# 2006 Lake Shirley
# Aquatic Vegetation and Water Quality Assessment

NOVEMBER 2006



**Prepared For:**

**Lake Shirley Improvement Corporation**

**Submitted By:**

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engineers | scientists | innovators

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## SECTION 1: INTRODUCTION

Geosyntec Consultants (Geosyntec) was contracted by the Lake Shirley Improvement Corporation (LSIC) to conduct a comprehensive macrophyte (vascular aquatic plant) survey and water quality monitoring of Lake Shirley in Lunenburg, MA, during the summer of 2006. The purpose of the survey was to:

1. provide an update on the composition and distribution Lake Shirley's macrophyte community, allowing the LSIC and the Lunenburg Conservation Commission to: (1) track changes in the Lake's plant community in response to drawdown and other lake management techniques; and (2) continue to track changes in the distribution and dominance of nuisance non-native plant species within the lake; and

2. provide an updated assessment of the baseline in-lake and tributary water quality for Lake Shirley.

Lake Shirley (Lunenburg, MA)

# SECTION 2: AQUATIC VEGETATION SURVEY

## 2.1 Methodology

On August 18, 2006, Geosyntec conducted a macrophyte survey of Lake Shirley. Aquatic vegetation was sampled from a boat. Plant species were identified at 66 sampling locations (see Figure 1), based (with minor modifications) on the sampling stations established by Geosyntec's 2002-2005 vegetation surveys. Plants were identified by visual inspection and by using an aquatic vegetation grappling hook to sample submerged vegetation. At each station, the dominant plant(s) were recorded, as well as estimates of plant growth density and biomass. As categorized in Table 1, plant density is an estimate of aerial coverage when looking down to the lake bottom from the water surface. Biomass estimates the amount of plant matter within the water column. For example, a sampling station with dense growth of low-growing plants may have a high density estimate but a relatively low plant biomass estimate. A station with dense growth of a long, ropey plant like Eurasian milfoil, with stems reaching the water surface, would have both high plant density and high biomass estimates.

In addition to recording information from the 66 sampling stations, a running documentation of plant growth densities was estimated throughout the lakewide survey. Survey locations were mapped with a Global Positioning System (GPS) unit and survey information was recorded on a hand-held PDA computer linked to the GPS. Prior to conducting the survey, the GPS/PDA unit was loaded with orthophotography and bathymetric contour information for Lake Shirley, allowing Geosyntec staff to confirm survey locations at all times to ensure accurate mapping. Based on the above information, an aquatic vegetation map of Lake Shirley (Figure 1) was developed using ESRI ArcView GIS software.

## 2.2 Vegetation Survey Results

The August 2006 vegetation survey noted some significant changes when compared to the conditions observed by Geosyntec in July 2005. In general, the growth of macrophytes (rooted aquatic plants) appeared to be diminished in many areas as a result of the severe algal bloom that affected Lake Shirley for much of the summer of 2006. Lakewide algae blooms can significantly reduce water clarity and the depth to which sunlight can penetrate the lake water and support plant growth. The health, vigor and growth densities of many macrophyte species will often decline to this "light limitation", as observed in Lake Shirley in 2006. In addition to the impacts of the 2006 algal bloom, it is also important to consider the cumulative effects on plant abundance due to the winter lake level drawdown program that has been conducted since 2003.

A listing of plant species present at each of sixty-six sampling stations is provided in Table 1, including information on vegetation density, plant biomass, and dominant plants at each station. A summary of the major findings of the 2006 vegetation survey is as follows:

**Invasive/Non-native Species:**

- As in 2005, invasive **Eurasian milfoil** (*Myriophyllum spicatum*) continues to be the most well-distributed and dominant plant in Lake Shirley. Geosyntec observed Eurasian milfoil at 79% of the sampling stations, and it was a dominant plant at 30% of the stations. In 2005, Eurasian milfoil was found at 92% of all stations and was dominant at 25% of all stations. Although this plant was well distributed around the lake, its overall abundance and growth density in many areas appeared diminished when compared to 2005. Eighteen out of twenty sampling stations (90%) where Eurasian milfoil was a dominant plant were determined to have either sparse (0-25% density) or moderate (26-50%) growth densities.

Eurasian milfoil

- Invasive **Fanwort** (*Cabomba caroliniana*) has declined significantly since 2005, when it was present at 62% of all sampling stations and a dominant plant at six stations. In 2006, Fanwort was found in very small quantities at only seven stations (11%). Fanwort, previously a dominant plant in Lake Shirley's southern basin, was not a dominant plant at any of the sampling stations in 2006.

Fanwort

- Invasive **Variable milfoil** (*Myriophyllum heterophyllum*) has also declined significantly since 2005, similar to the decline in fanwort described above. In 2006, this plant was observed at only five sampling stations, and was not a dominant plant at any of the stations. This plant was found at 23% (14) of the sampling stations in 2005 and was one of the most well-distributed and dominant plants in Lake Shirley as recently as 2003.

Variable Milfoil

- Non-native **European naiad** *(Najas minor) also* experienced a decline in both distribution (10 stations, 15%) and dominance (1 station in the southern basin). In 2005, this plant was found at twenty stations and was dominant at six stations. European naiad was first documented in Lake Shirley in 2003.

European Naiad



Geosyntec consultants

**Native Species:**

- **Coontail** (*Ceratophyllum demersum*) was second only Eurasian milfoil in its abundance and distribution throughout Lake Shirley. Coontail increased in distribution from 30 stations in 2005 to 47 stations (71%). It was a dominant plant at 16 stations (24%), an increase from 12 stations the previous year.

