Technical Report

Massachusetts Division of Marine Fisheries
Technical Report TR-57

River Herring Spawning and Nursery Habitat Assessment:

Fore River Watershed 2008-2010

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Abstract: River herring are native, anadromous fish that make spring spawning runs to coastal rivers in Massachusetts, among other New England states, 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*). River herring are important forage for many species of fish and wildlife and formerly supported valuable commercial, recreational, and subsistence fisheries. The Massachusetts Division of Marine Fisheries (*MarineFisheries*) conducts river herring spawning and nursery habitat assessments to assist habitat and population restoration efforts and to contribute to Massachusetts Department of Environmental Protection (MassDEP) water quality assessments. Great Pond Reservoir and Sunset Lake, in the Fore River Watershed, were assessed in 2008 and 2010, in collaboration with the Fore River Watershed Association, to support studies on the feasibility of river herring restoration. Within the watersheds, two main stem impediments and two impassable dams prevent river herring from reaching potential spawning and nursery habitat. The habitat assessment at Great Pond Reservoir resulted in the classification of *Suitable* for water temperature, dissolved oxygen, pH, total phosphorus, and water clarity. Total nitrogen, fish passage, and stream flow were classified as *Impaired*. Overall, the water and habitat quality of Great Pond Reservoir ranked highly for an urban watershed and relative to other assessments conducted to date. However, flow limitations necessitate management actions to ensure adequate outflow for juvenile herring emigration in the fall. All measured water quality parameters and best professional judgment classifications for Sunset Lake were *Impaired*, with the exception of dissolved oxygen. Sunset Lake had evidence of eutrophication, enhanced photosynthesis, the presence of invasive plants, and was managed for recreational purposes to have no outflow during the summer. These conditions, in addition to an impassible outlet dam, provide limited feasibility for supporting river herring habitat in Sunset Lake. The assessment results support the recommendation to pursue fish passage improvements that would allow the restoration of river herring to Great Pond Reservoir.

Introduction

The Fore River watershed (also called the Weymouth-Fore River) is located within the Boston Harbor Coastal Drainage Area of Massachusetts. The Fore River is the tidal segment of the watershed and drains to Hingham Bay on the south side of Boston Harbor (Figure 1). The estuary is located approximately 19 km south of the city of Boston and the watershed includes the towns of Braintree, Randolph, Holbrook, Quincy, and Weymouth. The total drainage area of the Fore River watershed is approximately 94 km^2. The primary headwater is the roughly 180 acre (73 hectare) Great Pond in Braintree and Randolph, which also serves as a municipal water supply reservoir. The 57 acre (23 hectare) Sunset Lake, as well as smaller waterbodies and wetlands, also contribute freshwater flows to the Fore River watershed. Farm River, which runs from the outlet of Great Pond to the confluence of the Cochato and Monatiquot Rivers, supply freshwater to the Fore River. Farm River receives flows from the Blue Hill River, which drains wetlands in the Blue Hills Reservation.

Cochato River flows originate from wetlands in Avon and Randolph, and Lake Holbrook in Holbrook. The Cochato River formerly supplied flow to the Richardi Reservoir, supplementing the Tri-Town water supply. This practice ceased in the 1980s, due to contamination from Baird and McGuire, a chemical manufacturing and holding facility that operated near the river in Holbrook from 1912 to 1983 (US EPA 2009). Monatiquot River connects to the Fore River and rises rapidly upstream of the tidal zone along a series of rocky ledges where historical dams were located, including Ames Dam and Armstrong Dam. The entire river length, from its origin to Hingham Bay, is 25 km. The U.S. Geological Service has maintained a Monatiquot River stream flow gauge at Commercial Street since 2006 (No. 01105583, drainage area = 74.3 km^2). The mean monthly discharge at this station for April during the 2006-2012 time series is 75 cfs.

The Massachusetts Division of Marine Fisheries (*MarineFisheries*) is responsible for managing river herring populations in the Commonwealth. This effort includes improving passageways between marine and freshwater areas and evaluating options for restoring degraded populations and habitats. The Fore River watershed was selected as a candidate for river herring habitat assessment and population restoration following discussions with the Fore River Watershed Association (FRWA) over increased observations of river herring in the Monatiquot River in the 1990s. Mutual interests over watershed restoration led to a partnership with FRWA to conduct a two-year river herring spawning and nursery habitat assessment that began in 2008 and resumed in 2010 following a staffing change.

Diadromous Fisheries. Historically, diadromous fish were important in the Fore River watershed as subsistence for Native Americans and European settlers and for commerce in the 1700s (Franklin 2003). However, the development of numerous grist, saw, and fulling mills eventually prevented passage to Great Pond and later, industrial discharges polluted much of the lower watershed. No evidence of river herring in the Fore River was noted during surveys in the 1910s (Belding 1921), nor in the 1960s (Reback and DiCarlo 1972). Evidence of river herring returning occurred in the late 1980s and early 1990s, as *MarineFisheries* and FWRA staff observed low numbers of adults on spring spawning runs (Chase 2006). The observed number of returning herring has increased in the last decade, with thousands viewed during run peaks in some years by the authors. One possible explanation for the increasing numbers of herring is that river water quality has improved with the ceasing of industrial discharges in recent decades, thereby encouraging the colonization of river herring from nearby Boston Harbor runs.

The Fore River has regional significance for supporting runs of other diadromous fish species. Traditionally, important fisheries occurred for American eel, Atlantic tomcod, and rainbow smelt. *MarineFisheries* has maintained a rainbow smelt fyke net station in the tidal zone of the Fore River since 2004. The smelt spawning run is one of the largest found in coastal Massachusetts (Chase and Childs 2001; Chase 2006). The fyke net is designed for smelt monitoring, but has also captured alewife as well as six other species of diadromous fish.

Water Supply Management. Great Pond Reservoir is the water supply for the Tri-Town Water Board, formed cooperatively with the towns of Braintree, Randolph, and Holbrook. It is split into the Upper and Lower Reservoirs by an earthen dyke. Lower Reservoir is the active water supply, and is referred to as Great Pond for this study. Two water

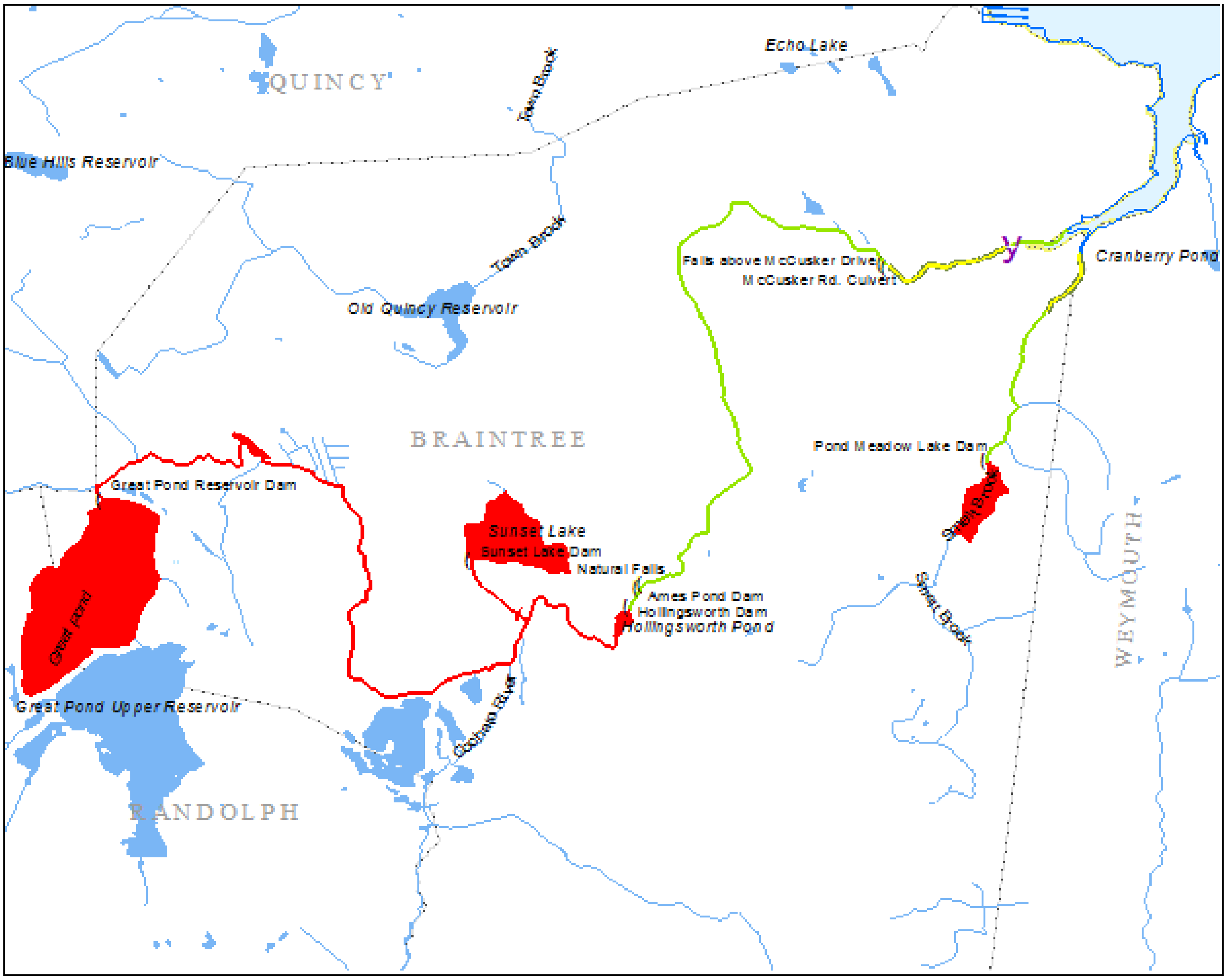

Figure 1. The study area and Fore River watershed. The green main stem river indicates possible diadromous fish passage; the red main stem river indicates a fully obstructed passage; yellow shading indicates rainbow smelt spawning habitat; the purple diamond indicates a *MarineFisheries* smelt fyke net station. Image source: MassDOT and *MarineFisheries* Diadromous Fish GIS Datalayer.

supply intakes in Great Pond are authorized by Water Management Act (WMA) registrations: one by the Braintree Water and Sewer Commission (BWSC -- WMA No. 41904001, 3.87 MGD) and the other by the joint water department for Randolph and Holbrook (WMA No. 41913301, 3.27 MGD). The BWSC registration also allows water withdrawal from Richardi Reservoir, which diverts Farm River surface water to the reservoir (Figure 2; refer to Gomez and Sullivan (2009) for more detailed site and street mapping). The authorized withdrawals for both intakes totals to 7.14 (mgd), equating to approximately 11 cfs. Upper Reservoir is not presently used for water withdrawals, although planning is underway to rehabilitate and deepen the basin for long-term water use goals.

