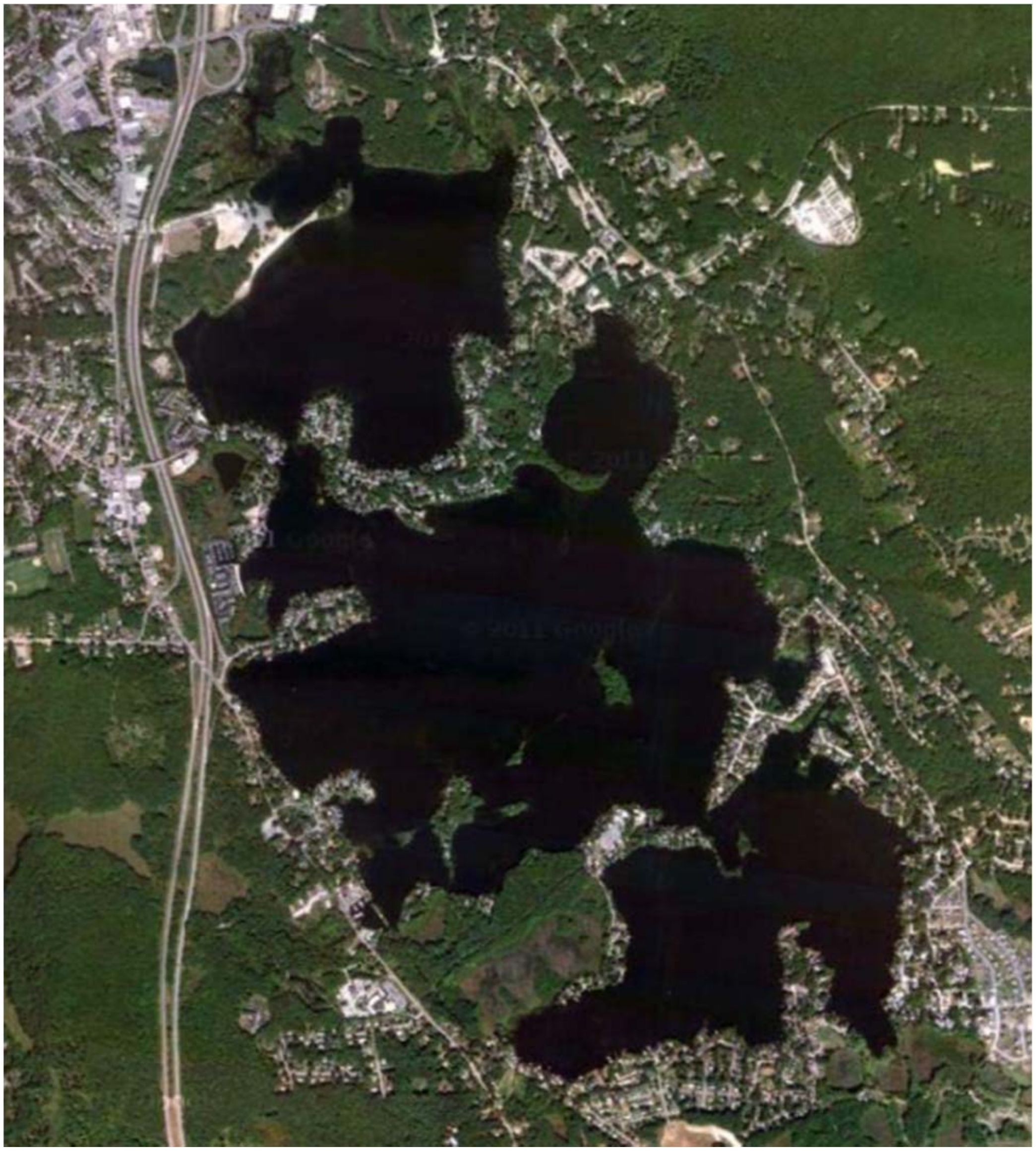
AN ANALYSIS OF
WEBSTER LAKE DATA, 2003-2011



PREPARED FOR THE WEBSTER LAKE ASSOCIATION

BY WATER RESOURCE SERVICES, INC.

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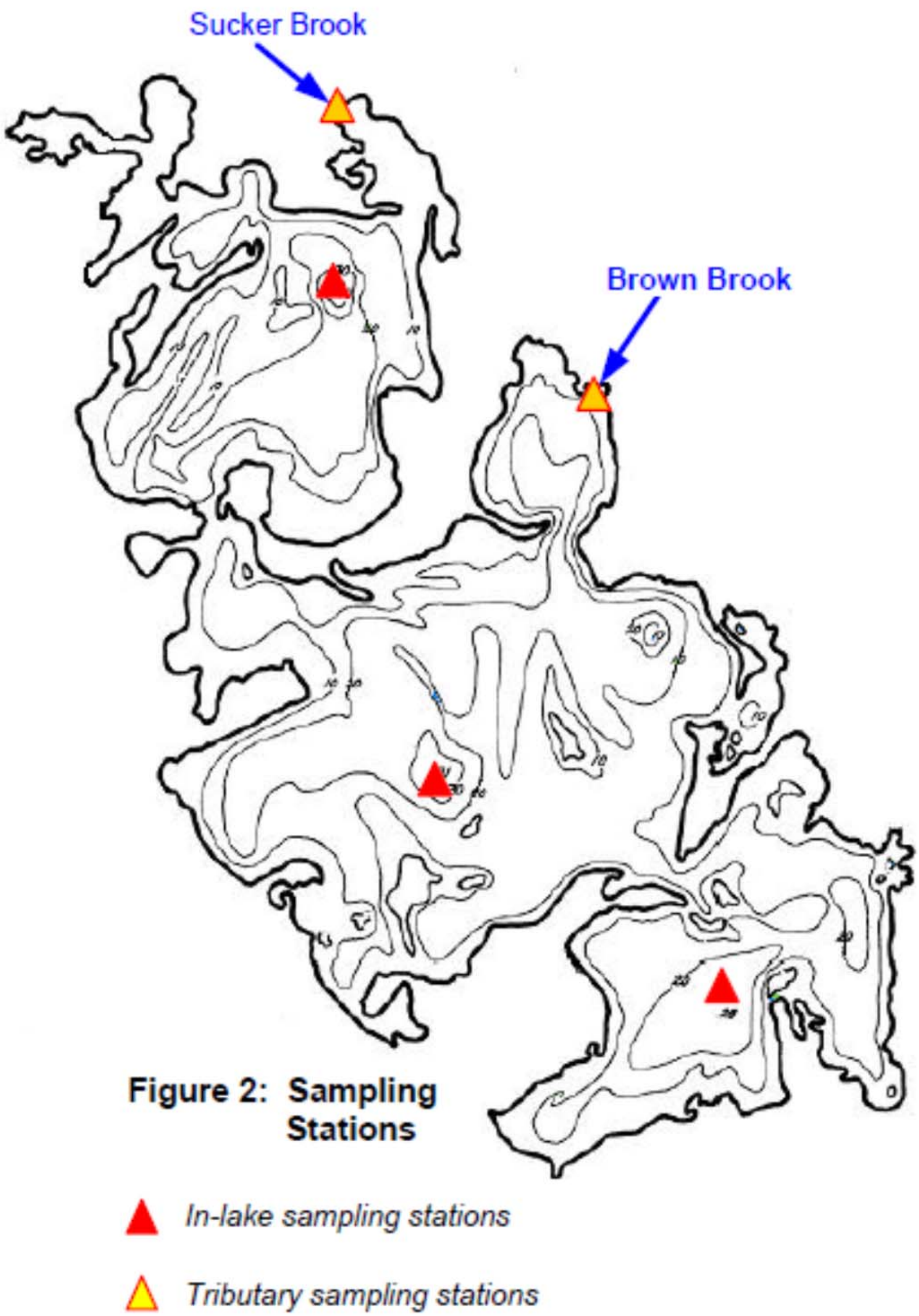
Contents

Background

Webster Lake, also known as Lake Chargoggagoggmanchaugagoggchaubunagungamaugg, is located just north of the Connecticut border in Webster, MA. It covers roughly 1270 acres in three main basins with a highly irregular shoreline and many coves (Figure 1). Maximum water depth is about 45 ft while average depth is about 13 feet. The north basin is the deepest, while the south basin is the shallowest (Figure 2). The Webster Lake Association has been active in monitoring and managing the lake since at least 2003, and this report is intended as a review of water quality and plant data from 2003 into 2011.

Figure 1. Webster Lake aerial.

Figure 2. Webster Lake bathymetry.



Aquatic Plants in Webster Lake

Webster Lake may have been surveyed on multiple occasions in the 1980s and 1990s as part of MA DEP and MA DFW programs, but the record for this analysis begins in 2003. A survey by Geosyntec covered 84 stations and produced a reasonably comprehensive list of aquatic plants for the lake and provided a semi-quantitative assessment, identifying dominant plants (Table 1). Even then, 84 stations over about 1270 acres of lake, about 800 of which appears suitable for plant growth, is not a very detailed survey.

Table 1. Dominant plants from 2003 Webster Lake survey.

Dominant Plants	Total Stations	Dominant Stations
Bladderwort (*Utricularia sp.*)	63	18
Variable Milfoil (*Myriophyllum*	45	14
White Water Lily (*Nymphaea odorata*)	35	11
Robbin's Pondweed (*Potamogeton*	30	9
Big-leaf Pondweed (*Potamogeton*	42	8
Bushy Pondweed (*Najas flexilis*)	30	7
Watershield (*Brasenia schreberi*)	23	6
Yellow Water Lily (*Nuphar variegatum*)	20	5
Stonewort (*Nitella sp.*)	26	4
Waterweed (*Elodea nuttallii*)	20	3
Eurasian Milfoil (*Myriophyllum spicatum*)*	16	3

* *Indicates non-native, invasive plant*. Note that bladderwort includes *Utricularia vulgaris, Utricularia purpurea* and *Utricularia radiata*.

Plant growth densities (% cover) and biomass (% water column filled) ratings for the 84 Webster Lake sampling stations during the July 2003 survey (Tables 2 and 3) suggest that a quarter of the stations had dense or very dense plant assemblages by cover and almost a quarter had at least dense assemblages by biomass. Variable watermilfoil (VWM) and Eurasian watermilfoil (EWM) were present and dominant in places, and fanwort was present but not a dominant. All of the other 29 species in the lake were native, although some of those can grow dense enough to cause nuisance conditions, especially in shallow coves such at the inlet of Sucker Brook (Figure 3).

Recommendations were made that appear to represent the start of modern plant management in Webster Lake. A mix of chemical and physical techniques were suggested and followed up on by the Association.

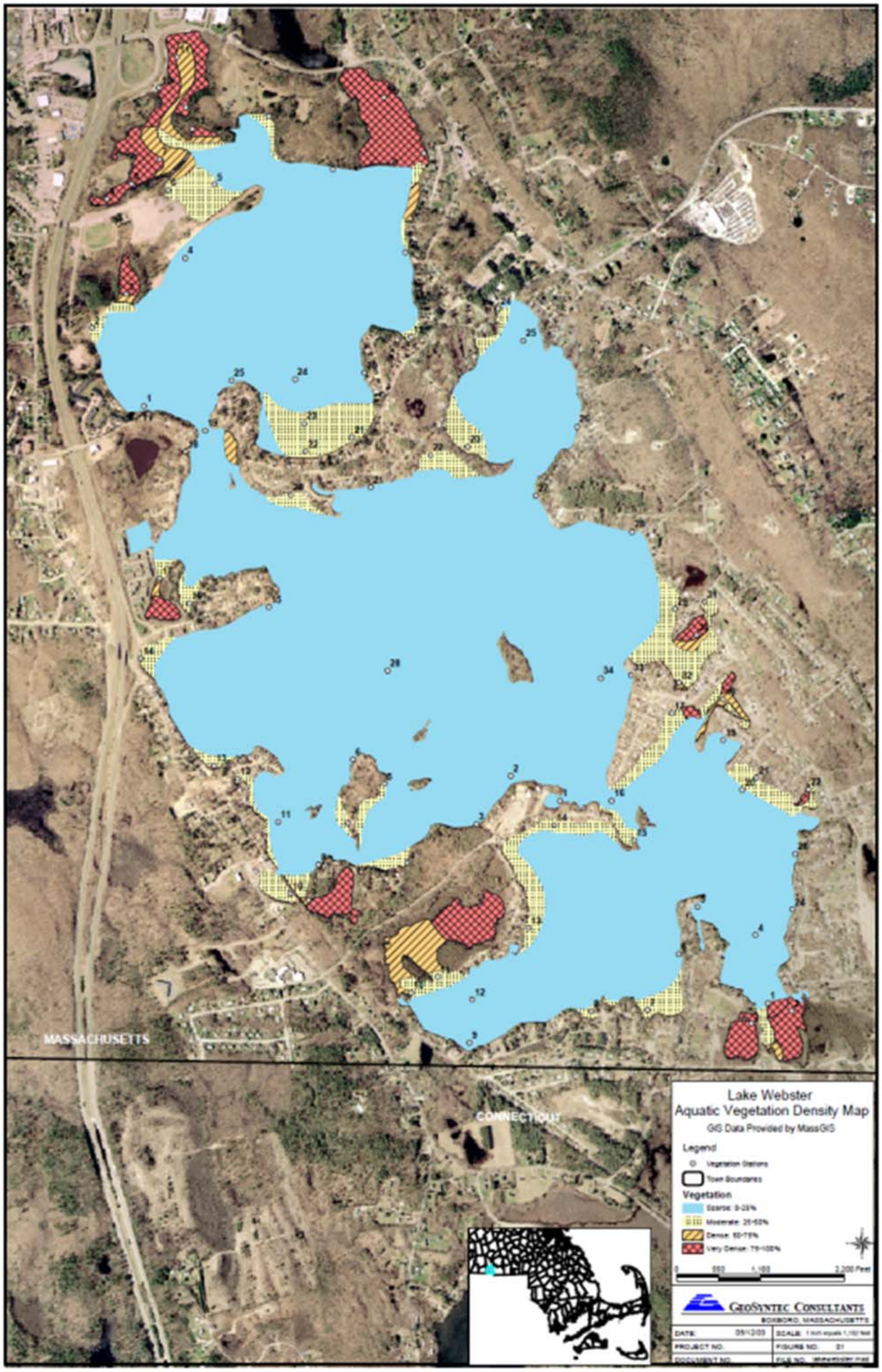
Table 2. Density (cover) ratings for plant survey stations in Webster Lake in 2003.

		# of stations				
		North Pond	Middle Pond	South Pond	TOTAL # of stations	TOTAL % of stations
DENSITY RATING	Sparse: 0-25% density	8	17	11	**36**	**43%**
	Moderate: 26-50% density	8	12	7	**27**	**32%**
	Dense: 51-75% density	2	4	2	**8**	**9.5%**
	Very Dense: 76-100% density	7	2	4	**13**	**15.5%**

Table 3. Biomass ratings for plant survey stations in Webster Lake in 2003.

		# of stations				
		North Pond	Middle Pond	South Pond	TOTAL # of stations	TOTAL % of stations
BIOMASS RATING	Low	15	25	15	**55**	**65.5%**
	Moderate	1	6	4	**11**	**13%**
	High	2	3	3	**8**	**9.5%**
	Very High	7	1	2	**10**	**12%**

Figure 3. Plant distribution in Webster Lake in July 2003.



Geosyntec surveyed the lake again on Sept 3, 2004, after diquat treatments for milfoil control in June 2004 by ACT. No data appear to be available, but control of milfoil (EWM and VWM) was reported and an increase in fanwort was noted. Sonar was recommended for 2005 for control of fanwort and EWM, plus focused harvesting for dense native species in the Sucker Brook inlet.

No 2005 report appears available, but ACT treated selected areas with Sonar (fluridone) for fanwort and EWM control and with Reward (diquat) for VWM control (Figures 4 and 5).

Geosyntec surveyed the lake again on Aug 15, 2006, focusing on 18 areas where action was recommended in the past (Table 4, Figure 6). This represented a reduction in area covered by the plant survey, and, while more manageable and appropriate for management planning, limits overall assessment of plant assemblages in the lake. A map of June 2006 herbicide treatment areas has also been provided (Figure 7). It does appear that control of EWM was substantial by this time, but that patches of VWM and fanwort were still common, and Sonar treatment effectiveness on fanwort was limited by heavy rains during the treatment period.

ACT conducted treatment and surveys in 2007. Included were Reward treatments targeting VWM in 13 different shoreline and cove areas with an area of 32.5 acres. In 2006 treatment covered 14 areas and approximately 50 acres in total. Desirable control of VWM appears to have been achieved, while desirable native submersed and floating-leaved species remained, including bladderwort, muskgrass, several species of pondweed, tapegrass and naiad. Waterlilies were not impacted in any of the treatment areas by the application of the Reward herbicide nor were any emergent species (e.g., pickerelweed, waterwillow, pipewort) affected. The Reward treatments at Webster Lake have shown excellent selectivity for predominantly the invasive milfoil alone.

The Sucker Brook inlet cove was again chemically treated during spring/summer 2007 with Sonar herbicide. A combination of Sonar PR and Q pellet formulations were applied, providing a gradual release of fluridone over a period of weeks. Better control of fanwort was reported than was achieved in 2006, but there was still some scattered fanwort later in summer. Sonar treatment of the far southeast cove in the lake's South Basin appears to have been very effective. Inspection of past treatment sites on July 25th, 2007 indicated desirable carry-over control of fanwort with generally sparse to light re-growth.

In 2006 and 2007, a Reward/Aquathol K combination was used to target milfoil growing in combination with dense and the taller broad-leaved pondweeds in Webster Lake. These pondweeds reach the water surface by late June and in some areas they interfere with swimming and other recreational uses. The 2006 and 2007 treatments have shown effective control of the taller milfoil and the largeleaf pondweed, yet a healthy under-story of "non-nuisance" native plants still remained, avoiding the loss of all plant cover.

About 25 hours of hydro-raking took place at a number of different sites around the lake in 2007. The work was performed during the week of June 4th. Hydro-raking offers an option for managing nuisance aquatic vegetation in beach/waterfront areas.

Figure 4. Areas treated in 2005 with Reward (diquat)

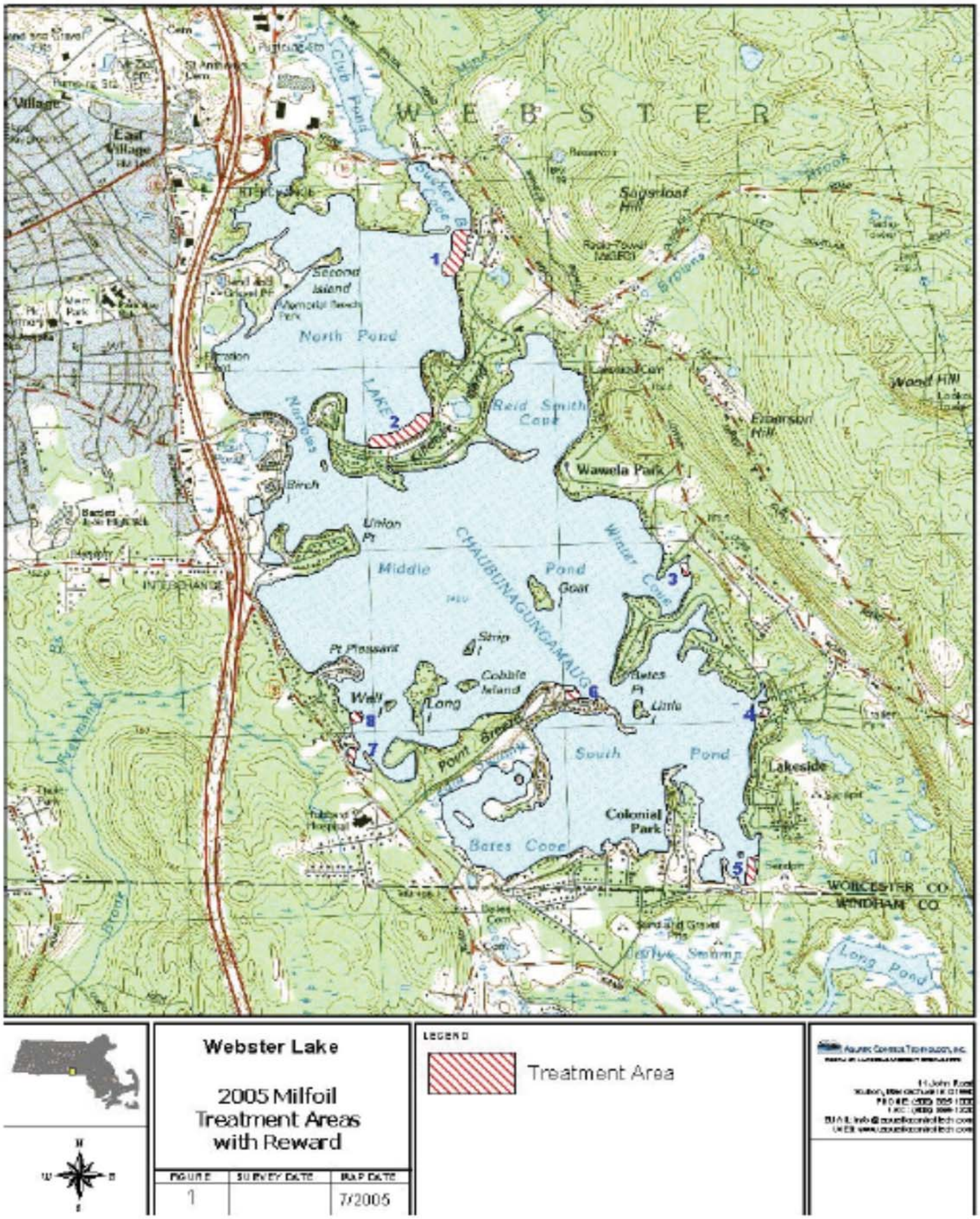


Figure 5. Areas treated in 2005 with Sonar (fluridone).

