# Water Quality Report: 2012

## Wachusett Reservoir Watershed

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Massachusetts Department of Conservation and Recreation
Commissioner Edward M. Lambert Jr
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## ABSTRACT

The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management (originally established by Chapter 372 of the Acts of 1984 as the Metropolitan District Commission Division of Watershed Management) was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in 51 communities and thousands of industrial users.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the new Office of Watershed Management. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2012 water quality data from the Wachusett and Sudbury watersheds. A report summarizing 2012 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

## Acknowledgements:

This report was prepared by the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management. Authors are Lawrence Pistrang, Environmental Analyst, David Worden, Senior Aquatic Biologist, and Jamie Carr, Aquatic Biologist. The sampling station map was produced by GIS analyst Craig Fitzgerald using the most recent data. Internal review was provided by Patricia Austin. Steve Sulprizio, David Worden, Jamie Carr, Allan Rantala, and David Getman collected the samples and were responsible for all field measurements. Plankton samples were analyzed by David Worden and Jamie Carr. Turbidity analysis was done by Steve Sulprizio, David Getman, Allan Rantala, Kelley Freda, or Lawrence Pistrang. All other lab analyses (bacteria, nutrients, and metals) were performed by MWRA staff.

The DCR/DWSP Office of Watershed Management once again thanks the staff and management of the MWRA Deer Island Lab for preparing and delivering sample bottles and performing all nutrient and metal analyses during the year. They also thank the MWRA staff at the Southborough Lab for completing all routine and special *E. coli* and fecal coliform analyses during the year.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# WATER QUALITY REPORT: 2012
# WACHUSETT RESERVOIR AND TRIBUTARIES

## 1.0 INTRODUCTION

The Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management (DCR/DWSP) was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to nearly 2.5 million people in 51 communities plus thousands of industrial users.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including development and implementation of a detailed watershed protection plan. The Division and the MWRA have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the most recent watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. Division staff also sample to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Watershed tributaries and reservoirs that receive their inputs comprise the two basic components of the water supply system. Each component requires a specialized program of monitoring activities and equipment suited to their unique characteristics and environmental settings.

Routine water quality samples for bacteria, specific conductance, turbidity, and temperature were collected from 23 stations on 19 tributaries. Nutrient samples were collected monthly from nine of these stations. Stormwater sampling was done monthly at four locations to supplement routine sampling. Samples were also collected from additional tributary locations to investigate water quality problems discovered during environmental assessment investigations. Samples were collected from Oakdale Brook, Beaman Pond Brook, Jordan Farm Brook, and Waushacum Brook during 2012. Results from all tributary sampling are discussed in Section 3.0.

Routine sampling in the Sudbury watershed was discontinued after sufficient data were gathered. Bacteria samples had been collected monthly from six tributaries for the past three years. All tributaries in the Sudbury Watershed had higher bacteria concentrations than most Wachusett tributaries, especially during wet weather. The Sudbury watershed is much more developed than the Wachusett watershed and it is not surprising that water quality is very poor.

Sampling of the Wachusett Reservoir was done once or twice weekly to monitor plankton concentrations, predict potential taste and odor problems, and recommend copper sulfate treatment as needed. Temperature, pH, dissolved oxygen, and specific conductance profiles were measured weekly in conjunction with plankton sampling. Quarterly nutrient samples were collected in May, July, October, and December at three depths from three reservoir stations. Fecal coliform samples were collected monthly or more frequently from 23 reservoir surface stations to document the relationship between bacteria and roosting populations of waterfowl on the reservoir. Results from all reservoir monitoring efforts are discussed in Section 4.0.

All bacteria, conductivity, turbidity, nutrient, and precipitation data collected are stored in an EXCEL spreadsheet (MASTERdataFILE2007-2012.xlsx) on the w: drive of the Division server at John Augustus Hall in West Boylston. An EXCEL spreadsheet of plankton data is also maintained on site in West Boylston. All data generated during tributary and reservoir water quality testing are discussed by parameter in sections 3.1 – 4.6 and are available upon request.

## 2.0 DESCRIPTION OF MONITORING PROGRAMS

Wachusett Environmental Quality staff collected routine water quality samples from 23 stations on 19 tributaries and from three stations on the Wachusett Reservoir in 2012. Stations are described in Tables 1 and 2 and are shown on Figures 1 and 2 on pages 3-5. Additional stations were sampled to support special studies or potential enforcement actions, and storm events were sampled on twelve separate occasions. Some samples were analyzed in-house including 1157 turbidity samples and 132 plankton samples. A total of 2314 physiochemical measurements (temperature and specific conductance) were done in the field at tributary stations, with another 6250 (temperature, specific conductance, dissolved oxygen, percent oxygen saturation, and pH) recorded on the reservoir. In addition, 1451 samples were collected and delivered to the MWRA laboratory in Southborough for *E. coli* or fecal coliform analysis, and 316 samples were collected and shipped to the MWRA Deer Island laboratory for 1572 analyses of nutrients and other parameters.

## 2.1 TRIBUTARY MONITORING

Each tributary station was visited weekly throughout the entire year, although samples were not collected at some stations during low flow or no-flow conditions. Temperature and specific conductance were measured in the field using a YSI Model 30 conductivity meter. Discrete samples were collected for analysis of *E. coli* and turbidity. All *E. coli* samples were delivered to the MWRA Southborough Lab for filtration. Turbidity samples were analyzed at the DCR West Boylston Lab using a HACH 2100N meter.

Nutrient samples were collected monthly from nine stations (shown on Table 1) and analyzed at the MWRA Deer Island Lab for total phosphorus, ammonia, nitrate-nitrogen, nitrite-nitrogen, UV-254, total organic carbon, and total suspended solids. All sample collections and analyses were conducted according to <u>Standard Methods for the Examination of Water and Wastewater 20th Edition</u>. Depth was recorded at six of the nutrient stations in order to calculate flow using rating curves developed by the USGS and modified by DCR Environmental Quality staff. Daily flow in Gates Brook and the Stillwater and Quinapoxet Rivers was obtained from continuous recording devices installed by the USGS.

Precipitation data from NOAA weather stations in Worcester and Fitchburg, from the USGS stations on the Stillwater River in Sterling and the Quinapoxet River in Holden, and from a DCR rain gage in West Boylston were collected daily to help interpret water quality changes and determine if these were impacted by stormwater flow.

TABLE 1

**WACHUSETT TRIBUTARY SAMPLING STATIONS (2012)**

| STATION | LOCATION | FREQUENCY |
|---|---|---|
| 1. Asnebumskit (Princeton) | upstream of Princeton Street, Holden | W |
| 2. Beaman 2 | Route 110, W. Boylston (homes) | W |
| 3. Boylston Brook | Route 70, Boylston | W |
| 4. Cook Brook (Wyoming) | Wyoming Street, Holden | W |
| 5. East Wachusett (140) | Route 140, Sterling | W |
| 6. French Brook (70) | Route 70, Boylston | W, M |
| 7. Gates Brook (1) | Gate 25, W.Boylston | W, M |
| 8. Gates Brook (2) | Route 140, W.Boylston | W |
| 9. Gates Brook (4) | Pierce Street, W.Boylston | W |
| 10. Gates Brook (6) | Lombard Avenue, W.Boylston | W |
| 11. Gates Brook (9) | Woodland Street, W.Boylston | W |
| 12. Hastings Cove Brook | Route 70, Boylston | W |
| 13. Jordan Farm Brook | Route 68, Rutland | W |
| 14. Malagasco Brook | West Temple Street, Boylston | W, M |
| 15. Malden Brook | Thomas Street, W.Boylston | W, M |
| 16. Muddy Brook | Route 140, W.Boylston | W, M |
| 17. Oakdale Brook | Waushacum Street, W. Boylston | W |
| 18. Quinapoxet River (Canada Mills) | Canada Mills, Holden | W, M |
| 19. Scarlett Brook | Worcester Street, W.Boylston | W |
| 20. Stillwater River (SB) | Muddy Pond Road, Sterling | W, M |
| 21. Trout Brook | Manning Street, Holden | W |
| 22. Waushacum (Prescott) | Prescott Street, W.Boylston | W, M |
| 23. West Boylston Brook | Gate 25, W.Boylston | W, M |

W = weekly (bacteria, temperature, specific conductance, turbidity)   M = monthly (nutrients)

## 2.2 RESERVOIR MONITORING

Temperature, dissolved oxygen concentration and percent saturation, specific conductance, and pH profiles were measured weekly during stratified conditions at Station 3417 (Basin North) in conjunction with routine plankton monitoring. Water column profiles were measured quarterly (May, July, October, December) at Station 3412 (Basin South) and Thomas Basin in conjunction with samples collected from the epilimnion, metalimnion, and hypolimnion for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, silica, UV-254, and alkalinity. All samples were analyzed at the MWRA Lab at Deer Island (see Section 4.0 for complete discussion).

MWRA personnel collected a regulatory fecal coliform sample seven times per week from the John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough. Fecal coliform samples were collected by Division staff from 23 reservoir surface stations (Figure 2) once or twice per month.

Figure 1 – sampling stations

(Available upon request)

TABLE 2

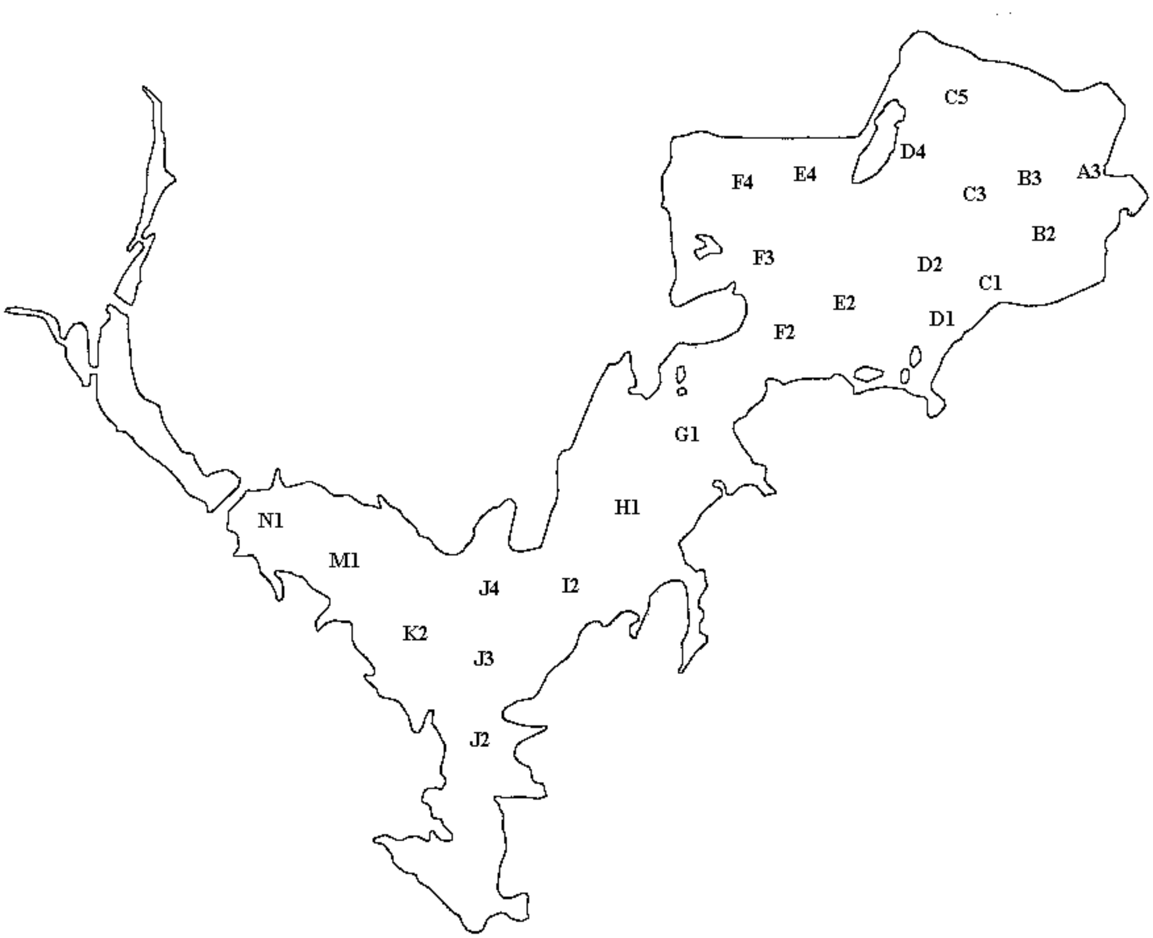
## WACHUSETT RESERVOIR SAMPLING STATIONS (2012)

| STATION | LOCATION | FREQUENCY |
|---|---|---|
| A. 3409 (Reservoir) | adjacent to Cosgrove Intake | W |
| B. 3417 (Reservoir – Basin North) | mid reservoir by Cunningham Ledge | W, Q |
| C. 3412 (Reservoir – Basin South) | mid reservoir off Scar Hill Bluffs | Q |
| D. Thomas Basin (Reservoir) | Thomas Basin | Q |

W = weekly (bacteria, temperature, conductivity, plankton, and water column profiles at Cosgrove or 3417)
Q = quarterly (plankton, profiles, nutrients)

FIGURE 2.

## RESERVOIR TRANSECT STATIONS



## 3.0 RESULTS OF TRIBUTARY MONITORING PROGRAM

### 3.1 BACTERIA

Fecal coliform concentrations were utilized as an indicator of sanitary quality for many years, but the Massachusetts Class A surface water quality standards were changed in 2007 and now use *E. coli* as the measured indicator organism. The statutory limit is "a geometric mean not to exceed 126 *E. coli* colonies per 100 mL and with no single sample to exceed 235 colonies per 100 mL". The geometric mean of 126 colonies per 100 mL was not exceeded at any tributary station during 2008 or 2009, but was exceeded at Gates Brook 4 in 2010, at both Gates Brook 4 and Gates Brook 6 in 2011, and at Gates Brook 4, Gates Brook 6, and Oakdale Brook in 2012 (Table 3). In addition, nearly every station has exceeded the single sample limit of 235 colonies per 100 mL since 2007, and no stations met the standard in 2011 or 2012.

Bacteria samples collected from the 23 tributary stations during 2012 contained a wide range of *E. coli* concentrations, from less than 10 MPN/100mL in nearly one fourth of all samples to a high of >24,000 MPN/100mL in Beaman Pond Brook during a June storm event. Many of the highest concentrations were recorded during or following rain events in August and September, and 65% of samples containing more than 1000 MPN/100mL were collected during or following wet weather. Samples collected during dry weather that exceeded 1000 MPN/100mL were primarily from sites with known or suspected wildlife presence (Gates, Scarlett, Asnebumskit, and Oakdale Brooks).

Annual geometric mean concentrations increased at 10 of 23 stations, although increases at six of them were minor. Annual geometric mean concentrations were the highest in seven years at five of these stations including three on Gates Brook (Table 3). This is the third consecutive year of increased bacteria concentrations in Gates Brook and a source of some concern. Investigations to determine the exact cause of the contamination and to develop means to remedy the situation are underway.

Changes in water quality from year to year can be due to variations in weather conditions, especially in the timing, frequency, and magnitude of precipitation events. These variations seem to be more commonplace than before, likely due to global climate change. More than sixty-seven inches of rainfall were recorded in Worcester in 2011, nineteen inches above the annual average and the highest in over thirty years. This was a likely cause of the increase in bacteria concentrations at many locations, but similar increases in concentrations were also noted in 2012 and annual rainfall was the lowest in five years, nearly five inches below the annual average. Elevated bacteria in tributaries might instead be related to the increased presence of wildlife or an as-yet undetermined cause. Because of the increased likelihood of short-term weather variations and the resultant difficulties in interpreting changes in water quality parameters, it is generally more informative to examine long term trends in water quality. Reliable data from many of the Wachusett watershed tributaries now extend over a period of more than twenty years and long term trends suggest that conditions at most locations remain stable or have improved. The next detailed assessment of long term trends is planned for publication in 2018.

