
Technical Report

**Massachusetts Division of Marine Fisheries**
**Technical Report TR-44**

# River Herring Spawning and Nursery Habitat Assessment: Upper Mystic Lake, 2007-2008

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**Commonwealth of Massachusetts**
**Executive Office of Energy and Environmental Affairs**
**Department of Fish and Game**
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# River Herring Spawning and Nursery Habitat Assessment: Upper Mystic Lake, 2007-2008

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**Massachusetts Division of Marine Fisheries**
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Mystic River Watershed Association staff recording water chemistry in Upper Mystic Lake.

**Abstract:** The Massachusetts Division of Marine Fisheries (*MarineFisheries*) conducts river herring [alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*)] spawning and nursery habitat assessments to assist habitat and population restoration efforts and to contribute to Massachusetts Department of Environmental Protection *(Mass*DEP) Waterbody Assessments. The Upper Mystic Lake was assessed during 2007-2008 in collaboration with the Mystic River Watershed Association. At the time, a large river herring run was present in the Lower Mystic Lake, but the Upper Mystic Lake was not accessible to river herring. With 165 acres of potential spawning and nursery habitat in the Upper Lake the creation of passage into the lake represented one of the highest priority restoration projects for river herring in the Boston Harbor Coastal Drainage Area. The assessment resulted in the classification of *Impaired* for dissolved oxygen, Secchi disc, nutrients, fish passage and stream flow and *Suitable* for water temperature and pH. The Upper Mystic Lake was found to remain stratified throughout the May-September monitoring period. The stratification contributed to an extensive area of cold, anoxic water that was unsuitable for aquatic life. Despite adverse conditions caused by the wide ranging hypolimnion, eutrophication and lack of fish passage, the shallow fringe and epilimnion of the Upper Mystic Lake had suitable conditions for river herring spawning and nursery habitat.

## Introduction

The Upper Mystic Lake is located in the Mystic River Watershed of the Boston Harbor Coastal Drainage Area. This watershed contains 44 ponds and lakes and properties of 21 towns and cities. Freshwater flows primarily originate in the Aberjona River which runs from Reading to the Upper Mystic Lake. The Mystic River begins at the outlet of the Lower Mystic Lake and runs for 11 km through urban communities north of Boston to the inner Boston Harbor. The Mystic River has the following major tributaries: Mill Brook, Alewife Brook, Malden River, and Chelsea River. The hydrology of the Mystic River watershed has been substantially altered by the construction of three dams. The present condition of two separate Mystic Lakes resulted from the construction of the Mystic Lakes Dam in 1864 to create a water supply for Somerville and Charlestown. Prior to the construction of the Craddock Dam in Medford Square in 1908 tidal flow reached the Lower Mystic Lake. Finally, the Amelia Earhart Dam separates the tidal waters of Boston Harbor from the freshwater Mystic River. The dam is located a short distance downstream of the Malden River confluence. The dam was built in 1967 with flood control and boat locking operations that impede tidal flow. The drainage area of the Mystic River at the Amelia Earhart Dam is 162.4 $km^2$ (Wandle 1984). A USGS stream flow gauge station has operated upstream of the Upper Mystic Lake on the Aberjona River since 1939 (#01102500; at 64.0 $km^2$ drainage area).

The watershed has a long history of industrialization and associated water quality degradation from pollution discharges. The leather processing industry was prominent in the watershed starting in 1838 until the 1980s: operations occurred at 54 sites in Woburn alone (Durant et al. 1990). The resulting contamination halted the use of the Upper Mystic Lake as a water supply in 1898. The Lower Mystic Lake is a natural kettle pond that is 65 acres with a maximum depth of 60 feet. The Upper Mystic Lake was created with the dam construction and is 165 acres with a maximum depth of 80 feet. The upper lake contains two shallow bays before connecting with the Aberjona River. The Mystic Lake Dam has no fishway and maintains a water surface difference of six feet between the two lakes using six stoplog bays that release water to a concrete spillway (CDM 2003). The Lower Mystic Lake supports one of the largest river herring runs in Massachusetts Bay. Fish passage into Upper Mystic Lake has been designated one of the highest priorities for anadromous fish restoration in the region by the Massachusetts Division of Marine Fisheries (*MarineFisheries*) (Reback et al. 2005). The dam is owned by the MA Department of Conservation and Recreation (DCR) and is slated for reconstruction with a fish ladder during 2010.

River herring are native anadromous fish that make spring spawning runs to coastal rivers in Massachusetts seeking suitable freshwater habitat for egg incubation and juvenile rearing. River herring is the common name for two similar species, the alewife (*Alosa psuedoharengus*) and blueback herring (*Alosa aestivalis*) that are important forage for

many species of fish and wildlife and formerly supported valuable commercial, recreational and subsistence fisheries. The assessment of river herring spawning and nursery habitat is a process conducted by *MarineFisheries* to aid in the management and restoration of diadromous fish resources and the evaluation of waterbodies by the Massachusetts Department of Environmental Protection (*MassDEP*) as required by Section 305(b) of the Clean Water Act (CWA). The river herring habitat assessment follows a *Mass*DEP-approved Quality Assurance and Program Plan (QAPP) on water quality measurements for diadromous fish monitoring (Chase 2010). *Mass*DEP will only accept data for 305(b) watershed assessments that were collected under an approved QAPP. The 305(b) process evaluates the capacity of waters to support designated uses as defined by Massachusetts Surface Water Quality Standards (SWQS). Waterbodies are assessed as *Support, Impaired* or *Unassessed* for specific designated uses such as Aquatic Life as part of the *Mass*DEP 305(b) reporting requirements. Impaired or threatened waters that require a Total Maximum Daily Load (TMDL) estimate for specified pollutants are placed on the 303(d) list. Starting in 2002, *Mass*DEP combined reporting requirements for the 303(d) list and 305(b) report into an Integrated List of Waters for Massachusetts (*Mass*DEP 2009). The QAPP relates diadromous fish life history to water quality criteria and contributes data to the 305(b) process for assessing the designated use of Aquatic Life.

Upper Mystic Lake was selected in 2007 for monitoring as part of a pilot effort by *MarineFisheries* to develop protocols for assessing the quality of river herring spawning and nursery habitat. The lake was a suitable candidate because of the interest and ongoing monitoring of the Mystic River Watershed Association (MyRWA) and the restoration potential created by DCR's planning to replace the dam between the Mystic Lakes. *MarineFisheries* formed a partnership with MyRWA to monitor the lake during the 2007/2008 river herring spawning and nursery seasons.

