Forge Pond Dam Fish Passage Improvement Feasibility Study and Preliminary Design

Jones River, Kingston, MA

FINAL FEASIBILITY REPORT

Prepared for:

Commonwealth of Massachusetts Division of Marine Fisheries

In partnership with:

City of Brockton

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

Commonwealth of Massachusetts Division of Ecological Restoration

Jones River Watershed Association

By:

Gomez and Sullivan Engineers, P.C.

JULY 2013

Executive Summary

Introduction

The Massachusetts Division of Marine Fisheries (*MarineFisheries*) is evaluating the feasibility of restoring populations of river herring and American eel to Silver Lake in Kingston, MA. This project has been primarily funded by a competitive grant received from the Gulf of Maine Council/National Oceanic and Atmospheric Administration (NOAA) Restoration Center by *MarineFisheries* and executed via a contract between *MarineFisheries* and Gomez and Sullivan Engineers, PC. The project has also received financial and in-kind support from the following partners: *MarineFisheries*, NOAA, the City of Brockton, the Massachusetts Department of Fish and Game, the Massachusetts Division of Ecological Restoration (DER), and the Jones River Watershed Association (JRWA).

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 through Forge Pond, a small impoundment created by Forge Pond Dam. **Figure ES-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). An aerial image of Forge Pond depicting the dam and the natural lake outlet is shown in **Figure ES-2**.

Three historic mill dams on the main stem 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 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.

The natural resources of the Jones River and Silver Lake make fish passage at Forge Pond Dam one of the highest ranking priorities of *MarineFisheries* 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 communities.

The goal of this project was to conduct a feasibility and alternatives analysis for providing fish passage at Forge Pond Dam and into Silver Lake. The target species are river herring and American eel, although benefits to all aquatic resources and water uses were considered. Preliminary design for fish passage improvement alternatives were developed to advance the project to the next phase of engineering plans and permitting if a preferred alternative is selected.

Figure ES-1: Jones River Watershed Map

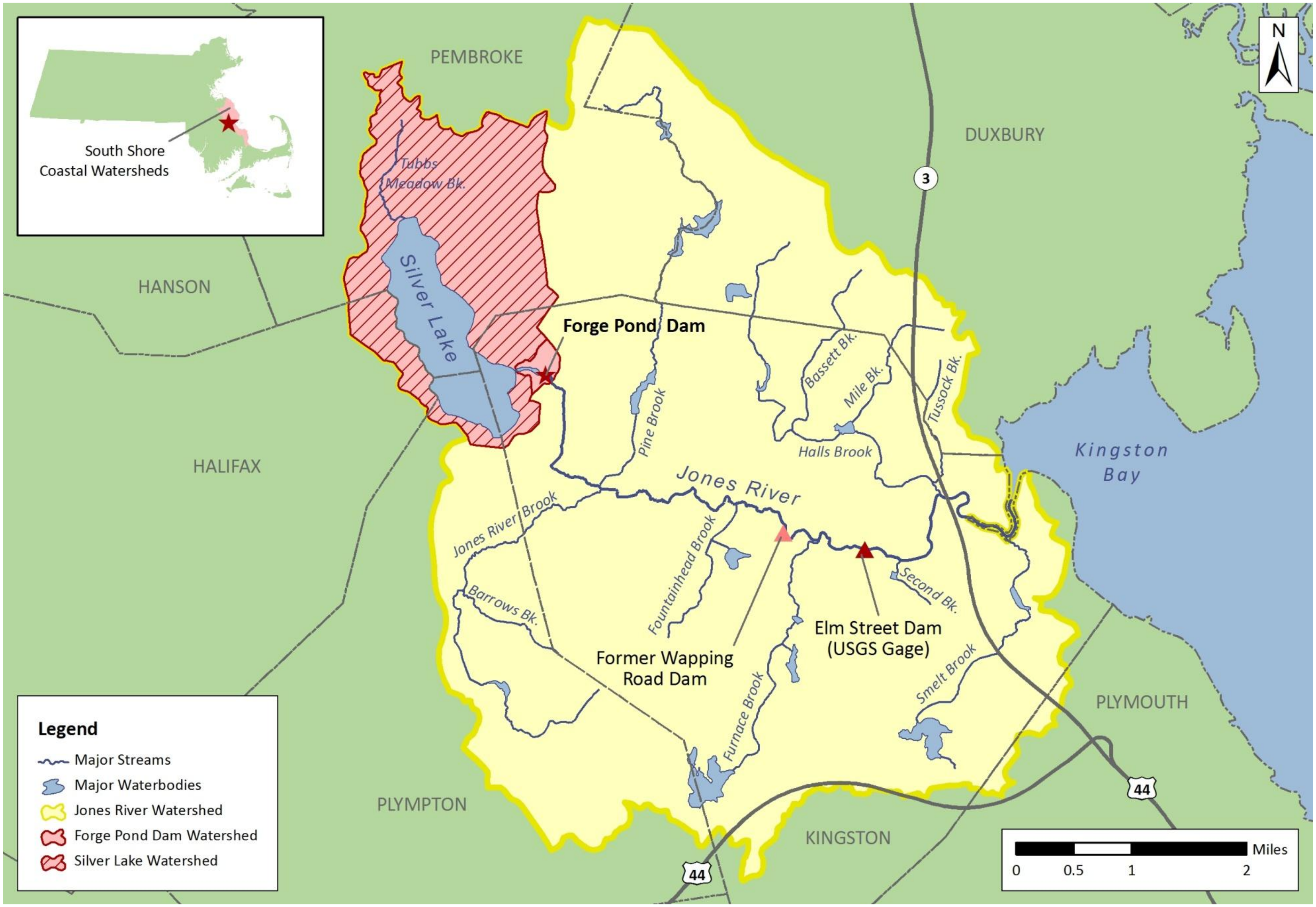
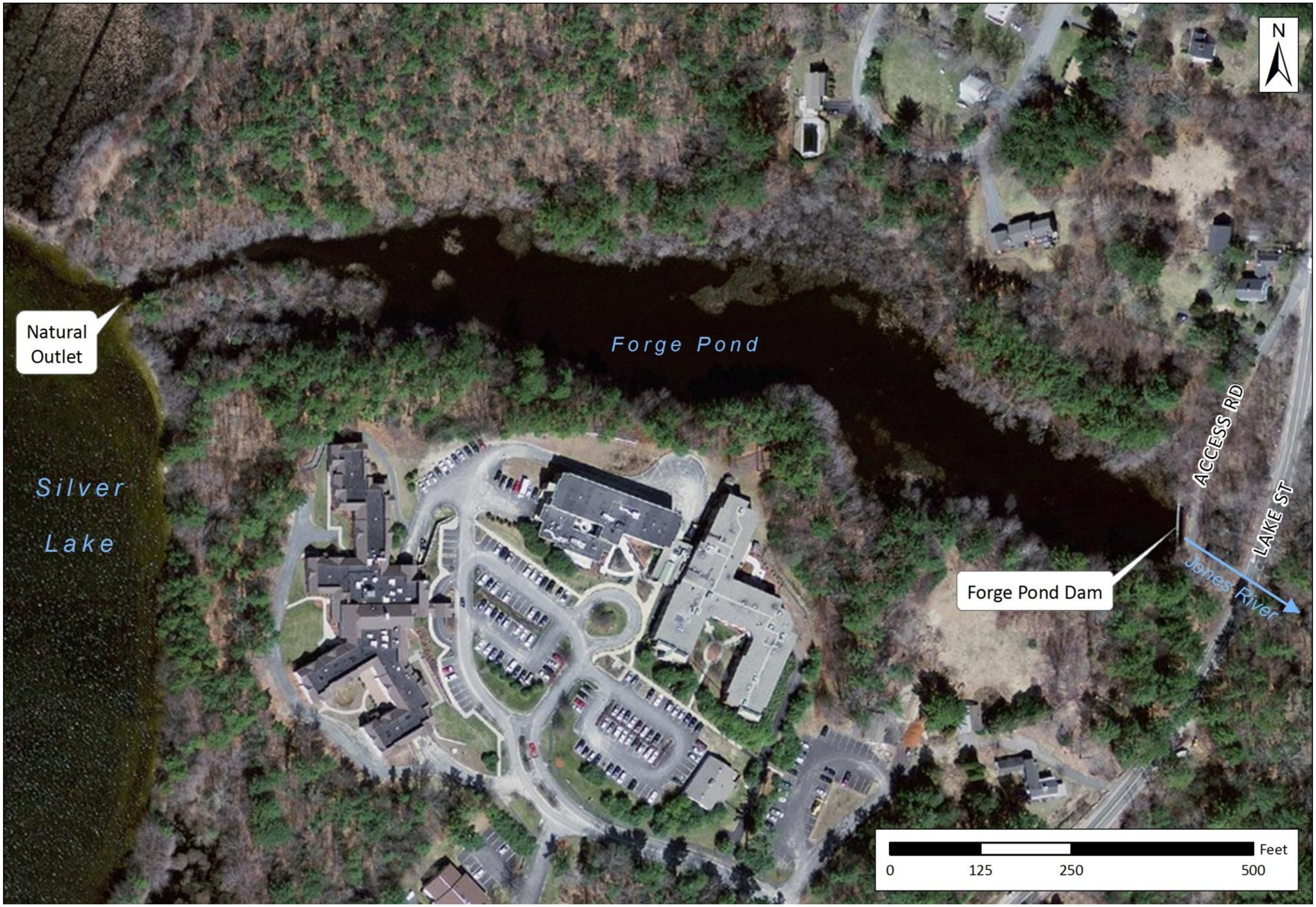


Figure ES-2: Forge Pond Map



Existing Environment

Structures

Built circa 1905, Forge Pond Dam is used to maintain the water level in Silver Lake artificially high for the purposes of water supply management. 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 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 (WAA, 2006).

Forge Pond Dam, shown below, is classified as a large, low hazard dam and is listed in fair to poor condition according to the 2003 inspection by the MA Office of Dam Safety. It has a 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, the most recent survey by Coler & Colantonio in 2003 documented the elevation as 47.6 feet NGVD 29. 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).

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. 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.

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. The target fish species that would likely benefit most from achieving fish passage into Silver Lake are the anadromous alewife and blueback herring, known collectively as river herring. A number of other species may also benefit from restoration activities, including the catadromous American river eel, as well as resident fish species and mussels in Silver Lake.

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

Table ES-1: Timing of Important Life Cycle Events for Target Species

Species	**Life Stage**	**Event**	**Month**									
			MAR	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
River herring	adults	*upstream migration*	🟦	🟦	🟦	🟦						
	juveniles	*downstream emigration*					🟦	🟦	🟦	🟦	🟦	
American eel	elvers	*upstream migration*		🟩	🟩	🟩	🟩					
	silver eels	*downstream emigration*							🟩	🟩	🟩	

Water depth in the river channel and through obstacles such as culverts must be sufficient to accommodate the physical dimensions of fish navigating upstream. 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 targets should be adjusted using site-specific information. Below sharp elevation changes, *MarineFisheries* recommends plunge pools with depths of 1-2 feet, depending on water flow and weir height.

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 (ft/s) and can reach burst speeds of 6.8 ft/s. Where these flows exceed maximum sustained swim speed, successful passage may still be possible, provided that fish can accomplish the needed swim speed without additional impendence such as low water depths. Passage rates are higher under lower velocities and shorter distances. For example, under a velocity of 1.6 ft/s 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.

Before pursuing fish passage at Forge Pond Dam, it was important to assess whether Silver Lake can presently provide adequate habitat for spawning and rearing river herring. *MarineFisheries* conducted a river herring spawning and nursery habitat assessments of Silver Lake during 2008-2009 in collaboration with the JRWA (Chase et al., 2013). The Silver Lake assessment documented suitable conditions to support river herring life history.

Brockton Water Supply System

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 ES-3**.

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 fresh and brackish water from the Taunton River in Dighton, MA. Authorized withdrawals from Brockton's active and emergency sources total 11.98 mgd (not including water permitted for purchase from Aquaria).

The City contracted with Aquaria in 2002 and began receiving water in December 2008, operating under Water Management Act Permit #9P-4-25-044.01, which recognizes Brockton's contract to purchase up to 4.07 mgd from Aquaria by 2018 (currently up to 3.5 mgd). Brockton may also 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.

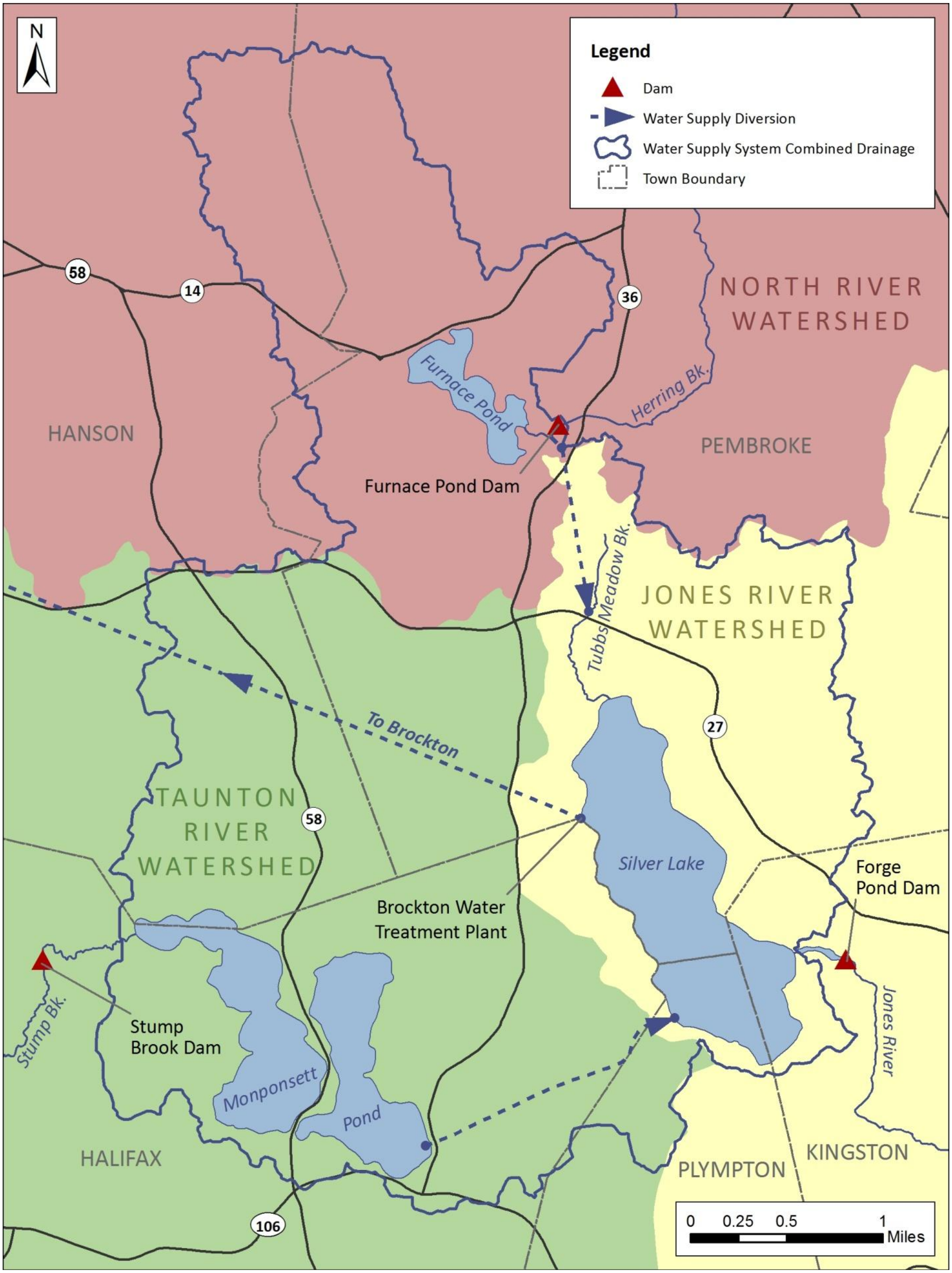
Hydrology & Water Use

Streamflow Data

Streamflow records are used to estimate frequency and duration of flows, mean annual flows, and the magnitude and frequency of floods. The USGS has maintained a streamflow gaging station (No. 01105870) on the Jones River just below the Elm Street Dam since 1966. 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 Flood Insurance Study (FIS), 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.

Figure ES-3: Silver Lake Water Supply System Map



Flow duration curves depict the average percentage of time that specific flowrates are equaled or exceeded at a particular site. The annual flow duration curve for the Jones River gage at Elm Street indicates a 50-percent flow duration value of 26 cfs, or about 1.3 cfs per square mile (cfsm).

The hydrology of Jones River was heavily studied as part of a watershed study conducted by GZA in 2003 to account for water flowing into and out of the Jones River basin and subbasins. 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. Even during dry years, the October minimum outflow to the river would fall no lower than 3.8 cfs.

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).

Target Flows for Fish Passage

For typical fish passage restoration projects, hydraulic analysis targets flow extremes within the migration 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 instructive to only analyze mean monthly flows at Forge Pond Dam under current conditions. Instead, this study evaluated fish passage alternatives to determine the range of flows needed to pass fish according to the criteria described above. This information was then analyzed in the context of Brockton’s water supply operations to determine whether providing the required flows during migration periods would be feasible.

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 elevation and natural outlet elevation over the available period of record (1996-2012). Silver Lake elevations were found to be above the 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.

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.

Diversion & Withdrawal Data

The average annual Silver Lake withdrawal[1] for the period of record (1996-2012) is 9.6 mgd (14.9 cfs), but can range from 8.95 to 10.37 mgd. 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, diversions have occurred outside this period. When waters levels rise at these ponds, shoreline residents can experience problems with basement flooding, septic system operation, loss of beach front, and water quality impacts. 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.

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. If water is diverted into Silver Lake from Monponsett or Furnace Ponds when Silver Lake is already full (at spillway crest elevation), the diverted water is effectively spilled downstream into the Jones River and does not add any net volume to the water supply. 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. 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.

The results of this “wasting” analysis further reinforce earlier statements that hydrologic analyses based on gage data do not accurately characterize the natural regime since they often include transferred flows from Monponsett and Furnace Ponds (up to 7 square miles of additional drainage area) when the diversions are on and water is also spilling over Forge Pond Dam. This unauthorized situation may occur due to a combination of factors including requests for flooding relief from Monponsett and Furnace Pond residents, as well as time consuming or difficult access to alternate locations for flood relief releases (i.e., Stump Brook Dam for Monponsett Pond and Furnace Pond Dam for Furnace Pond).

Safe Yield

Recently, the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) released the Massachusetts Sustainable Water Management Initiative (SWMI) framework (EEA, 2012), which describes the methodology for defining safe yield in each of the 27 Massachusetts watersheds, as well as how stream flow criteria will be applied by the DEP when issuing WMA permits. For the Jones River, the SWMI framework recommends using 25% of the estimated mean monthly unimpacted flows developed by the USGS as the approximate equivalent of 55% percent of the monthly 90th percentile flows for this area. The resulting estimated safe yield values are shown in **Table ES-2** below. Brockton’s historic withdrawals from Silver Lake (1996 – 2012) are shown in the table for reference.

---

[1] Note that Silver Lake withdrawals reported in this document are ‘finished’ volumes (as opposed to ‘raw’ volumes). An additional 1.2 mgd (on average during the period of record, 1996-2012) is also withdrawn from the lake for treatment processes (i.e., finished volume + 1.2 mgd average = raw volume). Treatment water is sent to lined lagoons for settling, after which some of the water is returned to the head works for reuse during in treatment processes, while some is sent in the form of settled residuals to drying beds where it can seep into the groundwater (Brockton, Nov 13, 2009). It is unclear when or whether this water returns to Silver Lake through groundwater flow.

Table ES-2: Jones River Estimated Safe Yield Derivation

Month	SYE Average Unimpacted Monthly Flow (cfs)	Potentially Allocatable Flow *(25% of Avg. Monthly Flow)* *cfs*	*MGD*	Average Brockton Withdrawals (MGD, 1996-2012)
JAN	42.57	10.64	6.88	9.8
FEB	44.30	11.07	7.16	9.7
MAR	46.58	11.65	7.53	9.4
APR	45.00	11.25	7.27	9.3
MAY	40.55	10.14	6.55	9.6
JUN	35.62	8.90	5.76	10.0
JUL	29.29	7.32	4.73	10.0
AUG	27.36	6.84	4.42	9.8
SEP	28.57	7.14	4.62	9.4
OCT	29.72	7.43	4.80	9.4
NOV	35.78	8.94	5.78	9.5
DEC	41.03	10.26	6.63	9.6
Annual Avg.	37.15	9.29	6.00	9.6
Avg. per 21.4 mi^2	1.74 cfs/mi^2	0.43 cfs/mi^2	0.28 MGD/mi^2	0.45 MGD/mi^2

Source: EEA, 2012

Current Water Use

Brockton is required to submit Annual Statistical Reports (ASRs) summarizing its water supply operations to the DEP. Over the period of available data, 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 Massachusetts Water Resources Commission (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.

In 2009, the Massachusetts Department of Conservation and Recreation (DCR) Office of Water Resources issued estimated water needs forecasts for Brockton, shown in **Table ES-3** below.

Table ES-3: DCR Projected Water Demands for Brockton and Whitman

Location	Projected Water Usage (mgd) *Assuming 65 gpcd and 10% UAW* 2015	2020	2025	2030*	*Assuming current gpcd and UAW* 2015	2020	2025	2030*
Brockton	10.29	10.46	10.61	10.74	9.17	9.31	9.44	9.56
Whitman	1.08	1.08	1.09	1.09	0.93	0.94	0.94	0.94
Total	**11.37**	**11.54**	**11.70**	**11.83**	**10.10**	**10.25**	**10.38**	**10.50**

The available data do not provide a clear picture of Brockton's expected water use trend. The City's population appears to have declined in recent years, but is expected to begin rising again by both the 2007 and 2011 MAPC projections, although at differing rates. Residential usage has typically remained relatively low, below the WRC target value of 65 gpcd, though it did spike briefly in 2010 to 66 gpcd. UAW rates have been sporadic and a trend cannot be identified, though there is potential for improved efficiency by maintaining UAW consistently below the WRC target of 10%. DCR plans to update Brockton's Water Needs Forecast in 2014, based on the 2010 census.

Hydraulic Analysis

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 the Jones River was developed from its headwaters at Silver Lake to just upstream of Grove Street to evaluate various fish passage alternatives. The USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) program was used to develop the model.

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 above, 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. The hydraulic modeling results show that Forge Pond Dam does currently pass the FIS 100-year flood (116 cfs) with 0.6 feet of freeboard below the walkway and 0.8 feet of freeboard below the left abutment. Fish passage alternatives requiring structural modifications to the dam need to be evaluated with the hydraulic model to ensure the spillway will still be able to pass the 100-year flood.

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 Forge Pond Dam for the entire migratory period of target species and throughout the study area extending from the natural outlet of Silver Lake to the Lake Street culvert. Possible scenarios were discussed with project partners, presented to the public, and narrowed to those with the greatest potential to be ecologically effective and feasible to install and operate at Forge Pond Dam. Those alternatives were then subjected to a more thorough analysis in which conceptual design, operational, and cost information was evaluated for each.

Alternative 1 – Fish Ladder

Background & Conceptual Design

Technical 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 (discussed here) or pool and weir type. 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.).

Also known as the Alaska steeppass or ASP, these structures are similar but more complex than the Denil design with higher energy dissipation 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 have mainly been used for river herring, but have provided effective passage for other anadromous species, as well as 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.).

Alaska steeppass fishways are also relatively inexpensive to design and install. However, both Denil and steeppass fishways may require regular maintenance to remove debris and adjust stop logs. Also, the inherent high flow energy of these fishways can be problematic for downstream passage of juvenile fishes or upstream passage for species with limited swimming capability.

Alaska steeppass flow requirements can range from approximately 2 to 4 cfs, which is less than the flow typically required for a Denil or pool and weir fishways system, making the steeppass more feasible given the already low flows at Forge Pond Dam. 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. Therefore, a steeppass fishway was selected for further analysis at the Forge Pond Dam site.

Using steeppass fishways for downstream passage is not usually the first choice, as the multi-plane baffles were designed mainly for upstream movements and fish may not be able to find the entrance during periods of higher flow. The most feasible option to cut a small notch in the spillway adjacent to the proposed fishway to take advantage of the plunge pool. During upstream migration periods, this notch could be closed with constructed stoplogs, or could be opened to provide additional attraction flow to the fishway as needed. An inlet section with stoplogs would also be built at the fishway entrance to control the flow through the fishway under varying head conditions and to shut off flow to the fishway when desired.

Ability to Meet Target Fish Passage Thresholds

For the selected slope of 20%, the fish ladder would require about 3 cfs at the minimum effective depth of 12 inches, up to about 4 cfs at the maximum effective depth of 20 inches. Similarly, the 1-foot-wide notch in the dam for downstream passage would require approximately 3 cfs through the range of recommended depths (1-1.9 feet of head in the notch). Therefore, 3 cfs was identified as the minimum flow needed to be supplied continuously during the months of April through November for this fish passage alternative. This equates to 2 mgd or a total volume of 488 MG for the entire period, which is about 20% of Brockton’s total average withdrawal volume of 2,349 MG during that same period.

Average Silver Lake elevation (1996-2012) is typically above the natural outlet elevation during the spring adult migration period (April through June), but drops below for most of the juvenile herring emigration period (August through November). Therefore, under existing water supply operating conditions, it is not likely that emigrating juvenile herring could pass over the natural outlet into Forge Pond, or that 3 cfs could be released from Forge Pond during this period to provide downstream passage through the notch. However, several options are available to increase the feasibility of a fish passage release. Possible alternatives include:

a) **Dredge outlet channel.** As an alternative or in addition to one or more of the options described below to increase the amount of water in the Silver Lake system, a physical approach could be taken. Sediment has accumulated in the natural outlet channel of Silver Lake due to the backwater effect of the dam and lack of flow. Dredging to lower the thalweg of the outlet channel would reduce the water surface elevation at which the disconnect between the two water bodies occurs. This option is described in more detail below.

b) **Develop alternative fish passage thresholds** that accept the limited ability to pass fish downstream in July and August. Juvenile herring would in effect be held back from emigration until September and the conserved 2 mgd from those two months would be dedicated to September and October. This alternative would require explicit guidance in a Forge Pond Dam and Fishway Operations and Maintenance Plan.

c) **Increase the amount that can be purchased from Aquaria.** Withdrawals from Silver Lake could be reduced by using Brockton's capability to purchase additional water from Aquaria—currently 3.5 mgd and up to 4.07 mgd by 2018 (or 4.5 mgd and 5.07 mgd, respectively, if Brockton makes use of its exclusive rights to the first 1 mgd of excess water produced by Aquaria with 15 days notice). Recognizing an impact on cost, operationally this would likely be the simplest option, if Aquaria can meet the demand.

d) **Divert water from Monponsett and/or Furnace Ponds.** On average (1996-2012), virtually no water is diverted from Furnace Pond from July through September, while relatively small diversions of less than 2 mgd from Monponsett Pond occur periodically during this time. Further analysis would be needed to determine whether these ponds have surplus volume to divert during dry periods while still meeting their minimum release requirements. This option is less desirable due to the lower water quality of these ponds compared to Silver Lake.

e) **Reduce Brockton's unaccounted-for water.** Brockton's UAW has averaged 13% or 1.3 mgd of their total average daily demand of 10 mgd from 2000-2011, ranging as high as 19% (2 mgd). Reducing UAW to the performance standard of 10% (1 mgd) could save an average of 0.3 mgd. Further analysis would be needed to identify the feasibility of reducing UAW.

f) **Reduce Brockton's demand.** Programs designed to encourage water conservation by public and private consumers could decrease dependence on Silver Lake. Further analysis would be needed to investigate feasibility and potential gains.

In analyzing the potential for dredging the natural outlet, it was determined that, without dredging the entire pond, the lowest elevation to which the outlet channel could feasibly be dredged would be approximately 45 feet (according to C&C's 2003 bathymetry survey of Forge Pond). This would involve shallow dredging (1.2 feet maximum) along approximately 600 feet of channel below the outlet, for a total volume of about 75 CY (assuming a conservative 10-foot-wide channel excavation). It should be noted that the outlet channel may naturally lower over time without dredging due to the proposed more continuous flow regime.

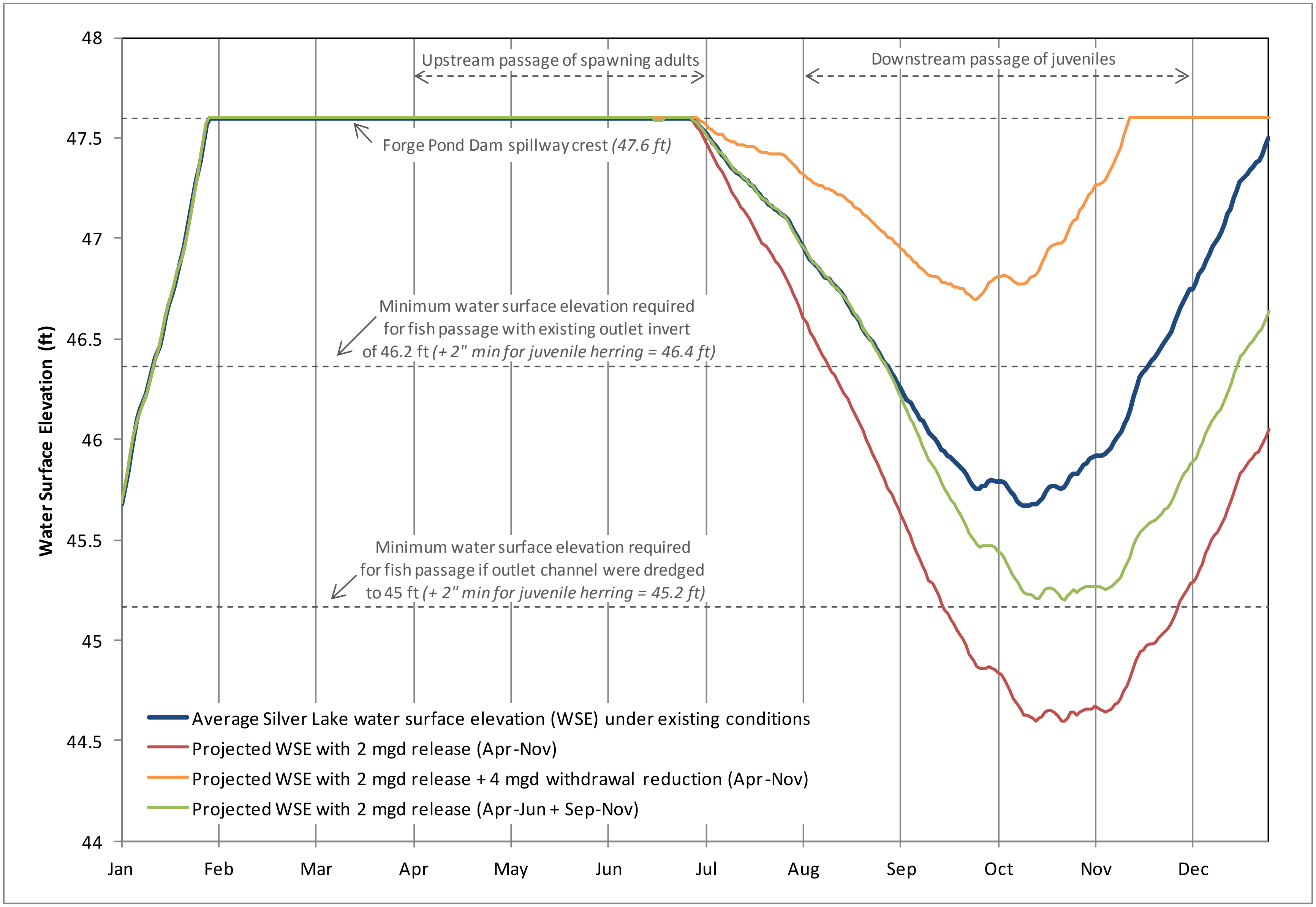
Using a Silver Lake stage-storage curve derived from bathymetry data collected in 2003, natural inflows estimated by GZA (2003), and average water supply withdrawal and diversion data (1996-2012), an analysis was conducted to determine the effect of a specified release from Silver Lake into the Jones River for the purpose of fish passage. Inflows to and outflows from Silver Lake were balanced to project the water surface elevation under existing conditions and several fish passage release scenarios, including:

- A scenario in which at least 3 cfs (2 mgd) is released from Silver Lake into the Jones River during the entire fish passage season (April through November)
- A scenario in which Brockton purchases additional water from Aquaria (up to 4.07 mgd, in this example) to allow for a corresponding reduction in withdrawals from Silver Lake and to provide a release of 2 mgd downstream during the entire fish passage season (April through November)
- A scenario in which fish passage releases are withheld for the months of July and August (at least 2 mgd released from April through June and September through November)

Projected water surface elevations for these scenarios are shown in **ES-4** on the following page. In addition to the minimum water surface elevation required to pass juvenile herring over the natural outlet (46.2 feet + 2 inches minimum depth = 46.4 feet), the minimum water level needed to pass juvenile herring over the proposed dredged outlet described above (45 feet + 2 inches minimum depth = 45.2 feet) is also plotted. This dredging option increases the flexibility of fish passage release and optional withdrawal reduction scenarios that are feasible.