Coontail

- **Robbin's pondweed** (*Potamogeton robbinsii)* also increased in distribution (34 stations, 52%) and dominance (19 stations, 29%). Along with Eurasian milfoil and Coontail, Robbin's Pondweed was one the three plant species that dominated the majority of Lake Shirley in 2006. This plant was found at 24 stations and dominant at seven stations in 2005.

Robbin's pondweed

Other native plant species worthy of note included:

- **Wild Celery** (*Valisneria americana*) continued to be well-distributed around the lake. Present at 34 stations (52%) and dominant at two stations, its growth was slightly less abundant than noted in 2005.

- **Bushy Pondweed** (*Najas flexilis*) has been reported to be one of the most abundant native species in Lake Shirley from 2002-2005. However, this plant was observed (and dominant) at only one sampling station (within Stump Cove) in 2006. This plant was found at 26 stations (39%) in 2005 and was dominant at 12 stations (18%).

Wild celery

- **Bladderwort** (*Utricularia spp.*) was well distributed throughout Lake Shirley from 2002-2005 (34 stations, 52% in 2005). Bladderwort species exhibited a significant decline in 2006, and were observed at only two sampling stations in the south basin.

**General Notes:**

- Overall, **27 species** (see Table 1) of aquatic plants were documented in Lake Shirley during the 2006 survey, compared to 25 species in 2005, 20 species in 2004, 21 species in 2003 and 27 species in 2002.

- As shown in the table on the following page, a majority of the Lake Shirley sampling stations were characterized by either sparse (0-25% density) or moderate (25-50% density) plant growth, with 88% of sampling stations reporting in these two categories. However, the number of stations with sparse growth (30 stations, 45%) nearly doubled since 2005 (18 stations, 27%). A corresponding decrease in stations with moderate density (28 stations, 42%) was also reported since 2005 (40 stations, 60%).

- In 2006, seven stations (11%) were in either the dense (50-75% density) or very dense (75-100% density) categories. This finding is similar to 2005, when eight stations (13%) were in either the dense or very dense categories.

- In 2006, six plant species where determined to be a dominant plant at one or more of the sampling stations. Of these six species, only three (Eurasian milfoil, Coontail and Robbin's

Pondweed) were well distributed and dominated most of the lake. In 2005, fourteen species were dominant at one or more stations.

Plant growth densities at the 66 sampling stations were as follows:

| **Density Rating** | **# of stations** | | | | | **% of stations** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2002 (64 stations) | 2003 (65 stations) | 2004 (66 stations) | 2005 (66 stations) | **2006** (66 stations) | 2002 | 2003 | 2004 | 2005 | 2006 |
| **Sparse: 0-25%** | 9 | 7 | 11 | 18 | **30** | 14% | 11% | 17% | **27%** | **45%** |
| **Moderate: 26-50%** | 23 | 47 | 38 | 40 | **28** | 36% | 72% | 58% | **61%** | **42%** |
| **Dense: 51-75%** | 23 | 9 | 11 | 5 | **6** | 36% | 14% | 17% | **8%** | **9%** |
| **Very Dense: 76-100%** | 9 | 2 | 6 | 3 | **1** | 14% | 3% | 9% | **5%** | **2%** |

Plant biomass at the 66 sampling stations was as follows:

| **Biomass Rating** | **# of stations** | | | | **% of stations** | | | |
|---|---|---|---|---|---|---|---|---|
| | 2003 (65 stations) | 2004 (66 stations) | **2005** (66 stations) | **2006** (66 stations | 2003 | 2004 | 2005 | **2006** |
| **1:** Scattered plant growth; or primarily at lake bottom | 45 | 53 | **51** | **39** | 69% | 80% | **77%** | **59%** |
| **2:** Less abundant growth, or in less than half of the water column | 19 | 8 | **14** | **22** | 29% | 12% | **21%** | **33%** |
| **3:** Substantial growth through majority of water column | 1 | 4 | **1** | **4** | 2% | 6% | **2%** | **6%** |
| **4:** Abundant growth throughout water column to surface | 0 | 1 | **0** | **1** | 0% | 2% | **0%** | **2%** |

An overview map of the vegetation survey results and a tally sheet, documenting the plant species and dominant plants at each of the sampling stations, are provided on the following pages.

