not required to protect the water quality at Quacumquasit Pond.

Table 11. Quacumquasit Pond MA36131 TMDL Load Allocation.

Source	*Current TP Loading (kg/yr)*	*Current TP Loading (kg/day)*	*Target TP Load Allocation (kg/yr)*	*Target TP Load Allocation (kg/day)*
Load Allocation				
Local NPS runoff, not including commercial, high density housing	44	0.12	42	0.12
Nonpoint source from backflooding of Quaboag*	54	0.15	13	0.04
Internal Loading	30	0.08	29	0.08
Septic System	42	0.12	40	0.11
Other	0	0	0	0
Waste Load Allocation				
Point source from backflooding of Quaboag*	8	0.02	2	0.01
Point source from local commercial, high density housing runoff (32% of 65)	21	0.06	20	0.06
Total Inputs	199	0.55	146	0.40

*The loading from backflooding is divided in this table to account for both point and nonpoint source contributions. Note that for purposes of NPDES permits the seasonal TMDL values should be used.

Implementation

The implementation of the TMDL will focus on the following issues for both ponds:

1) Optimization/upgrades to the Spencer WWTP to meet the new 0.2 mg/l (0.79 lb/day) permit limit.
2) Control of nonpoint and stormwater point source nutrients within the watershed

Implementation specific for Quacumquasit Pond includes:

3) Upgrade to the Quacumquasit flood gate to increase height by 18 inches.

Implementation specific for Quaboag Pond includes:

4) Establishment of targeted management zones for control of macrophytes.

Spencer WWTP Optimization/Upgrade

The first item, upgrades to the Spencer WWTP are already underway. The current interim limit of 0.3 mg/l has been met but the recent optimization study failed to consistently meet the 0.2 mg/l summer limit. Under such conditions, the permit calls for a phosphorus reduction feasibility study to be submitted within 6 months to evaluate options for meeting the summer 0.2mg/l (1.8 lb/day) final limit. The feasibility study is on hold pending the finalization of this report and it is expected that the feasibility study will focus on meeting the new loading limits of this TMDL.

Control of Nonpoint Sources

A small portion of the Quaboag watershed is also included in the NPDES Phase II stormwater permit issued to the town of Spencer for the urbanized area bordering Route 9 in Spencer. A Phase II permit issued to the Massachusetts Highway Department will cover stormwater discharges from state roads including Routes 9, 49 and 31, within the urbanized areas of the Quaboag watershed. It is recommended that the Phase II permits be expanded to cover areas outside the urbanized areas and include other towns in the watershed. The NPDES permits require six minimum control measures including public education, public participation, illicit discharge detection and elimination, construction site runoff control, post construction runoff control, and good housekeeping at municipal operations. The latter 'good housekeeping' control should include BMPs and a schedule of activities to control pollution. The permits also require the development of a stormwater management plan that must include mapping outfalls to receiving waters. Details on the Phase II permits are available at
http://www.mass.gov/dep/water/wastewater/stormwat.htm
.

This TMDL requires 32 percent reductions in phosphorus discharges from these nonpoint source areas. In order to achieve this both MassHighways and the Town of Spencer must conduct and report on roadway sweeping in the spring and fall on an annual basis. In addition, the Town of Spencer and MassHighways must conduct and report on an annual catchbasin inspection and cleanout program to restore 80% or more of the solids storage volume anytime the available solids storage volume is less than 50%, and maintain or improve all existing BMPs. Alternately, the permittees may install infiltration or other BMPs and document a total reduction of 32% of the total phosphorus loading to receiving waters to control the stormwater discharges within the Quaboag watershed. Both MassHighways and the Town of Spencer should work cooperatively with all parties to reduce runoff from roadways to waters within the Quaboag watershed. This includes installation of infiltration stormwater BMPs along streets and highways where necessary. In particular, the imperviously lined ditches (3 percent slope) along Route 49 near the Sevenmile River should be augmented with water quality swales to encourage infiltration and to eliminate the large discharges as evidenced by the sediment delta at the outfall in the river. In addition, EPA should consider adding additional areas within other towns to be required to obtain Phase II permits and fulfill TMDL requirements noted above.

Other stormwater discharges are due to roads in the watershed that are not included in the Phase II permits noted above but are included as point sources within the load allocations listed under commercial industrial and high density residential areas in Tables 4 and 5, above. The remaining roads are included in the nonpoint runoff allocations under the other landuse categories (e.g. forest, low density residential) in Tables 4 and 5 above. All of these landuse categories, which constitute the majority of the current phosphorus inputs are also targeted for nutrient reductions of 32 percent. The internal load of 603 kg/yr is assumed to be controlled over time with reductions proportional to the decrease in external loading.

Quacumquasit Pond Flood Gate

The specific implementation for Quacumquasit Pond includes a study of the current flood control gate and an evaluation of how this gate can be modified to further reduce backflooding to Quacumquasit Pond. It is proposed here that an 18 inch increase in gate height is required to reduce nutrient loading and meet the required 75% reduction targeted for this source (which includes both point and nonpoint components). Previous concerns about additional flooding of shoreline residences of Quaboag Pond as a result of keeping excess floodwater out of Quacumquasit Pond were evaluated by DEP and by the hydraulic experts at the Army Corps of Engineers. The ACOE summarized their findings (see Appendix C) by stating that Quacumquasit Pond represents a relatively small area for flood storage compared to Quaboag Pond and the surrounding wetlands in the Quaboag River system. As such, the effect of adding an additional 18 inches to the flood gate at Quacumquasit Pond would add only a few inches, at most, to a typical 2 foot flood in Quaboag Pond. In April of 2005 rainfall on top of saturated ground and some snowpack resulted in a flooding of Quaboag Pond and eight inches of water were running over Quaboag Street from the north (behind the houses) and dropping into Quaboag Pond, which was obviously at lower elevation. As such, it appears the problems of flooding the houses are more to do with upstream floodwater and flow restrictions at the Shore Road bridge, rather than backing up water from Quacumquasit gate area into Quaboag Pond as residents suggest.

The 18-inch addition would also add 18 inches to the normal winter elevation of Quacumquasit Pond, but this is comparable to the typical winter and spring floods that overtop the gate by the same amount now. The extra 18 inches of clean Quacumquasit water would also reduce the amount of Quaboag water entering if the enhanced flood gate is overtopped. If the 18 inches of additional winter elevation projected for Quacumquasit Pond is a problem then the gate could be raise periodically to lower the water held back in Quacumquasit during the fall, winter and spring months. It is expected that this modification to the gate could be accomplished for as little as $15,000 assuming an engineering analysis finds the current structure can be simply modified and is strong enough to handle the increased 18 inches of water pressure. This TMDL indicates a simple modification to the gate would meet the TMDL targeted reduction at a minimal cost. However, if the gate cannot be modified the alternative nutrient sources could be targeted for reductions, but at a higher cost and with some increased uncertainty about the amount of nutrients controlled by the BMPs. The alternative BMPs which would target local septic systems and other nonpoint source controls, or to an alum treatment aimed at the internal sediment recycling of phosphorus, both of which are likely to be more costly and less effective at nutrient reductions over the long term. Pumping of 100 shoreline septic systems every five years would cost about $18,000 and would likely reduce the load by only 10 kg/yr and obviously would need to be repeated. Alum treatment would likely cost in the range of about $40,000 and would reduce loading by an estimated 25 kg/yr over 20 years. For these reasons the modification to the gate is the recommended choice.

Quaboag Pond Zoned Management of Macrophytes

The specific implementation for Quaboag Pond includes modification to the aquatic macrophyte management strategy. In July of 2004 an herbicide treatment occurred on Quaboag Pond. A bloom of algae was reported to be in the water at the time, but this bloom expanded to become a large, persistent surface bloom of blue-green (cyanobacteria) that raised concerns about health impacts. Questions were raised as to the possible impact of the herbicide treatment in contributing to the bloom. Assuming the treated area (130 acres) had typical biomass density of *M. spicatum* of about 50 g/m^2 and contained about 100 mg P/m^2 (Smith and Adams, 1986), then the bed could have released as much as 53 kg of phosphorus as the plants decayed. If released quickly, the plant decay could raise the phosphorus concentration in the 4.45 million m^3 volume of Quaboag Pond by about 12 ppb, or a 40 percent increase from the typical level of 30 ppb up to approximately 42ppb, which is a substantial increase and enough to significantly contribute to a large bloom. Thus, large herbicide treatments, particularly contact herbicide treatments where the plants decay quickly, have the potential to contribute to algal blooms in subsequent weeks. Because large herbicide treatments are not a typical annual occurrence on Quaboag Pond this nutrient source is not included in the annual budget but is presented here for comparison purposes only. It should be noted that the major inlet to Quaboag Pond, the East Brookfield River had a high (50 ppb) TP concentration while the bloom was ongoing and thus a major source of the nutrients was likely to be from sources upstream in addition to plant decay in the pond due to herbicide treatments. The practice of using algicides to control blue-green blooms is not endorsed as a long term management method in the Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management In Massachusetts (Mattson et al., 2004), because such treatments are usually short-lived, contribute nutrient pulses to fuel future blooms, and have adverse impacts on biota and sediments. Alum and other long-term nutrient controls should be the considered as part of the lake management plan.