Assessment QAPP. The assessment of river herring spawning and nursery habitat, conducted by *MarineFisheries*, aids 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 MassDEP-approved Quality Assurance and Program Plan (QAPP) on water quality measurements for diadromous fish monitoring (Chase 2010). MassDEP 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 MassDEP 305(b) reporting requirements[1]. Degraded waters that require a total maximum daily load (TMDL) estimate for specified pollutants are placed on the 303(d) list. Starting in 2002, MassDEP combined reporting requirements for the 303(d) list and 305(b) report into an Integrated List of Waters for Massachusetts (MassDEP 2009). The QAPP relates diadromous fish life history to water quality criteria, allowing the contribution of data to the 305(b) process for assessing the designated use of Aquatic Life.

MassDEP Water Quality Status. The most recent MassDEP water quality assessment reports for the Weymouth and Weir River Basin include segments within the Fore River watershed (O'Brien et al. 2002; and Reardon 2010). The Cochato River segment (MA74-06) runs for 6.44 km, from Lake Holbrook to the confluence of Farm and Monatiquot Rivers. There are no municipal withdrawals from this segment, in

[1]For clarification while reading this document; MassDEP deisgnations are capitalized, habitat classifications are both italicized and capitalized, and best professional judgement reference conditions are in bold.

part due to the presence of the Baird and McGuire Superfund Site near the Holbrook and Randolph border (O'Brien et al. 2002). However, Braintree Municipal Golf Course has a WMA permit (No. 9P31904001) to withdraw 0.05 MGD from an irrigation pond in the segment.

The Farm River segment (MA74-07) runs from the outlet of Great Pond to the confluence with the Cochato and Monatiquot Rivers. This segment contains the two Tri-Town Water Board registrations of 7.14 MGD and includes the allowance to divert water from the Farm River to Richardi Reservoir, where it is pumped back to Great Pond Reservoir. This practice can result in the diversion of up to 80% of Farm River flows during June-September (O'Brien et al. 2002). The Cochato and Farm river segments were listed as *Unassessed* for Aquatic Life for the 1999 and 2004 MassDEP assessments (O'Brien et al. 2002; and Reardon 2010).

The Monatiquot River segment (MA74-08) runs from the confluence of Cochato and Farm Rivers to the tidal Fore River at Route 53. There are no regulated water withdrawals in this segment, although the Monatiquot River can be effected by summer diversions of Farm River flow to the Richardi Reservoir. The Monatiquot River was *Impaired* for Aquatic Life in 1999, due to an impacted benthic community, and *Unassessed* in 2004 (O'Brien et al. 2002; and Reardon 2010).

The Weymouth Fore River segment (MA74-14) runs downstream from Commercial Street into the tidal Hingham Bay. This segment was listed as *Support* for Aquatic Life in 1999 and *Unassessed* in 2004 (O'Brien et al. 2002; and Reardon 2010).

Sunset Lake (MA74020) is the one pond or lake in the watershed included in this MassDEP water quality assessment. It was listed as *Unassessed* for Aquatic Life in the 1999 and as *Impaired* due to the presence of the non-native macrophyte, Eurasian milfoil (*Myriophyllum spicatum*) in the 2004 MassDEP assessment (O'Brien et al. 2002; and Reardon 2010).

The MassDEP 2008 Integrated List of Waters (MassDEP 2009) records the Cochato River and Monatiquot River as Category 5 (TMDL required for pesticides, pathogens, and organic enrichment/low DO); the Weymouth-Fore River as Category 5 (TMDL required for pathogens); and the Farm River and Sunset Lake as Category 3 (*Unassessed*).

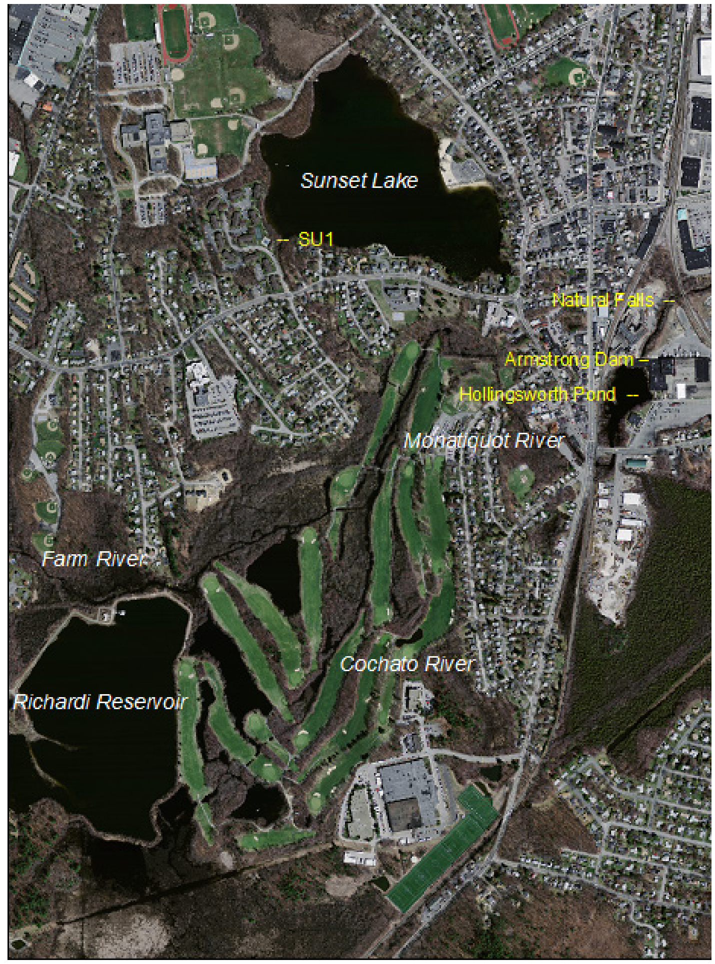

Figure 2. Fore River watershed at the confluence of the Cochato River and Farm River, Braintree.

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 (MassDEP 2007); US Environmental Protection Agency (US EPA) nutrient criteria recommendations (US EPA 2001); and the Best Professional Judgment (BPJ) of *MarineFisheries* biologists (Chase 2010). Monthly assessment trips were made to Great Pond and Sunset Lake from May to September, targeting the second and third week of each month. This period was used for sampling because it is when: water quality can exhibit the most impairment; and adult river herring spawning and juvenile occupation of the Great Pond would occur, if passage was available. Although river herring spawning does occur in April, the month is not sampled by design due to the typical lack of impairment during early spring. The assessment criteria for all parameters are summarized in Table 1 for Great Pond and Table 2 for Sunset Lake. Station parameter data are summarized in the Appendix.

Water quality measurements are made at the surface (0.3 m depth) and bottom (0.5 m from bottom) in the water column, and at mid-water column depths at deeper stations. The following basic water quality parameters were measured: water temperature, dissolved oxygen (DO), pH, specific conductivity, turbidity, and Secchi disc depth. Water temperature, DO, and pH were related to SWQS criteria. Monthly total phosphorus (TP) and total nitrogen (TN) samples were collected in 2010. The TP, TN, and Secchi disc data were related to US EPA nutrient criteria recommendations. The TP and Secchi disc data were also applied to the Carlson Trophic State Index (TSI) (Carlson 1977), a commonly used classification that relates water chemistry indicators to an expected range of trophic conditions. 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 of ≤10% or n = 1 (when N = 5-9) for parameter measurements at transect stations are acceptable for a *Suitable* classification. Criteria excursions greater than 10% of transect samples result in an *Impaired* classification (when N ≥ 10).

Assessment Stations. Stations were selected to provide a

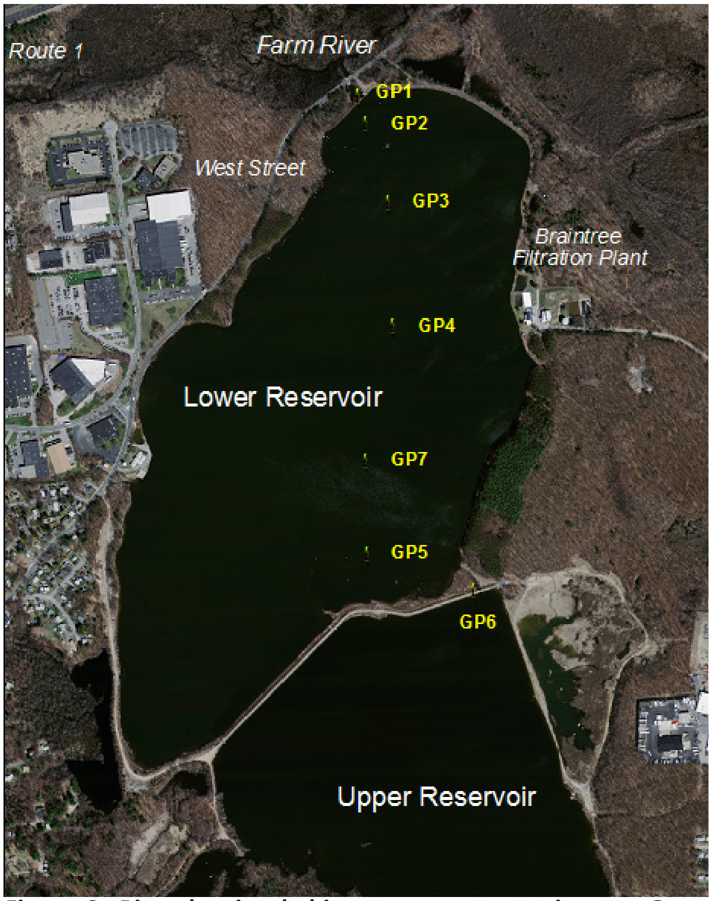

Figure 3. River herring habitat assessment stations at Great Pond.

