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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ABF</td>
<td>Aquatic Base Flow</td>
</tr>
<tr>
<td>ACO</td>
<td>Administrative Consent Order</td>
</tr>
<tr>
<td>ASR</td>
<td>Annual Statistical Report</td>
</tr>
<tr>
<td>BPJ</td>
<td>Best Professional Judgment</td>
</tr>
<tr>
<td>Brockton</td>
<td>City of Brockton, MA</td>
</tr>
<tr>
<td>C&amp;C</td>
<td>Coler &amp; Colantonio</td>
</tr>
<tr>
<td>cfs</td>
<td>cubic feet per second</td>
</tr>
<tr>
<td>cfsm</td>
<td>cubic feet per second per square mile</td>
</tr>
<tr>
<td>City</td>
<td>City of Brockton, MA</td>
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<tr>
<td>CDM</td>
<td>Camp, Dresser, and McKee, Inc.</td>
</tr>
<tr>
<td>CPCWDC</td>
<td>Central Plymouth County Water District Commission</td>
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<tr>
<td>CWMP</td>
<td>City of Brockton, MA DRAFT Comprehensive Water Management Plan</td>
</tr>
<tr>
<td>DCR</td>
<td>Massachusetts Department of Conservation and Recreation</td>
</tr>
<tr>
<td>DEP</td>
<td>Massachusetts Department of Environmental Protection</td>
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<tr>
<td>DER</td>
<td>Massachusetts Division of Ecological Restoration</td>
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<tr>
<td>MarineFisheries</td>
<td>Massachusetts Division of Marine Fisheries</td>
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<tr>
<td>DO</td>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>FIS</td>
<td>Flood Insurance Study</td>
</tr>
<tr>
<td>fps</td>
<td>feet per second</td>
</tr>
<tr>
<td>gpcd</td>
<td>gallons per capita per day</td>
</tr>
<tr>
<td>gpd</td>
<td>gallons per day</td>
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<tr>
<td>HMA</td>
<td>Hanson, Murphy &amp; Associates</td>
</tr>
<tr>
<td>ITA</td>
<td>Interbasin Transfer Act</td>
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<tr>
<td>JRWA</td>
<td>Jones River Watershed Association</td>
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<tr>
<td>LiDAR</td>
<td>Light Detection and Ranging</td>
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<tr>
<td>MassGIS</td>
<td>Massachusetts Office of Geographic Information</td>
</tr>
<tr>
<td>MG</td>
<td>million gallons</td>
</tr>
<tr>
<td>mgd</td>
<td>million gallons per day</td>
</tr>
<tr>
<td>NHESP</td>
<td>Natural Heritage &amp; Endangered Species Program</td>
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<tr>
<td>NGVD</td>
<td>National Geodetic Vertical Datum of 1929</td>
</tr>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<tr>
<td>PPI</td>
<td>Producer Price Index</td>
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<td>RIFLS</td>
<td>River Instream Flow Stewards</td>
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<td>SWQS</td>
<td>Surface Water Quality Standards</td>
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<tr>
<td>TN</td>
<td>Total Nitrogen</td>
</tr>
<tr>
<td>TP</td>
<td>Total Phosphorus</td>
</tr>
<tr>
<td>UAW</td>
<td>unaccounted-for water</td>
</tr>
<tr>
<td>USEPA</td>
<td>US Environmental Protection Agency</td>
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<td>US Fish and Wildlife Service</td>
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<td>WAA</td>
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<td>WMA</td>
<td>Water Management Act</td>
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<td>WRC</td>
<td>Massachusetts Water Resources Commission</td>
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1. **Introduction**

1.1 **Background**

The Massachusetts Division of Marine Fisheries (*MarineFisheries*), the Jones River Watershed Association (JRWA), and other project partners\(^1\) are evaluating the feasibility of restoring populations of river herring and American eel to Silver Lake in Kingston, MA, as well as considering additional benefits to all aquatic resources and water uses.

Silver Lake is an approximately 634-acre glacially formed lake that historically supported a large, native run of river herring. It is hydrologically connected to Cape Cod Bay by the 7.5-mile-long Jones River, which flows out of its southeast corner Forge Pond, a small impoundment created by Forge Pond Dam. However, a total of three historic mill dams on the mainstem Jones River have blocked fish passage and prevented river herring from reaching Silver Lake. In 2001, the lowermost dam at Elm Street was fitted with an upgraded fish ladder that efficiently passes river herring. In 2011, the second dam at Wapping Road (which presented a barrier to fish passage) was removed as part of a restoration project led by JRWA. Thus, Forge Pond Dam presents the remaining barrier to fish passage into Silver Lake.

Forge Pond Dam is owned and managed by the City of Brockton as a water control structure for Silver Lake, which has served as part of the City’s water supply for over 100 years. Water resources in the Jones River watershed are heavily managed for various anthropogenic purposes, including withdrawals for water supply and for cranberry bog operations located throughout the watershed. These management practices have artificially manipulated the magnitude, timing, and frequency of flows that would naturally occur in the Jones River and Silver Lake.

This project aims to document existing flow conditions and water supply management, as well as conduct new analyses to forecast the feasibility of providing fish passage at Forge Pond Dam under different scenarios of flow management and structural modifications (Chase, 2012). This Existing Information Report serves to compile relevant data from the various studies and reports that have been previously conducted. The next phase of the project will involve a more thorough hydrologic and hydraulic investigation, conceptual designs of fish passage options, and an alternatives analysis.

The natural resources of the Jones River and Silver Lake make fish passage at Forge Pond Dam one of the highest ranking priorities of *Marine Fisheries* for river herring restoration in Massachusetts. The living natural resources and water supply in the watershed have attracted many stewardship and management efforts from the Commonwealth, the City of Brockton, and the surrounding community.

1.2 **Existing Studies & Reports**

The value of the Jones River watershed is illustrated by the numerous relevant studies and reports that are available to assist this fish passage improvement project. The Jones River is the target of extensive monitoring of both aquatic resources and water quality. Silver Lake is a Class A drinking water reservoir that serves a large community and has received ongoing efforts from the City of Brockton to maintain an adequate water supply. The JRWA has conducted annual river herring counting at Elm Street Dam since 2005, and is active in partnerships to monitor flow and water quality throughout the watershed.

---

\(^1\) Project partners include the Massachusetts Division of Marine Fisheries (*MarineFisheries*), City of Brockton, National Oceanic and Atmospheric Administration (NOAA), Massachusetts Division of Ecological Restoration (DER), Town of Kingston, and Jones River Watershed Association (JRWA).
*MarineFisheries* has maintained a glass eel monitoring project at the Elm Street Dam since 2001 and a rainbow smelt fyke net in the tidal estuary since 2004, which has documented a total of eight species of diadromous fish in the Jones River. In 2008-2009, the JRWA and *MarineFisheries* conducted a river herring spawning and nursery habitat assessment in Silver Lake that documented suitable conditions to support river herring life history (Chase, 2012).

This existing information report was compiled primarily from the following sources, listed in reverse chronological order:

- **City of Brockton, MA DRAFT Comprehensive Water Management Plan** (City of Brockton, 2009) – Prepared by the City of Brockton to address the requirements of their modified Water Management Act (WMA) permit issued by the Massachusetts Department of Environmental Protection (DEP). Still in draft stage; not yet approved by the DEP. Referred to in this report as the draft CWMP.

- **Wapping Road Dam Feasibility Study** (Milone & MacBroom, 2009) – Prepared for the JRWA to investigate fish passage options for the Wapping Road Dam, which was successfully removed in October 2011. Referred to in this report as the Wapping Road Dam report.

- **South Coastal Watershed Action Plan** (Watershed Action Alliance (WAA) of Southeastern Massachusetts, 2006) – Studied several Massachusetts watersheds with input from nonprofit groups, public agencies, and private individuals. It made recommendations to protect and restore the south coast's natural resources, including the Jones River. Referred to in this report as the Watershed Action Plan.


- **Silver Lake Water Supply System Overview Report** (Hanson, Murphy & Associates (HMA), 2006). Prepared for the City of Brockton to assess the components of the Silver Lake water supply system and determine whether modifications to infrastructure and/or operating procedures should be considered, with the overall intent of maintaining the high water quality of Silver Lake. Referred to in this report as the HMA water supply inspection report.

- **Silver Lake Water Quality Assessment: A Silver Lake Community Awareness Project** (ESS Group, 2004) – Prepared for the JRWA and the Town of Kingston under benefit of Department of Environmental Management (DEM) Lakes and Ponds Grant Program to study water and sediment quality of Silver Lake for the purposes of understanding nutrient loading dynamics.

- **Jones River Watershed Study** (GZA, 2003) – Prepared for the DEM to conduct a water use inventory and an inflow/outflow analysis of the Jones River watershed and its subbasins.

- **Bathymetric Mapping of Silver Lake and Forge Pond** (Coler & Colantonio (C&C), 2003) – Prepared for the JRWA Silver Lake Stewardship Project with funding by the Massachusetts Watershed Initiative through the Executive Office of Environmental Affairs.
• **Silver Lake and Jones River Watershed Study** (Teal, 2000) – Teal, Ltd. conducted studies of the Jones River in 1989 and 2000. The 2000 study, conducted with the assistance of and for the JRWA, provided a historic framework for some of the important developments within the watershed. A variety of indices were studied whereby flows, water quality, vegetation, fish, and macroinvertebrate sampling occurred.

## 2. Existing Environment

### 2.1 Jones River Basin

The Jones River runs approximately 7.5 miles through the town of Kingston, Massachusetts from its headwaters in Silver Lake to Kingston Bay. With an area of approximately 29.8 square miles, it is one of the largest watersheds draining to Cape Cod Bay (GZA, 2003). **Figure 2.1-1** on the following page depicts the Jones River watershed and major features, including the smaller subbasins at the Forge Pond Dam spillway (4.2 square miles) and at the natural outlet of Silver Lake (4.1 square miles).

Silver Lake is the geographic headwater of the Jones River watershed. The lake falls within Pembroke, Kingston, and Plympton, with Halifax bordering most of its western edge. Silver Lake receives some flow from tributaries including Tubbs Meadow Brook in Pembroke and Mirage Brook in Kingston. The lake is recharged predominately from groundwater springs and thus would have excellent water quality under natural conditions (WAA, 2006).

Silver Lake is one of the largest natural lakes in Massachusetts, with a surface area of one square mile or about 634 acres (WAA, 2006). The Lake is just over two miles long, one-half mile wide, and has a maximum depth of over 70 feet, with an average depth of approximately 24 feet. The basin’s relatively narrow configuration, coupled with its deep depths, result in bottom contours that are moderately to steeply sloped. Calculations based on the bathymetric data indicate that the lake has an approximate volume of approximately 685 million cubic feet or 5.12 billion gallons (ESS, 2004).

Forge Pond Dam, owned by the City of Brockton, restricts flow from Silver Lake. Forge Pond is itself part of the Jones River and begins at the natural outlet of Silver Lake. An aerial image of Forge Pond depicting the dam and the natural lake outlet is shown in **Figure 2.1-2**.
Because the dam is higher in elevation than the natural outlet of Silver Lake, a disconnect can occur between the two water bodies when the lake level is drawn down below its outlet. Forge Pond has its own small watershed (approximately 0.1 square miles) and even when Silver Lake is drawn down, would provide some flow downstream. However as a result of the dam (which lacks a low level outlet), these small but potentially sustaining flows can trickle backwards into Silver Lake when the lake level is lower than the outlet, leaving the upper Jones River dry. Wetlands downstream, on the east side of Lake Street, provide base flow and replacement head to begin the Jones River when no water flows over the Forge Pond Dam (WAA, 2006).

Throughout the Jones River watershed, water resources are heavily managed for various anthropogenic purposes, including withdrawals for water supply and cranberry bog operations. These management practices have impacted the magnitude, timing, and frequency of flows that would naturally occur in the Jones River. Figure 2.1-3 is a flowchart developed by the JRWA depicting the various water supply withdrawals, dams, cranberry bogs, and other factors influencing the natural flow of the Jones River.
Figure 2.1-1: Jones River Watershed Map
Figure 2.1-3: Run-of-River Influences in the Jones River Watershed

Note: The Wapping Road Dam was removed in 2011 and no longer blocks fish passage. Source: JRWA, 2006.
2.2 Jones River Structures

Several dams, culverts, and other structures either currently present an obstacle to fish passage, historically have done so, or have the potential to do so under certain flows. This section examines the major structures along the mainstem of the Jones River relative to fish passage.

2.2.1 Elm Street Dam and Former Wapping Road Dam

The Elm Street Dam historically presented the first obstacle to fish moving upstream from the Kingston Bay. The dam was formerly equipped with a deteriorating, obsolete, notched weir-pool ladder. In 2001, this structure was fitted with an aluminum steeppass insert at the recommendation of Marine Fisheries (Reback et al., 2004). The JRWA conducts a yearly fish count at the ladder (since 2005), which has shown that river herring are now able to efficiently move beyond the dam.

The former Wapping Road Dam, which was not fitted with any fish passage structures, historically presented the next obstacle. Its removal in October 2011 opened up fish habitat on 3.7 miles of the Jones River mainstem and 18.3 miles of tributaries. The restoration effort was led by the JRWA.
2.2.2 Grove Street and Conrail Culverts

Upstream of the former Wapping Road Dam, the culverts at Grove Street and the Conrail crossing just below it were assessed for fish passage as part of this study. Water is passed under Grove Street via two corrugated metal pipe culverts separated by approximately 20 feet and having diameters of 2.9 feet and 3.8 feet. The Conrail opening consists of an open-bottom stone arched culvert approximately 6.6 feet wide.

Interestingly, during a May 3, 2012 site visit, no flow was observed at the culverts even though 1.2 cfs\(^2\) was being passed upstream at Forge Pond Dam. Presumably, water withdrawals were occurring for cranberry bog irrigation between Grove Street and the dam. However, even with no observable flow, both Grove Street openings as well as the Conrail culvert were backwatered throughout with a depth of over one foot (sufficient to pass herring) and velocities were negligible.

\(^2\) Flow reported by MA DER RIFLS staff (average of two flow measurements taken at the Lake Street culvert during the May 3, 2012 site visit).
2.2.3 Lake Street Culvert

Immediately below Forge Pond Dam (100 feet downstream), flow is passed under Lake Street via a concrete culvert approximately 55 feet long and 4 feet in diameter. During a site visit, the water depth in the culvert was approximately 0.5 feet when 1.2 cfs was being passed at the dam. This culvert will be included in the hydraulic model for this study to assess whether fish will be able to pass through it to/from the base of the Forge Pond Dam during migration periods.

The Massachusetts Division of Ecological Restoration (DER) has installed a gage to measure river stage height at the Lake Street culvert as part of their River Instream Flow Stewards (RIFLS) program. The site was established in 2003 to monitor streamflow impacts on the Jones River of management of the upstream Silver Lake for water supply. The data collected at this gage is discussed in Section 4.1.2.

Upstream face of Lake Street culvert with RIFLS staff gage Looking upstream from Lake Street culvert to access road and culverts below Forge Pond Dam, with Forge Pond in background

Photograph source: MA DER, 2006 (left) & 2007 (right)
2.2.4 Forge Pond Dam

Forge Pond Dam is the last remaining barrier preventing fish access to Silver Lake. The dam has no fish ladder and presents a barrier to upstream fish passage. Built circa 1905, the dam is owned by the City of Brockton and is used to maintain the water level in Silver Lake artificially high for the purposes of water supply management. It is classified as a large, low hazard\(^3\) dam and is listed in fair to poor condition according to the 2003 inspection summary obtained from the MA Office of Dam Safety. The next dam safety inspection is due in 2013.


**Figure 2.2.4-2** below is a schematic (not-to-scale) of Forge Pond Dam showing the 38-foot-wide spillway and three stoplog openings, each with an effective width of approximately 4.3 feet. Although there is some discrepancy regarding the spillway crest elevation (see discussion in Section 3.2.1), the most recent survey by Coler & Colantonio in 2003 documented the elevation as 47.6 ft NGVD 29,\(^4\) which is the elevation that will be used for the purposes of this study.

\(^3\) The low hazard classification means that dam failure may cause minimal property damage and loss of life is not expected. In Massachusetts, low hazard dams are inspected every 10 years. Even though it is not a physically large dam, Forge Pond Dam is classified as ‘large’ due to the relatively large amount of storage in Silver Lake.

\(^4\) National Geodetic Vertical Datum of 1929.
Figure 2.2.4-2: Forge Pond Dam Schematic – Elevation View

Note: Not to scale. Elevations based on NGVD 29. The elevation of the top of flashboards may be adjusted from 47.9 ft (current position) down to 46.1 ft depending on the number of boards used.

Figure 2.2.4-3 below is a plan view schematic of the Forge Pond Dam area down to the Lake Street culvert. The hydraulics below the dam are complex, as discharge at the dam can pass through one of three openings ranging in width between 5.5 and 6.5 feet that pass beneath an access road (former Lake Street). These openings have vertical walls and flat channel bottoms. During a site visit, the water depth through the openings was minimal when the flow at the dam was 1.2 cfs.

Figure 2.2.4-3: Forge Pond Dam Area Schematic – Plan View
2.3 Fishery Resources

2.3.1 Target Species

A primary goal of this project is to provide upstream and downstream fish passage into and out of Silver Lake for diadromous and resident species. The term “diadromous” refers to fish that migrate between fresh water and marine environments, and includes both anadromous and catadromous types. Anadromous fish hatch from eggs deposited at fresh water habitats, migrate as juveniles to salt water where they remain until maturity, then return to natal rivers to complete their reproductive cycle. Catadromous fish spawn in the ocean and migrate to fresh water to grow to adult size.

The target fish species that would likely benefit most from achieving fish passage into Silver Lake are the anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), known collectively (informally) as river herring. A number of other species may also benefit from restoration activities, including the catadromous American river eel (*Anguilla rostrata*), as well as resident fish species.

**River Herring**

In Massachusetts, more than 100 coastal rivers and streams are home to the anadromous alewife and blueback herring. Estimates of catch rates, spawning runs, and management goals of these two closely related species are often grouped together due to the difficulty in distinguishing them from one another (Nelson et al., 2011).

River herring are ecologically important because they serve as forage for many marine and freshwater fish predators such as striped bass, cod, and yellow perch, as well as birds. River herring also provide recreational and cultural benefits to citizens who value them for food and bait (Nelson et al., 2011). Additionally, their migration plays a role in the transfer of nutrients between freshwater and marine systems.

Historically, river herring were one of the most valuable anadromous fishes harvested commercially in Massachusetts and sold as food or commercial bait. In the early days, considerable interest was shown by the town of Kingston in the welfare of its several herring streams. Records show that in 1872 and 1873, Kingston deposited 3,000 alewives in Silver Lake. Attempts were made to transport as many fish as possible over the dams for spawning, and in 1913 an appropriation of $100 was made by the town to encourage the building of fishways (Belding, 1921).
In recent years, however, river herring abundance in several runs throughout Massachusetts has declined to historically low levels. In 2005, the declines prompted Marine Fisheries to establish a three-year moratorium on the sale and harvest of river herring throughout the state, which has since been extended and is still ongoing. In addition, the National Marine Fisheries Service has listed blueback herring and alewife as Species of Special Concern under their Endangered Species Act review process (Nelson et al., 2011) and is presently reviewing a petition to list river herring under the Act.

While both species are capable of spawning in a variety of freshwater environments, bluebacks spawn in more riverine areas, whereas alewifes tend to spawn in more lacustrine (ponds and lakes) areas. Alewifes begin to spawn in late March to mid-May when water temperatures reach about 10.5°C, but they have been observed in earlier months. Bluebacks begin to spawn later in the spring (late April through June) when water temperatures reach about 13.9°C. The eggs of both species are initially adhesive then become semi-bouyant and can remain where deposited or move downstream in higher stream flow. After utilizing the freshwater habitat for a nursery area for most of the summer, juvenile herring begin their migration to the ocean in July. Migration peaks usually occur in late summer and early fall but are variable and can continue into December. After maturing in the marine environment for until about 3 to 5 years of age, the fish return to their natal streams utilizing their olfactory sense to guide them (Nelson et al., 2011).