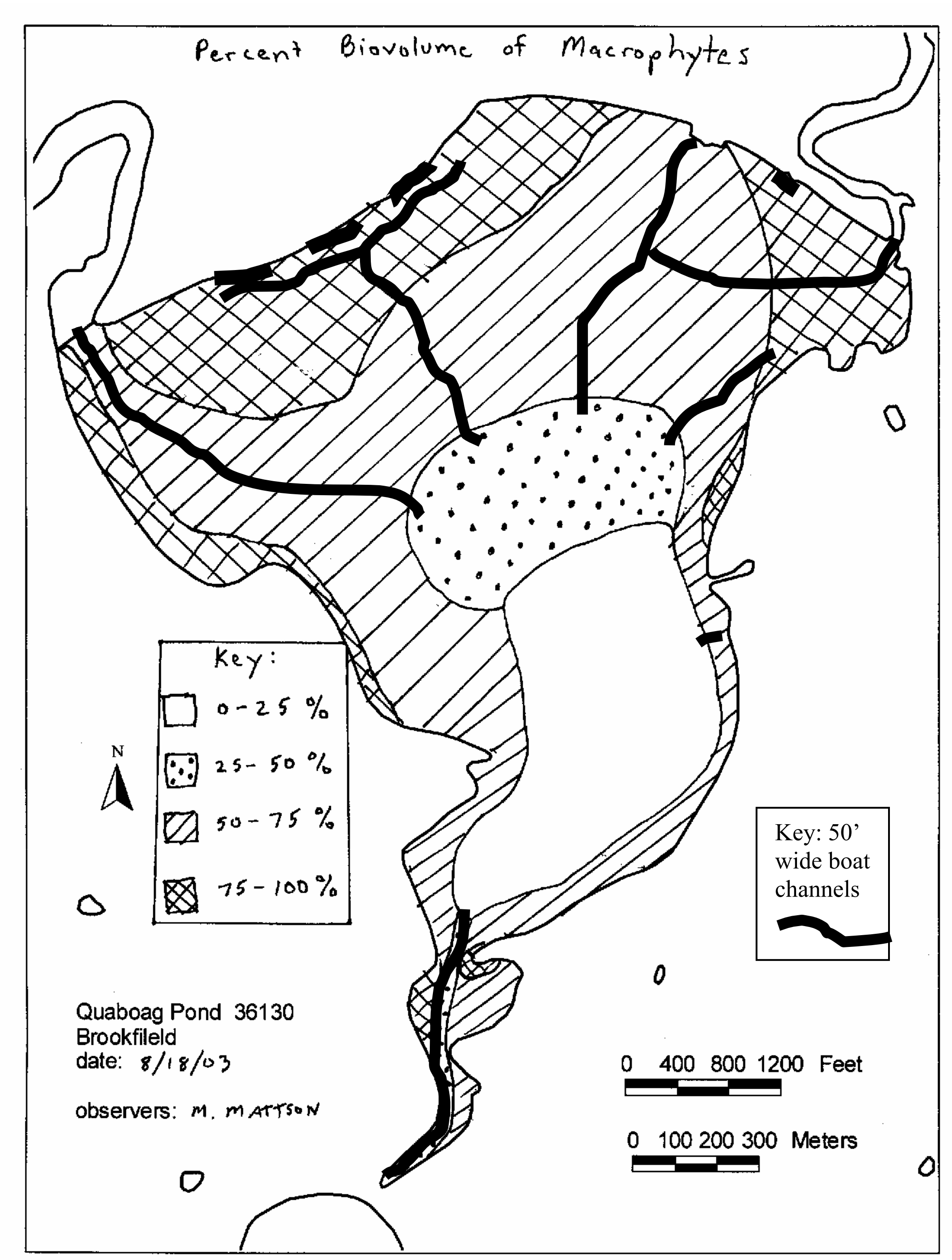


Figure 14. Proposed Boat Channel Locations.

The historic practice of using contact herbicides to control large areas of aquatic macrophytes in Quaboag Pond may contribute nutrient pulses to Quaboag Pond, which could significantly increase the size and extent of nuisance blue-green algal blooms in the pond. The proposed plan is to create a management map of the pond that includes specific limited areas or management zones, of high recreational use that are targeted for plant control via harvesting, herbicides or benthic barriers. These areas may include swimming beaches, boat launches and boating channels but should be limited to less than 5% of the lake area. The remaining 95% of the lake, which may include both open water areas as well as shallow littoral zones will be protected as natural areas where plant management does not occur. By reducing the area of herbicide treatment the amounts of nutrients released by decomposing plants will also be reduced and the blue-green blooms and associated fish kills are expected to be minimized. A proposed network of 50-foot wide boat channels is presented in Figure 14 below. The 3.2 miles of channels amounts to about 20 acres of macrophyte control and this is less than 5% of the surface area of the lake. The channels would allow small swimming areas near homes and near the unofficial beach on Shore Road and would provide boating access from all inlets and boat launch areas, both private and public, to the open water areas of the lake. By reducing the amount of plants killed, the amount of nutrient released will also be reduced, thus limiting the size and frequency of noxious blue-green blooms and fish kills. In addition the costs associated with plant control will be reduced compared to the 130-acre treatment used in past years. The recently awarded 319 grant will allow for a variety of methods to be used to control the plants, including herbicides, benthic barriers and harvesting. Data will be collected on each method to determine the costs and effectiveness of each treatment.

Responsibilities for Implementation

The Commonwealth has provided a strong framework to encourage watershed management through the recent modifications to on-site septic system regulations under Title 5 and by legislation requiring low phosphorus detergents. Because many of the nutrient sources are not under regulatory control of the state, engagement and cooperation with the Quaboag and Quacumquasit Lake Association, landowners, local officials and government organizations will be needed to implement this TMDL. The Massachusetts Department of Environmental Protection will be responsible for obtaining public comment and support for this TMDL. The proposed tasks and responsibilities for implementing the TMDL are shown in Table 11. The local citizens within the watershed will be encouraged to participate in the information gathering phase. The most important part of the information-gathering phase is to conduct a NPS watershed field survey to locate and describe sources of erosion and phosphorus within the watershed following methods described in the DEP guidebook "Surveying a Lake Watershed and Preparing and Action Plan" (DEP, 2001). Responsibility for remediation of each identified source will vary depending on land ownership, local jurisdiction and expertise as indicated in Table 12. For example, the lake association may organize a septic tank pumping and inspection program for all lakeside homeowners. Usually a discount for the pumping fee can be arranged if a large number of homeowners apply together. Farmers can apply for money to implement BMPs as part of the NRCS programs in soil conservation. Town public works departments will generally be responsible for reduction of erosion from town roadways and urban runoff. The Conservation Commission and Building Inspector will generally be responsible for ensuring the BMPs are being followed to minimize erosion from construction within the town. A description of potential funding sources for these efforts is provided in the Program Background section, above.

The major NPS implementation effort is already well underway with the recent award of a 319 nonpoint source grant to the Town of Brookfield (for Quaboag and Quacumquasit Lake Association) for $162,500 with a total commitment of $270,833 over three years. The major components for each lake will focus on the major sources of nutrients, enhancement of the floodgate, and on targeted macrophyte control. This may include urban BMPs in urban areas and septic system inspections and other rural BMPs in rural areas. Additional nutrient and erosion control will focus on enforcement of the wetlands protection act by the local Conservation Commission and various Best Management practices supported by the National Resource Conservation Service (NRCS formerly SCS). Best Management Practices (BMPs) for logging are presented in Kittredge and Parker (1995) and BMPs for general nonpoint source pollution control are described in a manual by Boutiette and Duerring (1994), BMPs for erosion and sediment control are presented in DEP (1997). See the web site
http://www.mass.gov/dep/water/resources/nonpoint.htm

for many of these publications. There is an Unpaved Roads BMP Manual available at http://www.mass.gov/dep/water/resources/nonpoint.htm All of these actions will be emphasized during the outreach efforts of the ongoing Quaboag and Quacumquasit 319 NPS grant to the Town of Brookfield .

The Department is recommending that the lake be monitored on a regular basis and if the lake does not meet the water quality standards additional implementation measures may be required. For example, if phosphorus concentrations remain high after watershed controls are in place, then in-lake control of sediment phosphorus recycling or control of other sources may be considered.

As new housing development expands within the watershed, additional measures are needed to minimize the associated additional inputs of phosphorus. A proactive approach to protecting the lake may include limiting development, particularly on steep slopes near the lake, changes in zoning laws and lot sizes, requirements that new developments and new roadways include BMPs for runoff management and more stringent regulation of septic systems. Examples of town bylaws for zoning and construction, as well as descriptions of BMPs are presented in the Nonpoint Source Management Manual by Boutiette and Duerring (1994), which was distributed to all municipalities in Massachusetts. Other voluntary measures may include encouraging the establishment of a vegetative buffer around the lake and along its tributaries, encouraging the use of non-phosphorus lawn fertilizers and controlling runoff from agriculture and timber harvesting operations. Such actions can be initiated in stages and at low cost. They provide enhancements that residents should find attractive and, therefore, should facilitate voluntary implementation. The National Resource Conservation Service is an ideal agency for such an effort and the residents will be encouraged to pursue NRCS' aid.

Reducing the supply of nutrients will not in itself result in achievement of all the goals of the TMDL and continued macrophyte management is an essential part of the implementation plan.

Table 12. TMDL Tasks and Responsibilities.