### *Mass*DEP Water Quality Status.

In the *Mass*DEP 2008 Integrated List the Upper Mystic Lake (Segment MA71043) was listed as *Unassessed* (Category 3) (*Mass*DEP 2009). Subsequently, the Upper Mystic Lake was listed as *Impaired* in the *Mass*DEP Mystic River Watershed Water Quality Assessment Report (Carr 2010). The *Impaired* listing was for Aquatic Life, due to the presence of non-native aquatic macrophytes (*Potamogeton crispus*) and dissolved oxygen exceedances. The Aberjona River (Segment MA71-01) was listed Category 5 (TMDL required) in the 2008 Integrated List due to a wide range of impairments. This segment was again assessed as *Impaired* for the Aquatic Life Use in Carr (2010) due to sediment contamination and poor water quality.

## Methods

The river herring habitat assessment methodology is fully outlined in *MarineFisheries'* QAPP (Chase 2010). The assessment relates river herring life history characteristics to three categories of reference conditions: Massachusetts SWQS (*Mass*DEP 2007), US Environmental Protection Agency (US EPA) nutrient criteria (US EPA 2001), and the Best Professional Judgment (BPJ) of *MarineFisheries* biologists. Monthly assessment trips were made to the Upper Mystic Lake during the May-September period when adult river herring spawning and juvenile occupation in the lake occurs. Water quality measurements are made at the surface (0.3 m depth) and bottom (0.5 m from bottom) and at consistent intervals at deeper stations. The following basic water quality parameters were measured: water temperature, dissolved oxygen (DO), pH, specific conductivity, turbidity, and Secchi disc. Water temperature, DO and pH were related to SWQS water quality criteria. Monthly sampling of total phosphorus (TP) and nitrate+nitrite (N+N) was conducted by MyRWA for their watershed baseline index monitoring (MyRWA 2008). The TP, N+N and Secchi disc data were related to US EPA nutrient criteria. Finally, QAPP reference conditions for Fish Passage, Stream Flow and Eutrophication were assigned with each monthly visit based on BPJ. The

sampling data were combined for the two seasons to produce a classification (*Suitable* or *Impaired*) for each parameter. Criteria excursions ≤10% or N=1 (when N = <10) for parameter measurements for each transect station are acceptable for a *Suitable* classification. All excursions that exceed the thresholds result in an *Impaired* classification.

Assessment Stations. Three stations were selected along a transect line towards the middle of the lake for monthly sampling (Figure 1). A shallow depth station was selected at the Tufts Boat House dock (MYS1), followed by a mid-depth station at about 10 m depth (MYS7) and a deep water station near maximum lake depth at about 22 m (MYS3). In addition, the dam outlet (MYS4) was monitored each month to evaluate Fish Passage and Stream Flow conditions, and eight other stations were sampled once or twice to record information at lake locations away from the transect (Table 1A, Appendix). MyRWA nutrient data adopted for this assessment were collected at their Upper Mystic Lake station UPL001 at the Medford Boat Club next to Mystic Lake Dam.

Nutrient Criteria. EPA nutrient criteria are based on the percentile distribution of total nitrogen (TN) and TP measurements. These data are often log-normally distributed, in which case the appropriate measure of central tendency is the geometric mean. For log-normal data the 50$^{th}$ percentile or median is equal to the geometric mean. Data are displayed as percentile box plots with the whiskers indicating the 10$^{th}$ and 90$^{th}$ percentiles, the box boundaries indicating the lower and upper 25$^{th}$ percentiles, and a line through the box indicating the 50$^{th}$ percentile. EPA's nutrient criteria were derived by calculating a 25$^{th}$ percentile for each of the four seasons with pooled data from all sampling stations in an Ecoregion. A median is then calculated from the four seasonal 25$^{th}$ percentiles that represents a threshold between minimally impacted and impaired habitats. The QAPP adopts this approach by relating median nutrient measurements to the EPA's 25$^{th}$ percentile for the Northeast Coastal Zone subecoregion #59 (US EPA 2001). The US EPA nutrient criteria are 8.0 ug/L for TP and 0.32 mg/L for TN. The thresholds are accepted in the QAPP while recognizing they are relatively low for urban watersheds and that N+N represents a subset of TN. With additional data collected over time, the QAPP intends to use the US EPA approach to develop TN and TP criteria specific to river herring spawning and nursery habitat in the region.


**Figure 1.** River herring habitat assessment stations in the Upper Mystic Lake.

## Results

Massachusetts SWQS Criteria.

*Water Temperature.* The metabolic and reproductive processes of ectothermic fish are directly related to water temperature. Temperature also provides cues for fish migrations and is a vital factor for lake stratification and productivity. Temperature thresholds for fish typically target critical warming ranges when acute impacts occur to early life stages. The QAPP adopted the *Mass*DEP criterion of ≤28.3 °C for water temperature as *Suitable* to support Aquatic Life for the nursery period of July-October and ≤26.0 °C from the scientific literature for the spawning period of May-June. A single ex-

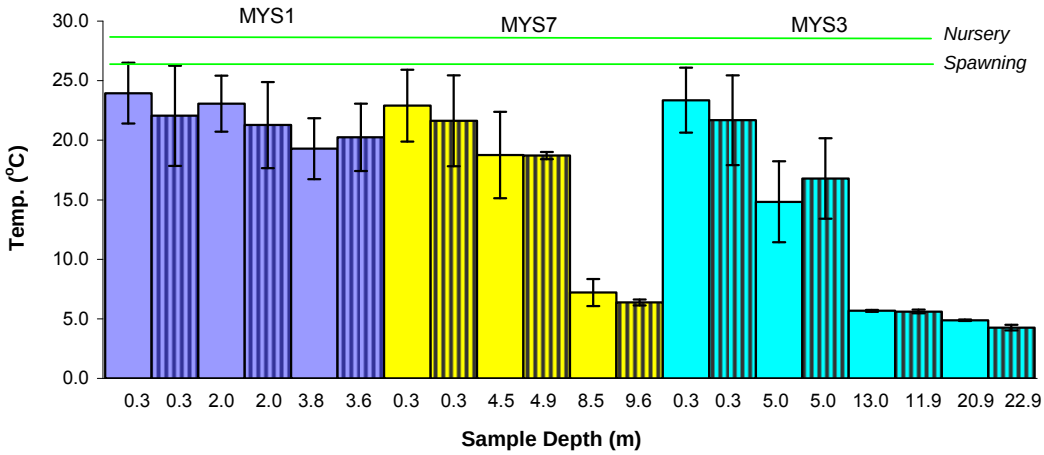


**Figure 2.** Water temperature measurements taken at Upper Mystic Lake. Station averages are presented (± 2 SE) for 2007 (blank bars) and 2008 (striped bars). The sample size range for the station bars is 3-5.

ceedance was recorded with a surface temperature of 26.1 °C at MYS1 on June 28, 2007. These data result in a *Suitable* classification for water temperature during 2007-2008. The lake was stratified for the entire sampling period with a thermocline present relatively high in the water column near 5-6 m. Bottom water temperature at deep stations remained cold throughout the summer (Figure 2). The mean temperature of deep station MYS3 for bottom measurements during May-September was 4.6 °C. The expansive area of cold water causes concerns over habitat limitation for juvenile river herring. However, information on the influence of low water temperature is insufficient to set a lower threshold for the current QAPP version.