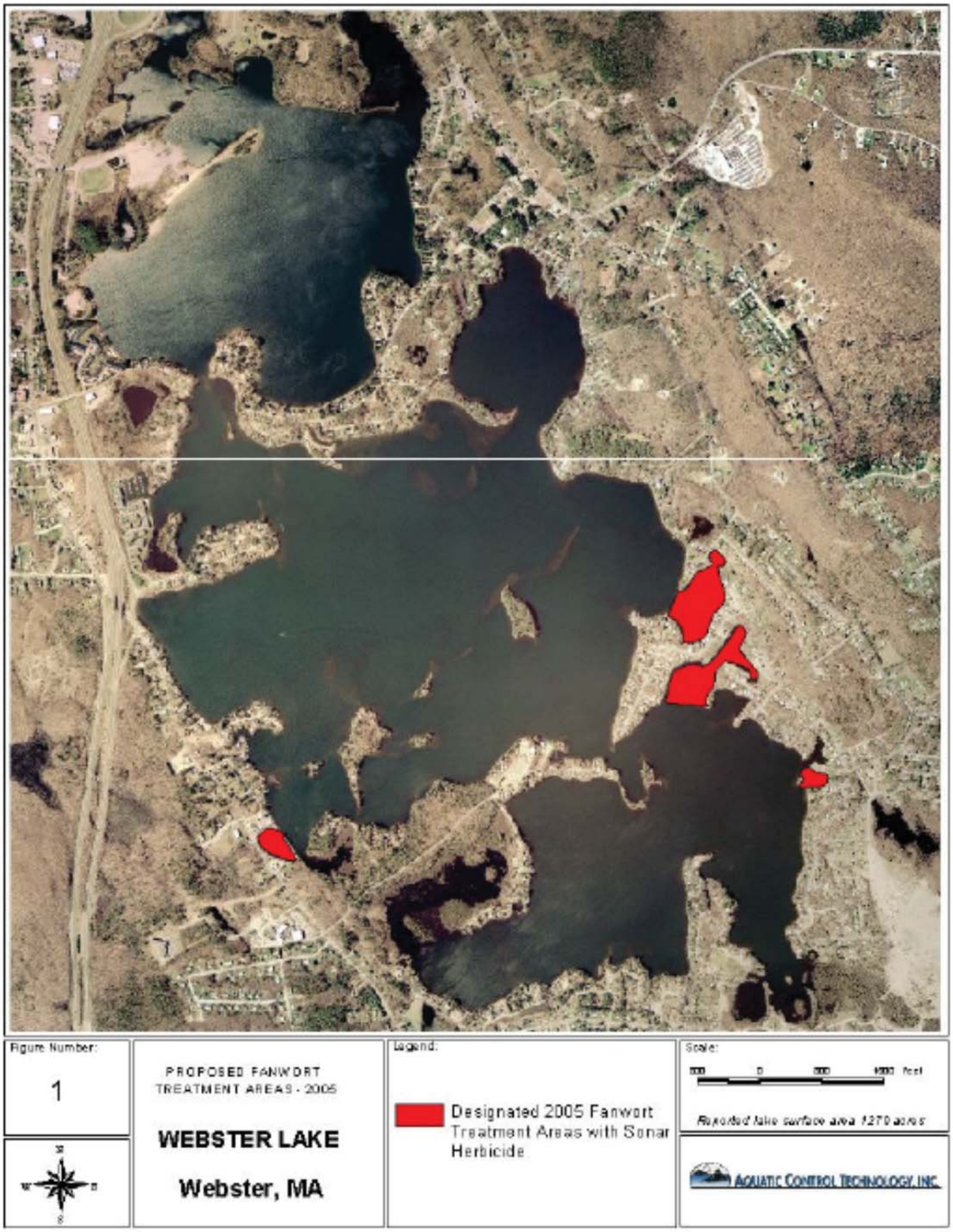


Table 4. Plant data from the 2006 survey.

Location: Lake Webster (Webster, MA)
Date: 8/15/06
Surveyed by: Bob Hartzel, Melissa Lowitz

- (pink) indicates a non-native species
- • species present at monitoring station
- **•** (green) species dominant at monitoring station

Plant Species	# stations present	# stations dominant	Monitoring Stations – Lake Webster: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Fanwort *(Cabomba caroliniana)* (non-native)	7	2			**•**	•	•		•	•				**•**						•
Variable milfoil *(Myriophyllum heterophyllum)* (non-native)	6	0				•	•		•					•			•			•
Purple Bladderwort *(Utricularia purpurea)*	14	6	**•**	•			•	•	**•**	•	**•**	**•**	•	**•**	•		•	**•**	•	
Wild Celery *(Vallisneria americana)*	13	0	•	•		•	•	•	•		•	•		•	•	•	•		•	
Common Bladderwort *(Utricularia vulgaris)*	12	4	•		•	•	•	•	**•**	**•**	**•**	**•**	•		•				•	
White water lily *(Nymphaea odorata)*	11	1	•		•	•	•			•	•	•		•			**•**	•		•
Bushy Pondweed *(Najas guadalupensis)*	9	2	•	•				•			•	•	**•**	•	•	**•**				
Pipewort *(Eriocaulon septangulare)*	9	1	**•**	•				•	•		•	•		•	•				•	
Robbins Pondweed *(Potamogeton robbinsii)*	7	2	•	**•**		•	•							•	•		**•**			
Stonewort *(Nitella sp.)*	7	0	•	•							•		•		•	•			•	
Watershield *(Brasenia schreberi)*	6	0	•		•		•		•					•				•		
Yellow Water Lily *(Nuphar sp.)*	6	0				•	•		•		•			•						•
Big-leaf Pondweed *(Potamogeton amplifolius)*	3	1														**•**			•	•
Heartleaf Pondweed *(Potamogeton pulcher)*	3	0					•					•				•				
Water Lobelia *(Lobelia dortmanna)*	3	0									•		•	•						
Musk Grass *(Chara sp.)*	2	0					•						•							
Filamentous Algae	2	0															•	•		
Robbins' Spike Rush *(Eleocharis robbinsii)*	1	1							**•**											
Pickerelweed *(Pontederin cordata)*	1	0			•															
Waterweed *(Elodea nuttallii)*	1	0																	•	
Rush *(Juncus sp.)*	1	0								•										
Snailseed Pondweed *(Potamogeton bicupulatus)*	1	0									•									
Flatleaf Bladderwort *(Utricularia intermedia)*	1	0									•									
Claspingleaf Pondweed *(Pontamogeton perfoliatus)*	1	0											•							
Arrowhead *(Sagittaria sp.)*	1	0	•																	
Plant Growth Density			1-3	3-2	1	2	4	1	3	1	2	1-2	2	4	2	1	3-1	1	1	1
Plant Biomass			1	1	1	1	1	1	3	1	1	1	1	3	2	1	1	1	1	1

Key to Density and Biomass Ratings

Rating	Density	Biomass
1	Sparse: 0-25% density	Low: plants typically growing only as a low layer near the lake bottom
2	Moderate: 26-50% density	Moderate: plants protruding well into the water column but generally not reaching the surface
3	Dense: 51-75% density	Substantial growth through majority of water column
4	Very Dense: 76-100% density	Abundant growth throughout water column to surface

Figure 6. Plant survey areas for 2006

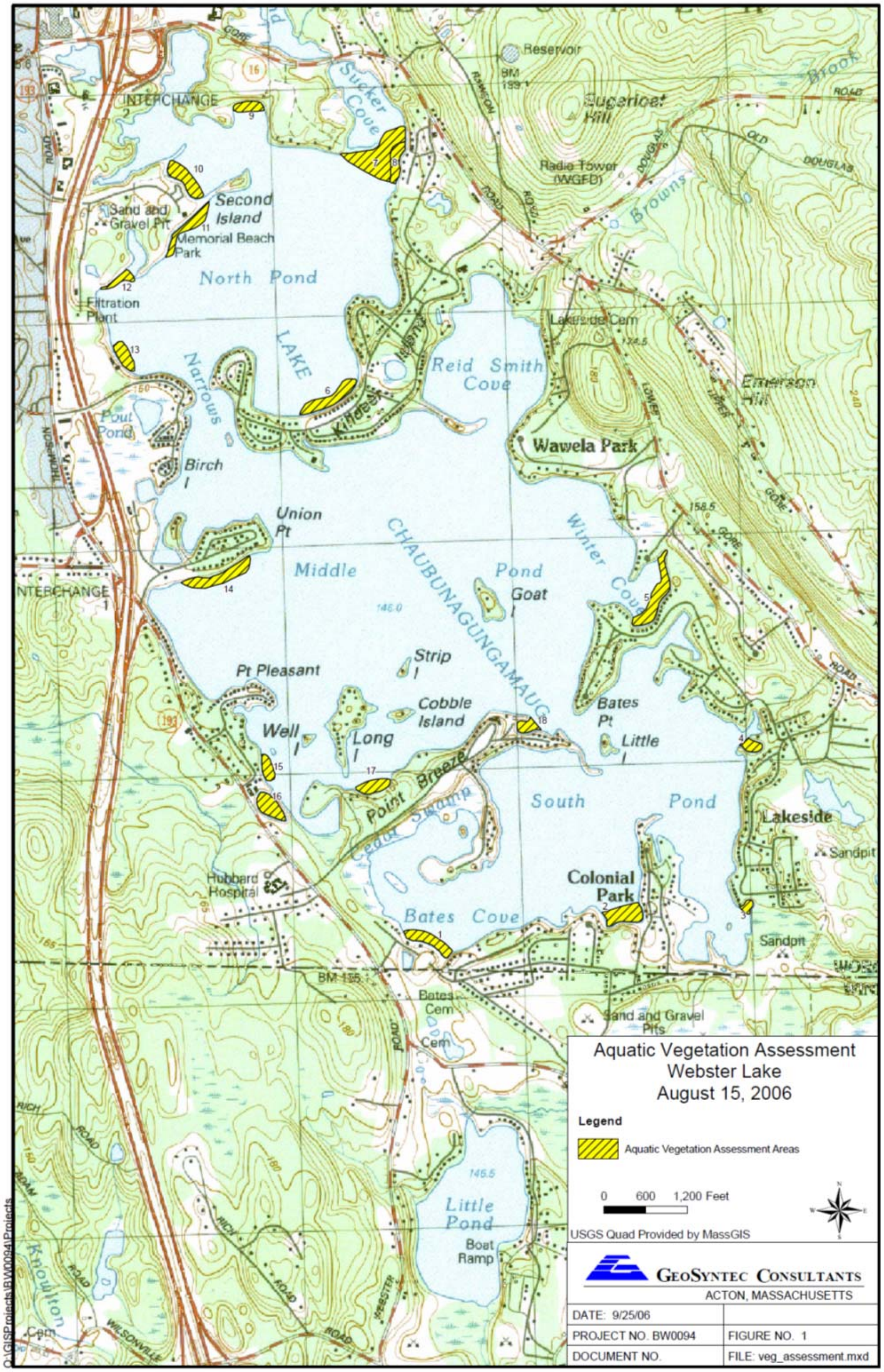
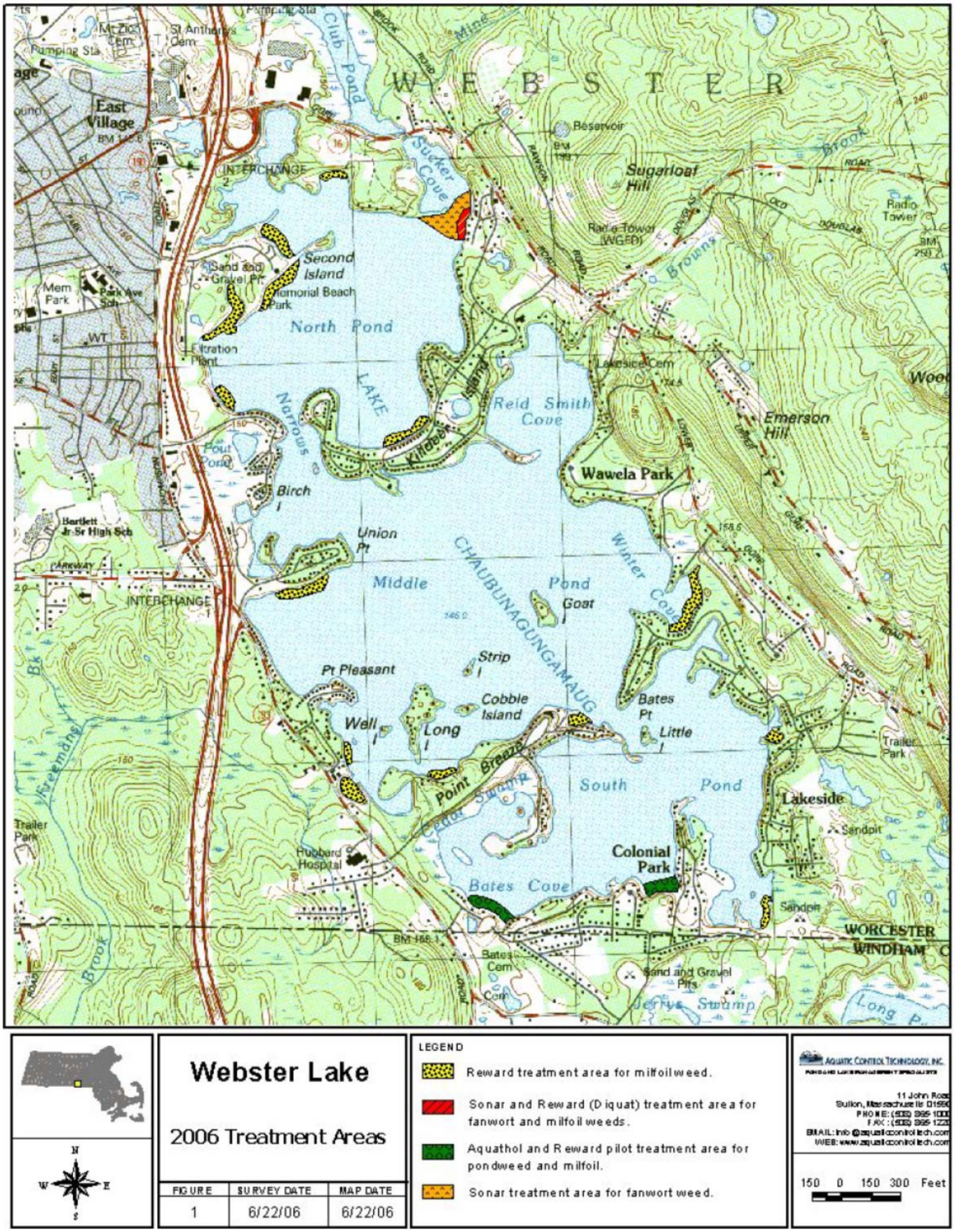


Figure 7. Treatment areas for 2006.



By the end of the 2007 plant control program, ACT was in a position to specify a flexible management program with various elements that could be applied as warranted from early season surveys. Complete control of nuisance vegetation in a 1500 acre lake is a difficult proposition, but the tendency of problem areas to be isolated in coves makes surveying and treatment somewhat easier, and a set of 25 expected potential treatment areas was established (Figure 8). An annual maintenance program costing on the order of $60,000 was outlined, with the flexibility to apply different techniques as warranted or treat more or less area as budgets allow. Reward, Sonar, Aquathol K and hydro-raking were the primary techniques, with suggestion of possible hand harvesting in areas of light regrowth of invasive species.

ACT conducted treatment and surveys in 2008. Reward was applied in June, with a survey on Aug 8th. No VWM was found in 14 of the 25 treatment areas, and most growths were small, scattered and sparse. Growths were indicative of regrowth from root crowns not damaged by the contact herbicide. No EWM was found.

ACT again conducted treatments and surveys in 2009. Sonar and Reward were applied in May (Figure 9) and June (Figure 10) based on early season assessments of established treatment areas and additional shoreline reconnaissance, and follow up surveys were conducted periodically, with a final post-treatment survey in late August. Regrowth indicated undamaged root crowns as the source. Several “no treatment” or “wildlife habitat preservation zones” were established around Webster Lake (Figure 11). These zones are located in areas with floating leaf and submersed plant species providing good habitat for a nursery to young warm water fish species. The areas also contain a wealth of floating islands, stumps and a variety of depths providing a variety of habitat functions for wildlife. The areas are also isolated from the main body of the lake enough so as to not pose a large threat of spread of the invasive species growing within them. Additionally, a total of about 18 hours of hydro-raking was performed along nine shorefront properties to remove accumulated plant matter and attached hyrdrosoils. The work was conducted between June 8th and June 10th.

The first detailed algae assessment was conducted in 2009. Samples were collected and analyzed by ACT. No blue-green algae taxa were present in any of the samples. Chlorophytes (green alga) were the dominant taxa for North Lake and South Lake and Chrysophytes (golden algae) were the dominant taxa in Middle Lake in the samples collected on June 16th. Chlorophytes were dominant in all three samples collected on August 28th. Over the course of the summer several small localized algae blooms occurred around the pond; the blue-green algae taxa Anabaena, Oscillatoria and Woronichinia were dominant in these samples.

Figure 8. Proposed treatment areas in Webster Lake as of 2008.

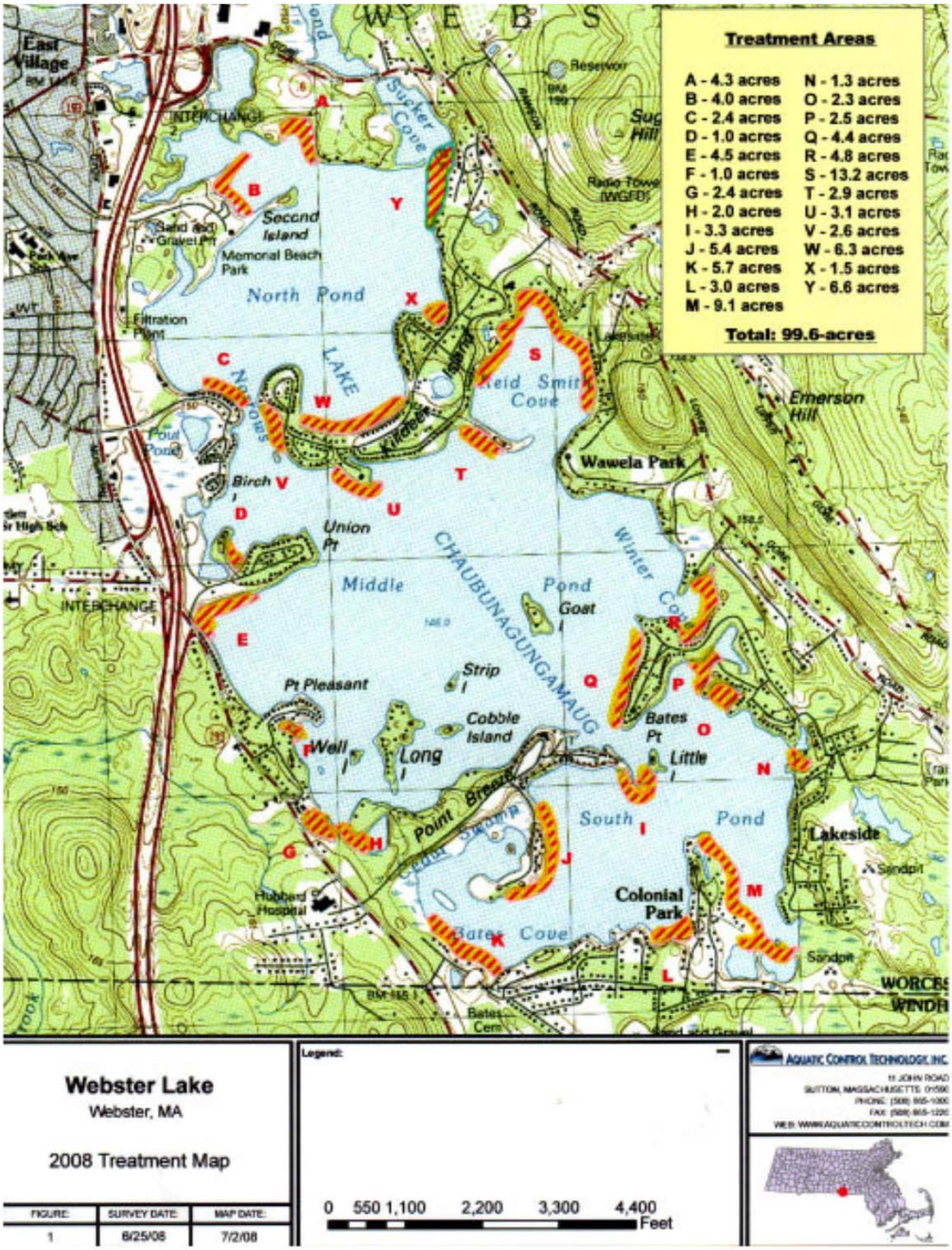


Figure 9. May 2009 treatment areas in Webster Lake.