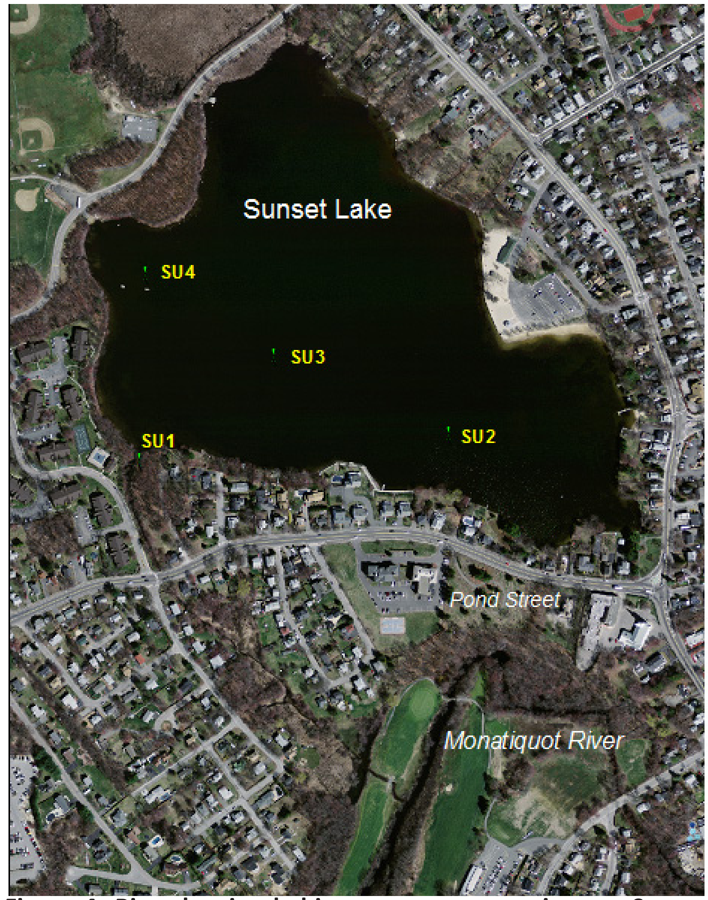

Figure 4. River herring habitat assessment stations at Sunset Lake.

transect running from the lake outlet to the lake inlet. These selected stations contained shallow, medium, and deep depth strata based on lake bathymetry. Additionally, several off-transect stations were visited periodically to gain information about other locations in the lake. However, this information does not influence classifications. The Great Pond assessment classification was based on stations GP2, GP3, and GP4 selected along a transect line running from the Great Pond outlet at West Street, across to the dyke separating Upper and Lower Reservoirs (Figure 3; Table A1). The Sunset Lake assessment classification was based on stations SU2, SU3, and SU4 selected along a transect from the Canal Street outlet, across the lake to the pump house for the high school irrigation system (Figure 4; Table A1).

Nutrient Criteria. The US EPA nutrient criteria recommendations are based on the percentile distribution of TN and TP measurements in a designated Ecoregion. The nutrient criteria were derived by calculating a 25th percentile for each of the four seasons with pooled data from all available sampling stations in an Ecoregion. A median is then calculated from the four seasonal 25th 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 25th percentile for the Northeast Coastal Zone subecoregion #59 (US EPA 2001).

Table 1. Summary of river herring habitat assessment criteria for Great Pond Reservoir, 2008/2010.

Parameter	Units	Sample Size (No.)	Acceptable Criteria	Exceedance (%)	Classification
Temperature (nursery)	°C	31	≤28.3	0	*Suitable*
Temperature (spawning)	°C	41	≤26.0	0	*Suitable*
DO	mg/L	64	≥5.0	2	*Suitable*
pH	SU	74	6.5 to ≥8.3	1	*Suitable*
Secchi disk	m	18	≥2.0	0	*Suitable*
TN	mg/L	5	≤0.32	40	*Impaired*
TP	ug/L	5	≤8.0	20	*Suitable*
Eutrophication	NA	10	BPJ	0	*Suitable*
Fish Passage	NA	10	BPJ	100	*Impaired*
Stream Flow	NA	10	BPJ	100	*Impaired*

Notes: Bottom DO measurements at deep stations in stratified lakes are excluded due to QAPP exemption. *Impaired* classifications result from exceedances of >10% of samples or >1 (when N<10) for transect stations.

Table 2. Summary of river herring habitat assessment criteria for Sunset Lake, 2008/2010.

Parameter	Units	Sample Size (No.)	Acceptable Criteria	Exceedance (%)	Classification
Temperature (nursery)	°C	38	≤28.3	0	*Suitable*
Temperature (spawning)	°C	20	≤26.0	20	*Impaired*
DO	mg/L	49	≥5.0	8.2	*Suitable*
pH	SU	58	6.5 to ≥8.3	21	*Impaired*
Secchi disk	m	16	≥2.0	38	*Impaired*
TN	mg/L	5	≤0.32	100	*Impaired*
TP	ug/L	5	≤8.0	80	*Impaired*
Eutrophication	NA	9	BPJ	44	*Impaired*
Fish Passage	NA	10	BPJ	100	*Impaired*
Stream Flow	NA	10	BPJ	100	*Impaired*

Notes: Bottom DO measurements at deep stations in stratified lakes are excluded due to QAPP exemption. *Impaired* classifications result from exceedances of >10% of samples or >1 (when N<10) for transect stations.

The US EPA nutrient criteria are 8.0 ug/L for TP and 0.32 mg/L for TN. The thresholds were accepted in the QAPP, while recognizing they are relatively low for urban watersheds. With additional data collected over time, the QAPP will use the US EPA approach to develop TN and TP criteria specific to river herring spawning and nursery habitat for coastal regions of Massachusetts.

Results

Massachusetts SWQS Criteria

Water Temperature. The metabolic and reproductive processes of ectothermic fish are directly influenced by water temperature, which also provides cues for fish migrations and is an important 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 MassDEP 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 Greene et al. (2009) for the spawning period of May-June.

No measurements at Great Pond exceeded either the spawning or nursery period threshold, resulting in a *Suitable* classification for water temperature.

Great Pond showed weak seasonal stratification during 2008 and 2010. The deep station, GP4, had a maximum depth of about 7.5 m, where the bottom temperature range was fairly stable between 17.5 and 21.5 °C (Figure 5). Sunset Lake had surface temperature exceedances at all transects, and one exceedance at a 0.8 m depth measurement on May 26, 2010. These four exceedances resulted in an *Impaired* classification for the spawning period. No exceedances were recorded at Sunset Lake for the nursery period. In contrast to Great Pond, Sunset Lake had sharper and more stable stratification at the deep station SU2 (maximum depth, 7.5 m), where the bottom temperature ranged from 10 to 14 °C (Figure 6). The May 26, 2010 surface temperature of 28.03 °C, at SU4, was the warmest measurement recorded at both locations during the assessment.

Water pH. The acidification of freshwater is a widely recognized concern for fish populations. Low pH can increase metal toxicity and disrupt ionoregulation in gill tissues. The QAPP adopted the MassDEP criterion of ≥6.5 to ≤8.3 for pH as *Suitable* to support Aquatic Life. Water pH outside of this range can be a threat to the growth and development of fish eggs and larvae, while highly acidic and alkaline waters (<4.0 and >9.0 pH) in some cases can cause lethal effects (NAS 1972; Haines and Johnson 1982).

Water pH at Great Pond was stable and slightly alkaline during the study period (Figure 7). Surface pH measurements for the two seasons averaged 7.44 at Great Pond. Of the 74 transect measurements, only one was <6.5, resulting in a classification of *Suitable* for pH at Great Pond. Sunset Lake had frequent early season surface measurements that exceeded the upper limit of the pH threshold (Figure 8).

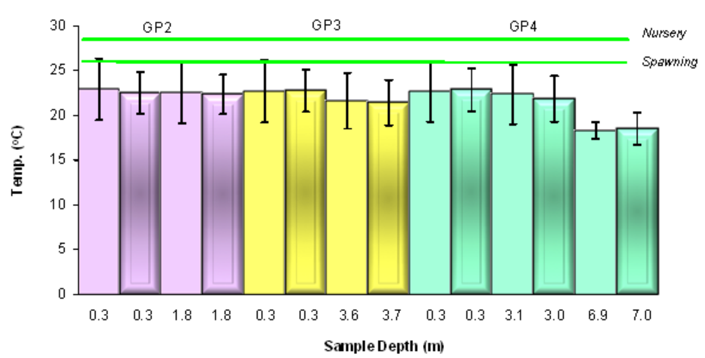

Figure 5. Water temperature measurements taken at Great Pond. Station averages (±2 SE) are presented for 2008 (blank bars) and 2010 (beveled bars). Five samples were recorded at each depth per season.