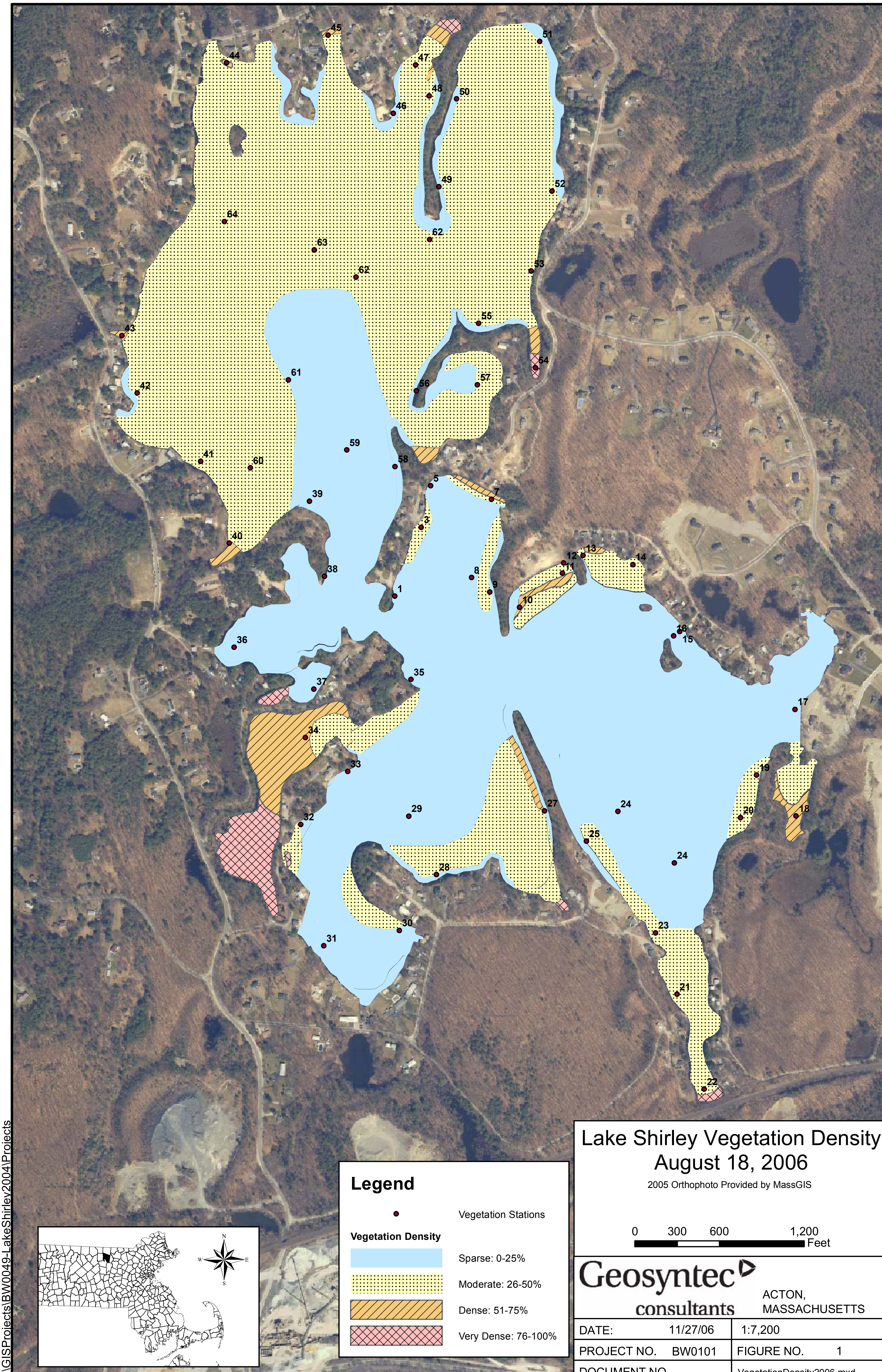

Lake Shirley Vegetation Density
August 18, 2006
2005 Orthophoto Provided by MassGIS
0
300
600
1,200
Feet
Legend
Vegetation Stations
Vegetation Density
Sparse: 0-25%
Moderate: 26-50%
Dense: 51-75%
Very Dense: 76-100%
Geosyntec
consultants
ACTON, MASSACHUSETTS
DATE: 11/27/06
1:7,200
PROJECT NO. BW0101
FIGURE NO. 1
DOCUMENT NO.
VegetationDensity2006.mxd
Q:\GISProjects\BW0049-LakeShirley2004\Projects