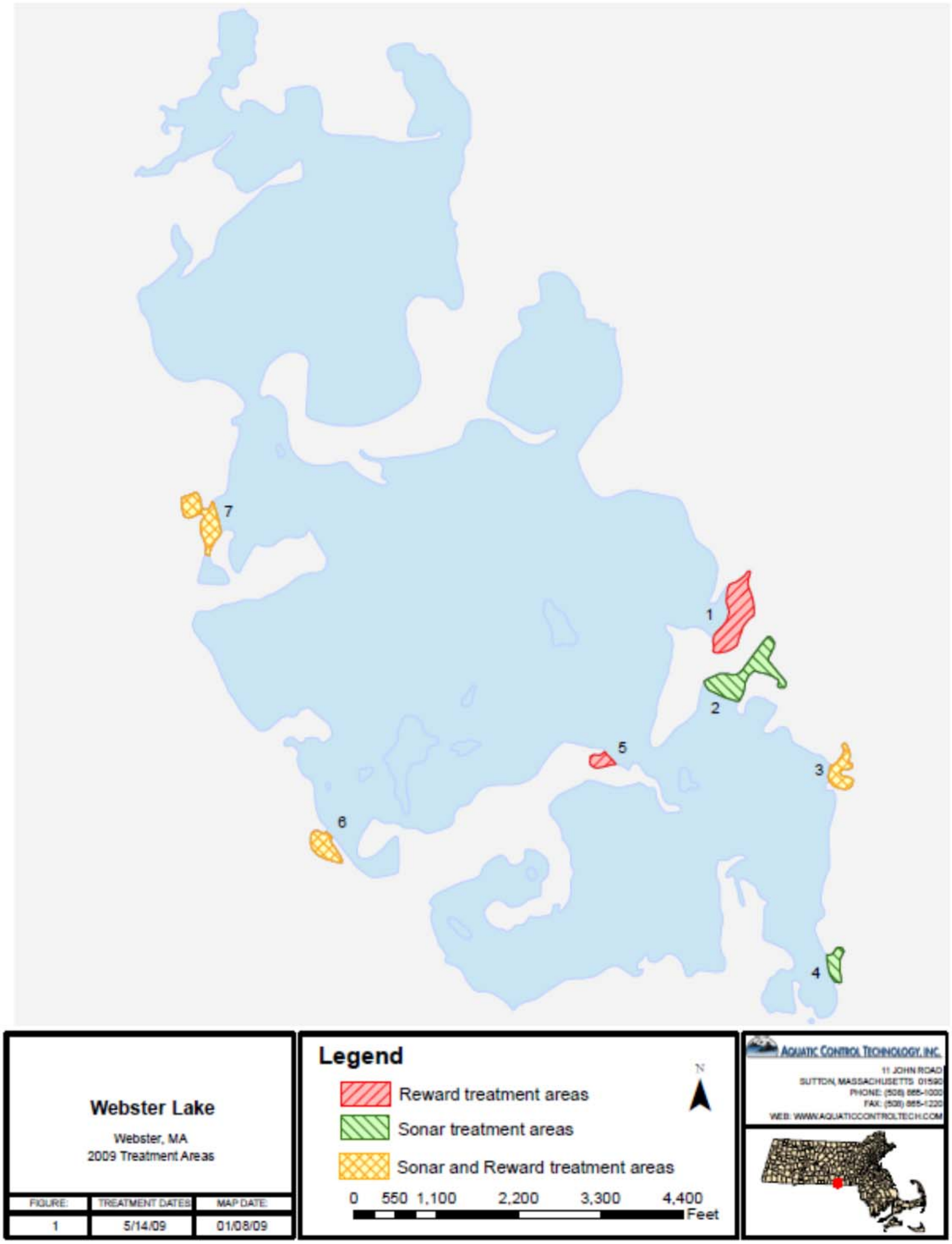


Figure 10. June 2009 treatment areas in Webster Lake.

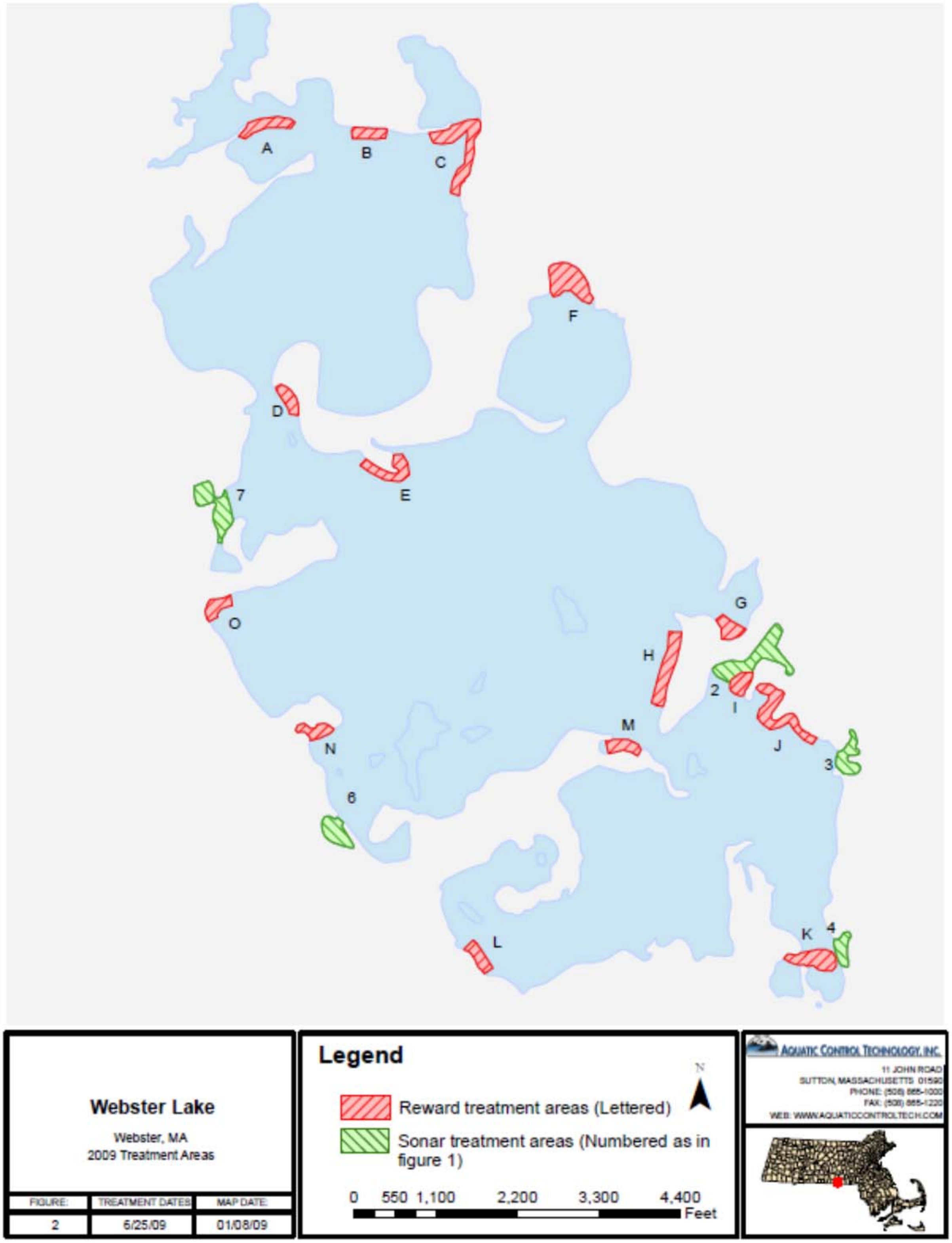
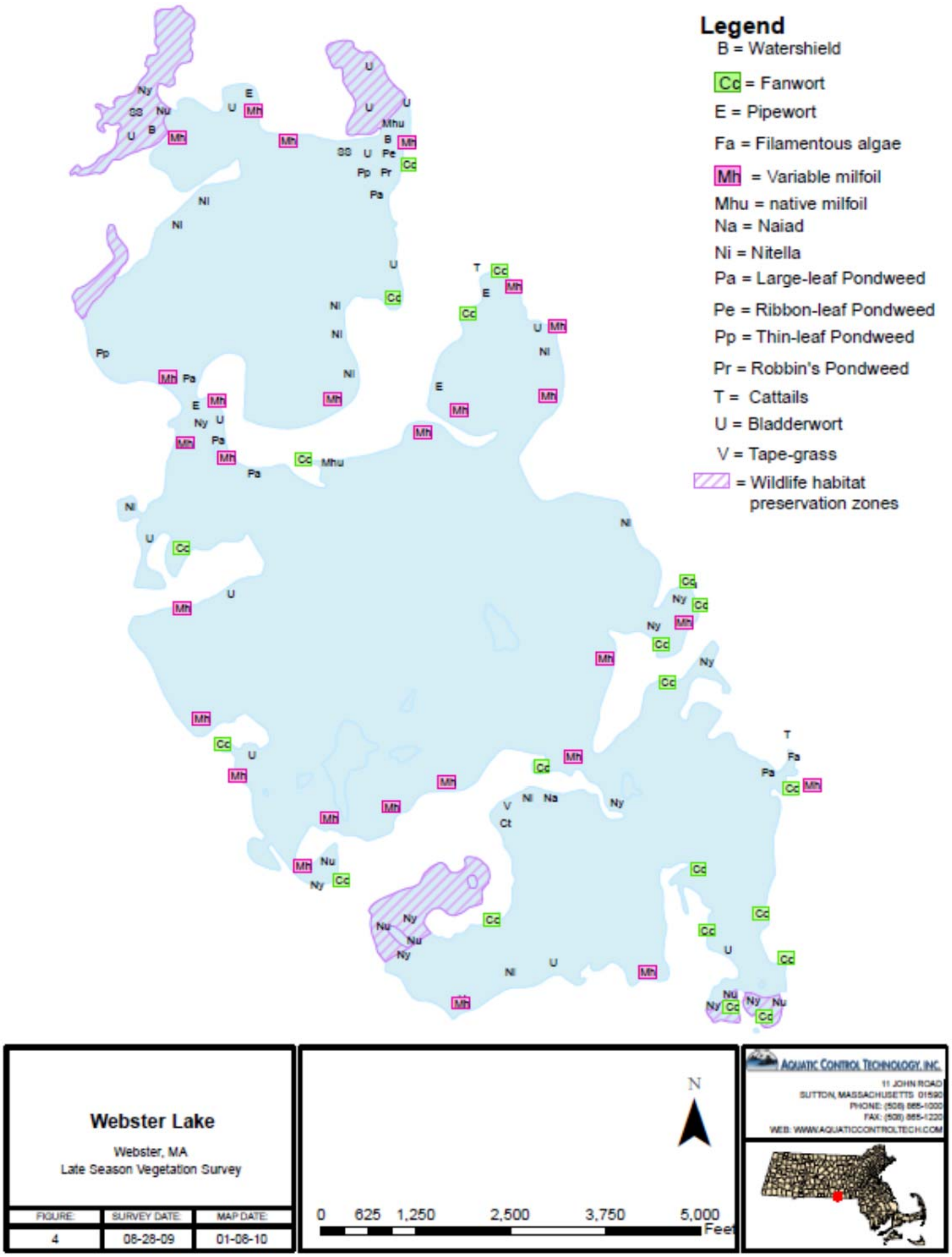


Figure 11. Wildlife conservation areas and general plant community features in Webster Lake in 2009.



ACT treatments and surveys in 2010 included Reward and Sonar, together and separately, with VWM and fanwort as the main target species (Figures 12 and 13). A late season survey provided an overview of plant distribution (Figure 14). Native species were less impacted than the target species, but 2010 was a very favorable growth year for aquatic plants, and many plant growths expanded from observed levels from 2009. No hydroraking was conducted in 2010 as a function of budget issues.

Algae were collected by ACT biologists on 5/28/10 and 8/4/10. For each of the sets one sample was collected mid-basin in South Lake, Middle Lake and North Lake. Similar to samples collected in 2009, Chlorophytes (green alga) and Chrysophytes (golden alga) were the dominant taxa for in the samples collected on May 28th. Overall the cell counts in May were desirably low and did not indicate bloom conditions. A small number of blue-green algae cells were observed in the Middle Lake Sample collected in May 2010. Overall the cell counts in August were desirably low and did not indicate bloom conditions. Chlorophytes were dominant in all three samples and no blue-green algal species were observed in August samples.

Over the last 8+ years a program of aquatic plant maintenance has been developed that minimizes adverse impacts, both to lake ecology and to human lake uses. Quantitative plant survey data are not sufficient to perform any statistical analyses, but collection of adequate data for such a large lake is expensive and plant management efforts are localized, making assessment of established management areas more practical. With the data available, it is apparent that the methods applied are allowing sufficient control for maintenance of designated lake uses, but are not providing lasting control of invasive species or nuisance native vegetation.

Use of Reward (diquat), a contact herbicide, provides localized control of VWM for a year or two, but does not kill the whole plant. Observed regrowth is indicative of surviving roots systems. The most effective alternative for VWM (2,4-D) is not approvable for use in lakes with sandy soils as a consequence of potential impacts to potable well supplies. Diquat will allow annual control, but will not likely reduce long term control needs.

Use of Sonar (fluridone), a systemic herbicide, should kill the entire plant for susceptible species, which include EWM and fanwort. However, Sonar requires extended contact time that is difficult to achieve in many areas. Additionally, higher concentrations are needed to kill fanwort, while lower levels can be effective on EWM. A complete kill is rarely achieved, but control of EWM appears effective in Webster Lake. However, regrowth of fanwort in many areas suggests that treatment is not as effective as it has been in some other lakes. Pelletized formulations have been used to minimize dilution and flushing effects, and temporary control is achieved, but repeated treatment appears necessary every few years.

Hydro-raking provides temporary relief from dense native plant assemblages, as can other physical means, but the cost is substantial and physical methods have not been widely applied in Webster Lake.

Lack of extensive quantitative plant data (such as point surveys with enough measurements make valid comparisons) precludes systematic analysis of changes in lake vegetation over time. Available maps indicate that conditions have not gotten worse; we just don’t have quantification of how much better they have been made by treatment. Based on treatment needs, problem areas have been reduced by about 75%. The program developed over the last 8+ years has achieved a desirable level of temporary control without obvious impact to lake ecology, but carries a significant annual cost.

Figure 12. May 2010 treatment areas in Webster Lake.

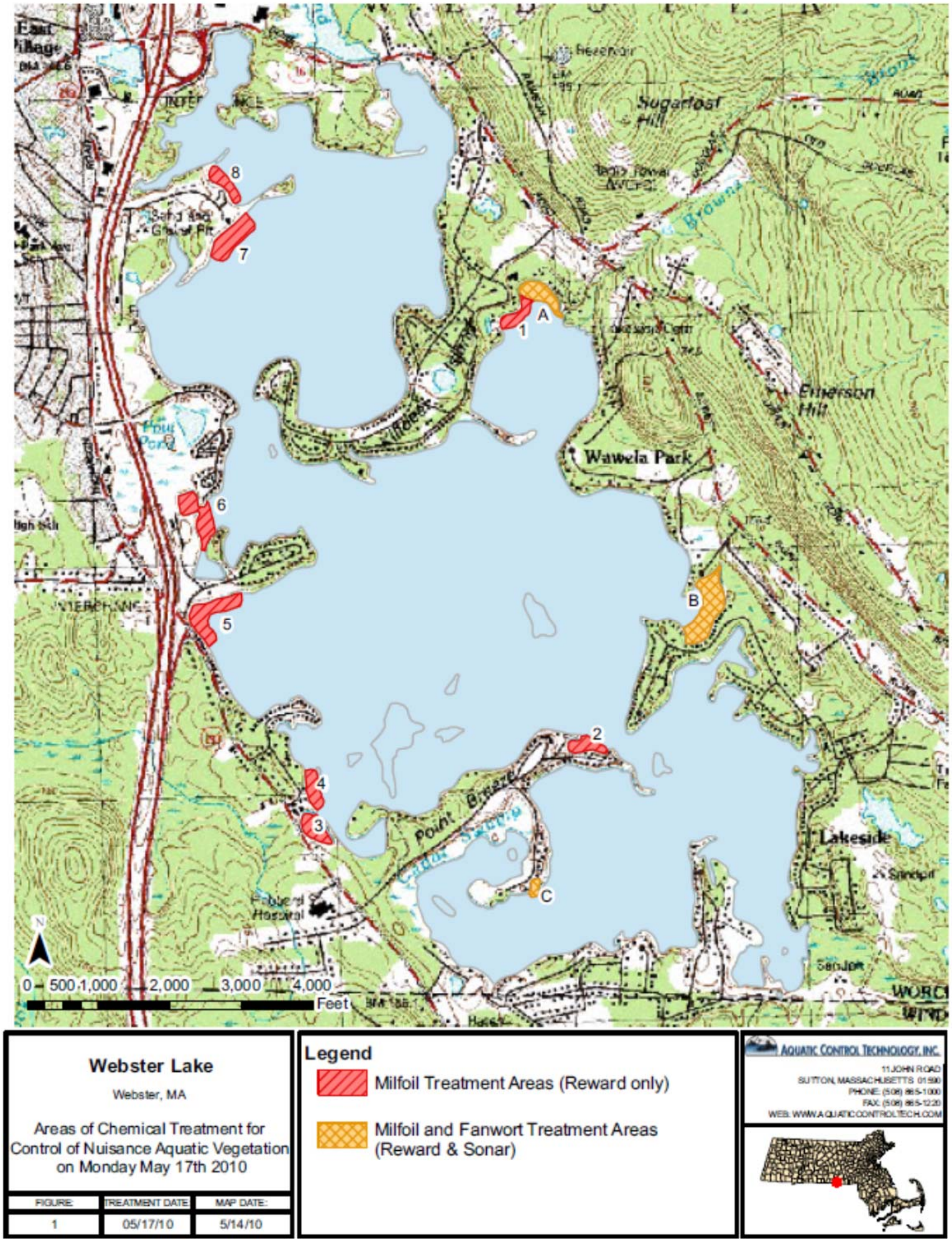


Figure 13. June 2010 treatment areas in Webster Lake.