Figure ES-4 shows that, with the purchase of up to 4.07 mgd from Aquaria as needed and a downstream release of 2 mgd throughout the fish passage season (April through November), the projected average water surface elevation remains high enough to pass juvenile herring over the natural outlet. Furthermore, the figure shows that if the outlet were dredged to an elevation of 45 feet, fish passage would be feasible without the purchase of additional water from Aquaria by withholding releases during July and August.

Figure ES-4: Projected Silver Lake Elevation with Fish Passage Release and Optional Withdrawal Reduction



Besides passing fish over the outlet into and out of Silver Lake, it is important to evaluate whether water depths are within suitable ranges throughout the entire upper Jones River assessment reach under the given fish passage requirement flow of 3 cfs. There are two areas of potential concern in meeting the minimum target of 0.5 feet. One is the former Lake St access road bridge, where the deepest opening (left side) has a water depth of approximately 0.3 feet under the required flow of 3 cfs. This would require a relatively simple fix to regrade the flat channel under the bridge opening to create a deeper, narrower thalweg that can be utilized by fish during lower flows.

The other area of concern for water depth under target flows is the relatively steep section extending approximately 1500 feet downstream of the Lake Street culvert. Steeper channel slopes typically cause lower water depths and higher velocities. However, model accuracy is lower in this area as detailed survey was not collected downstream of Lake Street for this study. Cross-sectional data was derived from LiDAR elevation data adjusted within channel to match thalweg elevations reported in the FEMA FIS. Rather than recommending collection of more detailed survey and enhancing of the hydraulic model in this area to further evaluate water depths, a site inspection during a test release of the required flow (3 cfs) may be more appropriate. Given the relatively small channel dimensions in this reach, small obstacles such as cobbles, boulders, and woody debris can play a big factor in water depths. Project partners are already scheduled to conduct debris removal throughout this reach in the near future and can make hand adjustments to increase water depths as needed.

As a final check of passage thresholds, it is important to ensure that fish will not encounter impassable velocity barriers when migrating upstream throughout the reach. Modeled average channel velocities do not exceed the typical cruising speed of 2.8 ft/s for adult river herring. However, the Lake Street culvert does pose a concern for high velocities under certain flows. Using the available scientific literature, it is estimated that about 55% of alewives and 74% of blueback herring are expected to pass through the culvert under the required fish passage flow of 3 cfs. Passage percentages continue to drop off as flows increase. Therefore, in addition to ensuring the effectiveness of the fish ladder, it will be important to maintain flows within acceptable ranges to maximize the percent of river herring that are able to pass through the culvert. Replacement of the Lake Street culvert with a more fish-passage-friendly crossing structure could mitigate the potential for a velocity barrier at this location.

Alternative 2 – Nature-Like Bypass Channel

Background & Conceptual Design

The concept of nature-like fishways is to restore a passage barrier such as a dam to a more natural, riverlike configuration by incorporating natural elements like rocks, boulders, and cobbles to dissipate flow energy, maintain velocities within a passable range for most fish, and provide resting pools. Nature-like fishways are perceived as having advantages over technical fishway designs (i.e., fish ladders) in that they create habitat as well as pathways around structures for many organisms in addition to target fish species.

Bypass channels are constructed as new auxiliary channels around a barrier. Slope and channel dimensions dictate 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 fish ladders, attraction characteristics are important, and fish must be able to find the bypass entrance. A bypass design should accommodate minimum depth and flow conditions for target species, but can also incorporate varying substrates and water depths to create low velocity resting zones for smaller, more weakly 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.).

Nature-like fishways generally have a low slope (below 5%) both to minimize velocity barriers and avoid resulting structural instability. Specifications for target species may include a channel width of about 10 feet and a minimum depth of 1.6 to 1.8 feet for 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, though it is thought that excessive lengths may decrease motivation of fish attempting to ascend (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 former Lake Street bridge and the dam, allowing herring to pass from the pool present just downstream of the bridge into Forge Pond upstream of the dam. However, the land abutting Forge Pond upstream of the bridge is private property, and any potential bypass channel would require consultation with landowners and the purchase of an easement. For the purpose of this study, the feasibility and conceptual design of a bypass channel is evaluated below on a physical level (i.e., topography, flow requirements, etc.).

The overall difference in elevation between the upstream and downstream inverts of a conceptual bypass channel at Forge Pond Dam 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. This would require the excavation of approximately 300-500 CY of material assuming a width of 10-15 feet would have to be excavated. 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 could be significantly higher than those needed for the fish ladder. Using the parameters given above (slope = 1.3%, depth = 1.6 feet, top width = 10 feet) and assuming a trapezoidal channel with 2V:1H side slopes and cobble substrate, flows would be on the order of 80 cfs. This is equivalent to 52 mgd, which is more than Brockton's average withdrawal from Silver Lake or natural inflows, thus a continuous release of this magnitude would not be feasible.

However, it is possible that a smaller channel could be designed to meet minimum passage requirements with lower flows. For example, the representative riffle/run cross-section downstream of Lake Street identified by GZA (2003) was found to have a maximum water depth of 0.7 feet when modeled under a flow of 3 cfs. This channel cross-section has a bottom width of approximately 2 feet and a top width (at 3 cfs) of about 16 feet**.**

The upstream entrance of a bypass channel at Forge Pond Dam would need to be fitted with a stoplog gate structure that could be used to close the bypass channel if needed or maintain flows within appropriate ranges under varying headpond fluctuations.

Ability to Meet Target Fish Passage Thresholds

Assuming the conceptual bypass channel design described above is feasible, a minimum flow of 3 cfs would be required during the upstream and downstream fish passage seasons (April through November). Because this is the same flow required by the fish ladder/downstream passage notch scenario, the ability to meet this target and the associated water depth and velocity impacts of this flow are identical. Refer to the fish ladder section above for a discussion.

To evaluate velocity within the bypass channel, the velocity distribution for the representative cross-section identified by GZA was plotted for the target flow of 3 cfs. The highest velocities within the deepest part of the channel would be in the 0.8 ft/s range. This is well below the adult river herring cruising speed of 2.8 ft/s and is not expected to pose a problem for upstream passage.

Alternatives 3 & 4 – Dam Removal (Partial & Full)

Background & Conceptual Design

Removal of Forge Pond Dam would meet the ultimate goal of 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 preferable option for fish passage at some dam barriers. Low head dams that no longer serve their function or present safety or liability hazards are often excellent candidates for removal. 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), as well as the physical feasibility of dam removal, were further investigated in this analysis.

This evaluation involved two alternatives—both a partial breach (Alternative 3) and full removal (Alternative 4) of the concrete dam structure. Either scenario is expected to cause a large drop in the water surface elevation throughout Forge Pond, due to the lack of backwater effect. Velocities will also increase through the impoundment. Assuming sediments in Forge Pond are free of contaminants, it may be feasible to allow them to be transported naturally downstream (known as passive sediment management), which would lead to a post-removal headcut, or unraveling of the accumulated sediment in a downstream to upstream direction. If sediments are not released downstream, either due to contaminants or for other reasons, a more active management approach can be taken to excavate the sediment and construct a stable natural channel through the former impoundment.

Therefore, to evaluate the dam removal options, the hydraulic model was updated within Forge Pond to reflect conditions with the sediment removed along a channel invert slope from the base of the existing dam to the Silver Lake outlet (approximately 0.2%). For modeling purposes, the representative riffle/run cross-section identified by GZA (2003) downstream of Lake Street was used to serve as a surrogate transect to simulate post-headcut or constructed channel conditions within Forge Pond. For the full dam removal option, the representative transect was also used to replace the cross-section at the existing dam, simulating removal of the main and overflow spillway sections. Concrete abutments between the dam and access road bridge were left in place to prevent scouring and undercutting of the bridge piers.

For the partial dam removal option, the dam cross-section was modified with a notch approximately 6 feet wide and the full height of the dam. Typically, the goal of partial dam removal is to avoid the high expense of full dam removal. However, in this case, Forge Pond Dam is relatively small and full removal would not be cost prohibitive. Instead, partial removal is being considered in this study because Forge Pond serves an important function to maintain storage for water supply. The relatively narrow notch in the dam selected for this conceptual design still presents the opportunity to manage water levels with stoplogs on a seasonal basis or as needed, while providing the benefit of full aquatic connectivity with stoplogs removed.

In an active sediment management scenario (i.e., dredging to construct a stable channel), approximately 0.05 to 2.0 feet of sediment would need to be removed from the existing channel, with a small area to be filled in as well. For conceptual design purposes, it was assumed that an area approximately 10-15 feet wide would be excavated to allow machinery access and appropriate grading and erosion control measures to prevent scouring.

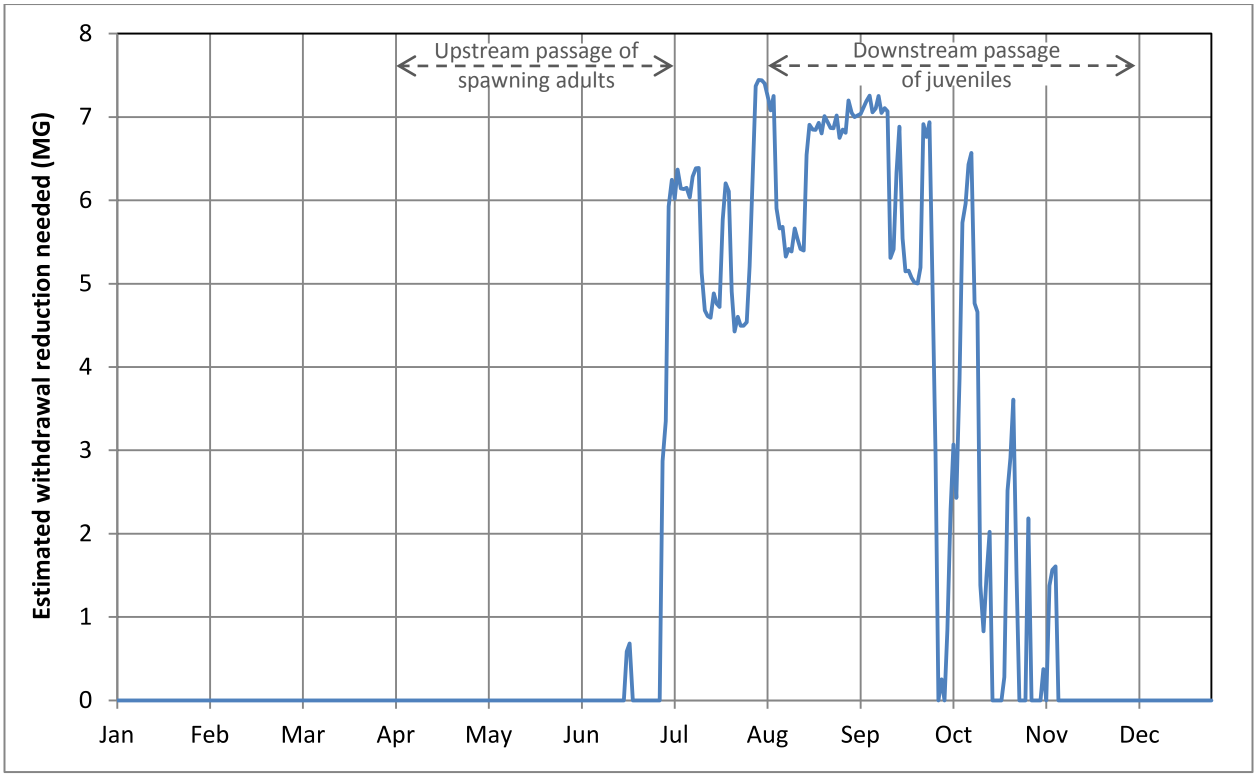
Ability to Meet Target Fish Passage Thresholds

For the purpose of this analysis, it was assumed that a channel similar to the representative cross-section identified by GZA can be constructed or will naturally form through the impoundment. As discussed previously, a flow of 3 cfs provides the minimum depth of 6 inches needed for fish passage in this cross-section.

However, unlike with previous alternatives, Silver Lake would not be able to provide a continuous release of 3 cfs through the fish passage seasons while still meeting Brockton's water supply demand under a dam removal scenario. The natural outlet would become the new water control for Silver Lake levels. If Brockton were to withdraw water in excess of natural lake inflows, the water level would drop below the outlet and fish would not be able to pass upstream. Thus, inflow must equal outflow in the post-dam removal system.

As before, the Silver Lake stage-storage curves and estimated inflows/outflows were used to project the amount by which water supply withdrawals would need to be reduced (e.g., offset by purchase from Aquaria) in order to maintain the elevation of the lake at the natural outlet (46.2 feet) and meet the minimum fish passage release of 3 cfs April through November. **Figure ES-5** below shows the estimated water supply withdrawal reductions needed for the dam removal scenario.

Figure ES-5: Estimated Withdrawal Reductions Needed for Fish Passage in Dam Removal Scenario



As the figure shows, withdrawal reductions exceeding 7 mgd would be needed, which exceeds the maximum amount that can be purchased from Aquaria at this time. This scenario would involve shifting approximately 627 MG of Brockton's annual demand from Silver Lake to Aquaria, mostly during July through October. Alternatives to make up the deficit were discussed in **Section 6.1.3** and include increasing the maximum amount that can be purchased from Aquaria, reducing UAW, reducing demand, and diverting water from Monponsett and/or Furnace Ponds.

Due to this finding, an additional alternative of constructing a new water control structure at the outlet of Silver Lake in conjunction with full dam removal was investigated. At a very conceptual level, this structure could take the form of an earthen and/or concrete dam with an integral fishway, such as a steeppass or bypass channel for upstream passage. A low level outlet could be used to provide releases and pass juvenile fish downstream when water surface elevations are low in the fall. The concerns of potential disconnect between two water bodies and sediment management that complicated other alternatives would be eliminated. With the construction of a new water control structure, water levels could be managed to meet the needs of both fish passage and water supply demands throughout the year as discussed above.

Assuming the construction of a stable channel of similar dimensions to the representative cross-section identified by GZA is feasible, the associated water depth and velocity impacts of a flow of 3 cfs are identical to that of the nature-like bypass scenario. Refer to the bypass section above for a discussion.

Summary and Next Steps

A summary of the fish passage improvements investigated in this feasibility analysis is presented as a decision matrix in **Table ES-4** on the following page. This table compares the relative benefit or impact of each alternative on various resources and considers other factors such as cost, permitting, operation and maintenance, etc. In future phases of this project, a weighted value could be given to each parameter as a means to rank the alternatives with consideration for the goals of project partners and other stakeholders.

This study has demonstrated that fish passage into Silver Lake is feasible. A minimum flow of 3 cfs can be provided during fish passage seasons within the existing constraints of the water supply system. An Alaska steeppass fishway at the dam would provide the simplest and least expensive solution to pass target species, but the enhancement of overall connectivity in the river system and passage for other species would be limited. Full dam removal would restore important habitat and flows in the upper Jones River; however, this option would have a much more significant impact on water supply management for the City of Brockton, and the lack of ability to manage flows may lead to more frequent occurrence of a velocity barrier to upstream fish passage at the Lake Street culvert. Construction of a new water control structure at the outlet of Silver Lake in conjunction with full dam removal would alleviate some of these issues, but would not fully restore habitat connectivity, is the most expensive alternative, and presents property ownership issues. Modifications to or replacement of the Lake Street culvert should be evaluated for any restoration scenario to ensure maximum fish passage efficiency.

Combinations of two or more alternatives together, implemented simultaneously or throughout several phases, will present additional options for fish passage restoration. The economic and political considerations of water supply in three basins will influence the approach.

Progress and findings of this feasibility study were presented in two public informational sessions held at the Silver Lake Regional High School in Kingston on November 14, 2012 and April 3, 2013. Both meetings were well attended by the public, stakeholders, agency staff, and project partners. Comments received during and after the meetings were all in support of the project. On May 16, 2013, an update was presented at the meeting of the Brockton Water Commission. The Commission was in favor of providing fish passage from a physical standpoint, as long as significant financial burdens to the water supply system are not incurred.

This feasibility study did not produce a preferred option based on recommendations of *MarineFisheries*, the project partners, and the City of Brockton. The study raised additional questions on how to reconcile restoration targets with water supply requirements. The next phase of this project will involve continued communication with project partners, the City of Brockton, and the public. A portion of funding secured from the Massachusetts Environmental Trust (MET) in 2012 will be used to conduct further feasibility analyses, particularly regarding the economic impacts of reducing water supply withdrawals from Silver Lake to improve the effectiveness of certain fish passage scenarios. If a preferred alternative can be agreed upon, the project will advance to future phases of securing funding, additional feasibility work, design, and construction to improve passage of target species between the Jones River and Silver Lake.

The full report and presentation are available at:

http://www.mass.gov/eea/agencies/dfg/dmf/publications/informational.html
and
http://jonesriver.org/projects/ecology/forge-pond-dam-fish-passage/

Table ES-4: Decision Matrix for Fish Passage Improvement Alternatives at Forge Pond

	0	1A	1B	2A	2B	3A	3B	4A	4B	4C
	No Action	**Fish Ladder**		**Bypass Channel**		**Partial Dam Removal**		**Full Dam Removal**		
		Existing Lake Outlet	*Dredged Lake Outlet*	*Existing Lake Outlet*	*Dredged Lake Outlet*	*Passive Sediment Mgmt.*	*Stable Channel Const.*	*Passive Sediment Mgmt.*	*Stable Channel Const.*	*New Structure at Outlet*
POTENTIAL BENEFITS										
Upstream passage of target fish species	None	Good	Good	Good	Good	Good	Excellent	Good	Excellent	Excellent
Downstream passage of target species	N/A	Good	Excellent	Poor	Excellent	Good	Excellent	Good	Excellent	Good
Passage of other species (connectivity)	None	Good	Good	Good	Good	Good	Good	Good	Excellent	Poor
Restoration of natural wetland habitat	None	None	None	None	None	Poor	Poor	Good	Excellent	Good
Improved water quality	None	None	None	None	None	Poor	Poor	Good	Excellent	Good
Improved aesthetics	N/A	Poor	Poor	Good	Good	Poor	Poor	Good	Excellent	Good
POTENTIAL IMPACTS										
Infrastructure (bridge scour)	None	None	None	None	None	Unknown	Unknown	Unknown	Unknown	Unknown
Spillway capacity	None	Low	Low	None	None	Low	Low	N/A	N/A	N/A
Water supply	None	Moderate	Low	Moderate	Low	Moderate	Moderate	High	High	Low
Rare/threatened/endangered species	None	None	None	None	None	Unknown	Unknown	Unknown	Unknown	Unknown
Historical resources (dam)	None	Low	Low	None	None	Unknown	Unknown	Unknown	Unknown	Unknown
Archaeological resources (sediment artifacts)	None	None	Low	None	Low	Unknown	Unknown	Unknown	Unknown	Unknown
Sediment (removal, contamination)	None	None	Low	Moderate	Moderate	High	High	High	High	High
OTHER FACTORS										
Flow requirements (~3 cfs for all)	N/A	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Velocity barriers (less ability to manage)	N/A	Low	Low	Moderate	Moderate	Low	Low	High	High	Low
Permitting	N/A	Low	Moderate	Moderate	Moderate	High	High	High	High	High
Land ownership issues	N/A	None	None	High	High	Low	Low	Low	Low	Low
Construction access issues	N/A	Low	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	High
Operation & maintenance	Moderate	Moderate	High	Moderate	High	High	High	Low	Low	Moderate
Estimated cost (engr. & const.)	N/A	$63,000	$192,000	$197,000	$301,000	$216,000	$563,000	$273,000	$622,000	$952,000

Ratings are based on best professional judgment and take into account several factors including relative benefit or impact. Refer to ***Section 6*** *for more details on the feasibility of each alternative.*

Table of Contents

List of Tables

List of Figures

List of Abbreviations

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

1. Introduction

1.1 Background

The Massachusetts Division of Marine Fisheries (*MarineFisheries*) is evaluating the feasibility of restoring populations of river herring and American eel to Silver Lake in Kingston, MA. This project has been primarily funded by a competitive grant received from the Gulf of Maine Council/National Oceanic and Atmospheric Administration (NOAA) Restoration Center by *MarineFisheries* and executed via a contract between *MarineFisheries* and Gomez and Sullivan Engineers, PC. The project has also received financial and in-kind support from the following partners: *MarineFisheries*, NOAA, the City of Brockton, the Massachusetts Department of Fish and Game, the Massachusetts Division of Ecological Restoration (DER), and the Jones River Watershed Association (JRWA).

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 main stem 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.

The natural resources of the Jones River and Silver Lake make fish passage at Forge Pond Dam one of the highest ranking priorities of *MarineFisheries* 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 communities.

Project Goals

The goal of this project was to document existing conditions and conduct a feasibility and alternatives analysis for providing fish passage at Forge Pond Dam and into Silver Lake. The target species are river herring and American eel, although benefits to all aquatic resources and water uses were considered. Preliminary design for fish passage improvement alternatives were developed to advance the project to the next phase of engineering plans and permitting if a preferred alternative is selected.

This report presents existing conditions and water supply operations (Sections 2 and 3), as well as the results of new hydrologic and hydraulic investigations conducted to evaluate the feasibility of providing fish passage at Forge Pond Dam under different scenarios of flow management and structural modifications (Sections 4 through 7).

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. *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 nine 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 et al., 2013).

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

- Sustainable Water Management Initiative Report: Monponsett Pond and Silver Lake Water Use Operations and Improvement (SWMI Project No. BRP 2012-06) (Shallenberger & Cooper, 2013) – Prepared by Princeton Hydro, LLC for the Town of Halifax and the Massachusetts Department of Environmental Protection (DEP).

- River Herring Spawning and Nursery Habitat Assessment: Silver Lake, 2008-2009 (Chase et al., 2013) – Prepared by *MarineFisheries* and the JRWA.

- 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 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.

- South Shore Coastal Watersheds 2001 Water Quality Assessment Report. (DEP, 2005). Included portions of the Jones River and estuary. Referred to in this report as the 2001 water quality assessment.

- 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.

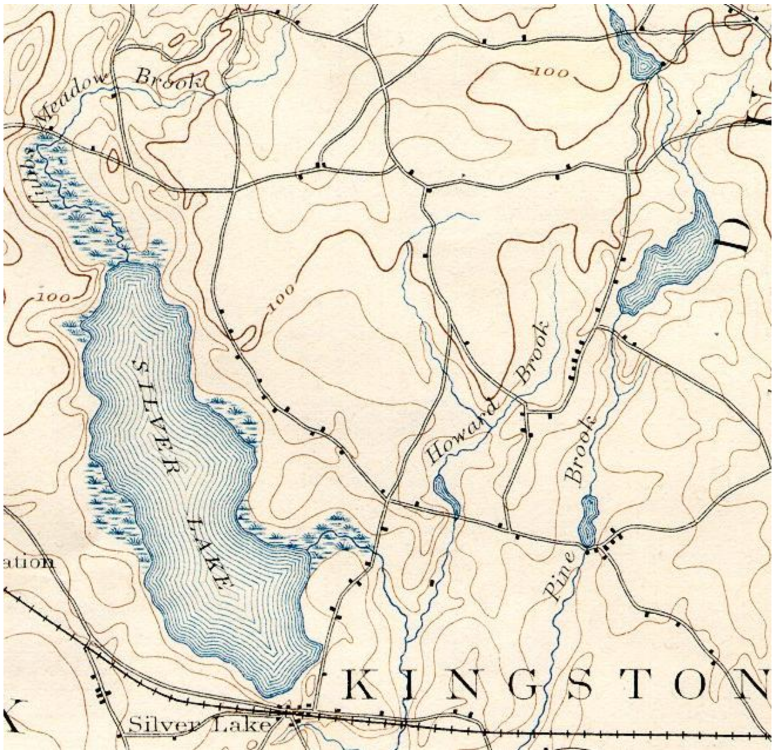
2. Existing Environment

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 the northern boundary of the Plymouth-Carver aquifer and the largest river drainage 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. 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).



Historic (1893) map of Silver Lake prior to the construction of Forge Pond Dam. 20-foot contour intervals indicate the natural level of the lake between 40 and 60 feet, mean sea level.

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).