The JRWA coordinates an annual river herring count at the Elm Street Dam fish ladder. Figure 2.3.1-1 below shows the estimated river herring run for the years 2005 through 2011. The 2011 herring run was estimated at about 3,597 (± 257). This was less than the estimate for 2010 but greater than estimates for 2005-2009. Factors that may be influencing river herring population dynamics in the Jones River watershed include the installation of the new fish ladder at Elm Street Dam in 2001 (perhaps responsible for the upward slope of the herring run) and the state moratorium on harvesting river herring since 2005 (JRWA, 2011a).

**Figure 2.3.1-1: River Herring Run Sizes in Jones River (2005-11)**

![Bar chart showing river herring run sizes (2005-2011)](source: JRWA, 2011a)
**American Eel**

The American eel is a catadromous fish that spends its lifetime in ponds and rivers and migrates to the ocean to spawn. All adult American eels spawn in the Sargasso Sea located in the Atlantic Ocean. The larvae drift into the Gulf Stream and mature into clear "glass eels" as they approach the coast in winter. Glass eels in Massachusetts run up coastal rivers from March to June and soon after develop into elvers (immature eels). American eel spend between eight and 25 years in freshwater rivers before the mature silver eels emigrate to marine waters between September and November.

American eels are the only catadromous fish in North America and have a semelparous life history where they spawn once upon reaching maturity then die. American eels are sexually dimorphic with adult females reaching a maximum length of about 40 inches and males only reaching 16 inches before maturity. Adults descend rivers in the fall, and juveniles travel upstream in the spring. American eels travel at a cruising speed of 2.4 fps and can reach a burst speed of 6.0 to 7.0 fps.

*MarineFisheries* has conducted young-of-the-year (YOY) abundance surveys using a Sheldon elver trap on the Jones River below the Elm Street Dam annually since 2001. Trap catches from 2005-2008 ranged from 18 to 21 thousand glass eels annually; the highest catches for this period among four YOY eel trap stations in Massachusetts. Trap catches in 2009 and 2010 declined to less than 10 thousand eels both years (Chase, 2011). The Jones River YOY eel data series was accepted as an ongoing relative index of abundance for the 2012 American Eel Stock Assessment by the Atlantic States Marine Fisheries Commission's American Eel Stock Assessment Subcommittee. The USFWS is currently reviewing a petition to be listed as a threatened species under the Endangered Species Act.

**Freshwater Mussels**

Silver Lake is a habitat for freshwater mussels. Because freshwater mussels are essentially sedentary filter feeders that spend most of their lives partially burrowed into the bottoms of rivers, lakes, and ponds, they are unable to flee from degraded environments and are vulnerable to the alterations of water bodies (NHESP, 2009a and 2009b). Although mussels are not a primary target species of this study, they may benefit indirectly from proposed alterations in Silver Lake water level management and water quality enhancements.

A mussel survey conducted in 2002 (McCoy, et al.) in the vicinity of the Silver Lake Sanctuary (near the natural outlet to Forge Pond) found the freshwater mussel species shown in Figure 2.3.1-2 below. The tidewater mucket and eastern pondmussel are listed as Species of Special Concern by the MA Natural Heritage & Endangered Species Program (NHESP). These species are currently known to exist in about two dozen lakes and ponds in Massachusetts, but less than 10 of these sites support sizable populations (NHESP, 2009a and 2009b).
A more thorough mussel survey was conducted in 1999 as part of the Silver Lake and Jones River Watershed Study (Teal, 2000), in which freshwater mussels were sampled along Silver Lake by collecting spent shells during receding water levels in the fall. This study addressed the findings of a mussel survey conducted by Normandeau Associates in 1997 that suggested that impacts from water level manipulations on mussel populations are probably minimal. However, collections of stranded mussels in 1999 indicate that the smaller sizes and younger age classes were not well represented in Normandeau’s study. Additionally, the shallow nature of Silver Lake’s shoreline zones (see description of bathymetry, Section 2.4.1) leads to significant exposure of mussel habitat with proportionally small declines in water level. The Teal study concluded that the shallow photic zones may provide important nurseries for freshwater mussels, and water level management may potentially have significant impacts upon the freshwater mussel populations in the long term.

### 2.3.2 Fish Passage Requirements

In order for diadromous fish to readily pass to and from their spawning habitat, certain physiological and behavioral needs and physical river conditions must be met, including seasonal flow magnitudes,
depths, and velocities. These characteristics vary among the target species. Important considerations for restoration activities are described below.

**Flow Timing**

Although it would be desirable to maintain a continuous, seasonally varying flow below Forge Pond Dam—not just flows needed to pass migratory fish—it is recognized that the Jones River watershed is a highly managed system and there will need to be a balance for both water supply and minimum flow needs.

For example, under the potential restoration scenario of a fish ladder being installed at Forge Pond Dam, rather than discharging flows to attract fish to the ladder throughout the full migration season, these releases could be triggered when herring are observed passing the Elm Street ladder. After the river herring run is complete, dam releases could be reduced to a lower level to pass post-spawning adults and then modified again to pass emigrating juvenile herring in the fall. A higher flow release may be needed to ensure juveniles find the exit from Silver Lake and Forge Pond.

Table 2.3.2-1 below summarizes key timeframes during which flows will be needed for the various life stages and events of the target species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Life Stage</th>
<th>Event</th>
<th>Month</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>River herring</strong></td>
<td>adults</td>
<td>upstream migration</td>
<td>MAR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MAY</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>JUN</td>
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<td></td>
<td></td>
<td>JUL</td>
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<td></td>
<td>AUG</td>
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<td></td>
<td></td>
<td>SEP</td>
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<td></td>
<td></td>
<td></td>
<td>OCT</td>
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<td></td>
<td></td>
<td>NOV</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>DEC</td>
</tr>
<tr>
<td></td>
<td>juveniles</td>
<td>downstream emigration</td>
<td>MAR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MAY</td>
</tr>
<tr>
<td><strong>American eel</strong></td>
<td>elvers</td>
<td>upstream migration</td>
<td>MAR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APR</td>
</tr>
<tr>
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<td>MAY</td>
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<td>JUN</td>
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<td>JUL</td>
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<td>AUG</td>
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<td>SEP</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>DEC</td>
</tr>
<tr>
<td></td>
<td>silver eels</td>
<td>downstream emigration</td>
<td>MAR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MAY</td>
</tr>
</tbody>
</table>

**Water Depth**

Water depth in the river channel and through obstacles such as culverts must be sufficient to accommodate the physical dimensions of fish navigating upstream. Adult alewife average 10 to 14 inches in length and weigh less than a pound. Blueback herring are generally smaller than alewife, averaging around 9.5 to 12 inches in length.

Scant literature exists with respect to required depths for passage; thus, general guidelines are used to estimate critical passage depths. Critical passage depth is typically estimated as 1.5 times the target species body thickness, which for alewife (the larger of the two river herring species) can be assumed to be 30% of total body length. For example, based on an adult alewife body length of 14 inches, body thicknesses can be estimated as 4 inches, and the minimum depth required for passage would be about 6 inches, which may also be suitable for blueback herring and other smaller species (Milone & MacBroom, 2009).

Bovee (1992) suggests lower minimum water depths of two thirds body depth, but recommends that this criterion should be tempered by the number and length of crossings the fish must make. Bovee
noted that if fish encounter few passage barriers, they can likely negotiate fairly shallow water. However, the same species moving up a stream with many obstacles may arrive at the spawning area in poor condition if passage depths are minimal.

Based on existing information and years of experience, MarineFisheries recommends a minimum water depth of 6 inches and a preferred range of 8-12 inches for the spawning migration of adult river herring. For the juvenile herring emigration, MarineFisheries recommends a minimum water depth of 2 inches and a preferred range of 4-8 inches. These guidelines can be adjusted using site-specific information, and address only depth for swimming; they do not reflect factors that can be affected by depth and have an influence on fish survival such as temperature, oxygen, and predation.

It should be noted that there is a direct correlation between water depth, temperature, and dissolved oxygen (DO) within a stream system. During warmer months (June to August) shallow streams will heat up and DO will decrease. In order to maintain sufficient levels of DO in the stream for herring and other aquatic organisms, flow management would be needed during warmer months to ensure adequate water depths. A more detailed water quality investigation would be needed to correlate water depth, temperature, and DO in the Jones River system and recommend appropriate flows.

**Velocity Barriers**

Diadromous and other migratory riverine species often encounter zones of high velocity flow, such as where flow is restricted going through a culvert, that impede their migrations. Adult river herring travel in schools at a cruising speed of 2.8 feet per second (fps) and can reach burst speeds of 6.8 fps. Where these flows exceed maximum sustained swim speed, successful passage may still be possible, provided that fish select an appropriate swim speed.

Several studies have investigated the swimming speeds of river herring (and other anadromous fish) through velocity barriers (Haro et al., 2004; Castro-Santos, 2006). Most of this research has been conducted at the Conte Anadromous Fish Research Center in Turners Falls, MA under controlled conditions in a flume. Haro et al. developed a model called SPRINTSWIM – Fish Swimming Performance Calculator to predict passage success rates for anadromous fish species (including alewife and blueback herring) under various velocity conditions and distances.

As expected, passage rates are higher under lower velocities and shorter distances. For example, under a velocity of 1.6 fps and distance of 49 feet (comparable to the length of the Lake Street culvert at 55 feet), 74% of alewives are predicted to successfully pass, whereas only 67% are predicted to pass a distance of 66 feet under the same velocity. Blueback herring appear to be stronger swimmers than alewife. The studies suggest that 83% to 95% of blueback herring between 8 and 10 inches in length would be able to travel a distance of 66 feet against linear flows of 1.6 fps compared to only 67% for alewives under the same conditions. Swimming performance also generally increases with fish length (Haro et al., 2004).

Although the program is based on experiments in a controlled environment (i.e., a flume) rather than natural conditions where velocities across a river cross-section will vary, its estimates represent the best available information at this time. For this study, the results of the hydraulic model will be input into the SPRINTSWIM program to assess whether river velocities during the migration season will be within a range to permit upstream passage of river herring, particularly at the Lake Street culvert downstream of Forge Pond Dam.
2.3.3 Water Quality of Silver Lake to Support River Herring Spawning & Rearing

Based on historical accounts and ongoing monitoring for river herring, smelt and eel, MarineFisheries has characterized the Jones River as one of the most valuable moderate-sized drainages on the Gulf of Maine coast for providing diadromous fish habitat. However, before pursuing fish passage at Forge Pond Dam, it is important to assess whether Silver Lake can presently provide adequate habitat for spawning and rearing river herring. MarineFisheries conducts river herring spawning and nursery habitat assessments to assist habitat and population restoration efforts and to contribute to DEP Waterbody Assessments (Chase, 2010a). Silver Lake was assessed during 2008-2009 in collaboration with the JRWA. Although the technical report for this study is still in preparation, the data was obtained for this report. The Silver Lake assessment documented suitable conditions to support river herring life history. Table 2.3.3-1 lists suitable ranges for various physical, chemical, and biotic criteria with regards to river herring spawning and nursery habitat. These thresholds were compiled by MarineFisheries from various sources, including DEP’s Surface Water Quality Standards (SWQS, 2007), the US Environmental Protection Agency’s (USEPA) Ambient Water Quality Criteria Recommendations (2001), scientific literature, and Best Professional Judgment (BPJ).

### Table 2.3.3-1: Physical, Chemical, & Biotic Criteria for River Herring Spawning and Nursery Habitat

<table>
<thead>
<tr>
<th>Variables</th>
<th>Suitable (SWQS or BPJ)</th>
<th>Minimally Impacted (25th percentile)</th>
<th>Notes/Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>REFERENCE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(July-Oct, nursery)</td>
<td>≤ 28.3</td>
<td>Maximum limit (DEP, 2007)</td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>≤ 26.0</td>
<td>Scientific literature and BPJ</td>
<td></td>
</tr>
<tr>
<td>(May-Jun, spawning)</td>
<td>≤ 20.0</td>
<td>7-day mean of daily max from logger data (DEP, 2007)</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>≥ 6.5 to ≤ 8.3</td>
<td>(DEP, 2007)</td>
<td></td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>≥ 5.0</td>
<td>(DEP, 2007)</td>
<td></td>
</tr>
<tr>
<td>Secchi disc depth (m)</td>
<td>≤ 2.0</td>
<td>75th percentile; EPA Ecoregion 14, sub-84 (USEPA, 2000b)</td>
<td></td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>≤ 1.7 (rivers only)</td>
<td>EPA Ecoregion 14, sub-59 (USEPA, 2000a)</td>
<td></td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>≤ 0.32</td>
<td>EPA Ecoregion 14, sub-59 (USEPA, 2000b)</td>
<td></td>
</tr>
<tr>
<td>TP (ug/L)</td>
<td>≤ 8.0</td>
<td>EPA Ecoregion 14, sub-59 (USEPA, 2000b)</td>
<td></td>
</tr>
<tr>
<td>Chlorophyll a (ug/L)</td>
<td>≤ 4.2</td>
<td>EPA Ecoregion 14, sub-59 (USEPA, 2000b)</td>
<td></td>
</tr>
<tr>
<td><strong>QUALITATIVE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish Passage</td>
<td>BPJ</td>
<td>Section 4.0 of QAPP (Chase, 2010a)</td>
<td></td>
</tr>
<tr>
<td>Stream Flow</td>
<td>BPJ</td>
<td>Section 4.0 of QAPP (Chase, 2010a)</td>
<td></td>
</tr>
<tr>
<td>Eutrophication</td>
<td>BPJ</td>
<td>Section 4.0 of QAPP (Chase, 2010a)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Water chemistry parameters relate to Massachusetts Class B SWQS for protecting Aquatic Life (DEP, 2007). USEPA reference conditions are recommendations and are reported here for the Northeast Coastal Zone ecoregion 59, with the exception of sub-ecoregion 84 (includes Cape Cod) for secchi disc depth (USEPA, 2000b). Additional references (75th percentile), variables, and criteria (optimal, unsuitable) may be developed following the application of projects under Section 4.0 of the QAPP for water quality measurements for diadromous fish habitat monitoring, from which this table was taken (Chase, 2010a).
Figures 2.3.3-1 through 2.3.3-5 present average water temperature, dissolved oxygen (DO), pH, Secchi disc depth (a measure of water clarity), and total nitrogen and phosphorous levels for Silver Lake collected during 2008 and 2009.

**Figure 2.3.3-1: Average Water Temperature of Silver Lake (2008-09)**

![Average Water Temperature of Silver Lake (2008-09)](image)

Notes: Station averages are presented (+/- 2 SE) for 2008 (blank bars) and 2009 (striped bars). Six samples were targeted for each depth. Green lines mark the thresholds for nursery and spawning temperatures recommended by the DEP SWQS and scientific literature, respectively. Source: Chase, 2010b.

**Figure 2.3.3-2: Average Dissolved Oxygen (DO) of Silver Lake (2008-09)**

![Average Dissolved Oxygen (DO) of Silver Lake (2008-09)](image)

Notes: Station averages are presented (+/- 2 SE) for 2008 (blank bars) and 2009 (striped bars). ‘SL1’, etc. labels indicate stations. Six samples were targeted each depth. Green lines mark the DEP SWQS threshold for DO (5.0 mg/L). Source: Chase, 2010b.
Figure 2.3.3-3: Average pH of Silver Lake (2008-09)

Notes: Station averages are presented (+/- 1 SD) for 2008 (blank bars) and 2009 (striped bars). Green lines mark DEP SWQS thresholds for pH. ‘SL1’, etc. labels indicate stations. Source: Chase, 2010b.

Figure 2.3.3-4: Average Secchi Disc Depth in Silver Lake (2008-09)

Notes: Average of measurements at various stations. Green lines represent USEPA Secchi disc depth thresholds for subecoregions #59 (project area) and #84 (Cape Cod). Because the criterion for subecoregion #59 of ≤4.9 m is
higher than typical water clarity seen in MA coastal drainages, the criterion for subecoregion #84 of ≤2.0 m was adopted by the QAPP as suitable to support aquatic life. Source: Chase, 2010b.

Figure 2.3.3-5: Average Total Nitrogen (TN) & Total Phosphorous (TP) of Silver Lake (2008-09)

Notes: N = 10. Green lines mark the US Environmental Protection Agency (EPA) water quality recommended thresholds for TN & TP. Data for Upper Mystic Lake (Medford, MA) are also shown for comparison, but are not relevant to this study. Source: Chase, 2010b.

Based on the data presented in Figures 2.3.3-1 through 2.3.3-5 and the thresholds provided in Table 2.3.3-1, Table 2.3.3-2 below summarizes the condition of Silver Lake water quality and other parameters in 2008-09 to support river herring spawning and rearing.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Sample Size (no.)</th>
<th>Acceptable Criteria</th>
<th>Exceedence</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. (nursery)</td>
<td>°C</td>
<td>53</td>
<td>≤ 28.3</td>
<td>2%</td>
<td>Suitable</td>
</tr>
<tr>
<td>Temp. (spawning)</td>
<td>°C</td>
<td>37</td>
<td>≤ 26.0</td>
<td>0%</td>
<td>Suitable</td>
</tr>
<tr>
<td>DO</td>
<td>mg/L</td>
<td>75</td>
<td>≥ 5.0</td>
<td>11%</td>
<td>Impaired</td>
</tr>
<tr>
<td>pH</td>
<td>SU</td>
<td>90</td>
<td>6.5 to ≤ 8.3</td>
<td>38%</td>
<td>Impaired</td>
</tr>
<tr>
<td>Secchi</td>
<td>mg/L</td>
<td>23</td>
<td>≥ 2.0</td>
<td>0%</td>
<td>Suitable</td>
</tr>
<tr>
<td>TN</td>
<td>mg/L</td>
<td>7</td>
<td>≤ 0.32</td>
<td>71%</td>
<td>Impaired</td>
</tr>
<tr>
<td>TP</td>
<td>μg/L</td>
<td>7</td>
<td>≤ 8.0</td>
<td>29%</td>
<td>Impaired</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>N/A</td>
<td>12</td>
<td>BPJ</td>
<td>0%</td>
<td>-</td>
</tr>
<tr>
<td>Fish Passage</td>
<td>N/A</td>
<td>12</td>
<td>BPJ</td>
<td>100%</td>
<td>Impaired</td>
</tr>
<tr>
<td>Stream Flow</td>
<td>N/A</td>
<td>12</td>
<td>BPJ</td>
<td>83%</td>
<td>Impaired</td>
</tr>
</tbody>
</table>

Notes: Data is preliminary pending further review and publishing of assessment report. Bottom measurements were excluded from DO classification due to QAPP exemption. Impaired classifications result from exceedances >10% at transect stations during two seasons. Source: Chase, 2010b.

Although Silver Lake was considered to have “suitable” water temperatures and water clarity (as measured by Secchi disc depth), it was found to be “impaired” in the areas of dissolved oxygen, pH, total
nitrogen and phosphorous, fish passage, and stream flow. Improving fish passage and stream flow are the objectives of this study. As discussed later, water quality parameters (dissolved oxygen, total nitrogen, phosphorus, pH, etc.) may also be improved through some of the water supply management recommendations of this study.

Currently, water is diverted from the impaired Monponsett and Furnace Ponds into the Class A drinking water reservoir of Silver Lake, often during times of particularly high nutrient levels. Runoff from surrounding development and septic systems flows more readily into the ponds when water levels are kept artificially high by Brockton, inundating yards and other developed areas. A water quality assessment conducted by ESS in 2004 estimated that the Monponsett Pond diversion represents the single largest surface water contributor (32%) of nutrient load to Silver Lake on an annual basis. Additional inputs likely come from Furnace Pond as well. Both Monponsett and Furnace Ponds are 303(d) listed waters, with intense residential development, failing septic systems, and poorly managed landscape impacts along their shores. The diversion of these poor quality waters into Silver Lake have caused its water quality to deteriorate drastically over the last decade (WAA, 2006). Reducing dependence on these diversions, especially during high risk periods, may improve water quality in Silver Lake.