**Table 1: Aquatic Vegetation Survey Tally Sheet**

**Location:** Lake Shirley (Lunenburg, MA)

**Date:** 8/18/06 **Surveyed by:** Bob Hartzel, Dan Bourdeau

• species present at monitoring station

**•** species dominant at monitoring station

## Monitoring Locations

| Plant Species | # stations present | # stations dominant | % stations present | % stations dominant | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 11 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 24A | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Eurasian milfoil** *(Myriophyllum spicatum)** | 52 | 20 | 79% | 30% | | | **•** | **•** | • | • | | • | • | • | **•** | **•** | **•** | **•** | • | **•** | • | • | • | • | | | • | • | **•** | **•** | • | • | | • | **•** | • | • | **•** |
| **Variable milfoil** *(Myriophyllum heterophyllum)** | 5 | 0 | 8% | 0% | • | • | | | | | | | | | | | | • | | | | | | | | | | | | • | | | | | | | | |
| **Fanwort** *(Cabomba caroliniana)** | 7 | 0 | 11% | 0% | | | | | | | | | | | • | | | | | | | | • | • | | • | | | | | | | | | | | | |
| **European Naiad** *(Najas minor)* | 10 | 1 | 15% | 2% | | | | | | | | | | | • | | | • | | • | **•** | | | | | | | | | | | | • | • | | • | | • |
| **Musk grass** *(Chara vulgaris)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Coontail** *(Ceratophyllum demersum)* | 47 | 16 | 71% | 24% | **•** | **•** | | | • | • | • | • | **•** | **•** | | | • | • | | **•** | | | **•** | • | • | • | • | • | | • | • | • | • | • | | | **•** | |
| **Grassy pondweed** *(Potamogeton gramineus)* | 13 | 0 | 20% | 0% | | | | | | | | | | | | | | | | • | • | | • | | | | | | | | | | • | | • | | | • |
| **Bushy pondweed** *(Najas flexilis)* | 1 | 1 | 2% | 2% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Common Bladderwort** *(Utricularia vulgaris)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | • | | | | | | | | | | | | | | | | |
| **Little Floating Bladderwort** *(Utricularia radiata)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Thin-leaf pondweed** *(Potamogeton pusillis)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | • | | | | | | | | | | | | | | |
| **Sago pondweed** *(Potamogeton pectinatus)* | 0 | 0 | 0% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Robbin's pondweed** *(Potamogeton robbinsii)* | 34 | 19 | 52% | 29% | | | **•** | **•** | • | • | | | | • | | | | | | • | | **•** | | | • | **•** | | | | | | | | | | | | |
| **Stonewort** *(Nitella sp.)* | 0 | 0 | 0% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Wild Celery** *(Valisneria americana)* | 34 | 2 | 52% | 3% | | | | | | | • | | • | | | • | • | • | • | | | | | • | • | • | | | | | | | | | • | • | • | • |
| **Yellow Water Lily** *(Nuphar variegatum)* | 2 | 1 | 3% | 2% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | • | |
| **White water lily** *(Nymphaea odorata)* | 3 | 0 | 5% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | • | • | | |
| **Ribbonleaf pondweed** *(Potamogeton epihydrus)* | 0 | 0 | 0% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Big-leaf pondweed** *(Potamogeton amplifolius)* | 2 | 0 | 3% | 0% | | | | | | | | | | | | | | | | | | • | | | | | | | | | | | | | | | | |
| **Small waterwort** *(Elatine minima)* | 0 | 0 | 0% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Bur Reed** *(Sparganium sp.)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Richardson Pondweed** *(Potamogeton richardsonii)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Hedge Hessop** *(Gratiola)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Duckweed** *(Lemna minor)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Big Duckweed** *(Spirodela polyrhiza)* | 2 | 0 | 3% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Water Meal** *(Wolffia sp)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Water Marigold** *(Megalodonta beckii)* | 1 | 0 | 2% | 0% | | | | | | | | | | | | | | | | | | • | | | | | | | | | | | | | | | | |
| **Plant Density Rating** | | | | | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Plant Biomass Rating** | | | | | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| Plant Species | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 62A | 63 | 64 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Eurasian milfoil** *(Myriophyllum spicatum)** | • | • | | • | **•** | | **•** | **•** | • | • | **•** | **•** | • | • | • | **•** | | **•** | • | • | **•** | • | • | | • | | **•** | • | | | | • |
| **Variable milfoil** *(Myriophyllum heterophyllum)** | | | | | | | | | | | | | | | | | • | | | | | | | | | | | | | | | |
| **Fanwort** *(Cabomba caroliniana)** | | | | • | | | | | | | • | • | | | | | | | | | | | | | | | | | | | | |
| **European Naiad** *(Najas minor)* | | | | | | | • | | | | | | • | | | | | | | | | | | | | | | | | | | |
| **Musk grass** *(Chara vulgaris)* | • | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Coontail** *(Ceratophyllum demersum)* | | **•** | • | | • | | • | • | • | • | • | | **•** | • | **•** | • | | | • | • | • | • | **•** | | **•** | **•** | • | | **•** | **•** | • | **•** |
| **Grassy pondweed** *(Potamogeton gramineus)* | • | | | | | | • | • | • | • | • | | • | | | | | | | | | | | | | | | | | | | |
| **Bushy pondweed** *(Najas flexilis)* | **•** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Common Bladderwort** *(Utricularia vulgaris)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Little Floating Bladderwort** *(Utricularia radiata)* | • | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Thin-leaf pondweed** *(Potamogeton pusillis)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Sago pondweed** *(Potamogeton pectinatus)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Robbin's pondweed** *(Potamogeton robbinsii)* | | | • | • | | | **•** | **•** | **•** | **•** | **•** | **•** | **•** | • | **•** | • | **•** | • | **•** | **•** | • | **•** | • | • | • | | | | • | **•** | **•** | **•** |
| **Stonewort** *(Nitella sp.)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Wild Celery** *(Valisneria americana)* | • | • | | **•** | • | | • | • | • | • | • | • | • | • | • | • | • | **•** | • | • | • | | | | • | | • | | | | | |
| **Yellow Water Lily** *(Nuphar variegatum)* | **•** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **White water lily** *(Nymphaea odorata)* | | | | | | | | | | • | | | | | | | | | | | | | | | | | | | | | | |
| **Ribbonleaf pondweed** *(Potamogeton epihydrus)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Big-leaf pondweed** *(Potamogeton amplifolius)* | | | | | | | | • | | | | | | | | | | | | | | | | | | | | | | | | |
| **Small waterwort** *(Elatine minima)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Bur Reed** *(Sparganium sp.)* | • | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Richardson Pondweed** *(Potamogeton richardsonii)* | | | | | | | • | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Hedge Hessop** *(Gratiola)* | | | | | | | • | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Duckweed** *(Lemna minor)* | | | | | | | | | | • | | | | | | | | | | | | | | | | | | | | | | |
| **Big Duckweed** *(Spirodela polyrhiza)* | | | | | | | | | | • | | | | | | | | | | | • | | | | | | | | | | | |
| **Water Meal** *(Wolffia sp)* | | | | | | | | | | | | | | | | | | | | | • | | | | | | | | | | | |
| **Water Marigold** *(Megalodonta beckii)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Plant Density Rating** | 3 | 1 | 1 | 1 | 1 | 0 | 1 | 2 | 1 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 2 | 1 | 2 |
| **Plant Biomass Rating** | 3 | 1 | 1 | 1 | 1 | 0 | 2 | 2 | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 4 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |