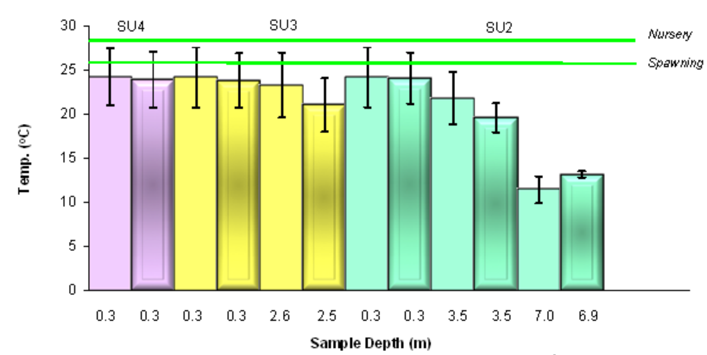

Figure 6. Water temperature measurements taken at Sunset Lake. Station averages (±2 SE) are presented for 2008 (blank bars) and 2010 (beveled bars). The sample size for the station bars is 4-5.

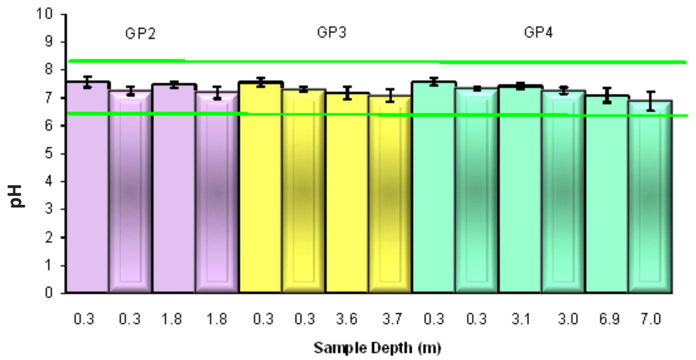

Figure 7. Water pH measurements taken at Great Pond. Station averages (±2 SE) are presented for 2008 (blank bars) and 2010 (beveled bars). The sample size is five per season per station. The green lines mark the MassDEP SWQS thresholds for pH.

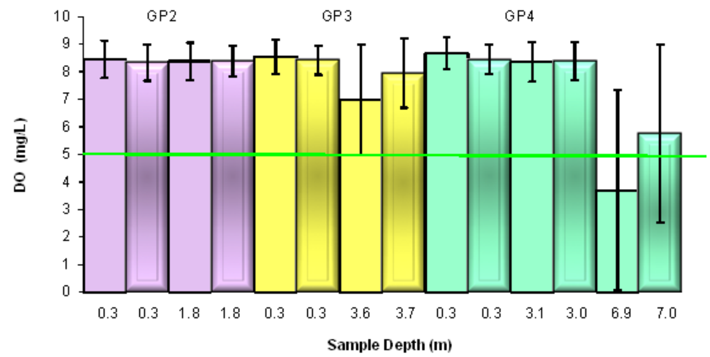

Figure 9. Dissolved oxygen measurements taken at Great Pond. Station averages (±2 SE) are presented for 2008 (blank bars) and 2010 (beveled bars). Five samples were recorded at each depth per season. The green line marks the MassDEP SWQS DO threshold.

Overall, 21% of the transect pH measurements were >8.3, resulting in an *Impaired* classification for pH at Sunset Lake. High pH, which can stress fish respiration, occurs in eutrophic conditions when daytime photosynthesis depletes carbonic acid in the water column. There was a large and significant difference (Student T-test, P<0.001) in average pH at Sunset Lake between the two years: surface measurements averaged 8.52 in 2008 and 7.20 in 2010. Only two of the twelve pH threshold excursions >8.3 occurred in 2010.

Dissolved Oxygen. Adequate DO concentrations are essential for the respiration and metabolism of aquatic life. Water DO is highly influenced by water temperature, as well as chemical and biological processes, resulting in seasonal and diurnal cycles. The QAPP adopted the MassDEP criterion of ≥5.0 mg/L for DO as *Suitable* to support Aquatic Life. Great Pond was classified as *Suitable* for DO with only one of the 64 transect station measurements below the 5.0 mg/L DO threshold. Bottom samples at the deep transect station are exempt from the DO classification in the QAPP, due to the influence of natural stratification. The bottom measurements at GP4 exceeded the DO threshold during half of the 10 measurements, with anoxia present for 3 of the 4 July and August samples. During this period, DO declined below 5.0 mg/L at a depth of 4-5 meters, then sharply declined to anoxia in the bottom meter of depth (6.5-7.5 m).

Sunset Lake was also classified as *Suitable* for DO, although marginally with 8.2% (4 of 49) of transect station measurements below the 5.0 mg/L DO threshold. Sunset Lake showed more evidence than Great Pond of the influence of stratification and photosynthesis on DO dynamics (Figures 9 and 10). Surface DO supersaturation (and elevated pH) was prevalent at Sunset Lake. All bottom measurements at the deep station, SU2, were anoxic, including during each September, when August storms fully mixed Great Pond. The average DO at the SU2 bottom depth was 0.34 mg/L with low variability (SD = 0.084). During summer, hypoxia formed higher in the water column at Sunset Lake (3-4 m) and anoxia was present in the bottom two meters of depth.

Nutrient Criteria

Nutrients. Nutrient samples were only collected during 2010, due to funding restraints in 2008. Surface samples of TN and TP were collected at GP4 in Great Pond and SU2 in Sunset Lake during each of the five site visits (Tables A4 and A5). The samples were collected and processed according to the project QAPP. The quality assurance review of 2010 data found no outliers and acceptable replicates. However, the detection limits were exceeded for five of the six field blank samples for both TN and TP, resulting in all nutrient data classified as *Conditional*.

The QAPP allows for a *Suitable* classification for TN and TP when a single exceedance occurs for small sample sizes (5-9). This was the case for Great Pond TP, where a low average TP was found (6.7 ug/L) with a single exceedance of 9.0 ug/L. The average total nitrogen at Great Pond of 0.301 mg/L was lower than the threshold, yet the classification

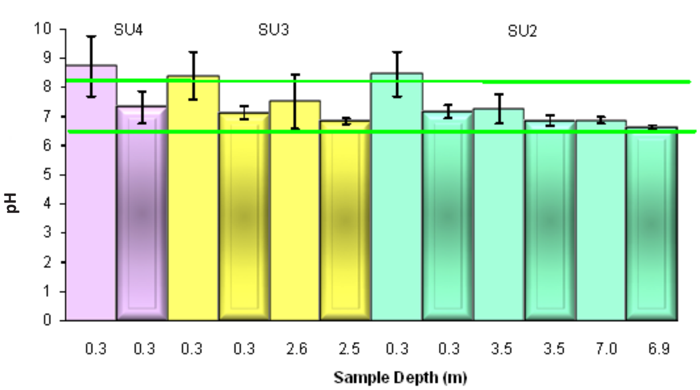

Figure 8. Water pH measurements taken at Sunset Lake. Station averages (±2 SE) are presented for 2008 (blank bars) and 2010 (beveled bars). The sample size for the station bars is 4-5. The green lines mark the MassDEP SWQS thresholds for pH.

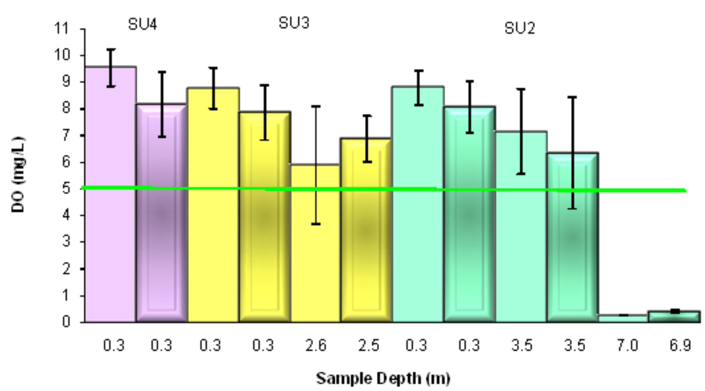

Figure 10. Dissolved oxygen measurements taken at Sunset Lake. Station averages (±2 SE) are presented for 2008 (blank bars) and 2010 (beveled bars). The sample size range for the station bars is 4-5. The green line marks the MassDEP SWQS DO threshold.

was *Impaired*, due to the occurrence of two moderate exceedances of the 0.32 mg/L threshold. Sunset Lake was classified as *Impaired* for TP (as well as TN) with only a single TP measurement under the criterion. Overall, the Great Pond TN and TP concentrations were relatively low among all *MarineFisheries* river herring habitat assessments conducted to date, and considering that the adopted EPA nutrient thresholds are conservatively low for Massachusetts surface waters.

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 depth to river herring life history, although it is widely accepted as an indicator of water quality. The US EPA Secchi disc criterion of ≥4.9 m for subecoregion #59 (Northeast Coastal) is higher than water clarity typically 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. No exceedances to the criterion were measured at the Great Pond transect stations, with an average of 3.35 m in 2008 and 3.65 m in 2010, resulting in a *Suitable* classification (Figure 11).

Sunset Lake had lower water clarity than Great Pond, with an average of 2.40 m in 2008 and 1.95 m in 2010 and a 40% exceedance of the Secchi disc threshold, resulting in an *Impaired* classification.

Best Professional Judgment

Fish Passage. The QAPP provides a process for using Best Professional Judgment (BPJ) to assess the capability of river herring to pass fishways and impediments. With each site visit, the type of impediment is documented and the potential for upstream passage of adult river herring and downstream passage of emigrating adults and juvenile river herring is assessed and classified as *Suitable*, *Impaired*, or *Unsuitable*. The BPJ assessment was readily made with little uncertainty, as no fishways are present in the Fore River watershed and several impassible dams prevented access to potential spawning habitat in Great Pond Reservoir and Sunset Lake during the study period.

Monthly inspections were made at the outlets of Great Pond Reservoir (GP1) and Sunset Lake (SU1). Both provided no access for fish passage and were classified as *Unsuitable* for fish passage. Two other main stem obstructions in the Monatiquot River were not visited every month because fish passage was known to be fully impeded from previous observations and investigations (Chase 2006; and Gomez and Sullivan 2009). The Armstrong Dam, with a 3.35 m spillway height, has no provisions for upstream passage. Secondly, no evidence of successful passage has been observed at the natural falls downstream of the Armstrong Dam.