2.4 Topography and Mapping

2.4.1 Bathymetry

As noted above, a hydrographic survey of Silver Lake and Forge Pond was conducted in 2003 by Coler & Colantonio, Inc. (C&C). The purposes of this survey were to describe the two water bodies for the JRWA, refine the understanding of shallow lake contours—especially relative to freshwater mussel habitat—and to inform lake water level management. During this time, a freshwater mussel survey as mentioned in Section 2.3.1 (McCoy et al., 2002). Figure 2.4.1-1 in Appendix A depicts the bathymetry contours of Silver Lake. Several contours were highlighted to show the water elevations at full pond, average September elevation, and lowest elevation on record since 1996 for discussion in Section 4.2.1.

Figure 2.4.1-2 in Appendix A shows the water depth measurements obtained throughout Forge Pond, which can be converted to bathymetry contours using the supplied reference water surface elevation. Water depths are shallow—between approximately 1 and 3 feet across much of the pond. Also depicted on this map are the 17 sediment depth measurements obtained by C&C during the survey. Sediment depths ranged from 0.7 feet to 3.1 feet with an average of 2.1 feet. The depth of sediment directly behind the dam was 2.4 feet. The spillway crest of Forge Pond Dam was surveyed as 47.6 feet NGVD 29. C&C installed a new reference benchmark on the concrete walkway across the dam at an elevation of 49.30 feet NGVD 29.

2.4.2 Upland Topography

Detailed upland topography in the project area was collected in winter/spring of 2011 using LiDAR (Light Detection and Ranging) technology as part of a regional mapping effort. These data have a vertical accuracy of 0.3 meters or approximately one foot. The LiDAR dataset has been obtained from the Massachusetts Office of Geographic Information (MassGIS) and will be used in this study to fill in upland areas for the hydraulic model. Figure 2.4.2-1 depicts the LiDAR terrain in the project area, including the upstream and downstream extents of the hydraulic model developed for this study. The downstream extent of the model was chosen to coincide with the upstream extent of the hydraulic model developed for the Wapping Road Dam removal analysis (Milone & MacBroom, 2009) so that a continuous model of the Jones River is available if needed.
Figure 2.4.2-1: LiDAR Topographic Map of the Project Area
2.4.3 In-Channel Survey

A limited number of Jones River channel elevation points were collected during the C&C survey between the dam and the Lake Street culvert.

Channel cross-sectional data were also obtained for the Federal Emergency Management Agency’s Flood Insurance Study (FEMA FIS) for the town of Kingston, which was published in 1985. Figure 2.4.3-1 shows a plan view map of major (lettered) FEMA transect locations from Forge Pond Dam to just below the Conrail culvert. Figure 2.4.3-2 shows the channel elevation profile and flood flow water surface profiles for this same reach. Note that the downstream extent of the hydraulic model developed for this study coincides with Transect ‘W’ as labeled in these figures. (This location also coincides with the upstream extent of the hydraulic model that was developed for the removal of the Wapping Road Dam as noted above.)

However, the best available copy of the FIS hydraulic model input data (which includes channel elevations) obtained from FEMA is largely illegible. Additionally, some of the FIS model input data that was able to be deciphered did not reflect existing conditions (most notably depicting a 35-foot wide, rectangular bridge opening at Grove Street rather than the existing double pipe culverts with a combined width under 7 feet). Therefore, in the new model for this study, FEMA data was primarily used to place cross-sections in the same locations and orientations as those in the FIS so that comparisons of computed flood water surface elevations could be made to calibrate the model. FIS-surveyed channel thalweg (lowest point) elevations interpolated from Figure 2.4.3-2 were also used to adjust the cross-sections downstream of Lake Street (based primarily on LiDAR data) as needed.

In October 2012, Gomez and Sullivan Engineers conducted a field survey to collect additional in the area of Forge Pond Dam, the access road just downstream, the Lake Street Culvert, and the Silver Lake outlet. A survey-grade real-time kinematic (RTK) GPS was used. Accuracy for this unit is typically within 0.03-0.1 feet horizontally and 0.05-0.2 feet vertically. The survey was tied into the benchmark set by C&C on the dam in 2003.

2.4.4 Land Ownership

Figure 2.4.4-1 depicts the tax parcels surrounding Forge Pond along with landowner information.

Note that for properties bordering the Jones River downstream of the dam, the property line extends to the thread of the river. However, properties abutting Forge Pond appear to extend only to the shoreline of the pond. Deeds for properties surrounding the pond describe the boundary with various phrases including:

- four feet above the high water mark of Forge Pond,
- by the margin of the pond,
- easterly bank of the channel of Jones River,
- according to the rights of flowage,
- by the river upstream, and
- by the pond.

Based on this information, it is assumed that properties abutting Forge Pond extend to the boundaries shown in Figure 2.4.4-1.
Figure 2.4.3-1: Plan View of FEMA FIS Transect Locations Downstream of Forge Pond Dam
Figure 2.4.3-1: FEMA FIS Water Surface Profiles Downstream of Forge Pond Dam
**Figure 2.4.4-1: Properties Abutting Forge Pond and Upper Jones River**

**KEY**

**LAND USE:**
- MUNICIPAL
- RESIDENTIAL
- BUSINESS

**ADDITIONAL PARCELS:**
- 8-30: WILLIAM & LINDA PERKINS
- 8-31: SCOTT & ELAINE FLAHERTY
- 15-1: CITY OF BROCKTON
- 8-40: SILVER LAKE REGIONAL SCHOOL
- 8-41: CITY OF BROCKTON

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**TOWN OF KINGSTON**

**NHP KINGSTON BUSINESS TRUST**

**SR. RESIDENTIAL REALTY LIMITED PARTNERSHIP**

**SR. RESIDENTIAL REALTY LIMITED PARTNERSHIP**

**CITY OF BROCKTON**

**SILVER LAKE REGIONAL SCHOOL**

**PROPERTY LINE IS THREAD OF JONES RIVER**
3. **Brockton Water Supply System**

3.1 **Overview**

The City of Brockton is located in the Taunton River Basin, which borders the western side of the Jones River watershed. In 1899, Legislation was passed which allowed Brockton to divert water from Silver Lake to meet its water supply needs. The Brockton water system currently derives its water supply from five active sources, with additional emergency supplies. Three of the active reservoir sources make up the Silver Lake system, from which over 90% of Brockton’s water supply needs are currently met:

- Silver Lake in the Jones River watershed
- Monponsett Pond in the Taunton River watershed
- Furnace Pond in the North River Watershed

In this system, water from Monponsett Pond and Furnace Pond is diverted into Silver Lake. Water is then drawn from Silver Lake, treated at a treatment plant on the lake’s shore, and sent 20 miles through pipes to the City of Brockton, where it is distributed to consumers and discharged into the Taunton River drainage. A map depicting transfers between these water supply reservoirs is shown in Figure 3.1-1.

Another source—Brockton Reservoir in the Taunton River basin—has provided a small contribution since 1994. This reservoir has its own treatment plant and is not part of the Silver Lake system. Brockton’s fifth active source is Aquaria—a desalinization plant that treats brackish water from the Taunton River in Dighton, MA. Brockton has purchased a nominal amount of water (350,000 gpd) from Aquaria since December 2008 for the purposes of water quality assurance, but has no plans to increase its reliance on this source other than during periods of drought or other water emergency. The City’s emergency source, Hubbard Avenue well, has not been used in many years due to environmental and institutional factors. Pine Brook was used as an emergency supply in the 1980s, but is no longer available as a source for Brockton. The land is now owned by the Town of Kingston, and the pipeline is no longer intact.

Authorized withdrawals from Brockton’s active and emergency sources total 11.98 mgd (not including water permitted for purchase from Aquaria). A summary of Brockton’s water supplies is provided in Table 3.1-1 below.

<table>
<thead>
<tr>
<th>Source</th>
<th>Registered or Permitted Withdrawal (mgd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver Lake</td>
<td>11.11</td>
</tr>
<tr>
<td>Monponsett Pond</td>
<td></td>
</tr>
<tr>
<td>Furnace Pond</td>
<td>0.83</td>
</tr>
<tr>
<td>Brockton Reservoir</td>
<td></td>
</tr>
<tr>
<td>Aquaria desalinization plant</td>
<td>up to 4.07*</td>
</tr>
<tr>
<td>Hubbard Avenue Well (emergency)</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>11.98</td>
</tr>
<tr>
<td>Administrative Consent Order Limit**</td>
<td>11.3</td>
</tr>
</tbody>
</table>

*The amount of water Brockton may purchase from Aquaria increases annually up to 4.07 mgd in 2018 as established in their agreement (see Table 3.3.3-1 for interim amounts). Not included in totals.

**110 percent of system-wide safe yield via a 1995 DEP Administrative Consent Order.
Figure 3.1-1: Silver Lake Water Supply System Map
3.2 Silver Lake System Components & Operations

The various components of Brockton’s complex Silver Lake water supply system are described in more detail below, followed by brief descriptions of the supplemental sources.

3.2.1 Silver Lake

HMA (2006) reported the surface area of Silver Lake (at elevation 47 feet NGVD 29) as 634.3 acres, based on MassGIS data from an aerial survey of April 2001. This was confirmed by area calculations of bathymetry contours provided by the Coler & Colantonio survey (2003, Appendix A). This surface area equates to about 17.3 million gallons per inch of depth. Because of the relatively flat bathymetry of the lake bottom at some locations, the surface area (and consequently the available storage capacity per inch of depth) decreases fairly quickly as the water level drops (HMA, 2006).

Brockton has assumed an operating band at Silver Lake of 15 feet from maximum elevation (47.5 feet NGVD) to the intake pipe (32.5 feet NGVD). This operating band is currently based on proposed standard operating procedures (SOP), as the draft CWMP has not yet been formally approved by the DEP. The operating band is used to determine lake storage (firm yield) assuming the single purpose of delivering water to Brockton system. The City attempts to keep reservoir levels above the natural outlet between Silver Lake and Forge Pond (which Brockton reports as elevation 45 feet, NGVD or 2.5 feet below maximum elevation). Based on data from the past 10 years, Brockton has accomplished this goal approximately 70 percent of the time. During this period, Brockton has been operating entirely in the top 7 feet of Silver Lake (Brockton, 2009).

Forge Pond

When the water level in Silver Lake is high enough to crest its natural outlet, it spills into Forge Pond. The area of the pond is approximately 5.5 acres, which equates to 150,000 gallons per inch of depth. The pond is shallow at approximately 2 feet, and therefore contains about 3.6 MG when full (level with Forge Pond Dam spillway crest). When the water level in Silver Lake drops below its natural outlet, it has been observed that water flows from Forge Pond back into Silver Lake resulting from groundwater flow into Forge Pond. Forge Pond is heavily silted and has become overgrown with vegetation leaving only a small channel at most times (HMA, 2006).

Forge Pond Dam

Forge Pond Dam is a concrete dam reportedly built circa 1905 (land was transferred to Brockton in December of 1905). The dam artificially raised the natural elevation of Silver Lake. When the level of Silver Lake is higher than the Forge Pond Dam spillway, water flows past the dam and down the Jones River. Dimensions, photographs, schematics, etc. of Forge Pond Dam were provided in Section 2.2.4.

As mentioned above, there has been some discrepancy as to the elevation of the spillway crest of the dam and other associated elevations (e.g., natural outlet, Silver Lake ‘full pond’ level, etc.). A summary of reported values from the various sources is given in Table 3.2.1-1.
Table 3.2.1-1: Comparison of Reported Elevations for Forge Pond Dam and Silver Lake

<table>
<thead>
<tr>
<th>Source</th>
<th>Reporter</th>
<th>Year</th>
<th>Reported Elevation (ft, NGVD 29)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility Study Survey</td>
<td>Gomez &amp; Sullivan Engrs. (GSE)</td>
<td>2012</td>
<td>Forge Pond Dam Spillway 47.6</td>
<td>Silver Lake Natural Outlet Inv. 46.2</td>
</tr>
<tr>
<td>Bathymetric Survey Report</td>
<td>Coler &amp; Colantonio</td>
<td>2003</td>
<td>Forge Pond Dam Spillway 47.6</td>
<td>Silver Lake Full Level 47.0</td>
</tr>
<tr>
<td>Draft CWMP</td>
<td>Brockton</td>
<td>2009</td>
<td>Forge Pond Dam Spillway 47.5</td>
<td>Silver Lake Full Level 47.5</td>
</tr>
<tr>
<td>Silver Lake System Overview Report</td>
<td>HMA</td>
<td>2006</td>
<td>Forge Pond Dam Spillway 47.0</td>
<td>Silver Lake Full Level 47.0 (implied)</td>
</tr>
<tr>
<td>Selected for use in this analysis</td>
<td>-</td>
<td>-</td>
<td>Forge Pond Dam Spillway 47.6</td>
<td>Silver Lake Full Level 47.6</td>
</tr>
</tbody>
</table>

Because the Coler & Colantonio survey provides the only elevation data obtained by a licensed surveyor, its reported elevations of 47.6 feet NGVD 29 for the Forge Pond Dam spillway crest has been selected for use in this analysis. However, for the full reservoir level of Silver Lake from which stage data are calculated, HMA’s finding that this elevation is equal to that of the dam spillway crest (based on simultaneous measurements taken in 2005) was used, making the Silver Lake full pond elevation also 47.6 feet NGVD 29. Where differing elevation values are mentioned in this text, it is for the purpose of providing context for the original statement, and will not be used in any calculations.

The Forge Pond dam has no gaging structures or means for control of water flow, except for the removal of stoplogs (HMA, 2006). However, according to Brockton, the City does not adjust the stoplogs.

**Natural Outlet of Silver Lake**

As mentioned above, Silver Lake and the adjacent Forge Pond are separated by the natural outlet of Silver Lake, which is lower than the spillway crest elevation of Forge Pond Dam. Historically, this location was the outlet to the Jones River before Forge Pond Dam artificially raised the level of the lake. Lack of flow due to the dam has led to additional sediment accumulation in this area. When the water level in the lake is higher than the natural outlet, it is submerged and the two water bodies act as one with a spillway at the Forge Pond Dam. When the level in Silver Lake is higher than the Forge Pond Dam spillway elevation, water from the lake spills over the dam and into the upper Jones River. When the water level in Silver Lake is lower than the elevation of the
natural outlet, Silver Lake and Forge Pond act as separate reservoirs. When this connectivity is lost, there are currently no physical structures in place to release water from Silver Lake to the Jones River.

As shown in Table 3.2.1-1, the 2003 C&C survey found the natural outlet to have an invert (low point) elevation of 45.92 feet NGVD 29. In 2005, HMA calculated the low point to be about 45.6 feet, based upon measurements taken on 12/8/05 and compared with the measured reference level at Silver Lake of +5.25 inches. In the 2009 draft CWMP, Brockton reported the outlet elevation (referred to as a berm) as 45 feet NGVD. These measurements would place the outlet invert anywhere from 1.7 to 2.6 feet below the elevation of the Forge Pond Dam spillway (47.6 feet according to the C&C survey). The outlet is a natural feature and may change over time; in fact, the various measurements indicate it may be raising due to sediment accumulation.

**Jones River**

Although Brockton is required to provide instream releases below Monponsett Pond (0.9 mgd) and Furnace Pond (0.3 mgd) as discussed later, there are currently no instream release requirements from Silver Lake/Forge Pond into the Jones River. This is a glaring omission that will be investigated in this study. Recommendations of minimum flows for aquatic habitat and fish passage will be made and their associated impacts to water supply operations will be analyzed.

**Tubbs Meadow Brook (from Furnace Pond Diversion Pipe)**

Silver Lake receives a small natural inflow from Tubbs Meadow Brook on the north end of the lake. The brook meanders through the woods and beneath Route 27, southeast of the intersection with Route 36. Tubbs Meadow Brook also receives and transmits water from the Furnace Pond Diversion pipe when it is being used (HMA, 2006).

**Monponsett Pond Diversion Pipe Outlet**

Water also enters Silver Lake from the 48-inch-diameter Monponsett Pond diversion pipe located on the southwesterly shore of the lake. HMA reported the top of this horizontal pipe at approximate elevation 46.8 feet\(^5\). The pipe is provided with a bar rack but inspection of the rack indicated that all but 2 bars on each side are missing, leaving a 30-inch-wide clear opening and allowing access into this pipe from the shore when the lake water level is low (HMA, 2006).

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\(^5\) Based upon water level measurements taken by HMA at this pipe on 12/8/05, likely referenced from a full pond water surface elevation of 47.0 feet.
Monponsett Pond Diversion Pipe Outlet

Google Earth image from 3/18/05 showing the Monponsett Pond plume entering Silver Lake

Water Treatment Plant Intake Pipe

Brockton (2009) reports the intake to the water treatment plant (WTP) at an elevation of 32.5 feet NGVD. Between this intake elevation and the spillway elevation of 47.5 feet (reported by Brockton) is a 15-foot operating band. According to the 1953 design drawings, the intake pipe for the WTP is located 285 feet off the westerly shore of the lake. The upward facing, 5-foot-square opening is covered with a bar rack and is attached to a 42-inch-diameter buried pipe leading to a screen house. Water flows into the intake opening and then into the pumphouse where two traveling screens and four raw water pumps are located (HMA, 2006). More detailed information about screen dimensions, mesh size, and purpose will be needed to evaluate and reduce the potential for mortality of fish in Silver Lake.

Water Treatment Plant

The Silver Lake WTP is a conventional treatment plant that treats water from Silver Lake directly and Furnace Pond and Monponsett Pond indirectly. Water is withdrawn from Silver Lake year-round, 24 hours/day. Brockton (2009) has reported the capacity of the plant to be 24 mgd.

Flow is recorded by a differential pressure transmitter type raw water flow meter. Withdrawal flow rates are a function of the number of pumps operating. The WTP has four raw water pumps, each with a capacity of 6,500 gpm—two pumps operate with variable frequency drives and two pumps are fixed speed. Operators manually turn the pumps on and off, selecting the number of pumps based on the observed demand (using storage tank levels as an indicator). Typically, during the high demand hours of 6 am to 10 pm, two pumps operate, withdrawing about 450,000 gallons per hour. During the low demand hours of 10 pm to 6 am, one pump operates, withdrawing about 350,000 gallons per hour (Brockton, 2009).

The water level of Silver Lake is read from inside the level house, located approximately 20 feet from the shore near the WTP. Recent WTP upgrades have allowed lake level to be determined automatically and recorded by the operators’ SCADA (Supervisory Control and Data Acquisition) system. Water levels are
recorded once per day (in the morning) in inches above (+) or below (-) a reference mark equal to the Forge Pond Dam spillway\(^6\) (Brockton, 2009).

Plant upgrades completed in April 2009 included systems to recycle lagoon supernatant back to the head of the plant (rather than being returned to Silver Lake).

### 3.2.2 Monponsett Pond

Monponsett Pond is located southwest of Silver Lake in Halifax, within the Taunton River basin. It is split into an east and west lake by Route 58 with a 6-foot-wide rectangular concrete conduit connection. The pond has a maximum depth of approximately 13 feet with a watershed area of approximately 6 square miles. Refer back to Figure 3.1-1 for the location of Monponsett Pond.

According to Brockton (2009), diversions from Monponsett Pond to Silver Lake take place between October and May when:

- Water level in Silver Lake is below full (47.5 feet NGVD); and
- Water levels in Monponsett Pond are above the minimum water level (52.0 feet NGVD). Brockton typically diverts water above a minimum water level of 52.5 feet.

In order to prevent flooding, diversions from Monponsett Pond to Silver Lake may occur throughout the year by written request from the Towns of Halifax or Hanson, or when the pond elevation exceeds 53.0 feet. Flooding in the vicinity of Monponsett Pond occurs when the water level is higher than the spillway elevation of 53 feet. Diversions between June and September require prior DEP authorization, a minimum of two days in advance (Brockton, 2009).

Water is also withdrawn from Monponsett Pond by local cranberry growers for consumptive and return uses at cranberry bogs in the area (Brockton, 2009).