Tasks	Responsible Group
TMDL development	**DEP**
Spencer WWTP NPDES development	**DEP and EPA**
Modifications to Spencer WWTP to meet permit limits. Assess potential impacts to groundwater if treatment wetlands are expanded as part of groundwater discharge permit.	**Town of Spencer**
Monitor TP concentrations during low flow conditions at Cooney Road site on Sevemile River and compare to treatment plant and Quaboag Pond concentrations.	**DEP**
Write grant and loan funding proposals, develop lake management plan to target nutrient reduction and boat channels while avoiding algicides. Investigate and install higher flood gate on Quacumquasit Pond as appropriate.	**Local Q&Q Lake Association, Towns, working with consultants and DEP**
Organize and implement TMDL education, outreach programs	**Local Q&Q Lake Association and Town working with consultants.**
Implement Phase II BMPs, twice yearly road sweeping, catchbasin inspection and maintenance, install infiltration or other BMPs	**Town of Spencer in urbanized areas and MassHighways**
Provide periodic status reports on Phase II	**Town of Spencer in urbanized areas and**

implementation of remedial actions to DEP	**MassHighways**
Pass town bylaws to control erosion from all lands, driveways. See http://www.umass.edu/masscptc/bylaws/Rt146OD_S.htm	**Town Selectmen, town meeting.**
Implement other remedial measures for discrete NPS pollution outside of Phase II	**See Table 6 below.**
Monitoring of effectiveness and costs of in-lake BMPs as part of 319 grant	**Town of Brookfield with Q&Q Lake Association**

Table 13. Guide to Nonpoint Source Control of Phosphorus and Erosion.

Type of NPS Pollution	Whom to Contact	Types of Remedial Actions
Agricultural		
Erosion from Tilled Fields	**Landowner and NRCS**	**Conservation tillage (no-till planting); contour farming; cover crops; filter strips; etc.**
Fertilizer leaching	**Landowner and NRCS and UMass Extension**	**Conduct soil P tests; apply no more fertilizer than required. Install BMPs to prevent runoff to surface waters.**
Manure leaching	**Landowner and NRCS and UMass Extension**	**Conduct soil P tests. Apply no more manure than required by soil P test. Install manure BMPs.**
Erosion and Animal related impacts	**Landowner and NRCS**	**Fence animals away from streams; provide alternate source of water.**
Construction		
Erosion, pollution from development and new construction.	**Conservation Commission, Town officials, planning boards**	**Enact bylaws requiring BMPs and slope restrictions for new construction, zoning regulations, strict septic regulations. Enforce Wetlands Protection Act**
Erosion at construction sites	**Contractors, Conservation Commission, Building Inspector**	**Various techniques including seeding, diversion dikes, sediment fences, detention ponds etc.**
Resource Extraction		
Timber Harvesting	**Landowner, logger, Regional DEM**	**Check that an approved forest cutting plan is in place and BMPs for erosion are being followed**

	forester	
Gravel Pits	**Pit owner, Regional DEP, Conservation Commission**	**Check permits for compliance, recycle wash water, install sedimentation ponds and berms. Install rinsing ponds.**
Residential, urban areas		
Septic Systems	**Homeowner, Lake associations, Town Board of Health, Town officials**	**Establish a septic system inspection program to identify and replace systems in non-compliance with Title 5. Discourage garbage disposals in septic systems.**
Lawn and Garden fertilizers	**Homeowner, Lake associations**	**Establish an outreach and education program to encourage homeowners to eliminate the use of phosphorus fertilizers on lawns, encourage perennial plantings over lawns.**
Runoff from Housing lots	**Homeowner, Lake associations**	**Divert runoff to vegetated areas, plant buffer strips between house and lake**
Urban Runoff	**Landowner, Town or city Dept. Public Works**	**Reduce impervious surfaces, institute street sweeping program, batch basin cleaning, install detention basins etc.**
Highway Runoff	**MassHighway,**	**Regulate road sanding, salting, regular sweeping, and installation of BMPs.**
Unpaved Road runoff	**Town or city Dept. Public Works or other owner**	**Pave heavily used roads, divert runoff to vegetated areas, install riprap or vegetate eroded ditches.**
Other stream or lakeside erosion	**Landowner, Conservation Commission**	**Determine cause of problem; install riprap, plant vegetation.**

Reasonable Assurances

Reasonable assurances that the TMDL will be implemented include both enforcement of current regulations, availability of financial incentives, and the various local, state and federal program for pollution control. Enforcement of regulations includes enforcement of the permit conditions for point sources (as well as Stormwater Phase II permits) under the National Pollutant Discharge Elimination System (NPDES). Enforcement of regulations controlling nonpoint discharges include local enforcement of the states Wetlands Protection Act and Rivers Protection Act; the Title 5 regulations for septic systems and various local regulations including zoning regulations. Financial incentives include Federal monies available under the 319 NPS program and the 604 and 104b programs, which are provided as part of the Performance Partnership Agreement between DEP and the USEPA. Additional financial incentives include state income tax credits for Title 5 upgrades, low interest loans for Title 5 septic system upgrades, Clean Water Act State Revolving Fund (SFR) loans, and cost sharing for agricultural BMPs under the Federal NRCS program.

Water Quality Standards Attainment Statement

The proposed TMDL, if fully implemented, will result in the attainment of all applicable water quality standards, including designated uses and numeric criteria for each pollutant named in the Water Quality Standards Violations noted above.

Monitoring

Monitoring of the BMPs initiated under the current 319 grant is included within the scope of the grant. Monitoring of the effectiveness of the enhanced flood control gate and monitoring of the operation of the gate is expected to document reductions in backflooding frequency. At the conclusion of the 319 grant a report is expected to detail which of the methods (harvesting, herbicides and benthic barriers) was most cost effective at controlling nuisance plants within the targeted recreational management zones with the least environmental impacts. Continued monitoring of the lakes by the local lake association should document changes in transparency and frequency of blue-green blooms. DEP will continue to monitor the Sevenmile River at Cooney Road to document phosphorus concentrations during times of extended droughts and at such times to take additional TP samples at the inlet to Quaboag Pond and Quaboag Pond itself to document the effects of drought on the relative TP loading from the Spencer WWTP. Quaboag Pond bluegreen algae (cyanobacteria) numbers have been monitored in the past two summers as part of an effort to control bluegreen blooms. Additional lake surveys by DEP in future years, as resources allow, should include Secchi disk transparency, nutrient analyses, temperature and oxygen profiles and aquatic vegetation maps of distribution and density. At that time the strategy for reducing plant cover and reducing total phosphorus concentrations can be re-evaluated and the TMDL modified, if necessary. Additional monitoring of dissolved oxygen levels and total phosphorus concentrations by local volunteer groups is encouraged.

Public Participation

Several meetings with local representatives of the Quaboag and Quacumquasit Lake Association have been held during the course of the study. A public meeting was held at 7 pm in the Brookfield Town Hall on May 25, 2005 to present the report to the public and to collect public comments (see below). The attendance list for the meeting is presented in Appendix E.

Public Comment and Reply

Public comments received at the public meeting and comments received in writing within a 15 day comment period following the public meeting will be considered by the Department. The final version of the report will include both a summary of comments and the Departmental replies. The final report will be sent to U.S. EPA Region 1 in Boston for final EPA approval.

References

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnol. Oceanogr. 22(2):361-369.

Chapra, S. 1975. Comment on "An Empirical method of estimating the retention of phosphorus in lakes." By W.B.

Kirchner and P.J. Dillon. Water Resour. Res. 11:1033-1034.

Cooke, G.D., E.B. Welsh, S.A. Peterson, P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. 2nd Ed. Lewis Publishers. Boca Raton.

BEC. 1986. Diagnostic/Feasibility Study of Quaboag and Quacumquasit Ponds (North and South Ponds). Prepared for the Town of Brookfield and Massachusetts Div. Water Pollution Control... Baystate Environmental Consultants, Inc. East Longmeadow, MA.

BEC, 1995. Aquatic Macrophyte Survey. Quaboag/Quacumquasit Ponds, Brookfield, East Brookfield, Sturbridge, MA. For East Brookfield, MA. Baystate Environmental Consultants, Inc. East Longmeadow, MA.

Boutiette, L.N.Jr., and C.L. Duerring. 1994. Massachusetts Nonpoint Source Management Manual. "The MegaManual" A Guidance Document for Municipal Officials. Mass. Dept. Environmental Protection., Boston, MA.

DEP. 1996. (Revision of 1995). Massachusetts Surface Water Quality Standards. . Mass. Dept. Environmental Protection, Division of Water Pollution Control, Technical Services Branch. Westborough, MA 114p. (Revision of 314 CMR 4.00 effective June 23, 1996).

DEP, 1997. Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas. A Guide for Planners, Designers and Municipal Officials. Massachusetts Dept. Environmental Protection., EOEA, State Commission for Conservation of Soil, Water and Related Resources, Natural Resources Conservation Service USDA.

DEP, 1999. Massachusetts Section 303(d) List of Waters- 1998. Department of Environmental Protection, Division of Watershed Management, Worcester, MA.

DEP, DWM. 1998. Commonwealth of Massachusetts, Summary of Water Quality, 1998. Department of Environmental Protection, Division of Watershed Management, Worcester, MA.

DEP, 2001. Massachusetts Volunteers Guide for Surveying a Lake Watershed and Preparing an Action Plan. Department of Environmental Protection, Boston MA.

Dillon, P.J. and F.H. Rigler. 1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. J. Fish. Res. Bd. Can. 31:1771-1778.

DWM, 2003. Quality Assurance Project Plan for Baseline Lakes Survey 2003. CN 128.0 Division of Watershed Management, Department of Environmental Protection, Worcester, MA

DWM, 2003. Quickguide for Nutrient Criteria Lakes Survey 2003. CN 165.1 Division of Watershed Management, Department of Environmental Protection, Worcester, MA

ESS, 2001. The Quaboag Watershed Sub-basin: Assessment to Identify Potential Point and Nonpoint Source Pollution DEP Project No. 00-04/MWI Environmental Science Services Inc. Wellesley, MA. August 24, 2001.

ESS, 2000. Quaboag and Quacumquasit Lake Management Summary and Recommended Actions. ESS Wellesley, MA.

Fugro East 1994. Seepage Survey of Quacumquasit and Quaboag Ponds, Brookfield, East Brookfield, and Sturbridge, Massachusetts. Fugro East Inc. Northborough, MA.