Water pH. The acidification of surface waters is a widely recognized concern for fish populations. Low pH can increase metal toxicity and disrupt ionoregulation at gill tissues. The QAPP adopted the *Mass*DEP criterion of ≥6.5 to ≤8.3 for pH as *Suitable* to support Aquatic Life. Water pH that exceeds this range can be a threat to the development of fish eggs and larvae, and highly acidic and alkaline waters (<4.0 and >9.0 pH) are lethal for some species. Four exceedances of the pH criterion were recorded; all on July 16, 2007 when high surface pH was found at all stations. The pH exceedances represent 3% of all pH measurements and no station had more than one exceedance during the two seasons. Therefore, these excursions allow a *Suitable* classification for water pH supporting Aquatic Life. Surface pH measurements were relatively high and remain a concern for the lake (Figure 3). The vertical pH distribution observed in the lake is consistent with eutrophic conditions where enhanced photosynthetic use of $CO_2$ in surface waters increases pH and reduced photosynthetic activity in the hypolimnion decreases pH (Wetzel 1983).

*Dissolved Oxygen.* Adequate DO concentrations are essential for the respiration and metabolism of aquatic life. Water DO is highly influenced by water temperature and chemical and biological processes resulting in seasonal and diurnal cycles. The QAPP adopted the *Mass*DEP criterion of ≥5.0 mg/L to DO as *Suitable* to support Aquatic Life. The DO sampling during 2007 and 2008 revealed a larger than expected hypolimnion. Even with bottom measurements excluded due to a QAPP exemption for stratified conditions, all three transect stations failed to meet the DO criterion. The deep transect station MYS3 was anoxic at the bottom and at 12 m, and 44% of the measurements failed to meet the

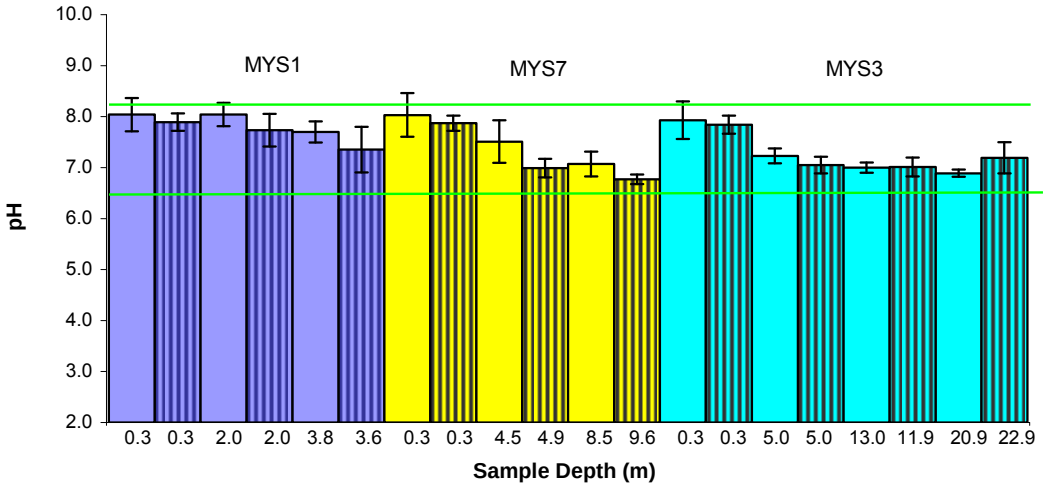


**Figure 3.** Water pH measurements taken at Upper Mystic Lake. Station averages are presented (± 2 SE) for 2007 (blank bars) and 2008 (striped bars). The sample size range for the station bars is 3-5. The green lines mark the *Mass*DEP SWQS thresholds for pH.

criterion at 5 m (Figure 4 and 5). Exceedances were recorded at four of the exploratory stations off the transect (MYS6, MYS8, MYS14, and MYS15; including an anoxic reading of 0.3 mg/L at 4.4 m for MYS14 on August 22, 2008. A synopsis of DO data indicates that an expansive hypolimnion contributes to low DO concentrations throughout the lake below a depth range of 4-6 m depending on location and month.

US EPA Nutrient Criteria.

*Nutrients.* MyRWA conducts monthly sampling of TP and N+N at station UPL001 at the Upper Mystic Lake as part of their Watershed Baseline Index. The MyRWA nutrient samples are processed by the Massachusetts Water Resources Authority laboratory under a separate QAPP (MyRWA 2008). The measurements of TP and N+N were routinely high for 2007 and 2008 and exceeded the reference condition for all samples. The N+N median of 10

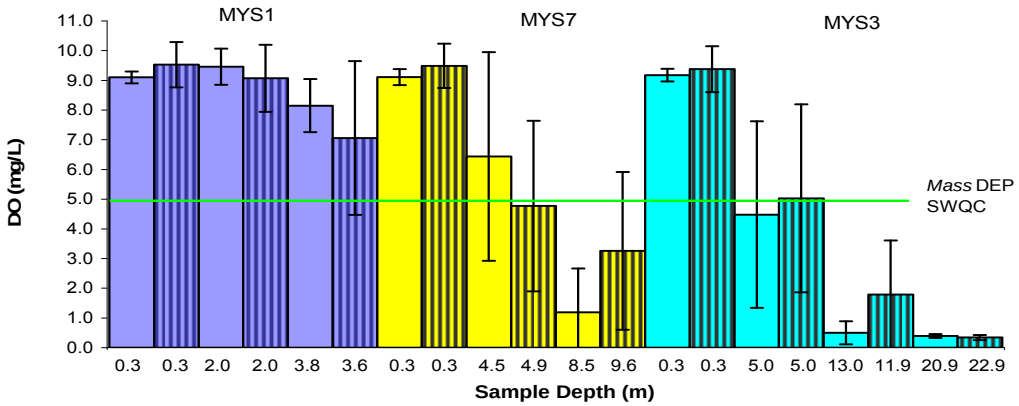


**Figure 4.** Dissolved oxygen measurements taken at Upper Mystic Lake. Station averages are presented (± 2 SE) for 2007 (blank bars) and 2008 (striped bars). The sample size range for the station bars is 3-5.