The Great Pond outlet is managed by the Tri-Town Water Board to maintain targeted water levels that support annual water supply needs. This practice results in little outflow with the exception of spring and late fall flows and storm events (Gomez and Sullivan 2009). No outflow was observed during any visit to GP1 in 2008 and 2010. Minor leakage was observed during 2008, between the board slots and the metal spillway crest boards. These leaks were repaired by 2010, resulting in nearly no leakage at the dam. Relative pond height was measured from the pond level to the top of the center metal board. Great Pond levels increased in 2008, resulting in 5 cm of freeboard at the dam boards in September (Figure 12). The conditions in 2010 were more consistent with expectations, as the pond level decreased each month, until a sharp increase in September.

The Sunset Lake outlet is made of granite blocks with three sluices that are slotted for holding removal wood boards. The Town of Braintree Department of Public Works (DPW) uses these boards to maintain Sunset Lake water levels for recreational purposes. Levels were maintained during both years to prevent outflow. No outflow occurred other than leakage for all but one visit, when a large rain event (September 2008) resulted in strong flow over all sluice boards.

The pond level was much lower in 2010 than 2008. Brain-

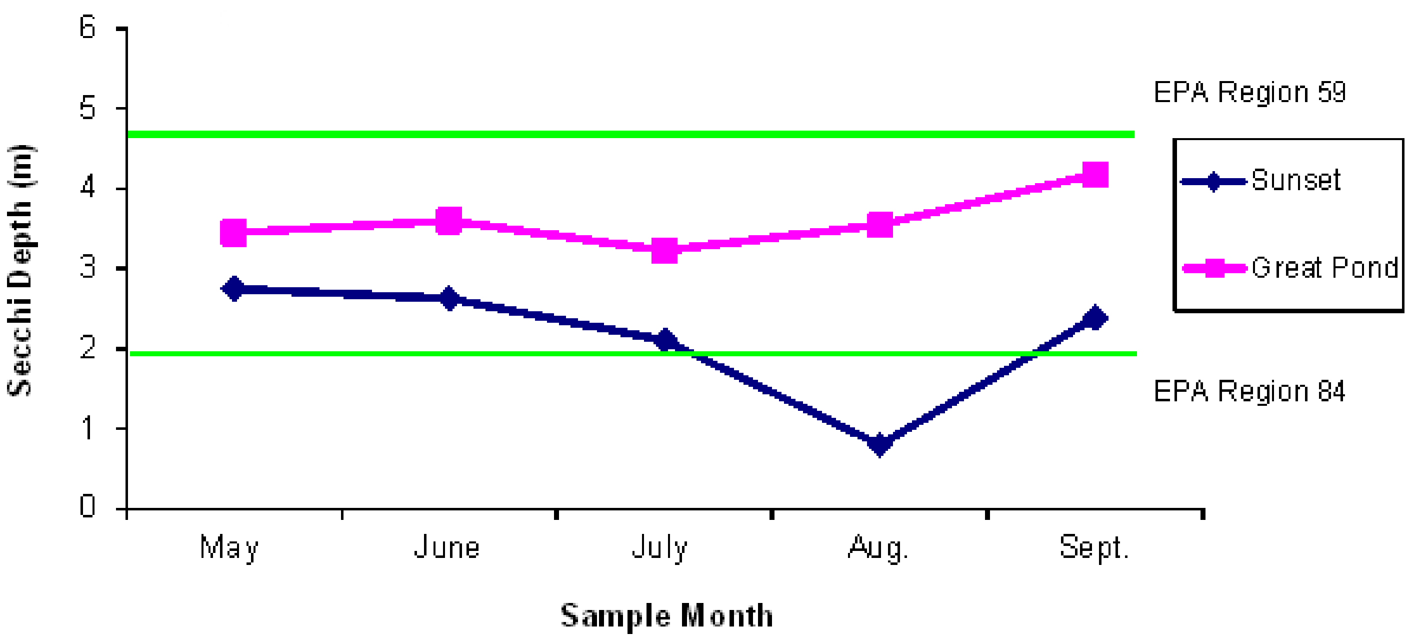

Figure 11. Secchi disc measurements taken at Great Pond, 2008 and 2010. The lines plot average Secchi disc depth measured each month at the three transect stations, SL2, SL3, and SL4 (N=4).

tree DPW removed the wood boards, setting single sheet metal plates in each of the sluices, and placed several cubic yards of dirt behind the boards to eliminate outflow. This work was done prior to May 2010. A combination of flow loss associated with the placement of the new plates and low precipitation resulted in lower pond levels for the 2010 season.

A feasibility study for restoring river herring to the Fore River watershed was funded by *MarineFisheries* and conducted by Gomez and Sullivan Engineers, P.C. during the habitat assessment study period (Gomez and Sullivan 2009). The study provided hydrologic and hydraulic data to assist in determinating the feasibility of restoring the river herring run to Great Pond. The study also contributes additional information on river locations that were not classified in the habitat assessment. The habitat assessment included additional site visits, during May and June each year, of all potential fish passage impediments. Below are brief summaries on each location based on observations from the habitat assessment and feasibility study.

McCusker Avenue Falls. Natural rock ledge in the Monatiquot River, 50 m upstream of McCusker Avenue, has been identified as a possible impediment to river herring passage (Reback et al. 2005). This location has been observed on numerous spring occasions during *MarineFisheries* smelt monitoring (Chase 2006). It was found to prevent upstream passage of rainbow smelt; however, at no time was it deemed to obstruct river herring. Further, the annual aggregation of large numbers of river herring below the upstream natural falls indicates herring are routinely passing this site.

Natural Falls. The natural falls downstream of Armstrong Dam were visited numerous times, in the interest of viewing successful passage of the river herring that aggregate below the falls each spring; however, no successful passage has been observed. This is of substantial interest because the Great Pond herring run supported a large and important fishery historically, meaning passage was possible at this site in the past. The rocky ledge presently supporting the falls creates too steep an elevation drop for herring to swim directly up the main flow. Two historic passage scenarios may have existed. One scenario is that the construction of the railroad embankment below the natural falls lowered the river bed and caused the tailwater to drop too low. The other possibility lies with what appears to be a remnant channel around the natural falls that still receives flow during high water. This channel may have been a natural bypass or was managed for herring passage years ago. For either avenue, improvements over the existing status are needed to pass river herring upstream.

Ames Pond Dam. Remnants of the Ames Pond Dam are located 50 m upstream of the natural falls, in the form of concrete stop log bays and a walkbridge. Stop logs are no longer present, allowing river flow to pass through each bay. The remnant dam sill and spacing of the concrete bays causes some backwatering and increases water velocity at the dam. Habitat assessment visits to this site did not find conditions that would prevent river herring from passing through most of the seven bays. However, in the interest of reducing velocity for passage and restoring the river channel, Gomez and Sullivan (2009) recommend either full removal or lowering of the sill elevation at Ames Pond Dam.

Armstrong Dam. The Armstrong Dam was not routinely monitored during the assessment, due to the certainty that no passage was possible over the 3.35 m spillway crest. Site visits in May and June produced observations of American eel and large snapping turtles, held up in pools created by the ledge below the spillway, as they attempted to migrate upstream. The Gomez and Sullivan study (2009) conducted hydraulic modeling to provide guidance on designing the fish passage options of a fish ladder and dam removal for this site.

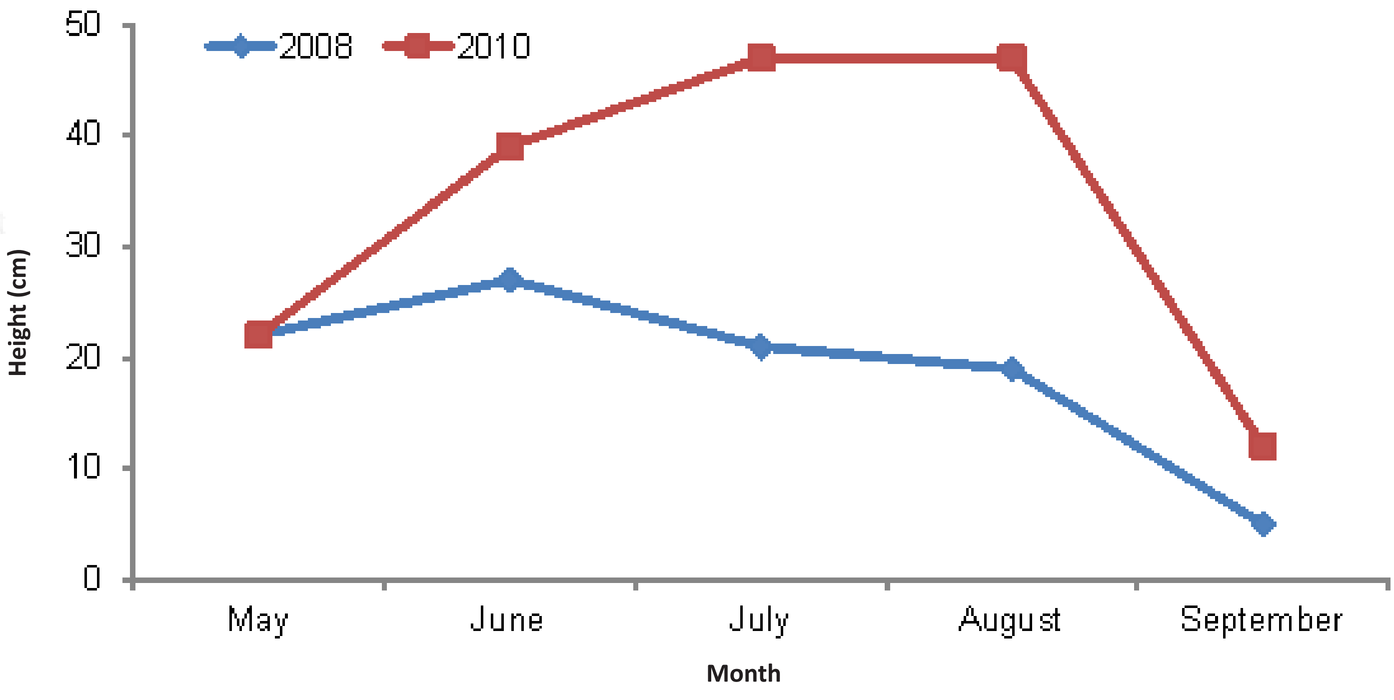

Figure 12. Pond level measurements at Great Pond (GP1) 2008 and 2010. Reference height (cm) is from water level to the top of the control board at the dam.