TABLE 3

## *E. coli* - TRIBUTARIES
## (MPN/100 mL)

| **STATION** | GMEAN (2012) | GMEAN (2011) | GMEAN (2010) | GMEAN (2009) | %>235 (2012) | %>235 (2011) | %>235 (2010) | %>235 (2009) |
|---|---|---|---|---|---|---|---|---|
| Asnebumskit (Princeton) | 45 | 37 | 53 | 32 | 24 | 16 | 36 | 22 |
| Beaman 2 | 48 | 49 | 111 | 45 | 19 | 18 | 44 | 22 |
| Boylston Brook | 33 | 31 | 21 | 35 | 17 | 10 | 8 | 8 |
| Cook Brook (Wyoming) | 21 | 20 | 23 | 14 | 10 | 10 | 16 | 10 |
| East Wachusett (140) | 18 | 20* | 19 | 14 | 6 | 8 | 4 | 2 |
| French Brook (70) | 38 | 37 | 39 | 22 | 14 | 8 | 9 | 0 |
| Gates Brook (1) | 29 | 54* | 28 | 27 | 10 | 16 | 6 | 4 |
| Gates Brook (2) | 101* | 83 | 100 | 47 | 20 | 16 | 25 | 6 |
| Gates Brook (4) | **225*** | **180** | **133** | 74 | 51 | 46 | 25 | 20 |
| Gates Brook (6) | **343*** | **227** | 103 | 64 | 65 | 58 | 27 | 10 |
| Gates Brook (9) | 80 | 63 | 97 | 38 | 25 | 18 | 29 | 6 |
| Hastings Cove Brook | 12 | 15 | 20 | 13 | 8 | 4 | 12 | 2 |
| Jordan Farm Brook | 19 | 28 | 38 | 27 | 6 | 12 | 20 | 14 |
| Malagasco Brook | 25 | 32* | 30 | 17 | 8 | 10 | 12 | 2 |
| Malden Brook | 27 | 36 | 44 | 24 | 10 | 8 | 4 | 4 |
| Muddy Brook | 20 | 29* | 25 | 16 | 2 | 10 | 6 | 0 |
| Oakdale Brook | **143*** | 75 | 39 | 24 | 41 | 27 | 18 | 8 |
| Quinapoxet River (C.Mills) | 37 | 37 | 46 | 35 | 8 | 6 | 12 | 6 |
| Scarlett Brook | 50* | 45 | 46 | 20 | 22 | 10 | 18 | 2 |
| Stillwater River (SB) | 42 | 49 | 46 | 35 | 10 | 16 | 16 | 8 |
| Trout Brook | 16 | | 23 | 17 | 2 | | 6 | 4 |
| Waushacum (Prescott) | 23 | 32 | 41 | 24 | 4 | 10 | 12 | 2 |
| West Boylston Brook | 54 | 73 | 107 | 50 | 14 | 22 | 24 | 19 |

*highest annual geometric mean (2006-2012)

The geometric mean of all 1145 tributary samples collected in 2012 was 41 MPN/100mL, identical to2011 and only slightly higher than in 2010, even though annual precipitation and flow conditions were very different each year. Rain events continue to be linked to poor water quality and the difference between dry weather and wet weather samples is clearly illustrated in Table 4 on the following page. Annual geometric mean of all dry weather samples from 2008-2012 was 19-31 MPN/100mL; annual geometric mean of wet weather samples was 76-96 MPN/100mL from 2008-2010 and then increased to 134 MPN/100mL in 2011 and 148 MPN/100mL in 2012. Most dry weather samples but usually less than half of all wet weather samples contained fewer than 126 MPN/100mL. The percentage of wet weather samples that contained more than 235 MPN/100mL was four times higher than the percentage of dry weather samples.

TABLE 4

**IMPACTS OF >0.2" RAINFALL ON *E. coli* CONCENTRATIONS**

| | dry 2012 | dry 2011 | dry 2008-2010 | wet 2012 | wet 2011 | wet 2008-2010 |
|---|---|---|---|---|---|---|
| **annual geometric mean (MPN/100mL)** | 28 | 30 | 19 - 31 | 148 | 134 | 76 - 96 |
| **% samples <126 MPN/100mL** | 83 | 84 | 82 - 92 | 47 | 48 | 45 - 65 |
| **% samples >235 MPN/100mL** | 10 | 9 | 3 - 10 | 41 | 37 | 21 - 40 |

Not every station responded similarly to storm events. No wet weather sample from Trout Brook contained more than 235 colonies per 100 mL. Samples collected from Muddy, Waushacum, East Wachusett, Jordan Farm, Hastings Cove, and Scarlett Brooks during or following wet weather rarely contained high concentrations of bacteria, but an equal number of wet weather samples with high or low concentrations were collected from a dozen locations including both the Stillwater and Quinapoxet Rivers. Most wet weather samples collected from Oakdale Brook and Gates Brook (9) and every wet weather sample from Gates Brook (4) and Gates Brook (6) contained more than 235 colonies per 100 mL.

Impacts from stormwater runoff are often greater in magnitude in subbasins with high concentrations of impervious surfaces (Gates Brook, Cook Brook) or agricultural operations (Jordan Farm Brook), but can be mitigated by the presence of ponds, wetlands, or beaver impoundments. The geometric mean of wet weather samples from the downstream station on Gates Brook was nine times higher than the mean of dry weather samples. A greater disparity was noted in Boylston, Beaman Pond, and French Brooks, however, with wet weather geometric means 11-23 times higher. Differences at all other sampling stations were less dramatic. This analysis may be confounded by variations in dry weather water quality and might not accurately reflect relative impacts of stormwater runoff.

Regardless of the timing, frequency, and magnitude of precipitation events, it is very clear that water quality is negatively impacted by unmanaged stormwater. The Division now supplements routine weekly sampling with focused stormwater sampling at four locations that allows calculation of pollutant loadings from storm events. Samples were also collected during or within 24 hours of storm events on 22 of 102 routine weekly sampling dates. Analysis and interpretation of stormwater impacts on water quality is included below and in Section 3.5.

Water quality impacts exhibit clear seasonal differences (Table 5). Bacteria numbers tend to be lower in the winter and spring months (December through May), with wet weather concentrations about two to five times higher than dry weather concentrations. Summer numbers are usually much higher, likely caused by low flow conditions that concentrate bacteria or large storm events that increase loading, but wet weather concentrations remain about three to four times higher than dry weather concentrations. Fall concentrations can be elevated or low depending upon the amount and timing of precipitation. Overall geometric mean was elevated in the fall of 2010, but lower in 2011 and 2012 due to less frequent fall storm events. Differences between wet weather and dry weather concentrations are much more pronounced in the fall than in other seasons.

TABLE 5

**SEASONAL EFFECT ON *E. coli* CONCENTRATIONS**
**(MPN/100 mL)**

| | WINTER | SPRING | SUMMER | FALL |
|---|---|---|---|---|
| **geometric mean (2009)** | 14 | 37 | 55 | 22 |
| **geometric mean (2010)** | 19 | 20 | 124 | 59 |
| **geometric mean (2011)** | 23 | 27 | 100 | 39 |
| **geometric mean (2012)** | 24 | 29 | 93 | 42 |
| | | | | |
| **geometric mean – dry (2010)** | 17 | 17 | 77 | 41 |
| **geometric mean – dry (2011)** | 18 | 21 | 80 | 24 |
| **geometric mean – dry (2012)** | 20 | 17 | 69 | 29 |
| | | | | |
| **geometric mean –wet (2010)** | 47 | 35 | 235 | 255 |
| **geometric mean –wet (2011)** | 74 | 59 | 253 | 466 |
| **geometric mean –wet (2012)** | 108 | 96 | 179 | 300 |

Multiple sample stations on Gates Brook have been used to locate the source of contamination. Bacteria concentrations are reduced as water nears the reservoir due to natural remediation and the highest concentrations historically have been found at Gates Brook 4 and Gates Brook 6.

TABLE 6

**ANNUAL GEOMETRIC MEAN *E. coli* – GATES BROOK STATIONS**
**(MPN/100 mL)**

| STATION | 2012 | 2011 | 2010 | 2009 | 2008 | 2007 | 2006 |
|---|---|---|---|---|---|---|---|
| **Gates 1** | 29 | 54 | 28 | 27 | 33 | 41 | 27 |
| **Gates 2** | 101 | 83 | 100 | 47 | 61 | 72 | 44 |
| **Gates 4** | 225 | 180 | 133 | 74 | 76 | 97 | 49 |
| **Gates 6** | 343 | 227 | 103 | 64 | 95 | 87 | 40 |
| **Gates 9** | 80 | 63 | 97 | 38 | 45 | 49 | 32 |

### 3.2 NUTRIENTS

Samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, total phosphorus, total organic carbon, total suspended solids, and UV-254 were collected monthly from nine tributary stations with available flow data and analyzed at the MWRA Deer Island Lab using methods with low detection limits. UV-254 samples were collected weekly from the Quinapoxet and Stillwater Rivers. Samples were preserved according to standard methods. Depth measurements were taken at six stream stations to determine flow using rating curves developed by the USGS and modified by DCR Environmental Quality staff. Daily flow was monitored in the Stillwater and Quinapoxet River and in Gates Brook using continuous USGS recording devices. All data are available upon request.

Annual mean nitrate-nitrogen concentrations in the nine tributaries ranged from 0.098 mg/L $NO_3$-N to 1.17 mg/L $NO_3$-N (Table 7). Nitrate concentrations in West Boylston and Gates Brooks remain higher than in other brooks, but have dropped considerably since 2007.

TABLE 7

## NITRATE-NITROGEN CONCENTRATIONS (mg/L)

| STATION | Muddy | French | Gates | Malagasco | Malden | Waushacum | W. Boylston | Stillwater | Quinapoxet |
|---|---|---|---|---|---|---|---|---|---|
| **ave2012** | 0.098 | 0.127 | 0.80 | 0.489 | 0.432 | 0.036 | 1.17 | 0.140 | 0.222 |
| **ave2011** | 0.089 | 0.154 | 0.93 | 0.426 | n/s | n/s | 1.09 | 0.156 | 0.185 |
| **ave2010** | 0.105 | 0.135 | 1.01 | 0.634 | 0.471 | n/s | 1.57 | 0.156 | 0.256 |
| **ave2009** | 0.072 | 0.105 | 1.03 | 0.504 | 0.403 | n/s | 1.25 | 0.122 | 0.196 |
| **ave2008** | 0.132 | 0.071 | 1.04 | 0.513 | 0.452 | n/s | 1.69 | 0.146 | 0.321 |
| **ave2007** | 0.113 | 0.094 | 1.10 | 0.735 | 0.423 | n/s | 2.05 | 0.178 | 0.325 |
| **max2012** | 0.176 | 0.307 | 1.12 | 0.802 | 0.595 | 0.135 | 1.65 | 0.259 | 0.356 |
| **max2011** | 0.303 | 0.377 | 1.26 | 0.925 | n/s | n/s | 1.64 | 0.434 | 0.390 |
| **min2012** | 0.053 | 0.032 | 0.444 | 0209 | 0.289 | 0.005 | 0.437 | 0.067 | 0.114 |
| **min2011** | 0.022 | 0.061 | 0.65 | 0.102 | n/s | n/s | 0.45 | 0.062 | 0.020 |

Nitrite-nitrogen was almost never detected. A single sample (French Brook, 7/19, 0.0121 mg/L) of the 108 samples collected contained more than the detection limit of 0.005 mg/L.

Ammonia was detected in all tributaries with most annual mean concentrations comparable to those recorded during the previous five years. The highest concentrations and annual means were again recorded from French Brook and Muddy Brook (Table 8).

TABLE 8

## AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

| STATION | Muddy | French | Gates | Malagasco | Malden | Waushacum | W. Boylston | Stillwater | Quinapoxet |
|---|---|---|---|---|---|---|---|---|---|
| **ave2012** | 0.069 | 0.045 | 0.007 | 0.014 | 0.011 | 0.019 | 0.013 | 0.008 | 0.012 |
| **ave2011** | 0.066 | 0.039 | 0.005 | 0.016 | n/s | n/s | 0.022 | 0.010 | 0.015 |
| **ave2010** | 0.061 | 0.120 | <0.005 | 0.010 | 0.010 | n/s | 0.012 | 0.011 | 0.014 |
| **ave2009** | 0.077 | 0.068 | 0.005 | 0.018 | 0.017 | n/s | 0.015 | 0.015 | 0.015 |
| **ave2008** | 0.068 | 0.061 | 0.008 | 0.014 | 0.025 | n/s | 0.014 | 0.012 | 0.013 |
| **ave2007** | 0.079 | 0.112 | 0.009 | 0.015 | 0.024 | n/s | 0.039 | 0.017 | 0.016 |
| **max2012** | 0.094 | 0.072 | 0.019 | 0.027 | 0.041 | 0.050 | 0.021 | 0.016 | 0.021 |
| **max2011** | 0.130 | 0.194 | 0.011 | 0.056 | n/s | n/s | 0.114 | 0.032 | 0.071 |
| **min2012** | 0.049 | 0.010 | <0.005 | <0.005 | <0.005 | <0.005 | 0.007 | <0.005 | 0.008 |
| **min2011** | 0.024 | 0.005 | <0.005 | 0.005 | n/s | n/s | <0.005 | <0.005 | <0.005 |

Phosphorus is an important nutrient, and is the limiting factor controlling algal productivity in Wachusett Reservoir. EPA Water Quality Criteria recommend a concentration of no more than 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving water bodies. Concentrations measured in nine Wachusett tributaries during 2012 ranged from 0.011 mg/L to 0.094 mg/L total P, with annual mean concentrations from 0.023 mg/L to 0.049 mg/L (Table 9). Most annual concentrations were comparable to the previous five years although Muddy Brook concentrations were higher than usual. There were more samples (seventeen) that exceeded the recommended maximum concentration of 0.05 mg/L than in previous years, although most were collected during or following rain or snow melt events.

TABLE 9

**TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)**

| STATION | Muddy | French | Gates | Malagasco | Malden | Waushacum | W. Boylston | Stillwater | Quinapoxet |
|---|---|---|---|---|---|---|---|---|---|
| **ave2012** | 0.027 | 0.049 | 0.025 | 0.044 | 0.028 | 0.029 | 0.035 | 0.023 | 0.027 |
| **ave2011** | 0.024 | 0.036 | 0.017 | 0.042 | n/s | n/s | 0.044 | 0.019 | 0.017 |
| **ave2010** | 0.015 | 0.055 | 0.013 | 0.026 | 0.019 | n/s | 0.016 | 0.016 | 0.017 |
| **ave2009** | 0.017 | 0.033 | 0.017 | 0.045 | 0.030 | n/s | 0.022 | 0.012 | 0.013 |
| **ave2008** | 0.013 | 0.038 | 0.020 | 0.055 | 0.027 | n/s | 0.035 | 0.016 | 0.024 |
| **ave2007** | 0.015 | 0.041 | 0.018 | 0.027 | 0.020 | n/s | 0.025 | 0.021 | 0.073 |
| | | | | | | | | | |
| **max2012** | 0.056 | 0.094 | 0.057 | 0.089 | 0.049 | 0.052 | 0.069 | 0.044 | 0.052 |
| **max2011** | 0.055 | 0.070 | 0.033 | 0.075 | n/s | n/s | 0.155 | 0.033 | 0.027 |
| | | | | | | | | | |
| **min2012** | 0.011 | 0.018 | 0.012 | 0.021 | 0.014 | 0.019 | 0.016 | 0.012 | 0.013 |
| **min2011** | 0.013 | 0.020 | <0.005 | 0.016 | n/s | n/s | 0.019 | 0.012 | 0.010 |

Silica concentration was measured from 2002-2011 with very little annual variation detected. Individual concentrations ranged from 1.36 mg/L to 21.7 mg/L with a mean concentration of all watershed samples collected of 8.08 mg/L. It was determined that sufficient data have been collected and no additional samples were collected during 2012.

Total suspended solids are those particles suspended in a water sample retained by a filter of 2μm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in Wachusett tributaries ranged from <5.0 mg/L to 48.0 mg/L, but only twenty of 108 samples contained more than the detection limit. Total suspended solids are not considered a parameter of concern except during storm events when measurements in excess of 100 mg/L are not uncommon.

Total organic carbon (TOC) and UV-254 measure organic constituents in water, and are a useful way to predict precursors of harmful disinfection byproducts. TOC in the tributaries ranged from 1.35 to 23.8 mg/L, with an overall mean of 5.00 mg/L. The highest readings were again recorded from Malagasco Brook and French Brook, with the lowest from West Boylston Brook and Gates Brook. Measurements of UV-254 were comparable to TOC measurements. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were from Malagasco and French Brooks, and the lowest annual means were from West Boylston Brook and Gates Brook.