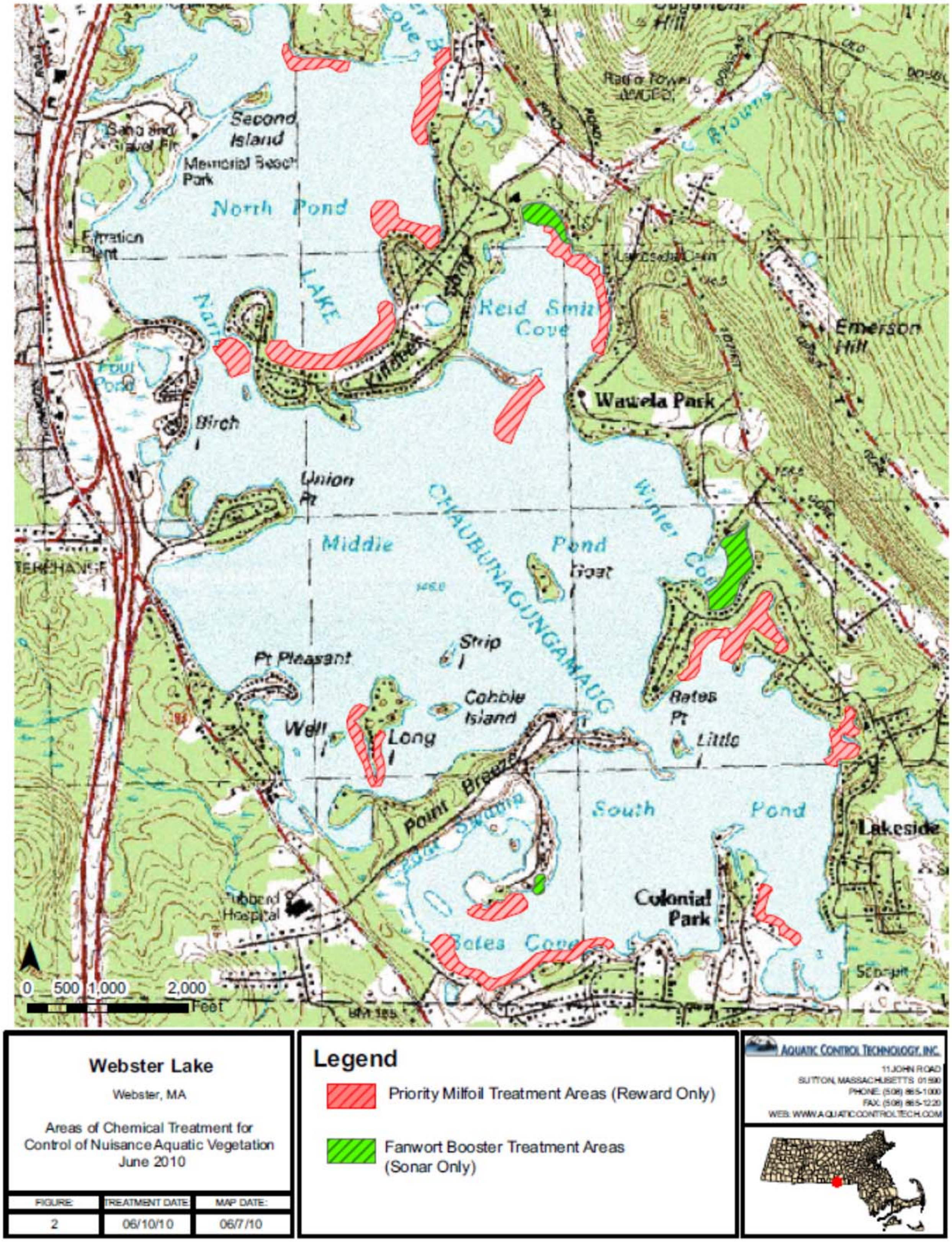
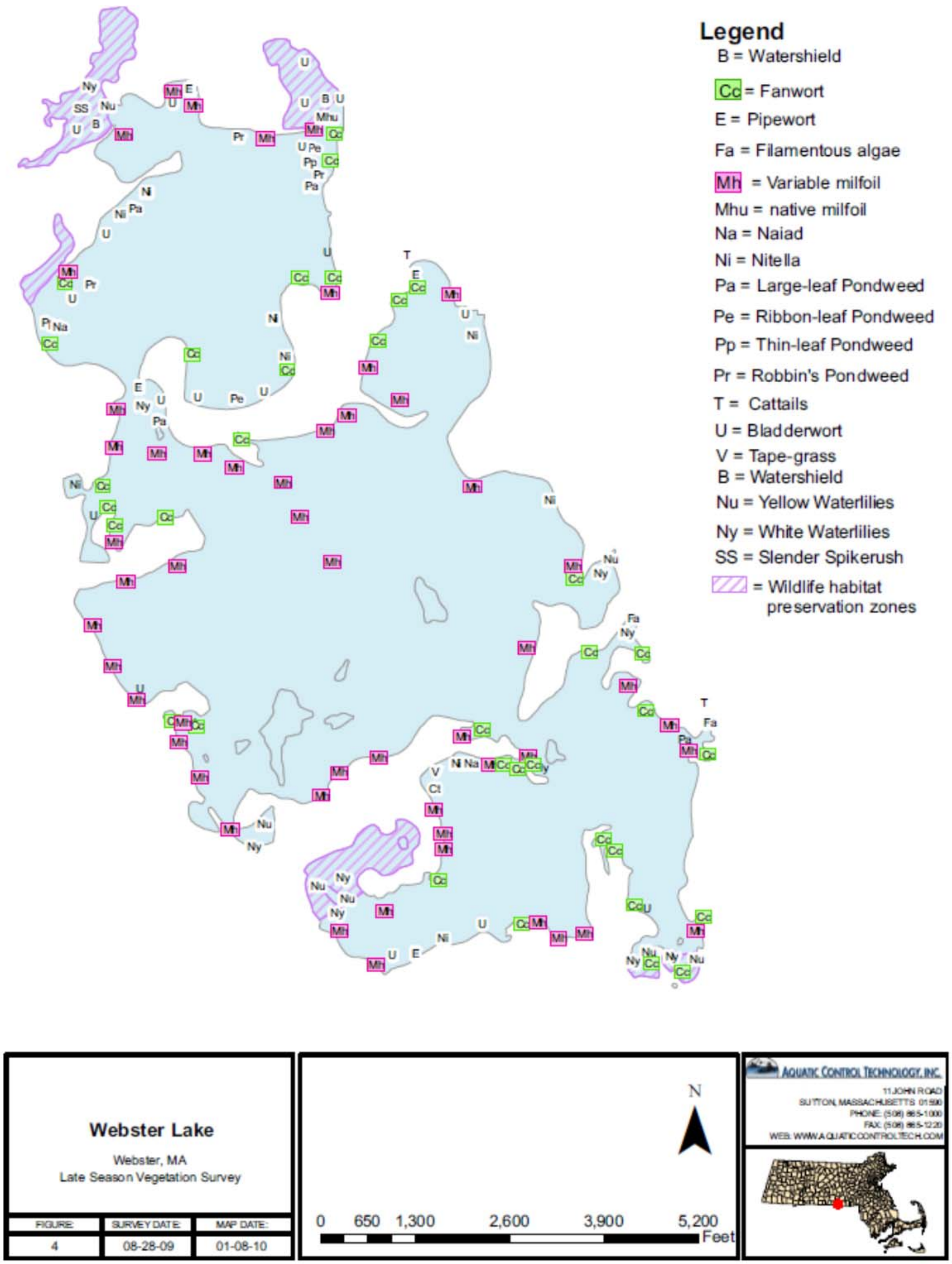


Figure 14. Wildlife conservation areas and general plant community features in Webster Lake in 2009.



Water Quality in Webster Lake

Limited professional monitoring occurred from 2003 through 2006, by Geosyntec, after which volunteers assumed responsibility for expanded monitoring. Efforts have been supported by grants, and a lot of data have been collected. Reporting has been done on hard copy data sheets and either placed on the Association website as PDFs or transferred to spreadsheets for posting. The collection of these data represents a major accomplishment not often achieved by lake associations, but there has been no systematic analysis of the data, either in terms of quality control or implications for the lake. This review seeks to provide that analysis.

Approach and Quality Control

Water quality sampling involves stations, frequency of sampling, and water quality features to be assessed. Choice of stations, sampling frequency, and what to measure is very important to any assessment that can result. Virtually no water quality assessment program collects 100% useable data. Problems with people, equipment and labs are always encountered, and collected data must be examined for reliability. This is not an easy task, as knowing how to spot unreliable data is not common knowledge, and sometimes is more art than science. The following measurements have been made, and the following suggestions for monitoring approach and guidelines for quality control checks are offered:

Stations

Water from each of three basins in Webster Lake has been sampled at the deepest point in each basin (Figure 2), with samples collected at depth increments from top to bottom. Data collected by field meters tend to be collected at intervals of 2 ft, while samples for the lab tend to be from the top and bottom, with some samples from a mid-depth range. As collecting more data with field meters carries no major cost, sampling at every 2 ft does no harm, and can highlight vertical changes that may indeed be important in lakes with depths of 28 to 45 ft. Such measurements may also allow discernment of bad values or inconsistencies, but it is hard for many people to tell when a change is real or a consequence of sampling error. In this analysis, data were organized to represent the surface, near bottom, and a mid-depth point for each sampling station in the three lake basins.

Water is also sampled from up to six tributary points, two of these on the same stream (Brown’s Brook with a sample near the inlet to Webster Lake and another just upstream of an auto salvage operation). The Unknown Tributary enters Brown’s Brook upstream of the lake and Mine Brook joins Sucker Brook before entering the lake. Mine Brook is large enough to warrant assessment even though it combines with Sucker Brook in a large wetland adjacent to the lake, and the sampling locations keep these streams separate.

The station known as LakeWake is a small tributary that can go dry, so the two main inlets are Sucker Brook and Brown’s Brook, the former entering the north basin of Webster Lake and the latter entering the middle basin, both on the east side (Figure 2). The outlet is also in the north basin, complicating system hydrology; flow patterns and detention time may vary substantially in each basin, and we know of no hydrologic assessment for these basins. The south basin flows to the middle basin which flows to the north basin, with water then leaving through a controlled outlet on the northwest side of the lake.

There is no real quality control to be exercised with regard to stations, other than ensuring each targeted station is sampled, which the Association handles well. It is not clear that so many vertical sites are needed at each station, and reducing the effort to a top, mid-depth and bottom may make volunteer effort easier, but there is nothing wrong with what is done now. It is helpful to have temperature and dissolved oxygen data at intervals throughout the water column, to facilitate profile examination, but the primary interest in assessing water quality is the top and bottom, with a mid-depth sample providing some additional information on where change may occur. Sampling the deepest point in each basin is important, and sampling Mine Brook, Sucker Brook, Brown's Brook and at LakeWake appears quite appropriate.

The Unknown Tributary has not been sampled lately, but does represent a less developed drainage area that may make a useful reference; other such reference streams may exist as well. Sampling upstream on Brown's Brook at LKQ20, just upstream of the auto salvage operation, may be important to compliance monitoring for that operation, but it is not clear why this is the Association's responsibility. It is worthwhile to compare data from the upstream and downstream locations on Brown's Brook to determine if there are any differences. It would also be highly desirable to collect storm water runoff samples from smaller, intermittent drainage channels and pipes, as the watershed is not large compared to the lake, and these localized sources, mostly draining land very near the lake, may be important to conditions in the coves.

Frequency

Water from each of three basins in Webster Lake has been sampled at least monthly, sometimes every two weeks, with sampling between April and October. More recently, the Association has settled into a pattern of sampling monthly from May through September. This seems to be an entirely appropriate sampling frequency for this system. It would be desirable to sample tributaries and additional drainage channels and pipes during storm events, as that is when most loading will occur, especially in the early parts of storms. It may also be helpful to collect a set of samples from under the ice in one or two years, to assess winter conditions. The May sampling would best occur as early in May as possible, to assess conditions prior to major biological activity each year. Growth of plants and algae, development of zooplankton populations, and hatching of fish can all affect water quality, and early May samples will tend to precede most of this activity. The September sampling would best occur as late in September as possible, to allow cooling and mixing to have at least started. Webster Lake does stratify during summer, but this stratification breaks down during September in most years. With an early May sampling and a late September sampling, this leaves the June, July and August samplings to cover the main recreation season, and these should be spaced roughly equidistant between the May and September samplings.

Water Quality Features

Temperature*:* The temperature of water has influence on many of its features, including oxygen content and physical state (water vs. ice), and affects biological processes (slower in colder water). While not usually of direct concern, knowing the temperature is very useful when interpreting other water quality data. The typical range for a lake in MA is 0 to 30 degrees C, or 32 to 86 degrees F. Water is warmest in summer and coldest in winter. If values outside this range are observed, there may be a problem with the temperature sensor, which can get covered by bacteria or other substances that will cause it to misread.

Dissolved Oxygen*:* The oxygen content of water, or DO, is very important to aquatic organisms and to the forms of many other water quality features. Fish and invertebrates cannot survive without oxygen for very long, although some have remarkable tolerance for at least short term exposure. Ammonium nitrogen cannot be converted to nitrate nitrogen without oxygen. Phosphorus can be released from sediments in the absence of oxygen. Values in MA lakes typically range from 0 to about 14 mg/L, although with excessive oxygen input from plants and algae, supersaturation is possible and values as high as 20 have been observed. For summer monitoring, and value higher than about 10 mg/L should be viewed as suspect, and values <0 mg/L are not possible. DO meter calibration is very important and subject to multiple influences; it should be checked every day the meter is used, before use, and again at the end of the day.

pH*:* The pH measures the hydrogen ion content of water, and is linked to how much acid is present. The actual value is the negative logarithm of H concentration, so a high value means a low H level and low values mean high H. Water with a pH of 7 is considered neutral. Whether water is acidic (pH <7) or basic (pH>7) can influence the solubility of metals and other substances, affects fish health, and can determine which algae will thrive. Forms of inorganic carbon in the water are strongly influenced by pH. The natural range in MA is about 4.0 to 9.0 standard units (SU) of pH, but values between 6.0 and 8.0 SU are much more common,, especially in lakes. Values outside the 6-8 SU range should be checked for accuracy, although consistently lower values (down to perhaps 5.5 SU) are plausible in streams draining wetlands. As with DO, the calibration of the pH meter is important and should be done at least at the start and end of any day of meter use.

Conductivity*:* The amount of dissolved substances in water affects the ability of that water to conduct electricity, with more dissolved solids leading to higher conductivity. The total dissolved solids content of water can be approximated in mg/L as 2/3 of the conductivity, measured in uS/cm. Conductivity does not tell us what the solids are, just how much is present. High conductivity could be caused by road salt, but can also be an indicator of nutrient pollution. Values in MA tend to range from about 20 uS/cm (very pure spring water) to about 500 uS/cm (road runoff early in a storm), although values >1000 uS/cm have been recorded around uncovered salt storage areas. Values <100 uS/cm generally indicate low solids content, while values >300 uS/cm are often associated with solids levels high enough to warrant investigation of the nature of those solids and how they might impact the lake. Conductivity probes should be calibrated, but are much less problematic that DO or pH probes.

Turbidity*:* Suspended solids in water will deflect light, increasing turbidity and decreasing visibility. Turbidity probes are basically measuring the loss of light from entry to exit along a straight path, and must be kept clean and calibrated so that the relationship between entering and departing light is reliable. Clean lakes have values <10 Nephalometric Turbidity Units (NTU), and often have values <2 NTU. Treated drinking water must have values <1 NTU, and most bottle waters target levels <0.1 NTU. Natural particles in lakes, including algae, pollen and suspended sediment, will impart some turbidity, and values between 1 and 5 NTU are common. While a decrease in clarity may be observed over this range, few people would have an issue with swimming in water with turbidity <5 NTU. Even 10 NTU may be acceptable, but as the value increases from that level, conditions deteriorate noticeably. Values >20 NTU would be visually unappealing, and values >100 NTU would have minimal visibility and likely a lot of color (such as the brown of sediment or the green of algae). High values (>20 NTU) at the bottom of a lake often indicate that the instrument has been allowed to hit the bottom, and is either in the bottom muck or has stirred it up. Values >10 NTU should trigger assessment of the source of the turbidity, and may involve consideration of probe placement, algal chlorophyll, suspended solids, and recent weather patterns. Values of <0 NTU are not possible, and values <1 NTU are rare in MA lakes.

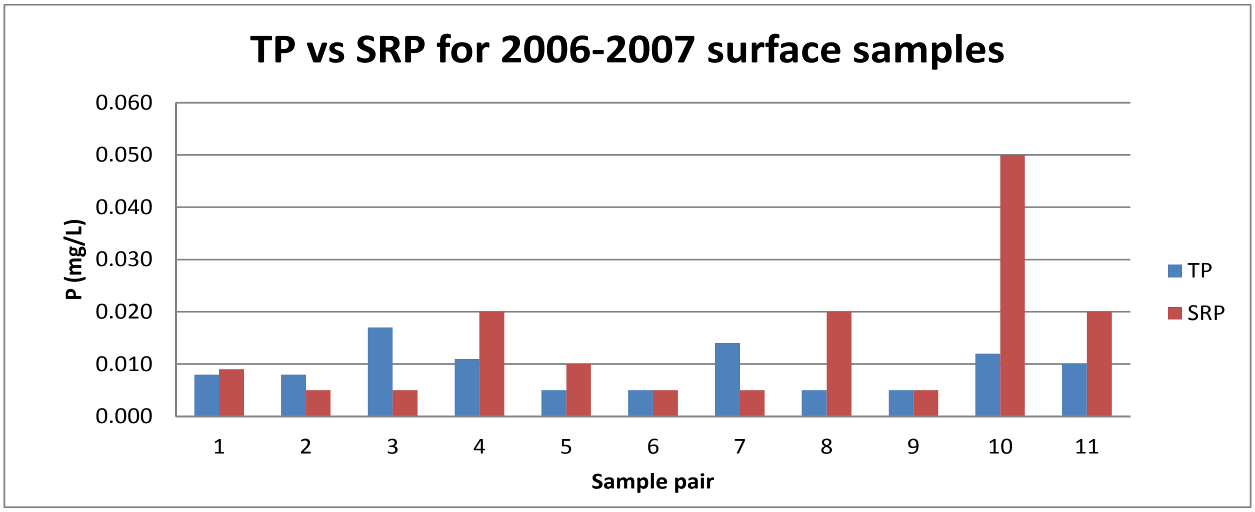
Phosphorus*:* Phosphorus (P) is the nutrient most often in shortest supply relative to the needs of plants and algae. Most plants get P from the sediment via roots, but algae have to get it from the water column in which they float. Phosphorus comes in various forms, not all of which are readily available to algae. Total phosphorus (TP) includes all forms and is determined in the lab after acid digestion of the sample, so that all P is converted to a soluble form that will react with added chemicals. Soluble reactive P (SRP) is that fraction that readily reacts with added chemicals, and cannot be larger than TP. In most lakes, SRP is not large on a routine basis, even if TP is large, since algae readily take up the SRP. Dissolved P (DP) is usually defined as a TP analysis run on a sample that has been filtered first, so it is intermediate to TP and SRP. DP is often taken as the best measure of P available to algae, although most relationships between P and other important variables, including algal chlorophyll, are based on TP.

Although some very sophisticated and expensive instruments can perform a TP analysis on site, most non-lab analyses are for SRP with a colorimeter. None of the non-lab instrument measurements of forms of P has been very reliable to date; P analysis is still best performed by a laboratory, and even then one must be careful to collect and process samples properly to avoid contamination and interconversion of types of P. Concentrations of P <0.01 mg/L will rarely support an algal bloom, while values >0.1 mg/L represent more P than even a severe blooms needs to develop. So the effective range in which lake managers are interested is about 0.01 to 0.10 mg/L. With such a narrow range of P values having such a large range of influence, a detection limit of no more than 0.01 mg/L is needed and one needs to be able to discern P concentrations at increments of no more than about 0.005 mg/L.

Values >0.1 mg/L are uncommonly found outside a wastewater treatment facility or downstream in the absence of substantial dilution, except in the deep waters of stratified lakes where P is being released from anoxic sediments. Values of 0 mg/L rarely exist in nature. Consequently, values <0.005 or >0.10 mg/L should be viewed with suspicion and verified. Blooms tend to become more abundant at TP >0.02 mg/L, and are usually common at TP >0.05 mg/L, although again, the form of P is important. But there does not have to be measureable SRP for a bloom to form, so that measurement is the least useful of all the possible P measurements.

Prior to 2006, samples were sent to Microbac Lab for TP analysis. In 2006 a colorimeter was obtained and used for SRP measures ever since. On multiple dates in 2006 and 2007 both lab TP and local colorimeter measures were made for surface samples from the lake. The results suggest that the resulting SRP data are not in good agreement with the corresponding TP data. SRP cannot be higher than TP, but is for 4 or 5 of the 11 sample pairs (Figure 15). Measurement with a colorimeter is more difficult at low P concentrations, and values are mostly low in Webster Lake. Although practice with the colorimeter may have improved results since that time, SRP remains less useful than TP, and it is suggested that lab results for TP would be preferable, at least for selected locations. If more SRP measures are collected over space and time to attempt to establish a pattern of P occurrence, that is fine, but the lack of TP data limits evaluation of loads and likely impacts on the system.

Figure 15. TP vs. SRP for paired samples in the Webster Lake monitoring program.



***Nitrate Nitrogen**:* Nitrogen comes in multiple forms, including dissolved inorganic forms such as nitrate and ammonium, organic types such as urea, and particulate forms such as leaves, algae, and soil. The most commonly measured forms are ammonium, nitrate and Total Kjeldahl nitrogen (TKN), which is ammonium plus particulate nitrogen converted to ammonium by digestion. Much like for TP, total nitrogen is the most useful measure, but cannot be determined well outside the lab. Nitrate nitrogen is the dominant inorganic form in oxygenated waters, and is fairly easy to measure in the field with existing technology. The Association can measure nitrate nitrogen with either a colorimeter or a probe, the latter part of an In Situ Troll system. Like any field measurement, careful maintenance and calibration of instruments is critical to reliable results.

When nitrate nitrogen is undetectable (usually somewhere between 0.10 and 0.02 mg/L), scarcity of inorganic nitrogen favors certain types of blue-green algae (more properly cyanobacteria), which can utilize nitrogen gas dissolved in the water, while other algae cannot. Elevated nitrate would be considered to be values >1.0 mg/L, so as with P, the range over which ecological impacts change substantially is fairly narrow. This is also a typical range for lakes in MA; values can approach 0 mg/L, but values >1.0 mg/L, while possible with sewage pollution or high fertilizer inputs, are cause for suspicion and verification.

Comparison of Association measurement of nitrate nitrogen by lab, colorimeter and troll probe is facilitated by measurement by pairs of methods at lake surface stations and in selected tributaries on multiple dates. All three methods were never applied to the same station on the same date, but in 2006 and 2007 the lab was compared to the colorimeter (Figure 16) and from 2008 to 2011 the colorimeter was compared to the troll probe (Figure 17). Values were mostly low for the lab vs. colorimeter comparison. While agreement is not very strong, the interpretation of the values would not vary between data sets for these two methods. For the comparison of the colorimeter vs. the probe, values were often higher, but agreement was generally poor; the values differed substantially for about 2/3 of the sample pairs. Greater agreement between lab values and either the colorimeter and the probe is needed before the non-lab values can be trusted. Agreement between the colorimeter and the probe would be preferred as well. The probe was considered experimental from the start of its use, but tends to agree more closely with the lab.

Figure 16. Method comparison for nitrate nitrogen by lab and colorimeter for Webster Lake.