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

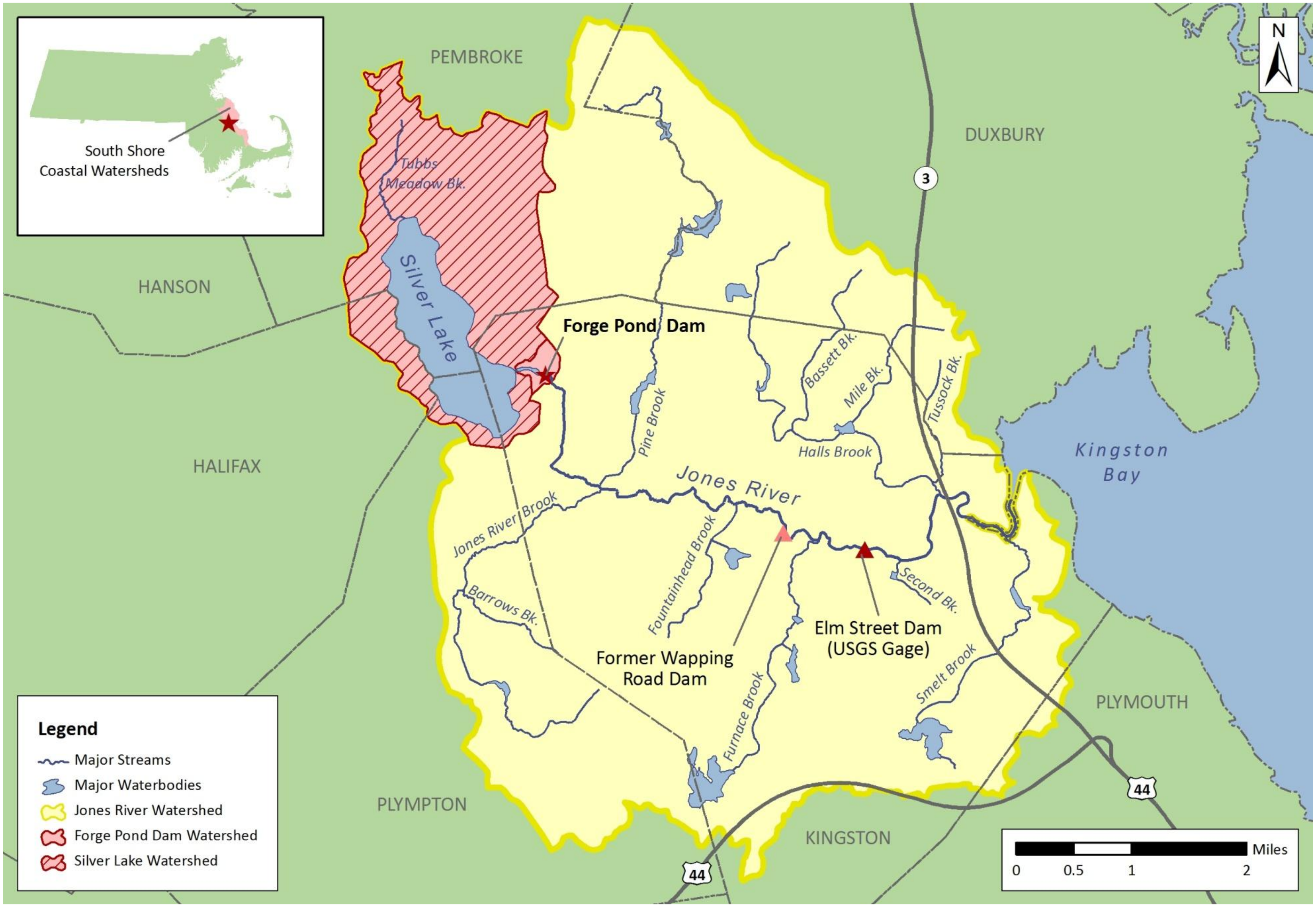


Figure 2.1-2: Forge Pond Map

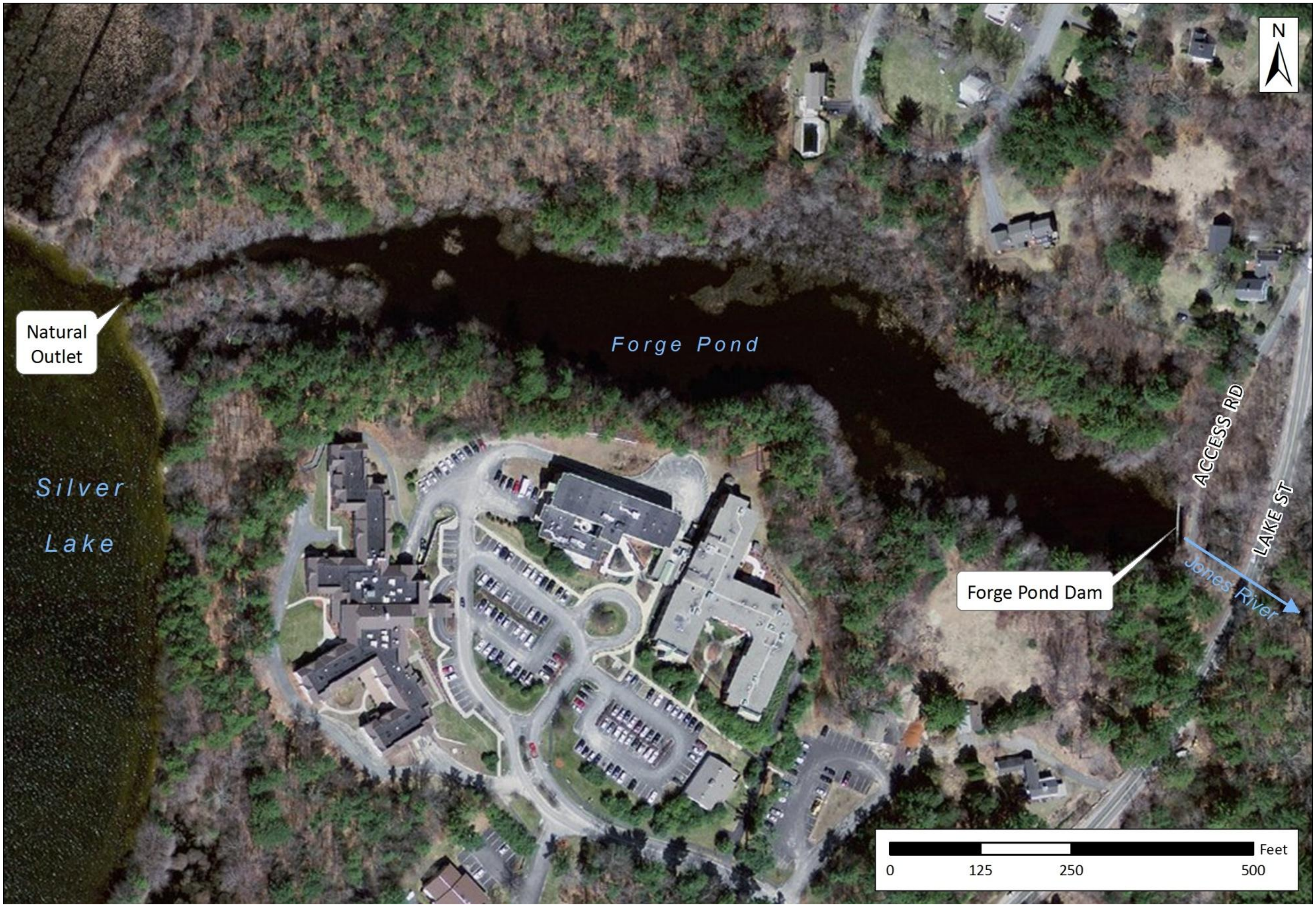
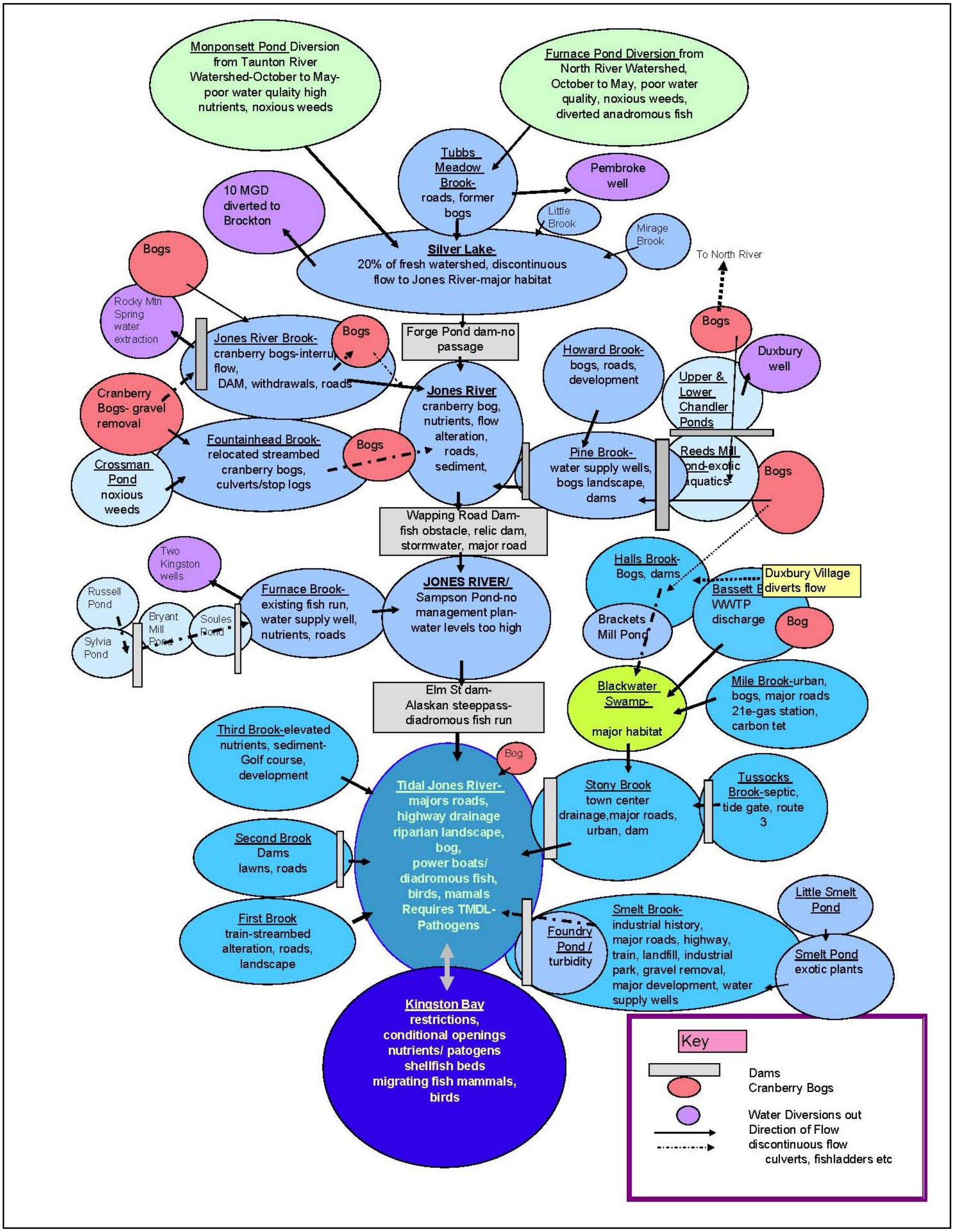


Figure 2.1-3: Run-of-River Influences in the Jones River Watershed



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 main stem 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 *MarineFisheries* (Reback et al., 2005). 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.

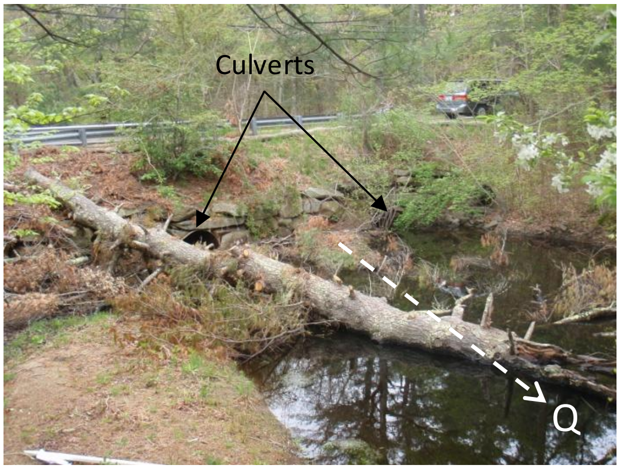
The former Wapping Road Dam, which was not fitted with any fish passage structures, historically presented the next obstacle. Its removal in October 2011 opened up fish habitat on 3.7 miles of the Jones River main stem and 18.3 miles of tributaries. The restoration effort was led by the JRWA.

Elm Street Dam and Fish Ladder

Site of Former Wapping Road Dam (looking downstream)

2.2.2 Grove Street and MBTA Railroad Culverts

Upstream of the former Wapping Road Dam, the culverts at Grove Street and the MBTA railroad 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 railroad opening consists of an open-bottom stone arched culvert approximately 6.6 feet wide. This culvert was first constructed in 1850, prior to the construction of concrete dams on the river.



Grove Street Culverts

MBTA Railroad Culvert

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 was 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.

Photograph source: MA DER, 2006.

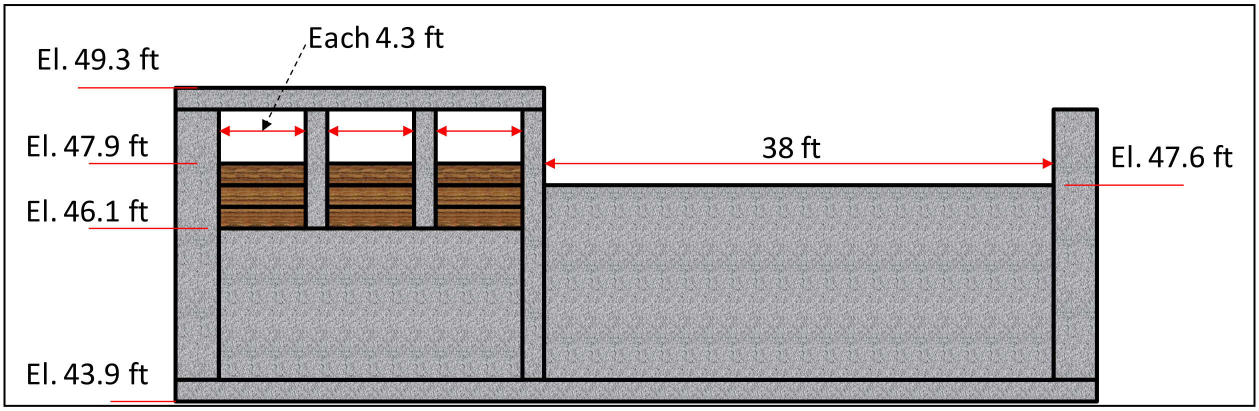
Figure 2.2.4-2 below is a schematic (not-to-scale) of Forge Pond Dam showing the 38-foot-wide spillway and three stoplog openings, each with an effective width of approximately 4.3 feet. Although there is some discrepancy regarding the spillway crest elevation (see discussion in **Section 3.2.1**), the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

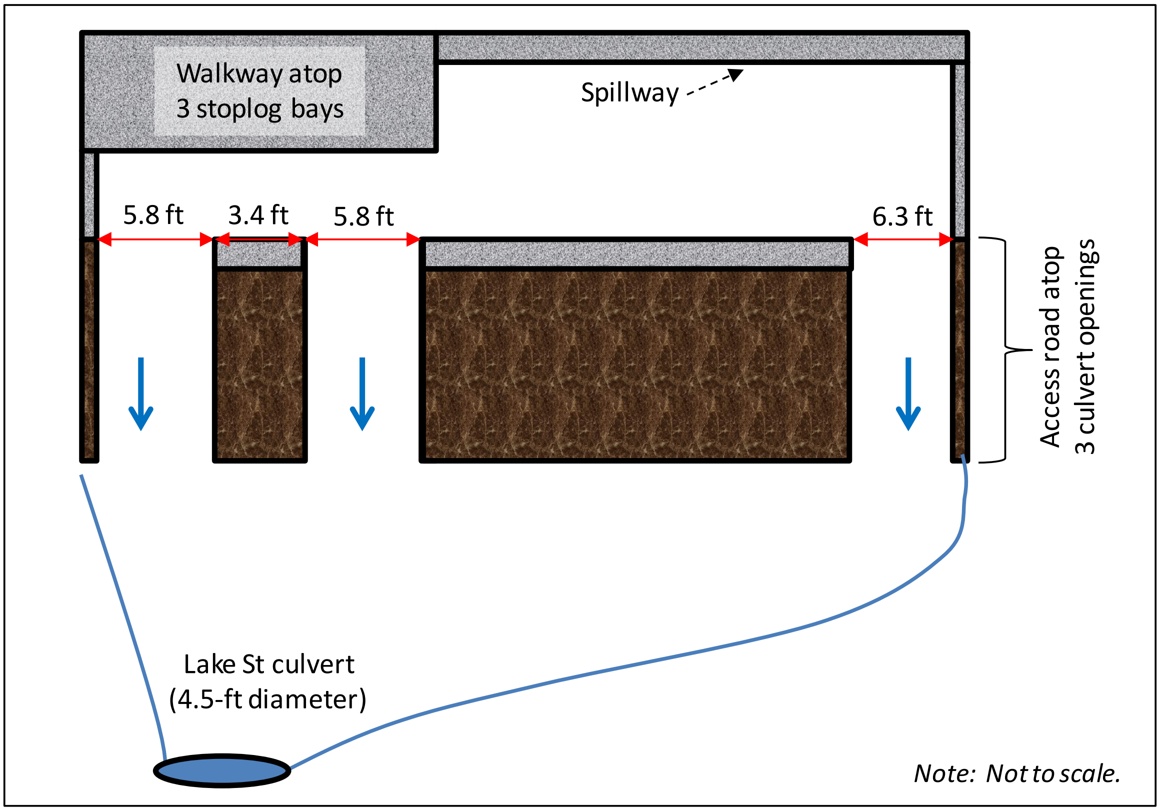
Figure 2.2.4-2: Forge Pond Dam Schematic – Elevation View



Note: Not to scale. Elevations based on NGVD 29. The elevation of the top of flashboards may be adjusted from 47.9 feet (current position) down to 46.1 feet 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 through the structure. 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



Note: Not to scale.

2.3 Fishery Resources

2.3.1 Target and Other 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 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.

Target Species – River Herring

In Massachusetts, more than 100 coastal rivers and streams are home to the anadromous alewife and blueback herring (Reback et al., 2005). 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).

*Blueback herring (*Alosa aestivalis*)*

*Alewife (*Alosa pseudoharengus*)*

Imagery Credit: Duane Raver/USFWS

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 other wildlife. 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.

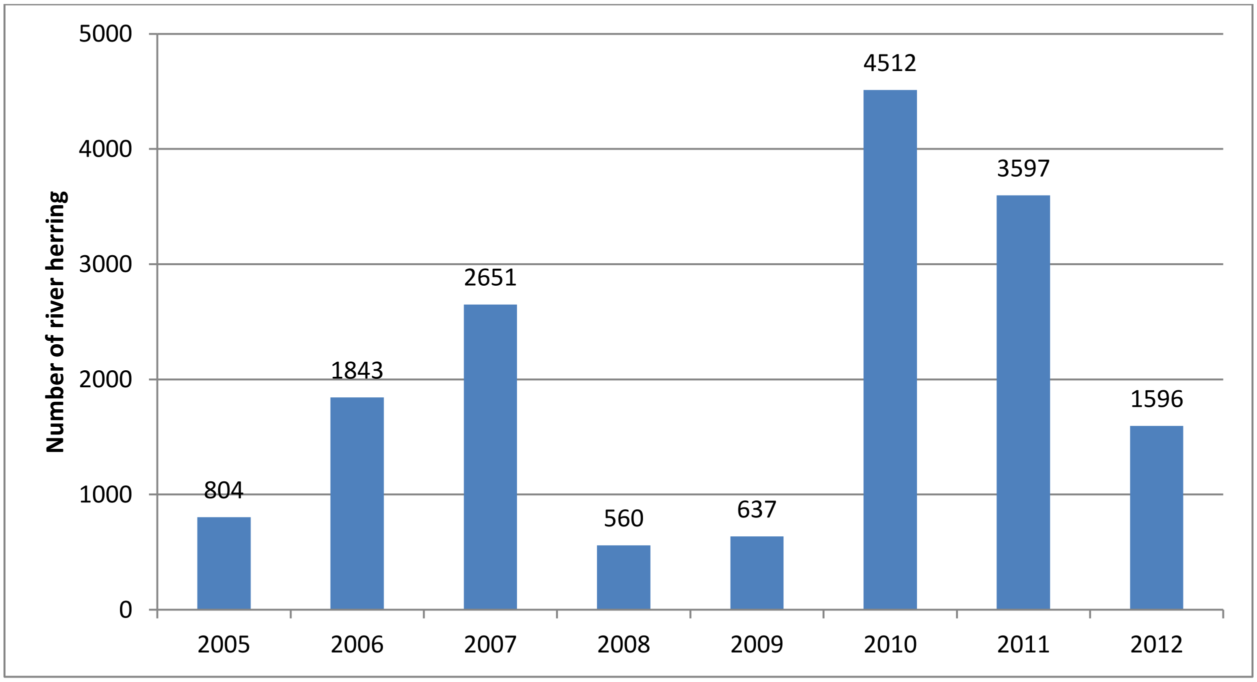
Historically, river herring were one of the most valuable anadromous fishes harvested commercially in Massachusetts and sold as food or commercial bait. In the early days, considerable interest was shown by the town of Kingston in the welfare of its several herring streams. Records show that in 1872 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 *MarineFisheries* 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 and is presently reviewing a petition to list river herring as threatened under the Act.

While both species are capable of spawning in a variety of freshwater environments, bluebacks spawn in more riverine areas, whereas alewives tend to spawn in more lacustrine (ponds and lakes) areas. Alewives begin to spawn in late March to mid-May when water temperatures reach about 10.5°C, but can arrive earlier following mild winters. 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 about 3 to 5 years of age, the fish use olfactory cues to guide them to their natal streams (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 and the state moratorium on harvesting river herring since 2005 (JRWA, 2011a).

Figure 2.3.1-1: River Herring Run Sizes in Jones River (2005-12)



Source: JRWA, 2011a

Target Species – American Eel

Imagery Credit: Duane Raver/USFWS

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 eel 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 feet per second (ft/s) and can reach a burst speed of 6.0 to 7.0 ft/s.

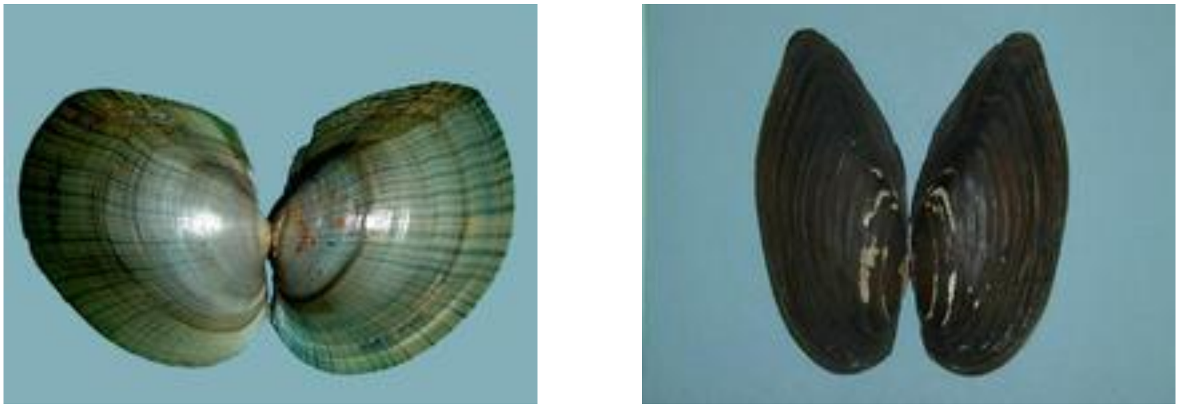
MarineFisheries has conducted young-of-the-year (YOY) abundance surveys using a Sheldon elver trap on the Jones River below the Elm Street Dam annually since 2001. Trap catches from 2005-2008 ranged from 18 to 21 thousand glass eels annually; the highest catches for this period among four YOY eel trap 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 (ASMFC, 2013). The USFWS is currently reviewing a petition to list American eel as an endangered species under the Endangered Species Act.

Other Species – 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 stabilization of Silver Lake water level management and water quality enhancements. Additionally, a stable and healthy population of these filter feeders can improve water quality, creating a positive feedback loop.

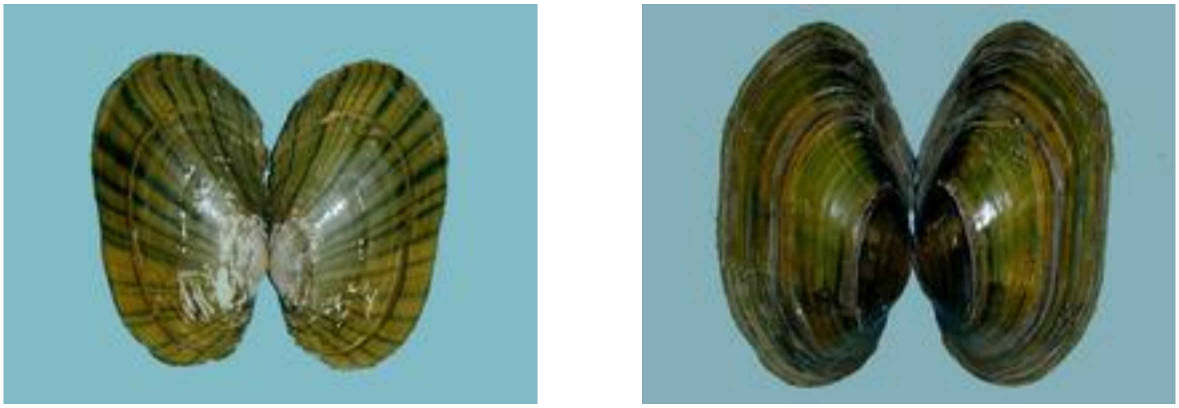
A mussel survey conducted in 2002 (McCoy, et al.) in the vicinity of the Silver Lake Sanctuary (near the natural outlet to Forge Pond) found the freshwater mussel species shown in **Figure 2.3.1-2** below. The tidewater mucket and eastern pondmussel are listed as Species of Special Concern by the MA 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).

Figure 2.3.1-2: Freshwater Mussel Species Present in Silver Lake



Tidewater mucket (Leptodea ochracea)
Species of Special Concern

Eastern pondmussel (Lagumia nasuta)
Species of Special Concern



Eastern lampmussel (Lampsilis radiata)

Eastern floater (Pyganodon cataracta)

Image source: American Museum of Natural History

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 impacts from water level manipulations on mussel populations are minimal. 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 bathymetry, **Section 2.4.1**) leads to significant exposure of mussel habitat with proportionally small declines in water level. The Teal study concluded that shallow photic zones may provide important nurseries for freshwater mussels, and water level management may have significant impacts upon the freshwater mussel populations in the long term.

2.3.2 Target Fish Passage Thresholds

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 Volume

It would be desirable to maintain a natural, seasonally varying flow below Forge Pond Dam—not just flows needed to pass migratory fish. However, it is recognized that the Jones River watershed is a highly impacted system and there will need to be a balance for both water supply and habitat 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. Additional consideration may be given to other species as their needs are demonstrated.

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 2.3.2-1: Timing of Important Life Cycle Events for Target Species

Species	Life Stage	Event	Month									
			MAR	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
River herring	adults	*upstream migration*	🟦	🟦	🟦	🟦						
	juveniles	*downstream emigration*					🟦	🟦	🟦	🟦	🟦	
American eel	elvers	*upstream migration*		🟩	🟩	🟩	🟩					
	silver eels	*downstream emigration*							🟩	🟩	🟩	

Flow 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 targets should be adjusted using site-specific information. Below sharp elevation changes, *MarineFisheries* recommends plunge pools with depths of 1-2 feet, depending on water flow and weir height.

The guidelines above only address 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. There is an association 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.

Flow Velocity

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 ft/s and can reach burst speeds of 6.8 ft/s. Where these flows exceed maximum sustained swim speed, successful passage may still be possible, provided that fish can accomplish the needed swim speed without additional impedance such as high water temperatures and/or low DO.

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. (2004) 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 ft/s 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 ft/s compared to only 67% for alewives under the same conditions. Within a given species, swimming performance 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 were 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 (see **Table 6.1.3-2** for results of this analysis).

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 was 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, 2010). Silver Lake was assessed during 2008-2009 in collaboration with the JRWA (Chase et al., 2013). The Silver Lake assessment documented suitable conditions to support river herring life history. **Table 2.3.3-1** lists acceptable 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).

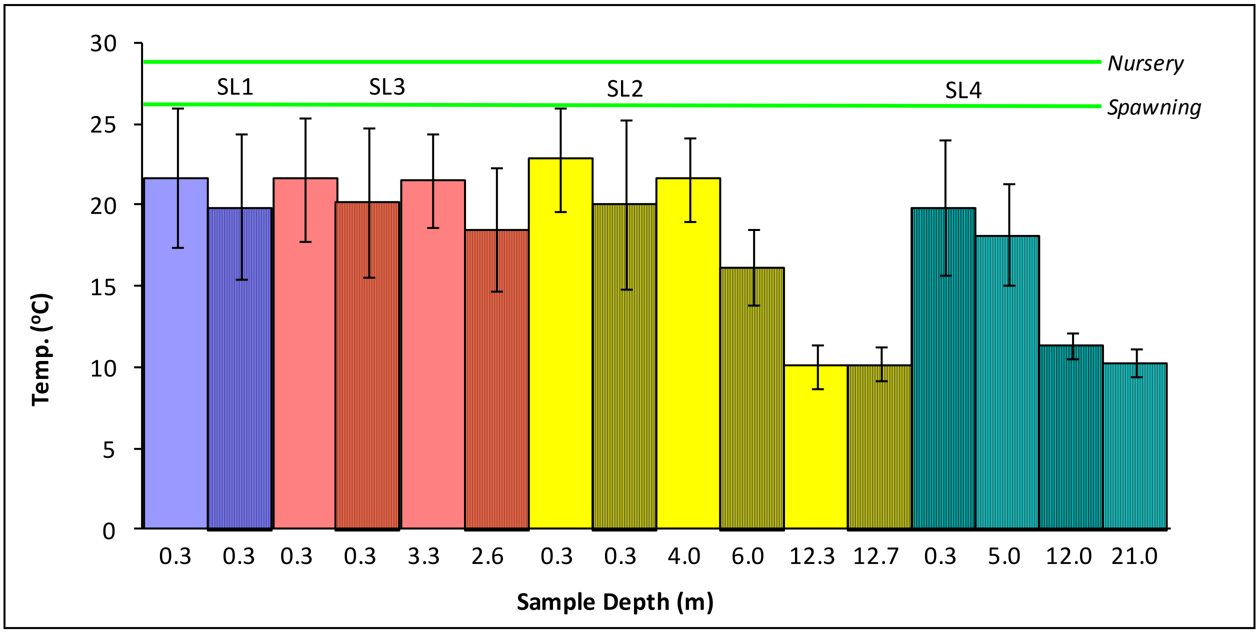
Table 2.3.3-1: Physical, Chemical, & Biotic Criteria for River Herring Spawning and Nursery Habitat

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

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 sub-ecoregion 59, with the exception of sub-ecoregion 84 (includes Cape Cod) for secchi disc depth (USEPA, 2000b). Additional references (75th percentile) 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, 2010).

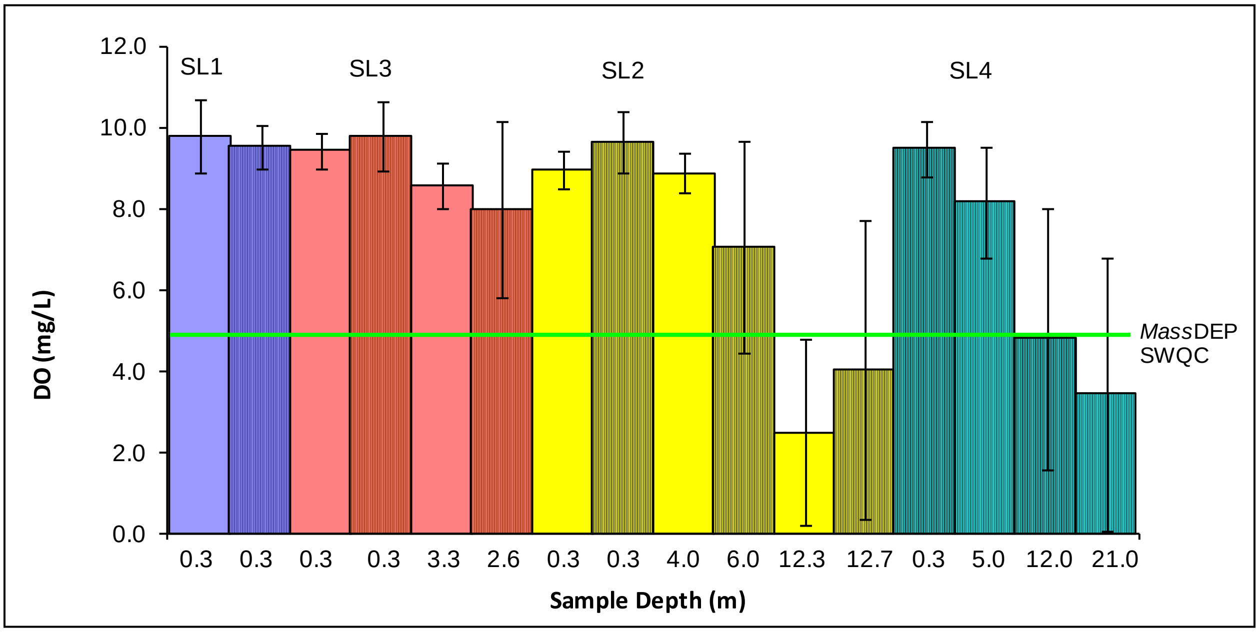
Figures 2.3.3-1 through **2.3.3-5** present average water temperature, dissolved oxygen (DO), pH, Secchi disc depth (a measure of water clarity), and total nitrogen and phosphorous levels for Silver Lake collected during 2008 and 2009.

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



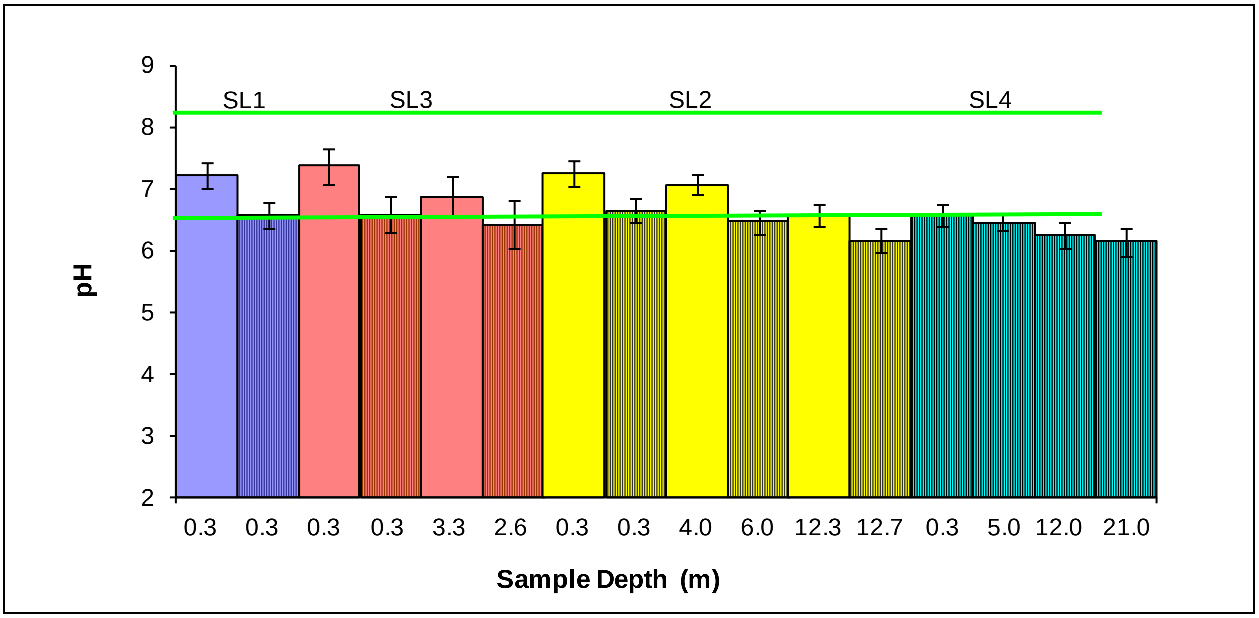
Notes: Station averages are presented (+/- 2 SE) for 2008 (blank bars) and 2009 (striped bars). Six samples were targeted for each depth. Green lines mark the thresholds for nursery and spawning temperatures recommended by the DEP SWQS and scientific literature, respectively. Source: Chase et al., 2013.