Monthly loads were calculated for nitrate-nitrogen, ammonia, total phosphorus, and total organic carbon by multiplying total monthly flow by monthly concentration for each parameter. Approved daily flow data for 2011-2012 are available for the Quinapoxet and Stillwater Rivers and for 2012 from Gates Brook, with weekly data available for the other locations. Updated stage-discharge relationships have been developed by Division staff to improve the accuracy of weekly flow information. Flows were estimated for the months of June and July for French Brook while a new discharge control structure was under construction.

Samples were also collected monthly for nitrite-nitrogen and total suspended solids, but most results were less than the detection limit and no useful loading information was developed.

TABLE 10

## ANNUAL NUTRIENT LOADING (kg) - 2012

| STATION | Muddy | French | Gates | Malagasco | Malden | Waushacum | W. Boylston | Stillwater | Quinapoxet |
|---|---|---|---|---|---|---|---|---|---|
| $NH_3$-N | 79 | 91 | 18 | 19 | 42 | 128 | 3 | 371 | 436 |
| $NO_3$-N | 108 | 283 | 2,159 | 497 | 1,159 | 303 | 254 | 5,948 | 7,608 |
| TOC | 3,635 | 13,579 | 6,659 | 11,362 | 8,697 | 24,924 | 542 | 126,964 | 126,532 |
| tP | 31 | 85 | 63 | 47 | 74 | 152 | 8 | 783 | 774 |

Calculated loads for 2011 were considerably higher (Table 11), but this was mostly the result of dramatically higher flows during that year. Annual flows in Wachusett tributaries in 2012 were only 34-64% of 2011 flows, and about half of the annual average flow during 2000-2012.

TABLE 11

## ANNUAL NUTRIENT LOADING (kg) - 2011

| STATION | Muddy | French | Gates | Malagasco | Malden | Waushacum | W. Boylston | Stillwater | Quinapoxet |
|---|---|---|---|---|---|---|---|---|---|
| $NH_3$-N | 98 | 177 | 25 | 45 | n/s | n/s | 14 | 546 | 1,031 |
| $NO_3$-N | 185 | 987 | 4,978 | 1,051 | n/s | n/s | 636 | 12,828 | 16,044 |
| TOC | 6,886 | 28,682 | 14,107 | 28,434 | n/s | n/s | 1,784 | 352,142 | 372,924 |
| tP | 49 | 139 | 100 | 110 | n/s | n/s | 35 | 1,587 | 1,681 |

Stormwater sampling was done to supplement routine monthly sampling and to more accurately characterize total annual loading. It was hypothesized that much of the annual loading was taking place during large storm events, and elevated concentrations of some parameters were noted during some storms, primarily in Gates Brook. Much of the increase in nutrient loading during storms appears due to the significant increase in flow rather than an increase in pollutant concentrations, especially in the two rivers where concentrations of most parameters during storm events were similar or only slightly higher than during dry weather. A more detailed discussion of stormwater data is included in Section 3.5.

Concentrations of metals have been measured monthly for a number of years from the Stillwater and Quinapoxet Rivers. Although some annual variation has been noted, it was determined that sufficient baseline data had been collected and no additional samples for metals analysis were collected during 2012.

## 3.3 SPECIFIC CONDUCTANCE

Fresh water systems contain small amounts of mineral salts in solution. Specific conductance is a measure of the ability of water to carry an electric current, dependent on the concentration and availability of these ions. Elevated conductivity levels indicate contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

Specific conductance was measured weekly at all twenty-three tributary stations. Very low values of 40-60 μmhos/cm were recorded from Trout Brook and Hastings Cove Brook during the year. Values greater than 800 μmhos/cm were recorded in more than forty percent of the samples from stations on Gates Brook, and very rarely from Oakdale, Beaman, Cook, and Asnebumskit Brooks following application of road salt. The maximum value (4739 μmhos) was recorded at Cook Brook on December 17$^{th}$.

Annual median specific conductance ranged from a low of 61 μmhos/cm (Trout Brook) to a high of 910 μmhos/cm (Gates Brook 4). Annual medians were comparable to previous years at most stations and were lower at Beaman Pond Brook, Cook Brook, Oakdale Brook, and Scarlett Brook. It was unclear if lower specific conductance was a result of water quality improvements or variations in rainfall and stream flow.

## 3.4 TURBIDITY

Weekly samples were collected from all tributary stations throughout the year. Individual measurements ranged from 0.12 to 24.4 NTU; a single sample from Scarlett Brook in September with a turbidity of 54.4 was likely the result of hydrant flushing. Annual median values ranged from 0.30 NTU in Cook Brook to 6.00 NTU in Muddy Brook. The overall watershed mean of 1.67 NTU (median of 1.07 NTU) was nearly identical to the previous three years.

Storm events continued to have an obvious negative impact on turbidity, with a watershed mean of 2.44 NTU for all storm samples but only 1.45 NTU for dry weather samples. Mean wet weather turbidity was significantly higher than dry weather turbidity at most locations, although not at West Boylston, Trout, Scarlett, East Wachusett, or Muddy Brooks.

## 3.5 STORMWATER SAMPLING

Stormwater sampling efforts continued in 2012 to help quantify the impacts from rain events. Standardized sampling methodologies were used to collect time-based discrete samples during both the rising and falling limb of the storm hydrograph and then to develop flow-based composite samples that were transported for analysis to the MWRA Deer Island lab. Sampling was done by hand until automatic samplers could be deployed at three of the four locations.

Stormwater sampling was done at some or all of four locations during selected storm events from January through December. Not all storms were sampled due to logistical issues or because of financial limitations related to lab analysis and overtime costs. Storm samples were collected approximately monthly throughout the year.

Samples for nitrate-nitrogen, nitrite-nitrogen, ammonia, total phosphorus, total organic carbon, and total suspended solids were collected at intervals ranging from ten minutes to two hours and then composited using flow data to create single samples that represent rising limb event mean concentrations. Samples were collected at greater intervals (2-24 hours) after peak flows were reached and composited to represent falling limb event mean concentrations. At times a single grab sample was collected to represent the falling limb. Collection of samples from Gates Brook, the Quinapoxet River, and the Stillwater River was done using automatic samplers and flow was measured at 10-15 minute intervals using USGS automated equipment; samples from the South Bay forest site were collected by hand and flow was determined by recording stage height and then using a previously developed stage-discharge relationship.

Bacteria samples were not collected from storm events in 2012 due to difficulties of transporting samples to the MWRA Southborough Lab within the six hour holding time. Sample results from 2011 clearly illustrated that bacteria concentrations rise dramatically during storm events and additional confirmation was determined to be unnecessary.

Nutrient concentrations measured in the Stillwater and Quinapoxet Rivers during the rising and falling limb of selected storms were similar to or only slightly higher than those in samples collected monthly during dry weather. This is likely due to the fact that polluted stormwater flow makes up only a small percentage of total flow in these large tributaries.

The same was not true for most parameters in Gates Brook. Ammonia, total phosphorus, and total organic carbon were elevated in both rising and falling limb composites, with concentrations 2-10 times higher than in dry weather samples. Concentrations in rising limb samples were usually higher than in falling limb samples. Total suspended solids, almost always below detection during routine sampling, averaged 53 mg/L in Gates Brook storm samples with a maximum recorded value of 118 mg/L. Nitrate-nitrogen concentrations were actually lower in storm samples than in dry weather samples, but the dramatic increase in flow during storms still resulted in an increase in nitrate-nitrogen loading during these events.

Stormwater nitrate concentrations measured at the South Bay forested site were comparable to those from Gates Brook during dry weather. Concentrations of ammonia were much higher than at any other location and similar to nitrate concentrations. Total phosphorus concentrations were also very high, similar to those measured in Gates Brook during storm events. Total organic carbon and total suspended solids were also present in concentrations similar to those recorded in Gates Brook.

Although stormwater from the South Bay forested site had nutrient concentrations higher than expected, because of low total flow measured during storm events (less than 200L per storm) the total nutrient load to the reservoir from this small undeveloped subbasin was only a tiny fraction of the nutrient load from any of the perennial tributaries.

It was hypothesized that much of the annual tributary nutrient loading was from stormwater runoff and that nutrient loading estimates would be greatly improved by including water quality data from selected storm events. Data collected during 2012 suggest that total phosphorus and total organic carbon loading may have been underestimated and nitrate-nitrogen and ammonia loading were overestimated prior to the inclusion of storm event information (Table 12). Continued collection of storm event water quality data will improve the reliability of nutrient loading estimates.

TABLE 12

**ANNUAL NUTRIENT LOADING (kg) USING STORM EVENT DATA**

| STATION | Stillwater | Stillwater-with storms | Gates | Gates-with storms | Quinapoxet | Quinapoxet-with storms |
|---|---|---|---|---|---|---|
| $NH_3$-N | 371 | 338 | 18 | 19 | 436 | 401 |
| $NO_3$-N | 5,948 | 5,531 | 2,159 | 2,135 | 7,608 | 7,072 |
| TOC | 126,964 | 143,300 | 6,659 | 7,503 | 126,532 | 134,105 |
| tP | 783 | 850 | 63 | 90 | 774 | 813 |

Stormwater samples analyzed for total suspended solids provided useful data. Concentrations from most samples collected during dry weather were less than the detection limit and only a very rough loading estimate could be developed by assuming concentrations at one half the detection limit. With additional information collected during storm events, it was determined that the initial estimate of 9385 kg of total suspended solids in Gates Brook during 2012 was less than half of the recalculated estimate of 19,207 kg. The opposite was true with estimates for the Quinapoxet River. An estimate developed using dry weather samples of 109,146 kg was actually higher than the recalculated estimate of 99,921 kg developed using stormwater data. Dry weather estimates from the Stillwater River of 91,559 kg were slightly lower than the recalculated estimate of 103,247 kg developed using stormwater data.

Unfortunately some of the estimates from the Stillwater River were impacted by the fact that a significant amount of flow data are missing. Although daily estimates of flow were provided by the USGS, more detailed and much more accurate 15-minute interval data were not available during three storms during August and September, and the daily USGS estimates do not appear to adequately reflect storm event fluctuations.

Precipitation events can dramatically impact flows as well as nutrient concentrations. To help improve nutrient loading estimates, the Division is monitoring storm events and developing a storm event data library that includes event mean concentrations, total storm flow, and a variety of associated information that allows a much more complete understanding of nutrient loading. Division staff will continue to collect data from storms of varying lengths, intensities, and seasons. Eventually there should be sufficient data available to estimate total annual loading using seasonal flow information and an established catalog of nutrient concentrations.

### 3.6 SPECIAL STUDIES

Macroinvertebrate samples were collected at a number of locations in spring 2012 and are currently being sorted, identified, and counted. Information obtained will be compared with historic data from the same locations and any significant changes will be addressed in a future water quality report.

Samples were collected from multiple sites on Oakdale Brook in February following weeks of elevated bacteria. No definitive source was identified, although wildlife was suggested as the likely cause. Additional samples were also collected from multiple sites on Beaman Pond Brook after a storm related sample was collected in June with an extremely high concentration of bacteria (more than 20,000 CFU/100mL). Once again no definitive cause was identified, although data implicated a source close to the headwaters. The stream dried up a few weeks later and flow was very irregular for the remainder of the year.

High concentrations of bacteria in Jordan Farm Brook have been an intermittent concern for the past few years. An attempt was made in September to finally pinpoint the source, and it appeared that an overflowing manure storage pit was the cause. Discussions with the farmer and federal officials have not yet resulted in a remedy, but are still underway.

More than two inches of rain from Hurricane Sandy in October led to elevated turbidity at a number of locations in the watershed, but the extreme conditions observed in Waushacum Brook suggested that something else was exacerbating the problem. Turbidity of 34.4 NTUs was recorded. Additional samples were collected and a site investigation conducted upstream that found problems related to a sand and gravel operation and an associated beaver population. Attempts to remediate the problem are ongoing.

## 4.0 RESULTS OF RESERVOIR MONITORING PROGRAM

### 4.1 FECAL COLIFORM

Bacterial transect samples were collected monthly or twice monthly throughout the year from twenty-three surface stations across the reservoir to document the relationship between seasonal bacteria variations and visiting populations of gulls, ducks, geese, and other waterfowl. Data were also used to judge the effectiveness of bird harassment activities. Sample locations were shown previously on Figure 2 and all data are included in Table 13. Staff were able to sample without interruption due to the unusual lack of ice cover during the winter of 2011-2012 and through the end of December 2012.

TABLE 13

**FECAL COLIFORM TRANSECT DATA (colonies/mL)**
**Wachusett Reservoir - 2012**

| | 1/11 | 1/24 | 2/7 | 3/7 | 4/11 | 5/15 | 6/14 | 7/25 | 8/29 | 9/20 | 10/23 | 11/16 | 11/28 | 12/20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cosgrove | 6 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 | 1 | 0 |
| B-2 | **10** | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 4 |
| B-3 | 9 | 5 | 3 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| C-1 | 9 | 1 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 |
| C-3 | 1 | 1 | 4 | 1 | 0 | **10** | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 1 |
| C-5 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 |
| D-1 | 5 | 3 | **14** | 9 | 2 | 1 | 1 | 0 | 0 | 4 | 4 | 1 | 1 | 3 |
| D-2 | **10** | 0 | **40** | **34** | 8 | 3 | 0 | 0 | 0 | 1 | 7 | 3 | 0 | 1 |
| D-4 | 3 | 2 | 4 | 8 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 |
| E-2 | **51** | 2 | **24** | 2 | 3 | 3 | 0 | 4 | 2 | 5 | **85** | 5 | 2 | **12** |
| E-4 | 0 | 1 | 9 | 3 | 0 | 4 | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 0 |
| F-2 | 4 | 5 | **15** | **10** | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 1 |
| F-3 | 3 | | **15** | 2 | 4 | 1 | 0 | 4 | 1 | **11** | 0 | 2 | 1 | 1 |
| F-4 | 7 | | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 8 | 0 | 0 | 0 | 1 |
| G-2 | **11** | 3 | **14** | 0 | 0 | 0 | 0 | 8 | 0 | **20** | 0 | 2 | 3 | 5 |
| H-2 | **26** | **13** | 7 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 7 | 2 |
| I-2 | **12** | **11** | 8 | 6 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 5 | 8 | **11** |
| J-2 | 6 | **18** | **10** | 1 | 0 | 1 | 0 | 1 | 0 | 3 | 0 | 9 | 5 | **17** |
| J-3 | **34** | **19** | **10** | 4 | 0 | 0 | 0 | 8 | 1 | 2 | 0 | **26** | **15** | **24** |
| J-4 | **50** | **161** | **15** | 4 | 0 | 7 | 0 | 1 | 1 | 2 | 0 | **16** | **31** | **26** |
| K-2 | **41** | **73** | **20** | 5 | 0 | 4 | 0 | 3 | 0 | 3 | 1 | **30** | **27** | **14** |
| M-1 | 3 | | 8 | 0 | 1 | **170** | 1 | 3 | **14** | **18** | 1 | 5 | **27** | **18** |
| N-1 | 5 | **22** | **11** | 1 | 0 | **161** | 0 | 0 | 1 | 2 | 1 | 4 | **24** | **42** |

samples collected in May and June following rain events

The lack of complete ice cover and the presence of significant numbers of waterfowl resulted in high fecal coliform concentrations at mid reservoir and at the south end on both sampling dates in January, but concentrations at the north end of the reservoir near the intake remained low. Elevated concentrations were recorded at mid reservoir in February and March before warmer temperatures melted ice cover from smaller area water bodies and most of the birds dispersed. Fecal coliform concentrations remained low throughout the spring and summer except for two very high values at the southwest end of the reservoir near Gates Brook and West Boylston Brook following heavy rain in May.

Waterfowl returned at the end of the summer and large groups of roosting birds led to a high concentration of fecal coliform at mid reservoir in October. Bird harassment activities were successful in moving birds south and away from the Cosgrove Intake, but elevated concentrations at sampling stations located at the south and southwestern end of the reservoir remained common through the end of the year.

Fecal coliform samples were collected seven days per week by MWRA staff from the John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough. EPA's fecal coliform criteria for drinking water require that a minimum of ninety percent of all source water samples contain less than 20 CFU/100mL. All 366 samples collected at Walnut Hill contained less than the standard, with a concentration of 10 CFU/100mL the maximum reported for the year and most samples containing 0 CFU/100mL. The Division has put considerable time and effort into implementing a rigorous bird harassment program, and the results in 2012 again proved to be very effective.