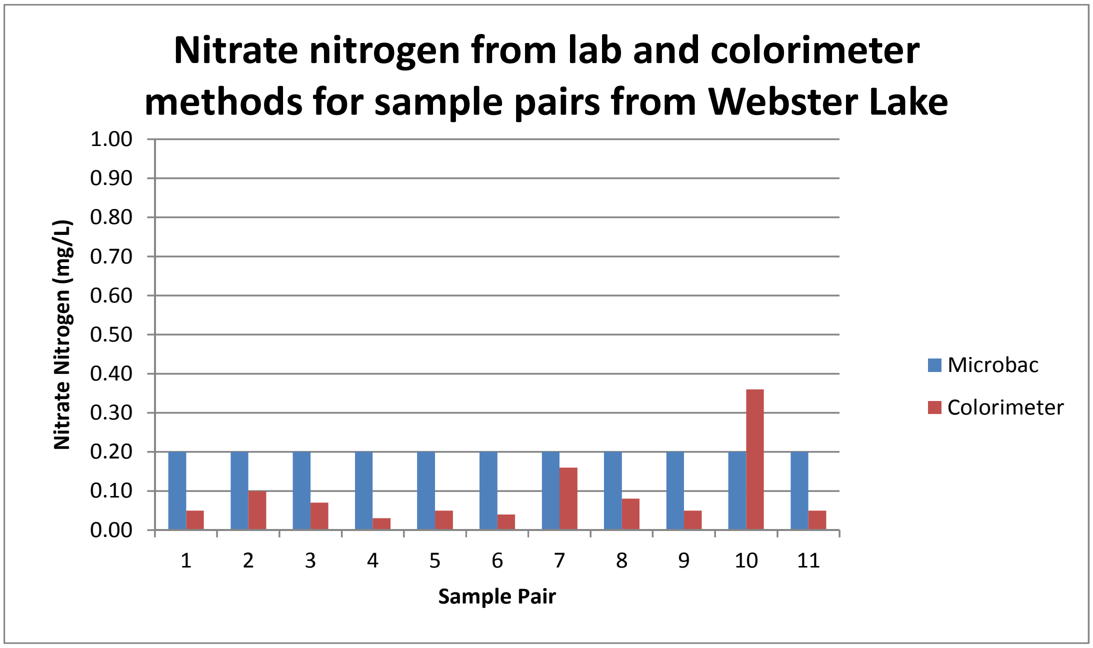
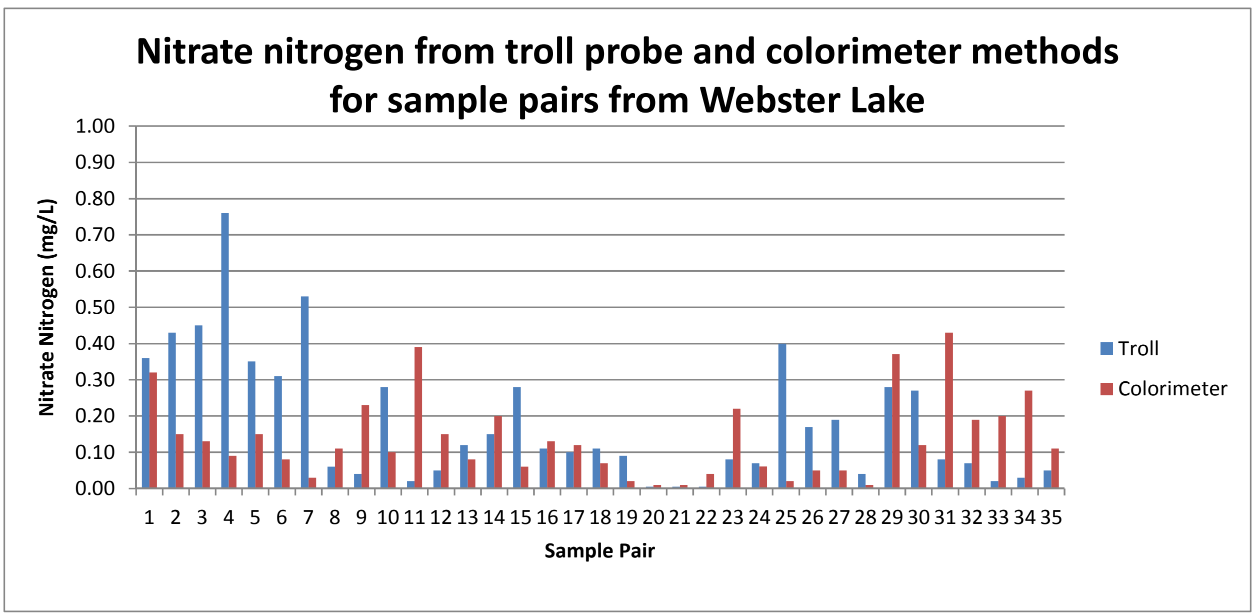


Figure 17. Comparison of nitrate nitrogen by colorimeter and troll probe for Webster Lake.

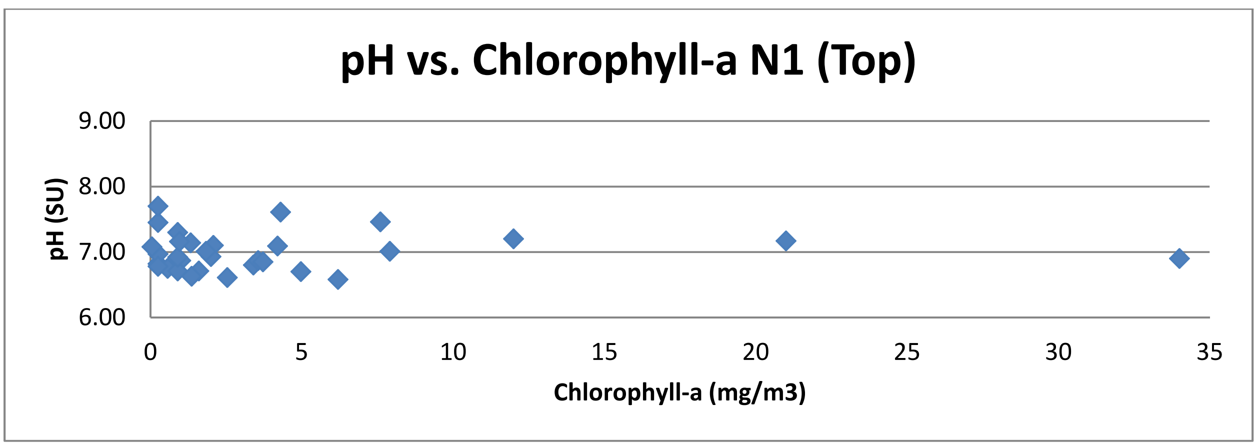


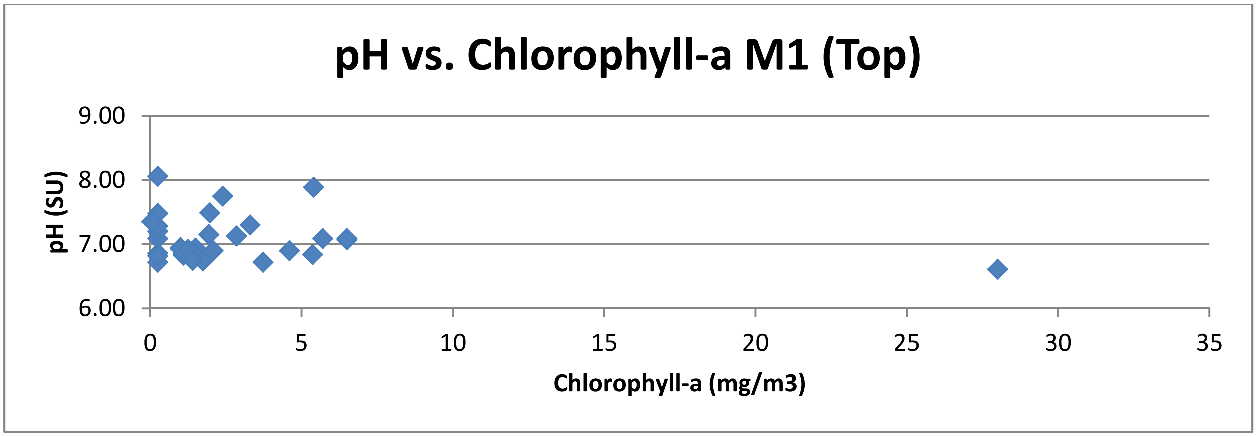
***Chlorophyll a**:* All photosynthetic organisms have chlorophyll a, the pigment most associated with photosynthesis. Other chlorophylls exists as well as auxiliary pigments (e.g., xanthophylls, carotenes, phycobilins), but the commonality of chlorophyll a (CHLA) allows this measurement to provide a surrogate for algal activity. The ratio of CHLA to biomass varies widely among algal groups, so comparisons of CHLA with cell counts, algal biomass, or suspended solids surrogates such as turbidity may not agree closely. But general guidelines have been developed by many organizations relating CHLA to blooms and suitability of the water for uses like drinking water and recreation. CHLA values <2 ug/L are considered low, while values >10 ug/L are usually considered high. Depending on the type of algae, the lake may not become unappealing for swimming until CHLA exceeds 15 or even 20 ug/L. Yet blue-green algae have the highest biomass to CHLA ratio of the algae, and if toxin producing blue-greens are present, CHLA values as low as 10 ug/L could still be a threat.

CHLA can be measured by an extraction procedure followed by spectrophotometric or fluorometric analysis in a lab, or in live state by field fluorometry. Field fluorometers present some practical problems for relating values to actual CHLA, but values for Webster Lake have been obtained from lab assessments, which should be fairly reliable. We do not know exactly what method is applied by the lab, and the observed reporting of values to two decimal places is questionable (the measurement is just not that accurate). Values <1 ug/L are suspect in all but the lowest fertility lakes, and values >100 ug/L, while possible in highly fertile systems, should be verified.

CHLA relates to many other water quality features. CHLA should show at least a rough proportional relationship with TP, turbidity and Secchi Disk Transparency, and should also be linked to pH, as algae remove carbon dioxide from the water during photosynthesis and that raises the pH. These relationships are influenced by other factors, such as cell size (affecting turbidity and transparency) and algal type (affecting biomass per unit of TP), and do not have to be linear. However, values for dependent water quality variables should rise (TP, turbidity, pH) or decline (Secchi) as CHLA increases when viewed graphically. However, none of the expected relationships are apparent when viewing graphic representations for Webster Lake data (Figures 18-20). This suggests a data problem, but with which data is unknown.

Figure 18. pH vs. CHLA for Webster Lake data.





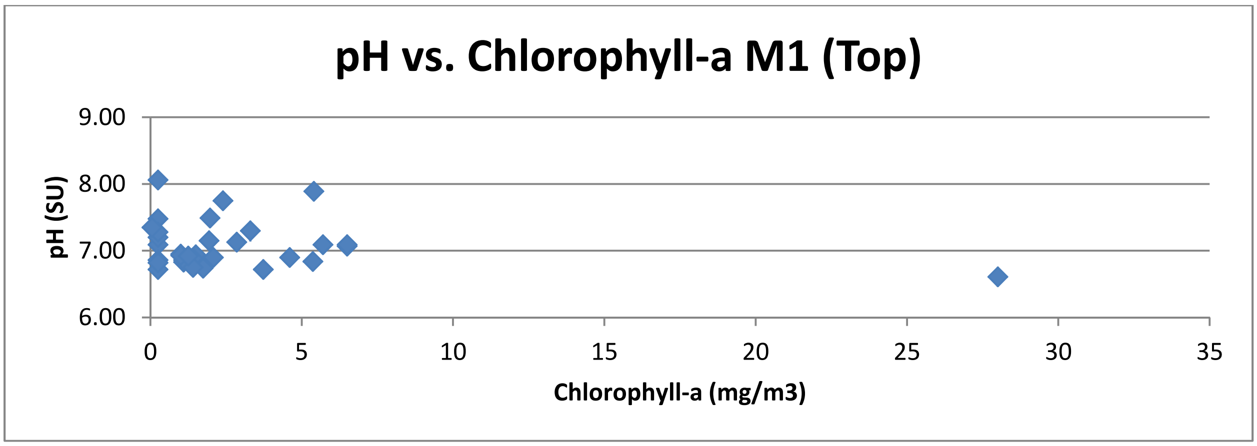
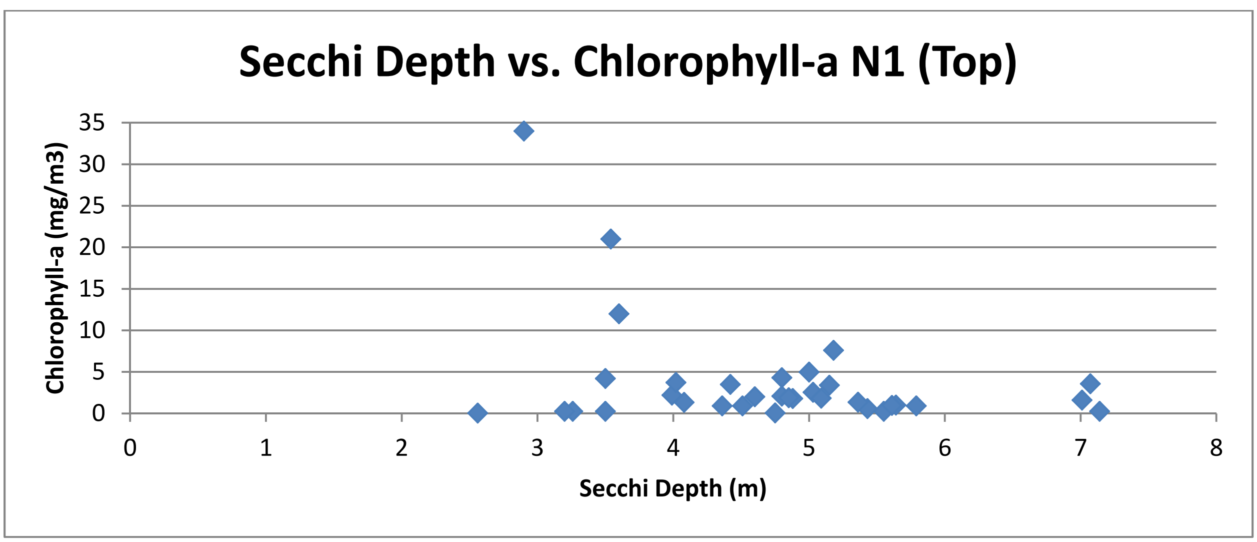
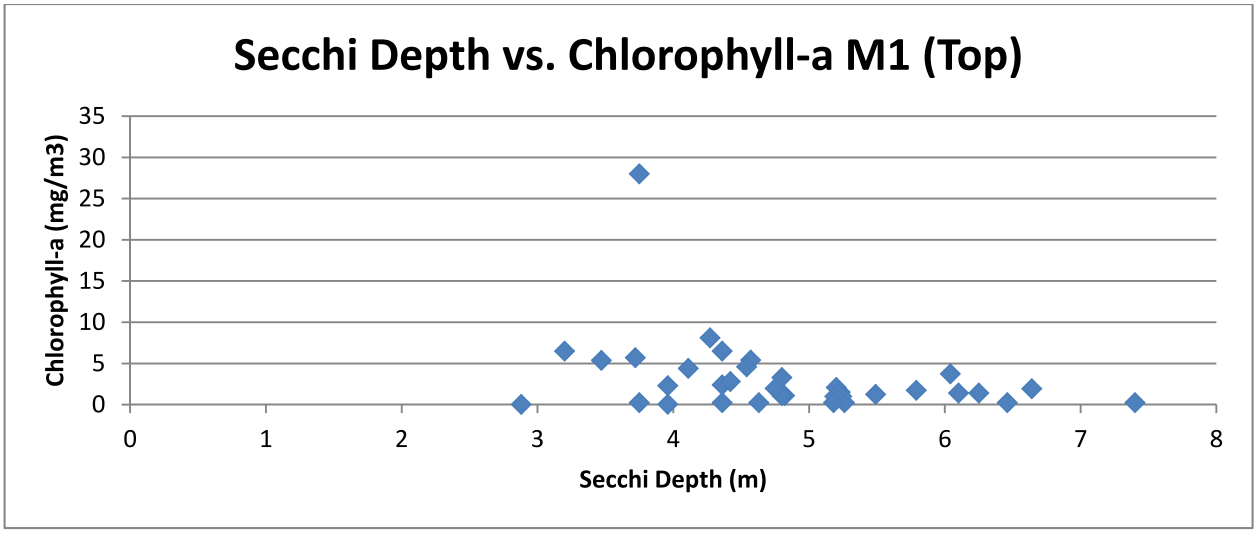


Figure 19. Secchi Depth vs. CHLA for Webster Lake data.





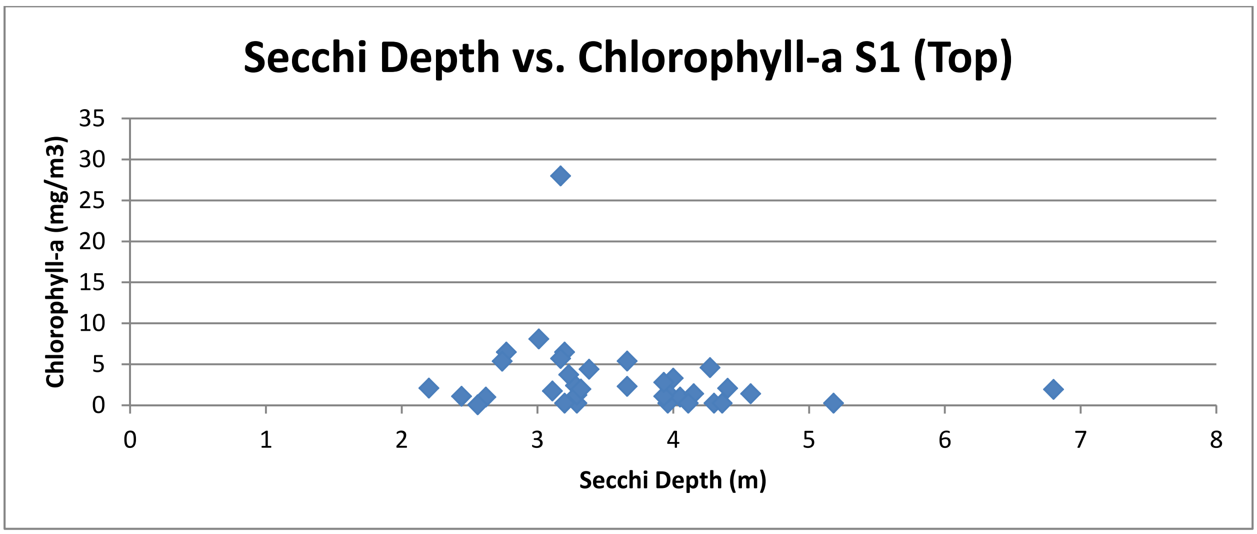
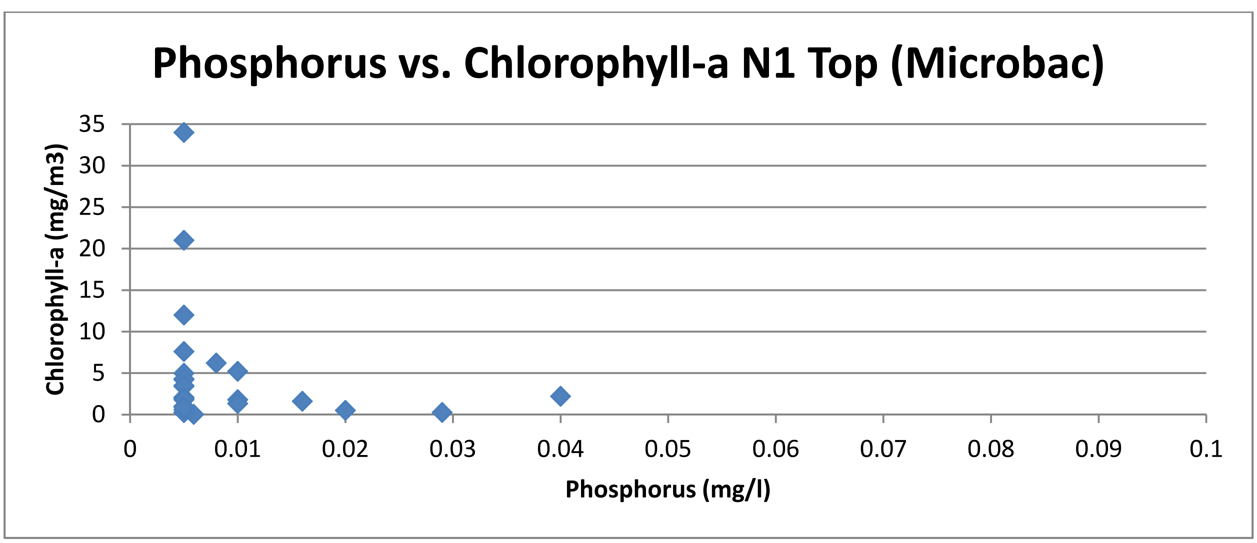
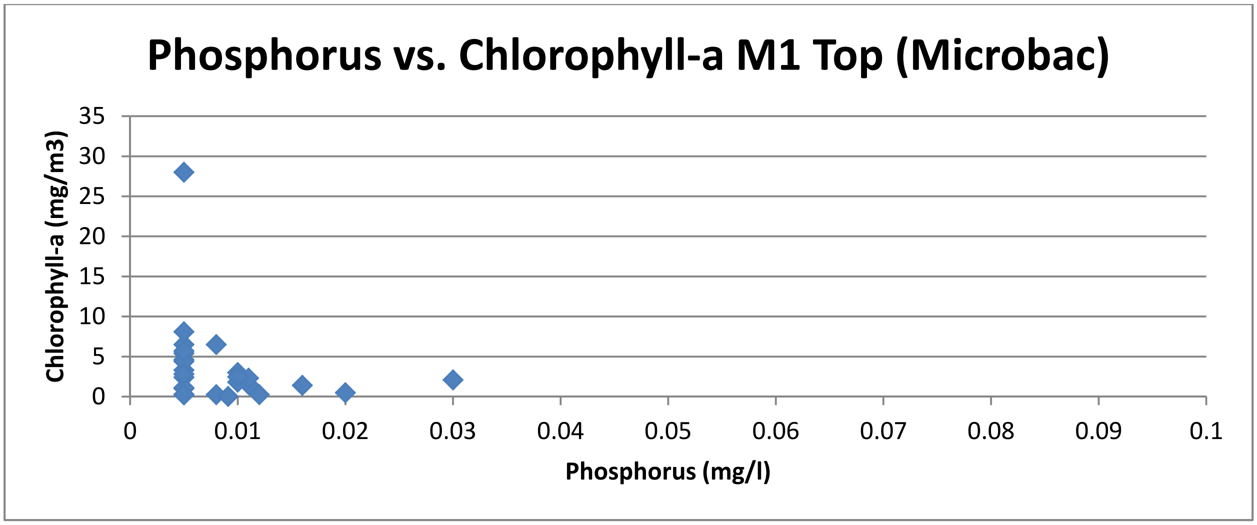
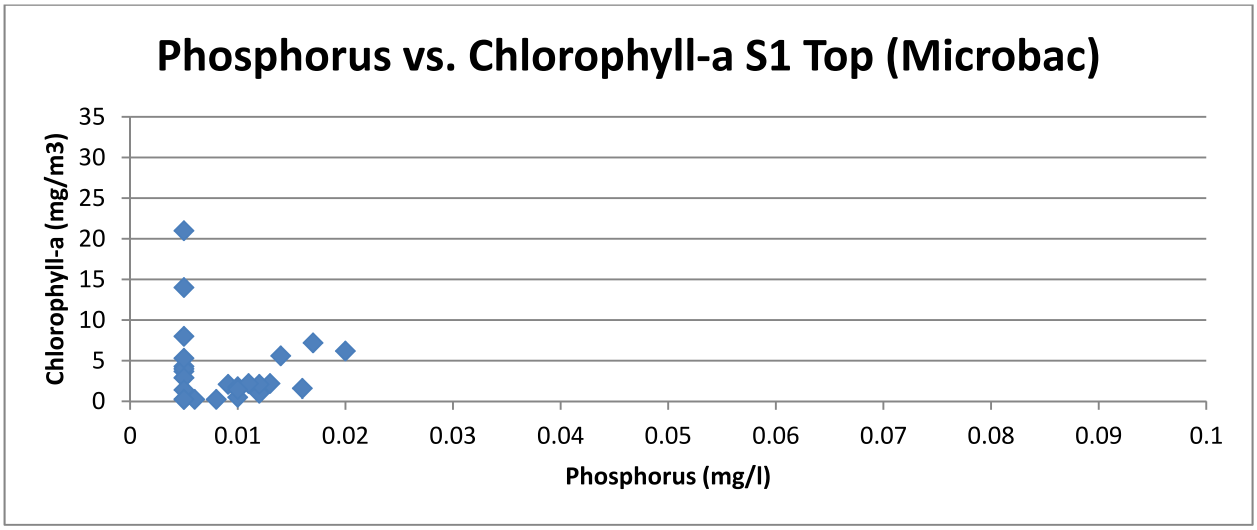


Figure 20. TP vs. CHLA for Webster Lake data.