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



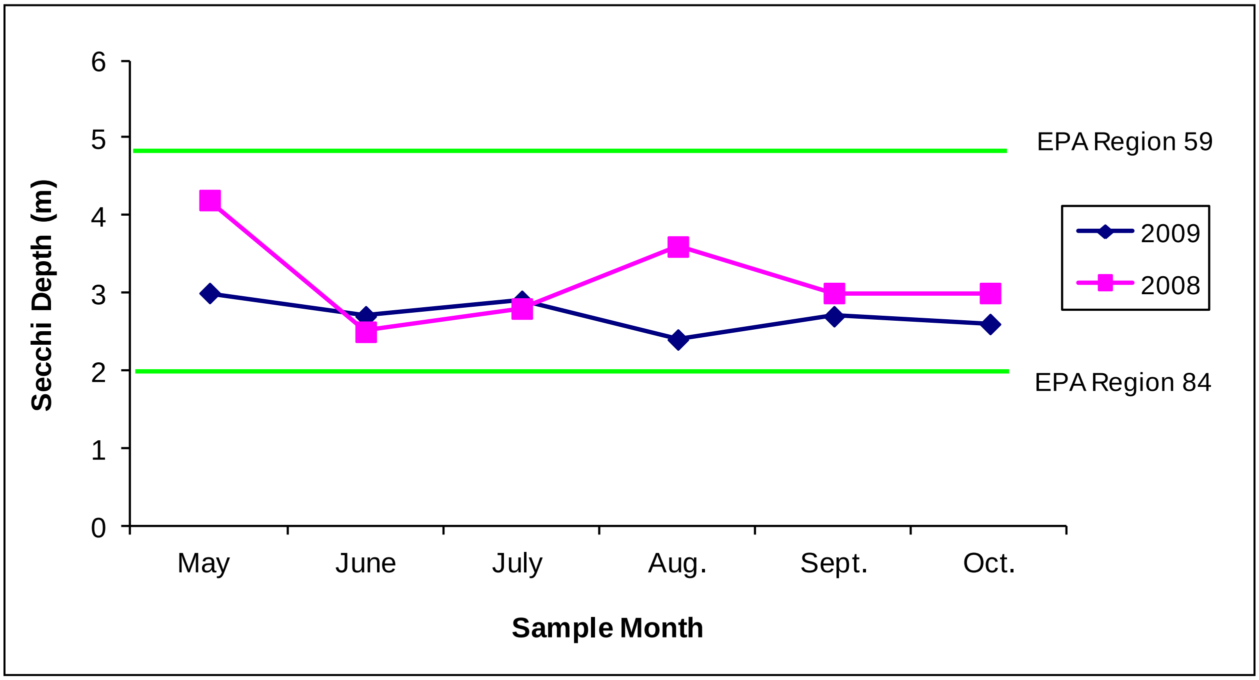
Notes: Station averages are presented (+/- 2 SE) for 2008 (blank bars) and 2009 (striped bars). 'SL1', etc. labels indicate stations. Six samples were targeted each depth. Green lines mark the DEP SWQS threshold for DO (5.0 mg/L). Source: Chase et al., 2013.

Figure 2.3.3-3: Average pH of Silver Lake (2008-09)



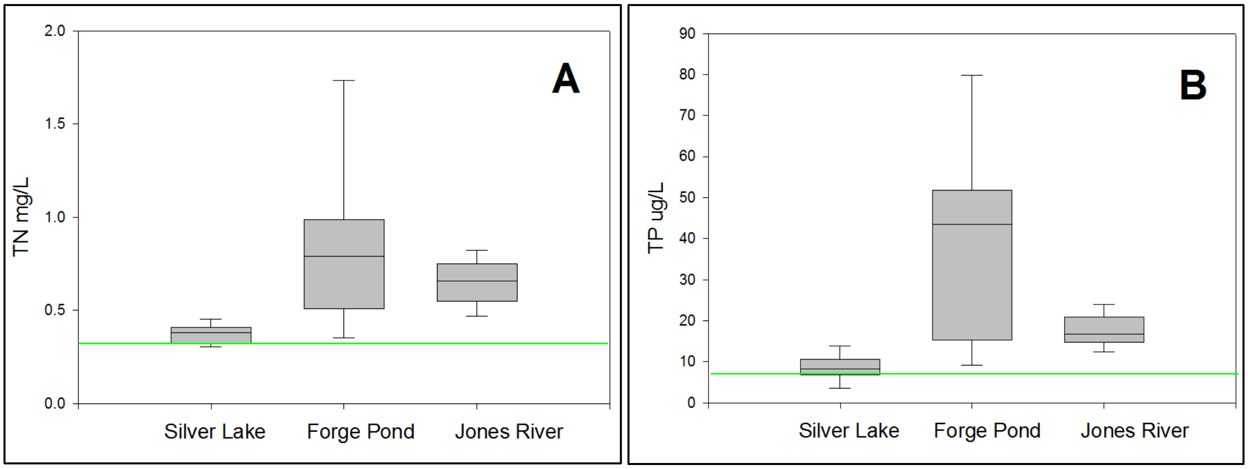
Notes: Station averages are presented (+/- 1 SD) for 2008 (blank bars) and 2009 (striped bars). Green lines mark DEP SWQS thresholds for pH. 'SL1', etc. labels indicate stations. Source: Chase et al., 2013.

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 et al., 2013.

Figure 2.3.3-5: Box Plots of 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. The line in boxes is the median and the error bars are 90% confidence intervals. Source: Chase et al., 2013.

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 2.3.3-2: Summary of River Herring Habitat Assessment at Silver Lake (2008-09)

Parameter	**Units**	**Sample Size** (no.)	**Acceptable Criteria**	**Exceedence**	**Classification**
Temp. (nursery)	°C	53	≤ 28.3	2%	Suitable
Temp. (spawning)	°C	37	≤ 26.0	0%	Suitable
DO	mg/L	75	≥ 5.0	11%	Impaired
pH	SU	90	6.5 to ≤ 8.3	38%	Impaired
Secchi	mg/L	23	≥ 2.0	0%	Suitable
TN	mg/L	25	≤ 0.32	76%	Impaired
TP	µg/L	25	≤ 8.0	56%	Impaired
Eutrophication	N/A	12	BPJ	0%	-
Fish Passage	N/A	12	BPJ	100%	Impaired
Stream Flow	N/A	12	BPJ	83%	Impaired

Notes: Bottom measurements at the deep stations were excluded from DO classification due to QAPP exemption. Impaired classifications result from exceedances >10% at transect stations during two seasons. Source: Chase et al., 2013.

Despite the common classification of "Impaired" (DO, pH, TN, TP, fish passage, and stream flow), Silver Lake was considered to have water quality that was supportive of river herring life history. Water temperature and Secchi disc were classified as "Suitable" and DO, pH, TN, and TP were found to be in ranges close to acceptable thresholds, which are conservatively designed to protect all aquatic life. The main concerns identified by the assessment were the potential for eutrophication impacts if nutrient loading was to increase and the obvious impairment of fish passage and stream flow. Improving fish passage and stream flow are the targets of the present study. As discussed later, water quality parameters (dissolved oxygen, total nitrogen, phosphorous, 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, heavy recreational use (motor boats, sea planes, etc.), and poorly managed landscape impacts along their shores. Lack of flows to Stump Brook downstream of Monponsett Pond also result in water quality impacts. The diversion of these poor quality waters into Silver Lake have caused its water quality to deteriorate 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

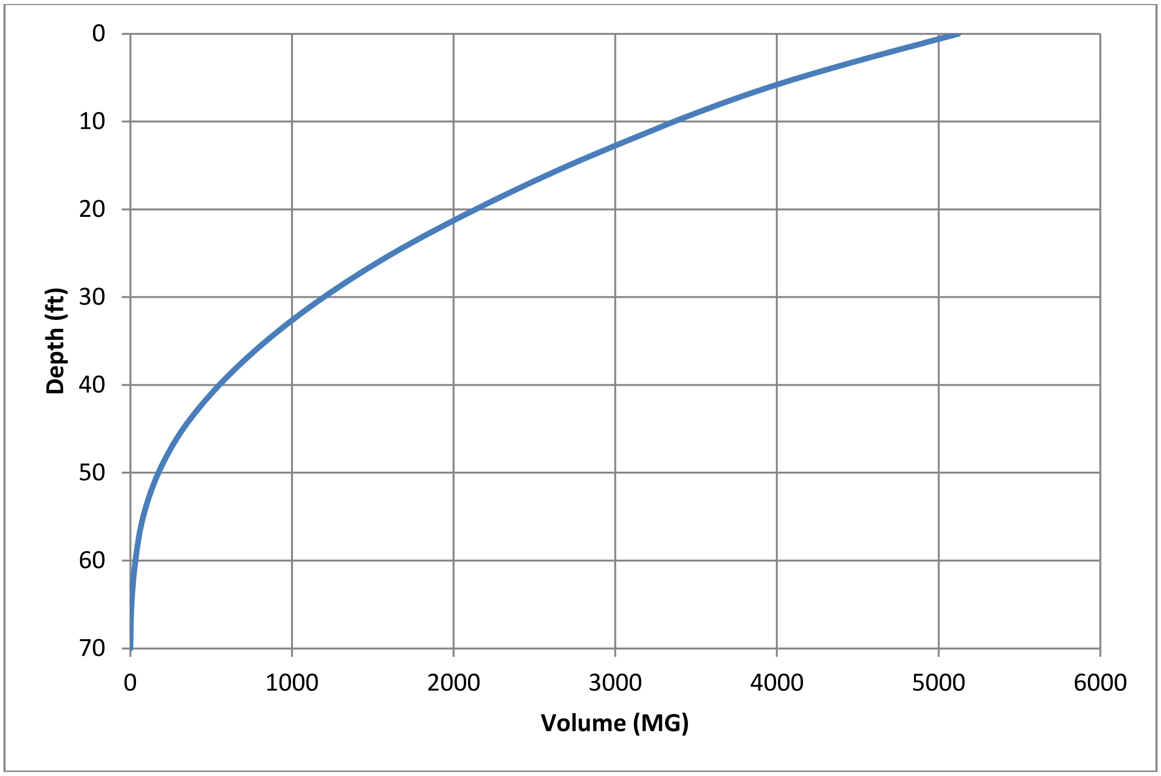
2.4.1 Bathymetry

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.

The bathymetry data collected by C&C was used to develop a stage-storage curve of Silver Lake, as shown in **Figure 2.4.1-3**.

Figure 2.4.1-3: Silver Lake Stage-Storage Curve

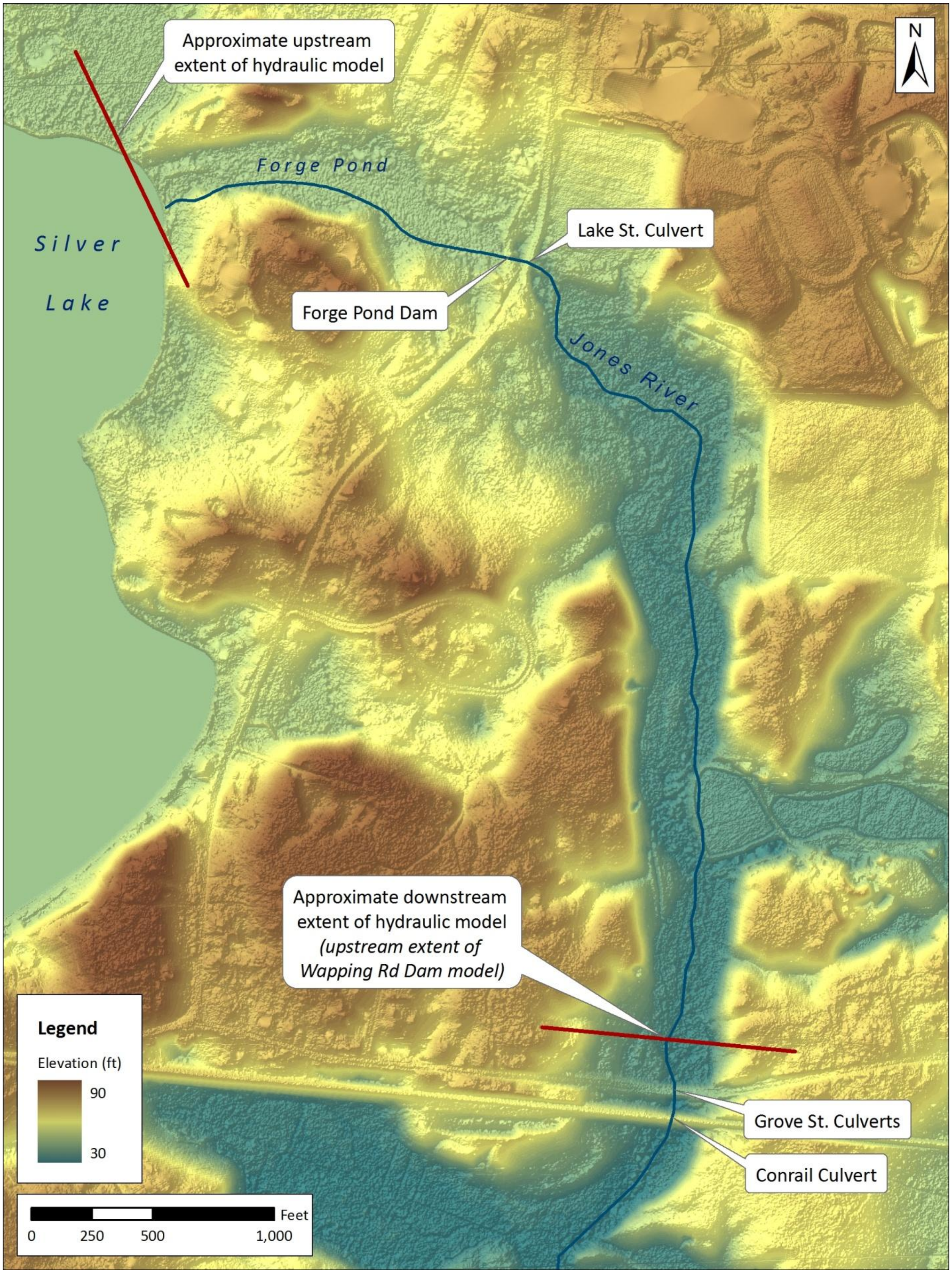


Derived from bathymetry data collected by Coler & Colantonio (2003)

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 elevation data in the area of Forge Pond Dam, the access road just downstream, the Lake Street Culvert, and the Silver Lake outlet. The intent of this survey was to collect spot elevations at specific locations for use in the hydraulic model, thus an updated site plan was not developed. 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 center of the river channel. 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

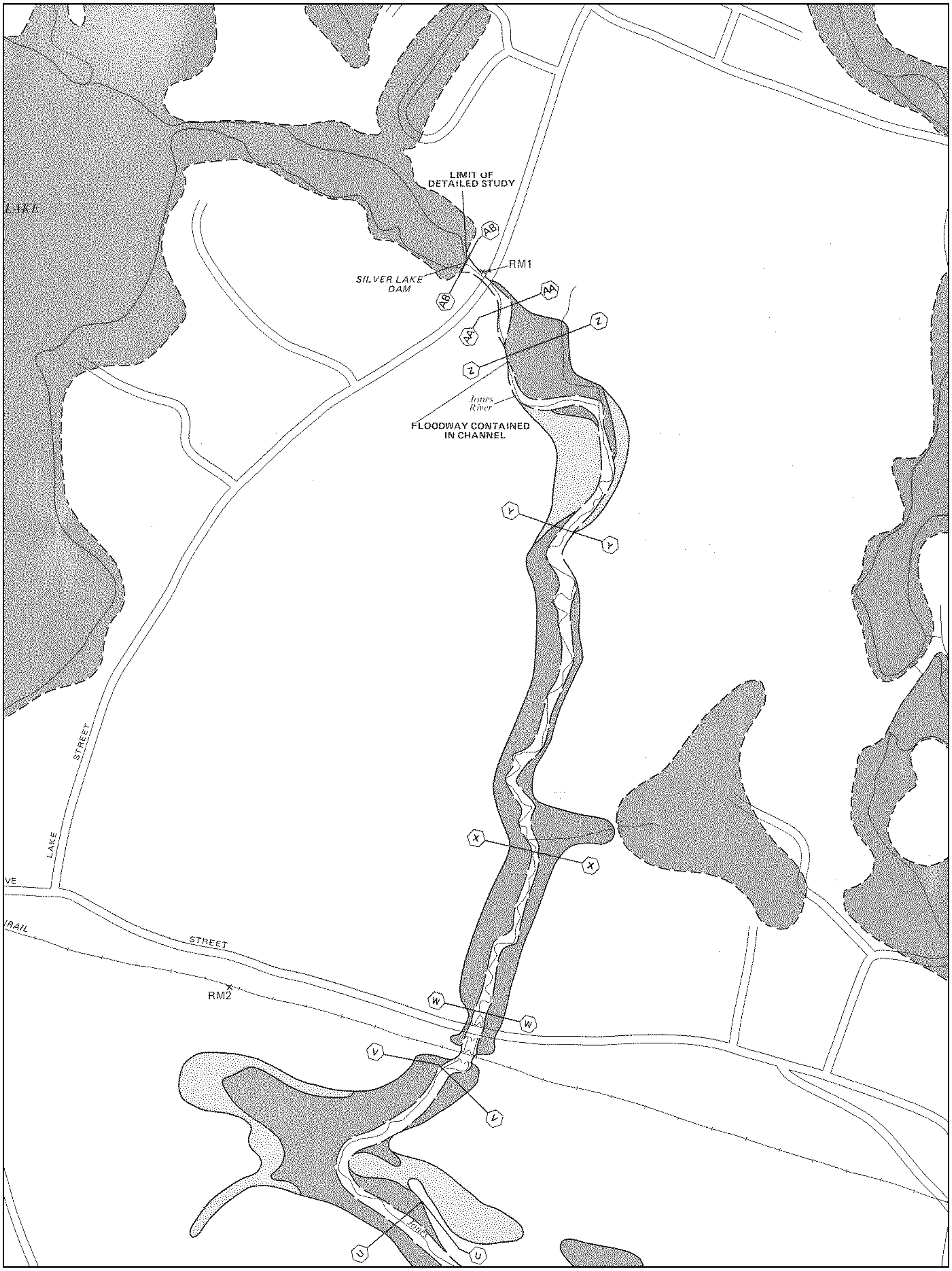


Figure 2.4.3-1: FEMA FIS Water Surface Profiles Downstream of Forge Pond Dam

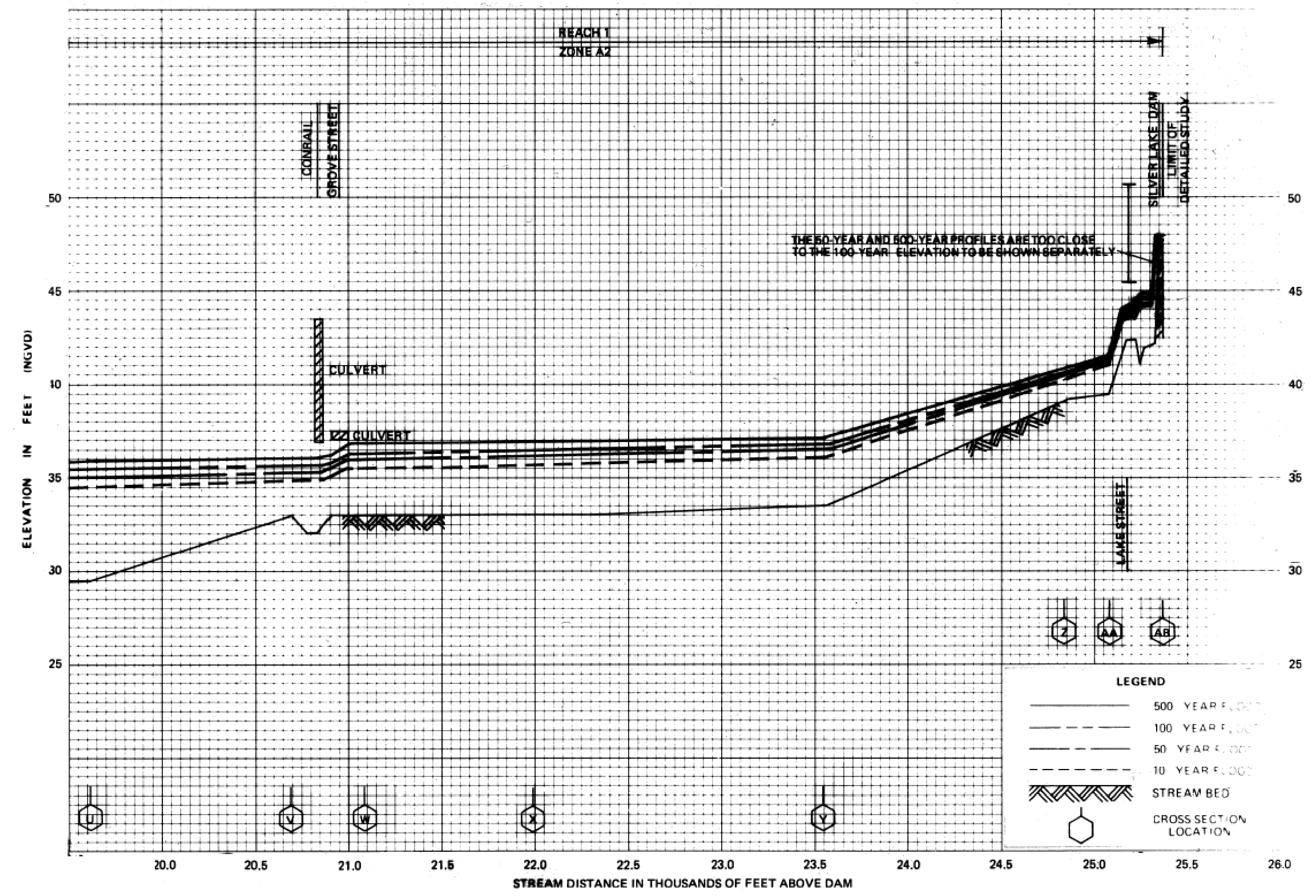
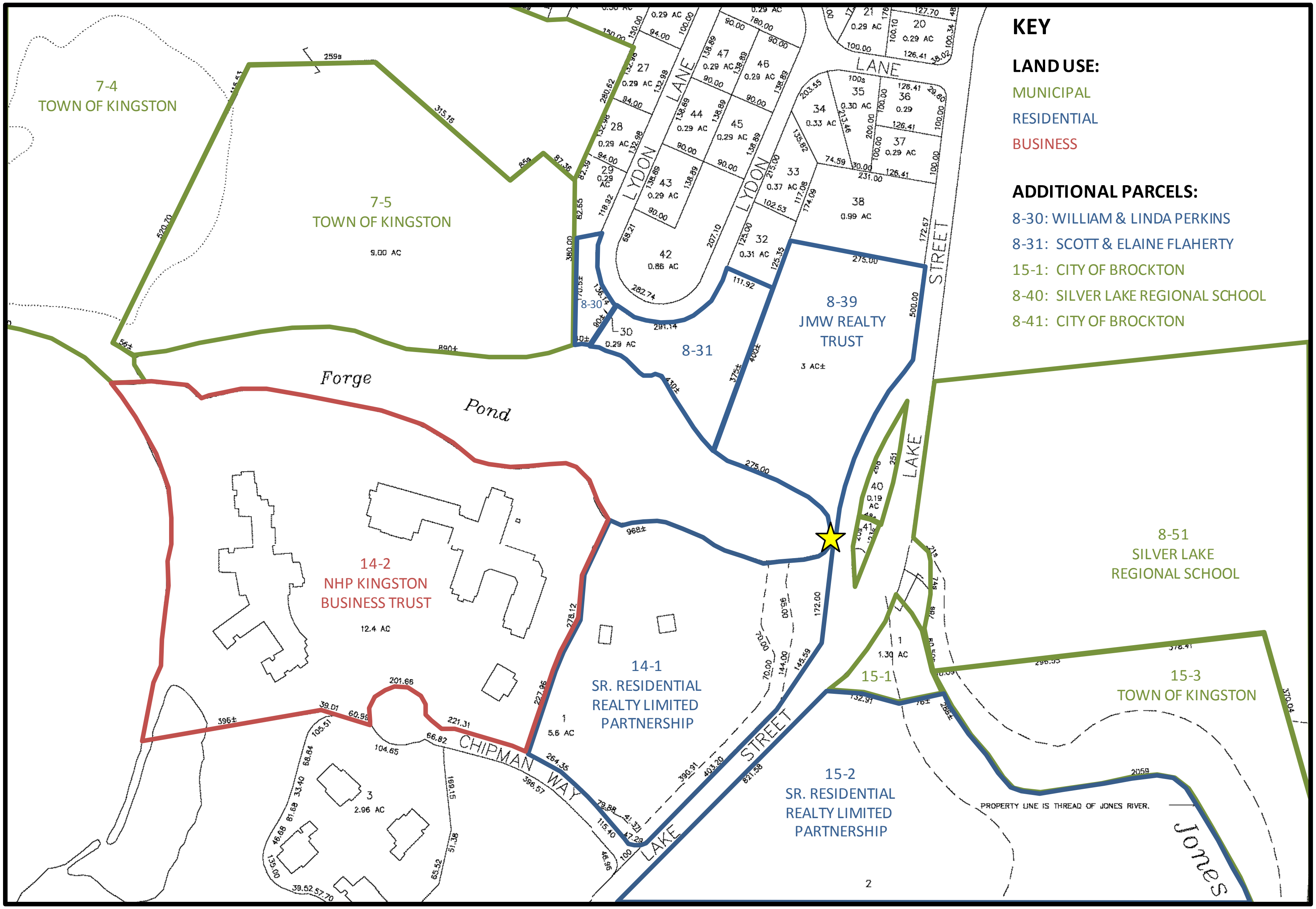


Figure 2.4.4-1: Properties Abutting Forge Pond and Upper Jones River



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 purchased a nominal amount of water (350,000 gpd) from Aquaria for a period of time, beginning in December 2008, for maintenance of facilities, but has no plans to increase its reliance on this source other than during periods of high demand, drought, or other water emergency (Brockton, 2009). 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.

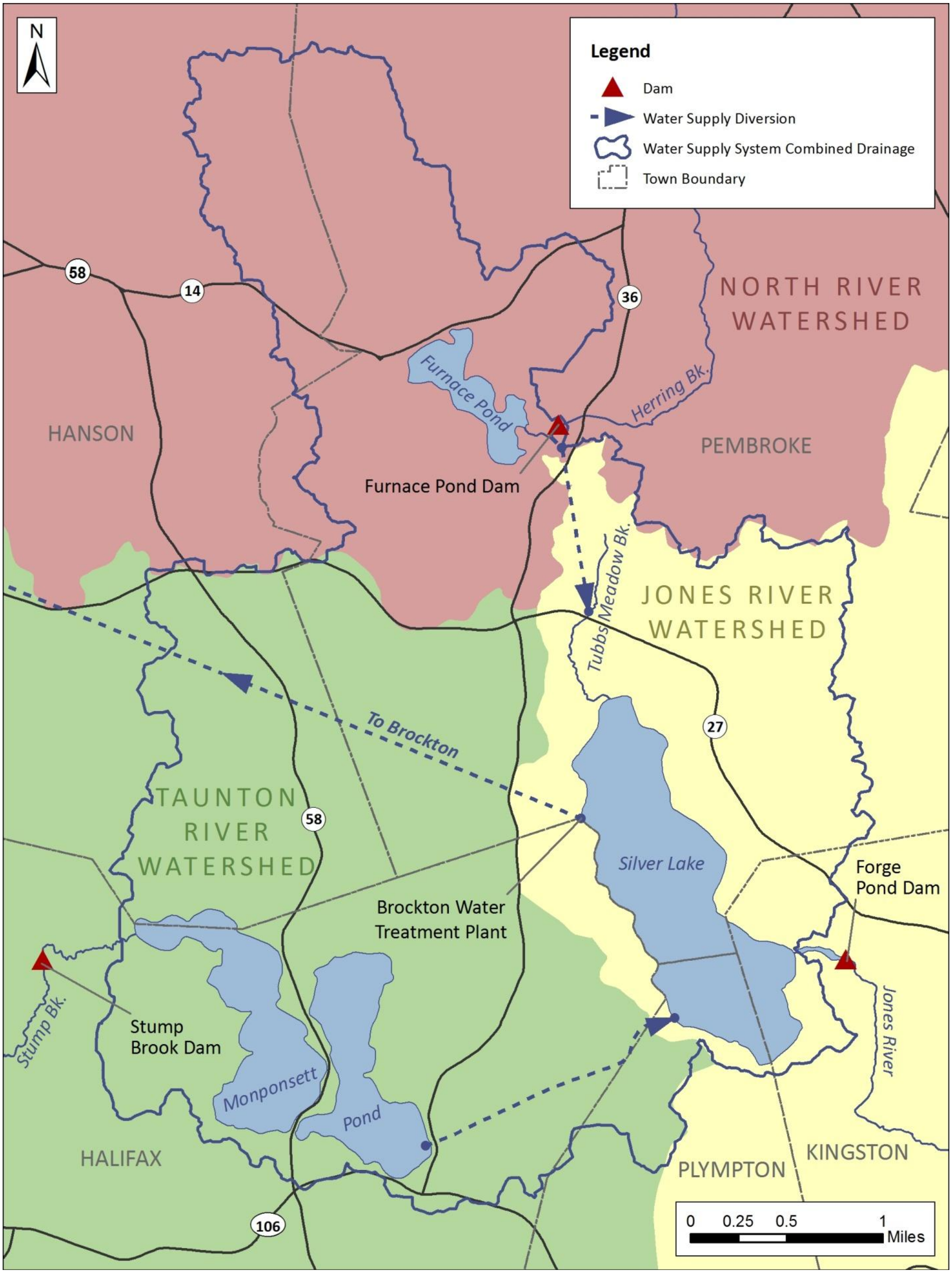
Table 3.1-1: Brockton Water Supply Summary

Source	**Registered or Permitted Withdrawal** (mgd)
Silver Lake	11.11 (registered volume)
Monponsett Pond	
Furnace Pond	
Brockton Reservoir (2005 WMA permit)	0.83
Aquaria desalinization plant	*up to 4.07**
Hubbard Avenue Well (emergency)	0.04
TOTAL	11.98
Administrative Consent Order Limit**	11.3

**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 (MG) 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

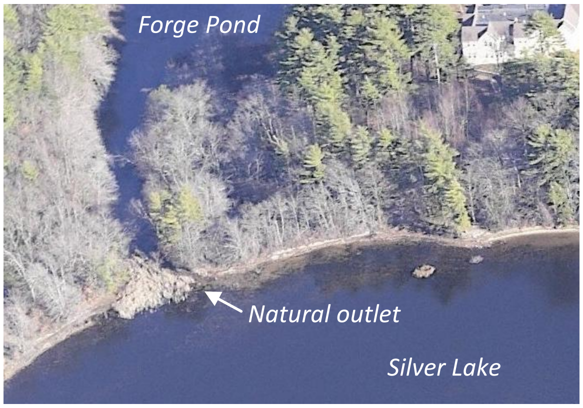
Source	Reporter	Year	Reported Elevation *(ft, NGVD 29)*			Comments
			Forge Pond Dam Spillway	Silver Lake Natural Outlet Inv.	Silver Lake Full Level	
Feasibility Study Survey	Gomez & Sullivan Engrs. (GSE)	2012	47.6	46.2	47.6	Surveyed using RTK GPS, tied into benchmark on dam surveyed by C&C (2003).
Bathymetric Survey Report	Coler & Colantonio	2003	47.6	45.92	47.0	Only licensed survey of the dam located for this study. Cited JRWA for Silver Lake full level.
Draft CWMP	Brockton	2009	47.5	45.0	47.5	No source cited.
Silver Lake System Overview Report	HMA	2006	47.0	45.6	47.0 *(implied)*	Incorrectly cited C&C survey. Confirmed Silver Lake full level & dam spillway are same by simultaneous readings in 2005.
Selected for use in this analysis	-	-	**47.6**	**46.2**	**47.6**	Based on GSE survey & HMA's finding that Silver Lake's full level is equal to the dam spillway crest.