Griffith, G.E., J.M. Omernik, S.M. Pierson, and C.W. Kiilsgaard. 1994. Massachusetts Ecological Regions Project. USEPA Corvallis. Massachusetts DEP, DWM Publication No. 17587-74-70-6/94-D.E.P.

Holdren, C.W., W. Jones and J. Taggart. 2001. Managing Lakes and Reservoirs. N. Am. Lake Manage. Soc. And Terrene Inst. In coop. With Off. Water Assess. Watershed Prot. Div. U.S. Environ. Prot. Agency, Madison, WI.

Horne, A.J. and C.R. Goldman. 1994. Limnology. 2nd Ed. McGraw-Hill Inc. New York.

Jones, J.R. and R.W. Bachmann. 1976. Prediction of phosphorus and chlorophyll levels in lakes. JWPCF 48:2176-2184.

Kirchner, W.B. and P.J. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lakes. Water Resour. Res. 11:182-183.

Kittredge, D.B., Jr. and Parker, M. 1995. Massachusetts Forestry Best Management Practices Manual. Mass. Dept. Environmental Protection. Office of Watershed Management and U.S.E.P.A. 56pp.

Larsen, Dd.P. and H.T. Mercier. 197. Phosphorus retention capacity of lakes. J.Fish. Res. Bd. Canada. 33:1742-1750.

Likens, G.E. 1972. Nutrients and Eutrophication.: The Limiting-Nutrient Controversy. Limnology and Oceanography, Special Symposia Volume I. 328pp.

Lycott, 1994. Final Report, Phase II Implementation Project Quaboag & Quacumquasit Ponds Town of Brookfield, MA. Lycott Environmental Research. Southbridge, MA.

Mattson, M.D., P.J. Godfrey, R.A. Barletta and A. Aiello. 2004. Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report. Edited by Kenneth J Wagner. Department of Environmental Protection and Department of Conservation and Recreation, Executive Office of Environmental Affairs, Commonwealth of Massachusetts.

Mattson, M.D. and R.A. Isaac. 1999. Calibration of Phosphorus Export coefficients for Total Maximum Daily Loads of Massachusetts Lakes. Lake and Reservoir Man. 15(3):209-219.

Reckhow, K.H. 1979. Uncertainty Analysis Applied to Vollenweider's Phosphorus Loading Criteria. J. Water Poll. Control Fed. 51(8):2123-2128.

Reckhow, K.H., M.N. Beaulac, J.T. Simpson. 1980. Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. U.S.E.P.A. Washington DC. EPA 440/5-80-011.
Rohm, C.M., J.M. Omernik, and C.W. Kiilsgaard. 1995. Regional Patterns of Total Phosphorus in Lakes of the Northeastern United States. Lake and Reservoir Man. 11(1): 1-14.

Schindler, D.W. and E.J. Fee. 1974. Experimental Lakes Area: Whole-Lake Experiments in Eutrophication. J. Fish. Res. Bd. Can. 31:937-953.

SCS, 1978. Flood Hazard Analyses Upper Quaboag River (including East Brookfield River, Seven Mile River, Turkey Hill Brook, Cranberry River, Great Brook) Worcester County, Massachusetts. USDA Soil Conservation Service, Amherst, MA.

Smith, C.S. and M.S. Adams. 1986. Phosphorus transfer from sediments by Myriophyllum spicatum. Limnol. Oceanogr. 31(6):1312-1321.

Snow, P.D., and F.A. DiGiano. 1976. Mathematical Modeling of Phosphorus Exchange Between Sediments and Overlying Water in Shallow Eutrophic Lakes. Sept. 1976 Report No. Env. E. 54-76-3, Envir. Eng. Dept. Civil Eng. Umass, Amherst, MA.

Vallentyne, J.R. 1974. The Algal Bowl – Lakes and Man. Ottawa, Misc. Spec. Publ. 22. Dept. of the Environ. 185pp.

Vollenweider, R.A. 1975. Input-Output Models with Special Reference to the Phosphorus Loading Concept in Limnology. Sch. Zeit. Hydrologic 37:53-84.

Vollenweider, R.A. 1976. Advances in Defining Critical Loading Leveles for Phosphorus in Lake Eutrophication. Mem. Ist. Ital. Idrobiol., 33:53-83.

Wetzel, R.G. 1983. Limnology. 2nd Ed. Saunders College Publishing. New York.

Appendix A. In-lake Models for Predicting Loads and Concentrations for Quaboag Pond (summer).

TABLE A1. IN-LAKE MODELS FOR PREDICTING PHOSPHORUS LOADS AND CONCENTRATIONS FOR QUABOAG POND, SUMMER PERIOD

PART 1: THE TERMS

Quaboag summer

SYMBOL	PARAMETER	UNITS	DERIVATION	VALUE
TP	Lake Total Phosphorus Conc.	ppb	From data or model	43
L	Phosphorus Load to Lake	g P/m2/yr	From data or model	1.65
TPin	Influent (Inflow) Total Phosphorus	ppb	From data	25
TPout	Effluent (Outlet) Total Phosphorus	ppb	From data	32
I	Inflow	m3/yr	From data	85369000
A	Lake Area	m2	From data	2.17E+06
V	Lake Volume	m3	From data	4.46E+06
Z	Mean Depth	m	Volume/area	2.0552995
F	Flushing Rate	flushings/yr	Inflow/volume	19.141031
S	Suspended Fraction	no units	Effluent TP/Influent TP	1.28
Qs	Areal Water Load	m/yr	Z(F)	39.340553
Vs	Settling Velocity	m	Z(S)	2.6307834
R	Retention Coefficient (from TP)	no units	(TPin-TPout)/TPin	-0.28
Rp	Retention Coefficient (settling rate)	no units	((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs)	0.1675004
Rlm	Retention Coefficient (flushing rate)	no units	1/(1+F^0.5)	0.1860449
	annual load	kg/yr	totalannualized summer load	3585
	ret days			19.068983

TABLE A2. IN-LAKE MODELS FOR PREDICTING PHOSPHORUS LOADS AND CONCENTRATIONS IN QUABOAG POND, SUMMER PERIOD

THE MODELS

				LOAD ANALYSIS	
		PREDICTION			**ESTIMATED**
NAME	**FORMULA**	**CONC. (ppb)**	**LOAD (g/m2/yr)**	**MODEL**	**LOAD (kg/yr)**
Mass Balance	TP=L/(Z(F))*1000	42		***Phosphorus***	
(minimum load)	L=TP(Z)(F)/1000		1.69	Mass Balance (no loss)	3671
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	35			
(K-D)	L=TP(Z)(F)/(1-Rp)/1000		2.03	Kirchner-Dillon 1975	4409
Vollenweider 1975	TP=L/(Z(S+F))*1000	39			
(V)	L=TP(Z)(S+F)/1000		1.80	Vollenweider 1975	3916
Chapra	TP=L(1-R)/(Z(F)*1000	54			
(C)	L=TP(Z)(F)/(1-R)/1000		1.32	Chapra 1975	2868
Larsen-Mercier 1976	TP=L(1-Rlm)/(Z(F))*1000	34			
(L-M)	L=TP(Z)(F)/(1-Rlm)/1000		2.08	Larsen-Mercier 1976	4510
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	34			
(J-B)	L=TP(Z)(0.65+F)/0.84/1000		2.08	Jones-Bachmann 1976	4518
Average of Model Values		39		Model Average	
(without mass balance)			1.86	(without mass balance)	4044

Appendix B. In-lake Models for Predicting Loads and Concentrations for Quacumquasit Pond (annual based on spring concentration).

TABLE B1. IN-LAKE MODELS FOR PREDICTING PHOSPHORUS LOADS AND CONCENTRATIONS FOR QUACUMQUASIT POND

PART 1: THE TERMS

SYMBOL	PARAMETER	UNITS	DERIVATION	VALUE
TP	Lake Total Phosphorus Conc.	ppb	From data or model	15
L	Phosphorus Load to Lake	g P/m2/yr	From data or model	0.22
TPin	Influent (Inflow) Total Phosphorus	ppb	From data	24
TPout	Effluent (Outlet) Total Phosphorus	ppb	From data	12
I	Inflow	m3/yr	From data	5.69E+06
A	Lake Area	m2	From data	9.11E+05
V	Lake Volume	m3	From data	8.33E+06
Z	Mean Depth	m	Volume/area	9.143798
F	Flushing Rate	flushings/yr	Inflow/volume	0.683073
S	Suspended Fraction	no units	Effluent TP/Influent TP	0.5
Qs	Areal Water Load	m/yr	Z(F)	6.245884
Vs	Settling Velocity	m	Z(S)	4.571899
R	Retention Coefficient (from TP)	no units	(TPin-TPout)/TPin	0.5
Rp	Retention Coefficient (settling rate)	no units	((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs)	0.587235
Rlm	Retention Coefficient (flushing rate)	no units	1/(1+F^0.5)	0.5475
	Annual load	kg/yr		199
	retention days			534.3497
	Inflow calculated from USGS			3.26E+06
	inflow from backflood			2430000

TABLE B2. IN-LAKE MODELS FOR PREDICTING PHOSPHORUS LOADS AND CONCENTRATIONS FOR QUACUMQUASIT POND

PART 2: THE MODELS

NAME	FORMULA	PREDICTION CONC. (ppb)	PREDICTION LOAD (g/m2/yr)	*LOAD ANALYSIS* MODEL	ESTIMATED LOAD (kg/yr)
Mass Balance	TP=L/(Z(F))*1000	35		***Phosphorus***	
(minimum load)	L=TP(Z)(F)/1000		0.09	Mass Balance (no loss)	85
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	14			
(K-D)	L=TP(Z)(F)/(1-Rp)/1000		0.23	Kirchner-Dillon 1975	207
Vollenweider 1975	TP=L/(Z(S+F))*1000	20			
(V)	L=TP(Z)(S+F)/1000		0.16	Vollenweider 1975	148
Chapra	TP=L(1-R)/(Z(F)*1000	17			
(C)	L=TP(Z)(F)/(1-R)/1000		0.19	Chapra 1975	171
Larsen-Mercier 1976	TP=L(1-Rlm)/(Z(F))*1000	16			
(L-M)	L=TP(Z)(F)/(1-Rlm)/1000		0.21	Larsen-Mercier 1976	189
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	15			
(J-B)	L=TP(Z)(0.65+F)/0.84/1000		0.22	Jones-Bachmann 1976	198
Average of Model Values		17		Model Average	
(without mass balance)			0.20	(without mass balance)	182

Appendix C. Letter from The Department Of The Army Corps Of Engineers.