*** Listed as a non-native, invasive plant by the Massachusetts Biodiversity Initiative (MA-DFW)**

| Key to Density and Biomass Ratings | | |
|---|---|---|
| Rating | Density | Biomass |
| **1** | Sparse: 0-25% density | Scattered plant growth; or primarily at lake bottom |
| **2** | Moderate: 26-50% density | Less abundant growth, or in less than half of the water column |
| **3** | Dense: 51 75% density | Substantial growth through majority of water column |
| **4** | Very Dense: 76-100% density | Abundant growth throughout water column to surface |

## SECTION 3: WATER QUALITY ASSESSMENT

### 3.1 Methodology

On August 18, 2006, Geosyntec conducted water quality monitoring at Lake Shirley to provide updated baseline data on overall lake and tributary conditions. Water quality data was collected with a YSI multi-parameter sampler and grab samples were taken to Thorstensen Laboratory (Westford, MA) for nutrient analysis (total phosphorus and ammonia-nitrogen). Sampling was conducted at the "deep-hole" of the Lake's northern and southern major basins (see Figure 2). The Lake's two primary surface water tributaries (Catacoonamug Brook and Easter Brook) were also sampled at their confluence with Lake Shirley.

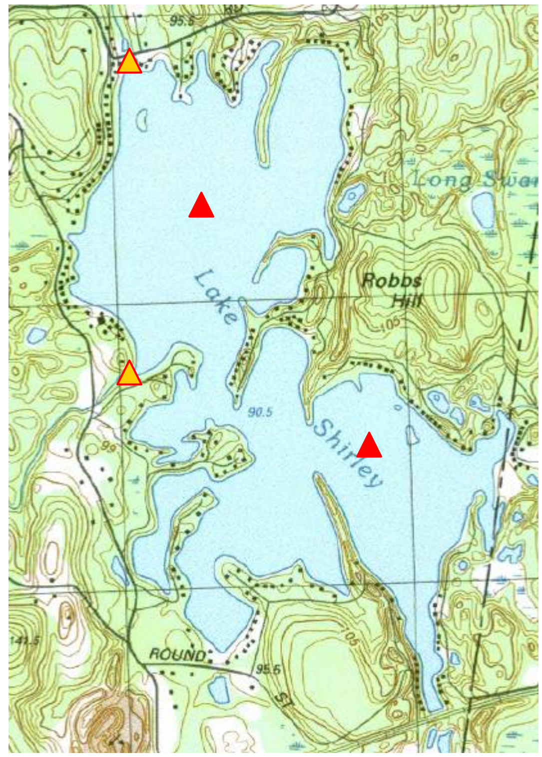



**Figure 2:** Sampling Stations Locations

*In-lake sampling stations*

*Tributary sampling stations*

The YSI unit was used to establish a water quality profile for the two deep-hole sampling locations, with measurements recorded for each parameter at two-foot intervals. Samples for nutrient analysis were taken with a Kemmerer sampler at the surface, bottom and thermocline at the two deep-hole stations. The following seven parameters were measured:

- pH;
- temperature;
- dissolved oxygen;
- specific conductance;
- turbidity;
- total phosphorus (lab analysis);
- ammonia nitrogen (lab analysis); and
- water clarity (Secchi disk).

The results of the monitoring program are presented in Table 2 on the following page and discussed in Section 3.2

**Table 2: Lake Shirley Water Quality Sampling Results, 8/18/06**

| Station | Depth (feet) | Temp. (C) | Dissolved Oxygen (mg/l) | pH | Specific Conductance (µmhos/cm) | Total Phosphorus (mg/l) | Ammonia Nitrogen (mg/l) |
|---|---|---|---|---|---|---|---|
| Easter Brook | surface | 19.7 | 7.5 | 7.0 | 217 | .04 | <.03 |
| Catacoonamug Brook | surface | 21.9 | 7.6 | 6.9 | 180 | .04 | <.03 |
| North Basin Deep Hole | surface | 26.0 | 12.3 | 9.2 | 208 | .05 | <.03 |
| | 3.0 | 24.3 | 10.7 | 8.5 | 197 | | |
| | 5.0 | 23.2 | 6.7 | 6.9 | 192 | <.01 | <.03 |
| | 7.0 | 22.4 | 0.9 | 6.7 | 189 | | |
| | 9.0 | 20.6 | 0.9 | 6.7 | 195 | .04 | 1.0 |
| **North Basin Secchi Disk (clarity):** 2.0 feet | | | | | | | |
| South Basin Deep Hole | surface | 27.4 | 11.7 | 9.1 | 217 | <.01 | <.03 |
| | 2.0 | 25.6 | 11.4 | 9.0 | 209 | | |
| | 4.0 | 24.3 | 9.5 | 7.8 | 202 | | |
| | 6.0 | 23.6 | 4.8 | 7.0 | 199 | | |
| | 8.0 | 22.5 | 1.0 | 6.9 | 204 | | |
| | 10.0 | 19.7 | 1.2 | 6.8 | 233 | | |
| | 12.0 | 17.7 | 0.8 | 6.8 | 216 | | |
| | 14.0 | 15.0 | 0.8 | 6.9 | 177 | | |
| | 16.0 | 13.7 | 0.7 | 7.0 | 169 | .05 | .21 |
| | 18.0 | 12.2 | 0.7 | 6.9 | 164 | | |
| | 20.0 | 11.2 | 0.7 | 7.0 | 157 | | |
| | 22.0 | 10.0 | 0.7 | 7.0 | 160 | | |
| | 24.0 | 9.4 | 0.7 | 7.0 | 166 | | |
| | 26.0 | 8.6 | 0.7 | 7.0 | 172 | | |
| | 28.0 | 8.2 | 0.8 | 7.0 | 175 | | |
| | 30.0 | 7.9 | 0.9 | 7.0 | 177 | .06 | 1.2 |
| **South Basin Secchi Disk (clarity):** 2.1 feet | | | | | | | |