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, the connection between Silver Lake and the adjacent Forge Pond is 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 distinct water bodies. 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 rising 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. In this study, recommendations of minimum flows for fish passage and aquatic habitat will be made and their associated impacts to water supply operations will be analyzed.

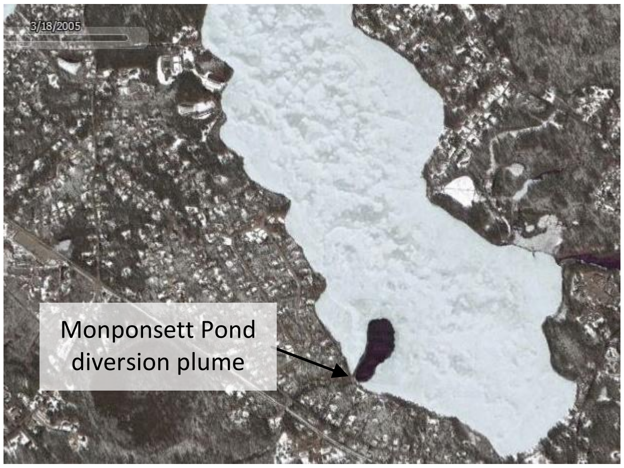
Tubbs Meadow Brook (from Furnace Pond Diversion Pipe)

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 (HMA, 2006). Tubbs Meadow Brook also receives and transmits water from the Furnace Pond Diversion pipe when it is being used to divert water from Furnace Pond, primarily due to flooding concerns and for water supply. Tubbs Meadow Brook flow is also impacted by the Town of Pembroke's water supply well, located nearby off Route 27.

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).

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

---

[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.

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).

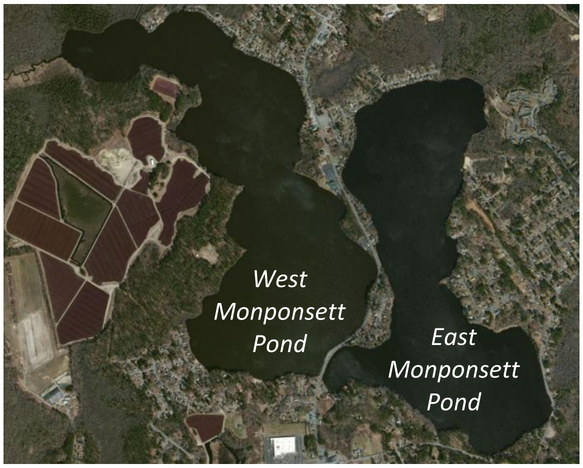
3.2.2 Monponsett Pond

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. The herbicide fluridone has been used in the pond for control of invasive plant growth of primarily fanwort and milfoil, which has become extensive in recent years (HMA, 2006).

---

[6] Brockton uses 47.5 feet NGVD for this elevation.

Stump Brook Dam and Fish Ladder

The natural discharge point of the interconnected ponds is through Stump Brook located on the northwesterly corner of the west lake. Stump Brook flows to Robbins Pond in Halifax which flows to the Satucket River in the Taunton River Watershed. 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.

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 dam also contains a low-level outlet that does not appear to be used.

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 x 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 (Brockton, 2009).

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 the last *MarineFisheries* fish passage survey (Reback et al., 2005) as in "good condition" and "passable function," 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 drought and severe drawdown at Silver Lake 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). As noted previously, diversions of this poor quality water impacts the nutrient level, DO, and temperature of Silver Lake, due to the input of about 30 mgd when the valve is open.

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 approximately 107 acres in size and shallow, 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, which occurs primarily due to flooding concerns but also for water supply (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).

Furnace Pond Dam, looking upstream

Furnace Pond Dam fish ladder, looking downstream

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 to serve nearby cranberry operations, 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, although Furnace Pond suffers greatly from poor water quality, invasive plants, and algae blooms. 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. The bar rack has been vandalized with some bars are bent. 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 is manually operated (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 water from the Taunton River estuary in Dighton, Massachusetts. The intake on the Taunton River is located just below the confluence with the Three Mile River. The plant can be operated to treat fresh water moving downstream, or brackish water from the tide.

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 recognizes Brockton’s contract to purchase up to 4.07 mgd from Aquaria. Aquaria operates under a separate WMA Permit #9P4425076.01 and an Interbasin Transfer Act Permit (see below). 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

Year No.	1	2	3	4	5	6	7	8	9	10	11-20
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018-27
Volume (mgd)	1.90	2.00	2.50	3.00	3.50	3.50	3.56	3.56	3.82	3.82	4.07

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 is not purchasing water from Aquaria, but is paying for its firm commitment volume. The City claims to target purchasing only a minimal amount of water from Aquaria on a daily basis for facility maintenance. 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).

3.4 Water Supply Costs

Brockton conducted an analysis of their costs to provide drinking water for their draft CWMP (2009). Since 1986, the City has contracted with Veolia Water (and its predecessors) for operation and maintenance of its water treatment facilities. Brockton's current agreement with Veolia includes a fixed annual cost based on an average annual treated flow of 10.8 to 13.2 mgd, plus a variable rate that raises or lowers the fixed fee for flows above or below that range. Based average demand at the time of the analysis (10.04 mgd), the cost to provide drinking water produced at Veolia-operated treatment facilities alone is approximately $325 per MG, or $0.325 per thousand gallons (Brockton, 2009).

Similarly, Brockton's agreement with Aquaria includes fixed and variable price components as follows (Brockton, 2002):

- **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 was required to pay $5,861,800 for the year based on a firm commitment volume of 3.5 mgd[7].

- **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.

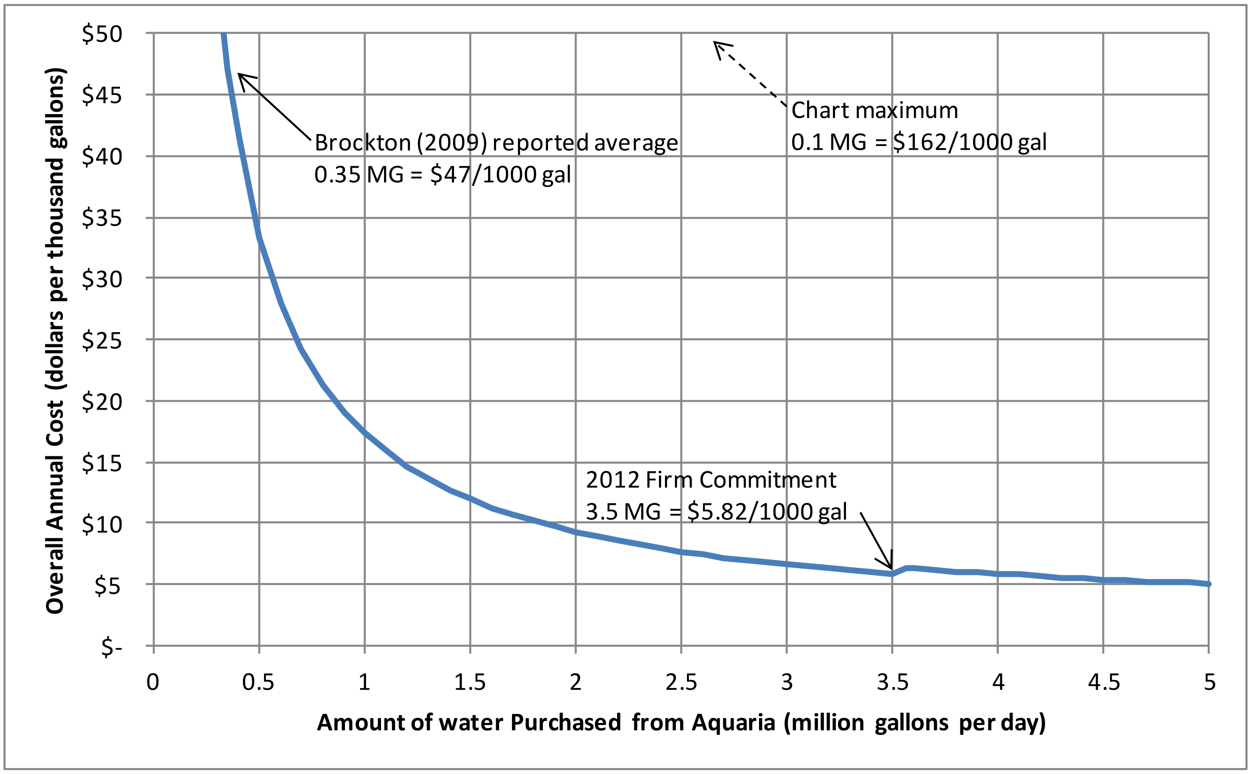
- **Excess Water Rate** – When actual use exceeds the firm commitment volume, the pricing for additional or "excess" water is set at $0.60 per 1,000 gallons used.

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 3.4-1** demonstrates this using Year 5 (2012) as an example.

---

[7] 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).

Figure 3.4-1: Overall Cost of Aquaria Water per Amount Purchased by Brockton (2012 Example)



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).

Based on average demand at the time of the analysis (10.04 mgd) and Veolia and Aquaria pricing, the City's reported practice of purchasing a nominal daily flow (350,000 gpd) from Aquaria and the remainder of its demand through Veolia 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 six 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.

A more detailed economic analysis is currently being conducted as part of the next feasibility phase of this project.

3.5 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, which are available from JRWA by request.

3.5.1 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 because it is a Great Pond governed by rights of access under the Great Pond legislation.

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).

3.5.2 Water Management Act Registrations and Permit

The Commonwealth of Massachusetts passed the Water Management Act (WMA) under Massachusetts General Law Chapter 21G (M.G.L. c. 21G) in 1986 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 acknowledges 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.

Before Brockton could operate under its registered amounts, on January 31, 1986 The MA DEP issued a Declaration of Water Supply Emergency in the City of Brockton, establishing guidance for the City to meet and authorizing the withdrawal of 110 percent of the City's estimated safe yield from all its sources of 10.3 mgd. This Emergency Declaration was extended every six months until the ACO was issued in November 1995 (see below).

3.5.3 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 allows for Brockton's total authorized withdrawals of 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**.

3.5.4 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 a letter from the DEP to Brockton (2004).

3.5.5 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 Conservation and Recreation (DCR) Office of Water Resources. 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 & Water Use

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).

Table 4.1.1-1: Jones River Drainage Area Comparisons

Location	Drainage Area (mi^2)		Drainage Area Ratio (Dam / Gage)	
	Natural	*Contributing**	*Natural*	*Contributing**
Jones River at Kingston Bay	29.8	25.7	-	-
Jones River at USGS Gage	19.8	15.7	0.212	0.006
Jones River at Forge Pond Dam	4.2	0.1		
Silver Lake at Natural Outlet	4.1	-	-	-

**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.*

It is important to note that although the additional drainage areas of Monponsett Pond (6 square miles) and Furnace Pond (1 square mile) are not included in the table, they do contribute to Jones River flow when these diversions are on while water is simultaneously spilling over Forge Pond Dam, which occurs fairly regularly (see **Section 4.2.2**). Therefore, hydrologic analyses of the Jones River (conducted for this study or previously) do not accurately characterize the natural regime since they often include transferred flows.

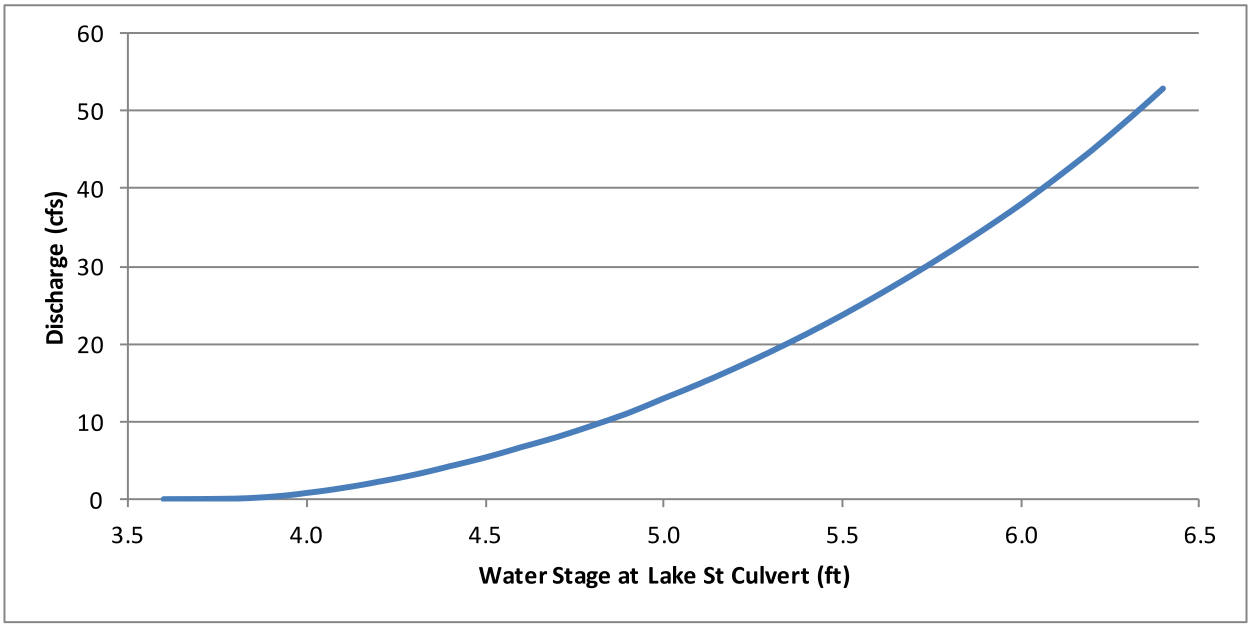
Annual and monthly flow duration curves were developed for the USGS gage using the full period of record (through March 2012) and are provided in **Figures 4.1.1-1** through **4.1.1-5** in **Appendix B**. Flow duration curves depict the average percentage of time that specific flowrates are equaled or 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 (cfsm). 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.

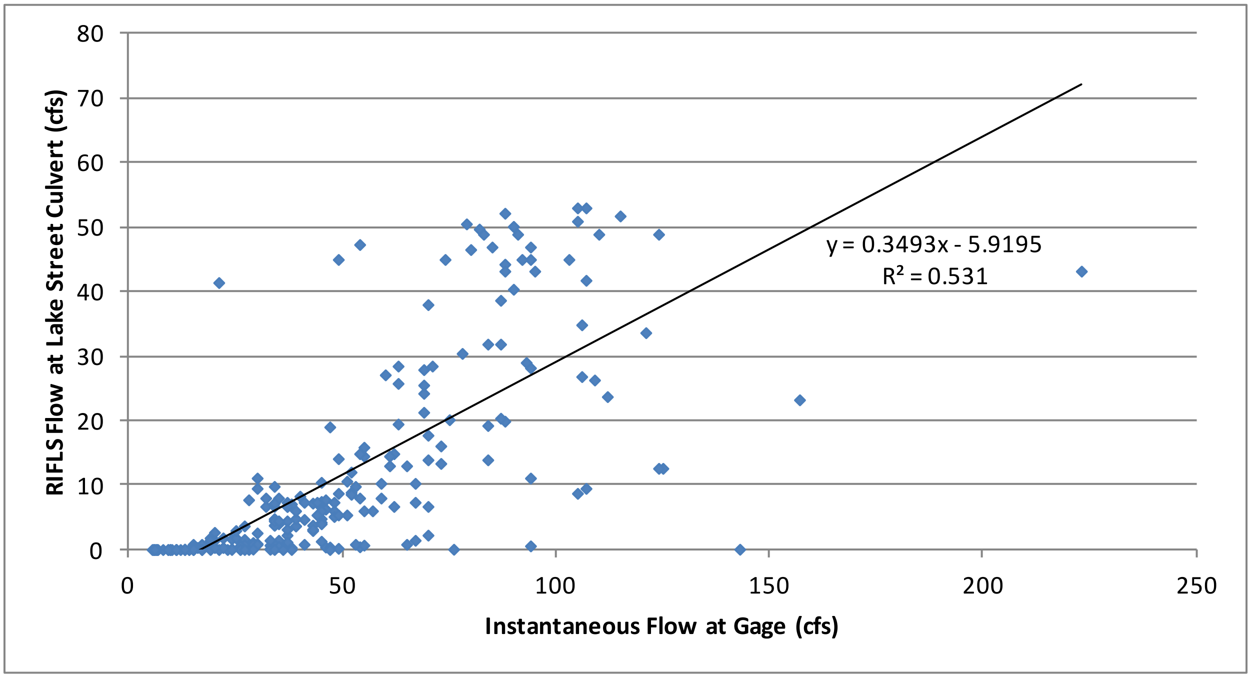
Figure 4.1.2-1: Rating Curve for Lake Street Staff Gage



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 ($R^2 = 0.53$). This may be due in part to the sporadic nature of the RIFLS observations, varying lag times between flow at the two gages, inconsistent tributary inflows below Lake Street, flow management for cranberry bog operations below Lake Street, or other unknown factors.

Figure 4.1.2-1: Comparison of Flow Measurements at Lake Street Culvert (RIFLS) and USGS Gage



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:

$$Q = C\,L\,H^{3/2}$$

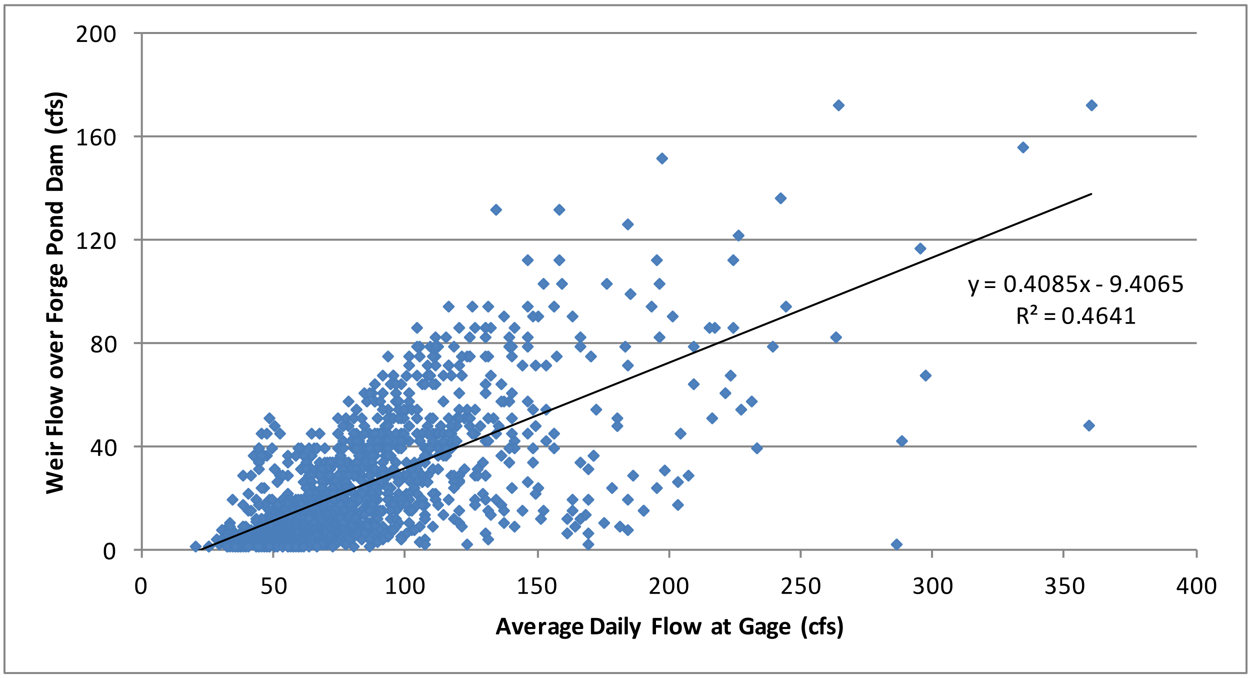
where **Q** = flow (cfs)
C = weir coefficient (ft)[8]
L = spillway length (ft)
H = head (height of lake level above spillway crest, ft)

---

[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 feet).

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 ($R^2 = 0.46$).

Figure 4.1.3-1: Weir Flow at Dam vs. Flow at Gage



The poor relationship could be due to one or more of the following issues with the weir flow analysis:

- 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.
- It was assumed that Silver Lake elevation is an accurate measure of head at the Forge Pond spillway, which has not been thoroughly tested.
- It was assumed that all three stoplogs were securely in place in all three bays, which was not always the case.

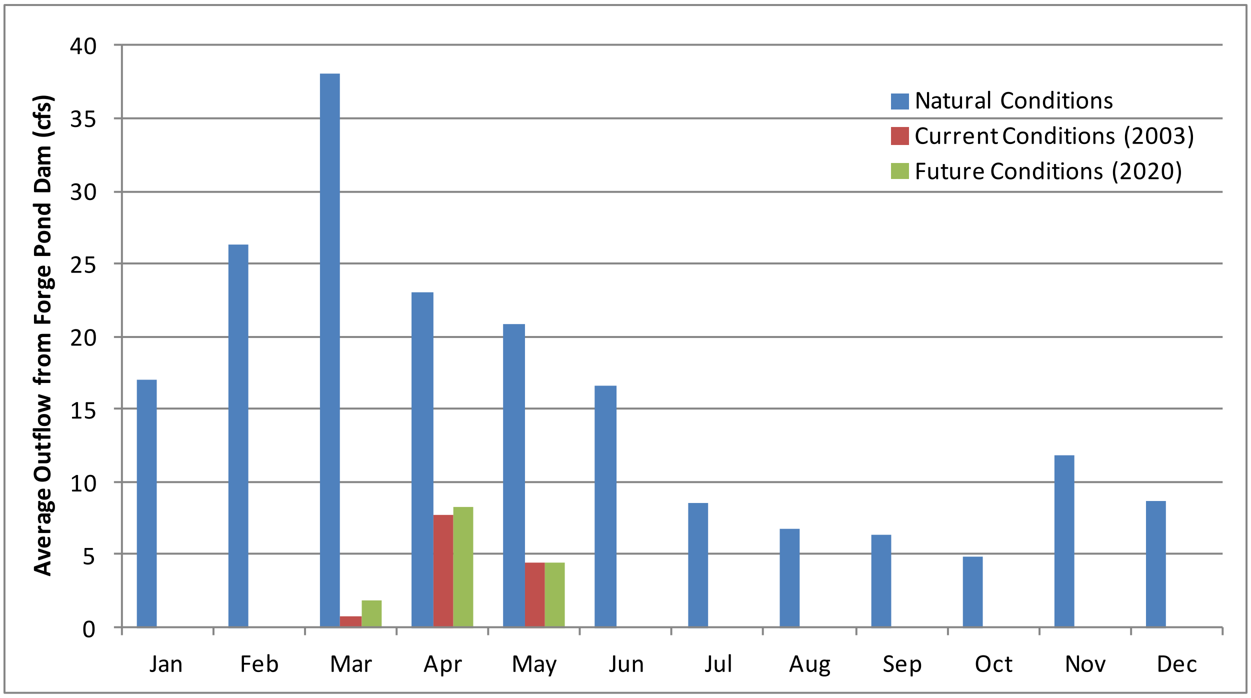
As another comparison between calculated weir flow and gage data, the highest Silver Lake stage values for the period of available record (1996-2012) occurred during the March 2010 flood, with reported stage values of 15.5 inches and 14 inches above the Forge Pond Dam spillway on March 15 and 16, respectively. 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**).

Photos taken during the March 15, 2010 flood at Forge Pond Dam from access road, looking upstream at submerged spillway (left) and downstream at submerged Lake Street culvert (right).

4.1.4 Natural Outflow from Silver Lake

The hydrology of Jones River was heavily studied as part of a 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, b) streamflow (as estimated from the USGS gage at Elm Street and adjusted for drainage area), c) induced aquifer leakage to Silver Lake as a result of relatively rapid water surface fluctuations, and d) 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**.

Figure 4.1.4-1: Predicted Outflow from Silver Lake under Natural, Current, and Future Conditions



Source: GZA, 2003

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 (as shown 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, 2003). Additionally, the very existence of the moderately sized Jones River beginning at a large glacial lake, as well as regional topography, geology, and history of anadromous fish runs, provide further evidence of year-round natural outflows from Silver Lake.

The USGS also estimated unimpacted base flows (i.e., not including surface runoff) for the entire Jones River using the Sustainable-Yield Estimator (SYE) application (Archfield et al., 2010). A drainage area of 21.4 square miles[9] (including Silver Lake) was used in the regional MODFLOW groundwater model. The resulting mean monthly flows are shown in **Table 4.1.4-1** below.

---

[9] This value is not consistent with the natural Jones River drainage area of 29.8 square miles reported in Table 4.1.1-1, but is the value that was reported to be used by the USGS in their analysis.

Table 4.1.4-1: Estimated Average Unimpacted Monthly Flows in the Jones River

Month	**SYE Estimated Average Unimpacted Monthly Flow** (cfs)
JAN	42.57
FEB	44.30
MAR	46.58
APR	45.00
MAY	40.55
JUN	35.62
JUL	29.29
AUG	27.36
SEP	28.57
OCT	29.72
NOV	35.78
DEC	41.03
Annual Avg.	37.15
Avg. per 21.4 mi^2	1.74 cfs/mi^2

Notes: A drainage area of 21.4 square miles (including Silver Lake) was used.
Values represent base flow only (surface runoff not included). Source: Archfield et al., 2010.

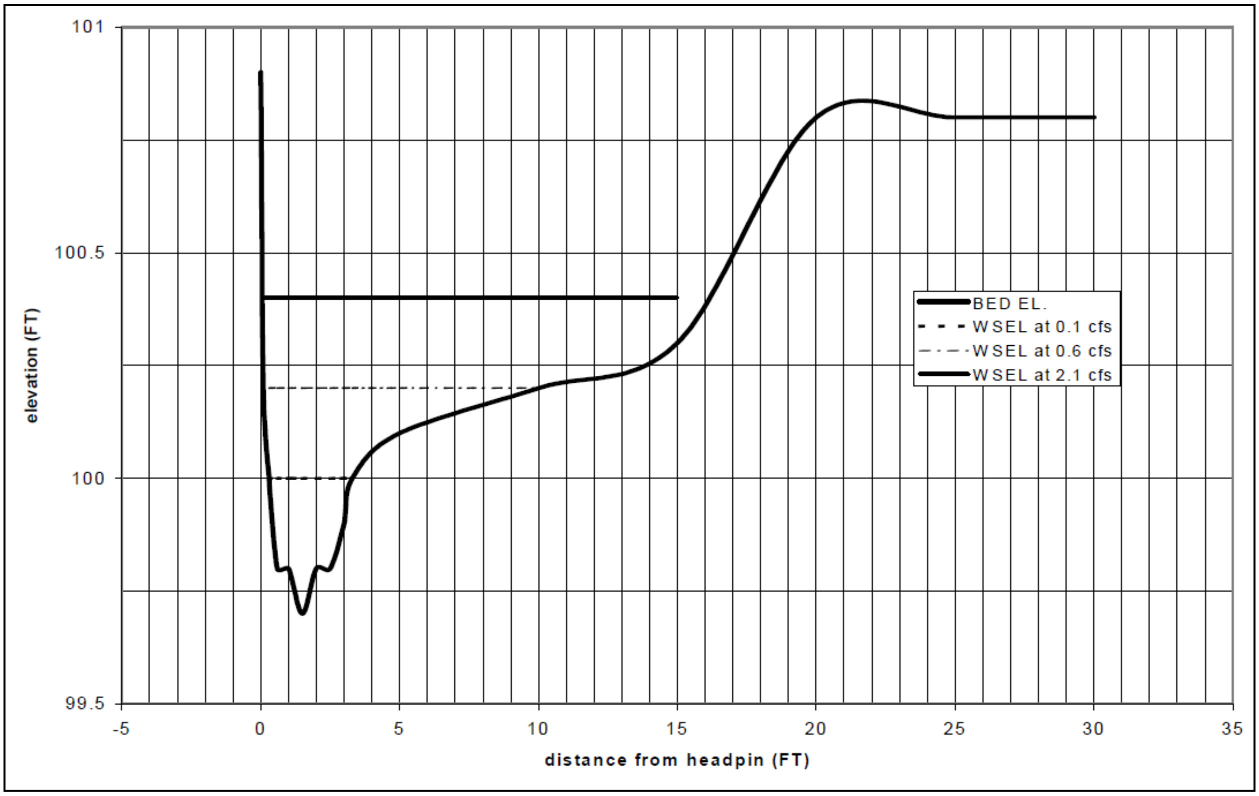
However, flow from Silver Lake to the Jones River under current, managed conditions is discontinuous. Typically, there is zero flow in normal precipitation years from June to the following January. In dry years such as 2000-2002, this no-flow condition has lasted as long as 23 months, following only 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 targets flow extremes within the migration 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 instructive to only analyze mean monthly flows at Forge Pond Dam under current conditions. Instead, this study evaluated 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 was then analyzed in the context of Brockton's water supply operations to determine whether providing the required flows during migration periods would be feasible. This analysis is presented in Section 6.

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 feet (4 inches), and a flow of 2 cfs would provide a depth of 0.5 feet (6 inches), which is within 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**.

Figure 4.1.5-1: Water Depths at Representative Riffle/Run Cross-Section Downstream of Lake Street



Note: Vertical scale exaggerated. Transect located 960 feet downstream of Lake Street. Source: GZA, 2003.

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 a minimum passage depth of 2.6 inches. However, according to *MarineFisheries* guidelines described in **Section 2.3.2**, this recommendation is only barely sufficient for emigrating juvenile herring (which require a minimum depth of 2 inches and prefer a range of 4-8 inches), while inappropriate for upstream migrating adult herring (which require a minimum depth of 6 inches and prefer 9-12 inches). GZA 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

Date		**Minimum Flow** (cfs)	
Start	*End*	*per mi^2*	*at dam (4.2mi^2)*
1-Jun	30-Sep	0.5	2.1
1-Oct	28-Feb	1	4.2
1-Mar	30-Apr	3.2	13.4
1-May	31-May	1	4.2

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

An analysis was conducted to determine the effect of releasing the instream flow recommendations shown in **Table 4.1.5-1** from Silver Lake into the Jones River. The following data were used:

- Silver Lake stage-storage curve derived from bathymetry data collected by Coler & Colantonio (2003), as shown in **Figure 2.4.1-3**
- Silver Lake natural inflows estimated by GZA (2003), as shown in **Figure 4.1.4-1**
- Average daily diversions from Monponsett and Furnace Ponds into Silver Lake (1996-2012), as shown in **Figure 4.2.2-3**
- Average daily withdrawals from Silver Lake (1996-2012), as shown in **Figure 4.2.2-3**
- Average January 1 Silver Lake water surface elevation (1996-2012), as shown in **Figure 4.2.1-6**

Using these data, inflows to and outflows from Silver Lake were balanced to project the water surface elevation under existing conditions and under a scenario where the seasonally fluctuating flows shown in **Table 4.1.5-1** are released from Silver Lake into the Jones River. The projected water surface elevations are shown in **Figure 4.1.5-1**.