The area surrounding Monponsett Pond is developed and the ponds are used for recreational purposes. Herbicides have been used in the pond for control of weed growth, which has become extensive in recent years (HMA, 2006).

### Stump Brook Dam and Fish Ladder

The normal discharge point of the interconnected ponds is through Stump Brook located on the northwesterly corner of the west lake. Water level in the lake is controlled by Stump Brook Dam which is located approximately 3,000 feet downstream from the mouth of the brook on Monponsett Pond. The dam has a spillway crest elevation of 53.0 feet.

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\(^6\) Brockton uses 47.5 feet NGVD for this elevation.
At the time the current dam was constructed, an earthen dam, located just upstream, was removed. According to the 1966 construction drawings, the top of the original dam was approximately at elevation 51.0 feet. Because the Acts of the Legislature precluded water diversion when the pond level is below 52.5 feet, the new dam was constructed with a crest elevation of 53.0 feet. The increased elevation provides approximately 28 MG of additional storage when the ponds are at the elevation of the crest. However, as noted above, at this level (53.0 feet), residents around the ponds experience problems with basement flooding, septic system operation, and loss of beach front, prompting requests from town officials in Halifax to discharge water from the ponds, which is typically achieved by diversion of additional water to Silver Lake. This type of overflow diversion usually occurs in the fall and winter months, but does occur in the spring and summer as well (HMA, 2006).

The dam contains a spillway and a 2-foot wide flume connected to a fish ladder below. Within the flume, there is an adjustable 2-foot by 2-foot sluice gate that can be used to control the water level in Monponsett Pond (between elevations 51.0 and 53.0 feet), which also releases to Stump Brook.

The adjustable weir fish ladder has been fitted with an upstream ultrasonic flow meter to approximate the flow down the ladder. Inspection of the meter by HMA in 2005 indicated that it was operational; however flow measurements appeared to be out of calibration. According to Brockton (2009), operators from the Silver Lake WTP monitor the gage weekly year-round and more frequently during diversions to check on the flow over the fish ladder and to Stump Brook. The stage-discharge equation used for the flow meter is based on a 2-foot flume width (equation is approximately discharge = 0.1035 * stage^{1.5}, with discharge in mgd, stage in inches). The flow meter only measures flow down the fish ladder; flow over the wider spillway is not metered. Operators also use depth of water over the flume to estimate adequate flow.

Brockton (2009) reports that releases to the fish ladder are made to Stump Brook when the diversion to Silver Lake is in use, when herring are running, or when requested by the towns of Halifax and Hanson. When the diversion is in use, a continuous flow of 0.9 mgd over the fish ladder is required (Brockton typically targets an average of 0.9 mgd over the diversion period). The gate of the fish ladder is also gradually lowered during summer months, when no water is being diverted, to keep a consistent flow in Stump Brook.

HMA (2006) noted that the design of the fish ladder is such that debris can build up in the areas between the steps of the ladder. Flow across the ladder appeared to be good but the intermediate pool
areas can be severely reduced by the collection of materials. Although the fish ladder has been classified in a report by MarineFisheries (May 2004) as "good/passable," the downstream waterways are very complex and may require additional work to fully address the concerns of fish passage.

HMA (2006) also reported that probing of the upstream face of the dam indicated a substantial build-up of silt, measuring approximately 2.3 feet deep in one area. This is likely the result of low or no flow stream velocity. The stagnated water has also resulted in significant vegetative and algal growth in the brook.

The dam is situated in the Burrage Pond wildlife management area (formerly a 1,600+ acre cranberry bog site) and is located remote from paved roadways making it somewhat difficult to access. From the WTP it takes approximately 20 minutes to reach Stump Brook Dam by car.

**Intake Pipe and Diversion Station (to Silver Lake)**

Transfer from Monponsett Pond to Silver Lake occurs through a gravity-fed aqueduct located in the southeastern corner of the east pond. A 48-inch gate valve at the Monponsett Pond diversion station is opened remotely or manually to initiate transfer from Monponsett Pond to Silver Lake. Water flows from the diversion station by gravity to Widgeon’s Point in Silver Lake. Recent WTP upgrades now permit remote valve operation through use of the operator SCADA system at the WTP (Brockton, 2009).

Brockton (2009) notes that while it is possible to open the valve partway, in practice the valve is generally operated as either fully open or fully closed. Typically, when the diversion is being used, the valve is fully open all day. The daily diversion volumes are generally the same from day to day.

The 48-inch-diameter intake pipe extends approximately 250' off shore, with a grated, upward facing inlet at elevation 46.0 feet (i.e., 7 feet below the surface of the pond at overflow level). The diversion station contains a gage glass for manually monitoring pond level and readings are referenced above or below elevation of 52.5 feet, which was the minimum elevation for diversion established by the 1964 legislation. In the Acts of 1981, Chapter 237, the minimum level was reduced to elevation 52'-0" in response to the severe drawdown that occurred at that time. Readings are recorded generally on a daily basis, along with the reading from a totalizing flow meter in the diversion pipe (HMA, 2006).

**3.2.3 Furnace Pond**

Furnace pond is located approximately one mile north of Silver Lake in the North River Basin, in the town of Pembroke. Refer back to Figure 3.1-1 for the location of Furnace Pond. Furnace Pond is relatively small at approximately 107 acres, with an average depth of 5 feet and maximum depth of 9 feet. The drainage area is approximately 1 square mile. The shoreline is heavily developed. The pond discharges to Herring Brook and eventually to the North River. Furnace Pond is hydrologically connected to Oldham Pond, which is a spawning destination for alewives. This pond is approximately 9 feet higher in elevation than Silver Lake and can therefore flow by gravity to Silver Lake when the diversion system is activated (HMA, 2006).
**Furnace Pond Dam and Fish Ladder**

The Furnace Pond Dam and fish ladder were constructed in 1966 as part of the control structures provided for by the 1964 Acts. The design and construction is very similar to the Stump Brook dam with adjustable weir fish ladder and low level bypass valve in the dam structure. The fish ladder has been modified slightly by the addition of wood baffles. The valve handles and stems on the fish ladder and bypass have been vandalized and appear to be inoperable. Debris and fallen trees have collected on the upstream face of the dam. Local observations indicate that herring do navigate the ladder during the spring spawning season. The dam site must be accessed on foot through a wooded area. The dam is located approximately a 15-minute drive from the WTP (HMA, 2006).

The dam and fish ladder were constructed to replace an existing flume and fish ladder, which were demolished. The original dam elevation was 56.0 feet, and the new dam height was increased to 56.5 feet plus 6 inches of additional height with wooden flashboards. The wood flashboards are currently removed. There are generally no complaints from the local residents regarding water level being too high. The weir, if operable, could be lowered an additional 20.5 inches (approximately to elevation 54.0 feet). The bottom of the 2-foot-square bypass opening in the dam is at approximately elevation 53.5 feet (HMA, 2006).

**Diversion Station and Bypass Pipe**

Water enters the Furnace Pond diversion station from a surface intake channel provided with a bar rack and skimming weir. Within the diversion station, an additional weir is provided with a crest elevation of 55.30 feet leading to the upward facing 24-foot-diameter intake pipe. When in use, water flows into the intake, through a flow meter and into a buried 30-inch-diameter concrete conduit leading to Tubbs Meadow Brook, approximately 3,000 feet to the south.

The intake pipe is also provided with a secondary valved discharge leading back to Herring Brook and downstream of the dam. Thus water can flow through the diversion channel and bypass the dam if desired. This connection is un-metered and the valve has a manual operator (HMA, 2006).
**Diversion Pipe to Tubbs Meadow Brook (to Silver Lake)**

From the diversion station, a buried 30-inch-diameter concrete pipe conveys water by gravity to a discharge point located approximately 3,000 feet to the south and about 100 yards north of Route 27, at the intersection with the headwaters of Tubbs Meadow Brook. The discharge is covered with a bar rack. This discharge point is located in a wooded area generally out of view of the roadway and adjoining properties. It then passes beneath Route 27, unprotected and collecting run-off from this low point along the road surface (HMA, 2006).

### 3.3 Other Sources (not in the Silver Lake System)

#### 3.3.1 Brockton Reservoir

Brockton Reservoir is a manmade reservoir in Avon, Massachusetts, located along its northern border with Brockton. It was constructed in 1880 and is currently part of the D.W. Field Park. The reservoir is fed by Beaver Brook and has a watershed area of approximately 2.6 square miles of predominantly forested land.

Historically, the reservoir was used more heavily for water supply; however, its use declined when the Monponsett and Furnace Pond diversions into Silver Lake were realized. In order to comply with the Water Management Act, the reservoir was brought back online in 1991. Water is withdrawn directly from the Brockton Reservoir to the Woodland Avenue water treatment plant (in Brockton).

Brockton Reservoir has a spillway and a low level outlet that allow water to flow to Waldo Pond and downstream. The spillway elevation is fixed at elevation 205.0 feet NGVD. Water that passes over the spillway or through the low level outlet flows to Waldo Pond and is lost to the water supply system (Brockton, 2009).

#### 3.3.2 Emergency Sources

The Hubbard Avenue Well was originally placed online in November 1982. It was operated for three months and then shut off after the City received water quality complaints. It was operated briefly in the fall of 1985 until it was shut down again following Hurricane Gloria. The well went into service again in 1986 and was used until 1987 when contamination was discovered at nearby sites. Because of the contamination in the area, DEP has not allowed its use as an active supply. The well now may only be used in emergency situations with permission of DEP.

The Hubbard Avenue Well is currently maintained by Brockton. The well is operated offline once a year to ensure reliability in case an emergency necessitates the reactivation of the well (Brockton, 2009).

#### 3.3.3 Aquaria Desalinization Plant

Aquaria LLC (Aquaria) owns and operates a desalination plant that treats brackish water from the Taunton River in Dighton, Massachusetts. The intake on the Taunton River is located just below the confluence with the Three Mile River.

The City contracted with this supplemental water supplier in 2002 and began receiving water in December 2008. The City operates under Water Management Act Permit #9P-4-25-044.01, which allows Brockton to purchase up to 4.07 mgd from Aquaria. However, Aquaria’s contractual agreement with Brockton (2002) does not require Aquaria to provide 4.07 mgd until Year 11 of water supply. Aquaria’s “firm commitment” volume increases annually according to the schedule in Table 3.3.3-1.
Table 3.3.3-1: Aquaria’s Firm Commitment Schedule

<table>
<thead>
<tr>
<th>Year No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (mgd)</td>
<td>1.90</td>
<td>2.00</td>
<td>2.50</td>
<td>3.00</td>
<td>3.50</td>
<td>3.50</td>
<td>3.56</td>
<td>3.56</td>
<td>3.82</td>
<td>3.82</td>
<td>4.07</td>
</tr>
</tbody>
</table>

However, according to the agreement, Brockton may purchase water in excess of the firm commitment volume for a fee if available, and has exclusive rights to the first 1 mgd of excess water produced by Aquaria with 15 days notice. Brockton also has the right to request increases in the firm commitment volumes.

Currently, the City targets purchasing only a minimal amount of water from Aquaria on a daily basis to ensure that the water entering the distribution system is within the drinking water quality standards of the Commonwealth. In their 2009 draft CWMP, Brockton reported that this volume averaged 0.35 mgd. Updated analysis of Brockton’s data indicates that Aquaria water use hovered around that average until August 2010 before peaking sharply (with a maximum of 3.2 mgd on August 21, 2010) and then resuming at a higher average of about 1.5 mgd until March of 2011. The average then dropped once again to an intermediate 0.8 mgd until May 26, 2011, after which no water has been purchased from Aquaria to date (through July 2012).

Brockton expects to increase its usage of Aquaria water during periods of high demand, drought, or other water emergency. However, Brockton only anticipates supplemental use of Aquaria water on a long-term basis due to the higher cost than its other sources (Brockton, 2009).

**Cost Analysis**

Brockton’s agreement with Aquaria includes the following price components:

- **Fixed Rate Component** – Regardless of the volume of water purchased, Brockton is obligated to pay for the full firm commitment volume (given in Table 3.3.3-1) on an annual basis at the rate of $167,480 per 0.1 mgd. Using the year 2012 (Year 5) as an example, Brockton is required to pay $5,861,800 for the year based on a firm commitment volume of 3.5 mgd.

- **Variable Rate Component** – The variable rate is based on the actual amount of water delivered to Brockton, and is set at $1.23 per 1,000 gallons used.

- **Excess Water Rate** – When actual use exceeds the firm commitment volume, the pricing for additional or “excess” water is set at $0.60 per 1,000 gallons used.

Since Brockton must pay for the annual firm commitment volume in full regardless of the actual amount of water used, the cost of Aquaria water on a per gallon basis naturally decreases as the amount purchased increases. Figure 3.3.3-1 demonstrates this using Year 5 (2012) as an example.

---

Note that Aquaria began to factor escalation into these base rates after Year 3 (i.e., after December 2011), which has not been considered in this analysis. The escalation factor is determined from the Producer Price Index (PPI) for Series ID #WPSSOP3400 (Commodities → Stage of Processing → Finished Goods, Excluding Food → Seasonally Adjusted). For reference, the PPI published for December 2011 was 1.14 times that published in December 2008, and thus all price rates would be scaled by a factor of 1.14 for the 2012 example (US Dept. of Labor, 2012).
Note: Overall cost includes a.) a fixed annual cost of $167,480 per 0.1 MG of the firm commitment volume (total annual cost of $5,861,800 for the 2012 example with a firm commitment of 3.5 MGD), b.) a variable rate of $1.23 per 1,000 gallons used, and c.) an excess rate of $0.60 per 1,000 gallons used over the firm commitment volume (i.e., over 3.5 MGD for the 2012 example). Note that Aquaria began to factor escalation into these base rates after Year 3 (i.e., after December 2011), but an escalation factor has not been included here (Brockton, 2002). The PPI published for December 2011 was 1.14 times that published in December 2008 (US Dept. of Labor, 2012).

Brockton conducted a cost analysis of purchasing water from Aquaria for their draft CWMP (2009). In addition to the Aquaria rates described above, this analysis also considered Brockton’s cost to provide water from its own systems. Since 1986, the City has contracted with Veolia Water (and its predecessors) for operation and maintenance of its water treatment facilities. Veolia’s agreement with the City includes fixed and variable price components as in the Aquaria agreement. Based on average demand at the time of the analysis (10.04 mgd) and Veolia and Aquaria pricing, the City’s practice of purchasing a nominal daily flow (350,000 gpd) from Aquaria for the purposes of water quality assurance resulted in an overall cost of $1,235/MG to provide drinking water.

Brockton noted that with an Aquaria purchase of 2 mgd (the allowable amount at the time of the draft CWMP), its cost would increase to $1,425/MG—approximately 15% more for almost 6 times the volume (2 mgd vs. 0.35 mgd). The draft CWMP further states that if Brockton purchased water at its contractual upper limit of 4.07 mgd (Year 11 and beyond), its cost of providing drinking water would increase to “more than $1,425/MG.” (This is the same as the value estimated for 2 mgd, so it is assumed that the cost difference between flow regimes above 2 mgd is negligible.)
Based on the City’s cost analysis, it appears that Brockton could be purchasing the maximum amount of water allowed by its agreement with Aquaria (currently 3.5 mgd for the year 2012, increasing to 4.07 mgd by 2018) for approximately 15% more than its current cost of providing water.

3.4 Legislation, Registrations, & Permits

Various legislations, registrations, and permits have defined the boundaries of Brockton’s water supply operations. Brief summaries of the requirements of each are described below. Copies of the legal documents are attached as appendices to Brockton’s draft CWMP (2009), with the exception of the Administrative Consent Order and Brockton’s agreement with Aquaria.

3.4.1 Acts of the Legislature

Legislation passed in 1899 granted the City of Brockton the right to withdraw water from Silver Lake for water supply. This did not grant Brockton exclusive rights to the water in Silver Lake, as Section 11 reserved the right for surrounding towns (Whitman, Plympton, Kingston, and Halifax) to take an independent supply from the lake.

Legislation passed in 1964 authorized the diversion of water from Furnace Pond in Pembroke and Monponsett Pond in Halifax and Hanson into Silver Lake from October to May (inclusive) to supplement water supply demands. As a result, the lake levels at both Furnace Pond and Monponsett Pond were elevated by approximately 0.5 feet and 2.0 feet, respectively.

The Acts of 1964, as amended in 1981, contained restrictions regarding the diversions, including:

- Minimum flows of 300,000 gpd (0.46 cfs) from Furnace Pond to Herring Brook and 900,000 gpd (1.39 cfs) from Monponsett Pond to Stump Brook
- At all times, sufficient flows passing downstream to allow for the passage of river herring when water is being diverted to Silver Lake
- No withdrawals below minimum water surface elevations of 56.0 feet in Furnace Brook and 52.0 feet in Monponsett Pond (NGVD 29)

The Acts of 1964 also established the Central Plymouth County Water District Commission (CPCWDC) to regulate the allocation of water in the area, but this group is not operational. Under this Act, diversions from Monponsett and Furnace Ponds may be prohibited when Silver Lake is at or above elevation 46.5 feet, but in practice this condition is not followed as the CPCWDC is the authorized authority to make these decisions, and it hasn’t met for years (JRWA, 2011b).

3.4.2 Water Management Act Registrations and Permit

The Commonwealth of Massachusetts passed the Water Management Act (WMA) to control and allocate the water resources in the state and to ensure adequate resources for the present and future. In January 1988, all water users had the opportunity to register their historic water use for the period 1981 to 1985. This registered an average day water use over that period that, if confirmed and approved by the state, became the “grandfathered” quantity allotted to the user. After the registration phase of the Act, the permitting process began in 1988. A permit is required if an existing or new user intends to or is using more than 100,000 gpd over the previously registered amount (GZA, 2003).
Brockton holds two WMA registrations and one WMA permit, as follows:

- **WMA Registration Statement #42104401 (South Coastal Basin)** – This registration includes Silver Lake and Furnace Pond, and authorizes an average daily withdrawal of 11.11 mgd from the Silver Lake system. Although Monponsett Pond is located within the Taunton River Basin, its withdrawal is included in the South Coastal registered average daily withdrawal.

- **WMA Registration Statement #42504402 (Taunton River Basin)** – This registration includes Monponsett Pond and the Hubbard Avenue well emergency source. The allowable withdrawal from the Hubbard Avenue well is 0.04 mgd. As stated above, use of this well requires prior permission from DEP under a Declaration of Water Supply Emergency. As noted for the South Coastal Basin registration, the Monponsett Pond withdrawal is included in the South Coastal Basin registration.

- **WMA Permit #9P-4-25-044.01 (Taunton River Basin)** – This permit includes Brockton Reservoir, which has an authorized average withdrawal of 0.83 mgd (daily average). Additionally, this permit authorizes the purchase of up to 4.07 mgd from Aquaria. It also required Brockton to develop the CWMP to improve environmental management of its sources.

### 3.4.3 Administrative Consent Order

Brockton continues to fall under the terms of an ACO—initially issued in November of 1995 and amended in February 1997 and November 1997—which restricts Brockton’s total authorized withdrawals to 11.3 mgd on a 12-month running average. This limit represents 110 percent of the system firm yield at the time the ACO was issued. For the Silver Lake system (including Monponsett and Furnace Pond diversions), the firm yield was estimated to be 9.4 mgd, based on a study performed in 1987. The firm yield of the Brockton Reservoir was estimated by DEP to be 0.83 mgd in 2004. These studies were performed utilizing simple regressions to relate precipitation to estimated reservoir inflow, and used a monthly time step (Brockton, 2009). Other investigations of estimated yield are discussed in Section 4.2.3.