Secchi Disk Transparency: The simple Secchi disk is one of the most powerful lake assessment tools for virtually no cost. It combines elements of turbidity, CHLA, color and depth while providing a simple measure of the visibility in a lake. There will be variability among users, based partly on eyesight and partly on local conditions at the time of measurement. User error can be reduced by the use of a view tube, which removes surface glare and wave action as compromising factors in measurement. We do not know if the Association uses a view tube, but with so many measurements made already, one could argue that changing the technique now would be inappropriate. However, whatever the specific method, the large number of values that can be obtained with volunteer effort is often able to counteract the impact of a few bad measurements or a slight bias introduced by a less than perfect method. Interpretation is not greatly affected by differences of a few tenths of a meter, limiting the impact of user error.

Values for MA lakes tend to range from about 0.3 m (1 ft) to 10 m (33 ft), although lakes with values consistently >7 m are rare in MA. Problem values often arise when users can see to the bottom and report that distance as the Secchi depth, or when plants obscure the disk before water clarity otherwise would. Measurements in Webster Lake are collected at deep sites with no plants, so these problems should not affect the data evaluated in this report. Having two people in the sampling boat is a good safety precaution, and having each make a measurement of Secchi depth is a good idea, allowing immediate comparison and potential rectification of any problem. Lowering the disk until unseen, then raising it until it is seen again, then repeating the process until the range is narrowed as much as possible is another good technique for limiting error. Some programs report both the depth at which the disk disappears and reappears as separate measurements, allowing identification of any wide ranges and possible problems.

Data Recording and Reporting

It is important to record all measurements at the time they are obtained, not relying on memory for later transcription. It is also important to review those data at the time of collection, in light of some of the thresholds discussed above and expected relationships among water quality features, to aid detection of any problems with the equipment or conditions. Lab samples cannot provide immediate data, but field meters do, and the resultant values can often tip off the user of potential problems. Consider the following possible issues:

1. Negative values are obtained; these cannot be correct for any of the features discussed in this review.
2. Values change drastically at one depth , then change back. This is possible, but not common, and warrants investigation. Even sharp changes with no return to previous values should be checked, but these can occur near the boundary of upper and lower water levels in a stratified lake.
3. Values that tend to covary do not. Secchi depth and turbidity should track each other fairly closely. Oxygen and temperature rarely increase and with water depth.
4. Values at the surface of the lake are very different among lake basins. This is possible, especially after a major storm, but the pattern among stations usually holds up. Surface temperature and oxygen are very similar on the surface at each sampling site in the lake. The lowest Secchi depth is almost always recorded in the south basin. Know the patterns and look for them. When deviations occur, make sure it is not measurement error.

Reporting of data can be in any convenient format, but comparisons are made within water quality variables over space and time. Ultimately, spreadsheets organized by water quality feature, with stations on one axis and dates on another, are what is needed. Water quality data since 2003 have been organized into spreadsheets in this fashion for this review, and the Association is encouraged to utilize these spreadsheets for further data analysis.

Quality Control Results

A major portion of this review effort went into determining the validity of values recorded in the past 8+ years. Values were eliminated when one or more of the following conditions were met:

1. Negative values were reported. None of the water quality features examined here could have negative values.
2. Values outside the reasonable range of values were reported with no corroborating evidence. Extremely high values are often possible, but should be validated by values from previous or subsequent sampling, other values from the same sampling, or even by unusual conditions (such as weather) that are consistent with the observed value.

3. Values in a series are inconsistent with other values in the series. For example, oxygen cannot approach zero 2 ft below being near saturation and then return to saturation after 2 more feet of water depth.
4. High or low values have a simple explanation that negates their validity. For example, elevated turbidity in bottom water samples was used to determine that the bottom had been reached, but was then reported as a water column value.

Additionally, all values less than the detection limit were reported as one half the detection limit. In some cases it was difficult to determine what the detection limit was, but no 0 values except for dissolved oxygen or temperature were allowed.

The resulting data tables, provided separately as Excel files, undoubtedly contain some erroneous values, but these could not be eliminated based on the available evidence. Another consideration is the implications for interpretation. More attention was paid to data where inclusion of erroneous values would alter the analysis of lake condition. Concern was lessened where potentially erroneous values were within the expected range and do not alter impressions of lake quality appreciably. Additionally, analysis is based on the cumulative data for each water quality feature and sampling location; individual values carry relatively little weight in this assessment.

Water Quality Summary

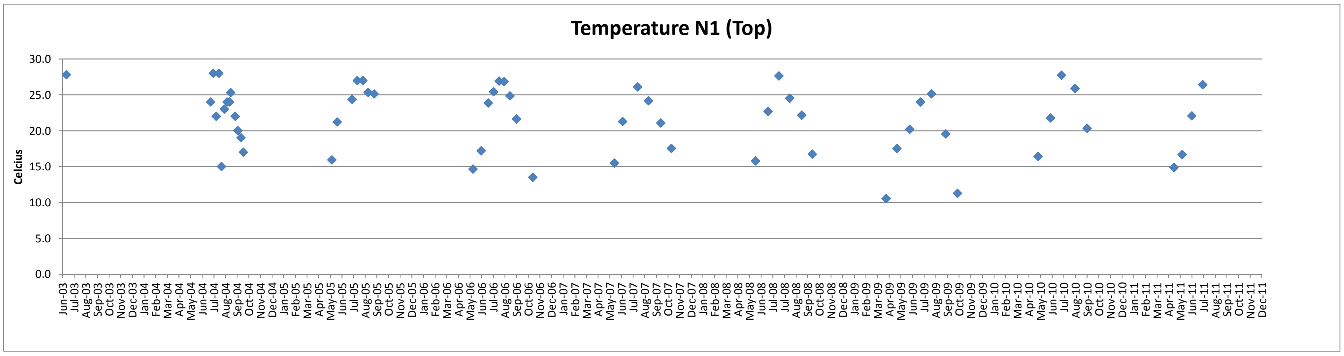
Complete tables and multiple graphic summaries are provided in the accompanying electronic spreadsheet; inclusion of all tables and graphs here would make this report excessively long, so examples are used wherever possible. However, the tables provide templates for data recording going forward and the graphics can be updated easily, allowing assessment of general conditions and trends on an ongoing basis. A summary is offered here for each water quality feature.

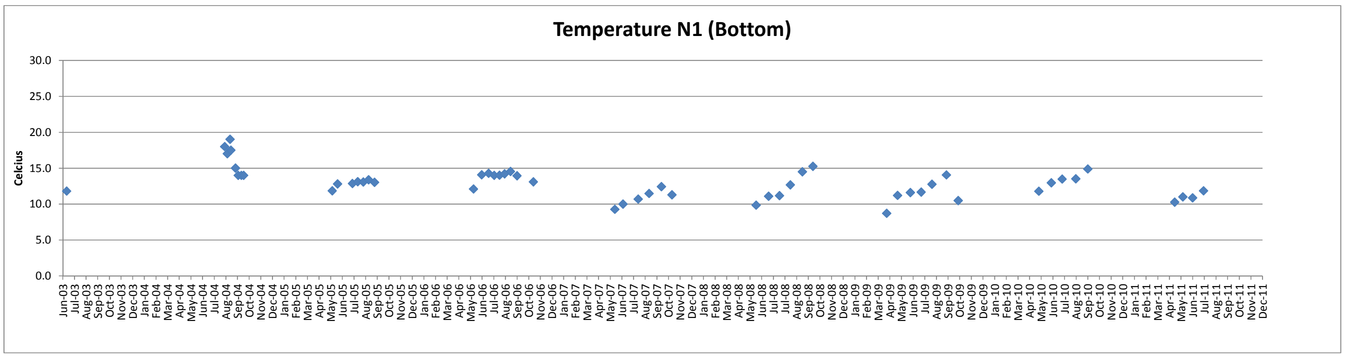
Temperature

Temperature values in Webster Lake follow the expected season trajectory. Using the north basin surface station as an example (Figure 21 upper panel), the summer peak each year is evident. Water temperature near the surface does not quite reach 30 C, but algal growth can be rapid at temperatures >25 C, making summer the ideal time for such growth. Cyanobacteria (blue-green algae) are favored by warm temperatures as well. Fall, winter and spring blooms are possible, but develop more slowly and tend to involve non-cyanobacterial groups of algae.

In comparison, bottom temperatures (Figure 21 lower panel) are lower and do not fluctuate as much. The deep water is isolated from the atmosphere and even the upper water layer by thermal stratification. There is some interaction between these water layers, mainly by diffusion and some active transport by organisms, but mixing is limited over the summer. When mixing does commence in the early fall, bottom temperature rise slightly, creating a slightly different pattern than for surface water.

Figure 21.Temperature at station N1 top (upper panel) and station N1 bottom (lower panel)





Comparison among stations (Table 5) indicates strong similarity in the thermal regime of the three lake basins. The north basin is the deepest and exhibits the greatest surface to bottom change. The south basin is shallower and slightly warmer as a result, but it still experiences stratification. The middle basin is intermediate to the other two, but all three can be considered thermally similar.

The tributary stations exhibit wider variation than in-lake stations, and lower overall averages. Streams are influenced more by cold groundwater inputs during summer and are less exposed to warming sunlight, so this is not surprising. The maximum value for Sucker Brook (SB16) may be an error, but could not be eliminated with available information, and is not a major factor in water quality interpretation.

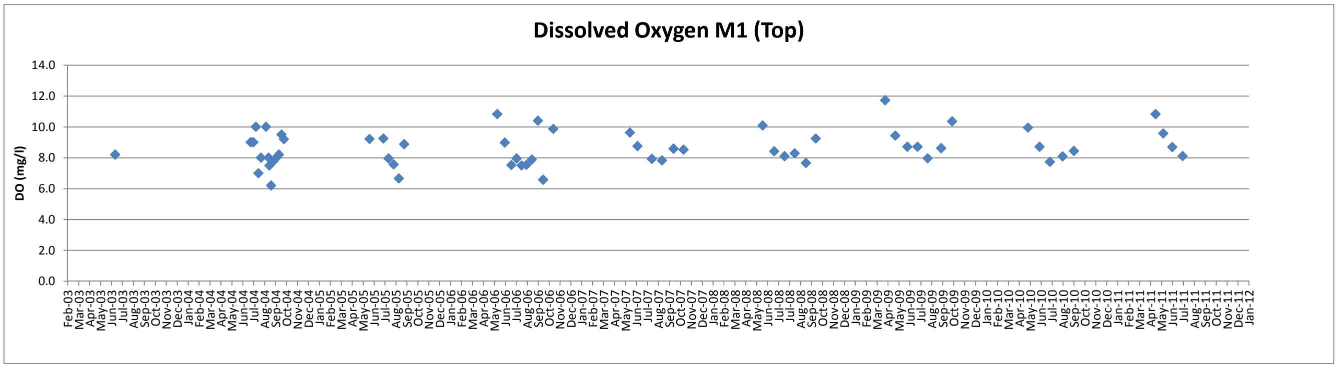
Table 5. Summary of temperature values for Webster Lake and tributaries.

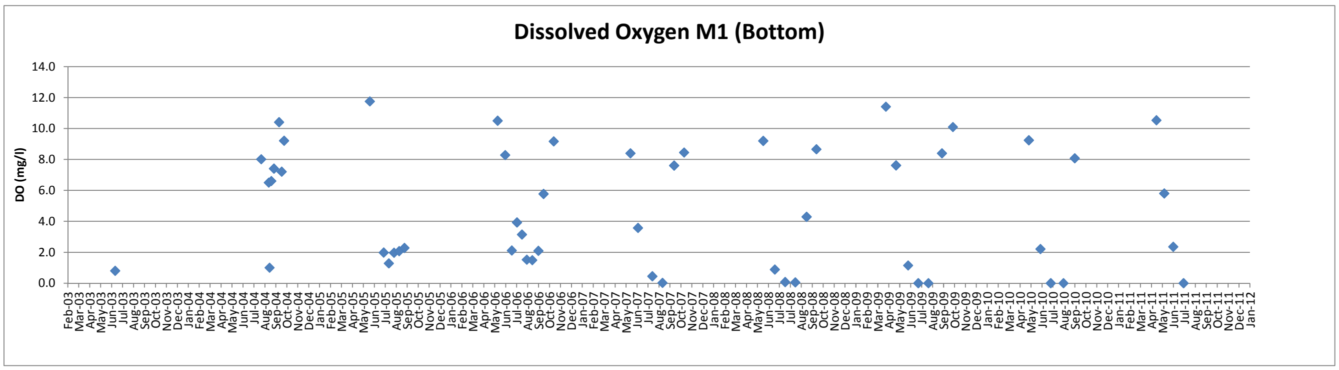
	Water Temperature (°C)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	58	21.6	28.0	10.5
N1 (Middle)	46	18.1	25.1	10.0
N1 (Bottom)	53	12.9	19.0	8.7
M1 (Top)	58	21.7	27.8	10.2
M1 (Middle)	47	19.9	25.6	10.0
M1 (Bottom)	54	16.4	25.0	9.6
S1 (Top)	60	21.8	28.3	10.3
S1 (Middle)	47	20.6	27.3	10.5
S1 (Bottom)	54	15.8	24.0	10.1
LKQ20	38	15.5	26.0	4.0
BB18	38	12.8	21.1	3.2
MB17	36	11.8	20.9	3.1
SB16	40	14.5	30.0	3.3
LakeWake	19	10.8	19.5	3.9
UN21	4	15.1	19.6	10.3

Dissolved Oxygen

Oxygen content of water is a function of temperature (oxygen is more soluble at lower temperatures), photosynthesis (which adds oxygen) and respiration (which removes oxygen). The observed pattern of oxygen over time, exemplified by the Middle Basin station (Figure 22), is consistent with temperature-mediated oxygen levels at the surface (top panel) and respiration-controlled oxygen at the bottom (lower panel). Elevated summer temperatures reduce dissolved oxygen slightly, with a range of about 3 mg/L; all values are sufficient to support aquatic life. Stratification maintains colder temperatures near the bottom of the lake, but respiration associated with decay of organic sediments depletes the oxygen over the summer, resulting in near zero values in July or August. Spring and fall values, during complete mixing, are similar to surface values. Depressed oxygen at the bottom of the lake will limit habitat value for aquatic organisms and promotes the release of available phosphorus from surficial sediments. This condition is natural to many lakes, but is exacerbated by human impacts, and is undesirable in relation to most lake uses. Mid-depth stations did not exhibit near zero oxygen levels, but the bottom stations approached zero for up to 90 days per summer (mid-June into September). Some years are better than others, but there is always at least a month of very low oxygen at the bottom of each lake basin each summer, limiting habitat and potentially facilitating phosphorus release.

Figure 22.Dissolved oxygen at station M1 top (upper panel) and station M1 bottom (lower panel)





Comparison among stations (Table 6) suggests that the oxygen regime is similar among the lake basins. The north basin is deeper and stratifies more strongly and over more of its depth, so the average deep water oxygen is slightly lower than in the other basins, but the difference is not appreciable. All three basins experience low oxygen at the bottom. Minimum oxygen in Brown's Brook (BB18 and LKQ20) is slightly low relative to the support of aquatic life, but such values are rare and average values are sufficient. All other tributaries indicated no substantial oxygen stress.

Table 6. Summary of dissolved oxygen values for Webster Lake and tributaries.

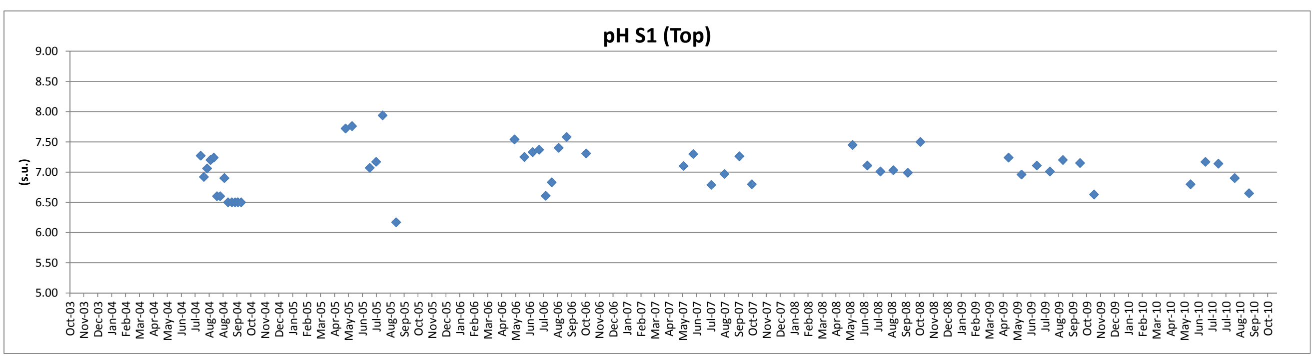
	Oxygen (mg/L)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	50	8.6	11.5	6.4
N1 (Middle)	45	7.4	13.3	2.9
N1 (Bottom)	50	3.5	11.0	0.0
M1 (Top)	59	8.6	11.7	6.2
M1 (Middle)	46	8.4	12.9	5.5
M1 (Bottom)	53	4.8	11.7	0.0
S1 (Top)	54	8.5	11.8	4.0
S1 (Middle)	46	8.5	15.6	5.5
S1 (Bottom)	52	4.3	11.8	0.0
LKQ20	38	8.6	13.1	3.6
BB18	39	10.0	15.3	3.4
MB17	37	10.3	15.9	5.6
SB16	41	9.2	14.8	4.8
LakeWake	19	10.8	13.1	7.0
UN21	5	9.0	10.6	7.7

pH

The pH in the lake is influenced by natural alkalinity (moderate to low in this area) and photosynthetic activity (which raises the pH), plus decomposition (which decreases the pH). A pH slightly less than neutral (7.0 SU) would be expected with no biological influences. Actual pH fluctuates by as much as 3 units (a 1000 fold change in hydrogen ion concentration), but most ranges are no more than about 1.5 units (about a 30-fold change). As exemplified by data for the south basin (Figure 23), surface pH (upper panel) averages around 7.0 but approaches 8.0 at times, undoubtedly linked to algal and rooted plant activity. Deep water pH (lower panel) tends to be lower, with many more values <7.0 SU, a consequence of limited photosynthesis in less lighted zones and more decomposition. Overall, however, there is less of a temporal pattern than for many other water quality features, suggesting an influence by weather, which can be erratic. When pH is raised or lowered in water in contact with the atmosphere, the equilibrium dictated by alkalinity is regained in proportion to mixing, which is dependent on weather conditions. Consequently, pH will exhibit daily to seasonal cycles, but the pattern may be altered or even obscured by weather anomalies.