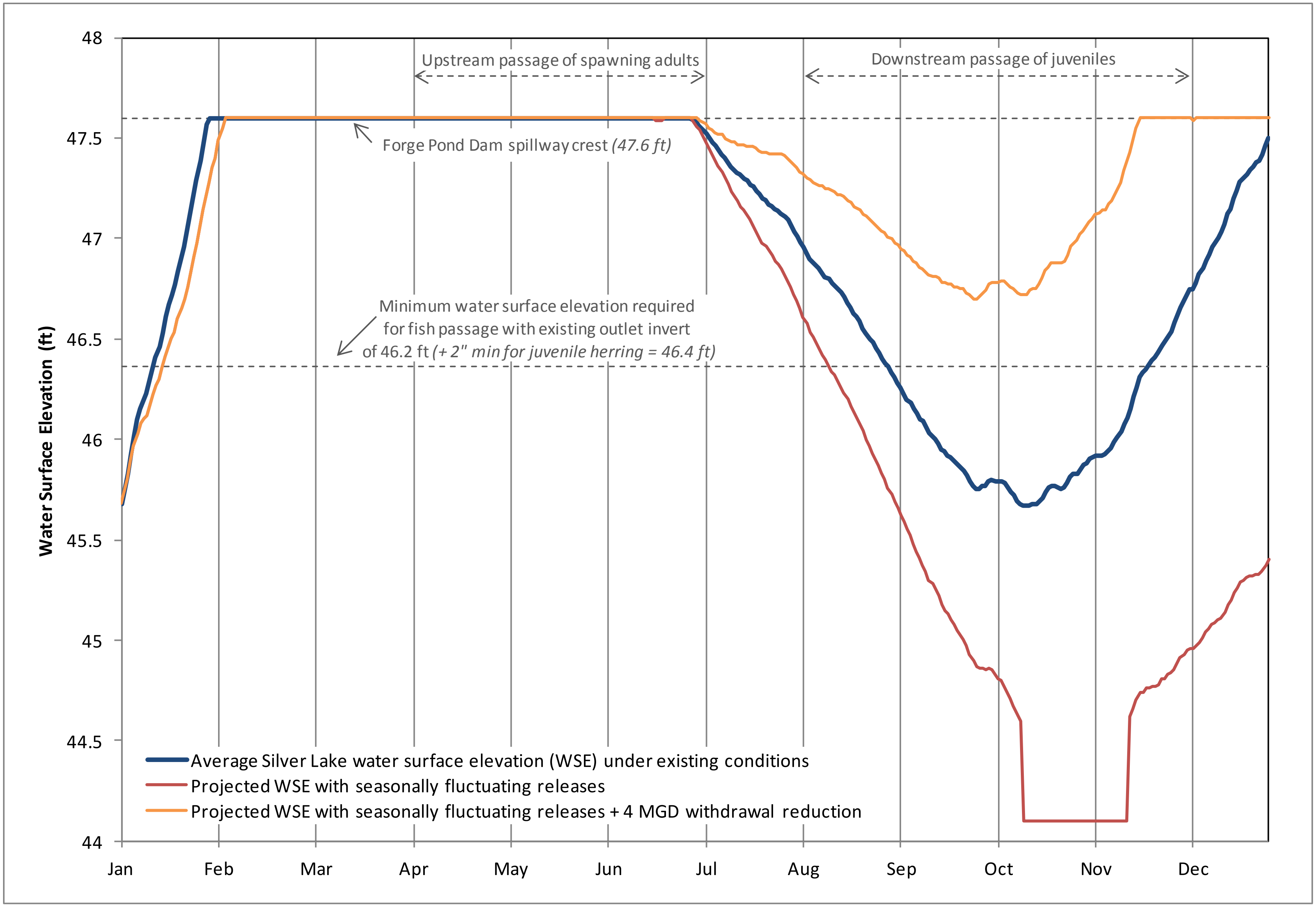
As **Figure 4.1.5-1** shows, the water surface elevation of Silver Lake is projected to remain at or above the spillway crest during most of the spring river herring adult migration period (April through June) under existing conditions as well as the specified release scenario, allowing for upstream passage of adult river herring. However, in both scenarios, the water surface is projected to drop below the natural outlet elevation during most of the juvenile herring emigration period (August through November). Therefore, under existing water supply operating conditions, it is not likely that emigrating juvenile herring could pass over the natural outlet into Forge Pond, or that the specified flows could be released from Forge Pond during this period.

However, several options may increase the feasibility of a seasonally fluctuating release, including offsetting water supply demands from Silver Lake with alternative sources. For example, withdrawals from Silver Lake could be reduced by using Brockton's capability to purchase additional water from Aquaria—currently 3.5 mgd and up to 4.07 mgd by 2018 (or 4.5 mgd and 5.07 mgd, respectively, if Brockton makes use of its exclusive rights to the first 1 mgd of excess water produced by Aquaria with 15 days notice).

To demonstrate this option, **Figure 4.1.5-1** also depicts the projected water surface elevation resulting from the seasonally fluctuating releases specified under a scenario in which Brockton purchases additional water from Aquaria to allow for a corresponding reduction in withdrawals from Silver Lake. Water could be purchased from Aquaria up to the maximum allowable amount (4.07 mgd assumed for this analysis) or the amount that would raise the water elevation up to full pond (spillway crest), whichever is less. This particular scenario would involve shifting approximately 739 MG of Brockton's annual demand from Silver Lake to Aquaria annually.

Figure 4.1.5-1 shows that, with the purchase of up to 4.07 mgd from Aquaria as needed, seasonally fluctuating releases to the Jones River as specified in **Table 4.1.5-1** are feasible. Additionally, under this scenario, the projected average water surface elevation would remain high enough to pass juvenile herring over the natural outlet.

Figure 4.1.5-1: Projected Silver Lake Elevation with Instream Flow Recommendations



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.

As noted previously, the additional drainage areas of Monponsett Pond (6 square miles) and Furnace Pond (1 square mile) often contribute to the Jones River during periods of high flow when these diversions are on (for the purpose of flood relief for residents on those ponds) and water is simultaneously spilling over Forge Pond Dam. Therefore, flood frequency estimates based on gage data do not accurately characterize the natural regime since they often include transferred flows.

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. This type of model relies on basin characteristics such as area, shape, slope, soil type, land use, etc. and does not account for artificial flow diversions such as those from Monponsett and Furnace Ponds. 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 previously, this assumption is likely only valid for lower flows. The FIS reported a 100-year flood flow of 116 cfs.

Log Pearson Type III Flood Frequency Analysis

The 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[10]. 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 PeakFQ program to estimate storm events for various recurrence intervals using the Bulletin 17B methodology, which creates a Log Pearson Type III statistical evaluation of the data[11]. 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). This could be due in part to the addition of Monponsett and Furnace Pond diversions during flood flows.

---

[10] 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.

[11] 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.

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 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

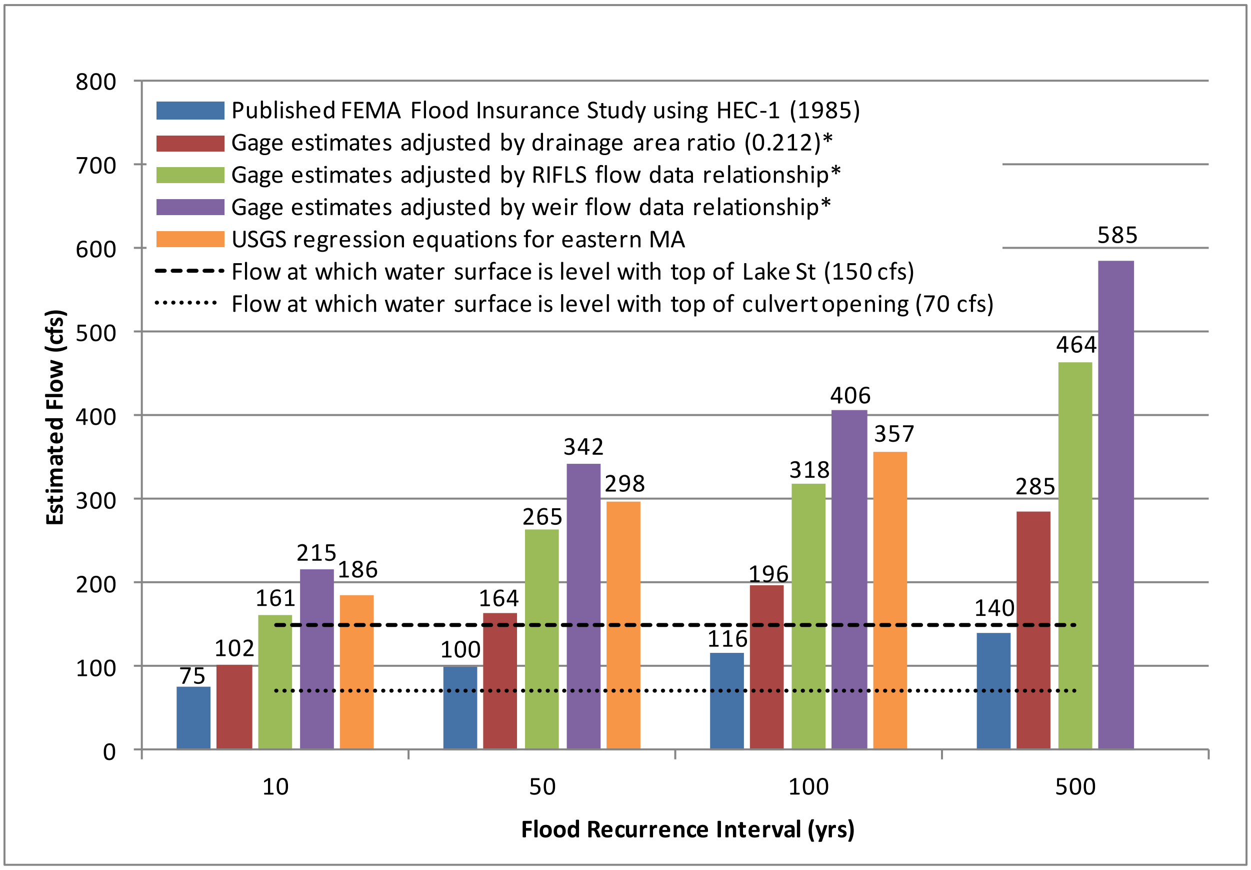
Lastly, regional regression equations developed for eastern Massachusetts by USGS (Wandle, 1983) were used estimate flood flows. These equations are based on drainage area only and do not account for artificial flow diversions such as those from Monponsett and Furnace Ponds. Equations for the 10-, 50-, and 100-year floods only have been developed as follows:

$$\mathbf{Q_{10}} = 72.12*A^{0.660}$$
$$\mathbf{Q_{50}} = 118.1*A^{0.645}$$
$$\mathbf{Q_{100}} = 143.1*A^{0.638}$$

where **A** represents drainage area (4.2 square miles 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



**Methods with an asterisk may incorporate out-of-basin diversions from Monponsett and Furnace Ponds (up to 7 additional square miles of drainage area).*

The estimated flows at which the water surface would reach the top of the culvert opening and the top of Lake Street are shown for reference[12]. Note that although the majority of flood flow estimates indicate that Lake Street would be overtopped, even during 10-year floods, no anecdotal evidence of this scenario was reported by project partners. The flood flows computed for the FEMA FIS are the only estimates projected to remain below the top of Lake Street through the 500-year flood.

Tabulated results of these analyses are presented in **Table 4.1.6-1**.

---

[12] These flows were calculated using the HEC-5 Chart 2 for 48" square edge concrete pipe (USDOT, 1965).

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

Recurrence Interval (yrs)	**Estimated Flood Flow** (cfs)					
	AT GAGE	**AT FORGE POND DAM**				
	Log Pearson Type III Analysis *('67-'09)**	FEMA FIS *(1985 HEC-1 model at Grove St)*	Pro-Rated from Gage Analysis*			USGS Regression Equation for Eastern MA *(based on DA = 4.2)*
			by natural DA ratio (19.8 / 4.2 = 0.212)	*by RIFLS relationship (y = 0.3493x - 5.9195)*	*by weir flow relationship (y = 0.4271x - 10.827)*	
10	479	75	102	161	215	186
50	775	100	164	265	342	298
100	926	116	196	318	406	357
500	1345	140	285	464	585	N/A

**Methods with an asterisk may incorporate out-of-basin diversions from Monponsett and Furnace Ponds (up to 7 additional square miles of drainage area).*

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 was not factored into the FEMA FIS 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 elevation[13] and natural outlet elevation[14]. **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 4.2.1-1: Percent of Time Silver Lake Elevations Equal or Exceed Threshold Levels

Silver Lake Elevation	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Above spillway crest	30%	40%	54%	72%	53%	26%	6%	4%	0%	2%	9%	22%	27%
Above natural outlet	64%	79%	91%	93%	93%	93%	73%	41%	18%	24%	33%	47%	62%

Period of record: Oct 1996-Mar 2012. Elevations of Forge Pond Dam spillway crest (47.6 feet) and natural outlet invert (45.9 feet) 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.

---

[13] 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).

[14] 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 elevation exceeds the Forge Pond Dam spillway crest only during April, a significant limitation to attract river herring to the base of Forge Pond Dam as needed to complete their life cycle. Additionally, on average, Silver Lake elevation drops below the natural outlet elevation from August through early January, effectively isolating Silver Lake from Forge Pond and preventing the passage of 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. Egg incubation is relatively brief; typically ranging from 2 to 4 days. However, 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 4.2.1-2: Surface Area and Storage Volume of Silver Lake at Key Elevations

Elevation	**Surface Area** (acres)	**Reduction in Surface Area Relative to Spillway Crest Elev.**	**Storage** (acre-ft)	**Reduction in Storage Volume Relative to Spillway Crest Elev.**
Spillway crest elevation (47.6 ft)	634	-	3,710	-
Avg. September elevation (44.7 ft)	613	-21 (-3%)	3,692	-19 (-0.5%)
Lowest elev. from 1996-2012 (40.6 ft)	503	-131 (-21%)	3,606	-104 (-2.8%)

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 (provided in **Table 4.1.5-1**). 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[15] 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 4.2.2-1: Average Water Supply Withdrawals from Silver Lake

Avg. Withdrawal	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
mgd	9.8	9.7	9.4	9.3	9.6	10.0	10.0	9.8	9.4	9.4	9.5	9.6	9.6
cfs	15.2	15.0	14.6	14.3	14.8	15.5	15.5	15.1	14.5	14.5	14.7	14.9	14.9
cfs/4.2 mi^2	3.62	3.57	3.48	3.40	3.52	3.69	3.69	3.59	3.45	3.45	3.50	3.55	3.55

Period of record: 1996-2012. October through May are months of authorized Monponsett and Furnace diversions.

<u>Monponsett and Furnace Pond Diversions</u>

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, loss of beach front, and water quality impacts. 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.

<u>Aquaria</u>

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 (or 4.5 mgd and 5.07 mgd, respectively, if Brockton makes use of its exclusive rights to the first 1 mgd of excess water produced by Aquaria with 15 days notice). However, Brockton has only purchased a nominal amount since their agreement began (targeting 350,000 gpd for facility maintenance), and has not purchased any Aquaria water since May 2011 to date (August 2012). 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).

---

[15] Note that Silver Lake withdrawals reported in this document are 'finished' volumes (as opposed to 'raw' volumes). An additional 1.2 mgd (on average during the period of record, 1996-2012) is also withdrawn from the lake for treatment processes (i.e., finished volume + 1.2 mgd average = raw volume). Treatment water is sent to lined lagoons for settling, after which some of the water is returned to the head works for reuse during in treatment processes, while some is sent in the form of settled residuals to drying beds where it can seep into the groundwater (Brockton, Nov 13, 2009). It is unclear when or whether this water returns to Silver Lake through groundwater flow.

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. If water is diverted into Silver Lake from Monponsett or Furnace Ponds when Silver Lake is already full (at spillway crest elevation), the diverted water is effectively spilled downstream into the Jones River and does not add any net volume to the water supply.

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. 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

Month	**Number of Days** *(Oct 1996- Jul 2012)*				**Percent of Time 'Wasting'**		
	Diverting *(from either Monponsett or Furnace Ponds)*	**Spilling** *(above Forge Pond Dam spillway crest)*	**'Wasting'** *(diverting + spilling on same day)*	**Total in Period of Record**	**vs. Spilling**	**vs. Diverting**	**Overall**
January	313	149	108	496	72%	35%	22%
February	302	182	140	452	77%	46%	31%
March	326	272	216	496	79%	66%	44%
April	252	326	212	480	65%	84%	44%
May	221	249	123	496	49%	56%	25%
June	64	118	48	480	41%	75%	10%
July	21	31	7	496	23%	33%	1%
August	11	23	10	465	43%	91%	2%
September[1]	13	2	0	450	0%	0%	0%
October[2]	129	13	13	496	100%	10%	3%
November	156	46	17	480	37%	11%	4%
December	279	111	80	496	72%	29%	16%
Annual	**2087**	**1522**	**974**	**5783**	**64%**	**47%**	**17%**

[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).*

The results of this "wasting" analysis further reinforce earlier statements that hydrologic analyses based on gage data do not accurately characterize the natural regime since they often include transferred flows from Monponsett and Furnace Ponds (up to 7 square miles of additional drainage area) when the diversions are on and water is also spilling over Forge Pond Dam. This unauthorized situation may occur due to a combination of factors including requests for flooding relief from Monponsett and Furnace Pond residents, as well as time consuming or difficult access to alternate locations for flood relief releases (i.e., Stump Brook Dam for Monponsett Pond and Furnace Pond Dam for Furnace Pond).

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).

In the context of the Massachusetts Water Management Act, Safe Yield is defined as: "the maximum dependable withdrawals that can be made continuously from a water source including ground or surface water during a period of years in which the probable driest period or period of greatest water deficiency is likely to occur; provided, however, that such dependability is relative and is a function of storage and drought probability."

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 a 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 not issued an 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[16].

Recently, the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) released the Massachusetts Sustainable Water Management Initiative (SWMI) framework (EEA, 2012), which describes the methodology for defining safe yield in each of the 27 Massachusetts watersheds, as well as how stream flow criteria will be applied by the DEP when issuing WMA permits. In most Massachusetts basins, a standard method using historical unimpacted flow estimates was used to determine Safe Yield for each major basin. Safe yield as a maximum annual limit for permitted water withdrawals in major basins was determined to be 55% of the 90th percentile (low) monthly flows combined into an annual average. However, the simulated unimpacted flow estimates in the standard format were not available for much of south coastal Massachusetts as a result of the thick aquifer deposits in this region. For the Jones River, the SWMI framework recommends using 25% of the estimated mean monthly unimpacted flows developed by the USGS (presented earlier in **Table 4.1.4-1**) as the approximate equivalent of 55% percent of the monthly 90th percentile flows for this area. The resulting estimated safe yield values are shown in **Table 4.2.3-1** below. Brockton's historic withdrawals from Silver Lake (1996 – 2012) are shown in the table for reference.

Table 4.2.3-1: Jones River Estimated Safe Yield Derivation

Month	**SYE Average Unimpacted Monthly Flow** (cfs)	**Potentially Allocatable Flow** *(25% of Avg. Monthly Flow)*		**Average Brockton Withdrawals** (MGD, 1996-2012)
		cfs	*MGD*	
JAN	42.57	10.64	6.88	9.8
FEB	44.30	11.07	7.16	9.7
MAR	46.58	11.65	7.53	9.4
APR	45.00	11.25	7.27	9.3
MAY	40.55	10.14	6.55	9.6
JUN	35.62	8.90	5.76	10.0
JUL	29.29	7.32	4.73	10.0
AUG	27.36	6.84	4.42	9.8
SEP	28.57	7.14	4.62	9.4
OCT	29.72	7.43	4.80	9.4
NOV	35.78	8.94	5.78	9.5
DEC	41.03	10.26	6.63	9.6
Annual Avg.	37.15	9.29	6.00	9.6
Avg. per 21.4 mi^2	1.74 cfs/mi^2	0.43 cfs/mi^2	0.28 MGD/mi^2	0.45 MGD/mi^2

Source: EEA, 2012

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 (2002-12) were requested. Brockton provided reports for all years except 2009.

---

[16] Again, these firm yields represent the amount of water that could be withdrawn for 180 days before the lake dropped below its intake structure (24 feet down), when Brockton would theoretically run out of supply.

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

Category	2000		2001		2002		2003		2004		2005	
	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total
Residential	5.04	47%	4.89	46%	4.95	50%	4.95	46%	4.75	47%	4.57	47%
Commercial	1.09	10%	1.05	10%	1.12	11%	1.08	10%	1.17	12%	1.07	11%
Industrial/Agriculture	0.29	3%	0.28	3%	0.23	2%	0.24	2%	0.23	2%	0.22	2%
Recreational	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Public Service	0.9	8%	0.77	7%	0.85	9%	0.82	8%	0.87	9%	0.85	9%
Hanson	0.03	0.3%	0.07	1%	0.04	0.4%	0.04	0.4%	0.03	0.3%	0.05	1%
Whitman	0.93	9%	0.97	9%	0.99	10%	1.01	9%	0.99	10%	0.95	10%
Estimated Municipal Use	1.17	11%	0.63	6%	0.57	6%	0.84	8%	0.57	6%	0.3	3%
Unaccounted-for-Water	**1.29**	**12%**	**2.04**	**19%**	**1.16**	**12%**	**1.71**	**16%**	**1.44**	**14%**	**1.64**	**17%**
Total Average Day Demand	**10.74**	**100%**	**10.7**	**100%**	**9.91**	**100%**	**10.69**	**100%**	**10.05**	**100%**	**9.65**	**100%**
Population	-		-		110,408		109,186		109,186		109,186	
Residential Usage (gpcd)	**-**		**-**		**45**		**45**		**44**		**42**	

Category	2006		2007		2008		2009		2010		2011	
	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total	Cons. (mgd)	% of Total
Residential	5.99	65%	5.33	55%	5.86	59%			6.26	68%	4.38	52.8%
Commercial	0.89	10%	0.49	5%	0.83	8%			1.98	22%	2.72	32.7%
Industrial/Agriculture	0.28	3%	0.13	1%	0.13	1%						
Recreational	0.01	0.1%	0.003	0%	0	0%						
Public Service	0.54	6%	1.92	20%	1.06	11%						
Hanson	0.04	0%	0.02	0.3%	0.05	0.5%						
Whitman	0.91	10%	0.92	9%	0.92	9%						
Estimated Municipal Use	-	-	0.13	1%	0.30	3%						
Unaccounted-for-Water	**-**	**-**	**0.82**	**8%***	**0.84**	**8%***			**0.92**	**10%**	**1.20**	**14.5%**
Total Average Day Demand	**9.28**	**93%**	**9.76**	**100%**	**9.97**	**100%**			**9.16**	**100%**	**8.30**	**100%**
Population	-		95,304		95,304		*Data not available*		94,185		93,810	
Residential Usage (gpcd)	**-**		**56**		**61**				**66**		**47**	

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%[17] 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 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[18]) 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[19] 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*			
	2015	**2020**	**2025**	**2030**	**2015**	**2020**	**2025**	**2030**
Brockton	100,542	102,424	103,993	105,561	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
Total	**114,652**	**116,606**	**118,228**	**119,850**	**40,101**	**40,402**	**40,584**	**40,765**

Note: Interpolated from population and employment projections developed by MAPC in 2007. Service population projections are based on percent of the community served by water supply (100% for Brockton, 98% for Whitman).

---

[17] 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.

[18] The Annual Statistical Report for 2006 was not included in DCR's analysis.

[19] 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

Location	Projected Water Usage (mgd)							
	Assuming 65 gpcd and 10% UAW				*Assuming current gpcd and UAW*			
	2015	2020	2025	2030*	2015	2020	2025	2030*
Brockton	10.29	10.46	10.61	10.74	9.17	9.31	9.44	9.56
Whitman	1.08	1.08	1.09	1.09	0.93	0.94	0.94	0.94
Total	**11.37**	**11.54**	**11.70**	**11.83**	**10.10**	**10.25**	**10.38**	**10.50**

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.*

In 2011, the MAPC updated the 2007 population projections that were used in DCR's analysis. MAPC notes that these updated projections supplement, but do not fully replace, the 2007 projections. The 2007 projections envisioned more robust growth region wide, applied slightly different assumptions about where that growth would go, and provided detail on a wide variety of outcomes beyond what was covered by the 2011 update. Updated (2011) population projections for Brockton, given in **Table 4.2.5-3** below, dropped an average of 7% from 2007 projections.

Table 4.2.5-3: Updated Population Projections for Brockton

Study Year	Projected Population				
	2015	*2020*	*2025*	*2030*	*2035*
2007	100,542	102,424	103,993	105,561	-
2011	94,599	95,500	96,250	97,000	98,000
Difference	-5.9%	-6.8%	-7.4%	-8.1%	-

Source: MAPC, 2007 & 2011

MAPC notes that, for purposes of local and regional planning, the two sets of projections are both valid pictures of the future, and may provide more utility in comparison to each other rather than as absolute benchmarks. Because the 2007 projections are conservatively higher, an updated water needs forecast was not conducted.

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 4.2.5-4**.

Table 4.2.5-4: Comparison of Brockton's Projected Water Supply Demands to Actual Water Use

2010 Actual		2010 Projection		2020 Projection	
Water Use (mgd)	Unaccounted-for Water (UAW)	Water Use (mgd)	Unaccounted-for Water (UAW)	Water Use (mgd)	Unaccounted-for Water (UAW)
9.16	10%	11.28	12%	12.01	10%

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.

The available data do not provide a clear picture of Brockton's expected water use trend. The City's population appears to have declined in recent years, but is expected to begin rising again by both the 2007 and 2011 MAPC projections, although at differing rates. Residential usage has typically remained relatively low, below the WRC target value of 65 gpcd, though it did spike briefly in 2010 to 66 gpcd. UAW rates have been sporadic and a trend cannot be identified, though there is potential for improved efficiency by maintaining UAW consistently below the WRC target of 10%. DCR plans to update Brockton's Water Needs Forecast in 2014, based on the 2010 census.

5. Hydraulic Analysis

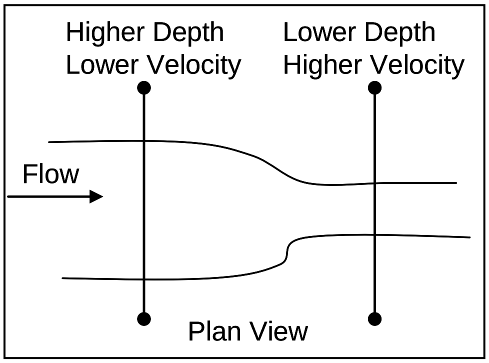
5.1 Background

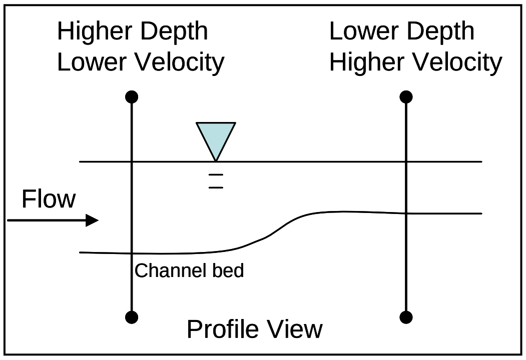
Hydraulic models of river systems are developed to simulate baseline conditions and predict water depths, velocities, and water surface profiles given various flows and alternate conditions. A hydraulic model of Forge Pond and the Jones River was developed from its headwaters at Silver Lake to just upstream of Grove Street to evaluate various fish passage 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 is capable of simulating 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

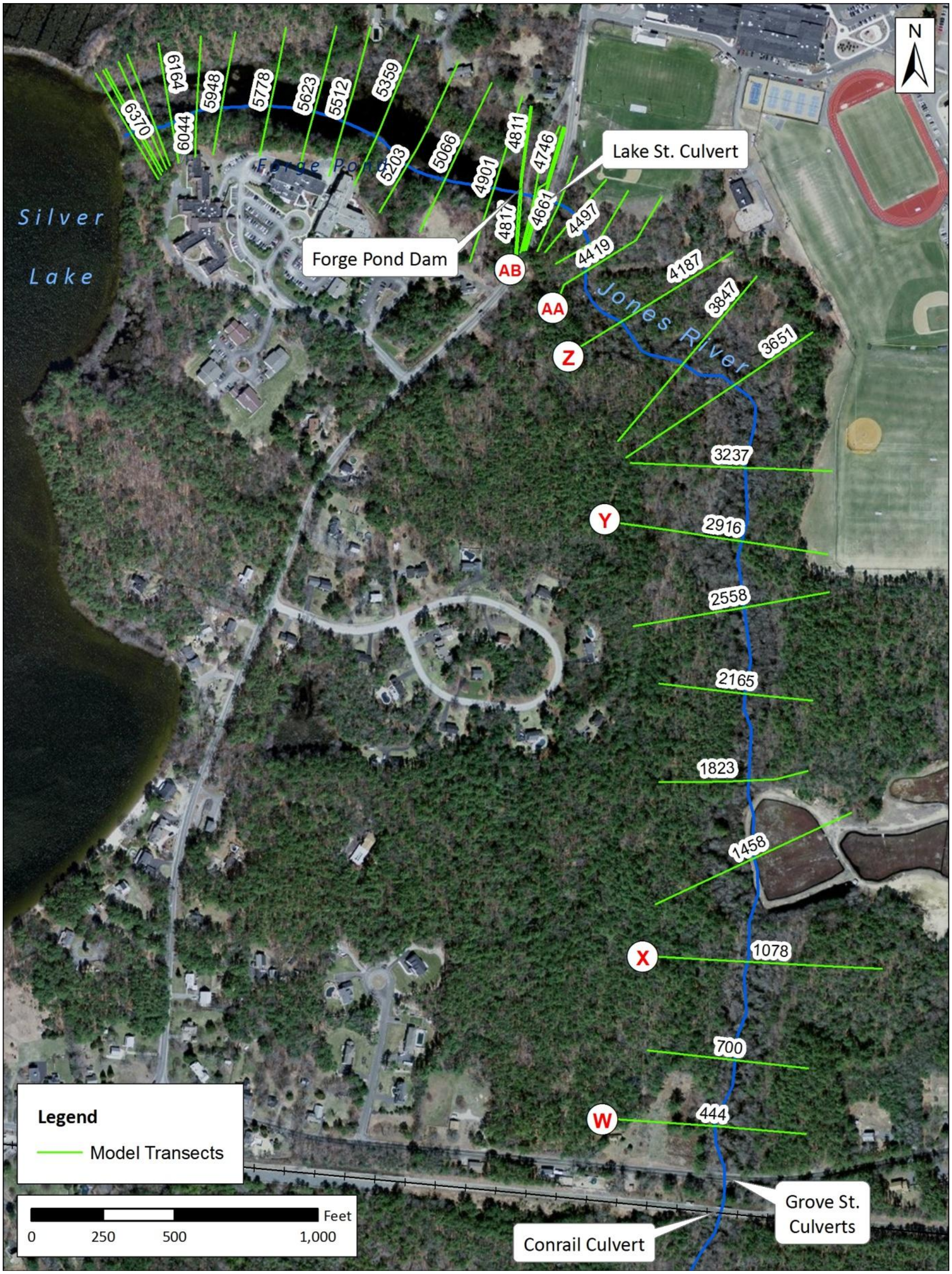
The various sources of topographic data available for this project were described in Section 2.4. Sources utilized are summarized in **Table 5.2-1** below.

Table 5.2-1: Summary of Topography Sources Utilized in the Model

Source	Reporter	Date	Coverage	Utilized For	Comments
Updated Survey	Gomez and Sullivan Engineers	Oct 2012	Lake Street to upstream face of dam (structural & channel data); natural outlet area	Structural geometries, channel cross-sections	Survey-grade real-time kinematic (RTK) GPS used.
LiDAR	MassGIS	2011	Entire project area	Upland topography for all cross-sections; channel data downstream of Lake Street (adjusted to FEMA thalweg elevations)	Vertical accuracy of 0.3 meters or approximately one foot.
Bathymetry Survey	Coler & Colantonio	2003	Silver Lake & Forge Pond. Limited structural/channel data between Forge Pond Dam & Lake St culvert.	Cross-sections within Forge Pond Dam; correlation of 2012 survey to benchmark	Surveyed in NAVD 88 datum and adjusted to NGVD 29.
Flood Insurance Study	FEMA	1985	Jones River up to Forge Pond Dam	Boundary conditions (starting water surface elevations); thalweg elevations downstream of Lake Street (used to adjust LiDAR data within banks)	FIS model channel input data mostly illegible upstream of Grove Street. Crude analysis--Grove Street & railroad structures both inaccurate.