### 3.4.4 Monponsett Pond Chapter 91 License

In accordance with the provisions of the 1964 Acts of the Legislature, the City obtained a license to “construct and maintain works to divert excess overflow water from Monponsett Pond to Silver Lake” in December 1965. Chapter 91 License No. 4987 includes the following conditions:

- Set the elevation of the Stump Brook Dam spillway crest at elevation 53.0 feet
- Set the elevation of the diversion intake to elevation 46.0 feet and screen at elevation 47.0 feet
- Protects the water rights of the cranberry growers
- Made provisions for a fish ladder
- Requires water level monitoring
- Requires maintenance of water level to protect against “inundation of lands in the watershed”

The conditions in this license require Brockton to protect the area against flooding when the level of Monponsett Pond exceeds elevation 53.0 feet. Although the pond will overflow to Stump Brook at the spillway when the water level exceeds elevation 53.0 feet, it has been Brockton’s practice to additionally divert water to Silver Lake or release water through the fish ladder to Stump Brook during these times of high water surface elevations. The DEP must be notified in advance of diversions made to Silver Lake.
between June and September in accordance with the requirements of the 1964 Acts of the Legislature (Brockton, 2009).

3.4.5 Aquaria Permits and Agreements

Interbasin Transfer Act

The transfer of water from one river basin to another within Massachusetts is regulated via the Interbasin Transfer Act (ITA) of 1983. The ITA is administered by the WRC with technical oversight provided by the Department of Environmental Management Office of Water Resources (DEM-OWR). There is no threshold that triggers regulation—any interbasin transfer developed after 1983 must be reviewed at some level. Transfers developed prior to 1983 (i.e., the Brockton Silver Lake System) were not subject to approval by the WRC.

In December 1995, the WRC determined that Aquaria was subject to the ITA as a transfer from the Massachusetts Coastal Basin to the Taunton River Basin. The WRC approved the Aquaria ITA application, with conditions, on August 14, 2003. The City of Brockton then filed a request to purchase water from Aquaria, which was approved by the WRC on March 11, 2004.

Water Management Act

Aquaria also holds its own WMA permit, #9P4-4-25-076.01, which was issued to Inima USA Corporation on May 31, 2005 and amended in March 2007 and March 2008.

Brockton-Aquaria Agreement

Brockton entered into an agreement with Aquaria on May 22, 2002 that entitles the City to purchase water for an initial term of 20 years, renewable for up to 30 additional years. As noted previously, while Brockton’s WMA permit allows the purchase of 4.07 mgd, Brockton’s agreement with Aquaria limits purchases through 2018 as detailed in Table 3.3.3-1.
4. Hydrology

4.1 Streamflow Data

Streamflow records are used to estimate frequency and duration of flows, mean annual flows, and the magnitude and frequency of floods. The following sections describe the various sources of streamflow data and statistics that have been calculated.

4.1.1 USGS Gage

The USGS has maintained a streamflow gaging station (No. 01105870) on the Jones River just below the Elm Street Dam since 1966. Records at the gage are generally considered good by the USGS; however, flow is regulated by the Elm Street Dam and influenced by the operations at Silver Lake and periodic tidal surges.

The natural drainage area at the gage is approximately 19.8 square miles, including the 4.1 square mile Silver Lake watershed. Several studies, including the FEMA FIS (1985), have reported the drainage area at the gage as 15.7, omitting the drainage area of Silver Lake based on the assumption that it is non-contributing due to water supply diversions. However, this logic is only valid during low flows, or during floods only if Silver Lake is drawn down and can accommodate the full storm flows generated (which is not likely as Brockton does not manage Silver Lake for flood control). Under most circumstances, water from Silver Lake during the 10-year storm and greater will be released into the Jones River (Milone & MacBroom, 2009). In fact, during large flow events, diversions from Monponsett Pond and Furnace Pond into Silver Lake can exacerbate flood flows in the Jones River.

A comparison of ‘natural’ and ‘contributing’ drainage areas throughout the Jones River watershed is presented in Table 4.1.1.1. Drainage area ratios (i.e., the drainage area at Forge Pond Dam divided by the drainage area at the gage) are used to pro-rate gage flows to a location of interest (i.e., the dam). Note that although the additional drainage areas of Monponsett Pond (6 mi$^2$) and Furnace Pond (1 mi$^2$) are not included in the table below, they do contribute to Jones River flow when these diversions are on while water is simultaneously spilling over Forge Pond Dam (see Section 4.2.2).

<table>
<thead>
<tr>
<th>Location</th>
<th>Drainage Area (mi$^2$)</th>
<th>Drainage Area Ratio (Dam / Gage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural</td>
<td>Contributing*</td>
</tr>
<tr>
<td>Jones River at Kingston Bay</td>
<td>29.8</td>
<td>25.7</td>
</tr>
<tr>
<td>Jones River at USGS Gage</td>
<td>19.8</td>
<td>15.7</td>
</tr>
<tr>
<td>Jones River at Forge Pond Dam</td>
<td>4.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Silver Lake at Natural Outlet</td>
<td>4.1</td>
<td>-</td>
</tr>
</tbody>
</table>

*Omits the 4.1-mi$^2$ drainage area of Silver Lake at its natural outlet, based on the FEMA FIS assumption that this area is non-contributing due to water supply diversions. However, this logic is only valid during low flows.

Annual and monthly flow duration curves were developed for the USGS gage using the full period of record (through March 2012) and are provided in Figures 4.1.1-1 through 4.1.1-5 in Appendix B. Flow duration curves depict the average percentage of time that specific flowrates are equaled or exceeded at a particular site. These curves are useful for better understanding the nature of the streamflow in a
particular river. For example, ‘flat’-sloped flow duration curves often indicate relatively little variability in flows, as compared to a site with a steep flow duration curve.

The annual flow duration curve for the Jones River gage at Elm Street (Figure 4.1.1-1 in Appendix B) indicates a 50-percent flow duration value of 26 cfs, or about 1.3 cfs per square mile (cfs/m). The flow duration curve is fairly flat, due to prevalent stratified drift in the watershed enabling a fairly constant discharge of groundwater to the river system (Persky, 1991).

4.1.2 Lake Street Gage

As noted above, the MA DER has installed a gage to measure river stage height just downstream (approximately 100 feet) of Forge Pond Dam at the Lake Street culvert as part of their River Instream Flow Stewards (RIFLS) program. The site was established in 2003 to monitor streamflow impacts on the Jones River of management of the upstream Silver Lake for water supply. Stage data are collected by volunteers and RIFLS staff and converted to flow using a rating curve developed and maintained by RIFLS, shown in Figure 4.1.2-1. Flow measurements are taken periodically to check the rating curve, which has been confirmed as recently as May 2012.

![Figure 4.1.2-1: Rating Curve for Lake Street Staff Gage](image)

Note: A stage of 3.5 feet corresponds to the invert of the Lake Street culvert, elevation 42.4 feet NGVD 29.

Discharge data for the Lake Street gage were provided by RIFLS for the period of September 2003 through September 2011. Approximately 262 measurements ranging from 0.016 cfs to 53 cfs were taken during this 8-year period. Instantaneous flow data (15-minute intervals) recorded at the Elm Street gage downstream were obtained from USGS for the same period to determine whether a correlation could be made between flows at the two locations. If a strong relationship were observed, it could be used instead of a ratio of drainage areas (as discussed above) to adjust flows from the gage to Forge Pond Dam. Thus, RIFLS flow readings were plotted against flow at the gage, as shown in Figure 4.1.2-2. However, no clear relationship could be established ($R^2 = 0.5$).
4.1.3 Weir Flow Calculations

The Brockton Water Commission provided daily records for water surface elevations of Silver Lake, Monponsett Pond, Furnace Pond, and Brockton Reservoir since October 1996. These data are recorded in inches above or below the reference mark for the associated reservoir (described in Section 3.2). For Silver Lake, the reference mark is the spillway crest of Forge Pond Dam. Readings are recorded daily.

When the level of Silver Lake is above the spillway crest (i.e., spilling over Forge Pond Dam), flow below the dam can be estimated using the weir flow equation:

\[ Q = C L H^{3/2} \]

where \( Q \) = flow (cfs)  
\( C \) = weir coefficient (ft)^8  
\( L \) = spillway length (ft)  
\( H \) = head (height of lake level above spillway crest, ft)

Silver Lake stage data recorded by Brockton was used to estimate flow at Forge Pond Dam for the period of record provided (1996-2012). Average daily flow data for the Elm Street gage were obtained from USGS for the same period to determine whether a correlation could be made between flows at the two locations. Again, if a strong relationship were observed, it could be used instead of a ratio of drainage areas to adjust flows from the gage to Forge Pond Dam. Calculated weir flow at the dam was plotted against flow at the gage, as shown in Figure 4.1.3-1. However, although the pattern appears slightly more consistent than that of the RIFLS data, no clear relationship could be established (\( R^2 = 0.5 \)).

---

8 Varies based on head and breadth of weir. Ranges from 2.57-2.83 for Forge Pond Dam and 2.76-3.56 for the stoplogs for the range of head found through the period of record (0.1-1.3 ft).
The highest Silver Lake stage values for the period of available record (1996-2012) occurred during the March 2010 flood, with reported stage values of 15.5 inches and 14 inches above the Forge Pond Dam spillway on March 15 and 16, respectively. These stages correspond to calculated weir flow values of 172 and 146 cfs, respectively. The Jones River gage at Elm Street recorded instantaneous peak flows of 400 cfs both days, which is just under the 10-year flood estimation of 479 cfs for that location (see Section 4.1.6).

Note that there are a few issues with the weir flow analysis—namely a,) it was not feasible to compare with instantaneous gage data because Silver Lake stage data is recorded once daily at an unknown time in the morning, b,) it was assumed that Silver Lake elevation is an accurate measure of head at the Forge
Pond spillway, which has not been thoroughly tested, and c.) it was assumed that all three stoplogs were securely in place in all three bays, which was not always the case.

4.1.4 Natural Outflow from Silver Lake

The hydrology of Jones River was heavily studied as part of watershed study conducted by GZA in 2003 to account for water flowing into and out of the Jones River basin and subbasins. GZA developed a water budget model for the Silver Lake subbasin based on a simplified monthly time step model. Inflows to the Silver Lake subbasin included a) direct precipitation, streamflow (as estimated from the USGS gage at Elm Street and adjusted for drainage area), b) induced aquifer leakage to Silver Lake as a result of relatively rapid water surface fluctuations, and c) diversions from Monponsett Pond and Furnace Ponds. Outflows from Silver Lake included a) flows over Forge Pond Dam, b) water supply withdrawals by Brockton, and c) evapotranspiration. GZA estimated the water budget under three conditions: natural (before human development), developed (current), and future (year 2020 water demand), as shown in Figure 4.1.4-1.

There is some persistent misconception that Silver Lake would not provide year-round flow to the Jones River under natural conditions. However, the GZA modeling effort showed that under natural conditions, the average flow leaving Silver Lake for the Jones River during normal years would range from 4.8 cfs in October to 38 cfs in March (pictured above). Even during dry years, the October minimum outflow to the river would fall no lower than 3.8 cfs (dry year results presented in GZA report).

However, flow from Silver Lake to the Jones River under current, managed conditions is discontinuous. Typically, there is zero flow in normal precipitation years from June to the following January. In dry...
years such as 2000-2002, this no flow condition has lasted as long as 23 months, following only one month of flow in 1999. During most years flow occurs at least between March and June (WAA, 2006).

### 4.1.5 Target Flows for Fish Passage

For typical fish passage restoration projects, hydraulic analysis generally targets flow extremes within the migrating season. For example, the Wapping Road Dam feasibility study evaluated mean monthly flows for August and April to ensure fish could pass at the low and high ends of seasonal flows. However, because little to no flow passes over the Forge Pond Dam for much of the year due to Silver Lake water supply withdrawals, it would not be beneficial to analyze mean monthly flows at Forge Pond Dam under current conditions.

Instead, this study will evaluate fish passage alternatives to determine the range of flows needed to pass fish according to the criteria described in Section 2.3.2. This information will then be analyzed in the context of Brockton’s water supply operations to determine whether providing the required flows during migration periods would be feasible.

GZA (2003) conducted a cursory level analysis of flows required to pass fish in the Upper Jones River channel downstream of Forge Pond Dam as part of their watershed study. Of the cross-sectional data collected by GZA, it was noted that Transect No. 960 (located 960 feet downstream of Lake Street) can be considered representative of much of the riffle/run habitat in the watershed, including typical channel slope and morphology river herring would need to negotiate. GZA estimated the projected mean depth at the transect as a function of flow. The data show that a flow of 0.6 cfs would be required to produce a wetted channel depth of 0.3 ft (4 inches), and a flow of 2 cfs would provide a depth of 0.5 ft (6 inches), which in the range of critical passage depths estimated in Section 2.3.2. These depths are depicted on the cross-section plot in Figure 4.1.5-1.
GZA recommended that, assuming there are relatively few obstructions, a minimum flow of about 0.5 cfs (about 0.12 cfsm from the Silver Lake watershed) should be provided from Forge Pond Dam during the critical passage months to meet the minimum passage depth of 2.6 inches as described in Section 2.3.2. GZA also noted that this target is exceeded by the following instream flow recommendations for aquatic habitat (modified from the USFWS Aquatic Base Flow (ABF) method), which are preferred for the watershed as a whole.

**Table 4.1.5-1: Instream Flow Recommendations for Aquatic Habitat**

<table>
<thead>
<tr>
<th>Date</th>
<th>Minimum Flow (cfs)</th>
<th>Minimum Flow (cfsm)</th>
<th>Minimum Flow (cfsm at dam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start</td>
<td>End</td>
<td>per mi²</td>
</tr>
<tr>
<td>1-Jun</td>
<td>30-Sep</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>1-Oct</td>
<td>28-Feb</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1-Mar</td>
<td>30-Apr</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>1-May</td>
<td>31-May</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

*Source: GZA, 2003 (modified from USFWS ABF method)*

These target flows for in-channel water depth will be evaluated more thoroughly by the hydraulic model, in addition to analyzing flows needed to generate appropriate water depths in the various structures (i.e., Lake Street culvert, access road culverts, and potential fish passage structures).
4.1.6 Flood Frequency Estimates

Estimated flood flows are often simulated in restoration projects to evaluate the potential impact of the proposed change on flood inundation areas and structures. Any structural modifications must also be designed to withstand high flow events—usually the flood that produces the highest velocity. Due to complex water management and its influence on flows in the Jones River, flood flows were estimated via several methods and compared, as discussed below. All estimates are summarized in Figure 4.1.6-1 and Table 4.1.6-1 at the end of this section.

FEMA FIS

The FEMA FIS for the town of Kingston (1985) provided flood flow rates at selected locations in the Jones River watershed. Flows were estimated based on a HEC-1 flood hydrograph computer model. The flood flows used for the Forge Pond Dam location were calculated approximately 1,350 feet downstream of Grove Street, where FEMA reported the drainage area as 1.3 square miles. For its computations, FEMA subtracted the drainage area of Silver Lake (4.1 square miles) based on the assumption that this area is non-contributing due to water supply diversions. However, as noted above, this assumption is likely only valid for lower flows. The FIS reported a 100-year flood flow of 116 cfs.

Updated Flood Frequency Analysis

The National Oceanic and Atmospheric Administration (NOAA) Fisheries Service recently published guidance for considering climate change when developing flood frequency estimates for New England rivers (Collins, 2011). The publication recommends extending the flood record beyond dated FEMA studies and recomputing flood flows. Thus, an updated flood frequency analysis was conducted to compare with the FIS estimates for the Jones River. Annual peak flows at the Elm Street gage for the period of record (published data available for 1967-2009) were entered into the USGS's PKFQW program to estimate storm events for various recurrence intervals using the Bulletin 17B methodology, which creates a Log Pearson III statistical evaluation of the data. These values were then pro-rated to the Forge Pond Dam location using the 'natural' drainage area ratio (19.8 / 4.2 = 0.212) as defined in Table 4.1.1-1. The pro-rated estimates are significantly higher than the FIS-reported values—especially at higher flood flows (up to double for the 500-year flow).

RIFLS Flow Data Relationship

Even though the relationship of RIFLS flow readings vs. flow at the Elm Street gage was not particularly strong as discussed in Section 4.1.2, the trendline equation shown in Figure 4.1.2-2 was used to adjust the updated flood frequency estimates at the gage to Forge Pond Dam. Results are considerably higher than the estimates adjusted by drainage area ratio—up to 60% higher for the 500-year flood.

Weir Flow Data Relationship

Similarly, the trendline equation for the relationship of weir flow over Forge Pond Dam (calculated using Silver Lake stage data) and flow at the USGS gage shown in Figure 4.1.3-1 was used to adjust the

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9 When the updated flood record includes a substantial period before 1970 (e.g., 20 years), NOAA also recommends computing pre-1970, post-1970, and full record curves and considering choosing the most conservative (larger) estimates for design flows. Since the bulk of the flood record for the Jones River gage falls after 1970 (1967-2009), no additional analysis was needed.

10 The PEAKFQ program only used 12 of the 43 peak flows available for the period of record (1969-78), citing “known effect of regulation,” which decreases the reliability of these estimates.
updated flood frequency estimates to Forge Pond Dam. These values are higher still than the estimates adjusted by the RIFLS relationship, though only by about 30%.

**USGS Regional Regression Equations**

Lastly, regional regression equations developed for eastern Massachusetts by USGS (Wandle, 1983) were used estimate flood flows. These equations are based on drainage area only and do not extend up to the 500-year flow:

\[
\begin{align*}
Q_{10} & = 72.12 \times A^{0.660} \\
Q_{50} & = 118.1 \times A^{0.645} \\
Q_{100} & = 143.1 \times A^{0.638}
\end{align*}
\]

where \( A \) represents drainage area (4.2 mi\(^2\) used). Estimates computed by this method were slightly lower than those calculated by the weir flow relationship.

A comparison of the various flood flow estimates at Forge Pond Dam is shown in **Figure 4.1.6-1**.

**Figure 4.1.6-1: Comparison of Flood Flows at Forge Pond Dam Estimated by Various Methods**

Tabulated results of these analyses are presented in **Table 4.1.6-1**.
Table 4.1.6-1: Comparison of Flood Flows at Forge Pond Dam Estimated by Various Methods

<table>
<thead>
<tr>
<th>Recurrence Interval (yrs)</th>
<th>AT GAGE</th>
<th>AT FORGE POND DAM</th>
<th>USGS Regression Equation for Eastern MA (based on DA = 4.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Updated Log Pearson Type III Analysis ('67-'09)</td>
<td>FEMA FIS (1985 HEC-1 model at Grove St)</td>
<td>Pro-Rated from Updated Gage Analysis</td>
</tr>
<tr>
<td>10</td>
<td>479</td>
<td>75</td>
<td>102</td>
</tr>
<tr>
<td>50</td>
<td>775</td>
<td>100</td>
<td>164</td>
</tr>
<tr>
<td>100</td>
<td>926</td>
<td>116</td>
<td>196</td>
</tr>
<tr>
<td>500</td>
<td>1345</td>
<td>140</td>
<td>285</td>
</tr>
</tbody>
</table>

For the purposes of this conceptual-level feasibility study, flood flows will only be used to compare ‘before’ and ‘after’ water surface elevations and inundation areas for any proposed structural modifications. Because permitting entities will likely request to see these changes relative to published FEMA data, this analysis will use flood flows estimated by the FIS.

However, if the project proceeds to the detailed design phase, it will be important to ensure the design can withstand conservatively high flood flows. Additionally, as noted above, diversions from Monponsett and Furnace Ponds into Silver Lake could add flow from up to 7 square miles of drainage area to the Jones River system, which has not been factored into any of these flood frequency estimates. Designers should work with project partners to determine appropriate estimates of flood flows to use as fish passage design criteria.
4.2 **Water Supply Data**

Information about Brockton’s water supply operations will also be analyzed in this study to determine whether flows desired for fish passage or other aquatic habitat enhancements can be feasibly passed below Forge Pond Dam while still meeting water supply needs.

4.2.1 **Lake Stage Data**

Silver Lake stage data were evaluated to determine the percentage of time lake elevations fell below the Forge Pond Dam spillway crest elevation¹¹ and natural outlet elevation¹². Figure 4.2.1-1 in Appendix B shows the annual Silver Lake elevation duration curve, which displays the percentage of time Silver Lake elevations are equaled or exceeded over the available period of record (1996-2012). Figure 4.2.1-1 shows that Silver Lake elevations are above the Forge Pond spillway crest elevation (i.e., spilling into the upper Jones River) 27% of the time, and exceed the natural outlet elevation 62% of the time.