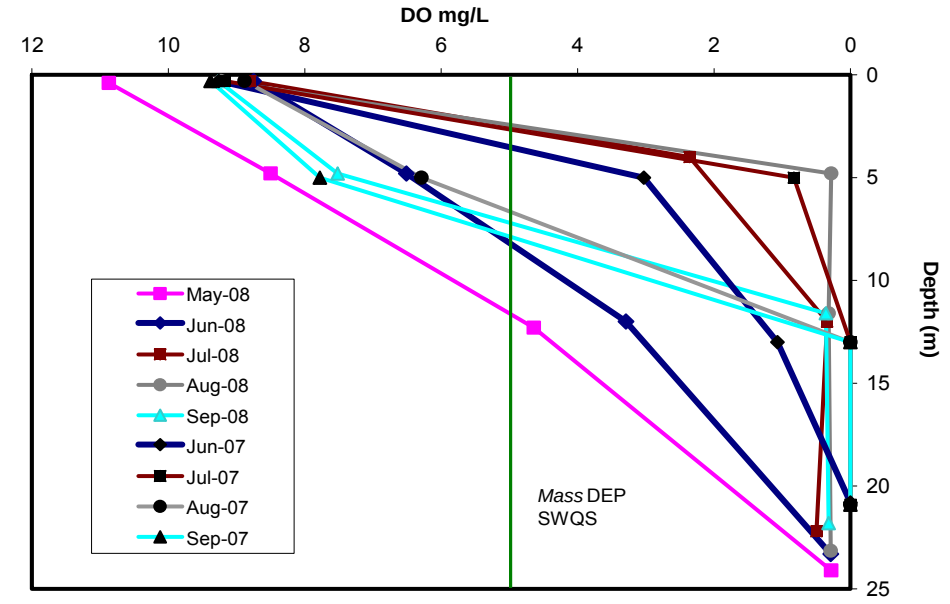


**Figure 5.** Water column profiles for dissolved oxygen at Station MYS3 in the Upper Mystic Lake, 2007-2008. The measurements made in 2007 are marked with black symbols.

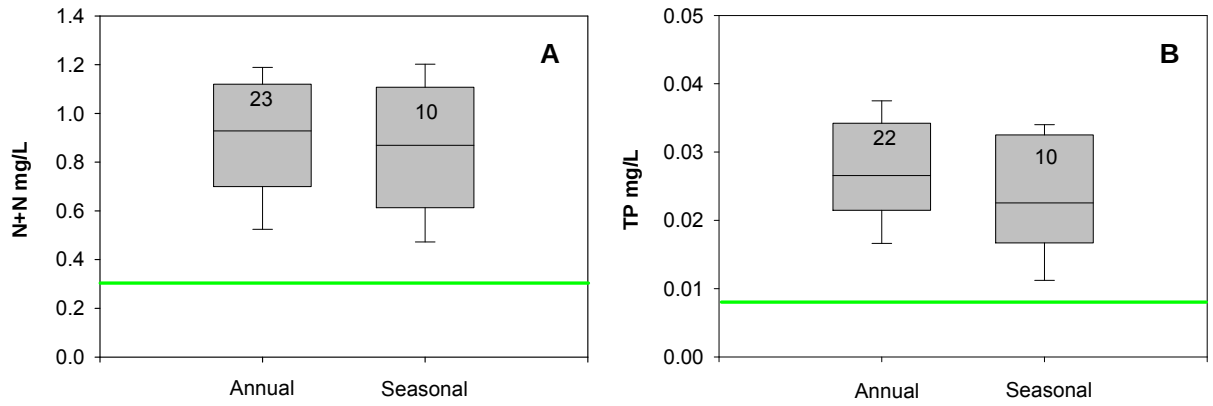


**Figure 6.** Box plots of nitrate-nitrite (A) and total phosphorus (B) measurements in Upper Mystic Lake during 2007-2008. Green lines represent the US EPA nutrient criteria. The sample sizes are noted in the boxes. See page 3 for description of the percentile data.

samples taken during the river herring assessment months was 0.869 mg/L and 0.928 mg/L for all 23 samples taken during 2007-2008 (Figure 6). The TP median of 10 samples taken during the river herring assessment months was 0.023 mg/L and 0.027 mg/L for all 22 samples taken during 2007-2008. These measurements indicate that nutrient concentrations in the urban Upper Mystic Lake are much higher than the average distribution of samples used to derive EPA's reference conditions for the Northeastern Coastal Plain and result in an *Impaired* classification for these parameters and the QAPP Eutrophication criteria.

*Secchi Disc.* Secchi disc is an easily measured proxy for the transparency of water to light. There is little information that directly links Secchi disc

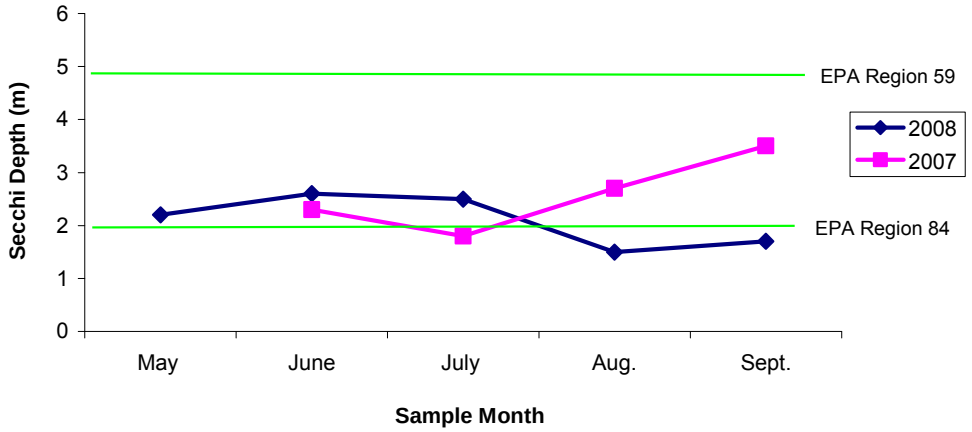


**Figure 7.** Secchi disc measurements taken at Upper Mystic Lake, 2007-2008. The lines plot average Secchi disc depth measured each month at the three transect stations: MYS1, MYS3, and MYS7 (N = 3).