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



Note: 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 (Milone & MacBroom, 2009).

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), which is located at the upstream face of Forge Pond Dam. This is most likely due to a lack of accurate survey data for the dam in the FIS, which was seen at other structures in the FIS model (i.e., the Lake Street, Grove Street, and MBTA railroad culverts). The updated model incorporates more accurate survey data and is conservatively higher.

Table 5.3-1: High Flow Calibration Results (FEMA FIS Flows)

FEMA XS ID	**Model Station**	**Location**	**Recurrence Interval** (yrs)	**FEMA Flow** (cfs)	**Water Surface Elevation** (ft)		
					Published	*Modeled*	*Difference*
AB	4817	Upstream face of Forge Pond Dam	10	75	47.7	47.7	0.0
			50	100	47.8	48.1	0.3
			100	116	47.9	48.6	0.7
			500	140	48.0	50.1	2.1
AA	4418	~250 ft Downstream of Lake St	10	75	41.0	41.0	0.0
			50	100	41.2	41.2	0.0
			100	116	41.3	41.3	0.0
			500	140	41.5	41.5	0.0
Z	4187	~475 ft Downstream of Lake St	10	75	40.3	40.3	0.0
			50	100	40.5	40.4	-0.1
			100	116	40.5	40.5	0.0
			500	140	40.9	40.6	-0.3
Y	2916	Adjacent to cranberry bogs	10	75	36.1	36.2	0.1
			50	100	36.5	36.6	0.1
			100	116	36.7	36.8	0.1
			500	140	37.0	37.2	0.1
X	1078	~900 ft Upstream of Grove St	10	75	35.7	35.6	-0.1
			50	100	36.2	36.1	-0.1
			100	116	36.5	36.4	-0.1
			500	140	37.0	36.9	-0.1
W	444	Upstream face of Grove St	10	75	35.5	35.5	0.0
			50	100	36.0	36.0	0.0
			100	116	36.3	36.3	0.0
			500	140	36.8	36.8	0.0

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 of observed water surface elevations—as shown in **Table 5.3-2**.

Table 5.3-2: Low/Moderate Flow Calibration Results (RIFLS Discharge Measurements)

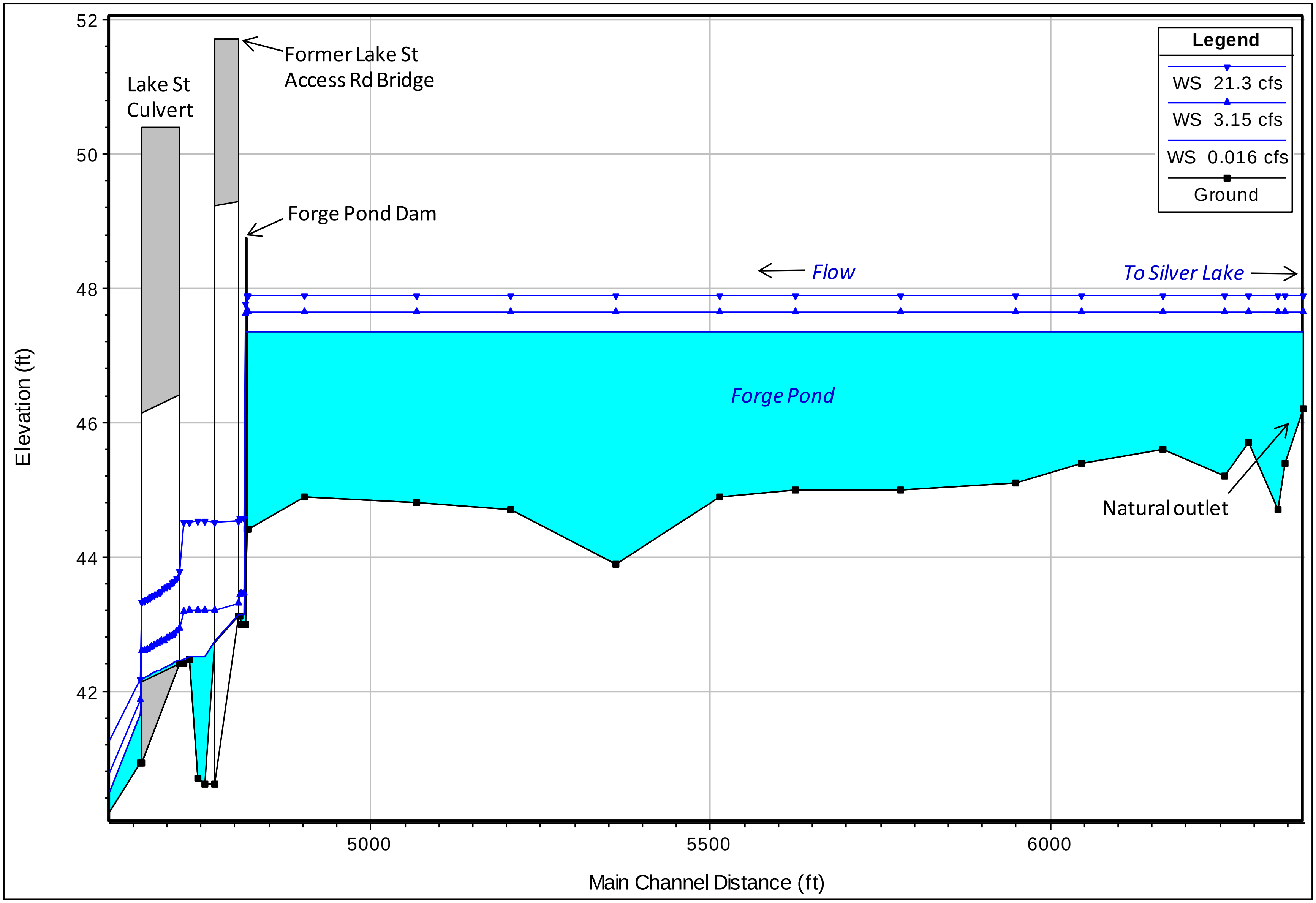
RIFLS Measurement		**Water Surface Elevation** (ft)		
*Stage**	*Flow (cfs)*	*RIFLS*	*Modeled*	*Difference*
3.6	0.016	42.5	42.5	-0.1
3.7	0.032	42.6	42.5	-0.1
3.8	0.087	42.7	42.6	-0.2
3.9	0.33	42.8	42.7	-0.1
4.0	0.82	42.9	42.8	-0.1
4.1	1.45	43.0	42.9	-0.1
4.2	2.25	43.1	43.1	-0.1
4.3	3.15	43.2	43.2	0.0
4.4	4.25	43.3	43.3	0.0
4.5	5.38	43.4	43.4	0.0
4.6	6.7	43.5	43.6	0.0
4.7	8	43.6	43.7	0.0
4.8	9.5	43.7	43.8	0.1
4.9	11.1	43.8	43.9	0.1
5.0	13	43.9	44.0	0.1
5.2	16.9	44.1	44.3	0.1
5.4	21.3	44.3	44.5	0.2

**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, corresponding to the range of flows observed by RIFLS and an intermediate flow (3 cfs).

Figure 5.4-1: Existing Conditions Water Surface Profile in Forge Pond

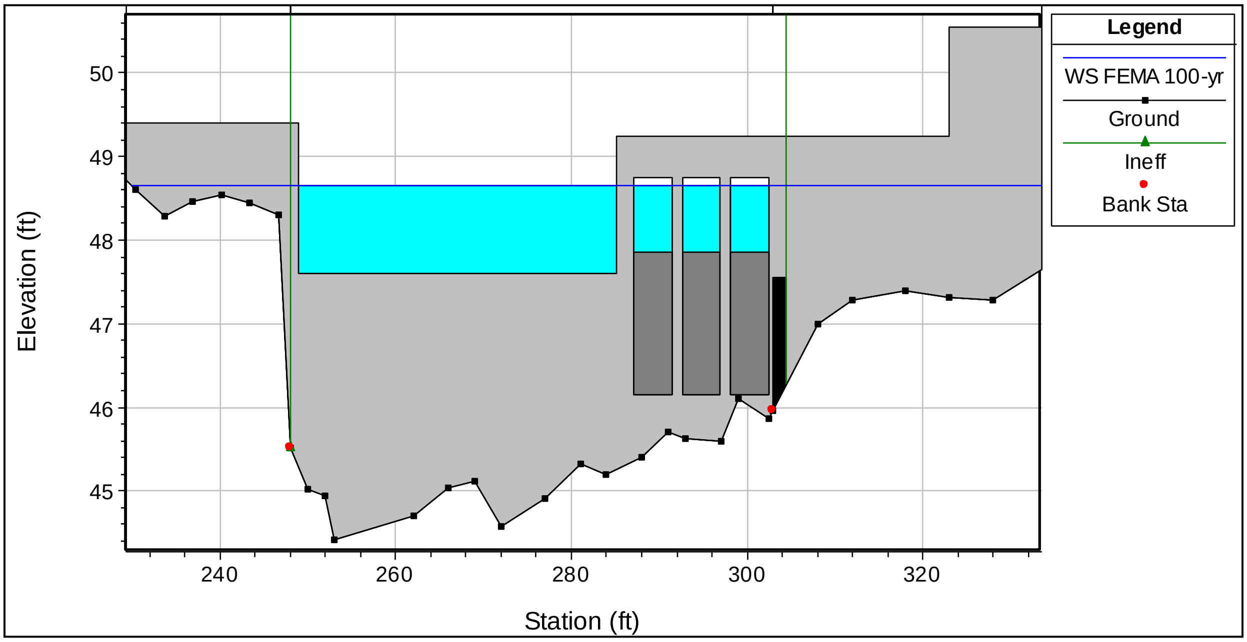


Spillway Capacity

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 and 0.8 feet of freeboard below the left abutment[20]. Fish passage alternatives requiring structural modifications to the dam need to 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.

---

[20] The stoplogs were conservatively assumed to be fully in place for this analysis.

6. 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 Forge Pond Dam and throughout the study area extending from the natural outlet of Silver Lake to the Lake Street culvert. Possible scenarios were discussed with project partners, presented to the public, and narrowed to those with the greatest potential to be ecologically effective and feasible to install and operate at Forge Pond Dam. Those alternatives were then subjected to a more thorough analysis in which conceptual design, operational, and cost information was evaluated for each. This section discusses relevant findings for each of the following fish passage alternatives for Forge Pond Dam:

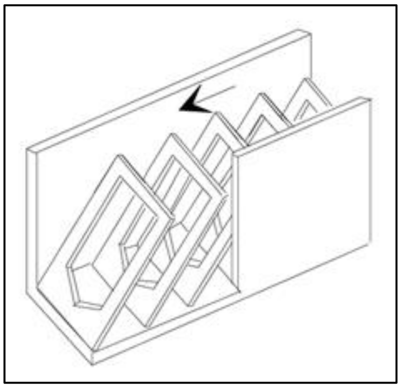
1. Fish Ladder
2. Nature-Like Bypass Channel
3. Dam Removal (Full and Partial)

6.1 Alternative 1 – Fish Ladder

6.1.1 Background

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 (discussed here) or pool and weir type. 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 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 typically 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 river herring and adult salmonids and in some cases American shad, other alosines, and other migratory and resident species (Brownell et al., n.d.).



Also known as the Alaska steeppass or ASP, these structures are similar but more complex than the Denil design with higher energy dissipation 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 have mainly been used for river herring, but have provided effective passage for other anadromous species, as well as 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.).

Alaska steeppass fishway installed at Main Street Dam #4 on the Parker River in Byfield, MA (November, 2000)

Alaska steeppass fishways are also relatively inexpensive to design and install. However, both Denil and steeppass fishways may require regular maintenance to remove debris and adjust stop logs. Also, the inherent high flow energy of these fishways can be problematic for downstream passage of juvenile fishes or upstream passage for species with limited swimming capability.

Alaska steeppass flow requirements can range from approximately 2 to 4 cfs, which is less than the flow typically required for Denil or pool and weir fishways, making the steeppass more feasible given the already low flows at Forge Pond Dam. 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. Therefore, a steeppass fishway was selected for further analysis at the Forge Pond Dam site.

6.1.2 Conceptual Design

Fishway

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, continuing into the pool downstream of the access road. Appropriate depths for in-channel fish passage will be easier to maintain on the river left side. Alternatively, the fish ladder could be fitted into one of the existing stoplog bays on the river right side of the dam, but the channel invert on this side of the spillway basin and through the two right bridge openings is higher, and minimum depths are less likely to be maintained.

The vertical barrier (dam) in the proposed fishway location is approximately 4.5 feet high from the channel bed to the spillway crest. 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. A 2.1-foot-deep notch would be removed near 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 shorter than one 10-foot-long pre-fabricated section. It is assumed that shorter sections can be requested from manufacturers, or a standard section could be cut to length on site.

An inlet section with stoplogs would be built at the fishway entrance, similar to the example shown for the Parker River in the photo 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.

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 of the existing 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

Using steeppass fishways for downstream passage is not usually the first choice, as the multi-plane baffles were designed mainly for upstream movements and fish may not be able to find the entrance during periods of higher flow.

Additionally, removing one or more stoplogs to pass fish downstream through an existing stoplog bay is not desirable due to the concrete apron below the bays. Passage through a 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, the most feasible option to cut a small notch (approximately 1 foot wide by 1.9 feet deep) in the spillway 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 could be closed with constructed stoplogs, or could be opened to provide additional attraction flow to the fishway as needed.

Given these parameters, conceptual layouts for a steeppass fishway and downstream passage notch at Forge Pond Dam were developed and are shown in **Figure 6.1.2-1** (plan view), **Figure 6.1.2-2** (profile view), and **Figure 6.1.2-3** (detail view) below.

Figure 6.1.2-1: Conceptual Plan of Proposed Alaska Steeppass Fishway

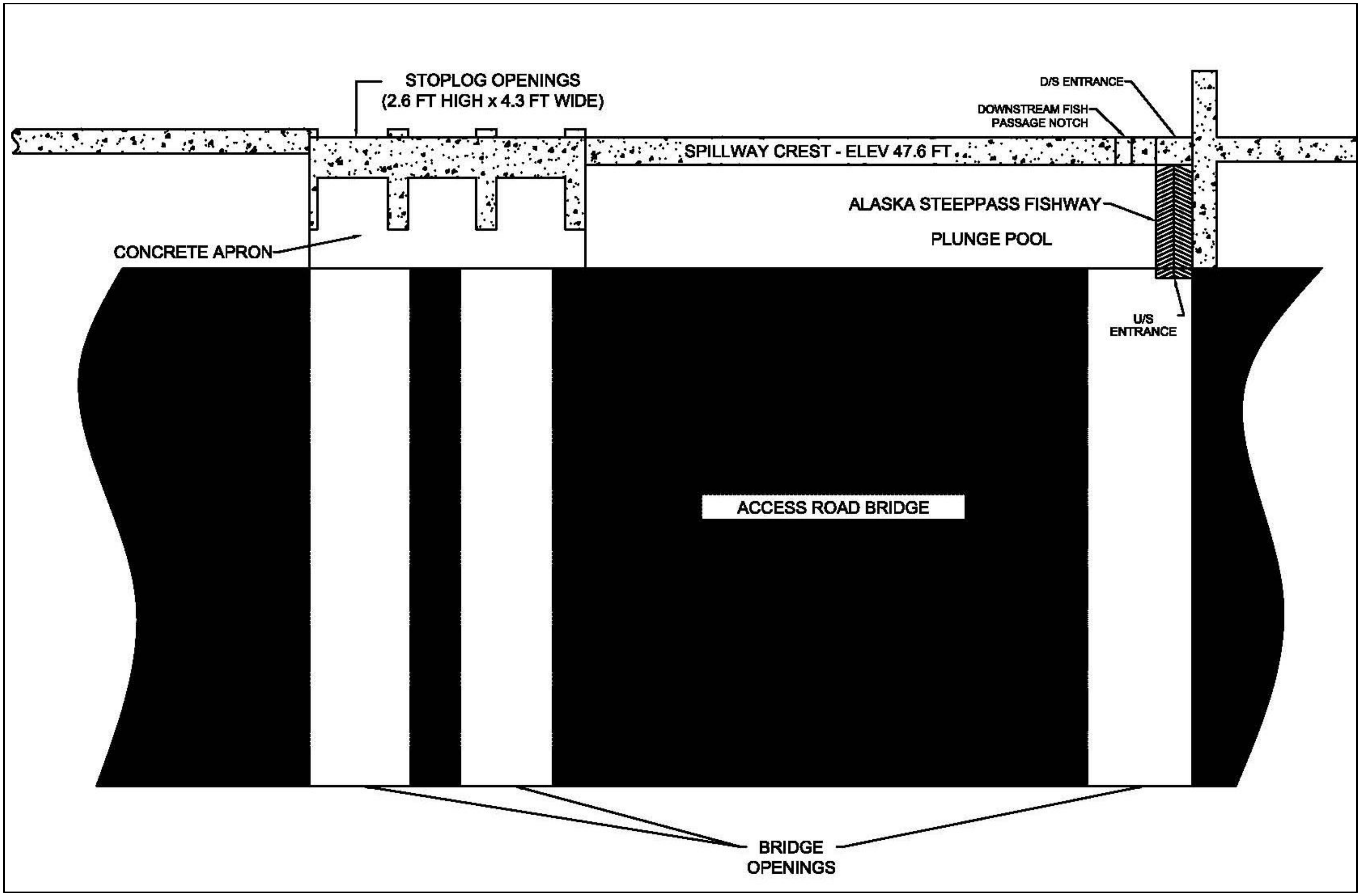


Figure 6.1.2-2: Conceptual Profile of Proposed Alaska Steeppass Fishway

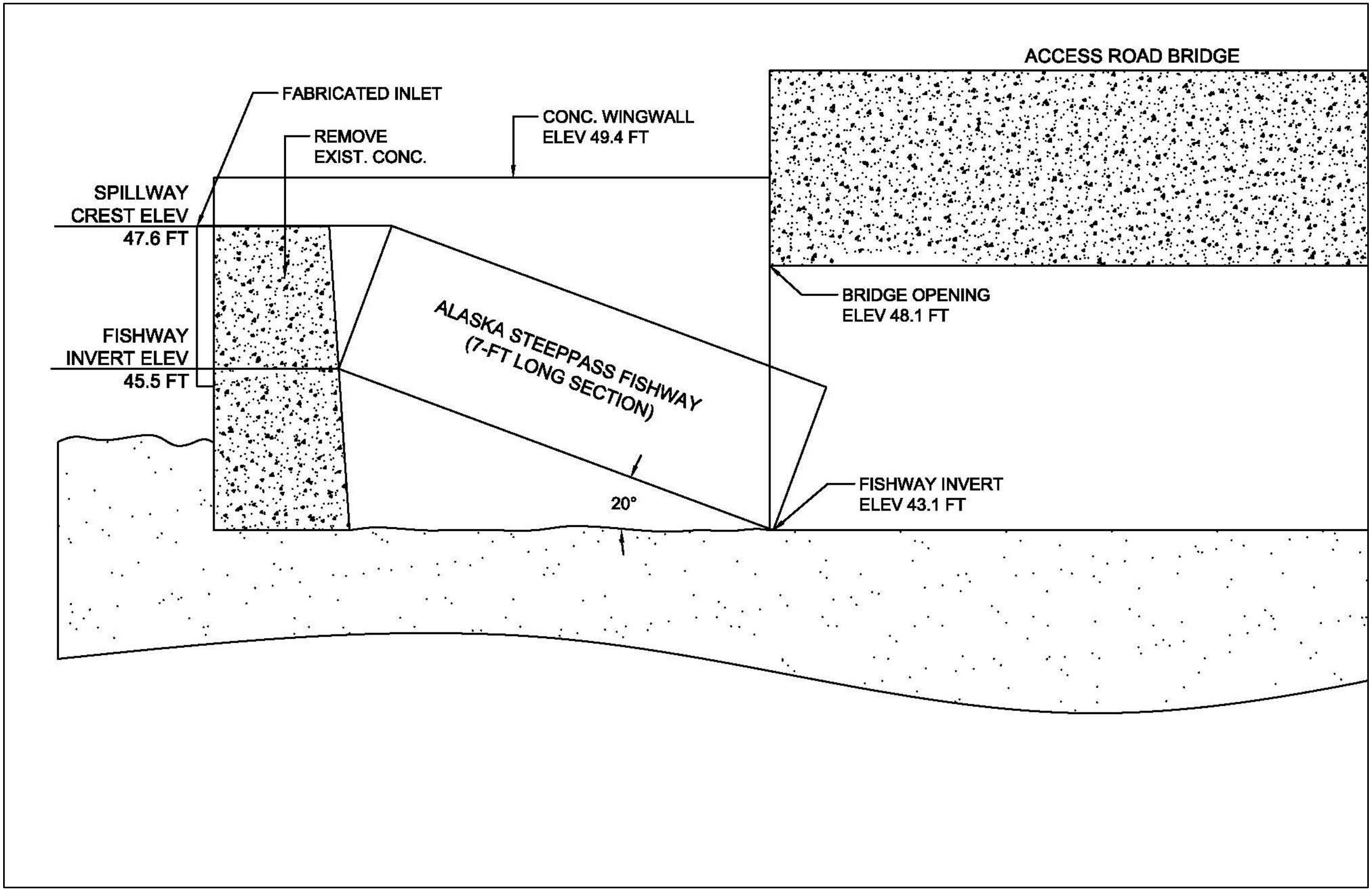
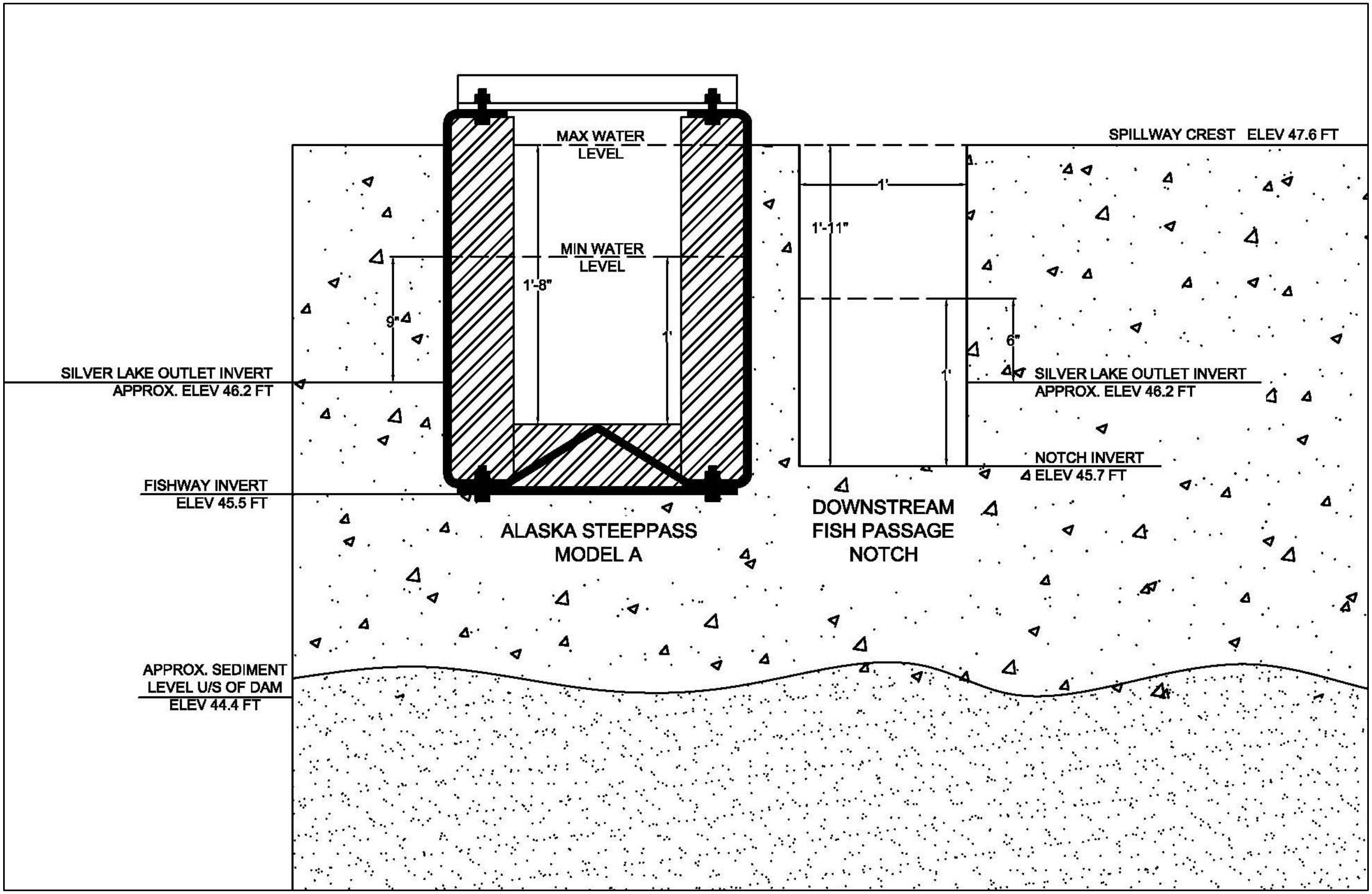


Figure 6.1.2-3: Conceptual Detail of Proposed Alaska Steeppass Fishway



6.1.3 Ability to Meet Target Fish Passage Thresholds

Flow Volume

For the selected slope of 20%, the fish ladder would require about 3 cfs at the minimum effective depth of 12 inches, up to about 4 cfs at the maximum effective depth of 20 inches. Similarly, the 1-foot-wide notch in the dam for downstream passage would require approximately 3 cfs through the range of recommended depths (1-1.9 feet of head in the notch). Therefore, 3 cfs was identified as the minimum flow needed to be supplied continuously during the months of April through November[21] for this fish passage alternative. This equates to 2 mgd or a total volume of 488 MG for the entire period, which is about 20% of Brockton's total average withdrawal volume of 2,349 MG during that same period.

To be most effective, the fish ladder should have a headpond elevation between the spillway crest (47.6 feet) and about 8 inches below. Additional flow (up to 3 cfs) can be accommodated through the downstream passage notch, which would also help to attract herring to the base of the fish ladder. Higher flows could be passed through the existing stoplog bays to prevent the fish ladder from becoming submerged, but may create velocity barriers downstream, as discussed later in this section.

As for the seasonally fluctuating releases described in **Section 4.1.5**, an analysis was conducted to determine the effect of a specified release from Silver Lake into the Jones River for the purpose of fish passage. The following data were used:

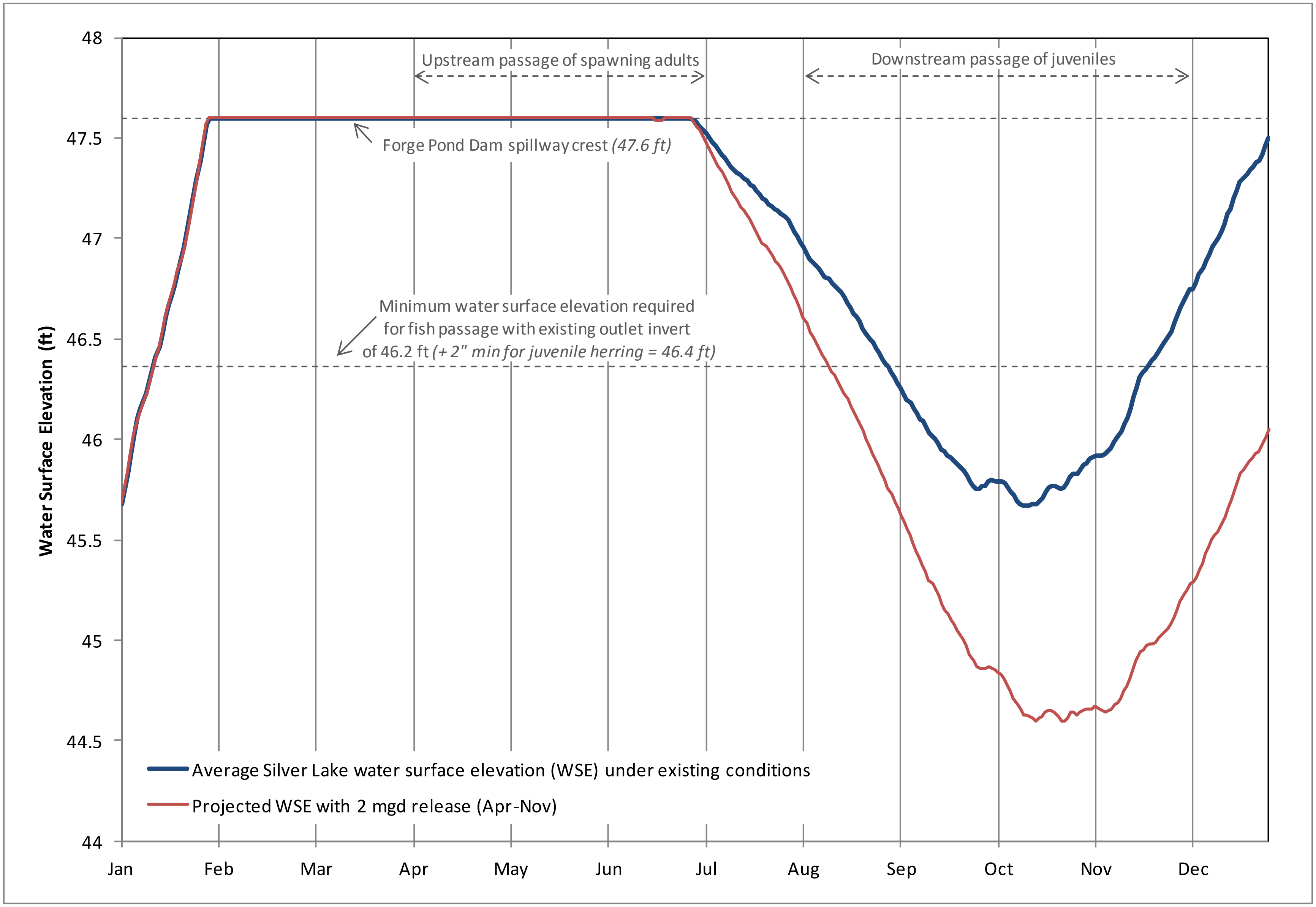
- Silver Lake stage-storage curve derived from bathymetry data collected by Coler & Colantonio (2003), as shown in **Figure 2.4.1-3**
- Silver Lake natural inflows estimated by GZA (2003), as shown in **Figure 4.1.4-1**
- Average daily diversions from Monponsett and Furnace Ponds into Silver Lake (1996-2012), as shown in **Figure 4.2.2-3**
- Average daily withdrawals from Silver Lake (1996-2012), as shown in **Figure 4.2.2-3**
- Average January 1 Silver Lake water surface elevation (1996-2012), as shown in **Figure 4.2.1-6**

Using these data, inflows to and outflows from Silver Lake were balanced to project the water surface elevation under existing conditions and under a scenario where at least 3 cfs (2 mgd) is released from Silver Lake into the Jones River from April through November to ensure fish passage. The projected water surface elevations are shown in **Figure 6.1.3-1**.

---

[21] Although July is not a primary month for river herring immigration or emigration, it has been identified as a potential period for upstream migration of the other target species, American eel, and possibly early emigration of juvenile herring. Therefore, the 3 cfs passage flow requirement was assumed to be continuous from April through November.