Monthly Silver Lake elevation duration curves were also developed as shown in Figures 4.2.1-2 through 4.2.1-5 in Appendix B. Table 4.2.1-1 summarizes these graphs with the average percentage of time Silver Lake elevations are above the Forge Pond Dam spillway crest and natural outlet elevations on a monthly and annual basis.

<table>
<thead>
<tr>
<th>Silver Lake Elevation</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Ann</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above spillway crest</td>
<td>30%</td>
<td>40%</td>
<td>54%</td>
<td>72%</td>
<td>53%</td>
<td>26%</td>
<td>6%</td>
<td>4%</td>
<td>0%</td>
<td>2%</td>
<td>9%</td>
<td>22%</td>
<td>27%</td>
</tr>
<tr>
<td>Above natural outlet</td>
<td>64%</td>
<td>79%</td>
<td>91%</td>
<td>93%</td>
<td>93%</td>
<td>93%</td>
<td>73%</td>
<td>41%</td>
<td>18%</td>
<td>24%</td>
<td>33%</td>
<td>47%</td>
<td>62%</td>
</tr>
</tbody>
</table>

*Period of record: Oct 1996-Mar 2012. Elevations of Forge Pond Dam spillway crest (47.6 ft) and natural outlet invert (45.9 ft) from 2003 Coler & Colantonio survey were used.*

The flow duration analysis results were reviewed in light of the life cycle of river herring and American eel. During river herring immigration (April through June), the Forge Pond Dam spillway crest elevation is exceeded and flow is passed downstream approximately 72%, 53%, and 26% of the time in April, May, and June, respectively. As elvers continue to immigrate into July, river flows are curtailed even further—overtopping the spillway crest just 6% of the time. Juvenile herring and silver eels would emigrate from Silver Lake in the fall. During September, October, and November, not only is virtually no flow passed downstream, but the majority of time water levels are also below the natural outlet invert, preventing fish in Silver Lake from even navigating to Forge Pond. A continuous flow would be needed below the dam for these fish to complete their life cycle.

Figure 4.2.1-6 in Appendix B shows Silver Lake water surface elevation throughout the year averaged over the full period of record (1996-2012). The elevations of the Forge Pond Dam spillway and the Silver Lake outlet invert are plotted for reference. The figure also shows the general time periods for migrating adult river herring, juvenile rearing, and emigrating juveniles.

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¹¹ For the existing conditions lake stage analysis, it was assumed that water would be conveyed below Forge Pond Dam via the spillway only as the stoplogs are not normally removed, according to Brockton (2009).

¹² Note that C&C surveyed elevations of 47.6 feet and 45.92 feet (NGVD 29) were used for the spillway crest and natural outlet, respectively, for all graphs in this section. The outlet invert was found to be slightly higher (46.2 feet) during the 2012 survey.
On average, Silver Lake elevations exceed the Forge Pond Dam spillway crest only during April, making it impossible to attract river herring to the base of Forge Pond Dam or complete their life cycle. Additionally, on average, Silver Lake elevations drop below the natural outlet elevation from August through early January, effectively isolating Silver Lake from Forge Pond and preventing the passage emigrating juvenile herring or silver eels downstream in the fall.

Figure 4.2.1-6 also shows that, during the spawning and egg incubation timeframe for river herring (April through June), Silver Lake elevations drop almost a foot. Deposited river herring eggs sink to the bottom where they adhere to stones, gravel, coarse sand, and other material. The time for eggs to hatch varies from 2 to 4 days. Thus, it would be important to manage water levels so as to not expose deposited eggs during this period.

If herring spawning and egg incubation were successful, juvenile herring would grow within Silver Lake during the summer months. The drawdown of Silver Lake elevations during the summer could have an impact on growth and survival as the littoral zone could be impacted (i.e., exposed). On average, the Silver Lake elevations in July, August, and September are 46.3, 45.5 and 44.7 feet, respectively (or 1.2, 2.0, and 2.8 feet below the Forge Pond Dam spillway crest elevation).

Refer back to Figure 2.4.1-1 in Appendix A for the Silver Lake bathymetric map highlighting contours for water elevations at full pond, average September elevation, and lowest elevation on record (1996-2012). Based on C&C’s data, the surface area and storage volume of Silver Lake at key elevations are shown in Table 4.2.1-2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Surface Area (acres)</th>
<th>Reduction in Surface Area Relative to Spillway Crest Elev</th>
<th>Storage (acre-ft)</th>
<th>Reduction in Storage Volume Relative to Spillway Crest Elev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spillway crest elevation (47.6 ft)</td>
<td>634</td>
<td>-</td>
<td>3,710</td>
<td>-</td>
</tr>
<tr>
<td>Avg Sep elevation (44.7 feet)</td>
<td>613</td>
<td>-21 (-3%)</td>
<td>3,692</td>
<td>-19 (-0.5%)</td>
</tr>
<tr>
<td>Lowest elev. from 1996-2011 (40.6 ft)</td>
<td>503</td>
<td>-131 (-21%)</td>
<td>3,606</td>
<td>-104 (-2.8%)</td>
</tr>
</tbody>
</table>

**Downstream Releases**

In their 2009 draft CWMP, Brockton conducted an analysis to evaluate the impact of a downstream release from Silver Lake to the Jones River on the yield of the water supply system. This investigation examined the releases recommended in GZA’s 2003 watershed study based on the USFWS ABF method. Brockton reported that if water was released at the GZA-recommended levels to Jones River only when lake levels were above the natural outlet elevation (assumed 45 feet by Brockton), the firm yield of Silver Lake would decrease by 0.6 mgd (from 10.4 mgd to 9.8 mgd). This study will further investigate the feasibility of a downstream release considering a.) reduced target releases for fish passage only as described in Section 4.1.4, b.) enhanced connectivity between Silver Lake and Forge Pond, and/or c.) higher Silver Lake levels due to incorporation of additional water into the Brockton water supply system from other sources (e.g., Aquaria).

4.2.2 Diversion and Withdrawal Data

Figure 4.2.2-1 in Appendix B shows average Silver Lake withdrawals and average diversions into Silver Lake from Monponsett Pond and Furnace Pond for the period of record (1996-2012). The average
annual Silver Lake withdrawal is 9.6 mgd (14.9 cfs), but can range from 8.95 to 10.37 mgd. Table 4.2.2-1 shows the average monthly withdrawals in cfs and mgd for the period of record.

<table>
<thead>
<tr>
<th>Withdrawal Units</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Ann</th>
</tr>
</thead>
<tbody>
<tr>
<td>mgd</td>
<td>9.8</td>
<td>9.7</td>
<td>9.4</td>
<td>9.3</td>
<td>9.6</td>
<td>10.0</td>
<td>10.0</td>
<td>9.8</td>
<td>9.4</td>
<td>9.4</td>
<td>9.5</td>
<td>9.6</td>
<td>9.6</td>
</tr>
<tr>
<td>cfs</td>
<td>15.2</td>
<td>15.0</td>
<td>14.6</td>
<td>14.3</td>
<td>14.8</td>
<td>15.5</td>
<td>15.5</td>
<td>15.1</td>
<td>14.5</td>
<td>14.5</td>
<td>14.7</td>
<td>14.9</td>
<td>14.9</td>
</tr>
</tbody>
</table>


**Monponsett and Furnace Pond Diversions**

The average annual diversions from Monponsett Pond and Furnace Pond to Silver Lake are 5.2 mgd (8.0 cfs), and 0.5 mgd (0.8 cfs), respectively. Although authorized diversions are permitted to occur from October through May, as Figure 4.2.2-1 shows, diversions have occurred outside this period as discussed in Section 3.2. When waters levels rise at these ponds, shoreline residents can experience problems with basement flooding, septic system operation, and loss of beach front. As a result, Brockton receives requests to divert water into Silver Lake to alleviate the issues. Although these requests more commonly occur in the fall and winter months, they also occur in the spring and summer.

**Aquaria**

In 2009, Brockton began using Aquaria as a water source, and relied slightly less on Silver Lake withdrawals to meet demand. According to Brockton’s agreement with Aquaria, Brockton could currently purchase up to 3.5 mgd from this source, increasing to 4.07 mgd by 2018. However, Brockton typically purchases only a nominal amount (350,000 gpd) to ensure water quality standards are met. Based on average Silver Lake withdrawals between pre- (1996-2008) and post- (2009-2012) Aquaria periods, the reduction in Silver Lake withdrawals has been approximately 0.9 mgd (1.4 cfs).

**Diversion vs. Spilling Analysis**

An analysis was conducted to determine the percentage of time that water diverted into Silver Lake from either Monponsett or Furnace Ponds is “wasted” (from the perspective of water supply) by spilling over Forge Pond Dam. During the period of record (1996-2012), water was being diverted into and spilling out of Silver Lake on the same day about 17% of the time, or almost half (47%) of the time water was being diverted overall. Considered another way, during 72% of the days water spilled over Forge Pond Dam, it was also being diverted into Silver Lake, which is in conflict with Brockton’s policy (and governing legislation) of diverting only when Silver Lake is less than full. Table 4.2.2-2 below presents these statistics on a monthly and annual basis.
### Table 4.2.2-2: Percent of Time Water Diverted into Silver Lake is Spilled Downstream

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of Days (Oct 1996 - Jul 2012)</th>
<th>Percent of Time ‘Wasting’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diverting (from either Monponsett or Furnace Ponds)</td>
<td>Spilling (above Forge Pond Dam spillway crest)</td>
</tr>
<tr>
<td>January</td>
<td>313</td>
<td>149</td>
</tr>
<tr>
<td>February</td>
<td>302</td>
<td>182</td>
</tr>
<tr>
<td>March</td>
<td>326</td>
<td>272</td>
</tr>
<tr>
<td>April</td>
<td>252</td>
<td>326</td>
</tr>
<tr>
<td>May</td>
<td>221</td>
<td>249</td>
</tr>
<tr>
<td>June</td>
<td>64</td>
<td>118</td>
</tr>
<tr>
<td>July</td>
<td>21</td>
<td>31</td>
</tr>
<tr>
<td>August</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>September</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>October</td>
<td>129</td>
<td>13</td>
</tr>
<tr>
<td>November</td>
<td>156</td>
<td>46</td>
</tr>
<tr>
<td>December</td>
<td>279</td>
<td>111</td>
</tr>
<tr>
<td>Annual</td>
<td>2087</td>
<td>1522</td>
</tr>
</tbody>
</table>

1 Water level was above the spillway only twice during September for the entire period of record.  
2 There were only 13 occurrences when water was spilling over the dam in October, all during which diversions were also occurring (11 in 1996, and 2 in 2005).

**Figures 4.2.2-2 through 4.2.2-12 in Appendix B depict much of the water supply data in more detail on annual graphs for the last 10 years (2002-2012). Silver Lake elevation is plotted with elevations of the dam spillway and natural outlet for reference. Monponsett and Furnace pond diversions are also displayed to evaluate the ‘wasting’ concept described above (diverting and spilling simultaneously). General fish life cycle timeframes are also included to provide context for the data.**

**4.2.3 Estimated Yield**

‘Safe yield’ and ‘firm yield’ are hydrologic terms that have been interpreted in different ways. One common definition of safe yield is “the maximum quantity of water which can be guaranteed during a critical dry period.” Knowledge of the safe yield associated with a water source (reservoir, aquifer, watershed, etc.) is important to prevent demand from exceeding the available and reliable supply. During periods when water is abundant, the available supply may far exceed the estimated safe yield, but during drought conditions supply will be reduced. Safe yield generally represents the long-term quantity of water which would be available under expected drought conditions, and traditionally does not account for the water needs of aquatic wildlife (GZA, 2003).

Brockton has conducted various analyses to determine the firm yield of its reservoir systems, which it defines as “the average daily withdrawal from a water supply system that can be sustained through the drought of record without entirely depleting the system storage” (2009). The safe yield of Silver Lake alone was reported as 4.5 mgd in 1955 report prepared by Camp, Dresser, and McKee, Inc. (CDM) for the City of Brockton. This study analyzed a 20 year drought event with 180 days of no precipitation, estimating the amount that could be withdrawn before reaching the point where the intake pipe would run dry. In 1987, CDM used a mass-balance reservoir model to determine that the safe yield of the
entire Silver Lake system (including transfers from Monponsett Pond and Furnace Pond) was 9.4 mgd. This finding was accepted by the DEP in the 1995 ACO where 10.33 mgd is considered the safe yield of the Brockton water supply system (including Brockton Reservoir and Hubbard Avenue well as well as the Silver Lake system) and other documents. However, the DEP has never issued any analysis or report determining the safe yield of Monponsett or Furnace Ponds (JRWA, 2011b).

In 2003, GZA performed a brief analysis of the firm yield of Silver Lake using the DEP’s firm yield estimating software package. The study indicated a firm yield of 4.7 mgd from the lake, neglecting diversions from Furnace and Monponsett Ponds. Diversions were neglected since they are not permitted during periods of typical drought conditions, which are anticipated to occur sometime between June and September. In reality, the diversions from Furnace and Monponsett Pond can only assure a Silver Lake elevation at or just above full pond at the end of May, and cannot guarantee substantially greater capacity for water use during the summer months. This is because the lake, under natural conditions (i.e., without diversions and water withdrawals), is anticipated to essentially refill during winter and spring, assuming average precipitation in the watershed (GZA, 2003).

CDM conducted an updated analysis of firm yield for the Brockton systems in 2007 for inclusion in the draft CWMP. This study investigated both the drought of record accepted by DEP (1964-1967) as well as another significant drought that occurred in the 1980s (1980-1983). Proposed firm yields for the Silver Lake system were reported as 10.4 mgd and 12.0 mgd for the 1960s and 1980s droughts, respectively.

4.2.4 Current Water Use

Brockton is required to submit Annual Statistical Reports (ASRs) summarizing its water supply operations to the DEP. For this study, ASRs for the last 10 years (since 2002) were requested. Brockton provided reports for all years except 2009.

In the draft CWMP, Brockton summarized water usage statistics for the years 2000 through 2005. Similar information was obtained from the remaining available ASRs to provide the summary of current usage statistics in Table 4.2.4-1. Note that the format of the ASRs varied widely from year to year and data was not always categorized in the same way, but an effort was made to present statistics as consistently as possible.
### Table 4.2.4-1: Available Brockton Water Supply Statistics for 2000-2011

<table>
<thead>
<tr>
<th>Category</th>
<th>2000 Cons. (mgd)</th>
<th>2000 % of Total</th>
<th>2001 Cons. (mgd)</th>
<th>2001 % of Total</th>
<th>2002 Cons. (mgd)</th>
<th>2002 % of Total</th>
<th>2003 Cons. (mgd)</th>
<th>2003 % of Total</th>
<th>2004 Cons. (mgd)</th>
<th>2004 % of Total</th>
<th>2005 Cons. (mgd)</th>
<th>2005 % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>5.04</td>
<td>47%</td>
<td>4.89</td>
<td>46%</td>
<td>4.95</td>
<td>50%</td>
<td>4.95</td>
<td>46%</td>
<td>4.75</td>
<td>47%</td>
<td>4.57</td>
<td>47%</td>
</tr>
<tr>
<td>Commercial</td>
<td>1.09</td>
<td>10%</td>
<td>1.05</td>
<td>10%</td>
<td>1.12</td>
<td>11%</td>
<td>1.08</td>
<td>10%</td>
<td>1.17</td>
<td>12%</td>
<td>1.07</td>
<td>11%</td>
</tr>
<tr>
<td>Industrial/Agriculture</td>
<td>0.29</td>
<td>3%</td>
<td>0.28</td>
<td>3%</td>
<td>0.23</td>
<td>2%</td>
<td>0.24</td>
<td>2%</td>
<td>0.23</td>
<td>2%</td>
<td>0.22</td>
<td>2%</td>
</tr>
<tr>
<td>Recreational</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Public Service</td>
<td>0.9</td>
<td>8%</td>
<td>0.77</td>
<td>7%</td>
<td>0.85</td>
<td>9%</td>
<td>0.82</td>
<td>8%</td>
<td>0.87</td>
<td>9%</td>
<td>0.85</td>
<td>9%</td>
</tr>
<tr>
<td>Hanson</td>
<td>0.03</td>
<td>0.3%</td>
<td>0.07</td>
<td>1%</td>
<td>0.04</td>
<td>0.4%</td>
<td>0.04</td>
<td>0.4%</td>
<td>0.03</td>
<td>0.3%</td>
<td>0.05</td>
<td>1%</td>
</tr>
<tr>
<td>Whitman</td>
<td>0.93</td>
<td>9%</td>
<td>0.97</td>
<td>9%</td>
<td>0.99</td>
<td>10%</td>
<td>1.01</td>
<td>9%</td>
<td>0.99</td>
<td>10%</td>
<td>0.95</td>
<td>10%</td>
</tr>
<tr>
<td>Estimated Municipal Use</td>
<td>1.17</td>
<td>11%</td>
<td>0.63</td>
<td>6%</td>
<td>0.57</td>
<td>6%</td>
<td>0.84</td>
<td>8%</td>
<td>0.57</td>
<td>6%</td>
<td>0.3</td>
<td>3%</td>
</tr>
<tr>
<td>Unaccounted-for-Water</td>
<td>1.29</td>
<td>12%</td>
<td>2.04</td>
<td>19%</td>
<td>1.16</td>
<td>12%</td>
<td>1.71</td>
<td>16%</td>
<td>1.44</td>
<td>14%</td>
<td>1.64</td>
<td>17%</td>
</tr>
<tr>
<td>Total Average Day Demand</td>
<td>10.74</td>
<td>100%</td>
<td>10.7</td>
<td>100%</td>
<td>9.91</td>
<td>100%</td>
<td>10.69</td>
<td>100%</td>
<td>10.05</td>
<td>100%</td>
<td>9.65</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>2006 Cons. (mgd)</th>
<th>2006 % of Total</th>
<th>2007 Cons. (mgd)</th>
<th>2007 % of Total</th>
<th>2008 Cons. (mgd)</th>
<th>2008 % of Total</th>
<th>2009 Cons. (mgd)</th>
<th>2009 % of Total</th>
<th>2010 Cons. (mgd)</th>
<th>2010 % of Total</th>
<th>2011 Cons. (mgd)</th>
<th>2011 % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>5.99</td>
<td>65%</td>
<td>5.33</td>
<td>55%</td>
<td>5.86</td>
<td>59%</td>
<td>6.26</td>
<td>68%</td>
<td>4.38</td>
<td>52.8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>0.89</td>
<td>10%</td>
<td>0.49</td>
<td>5%</td>
<td>0.83</td>
<td>8%</td>
<td>1.98</td>
<td>22%</td>
<td>2.72</td>
<td>32.7%</td>
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<td></td>
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<tr>
<td>Industrial/Agriculture</td>
<td>0.28</td>
<td>3%</td>
<td>0.13</td>
<td>1%</td>
<td>0.13</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational</td>
<td>0.01</td>
<td>0.1%</td>
<td>0.003</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Public Service</td>
<td>0.54</td>
<td>6%</td>
<td>1.92</td>
<td>20%</td>
<td>1.06</td>
<td>11%</td>
<td>1.98</td>
<td>22%</td>
<td>2.72</td>
<td>32.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanson</td>
<td>0.04</td>
<td>0%</td>
<td>0.02</td>
<td>0.3%</td>
<td>0.05</td>
<td>0.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whitman</td>
<td>0.91</td>
<td>10%</td>
<td>0.92</td>
<td>9%</td>
<td>0.92</td>
<td>9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated Municipal Use</td>
<td>-</td>
<td>-</td>
<td>0.13</td>
<td>1%</td>
<td>0.30</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unaccounted-for-Water</td>
<td>-</td>
<td>-</td>
<td>0.82</td>
<td>8%</td>
<td>0.84</td>
<td>8%</td>
<td>0.92</td>
<td>10%</td>
<td>1.20</td>
<td>14.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Average Day Demand</td>
<td>9.28</td>
<td>93%</td>
<td>9.76</td>
<td>100%</td>
<td>9.97</td>
<td>100%</td>
<td>9.16</td>
<td>100%</td>
<td>8.30</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td></td>
<td>95,304</td>
<td>Data not available</td>
<td>94,185</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93,810</td>
<td></td>
</tr>
<tr>
<td>Residential Usage (gpcd)</td>
<td></td>
<td></td>
<td>45</td>
<td>45</td>
<td>44</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Annual Statistical Reports (calculated values may differ slightly from published data).
*Brockton reported UAW values of 9.4% and 9.3% for 2007 and 2008. In a letter dated May 28, 2008, the WRC reported Brockton’s 2007 UAW as 11%.*
The largest single user group is residential (domestic) users, comprising an average of about 54% of the total demand over the available data record. The second largest usage was attributed to unaccounted-for water (UAW), which is unmetered use or leakage not documented under other categories. The WRC established a 10% performance standard for UAW in 1999. Brockton’s UAW for the available data record has ranged from 8% in 2007 and 2008 to 19% in 2001, with an average of 13%.