Bridges Upstream of Hollingsworth Pond. Four bridges are located less than a kilometer upstream of the Hollingsworth Pond: Plain Street Bridge, the MBTA train bridge, Washington Street Bridge, and Jefferson Street Bridge. The bridges were inspected during this habitat assessment, as well as the Gomez and Sullivan study (2009), and were found to present no elevation or velocity impediment to fish passage. The impoundment of Hollingsworth Pond, created by Armstrong Dam, extends to each of these bridges, causing a near level pool on both sides with low water velocity.

Farm River. The Farm River runs along a flat gradient that supports extensive wetlands and highly vegetated riparian buffer. Prior to the assessment, the potential for river herring to migrate through the slow-moving segments of the Farm River was uncertain. The FRWA conducted two canoe surveys of the Farm River: one prior to the habitat assessment in 2003 and one as part of the assessment in 2011. For both surveys, canoe passage was possible from West Street, at the Great Pond outlet, to the Monatiquot River confluence. There were locations where fallen branches had accumulated and had to be removed to pass a canoe. Some marshy segments had less channel definition during higher flow (2011) than average flow (2003). Overgrowth of vegetation, combined with debris build-up, required removal before the canoe could pass at 2-3 locations. These survey observations indicate that river herring can pass unimpeded up the Farm River to Great Pond, although periodic channel clearing is necessary to prevent large debris dams from disrupting the river channel. The surveys also noted that when the Richardi Reservoir diversion weir was deployed, canoe passage was not possible and river herring passage could be limited, depending on board placement at the diversion.

Richardi Reservoir Diversion. The Braintree Water Department operates a diversion weir in the Farm River next to the Richardi Reservoir to seasonally fill the reservoir, which is equipped with a pumping station to send water to Great Pond. When all stop logs are removed, there is no passage impediment for fish migrating to Great Pond at the diversion. Observations from the habitat assessment indicate that upstream passage would be possible at the diversion if as few as one bay was free of stop log boards. Spring movements of adult river herring are not expected to be impeded by the diversion operations. Restoration of river herring to Great Pond will require coordination of the seasonal operations of the diversion to accommodate upstream and downstream migration of river herring. The potential of the 51 acre Richardi Reservoir to serve as spawning and nursery habitat was not evaluated for the habitat assessment, due to the expected challenges of the diversion and pumping operation. However, this possibility should not be eliminated from future investigations on additional restoration options for the watershed.

Cochato River/Farm River Confluence. The confluence of the Cochato River and Farm River to the Monatiquot River at the Braintree Municipal Golf Course was visited during the habitat assessment to view fish passage conditions. A river channel fork separates the two tributaries at the Golf Course with no physical impediments to limit fish passage. The expected spring path for river herring at this confluence is the Farm River, given observed channel conditions and the flow calculations from Gomez and Sullivan (2009). However, this is not certain under lower flow conditions. Future restoration efforts should consider if stream channel improvements are needed to consolidated attraction flow for the Farm River at the channel fork.

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. A common example is a situation where stream flow would be adequate to provide upstream passage for spawning adult river herring or downstream passage of juveniles if an obstruction was not present. In that example the station would be classified as *Impaired* or *Unsuitable* for fish Passage and *Suitable* for stream flow. During the monitoring period of May through September, both outlets were classified as *Unsuitable* for stream flow because of active management to hold water back in Great Pond and Sunset Lake.

The Great Pond outlet (GP1) had no outflow during each of the 10 assessment inspections, but only minor leakage in 2008 that was repaired by the 2010 season. The Sunset Lake outlet (SU1) had a single observation in September 2008 with high flow over the sluice boards, which could have supported passage into Sunset Lake.

There was a change in management approach at the SU1 outlet from 2008 to 2010, as the installed metal boards with earth backfill greatly reduced leakage and overtopping frequency that likely occurred with the wood board stop logs observed in 2008. This change further reduced the potential for successful fish passage into Sunset Lake.

In addition to the lack of Sunset Lake outflow, the channel connecting Sunset Lake to Monatiquot River has restrictions to fish passage. The segment from SU1 to Pond Street is 120 m and was observed to be too shallow to support fish passage for all visits, except September 2008, following heavy rain. The straight channel appears man-made and had a maximum 2.5–5 cm of water depth with exposed cobble during most visits. The channel continues for about 350 m to meet the Monatiquot River at the golf course. A drainage ditch in the channel, before reaching the main stem, poses an elevation rise that herring are unable to pass. Similar to Richardi Reservoir, Sunset Lake presents difficult challenges for providing river herring access, yet future infrastructure projects should consider connectivity improvements to support aquatic life and American eel passage.

The Gomez and Sullivan (2009) study evaluated Tri-Town Board reports from 1989 to 2006 to assess Great Pond withdrawal rates relative to stream flow. Water use during this period was relatively consistent between 10 and 13 cfs (WMA authorization is 7.14 MGD or 11.05 cfs). Under most conditions for July through October, withdrawal rates exceeded available inflow. This resulted in declining water levels in Great Pond and the need to divert Richardi Reservoir water as a supplement. Both the assessment results and the Gomez and Sullivan (2009) report indicate that existing Great Pond outflows are not adequate for juvenile emigration in summer and may be limiting in low flow years for the latter half of the adult spawning migration in spring. Gomez and Sullivan (2009) provided analysis to support the consideration of flow augmentation to support the seasonal migration needs. The most direct solution proposed was to use existing operations at Richardi Reservoir to seasonally pump water as a specific supplement for fish passage.

Another option evaluated for improving river flow for river herring passage was to divert Cochato River flows to Richardi Reservoir for seasonal pumping to Great Pond. This was done formerly before the discovery of contaminated sediments and groundwater at the Baird and McGuire Superfund site. The drainage area of the Cochato River watershed is 27.7 km^2, which Gomez and Sullivan (2009) estimated could produce an average annual flow of 20 cfs. This amount of flow is presently supplying the Monatiquot River downstream of the Cochato and Farm river confluence. However, planned diversions of a portion of available Cochato River flows could provide the margin needed for seasonal migration needs. The most recent Superfund site sampling (US EPA 2009) found diminishing contaminants in groundwater at the site and no detection above action limits of contaminants in Cochato River surface water. Additional testing would have to provide convincing evidence that no contamination from the Superfund site would be present in the Cochato River water diverted to the Richardi Reservoir.

Eutrophication. The QAPP provides a process for using BPJ observations to assess if shoal transect stations are impacted by eutrophication. The indicators used are nutrients, DO, pH, turbidity, Secchi disc, and plant growth in the water column and substrate. When nitrogen and phosphorus data are available, the QAPP classification for eutrophication is based on US EPA criteria and not Best Professional Judgment.

The reference condition of eutrophication was classified as *Impaired* for TN and TP at Sunset Lake and TN at Great Pond based on the five nutrient measurements in 2010. Despite this status, there was little evidence of eutrophication at Great Pond. The TP average was low at 6.7 ug/L and the TN average of 0.301 mg/L was below the 0.32 mg/L criterion threshold. All BPJ eutrophication observations for GP2 in Great Pond were assessed as *Suitable*. There was limited water column plant growth and native vascular plants growing in the substrate. The water clarity was relatively high and the DO occurred in a suitable range.

Sunset Lake was classified as *Impaired* for both TN and TP, with only a single TP measurement under the threshold. Station SU4 at Sunset Lake was assessed as *Impaired* for BPJ eutrophication during each 2008 visit due to high substrate plant growth (75-100%), surface DO superstaturation, low bottom DO, and low water clarity. The conditions at SU4 changed dramatically in 2010 as bottom plant growth varied (5-40%) with improved water clarity and dissolved oxygen. The dense plant growth of pond weed and filamentous green algae in 2008 had given way to a largely silt bottom (60-90%) in 2010.

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 to 4 days. No spawning substrate classification was 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. Instead, the QAPP provides a qualitative protocol for assessing the percent composition of major substrate cover. To date, habitat monitoring during QAPP assessments supports the view that clean gravel is a better surface for egg survival than fine silt or dense periphyton growth.

The observations recorded on substrate conditions at GP2, off the Lower Reservoir Dam, found diverse substrata with native, vascular plants. The following average substrate proportions were estimated during 10 sampling dates: gravel (10%), sand (18.5%), silt (34%), periphyton (10.5%), and vascular plants (27%). The substrate base was comprised of mainly sand and gravel, with a thin and variable layer of silt. As the summer progressed, the proportion of periphyton and vascular plant coverage increased. Similar conditions and diversity were found during four sampling visits to GP5 off the dyke separating Upper and Lower Reservoirs. No invasive plants were observed in Great Pond during the assessment.

The substrate conditions at SU4 in Sunset Lake were starkly different between 2008 and 2010. All observations in 2008 were of 100% substrate cover of vascular plants, dominated by native waterweed and pondweed. In 2010, the plant growth diminished dramatically, as the bottom averaged 78% silt and only 14% vascular plants. Given the lapse of sampling in 2009, it is not clear if a plant die-off occurred after 2008. The invasive Eurasian milfoil was found in Sunset Lake during the habitat assessment, but only fragments were observed away from transect stations. Earlier work done by MassDEP on Sunset Lake also identified the presence of Eurasian milfoil (Reardon 2010).