Comparing stations (Table 7), the pattern of values is similar among lake basins, but there is variability in the maximum and minimum values that could represent data collection errors or localized effects that suggest some variation among basins. Certainly the pH declines with increasing depth, with surface values indicating photosynthetic influence (elevated above expected background) and bottom values indicating acid release from decomposition (depressed below expected background). Average values for tributaries range from 6.0 to 6.9, an expected range in this geographic area. Minimum and maximum values may include some erroneous values, but are within a believable range for the known features of the watershed.

Figure 23. pH at station S1 top (upper panel) and station S1 bottom (lower panel)



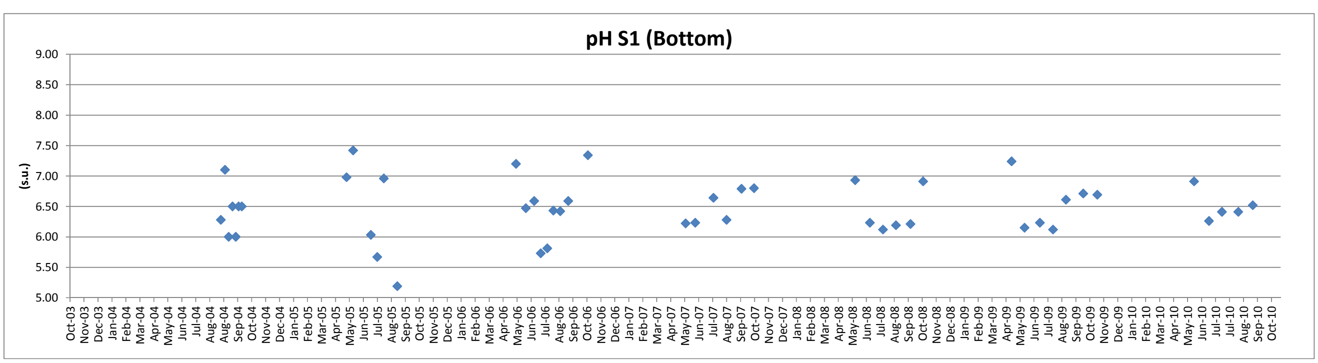


Table 7. Summary of pH values for Webster Lake and tributaries.

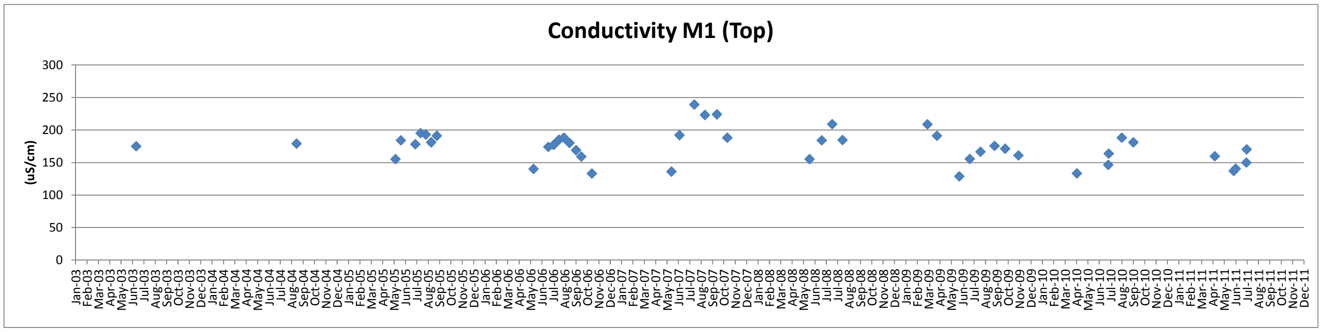
	pH (standard units)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	56	7.0	7.7	6.5
N1 (Middle)	45	6.6	8.4	5.5
N1 (Bottom)	49	6.4	7.4	5.7
M1 (Top)	58	7.0	8.1	6.5
M1 (Middle)	45	6.9	8.0	6.0
M1 (Bottom)	52	6.6	7.5	6.0
S1 (Top)	57	7.1	7.9	6.2
S1 (Middle)	45	7.0	8.4	6.1
S1 (Bottom)	51	6.5	7.4	5.2
LKQ20	38	6.5	8.5	5.9
BB18	39	6.7	7.9	5.2
MB17	37	6.0	7.7	5.0
SB16	41	6.3	8.0	5.5
LakeWake	19	6.9	7.5	6.0
UN21	5	6.8	7.3	6.5

Conductivity

Conductivity values in the Webster Lake system are low to moderate. Conductivity does not reveal the nature of the dissolved solids, but waters with the observed levels are not likely to be overly fertile. The pattern of conductivity (Figure 24) appears to reflect that of temperature, but the reason for this is unclear. Values climb somewhat during summer, with an overall range of 101 to 244 uS/cm, although most values are between 150 and 200 uS/cm. Conductivity increases with increasing dissolved solids content. Algae would be expected to turn dissolved substances into particulates, but rooted plants are known to be “leaky”, moving nutrients and other substances from the sediment into plant tissue and then into the water column. This might explain the observed pattern at the surface, as values decline as the summer ends, about the time that plants die off. However, the pattern is similar in the deep water (bottom panel), where plant influence during summer should be minimal. Low oxygen allows release of various substances from the bottom sediments, but mixing into the upper waters is limited in summer. Consequently, the reason(s) for the observed pattern remains speculative.

Comparison among stations (Table 8) suggests that the pattern of conductivity is similar among basins, with the highest values at the surface and a slight decline with depth. Values in the south basin are slightly but consistently higher than those in the north and middle basins. Conductivity in the tributaries tends to be more variable and lower than in the lake, except for the LakeWake station, which has slightly higher values than the lake, and the Mine Brook station, which has consistently very low values. Note that LakeWake discharges to the south basin, where conductivity is slightly higher than for the other basins, while Mine Brook discharges into the north basin.

Figure 24. Conductivity at station M1 top (upper panel) and station M1 bottom (lower panel)



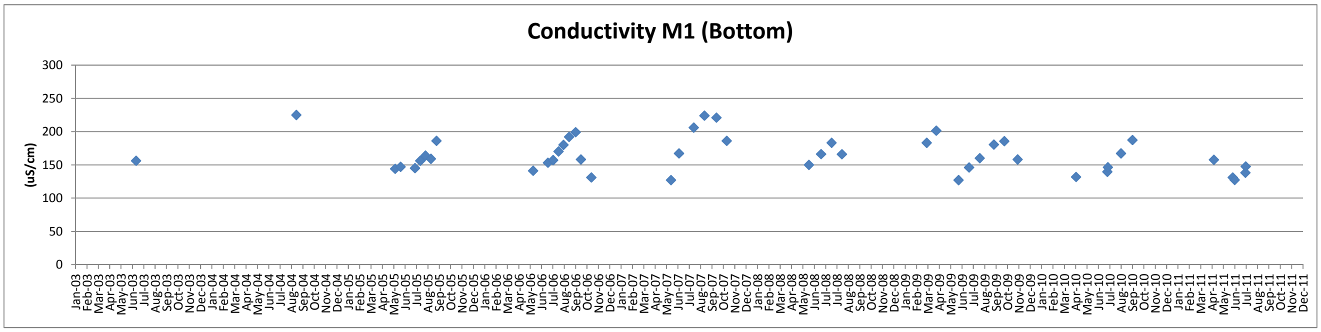


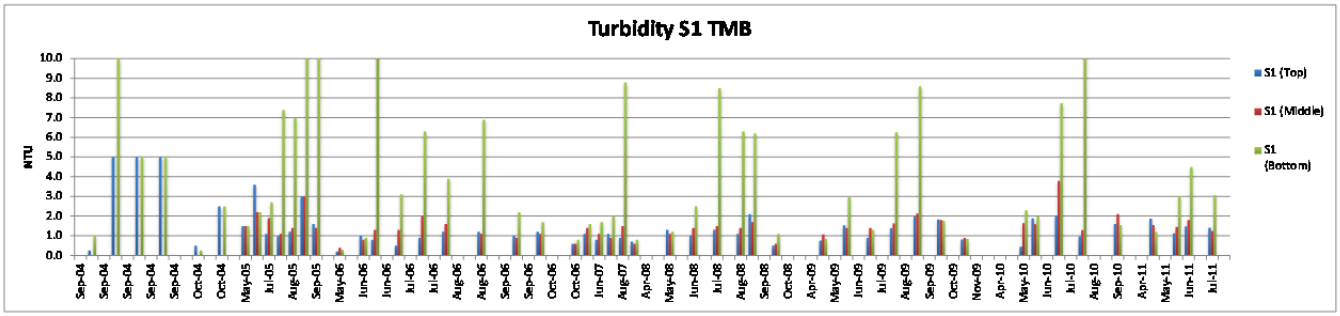
Table 8. Summary of conductivity values for Webster Lake and tributaries.

	Conductivity (uS/cm)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	45	166	225	124
N1 (Middle)	45	150	208	110
N1 (Bottom)	45	140	188	101
M1 (Top)	46	174	239	129
M1 (Middle)	46	166	232	129
M1 (Bottom)	46	165	225	127
S1 (Top)	46	178	244	131
S1 (Middle)	46	173	241	131
S1 (Bottom)	46	169	230	127
LKQ20	39	117	248	37
BB18	41	117	267	38
MB17	39	19	30	12
SB16	43	118	259	13
LakeWake	17	210	266	133
UN21	11	78	113	43

Turbidity

Turbidity tends to be <5 NTU at surface and mid-depth stations, and is usually <2 NTU (Figure 25), but is recorded at much higher levels in the deepest water. Many values were eliminated as representing probes either resting in the muck or having stirred up the bottom, but even then there are many higher values for the bottom that may represent transient conditions. Yet solids can accumulate in a layer slightly off the bottom, so these moderate values cannot be ruled out. Generally, surface conditions exhibit low turbidity, indicative of high clarity and appealing appearance. A few moderate surface values were recorded early in the program, and could represent either an instrument malfunction or elevated algal concentrations.

Figure 25. Turbidity at station S1 top, middle and bottom.



The pattern of turbidity is similar among lake basins (Table 9), with surface and mid-depth values quite low and slightly higher bottom values as a function of occasional elevated values that may be a function of the probe contacting the bottom. Tributaries exhibited a much wider range of values, some very high, but entirely possible in response to storm events. Even so, average values for all but Brown's Brook (BB18 and LKQ20) are acceptably low for streams. Problems with contaminants, especially solids, in Brown's Brook have been known for some time, but the higher averages recorded here are largely a function of just a few elevated values scattered over the monitoring period. Dry weather conditions appear to result in very low turbidity values in all tributaries.

Table 9. Summary of turbidity values for Webster Lake and tributaries.

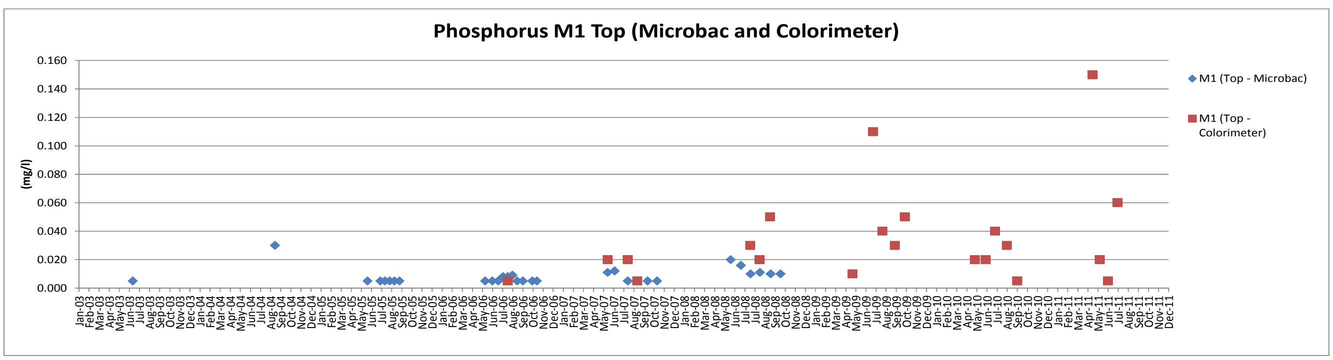
	Turbidity (NTU)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	48	0.9	3.4	0.3
N1 (Middle)	43	1.0	3.1	0.3
N1 (Bottom)	48	1.5	4.7	0.3
M1 (Top)	51	0.9	5.0	0.1
M1 (Middle)	44	1.0	2.8	0.1
M1 (Bottom)	51	2.1	10.0	0.0
S1 (Top)	50	1.5	5.0	0.2
S1 (Middle)	44	1.4	3.8	0.4
S1 (Bottom)	50	4.4	27.4	0.3
LKQ20	37	49.0	763.5	0.1
BB18	36	10.4	164.9	0.4
MB17	36	0.4	2.5	0.1
SB16	38	1.8	15.7	0.1
LakeWake	19	2.5	13.6	0.2
UN21	7	3.0	9.3	0.2

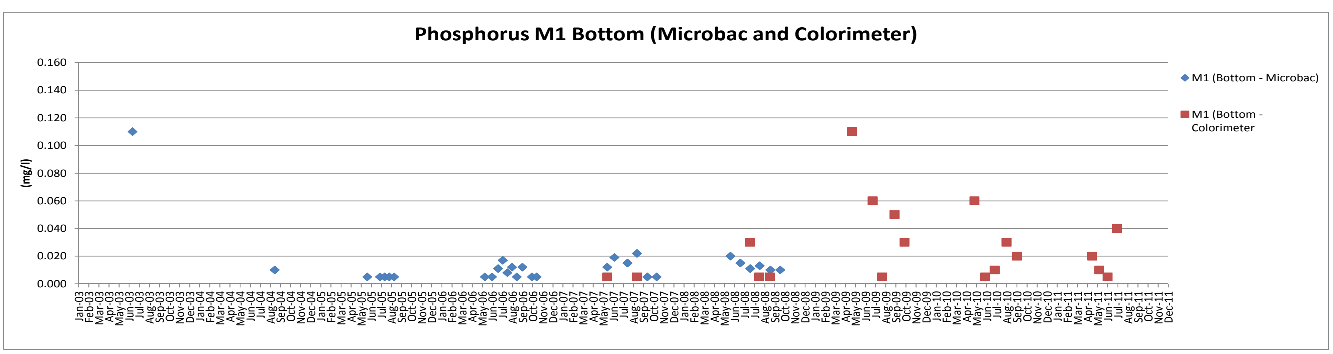
Phosphorus

While phosphorus (P) is not a direct problem in lakes, it is a key plant nutrient and excessive levels of bioavailable P in the water column can cause algal blooms. P that settles to the bottom becomes part of the sediment base and can support dense rooted plant growths. Soluble Reactive P (SRP) is all available to algae. Most Dissolved P (DP) is available, and includes more P forms than just SRP, but Particulate P (PP) is not immediately available. Total P is the sum or PP and DP, with SRP as a major fraction of DP. Because forms of P interconvert fairly readily, most relationships between P and water features such as algal chlorophyll or water clarity based on the Secchi disk utilize TP. SRP is not usually abundant; readings >0.03 mg/L for SRP would be unusual in MA lakes, while TP values can range from <0.01 mg/L (a common detection limit for labs) and 0.100 mg/L, with even higher values possible in deep water without oxygen (where P from the sediment may be released back into the water column).

Early in the monitoring program, TP was assessed at Microbac Lab. Starting in 2006, SRP was assessed with a colorimeter by volunteers, and after 2008 only SRP was measured. TP would be a more useful measure if only one form of P is to be assessed, but the pattern observed for TP and SRP in Webster Lake is troubling, as indicated by surface P at station M1 (Figure 26, upper panel). Where TP and SRP values are obtained for the same sample, SRP is larger in most cases, which is not really possible. After SRP became the sole P measure, its variability was high and questionably high values are obtained. These values could be correct if the sampling location was at the bottom of the lake, but it is not. In comparison, data for M1 near the bottom (Figure 26, lower panel) suggest higher TP near the bottom while TP was being measured, but a SRP pattern similar to that of the corresponding surface stations, with slightly lower values for many corresponding points. This does not inspire confidence in the colorimeter data for SRP, and suggests that this method may not be providing data adequate for assessing Webster Lake.

Figure 26. Phosphorus at station M1 by lab (TP) and colorimeter (SRP).





Focusing just on the available TP data, values are usually <0.02 mg/L, a general threshold for algal bloom support, and often <0.01 mg/L, a level below which blooms are very rare. Based on the SRP data, we would expect much more algae and chlorophyll and much less clarity that are actually measured in Webster Lake.

Comparing stations based on the TP data (Table 10), values are similar among the lake basins and increase with depth. Average levels at the surface and mid-depth would be expected to support desirable lake conditions (low algal concentrations, high clarity). Average values in deep water are also acceptable, but are slightly higher as a result of occasional high levels of TP in deep water. Maximum values, which range from 0.110 to 0.330 mg/L, are high enough to support major algal blooms if light penetrated that deep. However, these values occur in the lower, stratified portion of the lake during summer where there minimal light. This water layer is sequestered from the upper water layer, and only limited interaction occurs. If the high deep water concentrations were mixed with the lesser upper water concentrations, dilution would minimize impacts, but the resulting surface TP concentrations would be somewhat elevated (>0.02 mg/L) and much of it would be expected to be bioavailable, so algal blooms could be supported. As bottom conditions tend to worsen over time and expand into upper waters, this is a long-term concern for Webster Lake. However, at the present time this does not appear to be a threat in the open water portion of the lake. What occurs in more isolated coves may be related, but blooms in those coves are not a function of deep water P transfer.

Few TP values have been obtained for tributaries, and only Brown's Brook (BB18) has enough data to even speculate on its P load to the lake. Values average 0.017 mg/L, a very acceptable tributary value (anything <0.02 mg/L as a tributary average is desirable). However, it appears that most of these values represent dry weather conditions, and none represents a first flush of storm water, which is where most of the loading comes from. We simply do not have the right TP data to assess tributary loading to Webster Lake.

Table 10. Summary of total phosphorus values for Webster Lake and tributaries.

	Total Phosphorus (mg/L) (Microbac Lab)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	30	0.008	0.040	0.005
N1 (Middle)	24	0.009	0.023	0.005
N1 (Bottom)	29	0.018	0.110	0.005
M1 (Top)	30	0.008	0.030	0.005
M1 (Middle)	21	0.009	0.024	0.005
M1 (Bottom)	30	0.024	0.330	0.005
S1 (Top)	30	0.008	0.020	0.005
S1 (Middle)	20	0.012	0.034	0.005
S1 (Bottom)	30	0.022	0.150	0.005
LKQ20	0	0.000	0.000	0.000
BB18	12	0.017	0.110	0.005
MB17	0	0.000	0.000	0.000
SB16	2	0.013	0.020	0.005
Lake Wake	0	0.000	0.000	0.000
UN21	0	0.000	0.000	0.000

Reliance on SRP data, which are more plentiful, gives what appears to be a misleading impression of lake and tributary conditions (Table 11). In-lake values range from 0.027 to 0.042 mg/L, exhibit no vertical pattern, and would suggest high fertility with frequent algal blooms and low clarity. This is not the case in Webster Lake. There are still inadequate tributary data for 3 of 6 sampling stations, and for BB18, MB17 and SB16 it would be concluded that inputs were at least moderate. If the data represent mainly dry weather inputs, one might conclude that inputs are high, as the wet weather concentrations would be expected to be much larger. Again, these data do not appear reliable, and we suspect a methodological limitation. Collection of lab data for TP is advised, with an emphasis on wet weather data for streams.

Table 11. Summary of soluble reactive phosphorus values for Webster Lake and tributaries.

	Soluble Reactive Phosphorus (mg/L) (Field Colorimeter)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	20	0.028	0.110	0.005
N1 (Middle)	13	0.042	0.160	0.005
N1 (Bottom)	19	0.030	0.110	0.005
M1 (Top)	21	0.035	0.150	0.005
M1 (Middle)	11	0.031	0.120	0.005
M1 (Bottom)	19	0.027	0.110	0.005
S1 (Top)	21	0.036	0.140	0.005
S1 (Middle)	10	0.031	0.110	0.004
S1 (Bottom)	19	0.037	0.150	0.005
LKQ20	0	0.000	0.000	0.000
BB18	21	0.038	0.090	0.005
MB17	20	0.040	0.120	0.005
SB16	23	0.046	0.140	0.005
LakeWake	0	0.000	0.000	0.000
UN21	1	0.010	0.010	0.010

Nitrate Nitrogen

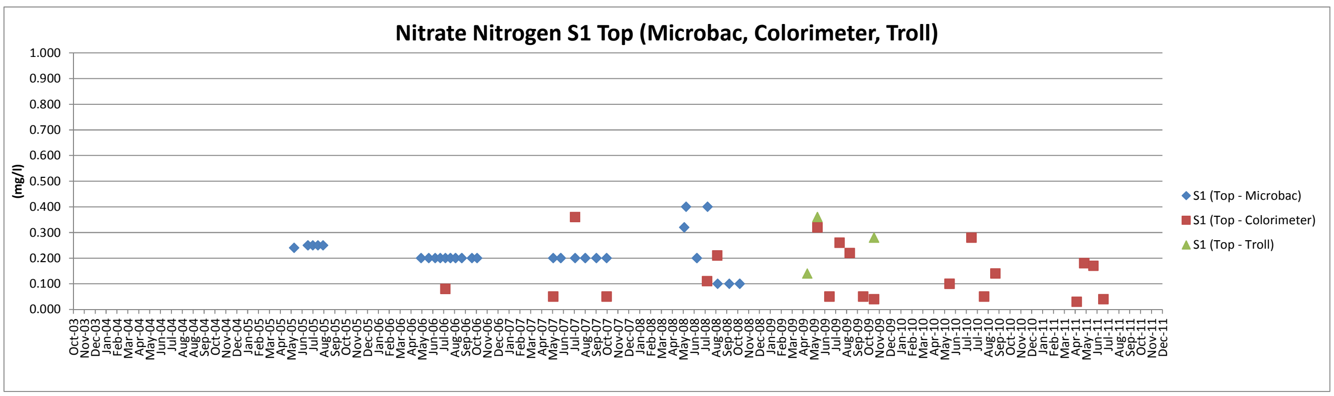
Nitrogen is another important plant and algae nutrient, but rarely determines if an algal bloom will be present. Rather, nitrogen mostly influences what types of algae will be present; low inorganic N (ammonium or nitrate forms) will favor certain types of blue-green algae that can utilize dissolved nitrogen gas, while high inorganic N tends to favor green algae. Blooms of either can impair lake use, but the blue-greens are more associated with unsightly surface scums, unpleasant odors, and possible toxicity. Other nutrients and water temperature are also influential, with diatoms and golden algae often dominating when there is a lot of silica present, water is colder, and mixing is stronger. During summer in MA, however, the concern is on P as a supporter of algal biomass and N as a determinant of green or blue-green dominance.