Gallons per capita per day (gpcd) is the average of daily residential water use measured in gallons used per person in the service area. The WRC uses a typical value of 65 gpcd when estimating projected water demands. Brockton’s residential usage has ranged from 42 gpcd to 66 gpcd over the available data record, with an average of 51 gpcd.

4.2.5 Projected Water Supply Needs

Water suppliers periodically estimate future water needs by extrapolating historical trends in population and demand using a number of base assumptions. Such extrapolations usually become less accurate as the prediction period is extended, due to influences that cannot be anticipated. A certain amount of variability can be expected among various forecasts due to use of different projection methodologies.

In a letter dated October 29, 2009, the Massachusetts Department of Conservation and Recreation (DCR) Office of Water Resources issued estimated water needs forecasts for Brockton. These demand estimates were calculated using the WRC policy (updated May 1, 2009). As a baseline for the projections, the DCR used water data from Brockton’s Annual Statistical Reports (average of years 2004, 2005, 2007, and 2008) and community population projections from the Metropolitan Area Planning Council (MAPC) (2008 base year). Two sets of projections were developed—one assuming typical WRC targets of 65 gpcd and 10% UAW, the other utilizing current trends in gpcd and UAW (estimated as 57 gpcd and 10% UAW for the base years provided). Population projections and DCR water demand estimates are given in Tables 4.2.5-1 and 4.2.5-1.

Table 4.2.5-1: Population Projections for Brockton and Whitman

| Location | Projected Population | Service | | | | Employment | | |
|---------|----------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Brockton| 100,542   | 102,424  | 103,993  | 105,561  | 37,484   | 37,885   | 38,113   | 38,341   | 37,484   | 37,885   | 38,113   | 38,341   | 37,484   | 37,885   | 38,113   | 38,341   |
| Whitman | 14,110    | 14,182   | 14,235   | 14,289   | 2,617    | 2,517    | 2,471    | 2,424    | 2,617    | 2,517    | 2,471    | 2,424    | 2,617    | 2,517    | 2,471    | 2,424    |

Note: Interpolated from population and employment projections developed by MAPC. Service population projections are based on percent of the community served by water supply (100% for Brockton, 98% for Whitman).

---

13 Brockton reported slightly higher values (around 9%) for 2007 and 2008 UAW, while the WRC reported Brockton’s 2007 UAW as 11% in a letter dated May 28, 2008.

14 It is unclear how DCR’s base average of 10% UAW for years 2004, 2005, 2007, 2008 was calculated. The data presented in Table 4.2.4-1 gives an average of 12% for those years using conservatively low UAW values of 8% for 2007 and 2008. If higher estimates of 11% for 2007 and 9% for 2008 are used, the average raises to 13%.
Table 4.2.5-2: DCR Projected Water Demands for Brockton and Whitman

<table>
<thead>
<tr>
<th>Location</th>
<th>Projected Water Usage (mgd)</th>
<th>Assuming 65 gpcd and 10% UAW</th>
<th>Assuming current gpcd and UAW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2015</td>
<td>2020</td>
<td>2025</td>
</tr>
<tr>
<td>Whitman</td>
<td>1.08</td>
<td>1.08</td>
<td>1.09</td>
</tr>
<tr>
<td>Total</td>
<td>11.37</td>
<td>11.54</td>
<td>11.70</td>
</tr>
</tbody>
</table>

Note: Brockton has historically (last 5 years) supplied an average of 0.05 mgd (ranging from 0.02 to 0.07 mgd) to communities other than Brockton and Whitman, which is not included in these estimates but may be considered by the DEP when issuing the WMA permit.

*The WRC methodology allows for a 5% buffer of 2030 demands to accommodate for uncertainty in growth projections, which the DEP may incorporate into the total at its discretion.

Brockton estimated projected demands for 2010 and 2020 as part of its draft CWMP. These projections were compared with actual data from the 2010 ASR as shown in Table 4.2.5-3.

Table 4.2.5-3: Comparison of Brockton’s Projected Water Supply Demands to Actual Water Use

<table>
<thead>
<tr>
<th>2010 Actual</th>
<th>2010 Projection</th>
<th>2020 Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.16</td>
<td>10%</td>
<td>11.28</td>
</tr>
</tbody>
</table>

Source: Brockton, 2009.

Actual data for 2010 were about 14-19% lower than projected values for average daily demand (9.16 mgd) and UAW (10%). The draft CWMP projected water use for year 2020 (12 mgd) is similar to the DCR estimate using standard assumptions of 65 gpcd and 10% UAW (11.5 mgd), but the draft CWMP value is slightly higher because it is based on a slightly higher assumed per capita consumption rate.
5. Hydraulic Analysis

5.1 Background

Hydraulic models of river systems are developed to simulate baseline conditions and predict water depths, velocities, and water surface profiles given various flows and alternate conditions. A hydraulic model of Forge Pond and Jones River was developed from its headwaters at Silver Lake to just upstream of Grove Street to evaluate various fish passage improvement alternatives. The USACE Hydrologic Engineering Center’s River Analysis System (HEC-RAS) program was used to develop the model.

HEC-RAS is designed to perform one-dimensional, steady, or gradually-varied flow calculations in natural and man-made channels, as well as unsteady flow routing and basic sediment transport computations. An inflow hydrograph (one in which flows vary on a daily or hourly basis) cannot be simulated within the model; rather the flow must be constant. The model can simulate depths and velocities for a single reach, a branched system, or a full network of channels. HEC-RAS can also simulate sub-critical, super-critical, and mixed flow regimes.

Hydraulic analyses performed by HEC-RAS are based on a step-wise solution of the one-dimensional energy equation. In instances of rapid change in the water surface elevation causing turbulence and energy loss, HEC-RAS instead uses the momentum equation for analysis. Abrupt changes in the water surface elevation may occur near bridge constrictions, inline structures (dams and weirs), confluence of two or more flows, rapid changes in channel bed elevation, and hydraulic jumps.

Changes in the channel morphology will directly impact water velocities and depths. The two common channel morphology changes that impact depth and velocity are channel constrictions or expansions (see plan view below) or changes in the channel bed slope (see profile view below).

At a channel constriction, water backs up, causing an increase in water depth and a corresponding decrease in velocity. Once through the constriction (assuming the same amount of flow), the water depth will decrease while velocities increase, as shown in the plan view above. Similarly, an increase in the bed slope (as shown in the profile view) will also cause water to back up, leading to an increase in water depth with a decrease in the velocity. An example of an artificial change in bed slope is a dam or weir structure.

In addition to channel morphology, another factor that influences the depth and velocity of water is channel roughness. Channel roughness refers to the size of the channel substrate, and is accounted for in a hydraulic model by inputting Manning’s ‘n’ values (roughness coefficients) for each cross-section. If
the channel is comprised of large substrate (i.e., cobble), the roughness coefficient will be greater than that in a channel comprised of small substrate (i.e., sand). A larger coefficient will cause greater turbulence/friction, reducing the water velocity and increasing water depth. For example, if a uniform channel with a constant flow is composed of cobble transitioning to sand, the velocities will be slower in the cobble section and faster in the sandy reach. Likewise, the depth will be higher in the cobble reach and shallower in the sandy reach.

Energy losses in the channel are associated with friction (solved with Manning’s equation) or with contraction and expansion (solved by multiplying a loss coefficient by the change in velocity head between transects). Flows over weirs and other inline structures (dams) are determined with the standard weir-flow equations. HEC-RAS also enables inclusion of gate structures that accompany inline structures such as dams.

5.2 Model Inputs

Topography

The various sources of topographic data available for this project were described in Section 2.4. Sources utilized are summarized in Table 5.2-1 below.

<table>
<thead>
<tr>
<th>Source</th>
<th>Reporter</th>
<th>Date</th>
<th>Coverage</th>
<th>Utilized For</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Updated Survey</td>
<td>Gomez and Sullivan Engineers</td>
<td>Oct 2012</td>
<td>Lake Street to upstream face of dam (structural &amp; channel data); natural outlet area</td>
<td>Structural geometries, channel cross-sections</td>
<td>Survey-grade real-time kinematic (RTK) GPS used.</td>
</tr>
<tr>
<td>LiDAR</td>
<td>MassGIS</td>
<td>2011</td>
<td>Entire project area</td>
<td></td>
<td>Vertical accuracy of 0.3 meters or approximately one foot.</td>
</tr>
<tr>
<td>Flood Insurance Study</td>
<td>FEMA</td>
<td>1985</td>
<td>Jones River up to Forge Pond Dam</td>
<td>Boundary conditions (starting water surface elevations); thalweg elevations downstream of Lake Street (used to adjust LiDAR data within banks)</td>
<td>FIS model channel input data mostly illegible upstream of Grove Street. Crude analysis--Grove Street &amp; railroad structures both inaccurate.</td>
</tr>
</tbody>
</table>

Channel cross-sections for the model were placed at existing FIS cross-section locations as well as approximately every 100-150 feet through Forge Pond, every 300 feet downstream of Lake Street, and as needed for more detail around the Forge Pond Dam/Lake Street structures. Figure 5.2-1 is a plan map showing the transect locations.
Figure 5.2-1: Map of Transect Locations for Hydraulic Model

Letters indicate FEMA FIS cross-sections.
Roughness Coefficients

Roughness coefficients (Manning’s ‘n’ values) used in the model ranged from 0.025 to 0.055 (smooth concrete to deep pool) in the channel and 0.05 to 0.10 (residential to wooded forest) on the banks and floodplains. These values were compared to n values used in the hydraulic model conducted downstream for the Wapping Road Dam removal project, and were found to be within a similar range.

Boundary Conditions

HEC-RAS requires a ‘boundary condition’ to start the model at its downstream extent. This can be a known water surface elevation, channel slope (to approximate the energy grade line using the normal depth method), rating curve, etc. For the high flow calibration run using FEMA FIS flood flows, known water surface elevations for FEMA cross-section ‘W’ (the downstream extent of the model) were used. These values were obtained from the FIS water surface profile.

For the low flow calibration run, the normal depth method was used as a downstream boundary condition. The channel slope is very flat at the downstream extent of the model, so a slope of 0.001 was used.

Flow Regime

The HEC-RAS model was run with a mixed flow regime, capable of calculating both sub-critical and super-critical water surface profiles associated with the mild channel slope present in the majority of the model and the steep slope section located downstream of Lake Street.

5.3 Calibration

Once the model geometry was developed, an initial HEC-RAS analysis was conducted to calibrate the model by comparing model results to observed measured water levels. Two sets of calibration flows were used—high flows (FEMA FIS flood flows) and low/moderate flows (RIFLS discharge measurements). Note that for both these calibration runs, the stoplogs in Forge Pond Dam were modeled with two bays in place and one bay missing one board to represent the conditions that were found at the time of the field survey.

High Flow Calibration

For the high flow calibration, FEMA FIS flood flows were used. As noted above, water surface elevations for the 10-, 50-, 100-, and 500-year floods were obtained from the FIS for cross-section ‘W’ for input as a downstream boundary condition, and for the remaining 5 lettered FEMA cross-sections (X through AB) for the purposes of calibration. Published FIS vs. modeled water surface elevations at each lettered cross-section are given in Table 5.3-1. Water surface elevations calibrated very well throughout the model, with the exception of the most-upstream lettered cross-section (AB). Here, modeled elevations were higher than FIS values.
### Table 5.3-1: High Flow Calibration Results (FEMA FIS Flows)

<table>
<thead>
<tr>
<th>FEMA XS ID</th>
<th>Model Station</th>
<th>Location</th>
<th>Recurrence Interval (yrs)</th>
<th>FEMA Flow (cfs)</th>
<th>Water Surface Elevation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Published Modeled Difference</td>
</tr>
<tr>
<td>AB</td>
<td>4817</td>
<td>Upstream face of Forge Pond Dam</td>
<td>10</td>
<td>75</td>
<td>47.7 48.3 0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
<td>47.8 48.4 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>116</td>
<td>47.9 48.6 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>140</td>
<td>48.0 50.1 2.1</td>
</tr>
<tr>
<td>AA</td>
<td>4418</td>
<td>~250 ft Downstream of Lake St</td>
<td>10</td>
<td>75</td>
<td>41.0 41.0 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
<td>41.2 41.2 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>116</td>
<td>41.3 41.3 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>140</td>
<td>41.5 41.5 0.0</td>
</tr>
<tr>
<td>Z</td>
<td>4187</td>
<td>~475 ft Downstream of Lake St</td>
<td>10</td>
<td>75</td>
<td>40.3 40.3 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
<td>40.5 40.4 -0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>116</td>
<td>40.5 40.5 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>140</td>
<td>40.9 40.6 -0.3</td>
</tr>
<tr>
<td>Y</td>
<td>2916</td>
<td>Adjacent to cranberry bogs</td>
<td>10</td>
<td>75</td>
<td>36.1 36.2 0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
<td>36.5 36.6 0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>116</td>
<td>36.7 36.8 0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>140</td>
<td>37.0 37.2 0.1</td>
</tr>
<tr>
<td>X</td>
<td>1078</td>
<td>~900 ft Upstream of Grove St</td>
<td>10</td>
<td>75</td>
<td>35.7 35.6 -0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
<td>36.2 36.1 -0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>116</td>
<td>36.5 36.4 -0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>140</td>
<td>37.0 36.9 -0.1</td>
</tr>
<tr>
<td>W</td>
<td>444</td>
<td>Upstream face of Grove St</td>
<td>10</td>
<td>75</td>
<td>35.5 35.5 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>100</td>
<td>36.0 36.0 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>116</td>
<td>36.3 36.3 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500</td>
<td>140</td>
<td>36.8 36.8 0.0</td>
</tr>
</tbody>
</table>

**Low/Moderate Flow Calibration**

To calibrate the model for low to moderate flows, RIFLS stage-discharge measurements were utilized. Rating descriptor points were taken from the rating table for the gage for flows ranging from 0.016 cfs (just a tenth of a foot deep in the Lake Street culvert) to 5.4 cfs (flowing about half full through the culvert). These flows calibrated extremely well—all within 0.2 feet—as shown in Table 5.3-2.
Table 5.3-2: Low/Moderate Flow Calibration Results (RIFLS Discharge Measurements)

<table>
<thead>
<tr>
<th>RIFLS Measurement</th>
<th>Water Surface Elevation (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage*</td>
<td>Flow (cfs)</td>
</tr>
<tr>
<td>3.6</td>
<td>0.016</td>
</tr>
<tr>
<td>3.7</td>
<td>0.032</td>
</tr>
<tr>
<td>3.8</td>
<td>0.087</td>
</tr>
<tr>
<td>3.9</td>
<td>0.33</td>
</tr>
<tr>
<td>4.0</td>
<td>0.82</td>
</tr>
<tr>
<td>4.1</td>
<td>1.45</td>
</tr>
<tr>
<td>4.2</td>
<td>2.25</td>
</tr>
<tr>
<td>4.3</td>
<td>3.15</td>
</tr>
<tr>
<td>4.4</td>
<td>4.25</td>
</tr>
<tr>
<td>4.5</td>
<td>5.38</td>
</tr>
<tr>
<td>4.6</td>
<td>6.7</td>
</tr>
<tr>
<td>4.7</td>
<td>8</td>
</tr>
<tr>
<td>4.8</td>
<td>9.5</td>
</tr>
<tr>
<td>4.9</td>
<td>11.1</td>
</tr>
<tr>
<td>5.0</td>
<td>13</td>
</tr>
<tr>
<td>5.2</td>
<td>16.9</td>
</tr>
<tr>
<td>5.4</td>
<td>21.3</td>
</tr>
</tbody>
</table>

*Stage is in feet relative to a ‘zero’ point of 3.5 feet (equal to the invert of the Lake Street culvert – 42.4 feet)

5.4 Existing Conditions

Once the model was calibrated, a range of flows from the RIFLS rating curve were selected to simulate water surface profiles under existing conditions. Figure 5.4-1 shows channel and water surface profiles from the natural outlet of Silver Lake down to the Lake Street culvert for flows of 0.016 cfs, 3 cfs, and 21.3 cfs.
Figure 5.4-1: Existing Conditions Water Surface Profile

Legend

- WS 21.3 cfs
- WS 3.15 cfs
- WS 0.016 cfs
- Ground

Main Channel Distance (ft)

FORGE POND DAM
Before considering conceptual plans for fish passage, it was important to determine whether Forge Pond Dam meets current dam safety regulations. Dams are designed to pass a certain spillway design flood (based on their size and hazard classification) without overtopping the abutments. Modifications to a dam, including installation of a fish passage structure, cannot reduce the spillway capacity below the dam’s design criteria.

As noted in Section 2.2.4, the 2003 dam safety inspection report for Forge Pond Dam classified it as a large, low hazard dam. According to MA Office of Dam Safety regulations, dams of this classification must pass the 100-year flood. Figure 5.4-2 shows that Forge Pond Dam does currently pass the FIS 100-year flood (116 cfs) with 0.6 feet of freeboard below the walkway. Fish passage alternatives requiring structural modifications to the dam will be evaluated with the hydraulic model to ensure the spillway will still be able to pass the 100-year flood.

**Figure 5.4-2: 100-year Flood Elevation at Forge Pond Dam**

> Note: The FIS 100-year flood flow of 116 cfs was used for this analysis as it represents the current legal record.
6. **Screening of Fish Passage Alternatives**

The first step in the evaluation of fish passage alternatives was to identify options with the greatest potential for effective application at the site. Fish passage alternatives were discussed with project partners and the following preliminary options were identified for further analysis:

- Technical fishway (fish ladder)
- Nature-like bypass channel
- Dam removal

At this stage in the conceptual feasibility analysis, some of these alternatives have been investigated more thoroughly than others to date. General information about each option is presented below. More detailed analyses of each, including budgetary estimates, will be conducted for the final feasibility study.

### 6.1 Technical Fishway (Fish Ladder)

Technical upstream fishways, or fish ladders, are engineered structures, typically made of concrete or aluminum, that pass water over a fish passage barrier (i.e., a dam) using a cascading effect that slows the water velocity to accommodate the swimming speed of target species. Fish ladders generally fall into one of two categories: baffled chutes or pool and weir type. Baffled chute fishways will be discussed here (Brownell et al., n.d.).

The basic design concept for baffled fishways is to reduce the total hydraulic head (elevation differential) to passable increments using a series of baffles, with each increment comprising a carefully controlled hydraulic step over a short distance. Baffles dissipate head energy to provide hydraulic conditions suitable for upstream fish movements. The Denil and the steeppass designs are two principal variations of baffled chutes in general use (Brownell et al., n.d.).

**Denil**

Denil fishways are the most common baffled chutes fishway because the single-plane baffle of a Denil fishway is easier to fabricate than the multi-plane baffles of the steeppass fishway. Because standard Denil fishways are less effective at energy dissipation than steeppasses, Denil fishways are somewhat longer for similar ease of passage. Denil fishways can be fabricated from many types of materials—metal, concrete, wood, etc.—and are relatively low cost in comparison with the larger pool-type technical fishways. Denil fishways in appropriate locations can be generally reliable for passage of adult salmonids and in some cases American shad, river herring, other alosines, and other migratory and resident species (Brownell et al., n.d.).