Additional Water Quality Data

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 MassDEP 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 sub-ecoregion #59 is ≤1.7 NTU (US EPA 2001).

Similar to the Secchi disc measurements, the turbidity data at Great Pond reflected consistently high water clarity. The average turbidity for all samples at the three transect stations was 0.64 NTU (N = 75, SD = 0.615). Sunset Lake was consistently more turbid than Great Pond with mid-summer observations of plankton blooms. The average turbidity for all samples at the three Sunset Lake transect stations was 2.7 NTU (N = 63, SD = 2.199).

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 MassDEP or US EPA reference conditions are provided for conductivity, therefore the QAPP does not have a conductivity criterion. High conductance in freshwater can indicate watershed contributions of natural alkaline compounds or ionic contributions from pollution sources. Specific conductivity at Great Pond was moderate with little variability among stations and depth strata. The average for all transect measurements was 0.346 mS/cm (N=78, SD=0.052). Sunset Lake specific conductivity had similar stability and a higher average of 0.504 mS/cm (N = 63, SD = 0.031).

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 with a score ranging 0-100. Scores near zero would indicate uncommonly nutrient poor and low productivity conditions, while scores near 100 indicate extremely degraded and highly productive conditions. 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 depths for all Great Pond and Sunset Lake transect measurements resulted in TSI scores of 41.8 and 48.6, respectively. The mean TP measurements for GP4 and SU2 resulted in TSI scores of 31.6 and 49.0, respectively. The Sunset Lake scores were both at the upper end of the mesotrophy range, a trophic class supportive of swimming and aesthetic uses, but having the potential for hypolimnetic anoxia during summer. The Great Pond Secchi disc TSI was at the lower end of the mesotrophy range. The TP TSI was at the higher end of the oligotrophy range, a trophic class marked by high water clarity and suitable oxygen for most of the year.

Off-Transect Stations

Two sampling stations off the assessment transect were visited in Great Pond; no time was allotted to visit any in Sunset Lake. Station GP7 was sampled once during an attempt to find a second, deeper section of Great Pond alleged to occur on the side near the Holbrook-Randolph filtration plant and the dyke separating the two reservoirs. No deep areas, such as GP4, were found near GP7. Station GP7 had a maximum depth of 4.2 m on September 16, 2010 and suitable water chemistry for all parameters, with no stratification present. Station GP5 was located in shallow water off the reservoir dyke and visited as a potential spawning habitat site on four dates. The depth at GP5 was 1.7 m and water chemistry was suitable for all measurements. The substrate at GP5 had a favorable diversity of sediment sizes and native, vascular plants.

QA/QC Summary

Field and laboratory measurements conducted for the habitat assessment were guided by sampling protocols and data quality objectives from the project's QAPP (Chase 2010), which relies on parameter-based precision and accuracy indicators. Data were classified as Final, Conditional, or Censored based on the agreement of precision and accuracy checks to QAPP criteria. All laboratory calibrations and precision checks in 2008 were acceptable; no field precision checks were made in 2008.

Despite high accuracy and precision, the turbidity data in 2008 was found to be consistently low relative to the 0.0 NTU standard. Through troubleshooting and discussions with the manufacturer, a calibration method error was identified for a new model of turbidity sensor (YSI #6136). These data were adjusted using an YSI-approved correction and classified as *Conditional*.

All laboratory calibrations, and laboratory and field precision checks in 2010 were acceptable. No exceedances of the SOP accuracy specifications during calibration were recorded, except for pH mV (± 50 mV at pH 7.00), which were exceeded each month with increasingly negative values during the season. This response can indicate a failing pH sensor and triggers an evaluation of the stability of pH measurements and calibration performance. The deviation of pH calibration values to the standard buffer ranged from 0.00 to 0.11 with an average of 0.02 for both 7.00 and 4.00 buffers. The allowable SOP deviation is 0.2 pH units. These results indicate high accuracy in measurements made by an aging (high mV), but stable sensor.

Diadromous Fish Observations

Relatively few observations of diadromous fish were made during the 10 habitat assessment trips to the Fore River watershed. River herring were seen in May both years, below the natural falls and the McCusker Avenue falls. The peak aggregations below the natural falls exceeded a thousand fish both years where the numbers below the McCusker Avenue falls were several dozen to roughly one hundred. American eel (large yellow eel life stage) were observed below the Armstrong Dam and low numbers of young-of-the-year eels were found in the Sunset Lake outlet channel. Relatively high catches of rainbow smelt, American eel, and Atlantic tomcod have been made at the *MarineFisheries* Fore River fyke net station during 2004-2014, while intermittent catches have been made of alewife, white perch, sea lamprey, and striped bass.

Conclusion

The restoration goal of establishing a large river herring run to Great Pond was supported by favorable habitat assessment results, hydraulic and hydrologic analyses in the feasibility study, and the collaboration and continued support from the property owners and water suppliers. Despite these promising results, the restoration goals face the significant challenges of having adequate Great Pond outflow and the relatively high cost of addressing passage obstructions at three locations.

The Great Pond Reservoir assessment demonstrated among the most favorable water quality conditions documented by QAPP river herring habitat assessments in Massachusetts during 2007-2013. A single TN exceedance prevented a finding of *Suitable* for all QAPP water quality criteria; an outcome not documented by this project to date and not expected for urban areas. Great Pond had diverse substrata with no identified invasive plants, no evidence of eutrophication, and limited seasonal stratification at deep strata (7.5 m). The classification of *Impaired* for fish passage and stream flow was not unexpected, given the historical impediments and water supply management.

The Gomez and Sullivan study (2009) review of Great Pond water level data found the lowest reservoir water levels in the fall, coinciding with the timing of the juvenile herring emigration. The habitat assessment confirmed these results with no observations of outflow at Great Pond Dam for all 10 assessment visits. However, the pond level was a mere 5 cm from the top board at the dam in September 2008 and 12 cm away in September 2010. These pond level margins are relatively small and not far from an elevation that would allow outflow to support downstream passage. Overall, the habitat assessment observations give additional support to the Gomez and Sullivan study (2009) conclusion that river herring restoration was feasible if the physical passage improvements are coupled with water supply operations to release flow in the fall when juvenile herring need to migrate downstream.

In contrast to Great Pond, Sunset Lake had substantially lower water quality. Only dissolved oxygen, among all measured water quality parameter and best professional judgment classifications, was classified as *Suitable* to support river herring spawning and nursery habitat. The DO measurements were a single additional exceedance away from an *Impaired* classification, and showed bottom anoxia occurred throughout most of the sampling period. Sunset Lake had evidence of eutrophication, enhanced photosynthesis, and the presence of invasive plants. These poor habitat conditions, in addition to an impassible outlet dam and no outflow during summer months (for recreational activities), provide limited feasibility for providing river herring spawning and nursery habitat in Sunset Lake.

Recommendations

The habitat assessment of Great Pond demonstrated suitable water and habitat quality to support river herring spawning and nursery requirements. Passage impediments to adult river herring upstream migrations as well as flow limitations to allow juvenile escapement were documented by the habitat assessment and the Gomez and Sullivan (2009) feasibility study on river herring restoration. While the fish passage and flow limitations are substantial, the Gomez and Sullivan study (2009) demonstrated feasible options for providing fish passage and water supply operations that could allow the essential fall emigration of juvenile herring. Secondly, the annual presence of thousands of river herring in the main stem Monatiquot River, and 180 acres of high quality and protected habitat suggest substantial potential for establishing a relatively large run in the watershed. Therefore, we recommend that restoring a native river herring run to Great Pond should be a top natural resource restoration priority for the region. In addition, we offer the following recommendations to advance the shared goals of protecting this important water supply and restoring river connectivity and river herring.

1. Support and technical assistance should be provided to the Tri-Town Water Board in their efforts to enhance the capacity of Upper Reservoir and rehabilitate the Reservoir Dam.

2. The recommended next steps for river herring restoration planning in the Gomez and Sullivan (2009) feasibility study should be pursued. This includes additional analyses related to passage improvements at the Armstrong Dam and the initiation of project designs for the other three passage improvement locations.

3. The potential of the Cochato River to contribute to future water supply and watershed restoration goals should be further investigated. Support should be given to efforts to determine the present status of contamination in groundwater and surface waters.

4. The river herring spawning and nursery habitat assessment data should be provided to MassDEP to support 305(b) reporting and to assist local water quality protection.

Acknowledgements

Much appreciation is due to Lou Dutton and other staff of the Braintree Water Department for providing technical information on water supply operations and lending the use of their boat for Great Pond assessment trips. We are thankful for the volunteer efforts of the Fore River Watershed Association during the habitat assessment and for their advocacy throughout the watershed. This includes the early inspiration for restoration potential from Carl Pawlowski and Abby Franklin. This assessment is the third habitat assessment report to follow the QAPP for water quality measurements conducted for diadromous fish habitat monitoring (Chase 2010) approved by MassDEP in November 2009. The field and laboratory efforts of *MarineFisheries* are supported by the Sportfish Restoration Act.

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Appendix

Table A1. Station locations sampled during the Fore River watershed habitat assessment, 2008 and 2010.