### 3.2 Analysis of Water Quality Monitoring Results

Given the limited nature of the sampling program conducted within the project scope of work, there are limits to the conclusions that can be derived from the results. However, this data does provide a "snapshot" of mid-summer conditions in 2006 and serves as a useful point of comparison for assessing long-term water quality trends. A summary analysis of the results of the August 18, 2006, water quality monitoring follows below.

- **Total phosphorus** (TP) is a measure of all organic and inorganic phosphorus forms present in the water. In freshwater lakes, phosphorus is usually the most important nutrient determining the growth of algae and aquatic plants. Because phosphorus is typically relatively less abundant than nitrogen, it is usually the "limiting nutrient" for biological productivity. In-lake TP concentrations greater than 0.025 mg/l are considered an indicator of conditions that can typically support abundant growth of rooted plants and/or algae.

  On the sampling date, TP measurements from the Lake Shirley tributaries measured 0.04 mg/l at both the Catacoonamug Brook inlet and the Easter Brook inlet. Although these measurements were above the eutrophication benchmark of 0.025 mg/l, they were significantly lower than the TP measurements from these sampling sites in recent years. TP measurements from Catacoonamug Brook during July sampling in 2004 and 2005 were 0.15 mg/l and 0.25 mg/l, respectively. TP measurements from Easter Brook during July sampling in 2004 and 2005 were 0.11 and 0.12, respectively.

  At the north basin deep hole, similar TP measurements were taken from the surface (0.05 mg/l) and at the bottom depth of nine feet (0.04 mg/l). At a "middle" depth of five feet, a TP measurement below the laboratory detection limit of 0.01 mg/l was reported. Overall, the TP measurements indicate conditions capable of supporting abundant aquatic plant and algae growth, although the reported surface and lake bottom TP concentrations are roughly half of what was reported at these depths in July 2005 (0.11 mg/l and 0.09 mg/l, respectively).

  The TP concentration at the surface of the south basin deep hole was below the laboratory detection limit of 0.01 mg/l. Levels well above the eutrophication benchmark described above were reported for the middle of the water column (0.05 mg/l at16 feet) and at the lake bottom (0.06 mg/l at 30 feet). Nutrient concentrations tend to be higher at the bottom of the water column, due to chemical reactions occurring at the lake water and bottom sediments meet.

- **Ammonia-Nitrogen** (AN) is a form of nitrogen that is readily assimilated by macrophytes, algae and bacteria. After phosphorus, nitrogen is usually the second most important nutrient for algae and plant growth in lakes. Elevated concentrations in surface waters can be an indicator of pollution from wastewater sources. At high in-lake phosphorus concentrations, nitrogen may become the limiting nutrient to plant growth. In addition, nuisance blue-green algal blooms are associated with lakes that have low nitrogen to phosphorus ratios.

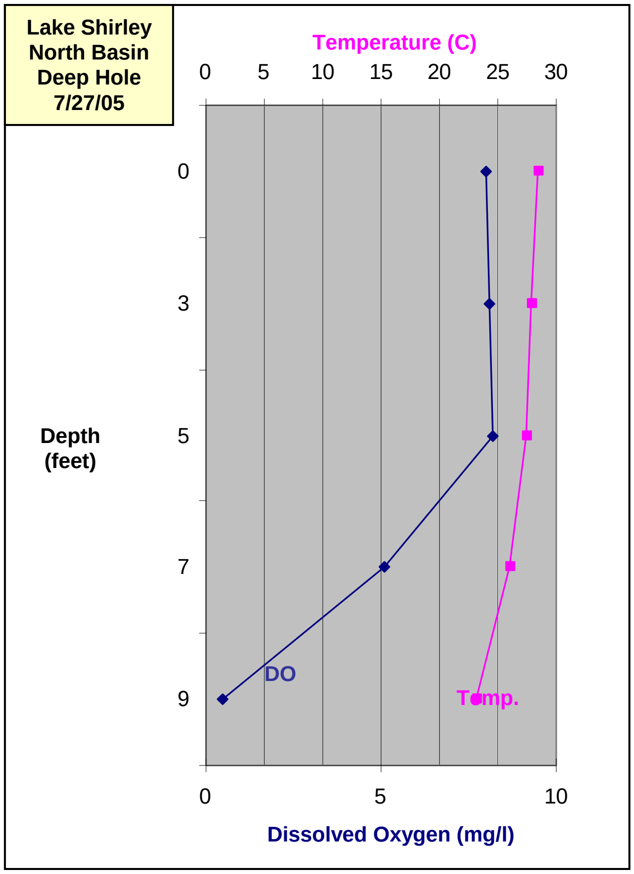
  Similar to the July 2003 -2005 sampling results, the AN levels measured on August 18, 2006 were low at the tributary and lake surface sampling locations (below the laboratory detection limit of 0.03 mg/l). Elevated AN levels were measures at the north basin and south basin deep hole sampling locations, indicating nutrient release due to summer oxygen depletion at the lake bottom (1.0 mg/l and 1.2 mg/l, respectively).