DEPARTMENT OF THE ARMY
NEW ENGLAND DISTRICT, CORPS OF ENGINEERS
696 VIRGINIA ROAD
CONCORD, MASSACHUSETTS 01742-2751

REPLY TO
ATTENTION OF

January 29, 2004

Engineering/Planning Division
Planning Branch

Ms. Donna Grehl, President
Quacumquasit and Quaboag Lake Association
Post Office Box 370
East Brookfield, Massachusetts 01515

Dear Ms. Grehl,

The purpose of this letter is to respond to your December 1, 2003 letter, which raised three questions concerning water levels at Quacumquasit and Quaboag Ponds, also known as South and North Pond, respectively, located in Brookfield, Massachusetts.

Mr. William Mullen P.E., a Hydraulic Engineer with this office, reviewed the Federal Emergency Management Agency's Flood Insurance Studies for the Towns of Brookfield and West Brookfield (dated January 1981 and December 1981 respectively), and, on January 8, 2004, inspected the ponds and their vicinity along with Mr. Mark Mattson, Ph.D. of the Massachusetts Department of Environmental Protection. The cursory investigation and brief site visit were funded under the U.S. Army Corps of Engineers Flood Plain Management Services (FPMS) Program. It should be emphasized that our responses are based on simple "rule of thumb" methods and engineering judgment that are not a substitute for appropriate hydrologic and hydraulic modeling which would provide more definitive answers. An enclosure with this letter provides additional backup material.

If the floodgate were increased an additional 18 inches, how much higher would a typical 2-foot spring flood reach in Quaboag Pond?

The maximum potential "lost" storage volume caused by preventing 18 inches of Quaboag Pond volume from back-flooding into Quacumquasit Pond is equal to 333 acre-feet. This displaced water will instead be "forced" into the available storage area downstream of Quacumquasit Pond, an area that we believe includes Quaboag Pond <u>and</u> the wetlands in the reach extending from Quaboag Pond downstream to Long Hill Road in the Town of West Brookfield. Based on computed areas of the pond and wetland, the "displaced" water could be expected to raise water levels in these areas an amount unlikely to exceed 0.2 feet.

Is the sandbar or some other location the control point for floodwaters in Quaboag Pond?

Control points for Quaboag Pond during major floods appear to include the Fiskdale Road Bridge in Brookfield, and the three bridges in West Brookfield (Long Hill Road, Conrail, and State Route 67). In addition, the river bottom profile shown in the FIS reports, indicates a channel bottom through a two-mile reach of West Brookfield that is actually higher than the channel bottom at the outlet of Quaboag Pond. This "perched" channel reach can be expected to play a significant role in controlling flood levels in Quaboag Pond, especially during common flood events. We do not believe that the sandbar plays a significant role on flood levels in Quaboag Pond.

Is there a relatively low cost and environmentally responsible remedy to lower floodwaters in Quaboag Lake?

Although not analyzed in detail it appears that a significant reach of the Quaboag River in West Brookfield would have to be dredged to lower water surface elevations significantly in Quaboag Pond. This could result in drainage of the wetlands upstream of Long Hill Road, and therefore environmental damages could be significant.

If you have any further questions or comments on this matter, please refer them to Mr. Mullen of our staff. He can be reached at 978-318-8559.

Sincerely,

John R. Kennelly
Chief of Planning

Enclosure

Copy Furnished:

Mr. Mark Mattson, PhD
Massachusetts Department
of Environmental Protection
627 Main St. 2nd Floor
Worcester, Massachusetts 01608

Quacumquasit and Quaboag Ponds (Brookfield, MA)
Supporting Information

It should be emphasized that the below responses are based on simple "rule of thumb" methods and engineering judgment that are not a substitute for appropriate hydrologic and hydraulic modeling which would provide more definitive answers.

If the floodgate were increased an additional 18 inches, how much higher would a typical 2-foot spring flood reach in Quaboag Pond?

Due to funding limitations that prevent us from performing detailed hydrologic and hydraulic modeling, we had to rely on "ballpark" calculations of the increased height in water surface elevation.

The maximum potential "lost" storage volume caused by preventing 18 inches of Quaboag Pond volume from back-flooding into Quacumquasit Pond is equal to the Quacumquasit Pond surface area of 222 acres times 1.5 feet (i.e. 18 inches) or 333 acre-feet. The "lost" storage volume represents only a small fraction of the runoff volume that could be expected from the Quaboag River's contributory drainage area during a typical spring flood. This displaced water will instead be "forced" into available storage downstream of Quacumquasit Pond. We have examined the 10-year flood profile (the smallest flood presented in FIS reports) for the Quaboag River, in order to get an idea of what might be expected during a "typical 2-foot spring flood". Examination of this profile indicates a drop in water surface elevation of only 1.2 feet over a 5.3-mile reach from the outlet of Quaboag Pond to Long Hill Road, located in the Town of West Brookfield. Subsequent inspection of U.S. Geological Survey topographical maps of the area indicates that water coming out of Quaboag Pond enters a large area of wetlands extending from the outlet of Quaboag Pond to Long Hill Road. The flood profile indicates nearly no drop in water surface elevation from Quaboag Pond to the wetlands downstream of North Pond. We believe that the water displaced from being stored in South Pond during a 10-year flood will now be temporarily stored in Quaboag Pond <u>and</u> the vast expanse of wetlands bordering the Quaboag River in the reach from Quaboag Pond to Long Hill Road. The "normal" surface area of Quaboag Pond and the wetlands, as shown on USGS maps, is approximately 1780 acres. The maximum volume of 333 acre-feet displaced from storage in Quacumquasit Pond is therefore likely to be dispersed over the 1780-acre "normal" pond/wetland area, or an even greater area, since higher water levels cover larger areas. The "displaced" water would thereby raise water levels in Quaboag Pond and the wetlands a small amount, an average of approximately 0.2 feet. It is recognized that the flow of floodwaters presents a dynamic situation; water is not merely stored, but instead continues to flow further downstream during the flood event. The 0.2-foot average increase in water level caused by the "lost" storage is, therefore, likely to represent a worst-case scenario.

Available information leads us to believe that a typical spring flood produces a maximum water surface elevation in Quaboag and Quacumquasit Pond of approximately 601-602 feet above the National Geodetic Vertical Datum (NGVD) of 1929. According to Brookfield's FIS, a 10-year flood produces a maximum water surface elevation in the ponds of 603.2 feet above NGVD. This information, along with an examination of channel bottom elevations of the Quaboag River, leads us to conclude that findings for the "typical 2-foot spring flood" are likely to be nearly the same as those of a 10-year flood, i.e. that displacing flood storage out of Quacumquasit Pond is likely to cause a rise in Quaboag Pond water surface elevation not to exceed approximately 0.2 feet during a "typical 2-foot spring flood".

Is the sandbar or some other location the control point for floodwaters in Quaboag Pond?

Examination of flood profiles for the Quaboag River presented in the FIS reports leads us to conclude that, for the 10, 50, 100, and 500-year floods, the main control points for Quaboag Pond floodwaters are the Fiskdale Road Bridge in Brookfield, and the three bridges in West Brookfield (Long Hill Road, Conrail, and State Route 67), although none of these bridges causes a large loss in "hydraulic head", and the loss at each of these bridges is nearly the same. In addition, the river bottom profile shown in the FIS reports indicates a channel bottom through a two-mile reach of West Brookfield that is actually higher than the channel bottom at the outlet of Quaboag Pond. This "perched" channel reach can be expected to play a significant role in controlling the relatively high water level associated with Quaboag Pond, especially during the more common flood events.

The sandbar at the outlet of Quaboag Pond is typically submerged by several feet of water, with the elevation of the "crest" of the sandbar estimated to be approximately 595-597 feet above NGVD. By comparing this crest elevation to any of the flood elevations (including the "typical 2-foot spring flood" with its maximum pond elevation of 601-602 feet above NGVD), it can be inferred that the sandbar has little or no impact on peak floodwater surface elevations in Quaboag Pond.

Is there a relatively low cost and environmentally responsible remedy to lower floodwaters in Quaboag Lake?

Although not analyzed in detail it appears that a significant reach of the Quaboag River in West Brookfield would have to be dredged to lower water surface elevations significantly in Quaboag Pond. This could result in drainage of the wetlands upstream of Long Hill Road, and therefore environmental damages could be significant.

-2-

Appendix D. Measured Flows vs. Flows Estimated from USGS Gage and flowfactor.