No.	Latitude	Longitude	Station Type	Depth Strata	Maximum Depth (m)	Sample (No.)	Location
GP1	42° 12.346	71° 02.661	Outlet	Dam	NA	10	Great Pond Reservoir dam outlet
GP2	42° 12.313	71° 02.651	Transect	Shallow	2.3	10	Off GP1 outlet and exposed boulders
GP3	42° 12.220	71° 02.615	Transect	Mid	4.4	10	Along transect at mid-reservoir
GP4	42° 12.074	71° 02.607	Transect	Deep	7.7	10	Along transect adjacent to water plant
GP5	42° 11.805	71° 02.650	Survey	Shallow	1.7	4	Opposite side of Lower Reservoir off dyke
GP6	42° 11.760	71° 02.482	Outlet	Dam	NA	1	Outlet stationat Upper Reservoir dyke
GP7	42° 11.914	71° 02.652	Survey	Mid	4.2	1	Sampled while looking for deeper hole
SU1	42° 12.085	71° 00.928	Outlet	Outlet	NA	10	Sunset Lake dam outlet
SU2	42° 12.102	71° 00.644	Transect	Deep	7.6	9	Off the Braintree Park Department beach
SU3	42° 12.156	71° 00.804	Transect	Mid	3.0	9	Along transect towards pump house at HS
SU4	42° 12.212	71° 00.921	Transect	Shallow	1.4	9	Sunset Lake off HS pump house

Table A2. Summary water chemistry data collected at station GP2 at Great Pond Reservoir, 2008 and 2010. The maximum sample size at each depth level was 10.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	10	22.73	3.116	22.12	≤26.0 / ≤28.3	100
pH	(SU)	10	7.42	0.249	7.36	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.39	0.711	8.31	≥5.0	100
DO Saturation	%	10	97.2	6.596	96.2	NA	
Turbidity	(NTU)	10	0.3	0.469	0.4	NA	
Specific Conductivity	(mS/cm)	10	0.350	0.055	0.353	NA	
TN	(mg/L)					0.320	
TP	(µg/L)					8.000	
Secchi disk	(m)					≥2.0	

Bottom-water (1.8 m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	10	22.45	3.050	21.89	≤26.0 / ≤28.3	100
pH	(SU)	10	7.34	0.237	7.36	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.38	0.657	8.26	≥5.0	100
DO Saturation	%	10	96.5	5.111	95.8	NA	
Turbidity	(NTU)	10	1.1	0.868	0.8	NA	
Specific Conductivity	(mS/cm)	10	0.350	0.055	0.352	NA	

Note: Temperature criterion is ≤26.0°C for May-June and ≤28.3°C for July-September.

Table A3. Summary water chemistry data collected at station GP3 at Great Pond Reservoir, 2008 and 2010. The maximum sample size at each depth level was 10.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	10	22.73	3.150	22.57	≤26.0 / ≤28.3	100
pH	(SU)	10	7.44	0.179	7.41	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.48	0.613	8.33	≥5.0	100
DO Saturation	%	10	98.3	5.742	96.9	NA	
Turbidity	(NTU)	10	0.6	0.512	0.6	NA	
Specific Conductivity	(mS/cm)	10	0.350	0.055	0.353	NA	
TN	(mg/L)					0.320	
TP	(µg/L)					8.000	
Secchi disk	(m)	6	3.4	0.173	3.3	≥2.0	100

Bottom-water (3.7 m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	10	21.53	3.012	20.85	≤26.0 / ≤28.3	100
pH	(SU)	10	7.13	0.251	7.17	≥6.5, ≤8.3	100
DO	(mg/L)	10	7.47	1.839	7.82	≥5.0	100
DO Saturation	%	10	83.9	18.002	88.9	NA	
Turbidity	(NTU)	10	0.6	0.570	0.5	NA	
Specific Conductivity	(mS/cm)	10	0.349	0.054	0.353	NA	

Note: Temperature criterion is ≤26.0°C for May-June and ≤28.3°C for July-September.

Table A4. Summary water chemistry data collected at station GP4 at Great Pond Reservoir, 2008 and 2010. The maximum sample size at each depth level was 10.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	10	22.78	3.124	22.55	≤26.0 / ≤28.3	100
pH	(SU)	10	7.46	0.169	7.41	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.56	0.595	8.59	≥5.0	100
DO Saturation	%	10	99.3	5.093	97.6	NA	
Turbidity	(NTU)	10	0.6	0.508	0.6	NA	
Specific Conductivity	(mS/cm)	10	0.350	0.054	0.353	NA	
TN	(mg/L)	5	0.301	0.061	0.273	0.320	60
TP	(µg/L)	5	6.7	1.564	6.3	8.000	80
Secchi disk	(m)	9	3.7	0.412	3.6	≥2.0	100

Mid-water (3.1 m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	10	22.09	3.133	21.08	≤26.0 / ≤28.3	100
pH	(SU)	10	7.34	0.153	7.33	≥6.5, ≤8.3	100
DO	(mg/L)	10	8.37	0.738	8.21	≥5.0	100
DO Saturation	%	10	95.6	4.579	94.8	NA	
Turbidity	(NTU)	10	0.6	0.541	0.6	NA	
Specific Conductivity	(mS/cm)	10	0.349	0.054	0.352	NA	

Bottom-water (6.9 m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	10	18.42	1.522	18.19	≤26.0 / ≤28.3	100
pH	(SU)	10	6.98	0.337	7.02	≥6.5, ≤8.3	90
DO	(mg/L)	10	4.73	3.784	5.17	≥5.0	50
DO Saturation	%	10	50.2	41.000	54.9	NA	
Turbidity	(NTU)	10	0.8	0.698	0.7	NA	
Specific Conductivity	(mS/cm)	10	0.353	0.057	0.353	NA	

Note: Temperature criterion is ≤26.0°C for May-June and ≤28.3°C for July-September.

Table A5. Summary water chemistry data collected at station SU4 at Sunset Lake, 2008 and 2010. The maximum sample size at the 0.3 m depth was 10; at 0.9 m, the maximum sample size was 5. TN and TP were sampled only in 2010.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	9	24.05	3.168	24.96	≤26.0 / ≤28.3	89
pH	(SU)	9	7.94	1.065	7.45	≥6.5, ≤8.3	56
DO	(mg/L)	9	8.78	1.270	9.35	≥5.0	100
DO Saturation	%	9	104.7	17.895	104.8	NA	
Turbidity	(NTU)	9	1.6	0.894	1.1	NA	
Specific Conductivity	(mS/cm)	9	0.503	0.032	0.489	NA	
TN	(mg/L)	5	0.546	0.159	0.473	0.320	0
TP	(µg/L)	5	22.4	17.049	19.8	8.000	20
Secchi disk	(m)	0				≥2.0	

Bottom-water (0.9 m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	4	23.49	3.550	24.26	≤26.0 / ≤28.3	75
pH	(SU)	4	7.42	1.132	6.92	≥6.5, ≤8.3	75
DO	(mg/L)	4	7.06	3.852	5.79	≥5.0	75
DO Saturation	%	4	84.8	49.870	69.0	NA	
Turbidity	(NTU)	3	4.2	2.458	2.9	NA	
Specific Conductivity	(mS/cm)	4	0.480	0.010	0.478	NA	

Note: Temperature criterion is ≤26.0°C for May-June and ≤28.3°C for July-September.

Table A6. Summary water chemistry data collected at station SU3 at Sunset Lake, 2008 and 2010. The maximum sample size at deach depth level was 10.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	9	23.95	3.220	24.82	≤26.0 / ≤28.3	89
pH	(SU)	9	7.69	0.860	7.35	≥6.5, ≤8.3	67
DO	(mg/L)	9	8.26	1.053	8.85	≥5.0	100
DO Saturation	%	9	98.2	13.404	97.8	NA	
Turbidity	(NTU)	9	1.7	1.083	1.2	NA	
Specific Conductivity	(mS/cm)	9	0.504	0.032	0.502	NA	
TN	(mg/L)					0.320	
TP	(µg/L)					8.000	
Secchi disk	(m)	7	1.95	0.865	2.05	≥2.0	57

Bottom-water (2.5 m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	9	22.03	3.517	20.68	≤26.0 / ≤28.3	100
pH	(SU)	9	7.14	0.673	6.89	≥6.5, ≤8.3	89
DO	(mg/L)	9	6.44	1.593	6.62	≥5.0	89
DO Saturation	%	9	73.7	18.736	76.3	NA	
Turbidity	(NTU)	9	2.8	1.379	3.2	NA	
Specific Conductivity	(mS/cm)	9	0.505	0.033	0.508	NA	

Note: Temperature criterion is ≤26.0°C for May-June and ≤28.3°C for July-September.

Table A7. Summary water chemistry data collected at station SU2 at Sunset Lake, 2005 and 2010. The maximum sample size at each depth level was 10.

Surface (0.3 m depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	9	24.12	3.098	24.75	≤26.0 / ≤28.3	100
pH	(SU)	9	7.73	0.841	7.37	≥6.5, ≤8.3	67
DO	(mg/L)	9	8.38	0.941	8.76	≥5.0	100
DO Saturation	%	9	99.9	11.997	100.5	NA	
Turbidity	(NTU)	9	1.5	1.058	1.0	NA	
Specific Conductivity	(mS/cm)	9	0.505	0.031	0.502	NA	
TN	(mg/L)	0				0.320	
TP	(µg/L)	0				8.000	
Secchi disk	(m)	8	2.4	1.208	2.6	≥2.0	63

Mid-water (3.5 m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	9	20.58	2.529	20.22	≤26.0 / ≤28.3	100
pH	(SU)	9	7.03	0.401	6.99	≥6.5, ≤8.3	100
DO	(mg/L)	9	6.70	1.970	6.87	≥5.0	78
DO Saturation	%	9	74.3	20.197	76.0	NA	
Turbidity	(NTU)	9	2.0	0.918	1.6	NA	
Specific Conductivity	(mS/cm)	9	0.498	0.029	0.510	NA	

Bottom-water (7.0m average depth)

Parameter	Unit	N	Mean	SD	Median	WQ Criterion	Meeting Criterion (%)
Temperature	(°C)	9	12.42	1.342	12.86	≤26.0 / ≤28.3	100
pH	(SU)	9	6.74	0.156	6.70	≥6.5, ≤8.3	100
DO	(mg/L)	9	0.34	0.084	0.33	≥5.0	0
DO Saturation	%	9	3.2	0.862	3.1	NA	
Turbidity	(NTU)	9	5.2	1.651	5.3	NA	
Specific Conductivity	(mS/cm)	9	0.528	0.036	0.542	NA	