## 4.2 WATER COLUMN CHARACTERISTICS

### 4.2.1 FIELD PROCEDURES

DCR staff routinely measure water column profiles in Wachusett Reservoir for the following hydrographic parameters: temperature, specific conductance, dissolved oxygen concentration, percent oxygen saturation, and hydrogen ion activity (pH). This involves use of a field instrument known as a multiprobe to record data starting at the surface and then recording repeated measurements as the instrument is gradually lowered to the bottom. Measurements are recorded at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

The multiprobe used by DCR to measure water column profiles is a "MiniSonde 5" along with a "Surveyor 4" water quality logging and data display system manufactured by Hydrolab Corporation (now part of the Hach Company located in Loveland, Colorado). These instruments are routinely charged and calibrated during the field season. At the conclusion of field work, data recorded by the logging system is downloaded to a PC as an EXCEL spreadsheet.

In 2011, the DCR multiprobe was upgraded to measure chlorophyll *a* by addition of a fluorometer and it has proved to be a valuable new tool for detecting aggregations of phytoplankton at depth. Chlorophyll *a* is the most abundant photosynthetic pigment in algae composing the phytoplankton community and the amount of chlorophyll measured in a sample commonly serves as a surrogate for total phytoplankton biomass. The standard laboratory method for determining the amount of chlorophyll in surface water involves filtering a sample to collect the phytoplankton, mechanical rupturing of the organisms collected, extraction of chlorophyll from the ruptured cells into an organic solvent, and lastly, analysis of the extract by spectrophotometry or chromatography.

Fluorometry takes advantage of the fact that chlorophyll fluoresces when irradiated with light of certain wavelengths; generally in the 410 to 470 nanometer range of blue light in the visible spectrum. When excited by light of this wavelength, chlorophyll molecules emit light in the 620 to 715 nanometer range of red light in the visible spectrum (longer wavelength and lower energy than the blue excitation radiation). The fluorometer installed on the DCR multiprobe induces chlorophyll fluorescence in the water column by shining a beam of blue excitation wavelength from the end of the probe. It then measures the longer wavelength light that is emitted by phytoplankton cells *in situ* due to chlorophyll fluorescence with a photodetector that is also located at the end of the probe.

Preliminary calibrations of the fluorometer were conducted based on comparisons to chlorophyll concentrations measured in duplicate samples submitted to MWRA laboratory staff at Deer Island. Refinement of the initial calibrations is ongoing, but during *in situ* measurements the relative intensity of the fluorometric signal as the instrument is lowered through the water column has been much more useful in pinpointing the depth of aggregations of phytoplankton than knowing absolute concentrations of chlorophyll.

#### 4.2.2 THERMAL STRATIFICATION: ANNUAL DEVELOPMENT OF WATER COLUMN STRUCTURE

Typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. The development of stratification structure usually begins in late April or early May when increasing solar radiation and atmospheric warming cause a progressive gain of heat in surficial waters. Stratification is most pronounced during summer when the water column is characterized by three distinct strata: a layer of warm, less dense water occupying the top of the water column ("epilimnion"), a middle stratum characterized by a thermal gradient or thermocline ("metalimnion"), and a stratum of cold, dense water at the bottom ("hypolimnion"). This thermal structure is weakened in fall as heat from the upper portion of the water column is lost to the increasingly cold atmosphere. In late October or early November, the last vestiges of stratification structure are dispersed by wind-driven turbulence and the entire water column is mixed and homogenized in an event known as fall "turnover."

Profile measurement during the period of thermal stratification is important for many reasons including the following: (1) to monitor phytoplankton growth conditions and detect "blooms" of potential taste and odor causing organisms associated with discrete strata of the water column (see section on phytoplankton), (2) to track the progress of the Quabbin "interflow" through the Wachusett basin during periods of water transfer (see below), and (3) to monitor water quality within each stratum and determine appropriate depths for vertically stratified nutrient sampling. During the stratification period, profiles are measured weekly at Basin North/Station 3417 in conjunction with plankton monitoring (see adjoining section).

#### 4.2.3 THE QUABBIN "INTERFLOW" IN WACHUSETT RESERVOIR

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of Wachusett Reservoir. During the years 1995 through 2011, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 94 percent. The period of peak transfer rates generally occurs from June through November.

However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 degrees C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 6 to 16 meters in the Wachusett water column. Interflow water quality is distinctive from ambient Wachusett water in having lower specific conductivity characteristic of Quabbin Reservoir (see below). Multiprobe measurements of conductivity readily distinguish the flow path of Quabbin water as it is transferred to Wachusett. The interflow penetrates through the main basin of Wachusett Reservoir (from the Route 12 Bridge to Cosgrove Intake) in about 3 to 5 weeks depending on the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to Cosgrove Intake in a “short circuit” undergoing limited mixing with ambient Wachusett Reservoir water.

In 2012, a sustained transfer was initiated in January and was continuous throughout the entire year. A volume of 63,878 million gallons (241,806,038 cubic meters) was transferred during this interval; equivalent to 97% of the volume of Wachusett Reservoir. This is the largest transfer in many years and the influence of the 2012 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

#### 4.2.4 SEASONAL PATTERNS IN PROFILE MEASUREMENTS

Thermal stratification of the water column and the presence of the Quabbin interflow stratum are major determinants of vertical gradients and patterns evident in profile measurements. Profiles depicting water column characteristics on June 11$^{th}$, July 25$^{th}$, October 23$^{rd}$, and November 13$^{th}$ (Figures 3 through 6 respectively) show how hydrographic parameters change with depth from early in the stratification period through fall “turnover” when mixing homogenizes the entire basin volume and restores equilibrium conditions with the atmosphere.

General trends in water column temperature and dissolved oxygen concentrations during the stratification period can be discerned in these profiles. Specifically, temperatures change in the epilimnion and metalimnion, but temperatures in the hypolimnion remain between 8 and 10°C throughout the summer. Dissolved oxygen values remain near 100 % saturation in the epilimnion most of the year due to this stratum being exposed to the atmosphere and mixing due to wind-induced turbulence. In contrast, saturation values in the metalimnion and hypolimnion decline progressively due to microbial decomposition processes and the isolation of these strata from the atmosphere. The supply of oxygen at depth cannot be replenished until thermal structure is dissipated and “turnover” occurs.

Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate "buffering system"). Generally, pH values in Wachusett Reservoir are unremarkable, ranging from around neutral (pH=7) to slightly acidic (pH=6). Specific patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration, but are not depicted in Figures 3 through 6 since this parameter typically exhibits only minor fluctuations.

Specific conductance ("conductivity") profiles in Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from Quabbin. The Quinapoxet and Stillwater Rivers are the two main tributaries to Wachusett Reservoir and are estimated to account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range between 60 and 240 uS/cm with an average value between 125 and 150 uS/cm. In contrast, the average conductivity value of Quabbin water is approximately 40 uS/cm.

During periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin typically range from 75 to 145 uS/cm depending on the amount of water received from Quabbin the previous year. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity.

Interflow penetration was observed at Basin North/3417 on June 11$^{th}$ (Figure 3) when the conductivity profile showed an abrupt deflection to lower values. The conductivity profile on this date was early in its development toward a typical interflow configuration with a thickness of seven meters forming between depths of 6 and 13 meters. This indentation or "bulge" in the conductivity profile intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. The epilimnion occupied the top five meters of the water column on this date and had reached a temperature of 23°C. Epilimnetic dissolved oxygen was at 107% saturation on this date due to photosynthetic activity by phytoplankton.

By July 25$^{th}$ (Figure 4), the epilimnion still occupied the top five meters of the water column and had reached a temperature of 25°C. The interflow stratum was well-established between 5 and 15 meters on this date with conductivity reaching minimum values of around 67 uS/cm. The steep gradient in temperature and density caused by the interflow can be seen in this profile where the temperature dropped 10°C between depths of 5 and 7 meters.

Also on July 25$^{th}$, a spike in dissolved oxygen concentrations formed at the epi-metalimnion interface at 6 to 7 meters when saturation values reached 117% (Figure 4). Phytoplankton aggregated at a discrete depth often become evident in profile measurements as a spike in dissolved oxygen concentrations due to their photosynthetic activity. A pronounced spike in chlorophyll concentration at 7 meters coincides closely with the spike in dissolved oxygen. As stated previously, calibration of the fluorometer was only preliminary, so the maximum concentration of 16 ug/L recorded at a depth of 7 meters is not certain, but the discreteness of the signal was striking (Figure 4).

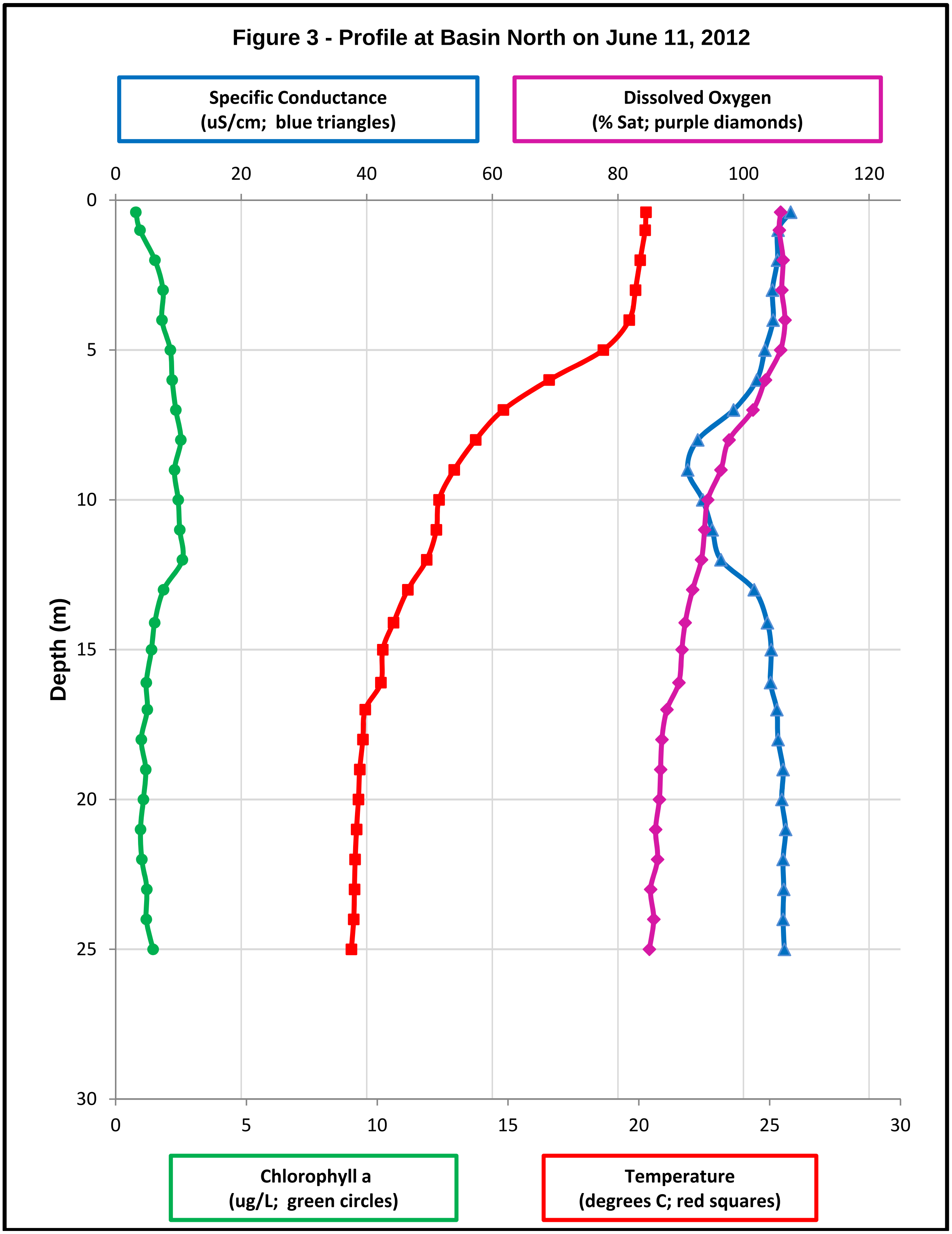


Figure 3 - Profile at Basin North on June 11, 2012
Specific Conductance
(uS/cm; blue triangles)
Dissolved Oxygen
(% Sat; purple diamonds)
0
20
40
60
80
100
120
Depth (m)
0
5
10
15
20
25
30
0
5
10
15
20
25
30
Chlorophyll a
(ug/L; green circles)
Temperature
(degrees C; red squares)

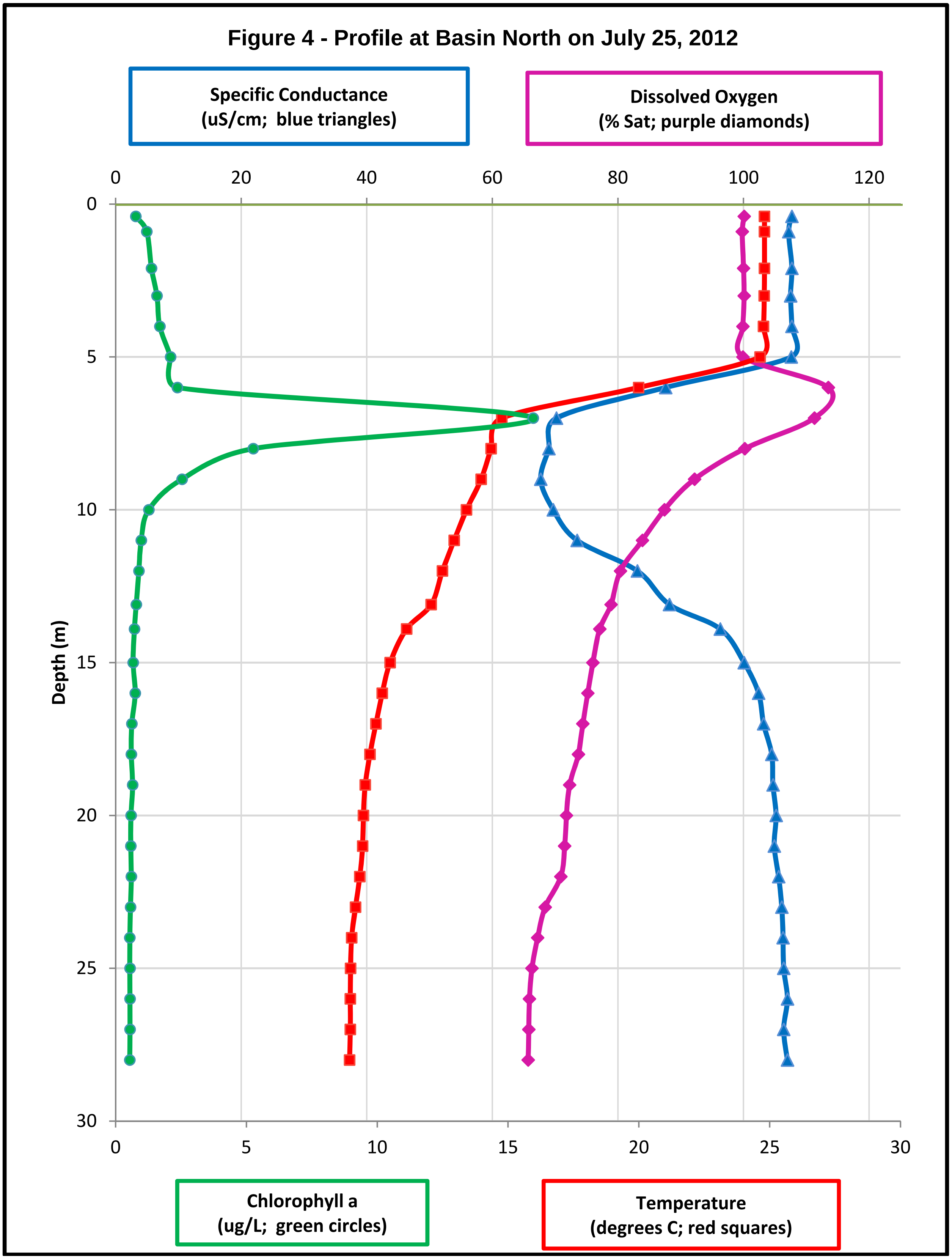


Figure 4 - Profile at Basin North on July 25, 2012
Specific Conductance
(uS/cm; blue triangles)
Dissolved Oxygen
(% Sat; purple diamonds)
0
20
40
60
80
100
120
Depth (m)
0
5
10
15
20
25
30
0
5
10
15
20
25
30
Chlorophyll a
(ug/L; green circles)
Temperature
(degrees C; red squares)