Site SMG, the established USGS gage 01175670 was used as the primary independent data source to estimate flows throughout the Quaboag watershed. The site is centrally located within the Quaboag watershed and in addition to daily historic flows is also a real-time data site with data available on the Internet at:
http://waterdata.usgs.gov/ma/nwis/uv?format=gif&period=31&site_no=01175670

Five other sites (SM01, SM02, CR01, EB04, and EB04a) had flows measured three times during the spring and summer at high, medium and low flow conditions by DEP staff using established protocols (CN68.0 Flow Measurement SOP). Semipermanent staff gauges were established at all sites. At sites SM02, CR01 and EB04 metal staff gauges were either attached to the concrete bridge apron or at SM02 attached to a wooden bridge piling in the water. At site SM01 a site approximately 80 meters upstream of the bridge on the west bank a nail was driven into an overhanging tree to serve as a reference point for measuring vertical distance to the water surface (a negative stage reading) with a hand tape measure. Similarly at site EB04a the top of the bridge guard rail on the north side of the bridge in the middle of the river was used as a reference point for distance to the water surface (negative staff reading). The Shore Road bridge at EB04a was marked in the flood report (SCS, 1978) as having a clearance elevation of 601.8 feet and the true elevation of the staff readings were measured to be 6 feet higher than the bottom of the I-beam on the bridge or 607.8 feet. The stage discharge relationship at this site appeared to be linear (see Figure D1 below). and was used as a estimation of the level of Quaboag Pond and the water level at the flood control gate at Quacumquasit Pond (see text). The other stage readings were not related to fixed base elevations and were used to confirm flows during other water quality sampling events.

The runoff flowfactor is the amount of runoff in cubic feet per second per square mile of watershed for the day in question. This factor was calculated for each day of the year at the primary USGS gage at site SMG. This flow factor was then multiplied by areas of each of the subwatersheds defined by the pourpoints at the other sites. Watershed areas were calculated by Arcview and are shown in Figure 12 of this report. The estimated daily flows by the flowfactor approach agreed very well with flows measured at the site as shown in Table D1 below. The average error was only 6.6 cfs and the largest error was less than 18 cfs. Some errors as low flow resulted in percent errors as large as –36%, but these are associated with very small flows, whereas during the high flows the estimated errors were less than 6% and thus the bulk of annual load of water was estimated fairly accurately with the flowfactor method.

Table D1. Flow Measurements vs. Estimated Flows at Sampling Sites.

Only selected data shown for the Primary site SMG and for flows from the Spencer WWTP. Note: the two measurements taken on 6/18/03 at EB04a were duplicate measurements taken by different crews with different types of flow meters.

Site	Description	Date	Stage	Measured flow	Est Flow	Percent error
	Primary site:		feet	cfs	cfs	%
SMG	USGS GAGE 01175670 Cooney Rd.	4/7/03		39	39	
SMG	USGS GAGE 01175670 Cooney Rd.	6/18/03		14	14	
SMG	USGS GAGE 01175670 Cooney Rd.	8/20/03		4.9	4.9	
	Sampling sites:					
SM01	Sevenmile at Rt 9.	4/7/03	4.375	132.07*	138.2	-5
SM01	Sevenmile at Rt 9.	6/18/03	4.915	54.2	49.6	8
SM01	Sevenmile at Rt 9.	8/20/03	5.2	14.5	17.4	-20
CR01	Cranberry R. @S. Spencer Rd.	4/3/03	28.81	31.69**	32.7	-3
CR01	Cranberry R. @S. Spencer Rd.	6/18/03	28.18	11.24*	9.0	20

CR01	Cranberry R. @S. Spencer Rd.	8/20/03	27.85	2.31**	3.1	-36
SM02	Sevenmile At Rt 49.	4/7/03	11.7	159.04*	168.2	-6
SM02	Sevenmile At Rt 49.	6/18/03	10.7	71.7**	60.4	16
SM02	Sevenmile At Rt 49.	8/20/03	10.22	18.1	21.1	-17
EB04	Outlet of Lashaway	4/7/03	79.85	115.24**	109.2	5
EB04	Outlet of Lashaway	6/18/03	79.35	42.24*	39.2	7
EB04	Outlet of Lashaway	8/20/03	78.9	10.09*	13.7	-36
EB04a	Inlet to Quaboag, Shore Rd.	4/3/03	6.93	405.87-	413.0	-2
EB04a	Inlet to Quaboag, Shore Rd.	6/18/03	8.63	130.10-	113.4	13
EB04a	Inlet to Quaboag, Shore Rd.	6/18/03	8.66	131*	113.4	13
EB04a	Inlet to Quaboag, Shore Rd.	8/20/03	9.19	29.3*	39.7	-35
SPEFF	Spencer WWTP final effluent#	4/7/03	1.0MGD	1.548		
SPEFF	Spencer WWTP final effluent#	6/18/03	0.64MGD	0.99072		
SPEFF	Spencer WWTP final effluent#	8/20/03	0.23MGD	0.35604		

Type of meter used:
- AA PRICE
* Swoffer
** Sontek
# Spencer WWTP DMR selected dates

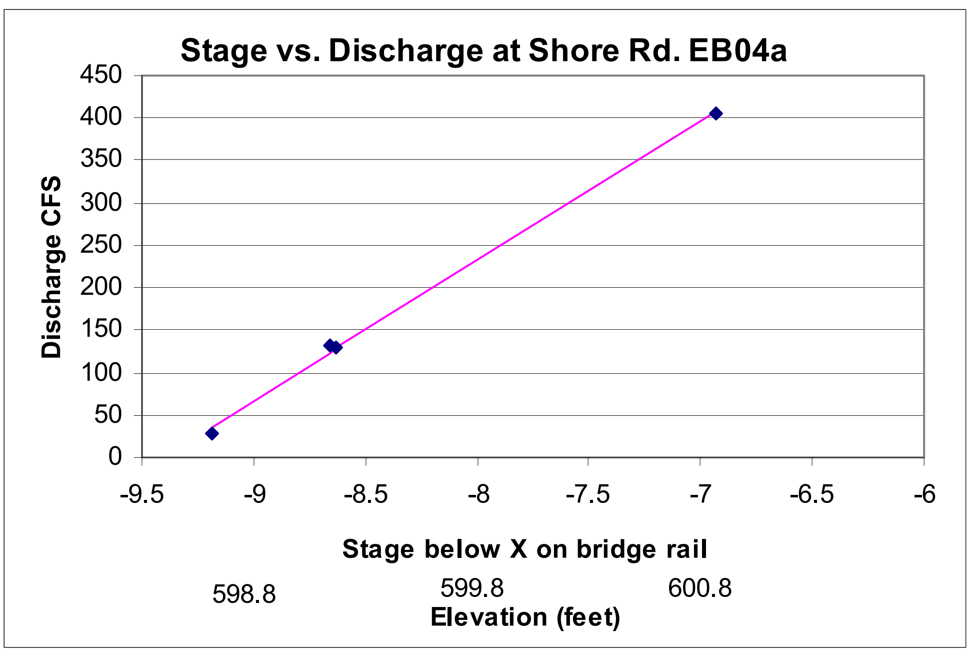


Figure D 1. Stage vs. Discharge at Site EB04a Shore Road.

Appendix E. Public Comment and Reply.

Comments were collected from discussions at the public meeting held on May 25, 2005 at the Brookfield Town Hall. Additional comments were sent to DEP after the meeting. In some cases, comments are edited and condensed for clarity. The list of attendees follows the comments.

Comments: public meeting 5/25/05

Comment from Spencer Town Administrator: The town of Spencer has raised fees and reduced TP loading and now meets 0.2mg/l and it is not cost effective to target them for additional controls, when 96% is coming from other sources. On Phase II issues, the state has cut back on funding to the town in recent years and it is very expensive to inspect and if needed, clean catchbasins two times per year and they don't want to put that money into it until the state provides assistance.

Reply: The Spencer WWTP is unusual in that it is one of the few town treatment plants which discharge to a tributary of a large natural pond (Quaboag Pond is a recognized great pond in Massachusetts). The state Water Quality Standards state in part: "There shall be no new or increased point source discharge to tributaries of lakes or ponds that would encourage cultural eutrophication or the growth of weeds or algae in these lakes or ponds. Any existing point source discharge containing nutrients in concentrations which encourage eutrophication or growth of weeds or algae shall be provided with the highest and best practical treatment to remove such nutrients." The limits proposed in the TMDL fall within those regulations and cap loadings that are being discharged today. Any increase in flow to the treatment plant will also require additional reductions in phosphorous concentrations to ensure that phosphorus loadings to the lake are not increased in the future. Further monitoring may lead to additional controls on the portion of the discharge to surface waters in the future but are not proposed at this time. The Department recommends that the Town of Spencer investigate the feasibility of obtaining a groundwater discharge permit and increasing the portion of discharge to groundwater, which would have significantly less effect on downstream surface waters. Street sweeping and catchbasin cleaning are two important BMPs that towns can use to reduce sediment and associated pollutant loadings to surface waters. The TMDL documents that these actions are necessary to achieve water quality standards in Quaboag Pond. Although funding sources are limited, the Department encourages towns, either individually or jointly, to apply for funding assistance from various state programs including the DEP section 319 (nonpoint source grants) and the State Revolving Fund Program (SRF); see watershed grants listed in http://www.mass.gov/dep/water/grants.htm#guides

Comment from concerned citizen living along channel on north (Quaboag) side of the flow gate: Claims his septic system is threatened by flooding and his shoreline impacted by erosion even with the current gate in operation and increasing the flood gate height by 18 inches would exacerbate the impacts (photos of flooding and erosion were included in letter).