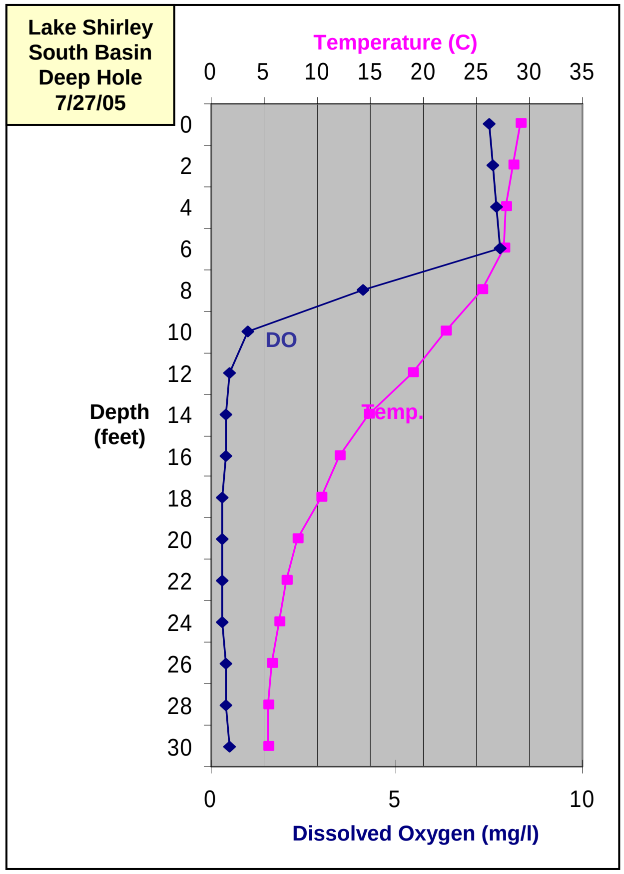
- **pH** is a measure of acidity based on the presence of hydrogen ions. A pH of 7.0 is neutral. Values below 7.0 indicate acidic waters and values above 7.0 indicate basic waters. The pH of a lake affects nutrient and sediment interactions and the composition of the fish population. Lake Shirley's pH ranged from 9.2 to 6.7 in the lake's north basin and from 9.1 to 6.8 in the lake's south basin. The lower values were found at depth and higher values found near the surface. Lower pH values found at depth are due to biological decomposition that leads to anoxic (oxygen-depleted) conditions and other chemical reactions that reduce pH. Most fish cannot tolerate a pH below four or above 11, and their growth and health is affected by long-term exposure to a pH less than 6.0 and over 9.5. The pH measurements were generally within the normal range for Massachusetts surface waters and consistent with past monitoring results for Lake Shirley, with the exception of several measurements near the lake surface that exceeded a pH of 8.5 .

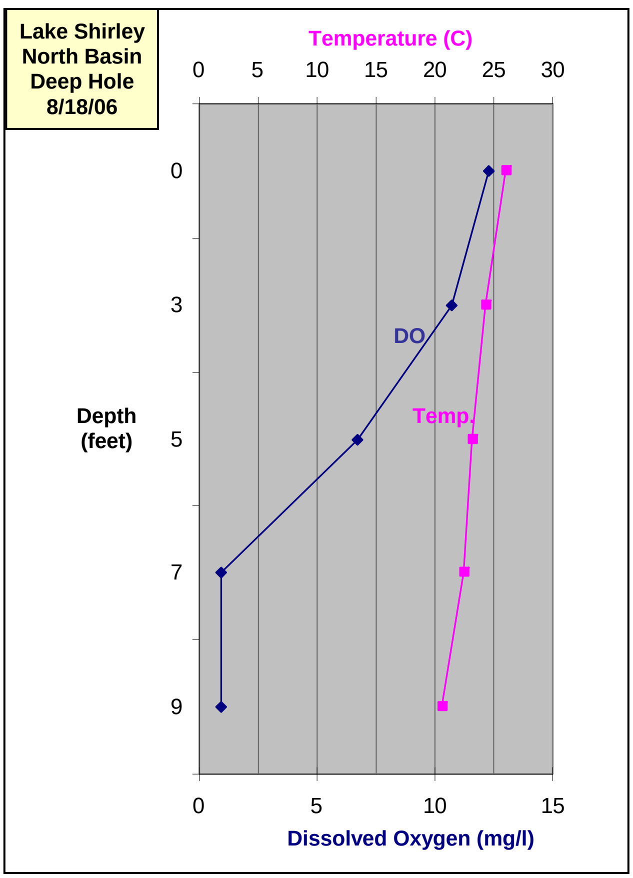
- **Temperature/Dissolved Oxygen** profiles from the deep hole locations are shown in the graphs on the following page. For comparison, the same graphs from July 2005 are also shown. The Massachusetts surface water quality standard for dissolved oxygen (DO) in warm water lakes is 5.0 mg/l, although concentrations in the hypolimnion (deep waters) of lakes are frequently below this level during the summer. DO levels have an important impact on fish and other aquatic biota within lakes. Low dissolved oxygen concentrations can impair the health and spawning of fish and other organisms. Anoxic (oxygen depleted) conditions in the hypolimnion are also associated with the release of phosphorus from lake sediments back into the water column, fueling summer algae and plant growth.