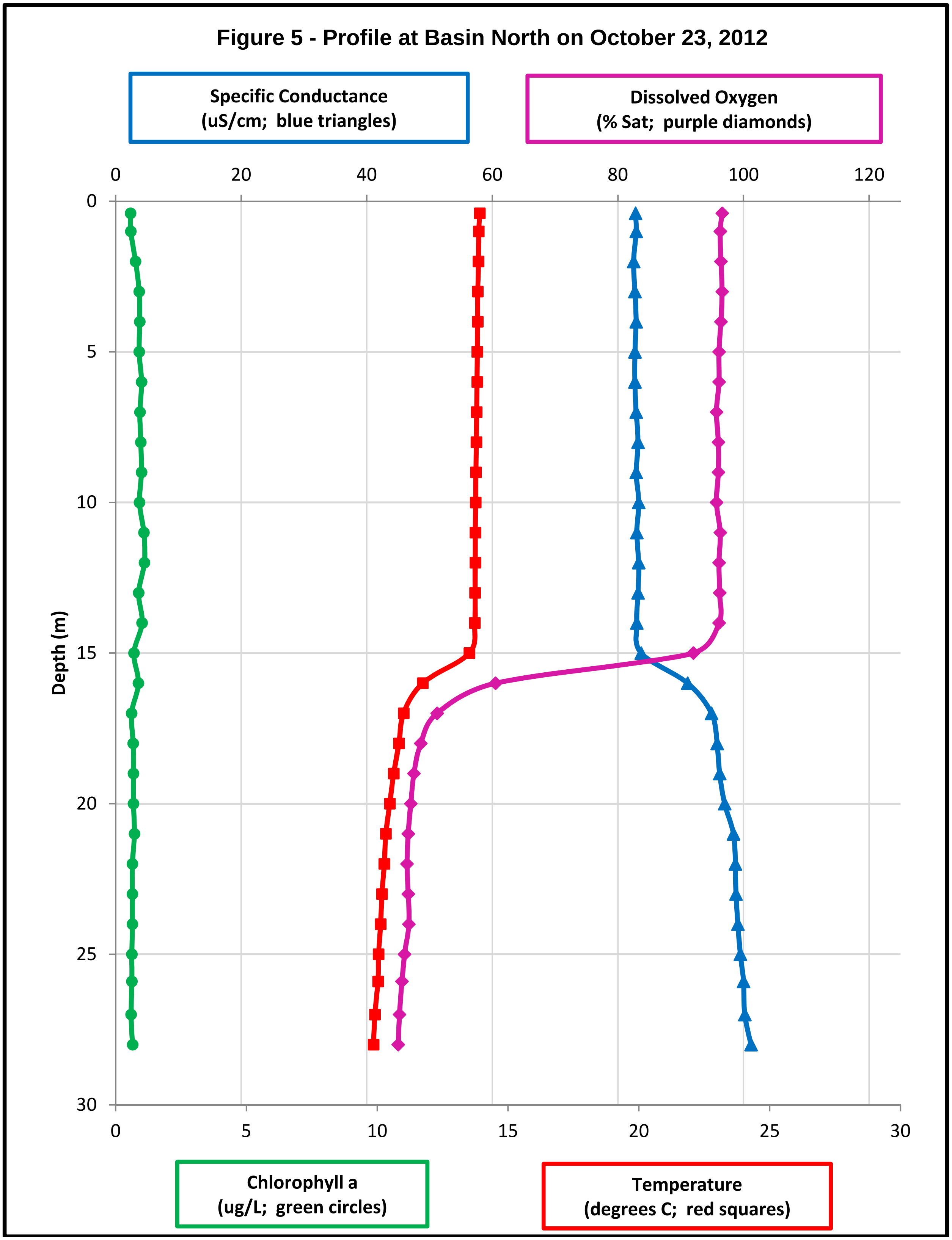


Figure 5 - Profile at Basin North on October 23, 2012
Specific Conductance
(uS/cm; blue triangles)
Dissolved Oxygen
(% Sat; purple diamonds)
0
20
40
60
80
100
120
Depth (m)
0
5
10
15
20
25
30
0
5
10
15
20
25
30
Chlorophyll a
(ug/L; green circles)
Temperature
(degrees C; red squares)

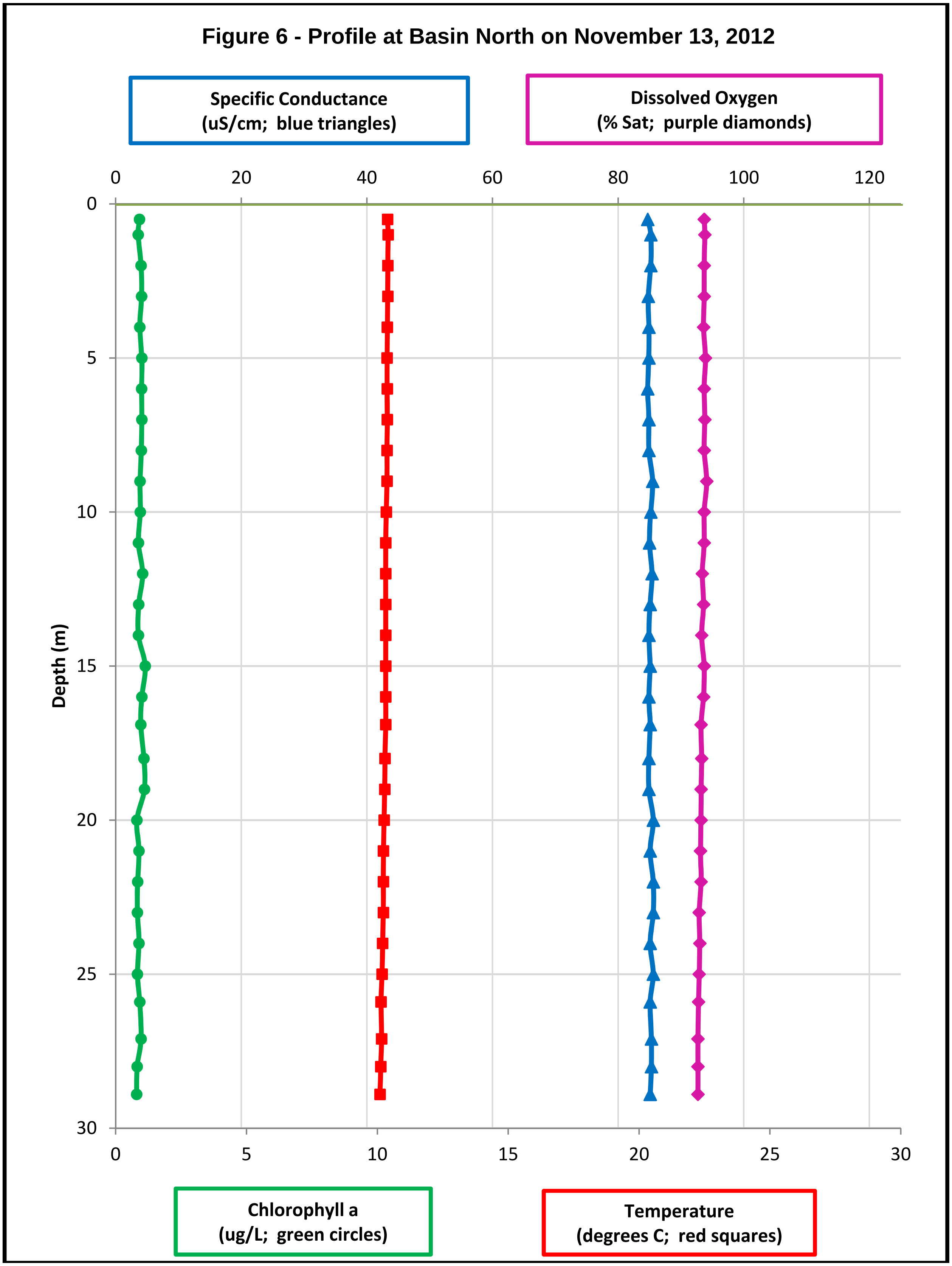


Figure 6 - Profile at Basin North on November 13, 2012
Specific Conductance
(uS/cm; blue triangles)
Dissolved Oxygen
(% Sat; purple diamonds)
Depth (m)
Chlorophyll a
(ug/L; green circles)
Temperature
(degrees C; red squares)

The epilimnion started to lose heat in late August and this continued through September. By October 23rd (Figure 5), heat losses and wind energy had eroded the thermocline downward such that the epilimnion occupied the top fifteen meters of the water column and the interflow stratum was homogenized within it. Dissolved oxygen remained near saturation in the epilimnion, but had declined to between 45% and 50% saturation in the hypolimnion. Phytoplankton activity was minimal at this time and the chlorophyll profile remained flat at very low values.

Hurricane Sandy arrived on October 29th, but the profile recorded October 31st at Basin North/Station 3417 (not depicted) showed that the hurricane did not cause the reservoir to "turn over." A density gradient associated with a 0.7°C temperature differential located between depths of 16 and 17 meters prevented Sandy from forcing the complete homogenization of the reservoir water column which constitutes "turnover." A residual hypolimnion characterized by undersaturated values of D.O. and elevated conductivity persisted below a depth of 16 meters.

However, soon afterward, a profile recorded on November 13th (Figure 6) documented that turnover had occurred, likely as a result of wind-induced turbulence associated with a snow storm on November 7th. The straight, vertical profile lines for all parameters are indicative of a completely homogenized water column lacking any stratification structure.

The profile recorded November 13th showed the water column isothermal at 10°C with conductivity measuring 85 uS/cm uniformly from surface to bottom. Fall turnover exposed the entire basin volume to the atmosphere, thereby replenishing dissolved oxygen concentrations throughout the water column which was uniformly oxygenated at around 93 percent saturation (around 10.5 mg/L).

## 4.3 NUTRIENTS

### 4.3.1 FIELD PROCEDURES

Nutrient dynamics in Wachusett Reservoir were documented through a program of quarterly sampling as follows: at the onset of thermal stratification (May), in the middle of the stratification period (July), near the end of the stratification period (October), and during a winter period of mixis before ice cover (December). Samples were collected at three main monitoring stations consisting of Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin (see Figure 1).

Grab samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003).

Modifications to the quarterly sampling program have consisted only of a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.05 mg/L from previous limits of 0.2 and 0.6 mg/L) and the addition of UV254 absorbance (in 2000) to the suite of parameters being measured. Measurement of UV absorbance at a wavelength of approximately 254 nanometers serves as a relative assay of the concentrations of organic compounds dissolved in the water.

#### 4.3.2 RESULTS OF NUTRIENT ANALYSES

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling and subsequent quarterly sampling through 2011 is used as a basis for interpreting data generated in 2012. Results from quarterly nutrient sampling in 2012 document concentrations of all nutrients that register entirely within historical ranges. In fact, due to the robust transfer from Quabbin in 2012 (equivalent to 97% of the volume of Wachusett Reservoir), nutrient concentrations for 2012 range on the low side of the historical spectrum (see Table 14 on the following page and the complete 2012 reservoir nutrient database in the Appendix at the end of this report).

This is especially true for ammonia which was near or below the minimum detection limit (MDL) of 5 micrograms/L for the whole year at all three sampling stations (Thomas Basin, Basin South, and Basin North in the epilimnion and metalimnion). This predisposition of the Quabbin transfer to dilute and ameliorate the influence of the Wachusett watershed on reservoir water quality has been observed and documented in previous reports.

The patterns of nutrient distribution in 2012 quarterly samples correspond closely to those documented in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003). These patterns consist most importantly of the following: (1) prominent seasonal and vertical variations with low epilimnetic concentrations in summer resulting from phytoplankton uptake, and conversely, higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter, (2) interannual fluctuations in nutrient concentrations and parameter intensities occurring across the system as a result of the divergent influences of the Quabbin transfer and the Wachusett watershed with temporary lateral gradients becoming pronounced for nitrate, silica, UV254, and conductivity, either increasing or decreasing downgradient of Thomas Basin depending on the dominant influence.

<u>Reference Cited</u>

Worden, David and Larry Pistrang. 2003. Nutrient and Plankton Dynamics in Wachusett Reservoir: Results of the MDC/DWM's 1998-2002 Monitoring Program, a Review of Plankton Data from Cosgrove Intake, and an Evaluation of Historical Records. Metropolitan District Commission, Division of Watershed Management.

**Table 14 - Wachusett Reservoir Nutrient Concentrations:**
**Comparison of Ranges from 1998-2011 Database[1] to Results from 2012 Quarterly Sampling[2]**

| Sampling Station[3] | Ammonia (NH3; ug/L) | | Nitrate (NO3; ug/L) | | Silica (SIO2; mg/L) | | Total Phosphorus (ug/L) | | UV254 (Absorbance/cm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1998-2011 | Quarterly'12 | 1998-2011 | Quarterly'12 | 1998-2011 | Quarterly'12 | 1998-2011 | Quarterly'12 | 2000-2011 | Quarterly'12 |
| Basin North/3417 (E) | <5 - 16 | <5 - 6 | <5 - 176 | <5 - 77 | 0.59 - 4.62 | 1.55 - 3.12 | <5 - 17 | 8 - 12 | 0.032 - 0.089 | 0.042 - 0.069 |
| Basin North/3417 (M) | <5 - 51 | <5 - 6 | <5 - 180 | 12 - 84 | 0.77 - 4.67 | 1.92 - 3.34 | <5 - 20 | 8 - 13 | 0.032 - 0.102 | 0.041 - 0.071 |
| Basin North/3417 (H) | <5 - 41 | <5 - 13 | 48 - 225 | 50 - 135 | 1.27 - 5.06 | 2.37 - 4.00 | <5 - 17 | 8 - 13 | 0.032 - 0.084 | 0.044 - 0.072 |
| | | | | | | | | | | |
| Basin South/3412 (E) | <5 - 15 | <5 | <5 - 176 | <5 - 74 | 0.56 - 4.58 | 1.47 - 3.25 | <5 - 20 | 6 - 14 | 0.031 - 0.101 | 0.041 - 0.069 |
| Basin South/3412 (M) | <5 - 39 | <5 - 6 | 11 - 184 | 18 - 77 | 0.95 - 4.80 | 1.84 - 3.14 | <5 - 22 | 7 - 13 | 0.032 - 0.128 | 0.041 - 0.077 |
| Basin South/3412 (H) | <5 - 44 | <5 - 17 | 49 - 224 | 49 - 127 | 1.64 - 4.78 | 2.74 - 3.94 | <5 - 37 | 8 - 14 | 0.036 - 0.111 | 0.048 - 0.071 |
| | | | | | | | | | | |
| Thomas Basin (E) | <5 - 18 | <5 | <5 - 201 | <5 - 48 | 0.62 - 7.44 | 1.60 - 3.14 | <5 - 27 | 7 - 19 | 0.026 - 0.305 | 0.033 - 0.110 |
| Thomas Basin (M) | <5 - 27 | <5 | <5 - 213 | 8 - 46 | 0.88 - 7.36 | 1.77 - 2.97 | <5 - 29 | 7 - 19 | 0.026 - 0.334 | 0.035 - 0.099 |
| Thomas Basin (H) | <5 - 57 | <5 - 11 | <5 - 236 | 11 - 43 | 0.92 - 7.39 | 1.85 - 2.74 | <5 - 29 | 6 - 16 | 0.027 - 0.345 | 0.035 - 0.077 |

Notes: (1) 1998-2011 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling through December 2011, except for measurement of UV254 initiated in 2000 quarterly sampling
(2) 2012 quarterly sampling conducted May, July, October, and December
(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

## 4.4 PLANKTON

#### 4.4.1 FIELD PROCEDURES

Plankton monitoring consists of three tasks conducted from a boat: measurement of water column "profiles" (see adjoining section on water column profile measurements), measurement of Secchi transparency, and grab sampling. This work is generally conducted at Basin North/Station 3417 during the late-April through early-November thermal stratification period. Basin North/Station 3417 is representative of the deepest portion of the basin and is outside the area adjacent to Cosgrove Intake where copper sulfate is applied on the infrequent occasions when "taste and odor" organisms attain problematic densities. The catwalk behind Cosgrove Intake is the backup location for grab sampling when boat operations are untenable due to foul weather, shortage of staff, or other contingencies. Seiche effects or turbulence from water withdrawals can destabilize stratification boundaries and obscure associated phytoplankton distribution patterns at Cosgrove Intake during summer, but samples collected from the catwalk during the late-November through early-April period of mixis are adequately representative of the main basin.