Reply: The Flood Hazard Analyses Upper Quaboag River (USDA, SCS, Amherst MA, 1978) has extensively studied the flood elevations for the Sevenmile and Quaboag River system including Quaboag Pond with associated backflooding into Quacumquasit Pond. Flood profile sheet 4 indicates a normal water level of Quaboag Pond of about 597 feet above sea level and indicates the expected ten-year flood with an elevation of 603.5 feet (or 6.5 feet) and the 100-year flood being another 1.5 feet above that. The USDA/SCS report also includes areal photographs of the Quaboag/Quacumquasit Pond systems with the 100-year flood noted on the map photos. It appears that the homes and property located near the flood control gate are presently located within the flood plain and are expected to be flooded on occasion. Smaller floods than these occur with regular frequency. Figure 13 shows four floods in the study year were over the top of the flood gate (elevation 599.5 feet) and in fact the system was naturally flooding again just this spring (2005) before your pictures were taken and again on October 15, 2005. On April 4, 2005 many homes on the Quaboag shoreline were surrounded by water and water was traveling 8 inches over the north Shore Road of Quaboag Pond with the pond at an elevation of about 603 feet at 4pm that day. According to the chief of Police who has to close the roads, this is a fairly common occurrence and certainly more frequently that once in ten years. The October flood was larger and actually overtopped the bridge and roadway at the Quacumquasit gate by 4 inches, and quickly filled Quacumquasit Pond to the same level, demonstrating again, that Quacumquasit does act to accept floodwaters in large floods, but the overall effect of lowering levels in Quaboag Pond even then is minor.

While it is true that the flood gate does hold back floodwater, and the flood level of Quaboag Pond could be lowered by allowing floodwaters to fill Quacumquasit Pond, the beneficial effect is both minor and temporary. As noted in the Army Corps of Engineers flood expert report, the area and storage capacity of Quacumquasit Pond is small in comparison to the flooded area of the Quaboag Pond/riverine wetland system. The ratio of flood storage areas is 8 fold higher in the Quaboag Pond/River/wetland side than in Quacumquasit Pond side (1780 acres vs. 222 acres). The 18 inches of water storage in Quacumquasit amounts to only 333 acre-feet and the resulting rise in water in the channel and Quaboag Pond and associated wetlands would only amount to less than 0.2 feet or about 2 ½ inches on top of a typical 2-foot flood. This is minor in comparison to the normal flooding that occurs in the area as the pond often varies several feet in elevation from season to season and year to year. It should be noted again that even if the gate is increased by 18 inches, the top of the gate would then be at an elevation of only 601 feet and all of the larger floods noted in the discussion above would overtop even the new gate, so Quacumquasit Pond would still be used for flood storage during those high water events. Water flowing over the top of the gate would essentially be skimming and reducing the peak flow of larger floods to a small extent. As noted in the Army Corps of Engineers report (see Appendix C above), the areas of the river that controls flood elevation in Quaboag Pond is in fact the shallow river bottom and the bridge abutments located far downstream of Quaboag Pond. According to the engineers (See Appendix C above), that is the area that controls flood levels in Quaboag Pond and surrounding areas, including the connecting channel.

The photos that were included in the comment letter show shoreline erosion undermining tree roots. According to our staff who have experience in this topic, such erosion appears more likely to be due to wave action or boat wakes rather than due to high water alone and the Department recommends planting vegetative buffers (cattails, sedges, willows) to protect the shoreline as described in the Massachusetts Buffer Manual (BRPC, 2003) which will be sent to you via the QQLA lake association. The Department is currently funding a 319 Nonpoint source grant to the town of Brookfield and the Quaboag and Quacumquasit Lake Association to address erosion such as observed in the photographs of your property. In fact, item 7 in the scope of services is directed to implementation of solutions to such erosion properties and the Department recommends you contact the QQLA to discuss including your property as a site for vegetative buffer remediation as part of the grant project.
References: Berkshire Regional Planning Commission, 2003. The Massachusetts Buffer Manual. BRPC, prepared for Mass. DEP.

Comment: Can't the entire Quaboag River be dredged to reduce floodwater elevations?
Reply: As noted in the Army Corps letter (see Appendix C, above), to substantially reduce the flood levels would require dredging the river bottom from Quaboag Pond to the Route 67 Bridge, approximately 4.9 miles downstream of Quaboag Pond. Assuming dredging would be 30 feet wide by six feet deep, this would amount to approximately 172,000 cubic yards or about $1.7 million assuming costs on the order of $10 per cubic yard of material removed. Lowering the water levels would likely negatively impact important wildlife wetland all along the Quaboag River system and such a project is unlikely to be granted the necessary permits due to the environmental impacts. It should be noted however, that some of the flooding of homes along the north shore of Quaboag Pond (from upstream floodwater that can't get through the Shore Road bridge fast enough as occurred in April of 2005) may be alleviated somewhat by reconstruction of the Shore Road Bridge and by cleaning out the sediment at the culverts between the river just upstream of the pond and the pond itself (and previously recommended in the BEC, 1986 report), but occasional floods would still be expected to flood homes built on the flood plane of the river and pond as noted in the USDA/SCS, 1978 report. The only reasonable alternative would be to construct flood control dams further upstream, having the effect of flooding other properties.

Comment: What is the depth extent of trout in Quacumquasit.
Reply: Although the Department of Fish and Game did not provide any detailed information on the depth that trout live in Quaboag Pond we can assume that they do extend at least as deep as 8m (26 feet) as indicated by the trout space diagram in Figure 9.

Comment: Discuss the alewife zooplankton issue.
Reply: As noted by the Fish and Game Department, alewives were introduced to the pond in 1981. Various studies (most notably Brooks and Dodson, 1965) have noted that when alewives are introduced to freshwater ponds, they consume large zooplankton such as Daphnia and allow smaller zooplankton (such as Bosmina) to increase in relative abundance. The smaller zooplankton are less efficient at grazing algae and thus such lakes tend to have more algae than would otherwise be expected. At this point, it would be extremely difficult to remove the alewives but it is expected that with continued stocking of large brown trout the alewife population will be kept in check. References: Brooks, J.L. and S.I. Dodson. 1965. Predation, body size and composition of plankton. Science. 150:28-35.

Comment: Does Lake Lashaway withdraw from the bottom?
Reply: Lake Lashaway normally discharges over the top of the spillway. During drawdowns in the fall the discharge pipe is used. The lowest elevation of the discharge pipe is about 10 feet below normal lake levels but the order of conditions allows only a 6-foot drawdown.

Comment: What uses are protected by the selected targets?
Reply: Quaboag Pond is a Class B warmwater and Quacumquasit Pond is a Class B coldwater and the uses include swimming and other contract recreation including boating. Other uses would include warmwater fishing in Quaboag and coldwater fishing in Quacumquasit. Both ponds must maintain good aesthetic quality. The selected targets must protect all of these uses.

Comments by USEPA Region 1:

EPA Comment 1: EPA has significant concerns with the basis for the proposed target of 30 ppb. It is considerably higher than EPA's ecoregion based criteria and higher than most literature values for total phosphorus levels that are protective of the water quality of lakes. It is also higher than the target used in the French River TMDL for impoundments with significantly shorter retention times. The discussion on why a higher target is justified is confusing, e.g., why would wind driven resuspension and macrophyte resuspension justify a higher target? In addition, the data were collected during more of a wet weather year vs. a more normal or even dry year. Data from normal or even dry weather years might cause the allocations to be different and even the target to be lower.

The facts do not seem to support that 30 ppb is a protective target let alone the contention that it represents a margin of safety. On page 44 the report indicates that approximately 40 ppb would achieve the swimming standard and approximately 43 ppb would protect the warm water fishery. However, on page 21 the report indicates that summer average phosphorus levels were measured at 43 ppb while chlorophyll a ranged from 10.2 - 35.1 ppb, levels that are acknowledged as representing near hypereutrophic conditions. The WWTP discharges continuously during the summer growing season and phosphorous has more of an impact during this time, especially if it is in the dissolved form.

The TMDL must target a level that will control accelerated or cultural eutrophication. This is the applicable criteria in the MA water quality standards although it is omitted from the discussion on page 20 of nutrient standards.

Reply: The 8ppb target suggested by the EPA Ecoregional approach would not be appropriate for a warmwater fishery in a lake with such a large watershed. In particular, it appears that Quaboag Pond water is naturally colored with dissolved organic carbon, presumably from upstream wetlands. Such waters are often high in phosphorus. The major tributary, the Sevenmile River upstream of Route 9 in Spencer (upstream of the treatment plant) was relatively high in TP, ranging between 37 and 39 ppb from June-August of the study year indicating relatively high background concentrations. While some of this phosphorus might be due to urban stormwater and nonpoint sources, historical data suggest the TP is high in concentration in the watershed even further upstream. Our analysis of Sevenmile River total phosphorus data collected at the USGS gage at Cooney Road in Spencer (74 % forested and upstream of any urban impacts and upstream of the treatment plant) shows the total phosphorus concentration in the stream is generally high in July from 40 ppb in 1998 to 30 ppb in 1999 and typically drops to 20 ppb by September in most years, which we believe are indicative of natural conditions within this watershed. Considering that the inlet stream is high in total phosphorus (reflecting primarily natural conditions) and Quaboag Pond chemistry is dominated by the stream, it seems reasonable to set the target in the same range as what naturally occurs in the watershed. Thus the Department believes the target of 30 ppb is appropriate until further evidence suggests a change is needed (see monitoring discussion below).