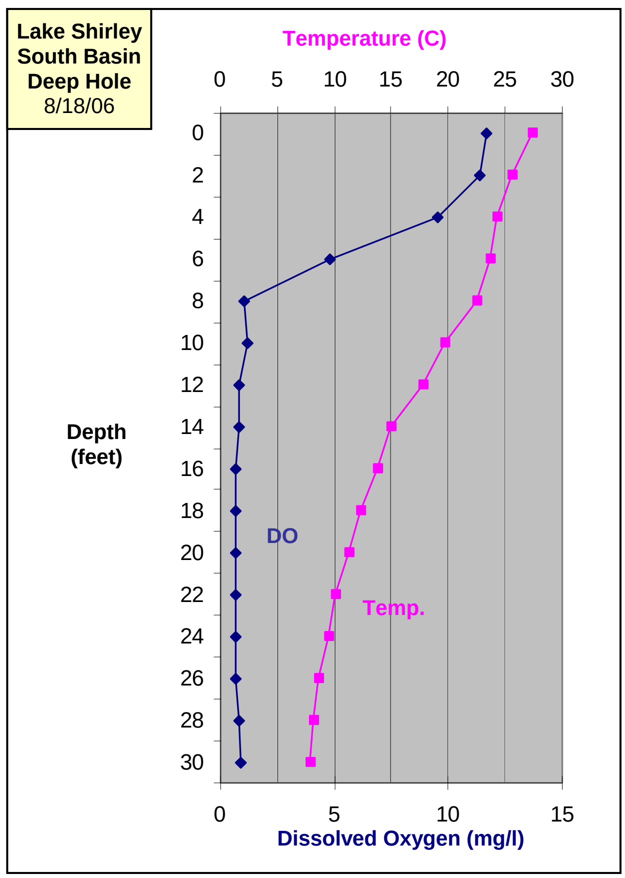
  Because of its shallow depth, the lake's north basin tends to be well mixed by wind action. As a result, Geosyntec's past monitoring at the north basin has shown relatively consistent DO concentrations throughout the water column. The August 2006 monitoring results yielded a break from this pattern, with relatively anoxic conditions (0.9 mg/l) recorded near the lake bottom and unusually high DO levels present near the water surface.

  The south basin deep hole is the deepest part of the lake, and is the only portion of the lake that typically exhibits significant summer thermal stratification. Similar to the 2005 monitoring results, DO levels on the sampling date became rapidly depleted at depths below six feet. All measurements from eight feet of depth to the bottom measurement at thirty-two feet were significantly below the warm water fishery standard of 5.0 mg/l, ranging in concentration from 0.7 mg/l to 1.2 mg/l. This profile of severe oxygen depletion at the south basin deep hole is generally consistent with the profiles reported in July of 1999, 2003, 2004 and 2005.


Lake Shirley
North Basin
Deep Hole
7/27/05
Temperature (C)
0 5 10 15 20 25 30
Depth
(feet)
0
3
5
7
9
DO
Temp.
0 5 10
Dissolved Oxygen (mg/l)


Lake Shirley
South Basin
Deep Hole
7/27/05
Temperature (C)
0 5 10 15 20 25 30 35
Depth
(feet)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
DO
Temp.
0 5 10
Dissolved Oxygen (mg/l)


Lake Shirley
North Basin
Deep Hole
8/18/06
Temperature (C)
0 5 10 15 20 25 30
Depth
(feet)
0
3
5
7
9
DO
Temp.
0 5 10 15
Dissolved Oxygen (mg/l)


Lake Shirley
South Basin
Deep Hole
8/18/06
Temperature (C)
0 5 10 15 20 25 30
Depth
(feet)
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DO
Temp.
0 5 10 15
Dissolved Oxygen (mg/l)

- **Specific conductance** measures the ability of water to conduct electricity by measuring the presence of ions in solution. Chloride is typically the predominant ion found in surface waters, including man-made sources of chloride ions such as wastewater and road salt. The primary natural sources of chloride ions in surface waters include the weathering of soils and rocks, and wet and dry precipitation. Regional variations in watershed geology can result in a wide range of "normal" conductance levels from lake to lake. However, abnormally high conductance levels can be an indicator of pollutants sources such as road salting, wastewater discharges, and runoff from developed areas.

  In-lake and tributary specific conductance levels measured at Lake Shirley on August 18, 2006 ranged from157 to 217 $\mu$mhos/cm. These results are within the normal range for Massachusetts surface waters, and fall within the approximate range of in-lake levels from 2002-2005.

- The **Secchi disk** is a weighted black and white disk that is lowered into the water by a calibrated chain until it is no longer visible. This method provides a measure of water clarity (light penetration) within the water column, which is primarily a function of algal productivity, water color, and turbidity caused by suspended particulate matter. Water clarity influences the growth of rooted aquatic plants by determining the depth to which sunlight can penetrate to the lake sediments. Secchi disk measurements below six feet generally indicate eutrophic conditions, and state regulations require that public swimming beaches have a minimum secchi disk clarity of four feet.

  

  On the sampling date, secchi disk clarity at Lake Shirley's south basin deep hole and north basin deep hole were 2.1 feet and 2.0 feet, respectively. These extremely low water clarity measurements are indicative of the highly turbid conditions caused by the algae bloom that affected Lake Shirley for most of the summer of 2006. For comparison, the July 2005 secchi disk clarity at the south basin deep hole was 11.5 feet, and clarity at the north basin deep hole exceeded the maximum depth of 9 feet.