Monitoring frequency is generally weekly in early spring, fall, and winter increasing to twice a week (usually Monday and Thursday) during the period from May through September when episodes of rapid population growth ("blooms") by "taste and odor" organisms generally occur. During the annual stratification period samples are collected as follows: (1) near the middle of the epilimnion at a depth of three meters and (2) at or near the interface between the epilimnion and metalimnion at a depth of six or seven meters, and (3) within strata pinpointed by distinctive profile measurements. Additionally, surface samples are collected in June when a bloom of the cyanophyte *Anabaena* frequently accumulates at the surface. During the period of mixis, collection of samples at two depths (generally 3 and 6 meters) suffices. Samples are collected using a Van Dorn Bottle and returned to the laboratory for concentration and microscopic analysis (details given below in next section).

Measurement of water column "profiles" entails the use of a Hydrolab multiprobe to record hydrographic parameters such as temperature, dissolved oxygen, hydrogen ion activity (pH), specific conductance, and chlorophyll *a* (see Section 4.2.1). These parameters are measured at one meter intervals as the multiprobe is lowered from the surface to record a profile of the entire water column. Secchi transparency is recorded as an approximate measure of the amount of particulates, mostly plankton, suspended in the water column.

During the stratification period, much interest is triggered when profile measurements show a spike in dissolved oxygen concentration and/or a spike in chlorophyll *a* concentration. These are indicative of photosynthetic activity associated with a phytoplankton bloom or aggregation within a specific stratum of the water column. Additional grab samples are collected where spikes in are indicated. Motile colonial chrysophytes ("golden-brown algae") such as *Chrysosphaerella*, *Dinobryon*, and *Synura* are known to produce subsurface blooms in Wachusett Reservoir and are the most potent "taste and odor" taxa generally encountered. The "aggregation stratum" that these organisms prefer is generally between 6 and 8 meters coincident with the steep temperature gradient at the interface between the epilimnion and the metalimnetic interflow (see Section 4.2.2).

Productivity by phytoplankton during the stratification period is almost exclusively restricted to the epilimnion (except for an occasional aggregation of chrysophytes in the upper margin of the metalimnion as mentioned above). The absence of significant photosynthetic activity below the epilimnion/interflow boundary has been documented consistently since 1987 by multiprobe measurements of water column profiles. Steadily declining concentrations of dissolved oxygen over the weeks of the stratification period indicate that microbial decomposition of sedimenting organic matter is the dominant biological process below this boundary.

#### 4.4.2 CONCENTRATION AND MICROSCOPIC ANALYSIS OF PHYTOPLANKTON

Prompt acquisition of information on phytoplankton densities is critical for agency decision-making on the need for algaecide applications to avoid taste and odor problems. The method of sand filtration for concentration of phytoplankton samples has long been in use by both MWRA and DWSP because it enables relatively rapid analysis of samples while subjecting organisms to minimal damage or distortion. The specific method used is documented in Standard Methods Twelfth Edition (1965, pages 669-671). In brief, the method entails gravity filtration of sample water placed in a funnel through a layer of fine sand followed by washing and gentle shaking of the sand with waste filtrate water in a beaker to detach organisms from the sand grains, and lastly, prompt decanting of the concentrated sample after the sand has been allowed to settle. A portion of the concentrated sample is then analyzed microscopically using quantitative techniques as presented below.

Phytoplankton taxa in concentrated samples are enumerated using a Sedgewick-Rafter (S-R) Cell which enables phytoplankton densities to be quantified. Each concentrated sample is mixed to homogenize the sample and then 1 ml of the sample is withdrawn with a pipette and placed into the S-R Cell. Initial inspection of phytoplankton within the S-R Cell is accomplished with a stereozoom microscope capable of magnification from 7X to 45X. Use of this instrument to scan the entire S-R Cell is important to detect colonies of certain motile taxa present at low densities such as *Synura* and/or colonies floating against the underside of the coverslip such as *Anabaena*. Analysis of surface samples collected in June is limited to scanning unless *Anabaena* is detected at densities amenable to enumeration using a compound microscope (see below).

Scanning of the entire S-R Cell enables colonial "taste and odor" organisms to be detected and quantified at very low densities. Colonies observed in the S-R Cell using the stereozoom microscope are quantified by counting the number of colonies and then measuring their average diameter using a compound microscope (see below). This information, along with the known concentration factor arising from sand filtration, is used to calculate and express densities of colonial "taste and odor" organisms as Areal Standard Units (see below).

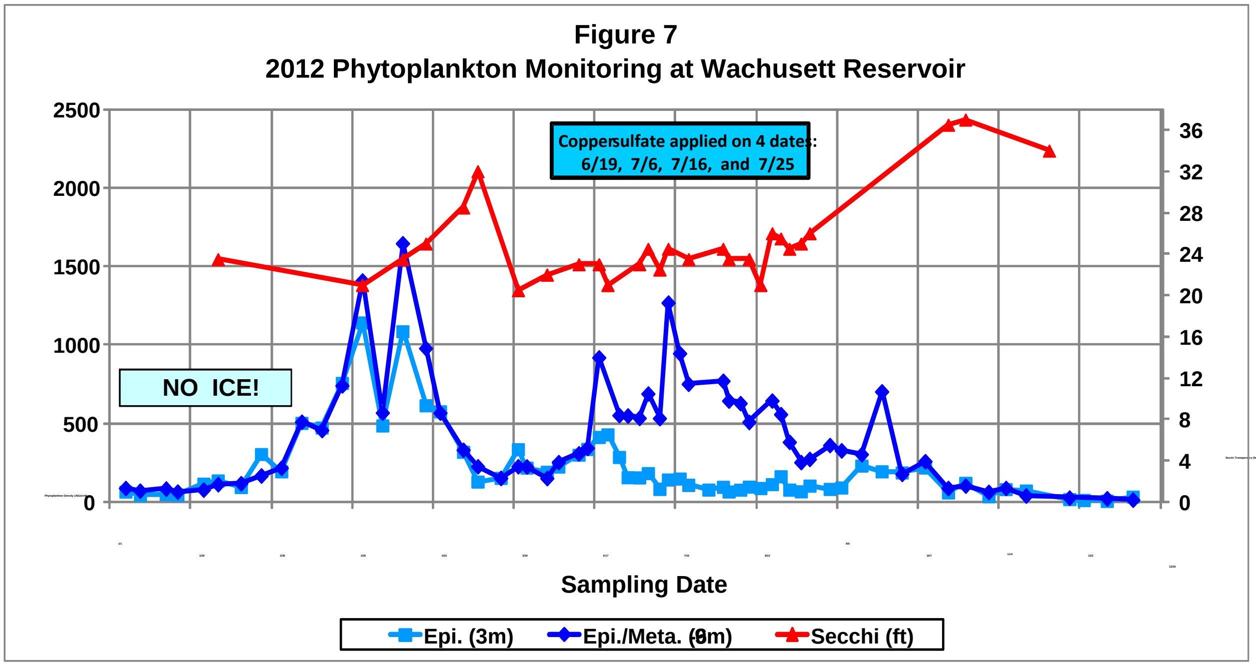
After the scanning procedure described above, microscopic analysis of phytoplankton samples is next performed with a compound microscope at a magnification of 200X using either bright field or phase-contrast illumination. Approximately 15 minutes are allowed for the phytoplankton to settle to the bottom of the S-R Cell before enumeration. Phytoplankton are enumerated in a total of 10 fields described by an ocular micrometer. The area of the ocular field is determined by calibration with a stage micrometer and the fields are selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

Phytoplankton densities are expressed as Areal Standard Units (ASUs; equivalent to 400 square microns) per milliliter. The area of each specimen viewed in each counting field is estimated using the ocular micrometer (the ocular field is divided into a 10 by 10 grid, each square in the grid having a known area at 200X magnification). In the case of taxa which form gelatinous envelopes or are enclosed in colonial mucilage, such as *Microcystis*, the area of the envelope is included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, is estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates, are not included in the count.

#### 4.4.3 MONITORING RESULTS

Phytoplankton monitoring results for 2012 are reminiscent of a pattern not observed since 2007 with relatively strong diatom activity in early spring (Figure 7). A proliferation of diatoms (mainly *Asterionella* and *Cyclotella*) in March reached a maximum density of 1,143 ASUs/mL on the 28th contributing to a total density of 1,410 ASUs/mL on that date in the grab sample collected at 6 meters. On April 11th, diatom densities were 1,088 ASUs/mL contributing to a total density of 1,647 ASUs/mL in the 6 meter grab sample. Densities of all taxa declined steadily after this peak and were less than 300 ASUs/mL at both sampling depths by May 2nd.

Following the spring period of diatom activity, the chrysophyte *Chrysosphaerella* migrated from the epilimnion down a depth of 7.5 meters in the metalimnion. In July and August of 2004, *Chrysosphaerella* aggregated in the metalimnion caused hundreds of consumers to register complaints of water having a "metallic" taste and odor. The repeat of this migration behavior in 2012 prompted MWRA to apply copper sulfate on June 19th, July 6th, July 16th, and July 25th in the treatment area adjacent to Cosgrove Intake.



No complaints were received, but this is likely due mostly to disinfection by ozone which replaced chlorine as the disinfectant in 2005. However, MWRA currently maintains and uses its copper sulfate boat and crew as another line of defense to ensure that consumers are protected from organisms that have previously caused "taste and odor" events.

After a peak *Chrysosphaerella* density of 1,020 ASUs/mL contributing to a total plankton density of 1,270 ASUs/mL in the metalimnion on July 12th, densities of all taxa subsided through July and August. During this time Secchi transparency increased as expected. Eventually, after a brief burst of activity by cyanophytes and the chrysophyte *Dinobryon* on September 24th, populations of all phytoplankton taxa declined and remained at low densities for the remainder of the year.

Flat calm conditions on the water on October 17th combined with the extremely low densities contributed to an exceptional measurement of water clarity. The all-time record for Secchi transparency at Wachusett Reservoir was recorded on this date: 36.5 feet (11.1 meters). Less than one week later, conditions again combined favorably for another exceptional measurement: a new record of 37 feet (11.3 meters) observed on October 23rd.

## 4.5 MACROPHYTES

### 4.5.1 THE THREAT OF INVASIVE ALIEN MACROPHYTES

In August of 2001, a pioneering colony of Eurasian Water-milfoil (*Myriophyllum spicatum;* referred to subsequently as "EWM") was observed for the first time in Oakdale Basin, a small basin in the upper reaches of the reservoir system (referred to as Upper Thomas Basin in previous reports; see Figure A). EWM is a nonindigenous, invasive species of macrophyte known to aggressively displace native vegetation and grow to nuisance densities with associated impairments to water quality. Prior to 2001, this plant was restricted to the uppermost component of the reservoir system, Stillwater Basin, where its distribution has been monitored since 1999.

The expansion of EWM into Oakdale Basin represented a significant increase in the risk of a potentially rapid and overwhelming dispersal of this plant into the main reservoir basin. The water quality implications of such an event are serious and include increases in water color, turbidity, phytoplankton growth, and trihalomethane (THM) precursors. These increases result from the function of this plant and macrophytes in general as nutrient "pumps," extracting nutrients from sediment and releasing them to the water column, mostly as dissolved and particulate organic matter.

Fanwort (*Cabomba caroliniana*) is another invasive nonindigenous plant that was restricted to Stillwater Basin in 1999, but which has since spread into Oakdale Basin. The spread of fanwort was more gradual than that of EWM but, in recent years, fanwort has become as problematic as EWM and both are targeted by annual control activities (see below). The most important mode of reproduction and dispersal of these species is by fragmentation. Vegetative fragments are generally released at the end of the growing season when the plants undergo senescence. These fragments float for some time before sinking to the bottom and can take root and become established in suitable habitat. Control measures targeting both these invasive species are discussed in the sections that follow.

#### 4.5.2 WACHUSETT RESERVOIR ALIEN MACROPHYTE CONTROL PROGRAM

The 2001 expansion of EWM into Oakdale Basin prompted DCR to design an invasive macrophyte control program which was implemented in 2002 and, in collaboration with MWRA, has continued to the present. The main components of this program have been the following: deployment of floating fragment barriers, deployment and maintenance of benthic barriers, annual hand-harvesting efforts, and routine scouting throughout the reservoir system by DCR to insure early detection of pioneering infestations (details of control efforts in previous years are provided in their annual reports). In addition to the components of the control program identified above, invasive control efforts in 2012 included significant use of an innovative technology for the first time: diver-assisted suction harvesting (DASH). Harvesting efforts initially focused on Oakdale Basin, but both EWM and fanwort have gradually spread throughout Thomas Basin, located directly downstream, so this basin is also targeted in annual removal efforts. Details of the 2012 invasive control program are summarized below.

<u>Removal of Invasive Macrophytes by DASH: Summary of ACT Efforts in 2012</u>

- Initial deployment of DASH boat from July 2nd through July 6th working in all target locations (5 work days including the 4th)
- The second DASH effort runs from August 27th through August 29th (3 work days)
- Estimate of EWM plants removed = 1,062; estimate of fanwort plants removed = 1,333; total diver-hours expended = 128

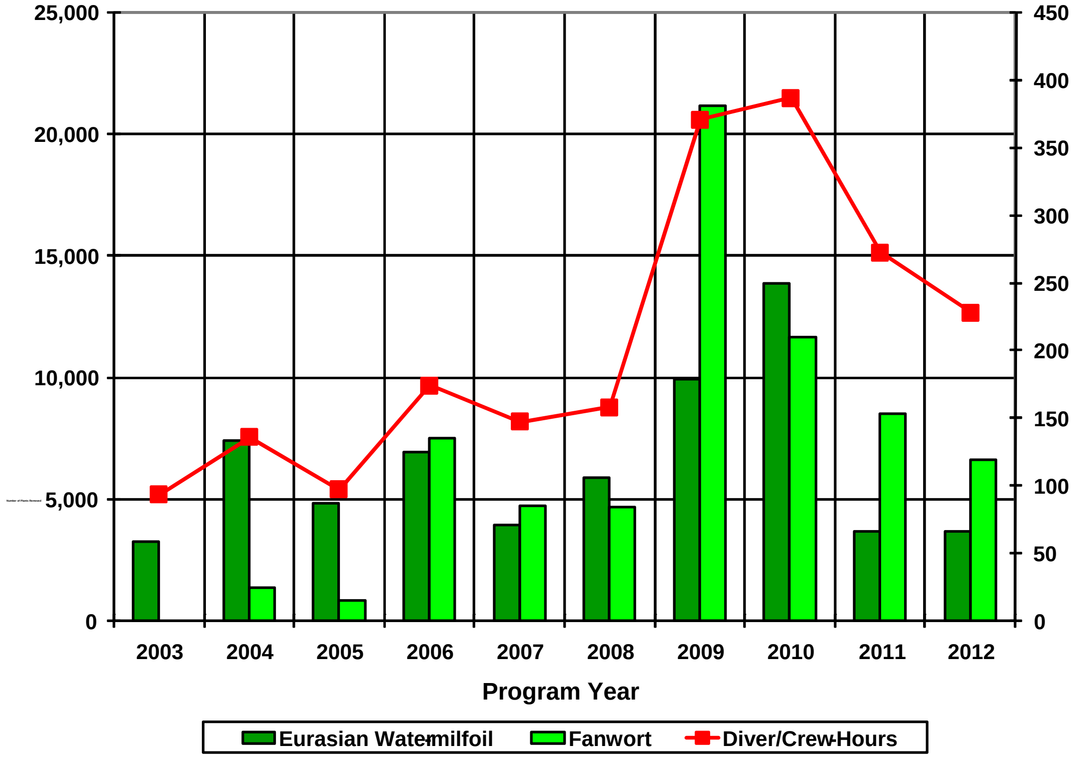
<u>Hand-Harvesting of Invasive Macrophytes: Summary of ACT Efforts in 2012</u>

- Preliminary GPS survey of Oakdale Basin conducted on June 8th
- Hand-harvesting in all target locations conducted from September 4th through September 7th (4 work days)
- Estimate of EWM plants removed = 2,633; estimate of fanwort plants removed = 5,259; total diver-hours expended = 100
- Post-harvesting GPS survey of Oakdale Basin conducted on September 26th; a few very scattered single specimens of EWM and fanwort are observed, but no significant populations

The number of fanwort specimens removed in 2012 continued the recent pattern of decline, but EWM was little changed (Figure 8). Not depicted in Figure 8 are results from the initial hand-harvesting effort in 2002 when 496.5 diver-hours were expended in removing an estimated 75,000 to 100,000 EWM plants.