Nitrate nitrogen (NN) is only one form of N, but it is the easiest to measure and is useful for determining susceptibility to blue-green dominance. When NN drops below 0.1 mg/L in oxygenated waters, it is likely that there is insufficient N available to green algae, and if P is sufficient, blue-greens may bloom. When

NN is >0.3 mg/L, greens are likely to dominate. NN >0.6 mg/L is considered a high value, and NN >1.0 mg/L is rare without some form of sewage or manure influence. There are multiple ways to assess NN, with both colorimetric and ultraviolet light methods providing acceptable results. Lab versions tend to be more sophisticated than field approaches, but over the likely range of NN to be encountered, any of these methods should be adequate if properly applied.

For Webster Lake, as exemplified by NN at the surface of the south basin (Figure 27), values ranged from <0.005 to 0.400 mg/L by all methods combined. There is no obvious difference between the methods overall, but where more than one method was applied to the same sample, the agreement among values is not strong. Added quality control is advised (split samples, duplicate samples, blanks). We did in fact eliminate a number of high values that were outside the range of reasonably expected values for this system, and were inconsistent over either time or space in a way that suggested testing problems. But there are still questions of accuracy in the remaining data. However, from these data it is apparent that NN spans the range over which blue-green or green algae might dominate. Both green and blue-green algae have bloomed in this lake, but only green algae have been abundant in the open water areas represented by the samples displayed in Figure 27. Blue-greens have been more common in coves, for which we do not have NN data.

Figure 27. Nitrate nitrogen at station S1 top by 3 methods.



Considering just the lab data for NN (Table 12), which include only the surface locations at each of the three lake basins, there is a range of 0.10 to 0.43 mg/L with an average of 0.22 for all three basins. This suggests that greens should be more abundant than blue-greens, consistent with limited algal observations by ACT in 2009-2011. In the coves where blue-green blooms have occurred, sampling of NN would be helpful in determining if the lack of inorganic N is a factor in supporting any such blooms.

Considering the colorimeter data for NN (Table 13), the range is 0.02 to 0.36 mg/L for the in-lake surface stations. This is a wider range that is more difficult to interpret, and not completely consistent with algal observations in recent years. In-lake surface station average values ranged from 0.08 to 0.14 mg/L, substantially less than for the corresponding lab data. For the tributaries, values ranged from 0.005 to 0.820, a very wide range for NN but not impossible for such streams. Tributary averages ranged from a low of 0.12 in Mine Brook to a high of 0.55 in LakeWake; these seem high, but cannot be ruled out, particularly since the pattern seems to match housing density in the contributing drainage areas (with those houses having septic systems that contribute N).

Considering the troll probe data (Table 14), in-lake averages and ranges from just a few samplings are similar to those from the lab, suggesting that this technology might be applicable. Averages and ranges for tributaries are similar to those for the colorimeter, while there are no lab data for the tributaries. A number of outlier values were eliminated from this database, and remaining values still leave a confidence gap, but it may be possible to collect valid NN data with the colorimeter and/or troll probe; more comparative testing is needed to validate these methods in this case.

Overall, it appears that there are variable inputs of NN from the tributaries and average levels in the lake that suggest that green algae are more likely to dominate in open water during summer than blue-greens. This is consistent with what know of both the algal community in the major lake basins and the presence of septic systems in the watershed, usually a primary contributor of NN.

Table 12. Summary of nitrate values for Webster Lake and tributaries by lab.

	Nitrate Nitrogen (mg/L) (Microbac Lab)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	28	0.220	0.430	0.100
N1 (Middle)				
N1 (Bottom)				
M1 (Top)	28	0.218	0.400	0.100
M1 (Middle)				
M1 (Bottom)				
S1 (Top)	28	0.216	0.400	0.100
S1 (Middle)				
S1 (Bottom)				
LKQ20				
BB18				
MB17				
SB16				
LakeWake				
UN21				

Table 13. Summary of nitrate values for Webster Lake and tributaries by colorimeter.

	Nitrate Nitrogen (mg/L) (Field Colorimeter)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	18	0.084	0.310	0.030
N1 (Middle)				
N1 (Bottom)				
M1 (Top)	20	0.081	0.160	0.020
M1 (Middle)				
M1 (Bottom)				
S1 (Top)	20	0.140	0.360	0.030
S1 (Middle)				
S1 (Bottom)				
LKQ20	4	0.151	0.240	0.052
BB18	19	0.137	0.390	0.030
MB17	19	0.118	0.400	0.005
SB16	19	0.264	0.820	0.060
LakeWake	2	0.545	0.800	0.290
UN21				

Table 14. Summary of nitrate values for Webster Lake and tributaries by troll probe.

	Nitrate Nitrogen (mg/L) (Troll Field Probe)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	2	0.275	0.430	0.120
N1 (Middle)	3	0.337	0.470	0.120
N1 (Bottom)	3	0.207	0.290	0.150
M1 (Top)	3	0.350	0.450	0.150
M1 (Middle)	4	0.373	0.460	0.170
M1 (Bottom)	4	0.415	0.650	0.240
S1 (Top)	3	0.260	0.360	0.140
S1 (Middle)	4	0.313	0.430	0.130
S1 (Bottom)	4	0.300	0.390	0.200
LKQ20	9	0.190	0.658	0.020
BB18	21	0.160	0.760	0.020
MB17	19	0.141	0.640	0.010
SB16	12	0.253	0.800	0.020
LakeWake	6	0.343	0.900	0.050
UN21	1	0.090	0.090	0.090

Chlorophyll a

Algal abundance, as represented by chlorophyll a (CHLA), is a primary concern in most lakes. There is nothing undesirable about elevated algal productivity as long as the resulting algae are consumed by zooplankton, which in turn are eaten by small fish, which are consumed by larger fish, which people like to catch while fishing. When algal biomass builds up, however, this signals an imbalance between algal production and consumption that should be addressed through management. Overall, CHLA values <2 ug/L are associated with very clear water, while values >10 ug/L create color and turbidity that some people find objectionable. Once CHLA reaches 20 ug/L, very few lake users find it acceptable.

CHLA for the surface locations in the three lake basins (Figure 28) are often <2 ug/L, usually <5 ug/L, and have exceeded 10 ug/L in only 6 samples representing four dates over 9 years. Values range from <0.1 ug/L to 34 ug/L, with basin averages ranging from 2.9 to 3.8 ug/L (Table 15). While occasional algal blooms occur, conditions are generally very favorable for all lake uses. Webster Lake appears to be one of the nicer MA lakes in this regard.

Figure 28. Chlorophyll a in 3 Webster Lake basins (north, middle and south).

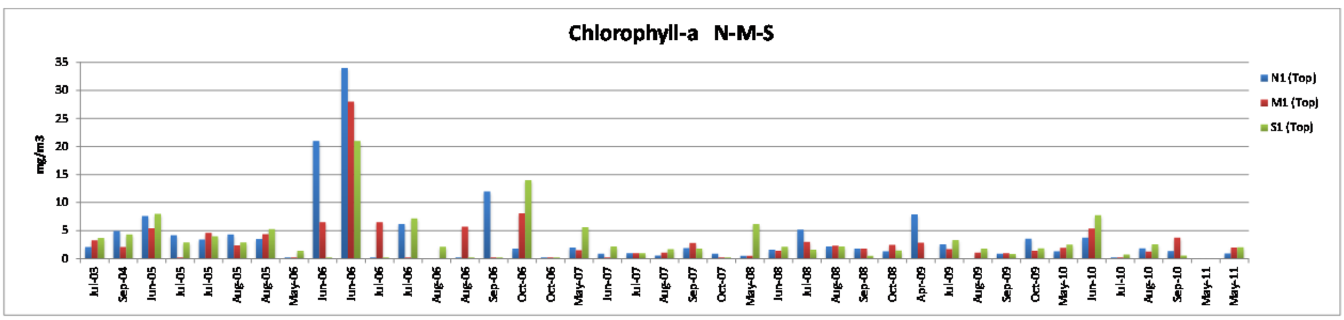


Table 15. Summary of chlorophyll a values for Webster Lake.

	Chlorophyll a (ug/L)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	40	3.76	34.00	0.03
N1 (Middle)				
N1 (Bottom)				
M1 (Top)	41	2.91	28.00	0.03
M1 (Middle)				
M1 (Bottom)				
S1 (Top)	40	3.22	21.00	0.05
S1 (Middle)				
S1 (Bottom)				
LKQ20				
BB18				
MB17				
SB16				
LakeWake				
UN21				

Secchi Disk Transparency

The depth to which a Secchi disk can be seen is a simple but meaningful measure of lake condition. There are sources of error, but the low cost of frequent measurement facilitates collection of a database that can overshadow occasional erroneous values or measurement bias. Both the actual value and the trend over time are very meaningful to lake management planning. While there is seasonal and interannual variability, clarity is generally high in Webster Lake and there is no indication of any decreasing trend over the last 9 years (Figure 29). Clarity does tend to decline over most summers by about a meter, but conditions are generally quite acceptable for all lake uses.

For the three basins of Webster Lake, sampled at the deepest point in each, Secchi Disk Transparency ranges from 2.2 to 7.4 m, with basin averages of 4.7 m in the north and middle basins and 3.7 m in the south basin (Table 16). Considering that measurements are only collected from late spring into early fall, with the highest clarity often observed in winter, this is a desirable range with some of the highest basin averages found in MA lakes. Clarity in the south basin is routinely lower than in the other two basins, suggesting greater amounts of suspended particles in that basin. As CHLA is not appreciably higher in the south basin (Table 15), this may be a function of resuspended sediment in the shallower south basin. Yet summer clarity in the south basin is still within a desirable range.

Figure 29. Secchi tranparency in 3 Webster Lake basins (north, middle and south).

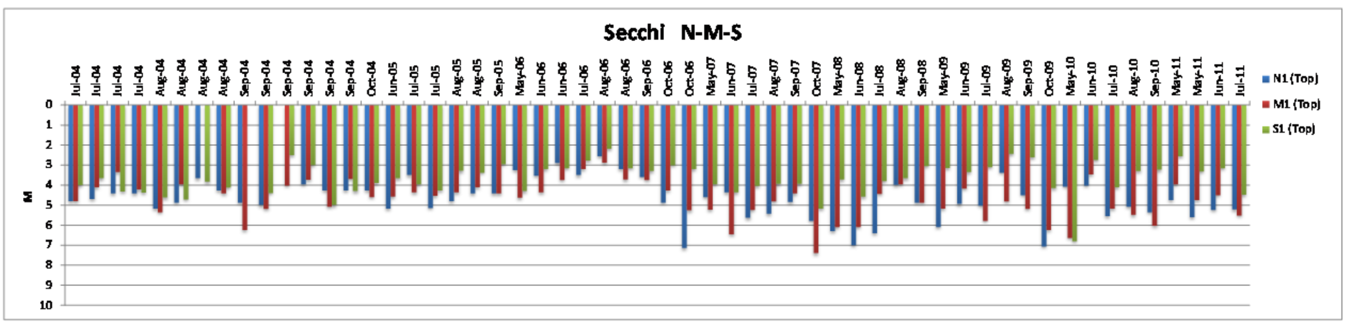


Table 16. Summary of Secchi transparency values for Webster Lake and tributaries.

	Secchi Transparency (m)			
Station	**# Obs.**	**Average**	**Maximum**	**Minimum**
N1 (Top)	55	4.7	7.1	2.6
N1 (Middle)				
N1 (Bottom)				
M1 (Top)	55	4.7	7.4	2.9
M1 (Middle)				
M1 (Bottom)				
S1 (Top)	55	3.7	6.8	2.2
S1 (Middle)				
S1 (Bottom)				
LKQ20				
BB18				
MB17				
SB16				
LakeWake				
UN21				

Storm Water Assessment

In 2005 CME provided a report that identified 185 storm water drainage points, 40 of which drained directly to the lake. While the three major tributaries (Brown's Brook entering the middle basin and Sucker Brook and Mine Brook discharging to the north basin) and the smaller stream leading to the south basin (called LakeWake) appear to represent the largest sources of water to the lake, it may well be that smaller discharges are very important to the water quality in the coves to which many of them discharge. Those smaller inputs of water could, if contaminated enough, actually outweigh the larger tributaries in terms of nutrient loading. Without actual data for flow and nutrient concentrations, especially during we weather, any statement about this is highly speculative. But it is reasonable to assume that the storm water drainage systems impact the coves to which they discharge, based on information on algae and rooted plants.

Of the 40 direct discharges to the lake, 8 were identified as the ones of greatest concern, based on the following considerations:

1. One or more discharges flowing into a confined area such as a cove.
2. Evident of sediment deposition gathered during field assessment.
3. Observable volume of sediment in the lake near the discharge.
4. Evidence of high velocity or high volumes of flow during storm events, including:
    a. Size of corresponding drainage area
    b. Amount of impervious surface in the drainage area
    c. Slope near the outlet
    d. Nature of any control structures

No water quality measurements were collected for this effort; the emphasis was on visual assessment. Brown's Brook is listed as one of the eight most influential storm drainage systems, as are two streams in the LakeWake area (one of which is the one sampled in the volunteer monitoring program), but the others are smaller drainage systems that are expected to have substantial impact on the coves into which they discharge:

1. Route I-395 drainage near the entrance to Union Point
2. Route 16 drainage into Sucker Brook Cove
3. Route I-395 drainage into the swamp near the previously mentioned North Village bridge and footpath.
4. Drainage near Point Breeze
5. Drainage into the marina area along Route 193
6. Brown's Brook into Reid Smith Cove (BB18 from the volunteer monitoring effort)
7. Streams discharging near Wakefield Avenue (includes LakeWake)
8. Stormwater discharge at the end of June Avenue

Several control systems have been designed and implemented since that time, but there are no data to demonstrate either the original impact of the storm water from targeted drainage areas or resulting improvements. The visual criteria used to prioritize storm water input points are reasonable, but quantification of nutrient inputs would improve the process and evaluation of results. As it is, there is no comprehensive loading analysis for nitrogen or phosphorus (or really any contaminant) to Webster Lake, and it is likely that such an analysis will have to consider storm water inputs. It would be possible to model the inputs and the resulting condition of the lake, and with the in-lake data that are available, a reasonable representation of reality would be possible. However, direct sampling of inputs (especially during wet weather), just as has been performed for the four largest tributaries, is needed to validate any model.

Note that wet weather sampling does not have to involve having volunteers go out in the rain. Inexpensive passive samplers can be set up to collect first flush storm water, which are then retrieved at the end of the storm (Figure 30). Additional sampling at the end of the storm, where flow continues, helps bracket the range of contaminant concentrations. Where there is not flow after the storm ends, this is also important information to record.

Figure 30. Passive storm water sampler for collection of first flush storm water.

Overall Condition Assessment

Webster Lake exhibits some problems that are likely to be related to watershed development and long term inputs, such as occasional algal blooms and low oxygen in deep water during summer stratification, but overall the condition of the lake is quite acceptable for its range of uses. Surface water clarity, assessed as either Secchi transparency or turbidity, is higher than for most MA lakes, mainly as a function of relatively low algal abundance as represented by low average chlorophyll a. Limited data for total phosphorus suggest that values are near the limit of detection for most in-lake surface samples, indicating low overall fertility that is consistent with clarity and chlorophyll a measurements. However, elevated phosphorus levels are found in deep water later in summer, most likely a function of release of P from sediments under anoxic conditions. This phosphorus appears to remain largely sequestered in deep water, minimally affecting surface fertility, but represents a concern for long term lake condition. Nitrate nitrogen is not depleted in surface waters based on most testing results, suggesting limited opportunity for cyanobacterial dominance in the open water portions of the three lake basins. However, occasional cyanobacterial blooms have occurred in certain coves, suggesting that localized water quality problems exist at times.

Other basic lake water quality features, including temperature and pH, exhibit temporal and spatial patterns that are consistent with known influences and do not represent a threat to any lake use. Conductivity exhibits a seasonal pattern that is not explained by any available information, but this also does not threaten lake uses; conductivity values in the lake reflect dissolved solids are mostly moderate.

Tributary inputs cannot be properly assessed based on the available nutrient data, and having few values for documented wet weather conditions limits even informed speculation on loading. Based on conductivity and turbidity, dissolved and suspended solids vary greatly among tributaries and in some cases over time in a single tributary, but more wet weather data are needed to facilitate an appropriate assessment. The watershed for Webster Lake is not large relative to lake area, and two sampled tributary systems enter the north basin, with one each for the middle and south basins. With the outlet in the north basin, there is a gradient of flushing that affects water quality among lake basins, yet most water quality features are similar among the basins. The greatest difference is lower clarity in the south basin (average Secchi reading of 3.7 m in the south vs. 4.7 m in the north and middle basins).

While a substantial portion of the lake is too deep to support rooted plant growths, and growths that interfere with lake uses are largely restricted to coves, those coves are major access points to the lake for many people. Overall coverage by invasive species has been reduced substantially, but rooted plant problems persist in the shallow coves around the lake and along some shoreline stretches, with invasive fanwort, variable watermilfoil and to a lesser extent Eurasian watermilfoil managed by annual herbicide applications. Dense native plant assemblages occur in some areas, and are managed partly by the same herbicides and by hydro-raking. A program of control has been developed over multiple years that recognizes the need to protect native species and habitat while attempting to control invasive species and limit recreational interference. While this program carries substantial cost and does not completely eliminate nuisance growths, there is no obvious alternative that would provide longer term results at a reasonable cost and without major impacts to non-target species. Adjustments have been offered and in some cases made to increase the effectiveness of the plant control program, but it is a slow process when so many factors are involved.

Recommendations for Future Monitoring and Management

With a large lake to monitor and manage, the Webster Lake Association has done an admirable job of achieving success while controlling costs. However, this review has suggested a few needs that should be met, albeit at increased cost unless some trade-offs are made:

Total phosphorus is more useful than soluble reactive phosphorus, but is best measured by a properly equipped laboratory. SRP can be used to examine patterns over space or time if suitable precision can be achieved, but loading analysis requires TP and most predictive relationships between P and lake features like clarity and chlorophyll are based on TP. At a minimum, surface and bottom measures of TP should be obtained monthly between May and September at each of the three lake basin stations and TP should be assessed in all tributaries.

Side by side comparisons of lab, colorimeter and troll probe measurements of nitrate nitrogen should be made to determine if the precision and accuracy of the on-site measures is sufficient to avoid lab assessment of this water quality feature.

While some sampling of tributaries during dry weather is useful, sampling of inputs to the lake should focus on wet weather inputs, which are likely to represent more than 2/3 and probably more than ¾ of all contaminant loading to Webster Lake. A goal of three to five storms per year being sampled would be appropriate. Sampling should include first flush sampling and late storm assessment, characterizing the range of inputs during wet weather. Additionally, this wet weather input assessment should be expanded to include direct drainage to the lake, especially to coves known to have occasional algal blooms.

Assessment of water quality in selected coves should be performed in addition to measurement at open water lake basin stations, particularly during July and August when algal blooms occasionally occur. Such assessment could best be supported by corresponding measurements of any storm water inputs to those coves.

To the extent that watershed management is occurring, it has the proper focus on source management and storm water controls. Gradual phasing out of high phosphorus lawn fertilizers will help, but residual phosphorus and other sources will continue to require storm water controls if Webster Lake is to be protected to an appropriate degree. The CME report noted the difficulty in applying storm water controls to some of the priority locations, and did not cover all 40 discovered direct discharge points at a level necessary to facilitate action. Storm water management should be pushed as close to the sources as possible, with low impact development (LID) techniques highly recommended for residential and commercial areas. Structural storm water controls still have high value, and will undoubtedly be necessary in multiple areas, but may not be completely adequate in some of the steeply sloped areas east of the lake or where space is limited.

Rooted plant control has been conducted in a responsible manner, with adaptive management applied. Quantitative data are limited, however, making annual choices a function of semi-quantitative early season surveys of defined areas considered to represent the most likely problem locations. This may be the best that can be expected with such a large lake, but some consideration should be given to a more major plant survey once every decade or so to provide the data necessary to more objectively evaluate progress in plant management.