depth to river herring life history, although it is widely accepted as an indicator of water quality. The US EPA Secchi disc criterion for subecoregion #59 of ≤4.9 m is a higher than typical water clarity seen in Massachusetts coastal drainages, therefore the criterion for subecoregion #84 (Cape Cod) of ≤2.0 m Secchi disc depth was adopted by the QAPP as *Suitable* to support Aquatic Life. The three primary transect stations had three exceedances of the Secchi disc criterion during 2007-2008, resulting in an *Impaired* classification (Figure 7). Water clarity was observed to decline throughout the lake during pelagic plankton blooms. Single exceedances were observed at five of the exploratory stations (MYS6, MYS9, MYS11, MYS14, and MYS15).

Best Professional Judgment.

*Fish Passage.* The process of assessing Fish Passage at the Mystic Lakes Dam (MYS4; Figure 8) was simplified by the absence of a fishway on the dam. Adult river herring cannot move upstream over the dam. Water flow exiting the Upper Mystic Lake passes over stoplogs in six bays onto an irregular concrete and stone spillway. The Lower Mystic Lake herring run was readily observed each spring by the presence of large concentrations of adult herring at the base of the dam. Locals have taken an interest in the inability of herring to run upstream and have manually moved them over the dam, both as individuals, and organized "bucket brigades" during 2005-2009 (Medford Boat Club and *MarineFisheries*). The bucket brigades moved from several hundred to several thousand adult river herring during two-day events in most years, except for 2007 when 19,358 river herring were moved. Because there was poor access to six adjustable bays, no physical measurements were made of depth or flows exiting the lake. Observations were recorded with each MYS4 visit on the capability for safe and efficient downstream passage of juvenile herring the dam. For each visit during 2007-2008, the classification for Fish Passage was *Impaired*.

Flows exiting the Upper Lake pass over the stoplogs and fall about 6 ft to the spillway. Juvenile herring can passively move over the stoplogs, however, plunge pools are absent and all pathways have some risk for physical damage and stranding. In 2007, lower flows caused poor conditions for emigrating juvenile herring. During the June, July and August visits, surface water in the Upper Lake was so low that exit flow occurred primarily through subsurface cracks in the stoplogs. On August 22, 2007 an extensive school of juvenile river herring was observed on the northeast shore of the lake. In August and again on September 21, 2007 there were several thousand juvenile herring attracted to the

outflow at the dam. The flow through the stoplog cracks was a deterrent to their passage and spillway path likely caused some mortality of herring that made it through the cracks. In 2008, higher flows and stoplog adjustments made to concentrate flow into one bay improved the opportunity for juvenile emigration. Despite this improvement, lower exit flows were observed on July 16, 2008 that created similar poor downstream passage conditions as seen in 2007.


**Figure 8.** Mystic Lakes Dam spillway, 2007.

*Stream Flow.* Stream Flow is a separate classification from Fish Passage because in some cases stream flow can influence passage and habitat quality independently of a structural impediment. For the Mystic Lakes Dam the two conditions are closely related. No QAPP measurements were made for Stream Flow at MYS4. The flow conditions were observed with each visit to MYS4 and in each case were classified as *Impaired* for Stream Flow based on BPJ relative to juvenile river herring emigration. Flow records from the USGS stream flow station on the Aberjona River revealed that 2007 discharge in the watershed was well below average and 2008 flows were above average. The daily average discharge during sampling trips in 2007 ranged from 4.2 to 8.7 cfs, representing 34-46% of the corresponding mean monthly discharge for the Aberjona River time series. The daily average discharge during 2008 sampling trips ranged from 8.8 to 65 cfs, representing 57-375% of the corresponding mean monthly discharge. On the five sampling trips when discharge was <10 cfs there was little exit flow except through stop log cracks.

*Eutrophication.* When nitrogen and phosphorus data are available, the QAPP classification for Eutrophication is based on US EPA criteria and not BPJ. Therefore, the high nutrient concentrations resulted in an *Impaired* classification for Eutrophication. If applied, the BPJ observations would have resulted in an inconclusive classification. Station MYS1 was monitored for eutrophic symptoms such as water clarity, DO and plant growth. This station had generally good water quality and consistently clean gravel bottom. Other stations did provide the following evidence that is more associated with the nutrient-based classification: expansive low DO in stratified waters, supersaturated DO in surface waters, high surface water pH, and cyanobacteria blooms.

*Spawning Substrate.* River herring deposit dermersal eggs that stick to whatever surface they encounter. After one day the eggs become non-adhesive and will hatch in 3-4 days. No spawning substrate classification is provided in the QAPP because of the wide variety of substrate used by river herring and the lack of consensus in the scientific literature on optimal or preferred substrate. The QAPP habitat monitoring to date indicates that clean gravel is a better surface for egg survival than fine silt or dense periphyton growth. MYS1 was the only station routinely assessed for spawning substrate. As monitoring progressed it was found that this station was a poor selection for substrate classification due to the influence of beach sand nourishment at the nearby Tufts boat house. By expanding observations to include the visible shoal bottom around MYS1 it was possible to determine that the natural bottom had more gravel and cobble with patches of rooted vascular plants. The substrate at MYS1 did not have a high presence of periphyton coverage (0-10% per sample trip).

Additional Observations and Measurements (not reference conditions).

*Turbidity.* Turbidity in water is caused by suspended inorganic and organic matter. Concentrations of organic material can relate to productivity and high levels of inorganic particulates can threaten aquatic life, especially filter feeders. No *Mass*DEP or US EPA reference conditions are provided for turbidity in lakes and ponds, therefore the QAPP does not have a turbidity criterion. The US EPA turbidity reference condition for rivers in subecoregion #59 is ≤1.7 NTU (US EPA 2001). A majority of turbidity measurements at all depths were in the range of 2-3 NTU, with a few higher values related to plankton blooms.