In addition to the activities of consultants summarized above, DCR staff maintained floating fragment barriers at two strategic "bottleneck" locations to restrict the movement of invasive fragments into downgradient portions of the reservoir system. These locations consist of the railroad bridge between Stillwater Basin and Oakdale Basin and the Beaman Street Bridge between Oakdale Basin and Thomas Basin. The floating fragment barriers were initially purchased and deployed at these locations in 2002.

**Figure 8**
**Harvesting of Invasive Macrophytes: 2003 - 2012**




Despite the deployment of the two floating fragment barriers, it is apparent that a small number of plant fragments are able to get past the barriers and into the main basin of the reservoir. Historically, evidence of this is represented by the occurrence of a handful of plants found in Powerline Cove. This cove is located immediately east of the Route 12 Bridge/Causeway on the northern shoreline of the main basin where powerlines span the reservoir. The number of EWM specimens removed from Powerline Cove increased dramatically compared to 2011 (Table 15). Specimens of EWM and fanwort have been detected and removed from this cove intermittently; EWM since 2002 and fanwort since 2007.

**Table 15 - Summary of Hand-harvesting Results in Powerline Cove**

| Year of Program and Species | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2112 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Eurasian Water-milfoil** | 14 | 0 | 0 | 21 | 18 | 1 | 0 | 59 | 22 | 75* | 103* |
| **Fanwort** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 17 | 7 | 4 | 5 |

* 2011 results revised upward to 75 from 68 based on review of DCR removal records; plants removed in 2012 were all accounted for by DASH operations except for 1 specimen of EWM removed by divers

During shoreline scouting on August 29, 2011 EWM was found for the first time in Horseshoe Cove, located along the Southern shore approximately 1 mile from both the Route 12 Causeway and Powerline Cove. These specimens were removed, but additional specimens were again detected in 2012. Also in 2012, EWM was detected for the first time in West Boylston Brook Cove (Table 16). This cove is located directly southwest of Powerline Cove on the opposite shoreline. These specimens in this cove were also removed by divers, but their comeback in recent years is troubling.

**Table 16 - Summary of Hand-harvesting Results in West Boylston Brook Cove**

| EWM Removed Recently | 2010 | 2011 | 2012 |
|---|---|---|---|
| Horseshoe Cove | 0 | 4 | 6 |
| W. Boylston Brook Cove | 0 | 0 | 13 |

The occurrence of EWM and fanwort in Powerline Cove, EWM in Horseshoe Cove, and EWM in West Boylston Brook Cove indicates that the established populations of these plants in the Stillwater Basin are producing fragments that are dispersing into the main basin. Despite deployment of floating fragment barriers and annual removal efforts in Oakdale and Thomas Basins, it may be necessary, in the future, to expand hand-harvesting efforts to vulnerable portions of the main basin and/or mount efforts to suppress the populations already established in Stillwater Basin where the fragments originate.

#### 4.5.3 SUPPLEMENTAL ALIEN MACROPHYTE CONTROL ACTIVITIES

Additional activities were conducted in 2012 in conjunction with the main components of the invasive control program. Details of these activities are presented below.

Response to the Discovery of Hydrilla in the South Meadow Pond Complex

In August of 2010, the invasive macrophyte Hydrilla (*Hydrilla verticillata*) was discovered in South Meadow Pond in the Town of Clinton. The South Meadow Pond complex is located only about 1,970 feet (600 m) north of Wachusett Reservoir, thus this infestation is at the “doorstep” of the reservoir just over the North Dike. Even though the South Meadow Pond complex is outside the DCR watershed and does not support access by trailered boats, the close proximity of the Hydrilla infestation to Wachusett Reservoir and the possible potential for transfer to the Reservoir by waterfowl or bait buckets necessitates special management and monitoring efforts.

Shortly after the discovery of Hydrilla in the South Meadow Pond complex in 2010, DCR and MWRA collaborated on response efforts and implemented a program to suppress Hydrilla using herbicides. An initial herbicide application of Reward and Cutrine Plus was performed on October 29, 2010 by staff from ACT in an attempt to knock down the surface accumulation of Hydrilla biomass. This was successful.

ACT’s treatment and monitoring plan went into full swing in 2011 with the application of Sonar herbicide (fluridone) in June. A lethal concentration of Sonar was maintained in the South

Meadow pond complex from late June through late August and post-treatment monitoring conducted by ACT on October 3, 2011 documented that this treatment was overwhelming effective with no viable Hydrilla growth observed anywhere in the pond system. ACT also documented that fall 2011 Hydrilla tuber counts were drastically reduced from fall 2010 levels.

ACT followed-up on the excellent control achieved in 2011 with a two phase application strategy in 2012 starting with the contact herbicide (Reward and Cutrine) followed by the systemic herbicide (Sonar). ACT performed several preliminary inspections of the system starting in early May in order to identify the onset of vegetative Hydrilla growth. The first active Hydrilla growth was observed on June 14th (very low density immature growth 2-3" tall). The pre-treatment survey and tuber sampling was conducted June 19th. Tuber density was well below the 2010 counts, but slightly elevated from the post-treatment 2011 numbers. Overall the Hydrilla regrowth that was observed was far less dense than pre-treatment 2011; however, Hydrilla was present in all of the areas where it was documented in 2011. No new areas of Hydrilla colonization were observed in the pond complex.

Phase 1: Contact Herbicide

On June 29th, the initial Reward (diquat) and Cutrine Plus treatment was performed. A total of approximately 15 acres of shoreline growth was treated. At the time of treatment the Hydrilla growth was 6-8 inches tall. The native plant assemblage, dominated by thin-leaf pondweed, floating-leaf pondweed and naiad, was robust and near the water surface in most areas where present. The herbicide was applied through weighted hoses within the shoreline areas of documented Hydrilla growth.

A post-Reward herbicide treatment inspection was conducted on July 17th to determine the level of Hydrilla control achieved; no Hydrilla growth was observed. Several additional interim inspections were performed to identify regrowth of Hydrilla. On July 24th, some very limited Hydrilla regrowth was observed in SMP-West, Mossy Pond, and Coachlace Pond consisting of widely scattered individual plants.

Phase 2: Systemic Herbicide

On August 1st, a Sonar One herbicide treatment (fluridone) targeting a system-wide concentration of approximately 7ppb was performed. At the time of treatment a slight increase in the density and maturity of the Hydrilla growth was noted. The Sonar One pellets were broadcast along the shoreline of the ponds to create a locally higher herbicide concentration in the areas where the Hydrilla is known to occur.

FasTEST samples (for measuring fluridone concentrations) were collected 21 days after treatment (DAT), 32 DAT, and 50 DAT. At the time of the final FasTEST sampling round no Hydrilla growth was observed. It was noted that attaining lethal fluridone concentrations in the areas of the two small patches in Mossy Pond was difficult. The use of bottom barrier in these areas should be considered for future management.

Long term control of Hydrilla in this complex will still require diligent monitoring over several years and additional applications of Sonar (fluridone) when regrowth of this tenacious invasive plant occurs as has happened in other treated systems. However, the impressive progress that ACT has made in the first two years of treatment is certainly an encouraging start.

#### 4.5.4 PLANS FOR ALIEN CONTROL EFFORTS IN 2012

The invasive nature of EWM and fanwort necessitate a long-term commitment to annual control efforts in the upper reaches of the Wachusett Reservoir system if their dispersal into the main basin is to be prevented. To meet this challenge, DCR and MWRA continue to work collaboratively to sustain annual control efforts and refine the control program as necessary.

Next year, during the 2013 growing season, plans call for a resumption of intensive DASH and hand-harvesting in Oakdale and Thomas Basins. As usual, an initial GPS survey of Oakdale Basin will be conducted in May or June followed by harvesting in areas observed to support regrowth of invasive macrophytes. Dive crews will conduct additional hand-harvesting efforts during the summer as needed to suppress regrowth that occurs subsequent to initial harvesting efforts.

Associated with hand-harvesting efforts, DCR staff will continue systematic scouting for invasive macrophytes throughout the reservoir system to identify and target any pioneering specimens found in new locations. Due to the Hydrilla infestation in South Meadow Pond, more intensive scouting of the reservoir will be maintained with more frequent inspections of the northern shoreline adjacent to the North Dike and Route 110 as done this year. An updated bathymetric map of the reservoir has been developed and divided into sections to ensure complete coverage and help focus scouting efforts on those areas most susceptible to colonization by Hydrilla and other invasive aquatic plants.

Finally, DCR staff will continue to maintain floating fragment barriers at their strategic "bottleneck" locations as done in previous years. In response to a release of invasive fragments from the barrier located at the Beaman Street Bridge during Hurricane Irene in August 2011, a floating containment boom (provided by MWRA) is available for deployment in a "chevron" configuration. During severe storm events with associated extreme flows from the Stillwater River, it appears that the permanent barrier at the Beaman Street Bridge can become overwhelmed with floating debris. The chevron boom provides an addition layer of protection against downstream transport of invasive fragments and also enables a crew on shore to rake the captured fragments out of the water to a disposal location on the eastern shore of Thomas Basin that is "high and dry."

## 4.6 FISH (2012 WACHUSETT RESERVOIR CREEL SURVEY)

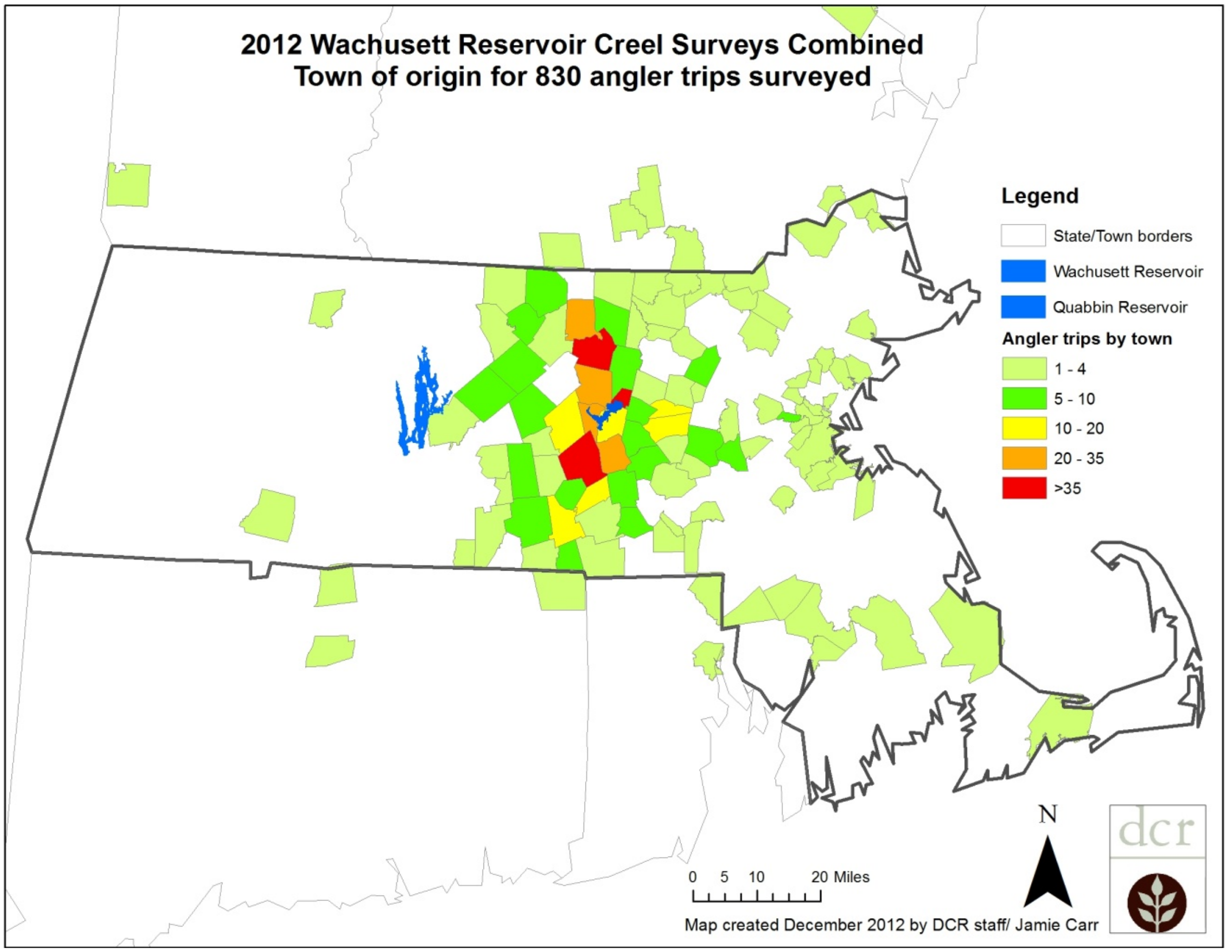
<u>Overview</u>

A creel survey is a survey of anglers to determine the species and number of fish caught in a specific water body over a specific time period. In this context, a creel survey of Wachusett Reservoir can serve as a tool used to assess the following: adult fish populations, fishing pressure, catch rate, and harvest. Fish are an important component of the reservoir ecosystem, and knowledge of fish populations in the reservoir is important to understanding the food web of the reservoir and its impacts upon water quality. This summary presents the results of the 2012 creel survey for documentation of this effort within the annual report. A final, more detailed analysis of the 2011 and 2012 creel survey results will be presented together within a separate stand-alone document.

Creel Survey Design

A roving creel survey with a stratified random sampling design was employed. Two weekday and one weekend day each week were chosen at random as creel survey days. The creel survey was conducted on 98 of the 238 possible days within the fishing season (April 7 – November 30). Each survey day consisted of two separate loops around the reservoir, an AM loop and a PM loop. On an assigned loop the creel clerk would count every visible angler and interview as many anglers as possible in completing one trip around the reservoir. A basic creel survey card was developed that enabled creel clerks to quickly collect basic information from an angler or group of anglers: time started fishing, size and number of fish caught, tackle used, etc. Creel surveys were performed by Wachusett Watershed Rangers, DCR Water Supply Protection staff, and Department of Fish and Wildlife staff.

**Figure 9**



Angler Count Results

Creel clerks counted 2,450 anglers and surveyed 1,334 anglers (54%). Of the anglers surveyed, 884 (66%) were unique anglers who indicated that they had not been surveyed before in 2012. Only 28 anglers were observed to be in violation of fishing laws or reservoir regulations (1.1%). Angler cooperation with interviews was very high, as only six anglers declined to cooperate (less than 0.25%).

Zip code information collected from anglers revealed angling trips had originated from 99 different Massachusetts towns. Six towns in New Hampshire, three towns in Connecticut, two towns in Rhode Island, and one town in Vermont were also represented (See Figure 9). Additionally, a handful of anglers at the reservoir gave their home zip code from far away locations including: Clearwater Florida, Gainesville Florida, Columbus Georgia, Fargo North Dakota and Puerto Rico.

Fish Caught

A total of 800 fish were caught by anglers interviewed in the creel survey, with 208 fish (26%) being kept by the angler. Catch and release appears to be a common practice as the majority of fish (74%) were caught and then released. As in 2011, Smallmouth Bass were the most frequently caught species, followed by Lake Trout (See Table 17). These two species combined for just under 2/3 of the total catch. Lake Trout represented the largest number of fish kept (96).