**Steeppass**

Also known as the Alaska steeppass, these are similar but more complex than the Denil design with higher energy dissipation (compared to the standard Denil design) that permits somewhat steeper angles, slower water velocities, and/or shorter ladders. Steeppasses are usually pre-fabricated from aluminum in modular 10-foot sections to allow for portability and remote installations. In Atlantic river basins, the short steeppass fishways can be effective passage for river herring, Atlantic salmon,
American shad, hickory shad, and many resident potamodromous fish species (i.e., fish that migrate only within fresh water). The functionality of a steeppass is best adapted to small river and stream systems and dams with limited headpond and tailwater level fluctuations (Brownell et al., n.d.).

Denil and steeppass fishways have similar advantages and disadvantages. Advantages of both steeppasses and Denil fishways include:

- Can be built of various materials, including wood, metal, or concrete.
- Relatively inexpensive to construct.

Disadvantages of both steeppasses and Denil fishways include:

- Prone to clogging with sticks and debris without regular maintenance.
- Limited tolerance for headwater and tailwater fluctuations.
- Can use too much water during low flow conditions, resulting in dewatering of upstream areas or providing too little water depth in the ladder itself.
- Need a larger minimum flow to operate compared to many pool-type ladders.
- Limitations on their length without resting pools or between resting pools may complicate design and utilization.
- In single, straight examples, sometimes the ladder entrance ends up being further downstream of the dam than would be optimal.
- In relatively deep channels, the fishway entrance is located in the upper part of the water column resulting in lesser attraction and conditions for benthic-oriented fishes.
- High energy can be problematic for weaker, smaller, adult or juvenile fishes.
- Baffles can descale, abrade, injure, or trap fish.

Less flow is required in a steeppass than a Denil system. Due to the already low flows at Forge Pond Dam, the steeppass fishway was selected for further analysis primarily for this reason. Alaska steeppass flow requirements can range from approximately 2 to 4 cfs.

Additionally, the ability of the steeppass to accommodate higher slopes and shorter sections is an advantage in the tight structural constraints downstream of Forge Pond Dam. The spillway basin between the dam and the access road bridge downstream is only approximately 6.5 feet wide. Using a slope of 20% (within the 15-30% allowable slope for steeppass installation) would allow the downstream
invert of the fish ladder to be placed just inside one of the access road bridge openings, while still allowing the fish ladder to clear the top of the opening and meet the spillway at an appropriate height.

Therefore, the location of the steeppass fishway is limited by the three bridge openings. The left bridge opening (looking downstream) is the most feasible location due to a deeper channel invert on that side of the spillway and through that bridge opening, into the pool downstream of the access road. Appropriate depths for in-channel fish passage are more likely to be maintained on the river left side. On the river right side, the fish ladder could be fitted into one of the existing stoplog bays, but the channel invert on this side of the spillway basin is higher, and minimum depths are less likely to be maintained.

Given these parameters, conceptual layouts for a steeppass fishway at Forge Pond Dam were developed and are shown in Figure 6.1-1 (plan view), Figure 6.1-2 (profile view), and Figure 6.1-3 (detail view), found at the end of this section.

The specific steeppass design evaluated is known as the Model A40, which measures 27 inches deep, 23 inches wide, and has 14-inch openings between the baffles (see Figure 6.1-3). The vertical barrier in the proposed fishway location is approximately 4.5 feet from the channel bed to the spillway crest. A 2.1-foot-deep notch would be removed from left edge of the spillway to obtain an upstream invert elevation of 45.5 feet.

Typically, the depth of flow through a steeppass is effective for fish passage between a minimum of 12 inches and a maximum of 20 inches (measured above the 5-inch baffle section at the base of the fishway). The selected invert elevation would ensure that through the range of effective fish passage depths at the fish ladder, the depth of flow at the natural outlet from Silver Lake would be approximately 9-12 inches, allowing herring to pass through to the lake.

Based on a slope of 20%, the required fishway length would be approximately 7 feet, which is equivalent to less than one 10-foot-long pre-fabricated section. It is assumed that shorter sections can be requested from fabrication companies, or a standard section could be cut on site.

A fabricated inlet section with stoplogs would be built at the fishway entrance (see Parker River example above). The stoplogs would be used to control the flow through the fishway under varying head conditions and to shut off flow to the fishway, when desired. The steeppass and inlet sections would be bolted together using joining plates.

For the selected fishway slope of 20%, about 2.7 cfs would be passed through the fish ladder at the minimum effective depth of 12 inches, while approximately 4.3 cfs would be conveyed at the maximum effective depth of 20 inches.

**Downstream Passage**

For herring outmigrating in the fall, safe downstream passage must also be provided. Downstream passage options considered include:

a) Opening the steeppass fishway by removing stoplogs to convey flow

b) Opening one or more stoplog bays to pass fish downstream to the concrete apron
c) Removing portion of the dam spillway adjacent to the fishway (e.g., ‘notching’ the dam) to allow fish to pass downstream into the plunge pool

Attempting to use a fishway for downstream passage may present issues, as fish may not be able to find the entrance during periods of higher flow, or the fishway may not be very effective in passing fish downstream.

Additionally, simply removing one or more stoplogs to pass fish downstream through a stoplog bay would not be a feasible option due to the concrete apron below this section. As previously stated, a plunge pool is present below the main spillway, but passage through the stoplog section would cause herring to drop approximately 3 feet onto concrete, potentially leading to injury or mortality. An open stoplog bay would also require significantly more flow than the fishway or a small notch in the dam (due to its larger width).

Therefore, it appears to be most feasible to cut a small notch (approximately 1 foot wide by 1.9 feet deep) in the dam adjacent to the proposed fishway to take advantage of the plunge pool. With an invert elevation of 45.7 feet, a flow depth of approximately 1 foot through the notch would equate to about 6 inches of depth through the Silver Lake outlet, which is likely the minimum that would be needed for outmigrating juveniles to locate the outlet.

During upstream migration periods, this notch would be closed with constructed stoplogs, or could be opened to provide additional attraction flow to the fishway as needed.

Similar to the flows required for the proposed upstream passage fishway, flows through a 1-foot-wide notch in the dam for downstream passage would range from 2.7 cfs at a recommended head of 1 foot, to 3 cfs at a maximum head of 1.9 feet.

Further analysis will be conducted to evaluate the feasibility of obtaining 2-4 cfs and maintaining necessary lake levels during upstream and downstream passage seasons. Additionally, this flow range will be simulated in the hydraulic model to determine whether it presents a velocity barrier to fish passage anywhere in the reach, particularly within the Lake Street culvert.
Figure 6.1-1: Conceptual Plan of Proposed Alaska Steeppass Fishway and Downstream Passage Notch
Figure 6.1-2: Conceptual Profile of Proposed Alaska Steeppass Fishway
Figure 6.1-3: Conceptual Detail of Proposed Alaska Steeppass Fishway and Downstream Passage Notch
6.2 Nature-Like Bypass Channel

The concept of nature-like fishways is to restore a passage barrier (commonly a dam) to a more natural, riverlike configuration by incorporating natural elements such as rocks, boulders, and cobbles to dissipate kinetic energy of water flow, keep velocities within a passable range for most fish, and provide resting pools. As such, nature-like fishways constructed of rocks and boulders without reinforcement, generally have a low slope below 1:20 (5%), commonly 1:30 (3.3%) to 1:40 (2.5%), both to keep water velocities low and to avoid structural instability that would result from higher water velocities at higher slopes (Brownell et al., n.d.).

Basic types of nature-like fishways include bypass channels and rock ramps. Due to the constriction of the access road bridge directly downstream of the dam, rock ramps were not considered in this analysis.

Bypass channels are constructed as new auxiliary channels around a barrier. As such, they can have variable dimensions and can potentially transport a significant proportion of total river flow, although design flows are typically less than 25% of river flows. Slope and internal structural design of bypass channels may dictate total allowable flows within the bypass, and in some circumstances bypass flows must be regulated or completely shut off (i.e., for maintenance or high flow events). As with technical fishways, attraction characteristics are important, and fish must be able to find the smaller channel of the bypass. A bypass design should accommodate target species that require minimum depth and flow conditions. Total length of the bypass channel should also be taken into account—excessive lengths may decrease motivation of fish attempting to ascend (Brownell et al., n.d.).

Nature-like fishways are perceived as having advantages over technical fishway designs in that they create habitat as well as pathways around structures. Designs can provide passage opportunities for a wide group of fishes across a large size range. Some nature-like fishway designs incorporate varying substrates and water depths to create low velocity or resting zones for smaller, more weakly swimming species, as well as deeper flow depths and higher velocities for larger or more strongly swimming species. However, few nature-like fishways have been quantitatively evaluated in terms of overall passage performance, and results vary (Brownell et al., n.d.).

Experience from existing nature-like fishways and technical fishways has been informative in developing preliminary design criteria for select species. Specifications for shad, river herring, and American eel criteria may include a target maximum slope of 5%, channel width of 10 feet, and a minimum depth of 1.6 to 1.8 feet for American shad and river herring and 0.8 feet for American eel. The maximum effective channel length and full height differential from the entrance to the exit is not well established at this time (Brownell et al., n.d.).

Due to the structural constrictions at Forge Pond Dam, any potential new channel would likely have to bypass both the access road bridge and the dam, allowing herring to pass from the pool present just downstream of the access road into Forge Pond upstream of the dam. One potential route for a bypass channel is shown in Figure 6.2-1. This was chosen based on the natural topography in an attempt to minimize both the channel slope and length.
Figure 6.2-2 below depicts an elevation profile (green line) along the proposed bypass route shown in Figure 6.2-1 based on the existing topography (from LiDAR).

The downstream invert elevation would be equal channel elevation downstream of the access road at approximately 42.4 feet. This would ensure a slight hydraulic drop into the pool present just downstream of the access road bridge opening (river left side) for the purposes of attraction flow. The upstream invert elevation would be set approximately equal to the Silver Lake outlet invert of 46.2 feet, which would ensure that when target water depths are met in the natural bypass channel, there will be sufficient depth for the herring to pass into Silver Lake.

The overall difference in elevation between the upstream and downstream inverts of the bypass channel would be approximately 3.8 feet over about 300 feet in length, which equates to a moderate slope of only 1.3%. However, significant grading would have to occur to ensure a slope of less than 5% along the entire route. Additionally, a section of the existing access road would have to be removed, or be fitted with a road crossing structure, which would not be desirable for fish passage. Although the road is no longer used for vehicle traffic, it is likely important for dam access and pedestrian use.

Flows required for a bypass channel would be significantly higher than those needed for the steeppass and downstream notch. Using the parameters given above (slope = 1.3%, depth = 1.6 ft, width = 10 ft) and assuming a trapezoidal channel with 1:4 side slopes and cobble substrate, flows would be on the order of 90 cfs.
6.3 Dam Removal

Removal of Forge Pond Dam would be the ultimate goal for full restoration of the upper Jones River for all aquatic habitat. Complete or partial removal of dams (partial removal is often called notching or breaching) has been shown to be a simple, viable option for fish passage at some dam barriers. Frequently, low head dams that no longer serve their function or present safety or liability hazards are excellent candidates for removal. The cost of full or partial removal of dams may be less than the cost of construction of a fishway or other structure. When implemented correctly, both full dam removal and notching have the added benefit of restoring connectivity of rivers in both upstream and downstream directions for a wide variety of fish and other aquatic species. Full dam removal also eliminates the potential for long-term maintenance and liability associated with structures remaining after notching (Brownell et al., n.d.).

However, Forge Pond Dam currently serves a very significant function as a control for water supply, as discussed throughout this report. The water supply impacts of removing the dam and relying on the natural level of Silver Lake (or installing an alternate structure at the outlet location) will be further investigated in this analysis.

If feasible, this alternative could entail partial breach or full removal of the concrete dam structure. Removal would cause a large drop in the water surface elevation throughout Forge Pond, due to the lack of backwater effect. Velocities would also increase through the impoundment. Assuming sediments are free of contaminants and allowed to be transported naturally downstream, a post-removal headcut would propagate through the impoundment. A headcut is an unraveling of the accumulated sediment in a downstream to upstream direction.

To evaluate the dam removal option, the hydraulic model will be updated within Forge Pond to reflect conditions with the sediment removed. The C&C bathymetry map of Forge Pond (Appendix A) show the depth of sediment longitudinally along Forge Pond, reporting total of 16 measurements. However, no information is available about sediment depths along transects. For modeling purposes, a “representative” transect below the Lake Street culvert will be used to serve as a surrogate transect within Forge Pond. GZA (2003) identified their Transect 960 (see Figure 4.1.5-1) as representative of riffle/run habitat throughout the watershed, so this cross-section will be used. In the hydraulic model, the dam will be replaced with the representative transect and the thalweg will be set to the elevation at the base of the dam. A uniform slope between the base of the dam and the Silver Lake natural outlet elevation will be used to simulate the proposed conditions and estimate the quantity of sediment to be removed.

The hydraulic model will also evaluate the range of flows that would be needed to meet minimum fish passage target depths in the new natural channel post-dam removal. It is anticipated that required flows will be the highest of the three alternatives.

In addition to water supply impacts, many other factors are important to consider, including but not limited to the following:

- **Forge Pond Sediment** – Although the C&C bathymetry survey (2003) collected limited sediment depth data in the Forge Pond Dam impoundment, the amount and geographic extent of sediment would have to be more thoroughly described by conducting sediment probing transects. The hydraulic model would then be used to conduct a sediment transport analysis to determine how much sediment would be transported downstream if the dam were removed.
Sediment cores would also have to be tested for contaminants to determine if downstream release of sediments is feasible.

- **Infrastructure Impacts** – The access road bridge is directly downstream of the dam and would need to be evaluated for potential structural impacts if the dam is removed. Velocities through the bridge openings will be evaluated to determine whether dam removal may result in potential scour of piers or abutments.

- **Wetland Impacts** – If dam removal is the preferred alternative, a formal wetland delineation would be required. Specifically, the type, function, and value of the wetlands would be quantified. In addition, consultation with state and federal agencies to identify any potential rare, threatened, or endangered species in the project vicinity would be necessary.

- **Historical Impacts** – If any federal money will be used to evaluate the feasibility of dam removal, or to physically remove the dam, the process will require Section 106 consultation. In short, a qualified historian would be required to evaluate whether the dam is eligible for the National Register of Historic Places. Additionally, a qualified archeologist would complete a Phase IA study to determine the likelihood that Native Americans or Euro American settled near this portion of the river. If the Phase IA study indicates that the area was potentially utilized historically, then a Phase IB study would be required. A Phase IB study is more intensive and requires digging test pits and logging what is found. Typically, if the dam is found to be eligible and its removal could impact artifacts, then a Memorandum of Agreement is developed among consulting parties, including the State Historic Preservation Officer.

- **Land Ownership and Aesthetics** – Landowners abutting the pond may have a preference about the aesthetics of the ponds versus a stream channel.

Some of these factors will be investigated further during the next phase of this feasibility study, while others are beyond the scope of this project.
7. References


APPENDIX A: Bathymetric Maps of Silver Lake & Forge Pond

Figure 2.4.1-1: Bathymetric Map of Silver Lake

Figure 2.4.1-2: Bathymetric Map of Forge Pond

Source: Coler & Colantonio, 2003
APPENDIX B – Hydrology Graphs

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Figure 4.1.1-1: Annual Flow Duration Curve for Jones River at USGS Gage

*Period of Record: 1996-2012*
Figure 4.1.1-2: Jan-Mar Flow Duration Curves for Jones River at USGS Gage

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Figure 4.1.1-4: Jul-Sep Flow Duration Curves for Jones River at USGS Gage

Figure 4.1.1-5: Oct-Dec Flow Duration Curves for Jones River at USGS Gage
Figure 4.2.1-1: Annual Elevation Duration Curve for Silver Lake

Silver Lake Elev. (ft, NGVD 29)

Percent of Time Silver Lake Elevation is Equaled or Exceeded

Period of Record: 1996 - 2012
Figure 4.2.1-2: Jan-Mar Elevation Duration Curves for Silver Lake

Figure 4.2.1-3: Apr-June Elevation Duration Curves for Silver Lake
Figure 4.2.1-4: Jul-Sep Elevation Duration Curves for Silver Lake

Period of Record: 1996 - 2012

- July Silver Lake Elevation
- August Silver Lake Elevation
- September Silver Lake Elevation
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)

Percent of Time Silver Lake Elevation is Equaled or Exceeded

July Silver Lake Elevation
August Silver Lake Elevation
September Silver Lake Elevation
Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)

Figure 4.2.1-5: Oct-Dec Elevation Duration Curves for Silver Lake

Period of Record: 1996 - 2012

- October Silver Lake Elevation
- November Silver Lake Elevation
- December Silver Lake Elevation
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)
When Silver Lake elevation drops below the natural outlet, water cannot flow into Forge Pond, and may flow backward into Silver Lake resulting from groundwater flow into Forge Pond.

When the Forge Pond water level exceeds the spillway crest, water is passed to Jones River.
Figure 4.2.2-1: Average Water Supply Diversions into and Withdrawals out of Silver Lake

Average Flow Rate (MGD)

Period of Record: 1996 - 2012
Figure 4.2.2-2: 2002 Silver Lake Elevation with Monponsett and Furnace Pond Diversions
Figure 4.2.2-3: 2003 Silver Lake Elevation with Monponsett and Furnace Pond Diversions
Figure 4.2.2-4: 2004 Silver Lake Elevations with Monponsett and Furnace Pond Diversions
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- Silver Lake Elev. (ft, NGVD 29)
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)
- Diversions from Monponsett Pond (MGD)
- Diversions from Furnace Pond (MGD)

- Spawning adults immigrating
- Juveniles rearing
- Juveniles emigrating
Figure 4.2.2-6: 2006 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

- Silver Lake Elev. (ft, NGVD 29)
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)
- Diversions from Monponsett Pond (MGD)
- Diversions from Furnace Pond (MGD)

Spawning adults immigrating
Juveniles rearing
Juveniles emigrating
Figure 4.2.2-7: 2007 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

- Silver Lake Elev. (ft, NGVD 29)
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)
- Diversions from Monponsett Pond (MGD)
- Diversions from Furnace Pond (MGD)

Events:
- Spawning adults immigrating
- Juveniles rearing
- Juveniles emigrating
Figure 4.2.2-8: 2008 Silver Lake Elevations with Monponsett and Furnace Pond Diversions
Figure 4.2.2-9: 2009 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

- Silver Lake Elev. (ft, NGVD 29)
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)
- Diversions from Monponsett Pond (MGD)
- Diversions from Furnace Pond (MGD)

Key events:
- Spawning adults immigrating
- Juveniles rearing
- Juveniles emigrating
Figure 4.2.2-10: 2010 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

- Silver Lake Elev. (ft, NGVD 29)
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)
- Diversions from Monponsett Pond
- Diversions from Furnace Pond

- Spawning adults immigrating
- Juveniles rearing
- Juveniles emigrating

Silver Lake Elev. (ft, NGVD 29) vs. Diversions to Silver Lake (MGD)
Figure 4.2.2-11: 2011 Silver Pond Elevations with Monponsett and Furnace Pond Diversions

- **Silver Lake Elev. (ft, NGVD 29)**
- **Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)**
- **Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)**
- **Diversions from Monponsett Pond (MGD)**
- **Diversions from Furnace Pond (MGD)**

**Key Events:**
- Spawning adults immigrating
- Juveniles rearing
- Juveniles emigrating
Figure 4.2.12: 2012 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

- Silver Lake Elev. (ft, NGVD 29)
- Forge Pond Dam Spillway Elev. (47.6 ft, NGVD 29)
- Silver Lake Outlet Elev. (approx. 46 ft, NGVD 29)
- Diversions from Monponsett Pond (MGD)
- Diversions from Pond (MGD)

**NOTE:** Data through July only.