*Specific Conductivity.* Conductivity is proportional to the concentration of major ions in solution. Specific conductivity is a measure of the resistance in a solution to electrical current that has been corrected to the international standard of 25 °C. The ionic composition of fresh water is usually dominated by dilute solutions of natural compounds of bicarbonates, carbonates, sulfates and chlorides. No *Mass*DEP or US EPA reference conditions are provided for conductivity, therefore the QAPP does not have a conductivity criterion. High conductance in freshwater can indicate high watershed contributions of natural alkaline compounds or ionic contributions from pollution sources. Surface measurements in the lake were in the range of 0.6 to 0.7 mS/cm which is relatively high for lakes in the region. Bottom measurements in the hypolimnion had higher conductivity in the 1.3 to 1.6 mS/cm range. The salinity concentration derived from specific conductivity in this range is about 0.7 ‰. These higher values could reflect ions from historical pollutants that may also contribute to stratification in the lake (Durant et al. 1990).

*Cyanobacteria.* In productive lakes where phosphorus concentrations are high, blue-green algae can prosper as they extract nitrogen directly from the atmosphere. Cyanophytes can dominate under these conditions and are generally indicators of excessive nutrient loads. On July 16, 2007 a fine green, pelagic alga was observed in abundance in the Upper Mystic Lake at all stations. The densities were highest along the windward shore near MYS1. A sample was collected and identified as a cyanobacteria of the genus *Anabaena* and most likely *Anabaena spiroides* by Joan Beskenis of *Mass*DEP (July 2007, *pers. comm.*). Summer blooms of cyanobacteria are an ongoing concern in the watershed and were flagged as a cause for an alert status for the Primary Contact designated use in the *Mass*DEP Mystic River Watershed Water Quality Assessment (Carr 2010). MyRWA is conducting ongoing monitoring on the occurrence of cynobacteria blooms in the watershed.

*Carlson Trophic State Index.* The Carlson Trophic State Index (TSI) (Carlson 1977) is a commonly used classification that relates water chemistry indicators to an expected range of trophic conditions. The TSI established relationships for TP, chlorophyll *a*, and Secchi disc depth. The TSI for each of these parameters relates to a numeric scale of trophic conditions based on the premise that increasing nutrients elevate plant productivity and result in reduced water clarity. The mean Secchi disc depth for the three transect stations during May-September measurements resulted in TSI scores of 47-48 and the TP mean for this period had a TSI of 49.4. These values are the upper end of the mesotrophic classification, which is characterized by increasing probability of summer hypolimnetic anoxia and loss of salmonid fish. The TSI for the mean TP for all measurements in 2007-2008 was 51.7; which is in the low end of the eutrophic classification.

*Other Stations.* The exploratory sampling at stations off the primary transect provided some additional observations in the Upper Lake. The two stations sampled in the Fore Bays were less than 2 m deep and displayed higher plant growth than seen at the transect stations. Observations of warmwater, freshwater fish were common in the Fore Bays. Two deep stations were sampled in addition to the transect deep station (MYS3). The DO measurements at MYS14 and MYS15 confirmed the findings of MYS3 that hypoxia was occurring near a thermocline at 4-6 m depth and an extensive anoxic layer persisted from 10-15 m off the bottom. Additional shallow stations (MYS11 and MYS12)

**Table. 1**. Summary of river herring habitat assessment criteria for the Upper Mystic Lake, 2007-2008. A classification of Impaired for each water quality parameter results from exceedances of >10% or >1 (when N <10) for transect station samples during the two-season assessment.

| Parameter | Units | Sample Size (No.) | Acceptable Criteria | Exceedance (%) | Classification |
|---|---|---|---|---|---|
| Temp. (nursery) | °C | 50 | ≤28.3 | 0 | *Suitable* |
| Temp. (spawning) | °C | 27 | ≤26.0 | 1 | *Suitable* |
| DO | mg/L | 70 | ≥5.0 | 26 | *Impaired* |
| pH | SU | 87 | 6.5 to ≤8.3 | 3 | *Suitable* |
| Secchi | m | 26 | ≥2.0 | 35 | *Impaired* |
| N+N | mg/L | 10 | ≤0.32 | 100 | *Impaired* |
| TP | ug/L | 10 | ≤8.0 | 100 | *Impaired* |
| Fish Passage | NA | 9 | BPJ | 100 | *Impaired* |
| Stream Flow | NA | 9 | BPJ | 100 | *Impaired* |

**Notes:**
1. Bottom measurements were excluded from DO classification due to QAPP exemption.
2. Secchi disc measurements were made only for surface samples.
3. The US EPA TN criteria was adopted for N+N samples.

had similar suitable substrate for river herring spawning as MYS1 with gravel, cobble, rooted plants, and low periphyton growth.

## Conclusion

Upper Mystic Lake was classified as having impaired river herring spawning and nursery habitat during 2007-2008 due to exceedances of reference conditions for water quality, Fish Passage and Stream Flow (Table 1). Water quality impairment was evident from field measurements of dissolved oxygen, Secchi disc depth, N+N and TP. Upper Mystic Lake appears to function as a typical dimictic lake in temperate regions with spring and fall periods of circulation and summer stratification. However, the natural stratification appears to be exacerbated from the influence of damming, eutrophication, and possibly, historic pollution sources resulting in an expansive hypolimnion for much of the period when river herring are present. Despite these conditions, during the assessment period, Upper Mystic Lake provided spawning and nursery habitat for river herring, as evidenced by the large numbers of juvenile herring observed in 2007 following the volunteer effort to pass nearly 20,000 adult herring over the dam (Figure 9). The shallow fringe of Upper Mystic Lake had suitable conditions for river herring spawning and nursery habitat and the eplimnion appeared to have suitable water quality to support aquatic life.


**Figure 9.** River herring bucket brigade at Mystic Lakes dam, 2007.

## Recommendations

The impairment to fish passage at the Mystic Lakes dam will be mitigated with the DCR dam reconstruction with an attached fish ladder. The first phase of reconstruction was completed in June 2010 including the installation of a fish ladder. The second phase of the reconstruction will be completed during the winter of 2011. The new fish ladder will provide immediate benefits by expanding the spawning and nursery habitat area available to the Mystic River herring run. The combined influence of the Mystic Lakes dam and watershed nutrient loading on lake water quality will remain after the dam reconstruction. Despite the identified impairments, at 165 acres, the Upper Mystic Lake has a large area of suitable habitat that provides significant restoration potential for river herring in the region. Successful efforts to reduce the spatial range of the anoxic hypolimnion could benefit recruitment for the Mystic River herring run. The following recommendations are offered to local, state, and federal authorities and private groups interested in improving the aquatic habitats in Upper Mystic Lake:

1. Local efforts to reduce the nutrient load in the Mystic River Watershed should be encouraged.

2. A growing body of knowledge on historical pollutants in the watershed is presently being assembled from research and industrial pollution mitigation efforts. This information should be summarized and considered in context of the identified impairments in Upper Mystic Lake to seek water quality improvements.