While hypereutrophic conditions and toxic bluegreen cyanobacterial blooms should be avoided the evidence suggests that Quaboag Pond might be expected to be a eutrophic system naturally. EPA is correct that our water quality standards do state point sources must be limited to control accelerated or cultural eutrophication and this will be added to the final report. In the final TMDL report the target wasteload allocation for the Spencer WWTP has been capped at existing loads and additional restrictions on the operation of the Spencer WWTP are suggested to reduce loads during summer low flow period. In addition, the Department has changed the modeling method used to set the TMDL loading. The data suggest Quaboag Pond does not retain phosphorus (inlet concentrations are about the same as in-lake concentrations). Instead of relying on the traditional lake models that assume some phosphorus retention in Quaboag Pond, the final report now uses a simple mass balance approach. In this approach, the current TP concentration levels of 43 ppb must be reduced to 30 ppb and this implies a 30 percent reduction in loading. Thus the new TMDL load is 3710kg/yr * 0.70 or 2588 kg/yr instead of the draft target load of 2822 kg/yr. Thus, additional BMPs will be required to attain this lower TMDL target load and this requires additional BMPs, including forestry BMPs.

Because of the lack of information on natural background during drought conditions the Department is also recommending that monitoring continue at the Cooney Road station (currently conducted by DEP), the inlet to Quaboag Pond at Shore Road, and at Quaboag Pond itself for several more years in order to document the effects of low flow on background TP concentrations. If background concentrations during low flow drop to less than 30 ppb at the Cooney Road site but are significantly higher at the inlet site due to the treatment plant discharge, then the TMDL may be revised to further protect the pond during low flow conditions.

EPA Comment 2: On page 15 of the report it indicates that the 1985 Diagnostic Feasibility Study estimated the Spencer WWTP loading as 45% of the total loading. The current estimate is that it constitutes 4% of the total loading. This discrepancy is not explained solely by the improved level of treatment and should be clarified in the final report. A more interesting measure would be what percent of the current loading that is in excess of the baseline loading (entire watershed is forested) does Spencer represent.

Reply: The reduction in loading from the Spencer WWTP does agree within measurement error with the current loading analysis. The BEC D/F study reported the WWTP contributed 2793 kg/yr of the 6152 kg/yr total load or 45%. The WWTP load was reduced to current level of 131 kg/yr or a reduction of 2662 kg/yr. Subtracting the WWTP reduction from the historic load of 6152 gives 3490 kg/yr that agrees within 220 kg/yr of the current loading estimate of 3710 kg/yr or within 6 percent. This is within measurement errors of the analysis.

It is interesting to show how the current load of 131kg/yr would compare to an entirely forested watershed. Assuming the 76.7 sq mile watershed were forested, or 19867 ha times 0.13 kg/ha = 2583 kg/yr for the forested condition based on the Mattson and Isaac NPSLAKE model. It should be noted that this estimate is essentially the same as the proposed TMDL. Thus, 131/2553 = 5.1%, but we have to ask is it appropriate to set the target at forested condition? The target EPA has proposed (8 ppb) probably could not be met even if we reverted the entire watershed to a forested condition.

EPA Comment 3: Discussions on internal recycling and wind driven resuspension of phosphorus are confusing. At times the report seems to indicate that recycling is not significant and at other times the report indicates that recycling may be significant. Discussions on internal recycling and how it is accounted for in the modeling and in the allocations should be addressed in one section of the report.

Reply: The internal recycling discussion has been rewritten to include internal sources for Quaboag Pond in the budget, models and in the TMDL allocation. Because this source is difficult to control in a large flow thru type lake (alum has limited effectiveness and wind resuspension is difficult to control) we have assumed that such internal sources will decrease proportionally over time as external loads decrease.

It has been shown in the literature that wind driven resuspension of sediments and TP can be a significant factor in large lakes with a long fetch. The fetch for Quaboag Pond is listed as 2.29km in the BEC D/F study. This distance is an order of magnitude higher than the small ponds in the French basin and thus resuspension will likely be naturally higher in Quaboag. If internal sources do not decline as expected a study of alum treatment (perhaps repeated low dose flocculation rather than bottom sealing) may be considered.

EPA Comment 4: The TMDL needs to establish a water quality based load limit for Spencer. Only the technology standard is referenced relative to the Spencer allocation. This technology standard is an order of magnitude higher than what is achievable for municipal dischargers. If non-point source loading reductions are to be pursued instead of point source loading reductions there must be reasonable assurance that the non-point source reductions will be achieved. The lack of definitive data on non-point sources and the lack of an effective state regulatory mechanism for addressing non-point sources highlights the fact that this reasonable assurance does not exist.

Reply: We are unaware of any wastewater treatment plant consistently meeting an order of magnitude less TP concentration (e.g., 0.02 mg/l). At this time we are considering best practical treatment to be 0.2mg/l combined with a groundwater discharge to limit volumes and loads. At some point we may have to impose lower limits, but it seems reasonable at this time to take an adaptive management approach with a phased implementation.

Comments by MassHighway: MassHighway has very limited maintenance budgets and staff. The cost-effectiveness, and necessity, of cleaning catch basins twice per year should be closely evaluated rather than arbitrarily set. Evaluation criteria includes sediment accumulation rates, and phosphorus concentrations in catch basin sediments. For example, catch basins at the sag of a hill will accumulate sediments at a greater rate than those at the crest of a hill. MassHighway's approach to monitoring and cleaning catch basins is included in our NPDES Storm Water Management Plan.

Reply: DEP has attempted to develop a mutually acceptable study scope with MassHighway several years ago to determine loading estimates for sediments and associated pollutants including phosphorus from roadways under typical sweeping and catchbasin cleaning schedules. MassHighways has not addressed these concerns in any study of the problem to date. Until a complete and acceptable study of the problem is conducted we will rely on literature recommendations and best professional judgment to establish BMPs for this TMDL.

Comments of Massachusetts Division of Fisheries and Wildlife: After careful review by staff botanists and zoologists at NHESP, we have concluded that the proposed project is unlikely to have any significant impact on state listed species in the vicinity. We are satisfied that the effects of raising the gate 18 inches would be negligible on the Dwarf bulrush population, which depends on the narrow shoreline ecotone between the waters edge and dry land. The fisheries section has historically managed Quaboag Pond (North Pond) as a warmwater fishery and Quacumquasit Pond (South Pond) as a coldwater fishery. The Division annually stocks brown trout (*Salmo trutta*) in South Pond and it is the only water in the state with special regulations governing taking of brown trout. In 1981 alewives (*Alosa pseudoharangus*) were introduced to South Pond to supplement the forage base. In 1985 there was a major dieoff of alewives, but no major fish kills have been reported since then. Increasing the height of the flood gate at South Pond to prevent backflooding is reasonable provided it is operated in a manner that minimizes impacts to boat traffic between the pond and spring and fall migrations of fish such as northern pike. Establishing targeted management zones (boat channels etc.) is consistent with recommendations outlined in the Eutrophication and Aquatic Plant Management Final Generic Environmental Impact Report as long as the recommendations are followed, particularly in the use of a dedicated harvester at the pond to prevent the spread of invasive aquatic species. This will benefit the fisheries habitat of the pond in the long term.

Reply: Your comments are noted. Along with the targeted plant management zones MassDEP has added additional language to note that copper sulfate is a short-term treatment and also not recommended by the Eutrophication and Aquatic Plant Management Final Generic Environmental Impact Report.

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
Central Regional Office, 627 Main Street, Worcester, MA 01608

MITT ROMNEY
Governor

KERRY HEALEY
Lieutenant Governor

ELLEN ROY HERZFELDER
Secretary

ROBERT W. GOLLEDGE, Jr.
Commissioner

MEETING ATTENDEES LIST

Meeting: Quaboag & Quacumquasit Pond TMDL Public Meeting
Presenters: MARK MATTSON Russ Isaac
Date: 5/25/05 Place: Brookfield Town Hall

	Name	Affiliation or address	phone or email
1)	[illegible] Cappobianco	38 Pine Ln	paprika@charter.NET
2)	Richard Hartley	MDFW	(508) 792-7270
3)	John Michelli	108 Canal Rd E. Brookfield	508-867-891[illegible]
4)	[illegible]	60 S. Shore Dr. Sturbridge	508-347-9547 88la@charter.net
5)	Steve Halterman	DEP	
6)	H J Mc Afee	131 W Main St Spencer	
7)	Mark Robidoux	SWWTP	508-885-7542
8)	Dick & Paula Woodard	Brookfield	508-867-2321
9)	Audrey Flannery	South Pond Brookfield	508-867-4005
10)	Beverly A Lund	14 Pine Lane	508-867-6323
11)	Annette [illegible]	10 Pine Lane	508-867-9031
12)	[illegible]	30 Pine Lane	508-849-5714

W:\DWM\TMDL\attendee.doc

Page 1 of 2

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
Central Regional Office, 627 Main Street, Worcester, MA 01608

MITT ROMNEY
Governor

KERRY HEALEY
Lieutenant Governor

ELLEN ROY HERZFELDER
Secretary

ROBERT W. GOLLEDGE, Jr.
Commissioner

MEETING ATTENDEES LIST

Meeting: Quaboag & Quacumquasit Pond TMDL
Presenters: MARK MATTISON Russ Issa
Date: 5/25/05 Place: Brookfield Town Hall

	Name	Affiliation or address	phone or email
1)	Carl Nielsen	158 Lane 8	508.347.9401
2)	Carl Nielsen	ESS	401 330 1224
3)	Cindy Laporte	172 Stone Rd	508-867 3075
4)	Dan Laporte	"	"
5)	John T. O'Leary Jr.	10 West Main	508-867-8426
6)	Michelle S[illegible]	108 So Shore Dr	508 347-5687
7)	Peter Levin	50 South Shore Drive Sturbridge	508 347-1804
8)	Norman Tremblay	38 Allen Rd Brookfield	867-7624
9)	Marita Tasse	112 So Shore Dr Stur	347 2464
10)	Jim Emery	100 Quaboag rd	508 353 1403
11)	Carter Terenzini	Town of Spencer	508.885.7500 x 155
12)			

W:\DWM\TMDL\attendee.doc

Page _ of _