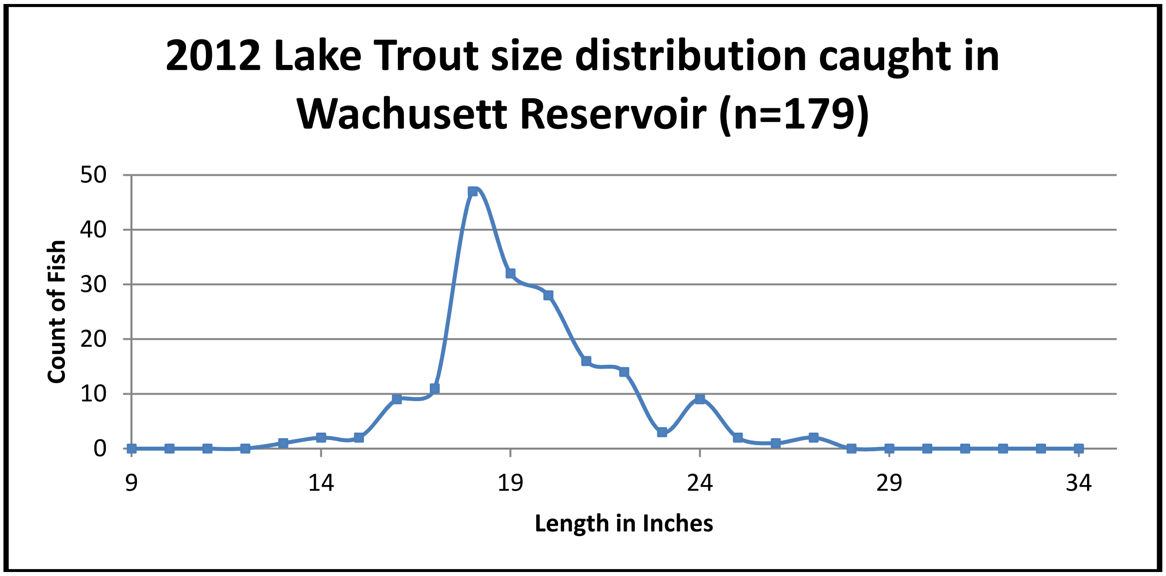
**Table 17: Fish Species Caught**

| Species | caught | kept | % kept |
|---|---|---|---|
| Smallmouth Bass | 325 | 46 | 14.2% |
| Lake Trout | 179 | 96 | 53.6% |
| Sunfish | 106 | 10 | 9.4% |
| Largemouth Bass | 75 | 1 | 1.3% |
| Yellow Perch | 21 | 4 | 19.0% |
| White Perch | 12 | 4 | 33.3% |
| Rainbow Trout | 29 | 18 | 62.1% |
| Black Crappie/calico Bass | 5 | 0 | 0.0% |
| Rock Bass | 5 | 0 | 0.0% |
| Landlocked Salmon | 34 | 26 | 76.5% |
| Brown Bullhead | 2 | 2 | 100.0% |
| Chain Pickerel | 7 | 1 | 14.3% |
| Total | 800 | 208 | 26.0% |

A graph of the Lake Trout size distribution for fish caught in the Wachusett Reservoir in 2012 shows that the most commonly caught Lake Trout size was 18 inches in length (Figure 10). More than half (58%) of lake trout caught were 19 inches in length or less, while 42% were 20 inches or greater in length.

The total catch divided by the total angling effort is referred to as the catch per unit effort. In 2012, the catch per unit effort was 0.14 fish per hour of effort. Put another way, on average it took anglers 7.4 hours to catch one fish per line. 416 surveys indicated that fish had been caught at the time they were interviewed (54%), while 354 surveys indicated that no fish had been caught at the time they were interviewed (46%).

**Figure 10**




Initial Conclusions

Initial conclusions based on the raw data from the first two years of the survey are listed below:

- The majority of angling trips to Wachusett Reservoir originate from nearby towns, but many anglers are willing to travel a good distance to fish the reservoir. Some anglers plan their long distance trips to the area from other parts of the country based on their preferred fishing season on the reservoir.
- The Wachusett Watershed Rangers have a strong presence and the majority of anglers are familiar with the rangers and regulations. Compliance with angling laws and watershed regulations by anglers at the reservoir is very high (>99%).
- Anglers were happy to cooperate and were genuinely interested in the creel survey and its results.
- Based on the catch per unit effort rates, game fish populations are likely present in relatively low densities, but can reach trophy size.
- The Wachusett Reservoir is primarily a catch and release fishery as over 70% of the fish caught are released; when fish are kept nearly all are eaten by the angler (some, especially small yellow perch, are kept to be used as bait).
- Trends in game fish populations can be inferred if the creel survey is repeated at regular intervals.

## 5.0 SAMPLING PLAN FOR 2013

The Wachusett watershed sampling program for 2013 closely follows protocols used for the past two years. Temperature, specific conductance, *E. coli*, and turbidity will be again be measured weekly at twenty-three stations on nineteen tributaries during dry and wet weather. After years of an expanded sampling program to collect sufficient background data as well as to address issues that had been identified in previous water quality summaries and Environmental Quality Assessment reports, sampling was reduced in 2011 to include only direct tributaries to the reservoir and stations deemed historically significant or potentially threatened. Additional sampling will be done as needed during 2013 if water quality conditions change and problems are noted, and to help locate occasional sources of contamination. Samples will also be collected to support any potential enforcement actions required by other Division staff. Nutrient samples will be collected monthly from nine tributary stations with available flow data and weekly UV-254 will continue to be collected from the Stillwater and Quinapoxet Rivers.

The routine sampling program will again separate out the effects of storm events on tributary water quality from standard dry weather water quality data using detailed precipitation data from several stations in or near the watershed. Sampling at four locations to collect specific information on stormwater quality will be done approximately monthly as weather permits. Three of the locations (Gates, Stillwater, Quinapoxet) will remain unchanged, but the fourth (Waushacum Brook) will be new to the stormwater sampling program.

Understanding watershed hydrology is a necessary part of any water quality monitoring program. A continuation of the expanded hydrology monitoring program is planned for 2013. Precipitation data from NOAA weather stations in Worcester and Fitchburg, from the USGS stations on the Stillwater River in Sterling and the Quinapoxet River in Holden, and from a DCR rain gage in West Boylston will be collected daily. Snow pack measurements and calculation of snow-water equivalent amounts will be done regularly during the winter months throughout the watershed.
Depth will be recorded at six stations and flow calculated using rating curves developed by DCR Environmental Quality staff. Daily flow in Gates Brook and the Stillwater and Quinapoxet Rivers will be obtained from continuous recording devices installed by the USGS.

Sampling at all active logging operations will continue with turbidity samples collected above and below each proposed stream crossing during dry and wet weather prior to the start of any activity to establish baseline conditions, during the installation of all temporary bridges or pole crossings, regularly throughout active logging operations, and after all activity has ceased. Sampling will also occur where timber harvesting is taking place within fifty feet of a stream or steep slopes are present.

Monitoring of potential long term water quality impacts from forest management activities will begin during spring 2013. This study will help assess impacts of active forest management and test the theory that DWSP forestry management methods do not result in long term measurable impacts on stream water quality due to alterations to forest structure and composition. Water quality and water quantity data will be collected and used to estimate nutrient loading. These loading estimates from the active forestry site will be compared to loading estimates from the control subbasin and from other subbasins across the Wachusett watershed to determine if Conservation Management Practices and other DWSP forestry management methods prevent measurable impacts upon stream water quality from logging operations.

The monitoring effort will utilize paired subbasin sampling at and near a single forestry site in the Wachusett watershed. DWSP Foresters and Environmental Quality staff will review possible locations and chose a forested subbasin with no other land use (if possible) where significant logging is proposed. A second subbasin (preferably nearby) with similar topography, land use, and water resources where logging is not proposed will be selected as the control. Downstream sampling locations in both subbasins will be selected that have appropriate characteristics to allow for construction of weirs or the use of the natural channel with a staff gage to establish a rating curve.

Sampling will include monthly dry weather grab sampling and quarterly storm event monitoring using automatic samplers. Parameters will likely include turbidity, total suspended solids, total organic carbon, ammonia, nitrate, nitrite, total phosphorus, and UV-254. To supplement water quality sampling data, DWSP aquatic biologists will utilize macroinvertebrate sampling to biomonitor streams in both the harvested and the control subbasin. Samples will be collected in the late spring (May-June) both before and following logging activities. Regular documentation of tributary flow and of precipitation amounts and intensity will also be done.

Temperature, dissolved oxygen, pH, and conductivity profiles will be measured weekly from the reservoir at Basin North/Station 3417 in conjunction with weekly or twice weekly plankton monitoring. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and total silica will be collected at Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin using standard methodologies used in the past.

Movement of water and contaminants through the reservoir remains the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Monthly, biweekly, or weekly bacterial transect sampling will be done during ice-free periods to help further understand the effect of avian populations and water movement on fecal coliform levels throughout the reservoir.

# APPENDIX

**Results of Quarterly Nutrient Sampling:**
**Total Phosphorus (mg/L; MDL = 0.005 mg/L)**

| | | Sampling Date | | | |
|---|---|---|---|---|---|
| ID | Sampling Station | 05/07/12 | 07/25/12 | 10/22/12 | 12/03/12 |
| MD25 | Basin North (E) | 0.012 | 0.008 | 0.008 | 0.010 |
| MD61 | Basin North (M) | 0.013 | 0.010 | 0.008 | 0.008 |
| MD62 | Basin North (H) | 0.013 | 0.009 | 0.010 | 0.008 |
| MD26 | Basin South (E) | 0.014 | 0.006 | 0.007 | 0.009 |
| MD63 | Basin South (M) | 0.013 | 0.007 | 0.009 | 0.009 |
| MD64 | Basin South (H) | 0.014 | 0.008 | 0.010 | 0.009 |
| MD27 | Thomas Basin (E) | 0.019 | 0.007 | 0.010 | 0.009 |
| MD65 | Thomas Basin (M) | 0.019 | 0.007 | 0.009 | 0.010 |
| MD66 | Thomas Basin (H) | 0.016 | 0.006 | 0.008 | 0.011 |

**Results of Quarterly Nutrient Sampling:**
**Ammonia (mg/L; MDL = 0.005 mg/L)**

| | | Sampling Date | | | |
|---|---|---|---|---|---|
| ID | Sampling Station | 05/07/12 | 07/25/12 | 10/22/12 | 12/03/12 |
| MD25 | Basin North (E) | *0.005* | *0.005* | 0.006 | *0.005* |
| MD61 | Basin North (M) | *0.005* | *0.005* | 0.006 | *0.005* |
| MD62 | Basin North (H) | 0.012 | 0.008 | 0.013 | *0.005* |
| MD26 | Basin South (E) | *0.005* | *0.005* | *0.005* | *0.005* |
| MD63 | Basin South (M) | 0.005 | 0.006 | *0.005* | *0.005* |
| MD64 | Basin South (H) | 0.010 | 0.007 | 0.017 | *0.005* |
| MD27 | Thomas Basin (E) | *0.005* | *0.005* | *0.005* | *0.005* |
| MD65 | Thomas Basin (M) | *0.005* | *0.005* | *0.005* | *0.005* |
| MD66 | Thomas Basin (H) | *0.005* | 0.011 | *0.005* | *0.005* |

Note: values show in italics are <MDL

**Results of Quarterly Nutrient Sampling:**
**UV254 (A/cm)**

| | | **Sampling Date** | | | |
|---|---|---|---|---|---|
| ID | Sampling Station | 05/07/12 | 07/25/12 | 10/22/12 | 12/03/12 |
| MD25 | Basin North (E) | 0.069 | 0.056 | 0.042 | 0.045 |
| MD61 | Basin North (M) | 0.071 | 0.047 | 0.041 | 0.044 |
| MD62 | Basin North (H) | 0.072 | 0.065 | 0.058 | 0.044 |
| MD26 | Basin South (E) | 0.069 | 0.057 | 0.041 | 0.047 |
| MD63 | Basin South (M) | 0.077 | 0.043 | 0.041 | 0.048 |
| MD64 | Basin South (H) | 0.071 | 0.065 | 0.056 | 0.048 |
| MD27 | Thomas Basin (E) | 0.110 | 0.060 | 0.042 | 0.033 |
| MD65 | Thomas Basin (M) | 0.099 | 0.039 | 0.043 | 0.035 |
| MD66 | Thomas Basin (H) | 0.077 | 0.035 | 0.044 | 0.039 |

**Results of Quarterly Nutrient Sampling:**
**Nitrate (mg/L; MDL = 0.005 mg/L)**

| | | **Sampling Date** | | | |
|---|---|---|---|---|---|
| ID | Sampling Station | 05/07/12 | 07/25/12 | 10/22/12 | 12/03/12 |
| MD25 | Basin North (E) | 0.077 | *0.005* | 0.020 | 0.051 |
| MD61 | Basin North (M) | 0.084 | 0.012 | 0.019 | 0.052 |
| MD62 | Basin North (H) | 0.101 | 0.135 | 0.132 | 0.050 |
| MD26 | Basin South (E) | 0.074 | *0.005* | 0.021 | 0.049 |
| MD63 | Basin South (M) | 0.077 | 0.018 | 0.021 | 0.044 |
| MD64 | Basin South (H) | 0.089 | 0.127 | 0.112 | 0.049 |
| MD27 | Thomas Basin (E) | 0.048 | *0.005* | 0.020 | 0.023 |
| MD65 | Thomas Basin (M) | 0.046 | 0.008 | 0.020 | 0.028 |
| MD66 | Thomas Basin (H) | 0.043 | 0.011 | 0.021 | 0.034 |

Note: values show in italics are <MDL

**Results of Quarterly Nutrient Sampling:**
**Silica (mg/L)**

| | | Sampling Date | | | |
|---|---|---|---|---|---|
| ID | Sampling Station | 05/07/12 | 07/25/12 | 10/22/12 | 12/03/12 |
| MD25 | Basin North (E) | 3.12 | 1.55 | 1.80 | 2.43 |
| MD61 | Basin North (M) | 3.34 | 1.92 | 1.92 | 2.50 |
| MD62 | Basin North (H) | 3.47 | 4.00 | 3.68 | 2.37 |
| MD26 | Basin South (E) | 3.25 | 1.47 | 1.88 | 2.42 |
| MD63 | Basin South (M) | 3.14 | 2.04 | 1.84 | 2.47 |
| MD64 | Basin South (H) | 3.40 | 3.94 | 3.52 | 2.74 |
| MD27 | Thomas Basin (E) | 3.14 | 1.60 | 2.07 | 2.03 |
| MD65 | Thomas Basin (M) | 2.97 | 1.77 | 2.11 | 2.10 |
| MD66 | Thomas Basin (H) | 2.74 | 1.85 | 2.21 | 2.28 |

**Results of Quarterly Nutrient Sampling:**
**Alkalinity (mg/L)**

| | | Sampling Date | | | |
|---|---|---|---|---|---|
| ID | Sampling Station | 05/07/12 | 07/25/12 | 10/22/12 | 12/03/12 |
| MD25 | Basin North (E) | 6.42 | 7.48 | 6.12 | 6.46 |
| MD61 | Basin North (M) | 5.82 | 5.16 | 6.14 | 6.38 |
| MD62 | Basin North (H) | 5.92 | 7.06 | 6.64 | 6.46 |
| MD26 | Basin South (E) | 6.34 | 7.30 | 6.00 | 6.30 |
| MD63 | Basin South (M) | 6.32 | 5.10 | 6.00 | 6.32 |
| MD64 | Basin South (H) | 6.24 | 7.06 | 6.52 | 6.38 |
| MD27 | Thomas Basin (E) | 6.92 | 8.14 | 5.44 | 4.20 |
| MD65 | Thomas Basin (M) | 6.30 | 5.08 | 5.40 | 4.34 |
| MD66 | Thomas Basin (H) | 5.24 | 4.32 | 5.36 | 4.62 |

**Results of Quarterly Nutrient Sampling:**
**Total Kjeldahl Nitrogen (mg/L; MDL = 0.05 mg/L)**

| | | Sampling Date | | | |
|---|---|---|---|---|---|
| ID | Sampling Station | 05/07/12 | 07/25/12 | 10/22/12 | 12/03/12 |
| MD25 | Basin North (E) | 0.154 | 0.224 | 0.150 | 0.176 |
| MD61 | Basin North (M) | 0.127 | 0.214 | 0.224 | 0.339 |
| MD62 | Basin North (H) | 0.145 | 0.178 | 0.174 | 0.164 |
| MD26 | Basin South (E) | 0.161 | 0.208 | 0.152 | 0.149 |
| MD63 | Basin South (M) | 0.134 | 0.169 | 0.166 | 0.215 |
| MD64 | Basin South (H) | 0.144 | 0.181 | 0.157 | 0.170 |
| MD27 | Thomas Basin (E) | 0.207 | 0.249 | 0.189 | 0.226 |
| MD65 | Thomas Basin (M) | 0.180 | 0.107 | 0.189 | 0.192 |
| MD66 | Thomas Basin (H) | 0.177 | 0.100 | 0.142 | 0.222 |