3. The river herring spawning and nursery habitat assessment data should be provided to *Mass*DEP to support 305(b) reporting and to assist local water quality remediation.

4. *MarineFisheries* should work with DCR and local partners to optimize operations, maintenance and monitoring of the new fish ladder at the Upper Mystic Lake Dam.

## Acknowledgements

Much appreciation is due to the Mystic River Watershed Association and the co-authors for their volunteer efforts to assess water and habitat quality in the Upper Mystic Lake. This is the first habitat assessment report to follow the QAPP for water quality measurements conducted for diadromous fish habitat monitoring (Chase 2010) approved by *Mass*DEP in November 2009. We thank the following reviewers of draft reports: Patrick Herron, MyRWA; Richard Chase, Laurie Kennedy and Gerald Szal, *Mass*DEP; Caleb Slater *MassWildlife*; and Bruce Estrella, *MarineFisheries*. The ongoing river herring restoration efforts in the Upper Mystic Lake benefit from the inspiration provided by Chuck Roache of the Medford Boat Club through his organization of the herring bucket brigade and dedication to the watershed.

## Literature Cited

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography 22: 361-369.

Carr, J.W. 2010. Mystic River Watershed 2004-2008 Water Quality Assessment Report. Mass. Division of Watershed Mgt., Dept. of Environ. Protection, No. 71-AC-2, March 2010.

Chase, B.C. 2010. Quality Assurance Program Plan (QAPP) for Water Quality Measurements Conducted for Diadromous Fish Habitat Monitoring. Version 1.0, 2008-2012. Mass. Div. of Mar. Fish., Tech. Report No. TR-42. http://www.mass.gov/dfwele/dmf/publications/tr42.pd

CDM. 2003. Mystic River Hydrologic and Hydraulic Study Report. MDC Contract No. P83-1250 -S2A. *Prepared by* Camp Dresser and McKee *for* Metropolitan District Commission, Boston, MA.

Coughlin, K. 2008. Summary of CSO receiving water quality monitoring in Upper Mystic River/Alewife Brook and Charles River, 2007. Boston: Massachusetts Water Resources Authority. Report 2008-07. 42 pp.

Durant, J.L. Zemach, J.J., and H.F. Hemond. 1990. The History of Leather Industry Waste Contamination in the Aberjona Watershed: A Mass Balance Approach. Journal of the Boston Society of Civil Engineering, Fall, 1990.

*Mass*DEP. 2007. Massachusetts Surface Water Quality Standards. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch, Westborough, MA (Revision of 314 CMR 4.00, January 2007).

*Mass*DEP. 2009. Massachusetts Year 2008 Integrated List of Waters. Final Listing of the conditions of Massachusetts' Water Pursuant to Sections 303(d) and 305 (b) of the Clean Water Act. Mass. Division of Watershed Mgt., Dept. of Environ. Protection, CN: 281.1

MyRWA. 2008. Mystic River Watershed Baseline Index Report 2001-2007. Mystic River Watershed Association, April, 10, 2008. 15 p.

Reback, K.E., P.D. Brady, K.D. McLauglin, and C.G. Milliken. 2005. A survey of anadromous fish passage in coastal Massachusetts: Part 4. Boston and North Coastal. Mass. Div. of Mar. Fish., Tech. Report No. TR-18. http://www.mass.gov/dfwele/dmf/publications/technical.ht

Wandle, S. W. Jr. 1984. Gazetteer of hydrologic characteristics of streams in Massachusetts – coastal rivers basins of the North Shore and Massachusetts Bay. U.S. Geological Survey, Boston, MA, Water-Resources Investigations Report 84-4281, 60 pp.

Wetzel, R.G. 1983. Limnology. 2nd Edition, Saunders College Publishing, Philadelphia.

US EPA. 2001. Ambient Water Quality Criteria Recommendations. Lakes and Reservoirs in Nutrient Ecoregion XIV. Office of Water, US Environ. Protection Agency, Washington, DC, Document EPA 822-B-01-011. http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/lakes/lakes_14.pd

## Appendix

**Table A1.** Station locations that were sampled in the Upper Mystic Lake during 2007-2008.

| No. | Latitude | Longitude | Station Type | Depth Strata | Max. Depth (m) | Sample (No.) | Location |
|---|---|---|---|---|---|---|---|
| MYS1 | 42º 25.890 | 71º 08.846 | transect | shallow | 4.5 | 9 | Tufts Boat House dock |
| MYS2 | 42º 25.971 | 71º 08.825 | survey | mid | 9.0 | 1 | MIT buoy near eastern shore |
| MYS3 | 42º 26.017 | 71º 08.932 | transect | deep | 24.0 | 4 | 2007 bouy (MYS3 = MYS10) |
| MYS4 | 42º 25.846 | 71º 08.908 | survey | outlet | NA | 9 | Mystic Lakes Dam spillway |
| MYS6 | 42º 25.965 | 71º 09.130 | survey | mid | 9.0 | 1 | off Medford Boat Club |
| MYS7 | 42º 25.898 | 71º 08.855 | transect | mid | 11.0 | 8 | off Tufts Boat House dock |
| MYS8 | 42º 26.162 | 71º 08.838 | survey | mid | 14.0 | 1 | MIT buoy near eastern shore (2) |
| MYS9 | 42º 26.463 | 71º 08.998 | survey | shallow | 1.8 | 2 | Lower Fore Bay |
| MYS10 | 42º 26.015 | 71º 08.931 | transect | deep | 24.5 | 5 | 2008 bouy (<20 ft. from MYS3) |
| MYS11 | 42º 26.246 | 71º 09.114 | survey | shallow | 2.8 | 1 | western shore |
| MYS12 | 42º 26.402 | 71º 08.832 | survey | shallow | 1.9 | 1 | DCR beach on north shore |
| MYS14 | 42° 26.036 | 71° 08.874 | survey | deep | 18.0 | 1 | middle of lake |
| MYS15 | 42º 26.144 | 71º 08.967 | survey | deep | 22.1 | 1 | MIT buoy on NW side of Lake |
| MYSA1 | 42º 26.575 | 71º 08.568 | survey | shallow | 1.0 | 1 | outlet of Aberjona River |

**Table A2.** Summary water chemistry data collected at station MYS1 in the Upper Mystic Lake, 2007-2008. The maximum sample size at each depth level was nine. Secchi disc measurements were only recorded at the surface.

Surface (0.3 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 9 | 22.90 | 3.810 | 23.14 | ≤26/ ≤28.3 | 89 |
| DO | (mg/L) | 9 | 9.34 | 0.653 | 9.02 | ≥5.0 | 100 |
| pH | (SU) | 9 | 7.95 | 0.253 | 8.01 | ≥6.5, ≤8.3 | 89 |
| Turbidity | (NTU) | 9 | 2.9 | 1.475 | 1.7 | NA | NA |
| Sp. Cond. | (mS/cm) | 9 | 0.634 | 0.073 | 0.624 | NA | NA |
| Secchi | (m) | 9 | 2.3 | 0.535 | 2.4 | ≥2.0 | 67 |

Mid-water (2.0 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 9 | 22.07 | 3.342 | 22.65 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 9 | 9.24 | 0.990 | 9.08 | ≥5.0 | 100 |
| pH | (SU) | 9 | 7.86 | 0.331 | 8.03 | ≥6.5, ≤8.3 | 100 |
| Turbidity | (NTU) | 9 | 2.4 | 1.379 | 2.0 | NA | NA |
| Sp. Cond. | (mS/cm) | 9 | 0.625 | 0.070 | 0.624 | NA | NA |

Bottom-water (3.7 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 9 | 19.82 | 2.777 | 19.59 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 9 | 7.54 | 2.195 | 8.42 | ≥5.0 | 78 |
| pH | (SU) | 9 | 7.51 | 0.418 | 7.60 | ≥6.5, ≤8.3 | 100 |
| Turbidity | (NTU) | 9 | 3.7 | 3.096 | 2.5 | NA | NA |
| Sp. Cond. | (mS/cm) | 9 | 0.610 | 0.073 | 0.599 | NA | NA |

**Table A3.** Summary water chemistry data collected at station MYS7 in the Upper Mystic Lake, 2007-2008. The maximum sample size at each depth level was eight. Secchi disc measurements were only recorded at the surface.

Surface (0.3 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 8 | 22.11 | 3.572 | 22.92 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 8 | 9.35 | 0.673 | 9.21 | ≥5.0 | 100 |
| pH | (SU) | 8 | 7.93 | 0.247 | 7.89 | ≥6.5, ≤8.3 | 88 |
| Turbidity | (NTU) | 8 | 2.3 | 1.537 | 1.8 | NA | NA |
| Sp. Cond. | (mS/cm) | 8 | 0.634 | 0.077 | 0.625 | NA | NA |
| Secchi | (m) | 8 | 2.3 | 0.673 | 2.4 | ≥2.0 | 63 |

Mid-water (4.7 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 8 | 17.36 | 4.244 | 18.66 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 8 | 5.39 | 3.046 | 6.41 | ≥5.0 | 63 |
| pH | (SU) | 8 | 7.18 | 0.365 | 7.14 | ≥6.5, ≤8.3 | 100 |
| Turbidity | (NTU) | 8 | 2.5 | 1.331 | 2.0 | NA | NA |
| Sp. Cond. | (mS/cm) | 8 | 0.675 | 0.119 | 0.625 | NA | NA |

Bottom-water (9.2 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 8 | 6.69 | 0.709 | 6.40 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 8 | 2.47 | 2.595 | 1.78 | ≥5.0 | 25 |
| pH | (SU) | 8 | 6.88 | 0.207 | 6.825 | ≥6.5, ≤8.3 | 100 |
| Turbidity | (NTU) | 8 | 2.6 | 0.966 | 2.5 | NA | NA |
| Sp. Cond. | (mS/cm) | 8 | 0.895 | 0.124 | 0.96 | NA | NA |

**Table A4.** Summary water chemistry data collected at station MYS3 in the Upper Mystic Lake, 2007-2008. The maximum sample size at each depth level was nine. Secchi disc measurements were only recorded at the surface.

Surface (0.3 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 9 | 22.43 | 3.533 | 23.29 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 9 | 9.29 | 0.635 | 9.23 | ≥5.0 | 100 |
| pH | (SU) | 9 | 7.88 | 0.270 | 7.85 | ≥6.5, ≤8.3 | 89 |
| Turbidity | (NTU) | 9 | 2.4 | 1.482 | 1.8 | NA | NA |
| Sp. Cond. | (mS/cm) | 9 | 0.632 | 0.072 | 0.624 | NA | NA |
| Secchi | (m) | 9 | 2.4 | 0.708 | 2.2 | ≥2.0 | 67 |

Mid-water (4.8 m depth)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 9 | 15.92 | 3.538 | 16.47 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 9 | 4.79 | 3.170 | 6.29 | ≥5.0 | 56 |
| pH | (SU) | 9 | 7.13 | 0.182 | 7.16 | ≥6.5, ≤8.3 | 100 |
| Turbidity | (NTU) | 9 | 2.8 | 1.699 | 2.1 | NA | NA |
| Sp. Cond. | (mS/cm) | 9 | 0.666 | 0.098 | 0.625 | NA | NA |

Lower-water column (12.4 m)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 9 | 5.65 | 0.141 | 5.65 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 9 | 1.01 | 1.766 | 0.34 | ≥5.0 | 0 |
| pH | (SU) | 9 | 7.01 | 0.158 | 7.01 | ≥6.5, ≤8.3 | 100 |
| Turbidity | (NTU) | 9 | 2.7 | 1.306 | 2.3 | NA | NA |
| Sp. Cond. | (mS/cm) | 9 | 1.005 | 0.044 | 1.017 | NA | NA |

Bottom-water measurement (22.0 m)

| Parameter | Units | N | Mean | SD | Median | WQ Criteria | Meeting Criteria (%) |
|---|---|---|---|---|---|---|---|
| Temp. | (°C) | 9 | 4.55 | 0.377 | 4.62 | ≤26/ ≤28.3 | 100 |
| DO | (mg/L) | 9 | 0.02 | 0.388 | 0.28 | ≥5.0 | 0 |
| pH | (SU) | 9 | 7.06 | 0.294 | 6.96 | ≥6.5, ≤8.3 | 100 |
| Turbidity | (NTU) | 9 | 2.6 | 2.008 | 2.8 | NA | NA |
| Sp. Cond. | (mS/cm) | 9 | 1.408 | 0.069 | 1.392 | NA | NA |

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