Figure 6.1.3-1: Projected Silver Lake Elevation with Fish Passage Release



As **Figure 6.1.3-1** shows, the water surface elevation of Silver Lake is projected to remain at or above the spillway crest during most of the spring adult migration period (April through June) under existing conditions as well as the fish passage release scenario, allowing for upstream passage of adult river herring. However, in both scenarios, the water surface is projected to drop below the natural outlet elevation during most of the juvenile herring emigration period (August through November). Therefore, under existing water supply operating conditions, it is not likely that emigrating juvenile herring could pass over the natural outlet into Forge Pond, or that 3 cfs could be released from Forge Pond during this period to provide downstream passage through the notch.

However, several options are available to increase the feasibility of a fish passage release. Possible alternatives include:

a) **Dredge outlet channel.** As an alternative or in addition to one or more of the options described below to increase the amount of water in the Silver Lake system, a physical approach could be taken. Sediment has accumulated in the natural outlet channel of Silver Lake due to the backwater effect of the dam and lack of flow. Dredging to lower the thalweg of the outlet channel would reduce the water surface elevation at which the disconnect between the two water bodies occurs. This option is described in more detail below.

b) **Develop alternative fish passage thresholds** that accept the limited ability to pass fish downstream in July and August. Juvenile herring would in effect be held back from emigration until September and the conserved 2 mgd from those two months would be dedicated to September and October. This alternative would require explicit guidance in a Forge Pond Dam and Fishway Operations and Maintenance Plan.

c) **Increase the amount that can be purchased from Aquaria.** Withdrawals from Silver Lake could be reduced by using Brockton's capability to purchase additional water from Aquaria—currently 3.5 mgd and up to 4.07 mgd by 2018 (or 4.5 mgd and 5.07 mgd, respectively, if Brockton makes use of its exclusive rights to the first 1 mgd of excess water produced by Aquaria with 15 days notice). Recognizing an impact to cost, operationally this would likely be the simplest option, if Aquaria can meet the demand.

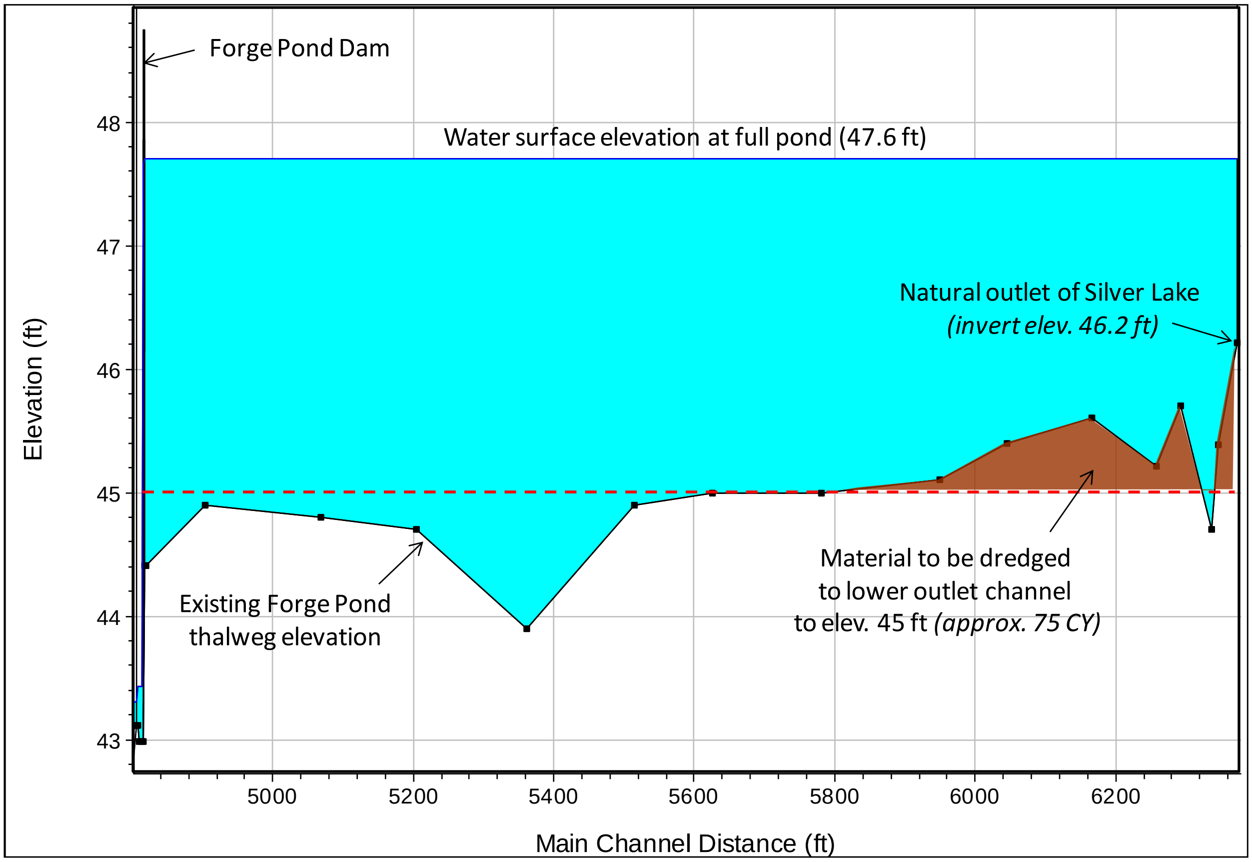
d) **Divert water from Monponsett and/or Furnace Ponds.** On average (1996-2012), virtually no water is diverted from Furnace Pond from July through September, while relatively small diversions of less than 2 mgd from Monponsett Pond occur periodically during this time. Further analysis would be needed to determine whether these ponds have surplus volume to divert during dry periods while still meeting their minimum release requirements. This option is less desirable due to the lower water quality of these ponds compared to Silver Lake.

e) **Reduce Brockton's unaccounted-for water.** Brockton's UAW has averaged 13% or 1.3 mgd of their total average daily demand of 10 mgd from 2000-2011, ranging as high as 19% (2 mgd). Reducing UAW to the performance standard of 10% (1 mgd) could save an average of 0.3 mgd. Further analysis would be needed to identify the feasibility of reducing UAW.

f) **Reduce Brockton's demand.** Programs designed to encourage water conservation by public and private consumers could decrease dependence on Silver Lake. Further analysis would be needed to investigate feasibility and potential gains.

In analyzing the potential for dredging the natural outlet, it was determined that, without dredging the entire pond, the lowest elevation to which the outlet channel could feasibly be dredged would be approximately 45 feet[22] (according to C&C's 2003 bathymetry survey of Forge Pond). As shown in **Figure 6.1.3-2** below, this would involve shallow dredging (1.2 feet maximum) along approximately 600 feet of channel below the outlet, for a total volume of about 75 CY (assuming a conservative 10-foot-wide channel excavation).

Figure 6.1.3-2: Profile of Potential Dredging of Silver Lake Outlet Channel



It should be noted that the outlet channel may naturally lower over time without dredging due to the proposed more continuous flow regime. If selected as the preferred alternative, a fish ladder could be installed as the first phase of the project, followed by dredging in a later phase if significant lowering of the outlet channel is not observed.

As before, the stage vs. storage curve for Silver Lake was used to estimate projected water surface elevations for several modified scenarios:

- A scenario in which Brockton purchases additional water from Aquaria (up to 4.07 mgd, in this example) to allow for a corresponding reduction in withdrawals from Silver Lake and to provide a release of 2 mgd downstream during the entire fish passage season (April through November)

---

[22] If the outlet is dredged to an elevation of 45 feet, (a drop of 1.2 feet), the inverts of the fish ladder and downstream passage notch should be lowered by approximately one foot from the conceptual plans shown to allow at least 6 inches over the outlet when the fish ladder is flowing within its effective range.

- A scenario in which fish passage releases are withheld for the months of July and August (at least 2 mgd released from April through June and September through November)

Projected water surface elevations for these scenarios, in addition to the scenarios presented earlier in Figure **6.1.3-1**, are shown in **Figure 6.1.3-3** on the following page.

Note that although the minimum fish passage flow requirement is only 2 mgd, water could be purchased from Aquaria up to the maximum allowable amount (4.07 mgd assumed for this analysis) or the amount that would raise the water elevation up to full pond (spillway crest), whichever is less. This will incrementally add a net gain of up to 2.07 mgd[23] to the system for reserve storage during drier periods. This particular scenario would involve shifting approximately 566 MG of Brockton's annual demand from Silver Lake to Aquaria annually.

In addition to the minimum water surface elevation required to pass juvenile herring over the natural outlet (46.2 feet + 2 inches minimum depth = 46.4 feet), the minimum water level needed to pass juvenile herring over the proposed dredged outlet described above (45 feet + 2 inches minimum depth = 45.2 feet) is also plotted. This dredging option increases the flexibility of fish passage release and optional withdrawal reduction scenarios that are feasible.

Figure 6.1.3-3 shows that, with the purchase of up to 4.07 mgd from Aquaria as needed and a downstream release of 2 mgd throughout the fish passage season (April through November), the projected average water surface elevation remains high enough to pass juvenile herring over the natural outlet. Furthermore, the figure shows that if the outlet were dredged to an elevation of 45 feet, fish passage would be feasible without the purchase of additional water from Aquaria by withholding releases during July and August.

Flow Depth

Besides passing fish over the outlet into and out of Silver Lake, it is important to evaluate whether water depths are within suitable ranges throughout the entire upper Jones River assessment reach under the given fish passage requirement flow of 3 cfs. **Table 6.1.3-1** below provides the maximum channel depth and average channel velocity under a modeled flow of 3 cfs for all model cross-sections.

---

[23] 4.07 mgd purchase – 2 mgd downstream release for fish passage = 2.07 mgd net storage gain

Figure 6.1.3-3: Projected Silver Lake Elevation with Fish Passage Release and Withdrawal Reduction

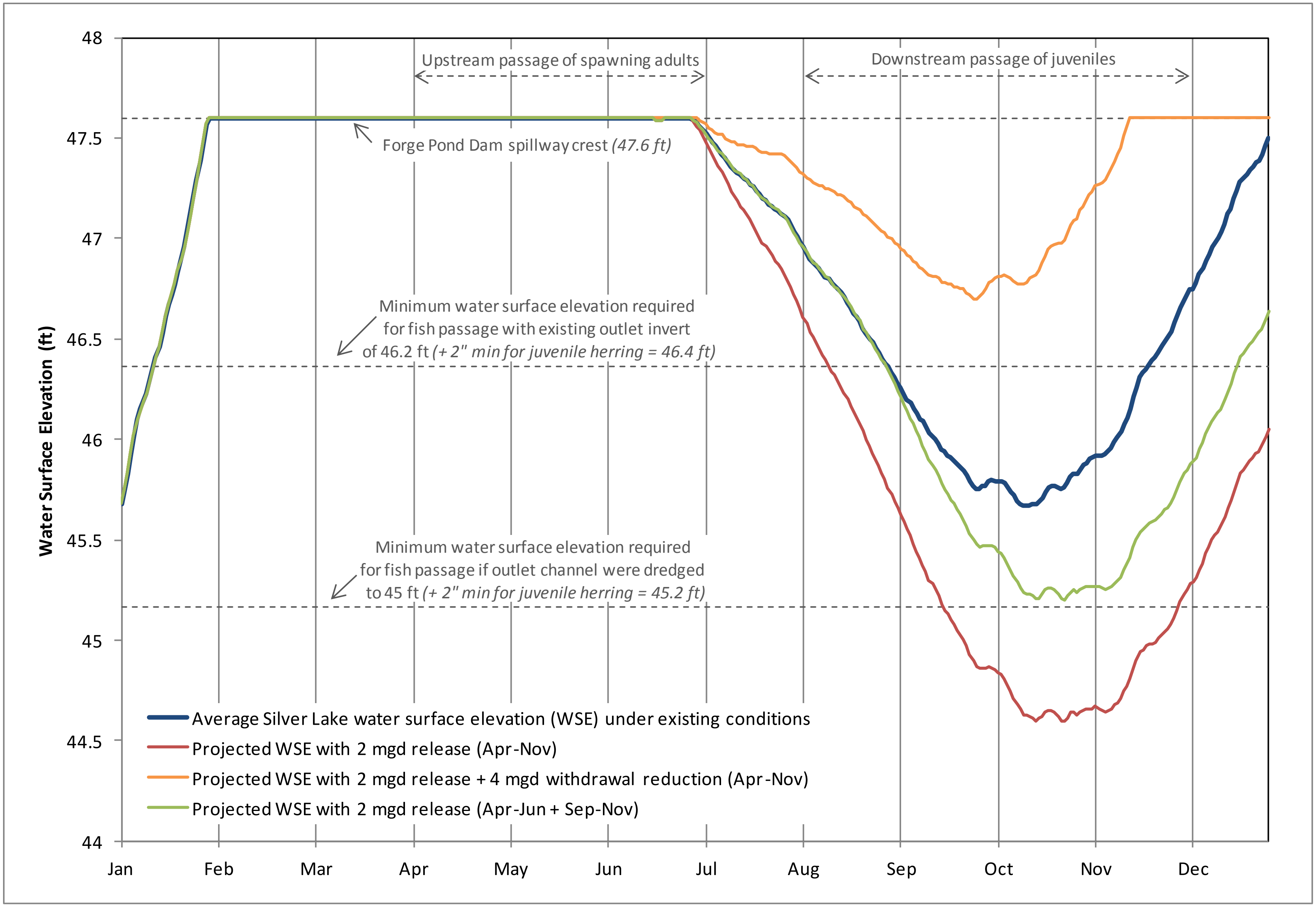


Table 6.1.3-1: Modeled Water Depth and Velocity in the Jones River at 3 cfs

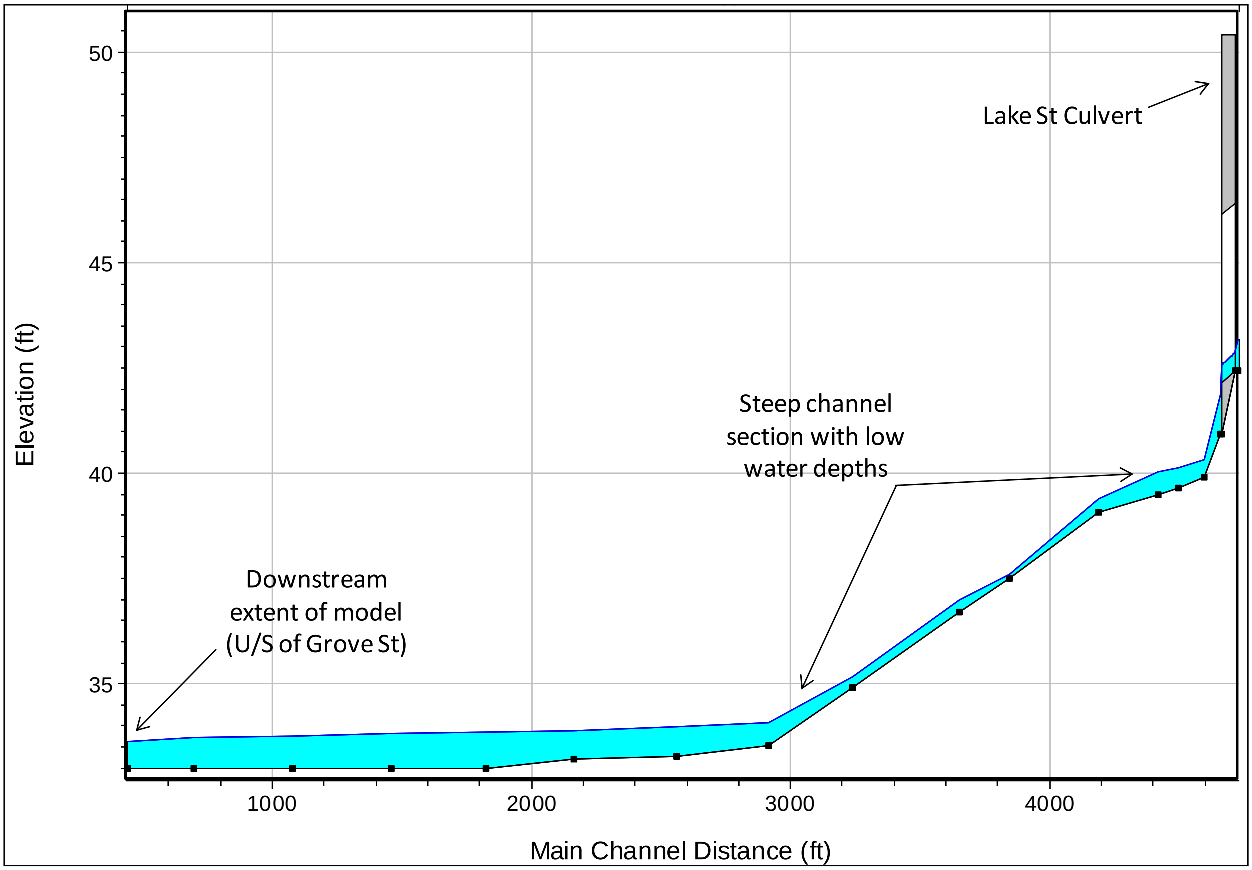
Model Station	Location	Max Water Depth at 3 cfs (ft)	Avg Channel Velocity at 3 cfs (ft/s)
6370	Silver Lake Outlet	1.49	0.07
6343	Forge Pond	2.31	0.03
6334		3.00	0.06
6290		2.00	0.05
6256		2.49	0.07
6164		2.10	0.05
6044		2.30	0.02
5948		2.60	0.01
5778		2.70	0.01
5623		2.70	0.01
5512		2.80	0.01
5359		3.80	0.01
5203		3.00	0.01
5066		2.90	0.01
4901		2.80	0.01
4817	U/S Face of Dam (FEMA AB)	3.29	0.02
4814	D/S Face of Dam	0.44	0.26
4811		0.44	0.26
4808	U/S Face of Access Rd	0.31	0.34
4756	D/S Face of Access Rd	2.56	0.09
4746		2.49	0.09
4733		0.70	0.44
4725	U/S Face of Lake St	0.75	0.63
4661	D/S Face of Lake St	0.93	1.36
4596		0.43	2.67
4497		0.48	0.49
4419	FEMA AA	0.55	0.83
4187	FEMA Z	0.39	0.60
3847		0.44	0.54
3651		0.33	0.43
3237		0.26	2.30
2916	FEMA Y	0.56	0.41
2558		0.71	0.34
2165		0.67	0.37
1823		0.84	0.20
1458		0.81	0.31
1078	FEMA X	0.76	0.24
700		0.72	0.28
444	U/S of Grove St (FEMA W)	0.64	0.61
	MAX	3.80	2.67
	MIN	0.26	0.01
	AVG	1.53	0.37

Regarding water depth, there are two areas of potential concern in meeting the minimum target of 0.5 feet. One is the former Lake St access road bridge, where the deepest opening (left side) has a water depth of approximately 0.3 feet under the required flow of 3 cfs. This would require a relatively simple fix to regrade the flat channel under the bridge opening to create a deeper, narrower thalweg that can be utilized by fish during lower flows. For this conceptual analysis, it was assumed that the thalweg would be lowered by 0.5 feet on one side of the channel and sloped to meet the existing grade on the opposite side, resulting in a triangular channel cross-section with a maximum depth of about 0.6 feet at 3 cfs. Creation of this low-flow channel would involve excavation of about 3 CY of material.

The other area of concern for water depth under target flows is the relatively steep section extending approximately 1500 feet downstream of the Lake Street culvert, as shown in **Figure 6.1.3-4** below. As discussed above, steeper channel slopes typically cause lower water depths and higher velocities. However, model accuracy is lower in this area as detailed survey was not collected downstream of Lake Street for this study. Cross-sectional data was derived from LiDAR elevation data adjusted within channel to match thalweg elevations reported in the FEMA FIS.

Rather than recommending collection of more detailed survey and enhancing of the hydraulic model in this area to further evaluate water depths, a site inspection during a test release of the required flow (3 cfs) may be more appropriate. Given the relatively small channel dimensions in this reach, small obstacles such as cobbles, boulders, and woody debris can play a big factor in water depths. Project partners are already scheduled to conduct debris removal throughout this reach in the near future and can make hand adjustments to increase water depths as needed.

Figure 6.1.3-4: Water Surface Profile Downstream of Lake Street under a Flow of 3 cfs



Flow Velocity

As a final check of passage thresholds, it is important to ensure that fish will not encounter impassable velocity barriers when migrating upstream throughout the reach. **Table 6.1.3-1** above shows that average channel velocities do not exceed the typical cruising speed of 2.8 ft/s for adult river herring. However, the Lake Street culvert does pose a concern for high velocities under certain flows. **Table 6.1.3-2** below provides the estimated percent of river herring (by species) predicted to successfully pass through the 55-foot-long Lake Street culvert under a given range of modeled flows and resulting maximum culvert velocities.

Table 6.1.3-2: Percent of River Herring Predicted to Pass Lake Street Culvert under a Range of Flows

Flow (cfs)	**Water Depth at Upstream Face of Culvert** (ft)	**Max Culvert Velocity** (ft/s)	**Percent of Herring Predicted to Successfully Pass Lake St Culvert**	
			Alewives	*Blueback*
0.15	0.2	1.6	74%	92%
1.5	0.5	3.3	63%	83%
3	**0.8**	**4.0**	**55%**	**74%**
6	1.1	4.9	46%	63%
16	1.9	6.6	23%	33%
41	3.0	8.2	3%	7%
80	4.5*	9.8	0%	0%

**The 4-foot-diameter culvert is submerged by 0.5 feet under a flow of 80 cfs. Published passage rates for a 49-foot barrier length were used to approximate the 55-foot-long Lake Street culvert.*
Source: SPRINTSWIM – Fish Swimming Performance Calculator (Haro et al., 2004)

As the table shows, using the available scientific literature, it is estimated that about 55% of alewives and 74% of blueback herring are expected to pass through the culvert under the required fish passage flow of 3 cfs. Passage percentages continue to drop off as flows increase. Therefore, in addition to ensuring the effectiveness of the fish ladder, it will be important to maintain flows within acceptable ranges to maximize the percent of river herring that are able to pass through the culvert. Replacement of the Lake Street culvert with a more fish-passage-friendly crossing structure could mitigate the potential for a velocity barrier at this location.

6.1.4 Potential Benefits, Impacts, and Other Factors

Passage Effectiveness

Upstream passage of target species via an Alaska steeppass fishway is expected to be effective. Downstream passage in the fall is not as predictable, but can be improved with dredging or natural erosion of the outlet channel. Passage of other aquatic species and overall connectivity of the river will be limited but will improve over existing conditions. Denil and steeppass fishways have been demonstrated to pass most freshwater fish species (adult stages) present in coastal drainages in Massachusetts.

Water Supply

As described above, for this alternative to satisfy the full migratory period of April through November, an additional 2 mgd would need to be released to the Jones River. This would likely require the purchase of up to 4.07 mgd (when permitted) throughout the entire period and/or dredging of the outlet. Silver Lake water levels would have to be monitored and adjusted as needed to provide flows within an appropriate range to allow for effective fish passage and minimize the risk of velocity barriers.

Infrastructure

As described above, Forge Pond Dam is classified as a large, low hazard dam which currently passes the 100-year flood as required. Cutting notches and affixing structures to the spillway could reduce its capacity to pass flood flows. To check the impact to spillway capacity, the effective length of the spillway was decreased by 6 feet to conservatively account for any loss in conveyance due to the 1.5-foot-wide steepass, 1-foot-wide downstream passage notch, and any associated inlet structures, etc. This conservative modification only increases the 100-year flood elevation by 0.05 feet, maintaining the capacity of the spillway within the required range.

If progressed to final design, hydraulic computations should be used to check the need for scour protection at the base of the fish ladder, but this area is already armored with concrete and large stones, so little to no impact to downstream structures is expected.

Sediment

Minimal impact to the sediment accumulated in Forge Pond would occur with the installation of a fish ladder. As described above, a channel through the pond may naturally form as continuous flows transport sediment downstream. This will occur slowly over time and should not create a significant water quality impact.

If the outlet channel were to be dredged, sediment would have to be tested for contaminants and disposed of properly. Erosion and sediment control during construction would minimize impacts to water quality.

Natural & Historic Resources

Forge Pond Dam is a potential historical resource that could be impacted by the cutting of notches and affixing of structures such as the fish ladder and inlet gates. The Massachusetts Historical Commission (MHC) would have to be consulted and approve the design. Other resources such as water quality, wetland habitat, wildlife, and archeological resources may not be improved or impacted, with the exceptions of potential improvements to aquatic resources and water quality that result from increases in released flow, as well as temporary minor construction impacts that will be mitigated.

Construction & Access

Construction access would be relatively simple for the installation of a steeppass fishway, possibly requiring only a short section of temporary access road from the existing former Lake Street to the left dam abutment. A construction easement may have to be obtained from a private landowner for this access route. A crane may be required to lift and set the fishway in place, which could potentially operate from the former Lake Street bridge (structural analysis would have to be conducted).

Access would be more difficult for the optional component of dredging the outlet channel. The Silver Lake Sanctuary (owned by the Town of Kingston) located just north of Forge Pond contains a network of dirt roads that lead to the outlet site. Assuming these roads can be utilized (both from a landowner easement and load capacity standpoint), a temporary access road would still have to be constructed along the length of channel to be dredged (approximately 600 feet). This area has extremely soft sediments and special access measures may be needed (e.g., draining the pond and allowing the sediment to dry out for 6-12 months, constructing access platforms, etc.). Alternately, hydro-dredging (using suction via boat) may be possible, which could significantly simplify access and reduce costs. However, erosion protection measures could not be applied underwater, and it is unknown how quickly a hydro-dredged channel would fill back in with sediment.

Water control during construction is not expected to be an issue. Silver Lake can be drawn down below the outlet level and Forge Pond can be drawn down to the level of the existing stoplog sill. Any minor inflows to Forge Pond can be routed through the stoplog bays. Sandbags can be placed as needed to isolate the relatively small areas needed for construction.

Operation & Maintenance

MarineFisheries requires operation & maintenance (O&M) plans for all fishways in Massachusetts to be prepared in coordination with property owners to ensure efficient passage is compatible with existing uses. The O&M plan would include guidance for regular inspection before and during the fish passage season to remove debris and check for damage or other issues. Stoplog management would involve removal and replacement of stoplogs in the fishway, downstream passage notch, and existing stoplog bays as needed at the change of fish passage seasons or to regulate higher flows. An automated water level sensor at the dam that can be monitored remotely would assist with stoplog management.

In the outlet dredging scenario, it is possible that the outlet could refill with sediment over time and need to undergo maintenance dredging periodically. However, it is likely that continuous releases will transport excess sediment downstream and maintain the channel naturally.

6.1.5 Cost Opinion

A budgetary cost estimate to install an Alaska steeppass fishway at Forge Pond Dam is presented in **Tables 6.1.5-1 and 6.1.5-2** on the following page. The estimate is broken into two components – installation of the fish ladder only (Alternative 1A), and the optional component to dredge the outlet channel. The total of these estimates is considered Alternative 1B. Note that estimates for the optional dredging component reflect services in addition to those already being performed for the main fish ladder component. Economies of scale have been factored where appropriate (i.e., if a common permit is required for both components, it is assumed that they can be incorporated into one permit for minimal additional effort, rather than doubling the effort).

Assumptions for this preliminary budgetary cost estimate include the following (correspond to numbers in the cost estimate):

1. No water diversion is necessary as Silver Lake can be drawn down below outlet and natural inflows to Forge Pond can be routed through existing stoplog bays.
2. The Town of Kingston allows for use of Silver Lake Sanctuary roads and approves of plan to access outlet site.
3. No sediment contamination is found in the outlet channel to be dredged.

Table 6.1.5-1: Estimated Cost to Install Fish Ladder at Forge Pond Dam

Description	Est. Cost
ENGINEERING & PERMITTING	**$19,500**
Engineering design, drawings, & technical specifications	$10,000
Permitting	$9,500
CONSTRUCTION	**$43,164**
Mobilization & demobilization (10% of construction subtotal)	$3,270
Erosion & sediment control (oil boom, silt fencing)[1]	$2,000
Temporary construction access (to left dam abutment)	$4,000
Fabricated aluminum steeppass fishway section	$7,500
Fabrication of inlet section	$3,000
Timber stop logs	$200
Notching of dam to accept fishway and stoplogs for downstream passage	$5,000
Installation of fishway, inlet section, and stoplog slots	$10,000
Grading under bridge opening to create low flow channel	$1,000
Construction contingency (20% of subtotal)	$7,194
TOTAL COST TO INSTALL FISH LADDER (Alt 1A) *(Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$63,000**

Table 6.1.5-2: Optional – Estimated Additional Cost to Dredge Silver Lake Outlet

Description	Est. Cost
ENGINEERING & PERMITTING *(in addition to services above for fish ladder)*	**$49,000**
Sediment testing & analysis	$4,500
Additional hydraulic modeling to design erosion protection	$2,000
Resource delineation	$2,500
Engineering design, drawings, & technical specifications	$10,000
Permitting	$30,000
CONSTRUCTION	**$79,750**
Mobilization & demobilization (10% of construction subtotal)	$5,800
Erosion & sediment control (oil boom, silt fencing)[1]	$3,000
Temporary construction access (along outlet channel to be dredged)[2]	$45,000
Excavation of outlet channel[3]	$5,000
Hauling of excavated material	$1,000
Erosion protection for dredged outlet	$4,000
Construction contingency (25% of subtotal)	$15,950
ADDITIONAL COST TO DREDGE LAKE OUTLET CHANNEL *(Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$129,000**
GRAND TOTAL (Alt 1B) *(Install Fish Ladder + Dredge Lake Outlet Channel)*	**$192,000**

6.2 Alternative 2 – Nature-Like Bypass Channel

6.2.1 Background

The concept of nature-like fishways is to restore a passage barrier such as a dam to a more natural, riverlike configuration by incorporating natural elements like rocks, boulders, and cobbles to dissipate flow energy, maintain velocities within a passable range for most fish, and provide resting pools. Nature-like fishways are perceived as having advantages over technical fishway designs (i.e., fish ladders) in that they create habitat as well as pathways around structures for many organisms in addition to target fish species. Basic types of nature-like fishways include bypass channels and rock ramps (Brownell et al., n.d.). 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. Slope and channel dimensions dictate 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 fish ladders, attraction characteristics are important, and fish must be able to find the bypass entrance. A bypass design should accommodate minimum depth and flow conditions for target species, but can also incorporate varying substrates and water depths to create low velocity resting zones for smaller, more weakly 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.).

Nature-like fishways generally have a low slope (below 5%) both to minimize velocity barriers and avoid resulting structural instability. Specifications for target species may include a channel width of about 10 feet and a minimum depth of 1.6 to 1.8 feet for 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, though it is thought that excessive lengths may decrease motivation of fish attempting to ascend (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 former Lake Street bridge and the dam, allowing herring to pass from the pool present just downstream of the bridge into Forge Pond upstream of the dam. However, the land abutting Forge Pond upstream of the bridge is private property, and any potential bypass channel would require consultation with landowners and the purchase of an easement. For the purpose of this study, the feasibility and conceptual design of a bypass channel is evaluated below on a physical level (i.e., topography, flow requirements, etc.).

6.2.2 Conceptual Design

Both banks downstream of the former Lake Street bridge are fairly steep, and any bypass channel would have to cross the bridge, requiring a large amount of excavation. In an attempt to minimize bypass channel slope, length, and the amount of material needing to be excavated, the topography of the site (based on LiDAR data) was evaluated. A bypass channel on the north or river left overbank (looking downstream) appears to be slightly more feasible due to a more moderate existing bank slope, as well as the presence of a long concrete retaining wall extending from the dam on the river right side. **Figure 6.2.2-1** on the following page shows one potential layout for a bypass channel on the left bank.

Figure 6.2.2-1: Potential Bypass Channel Route

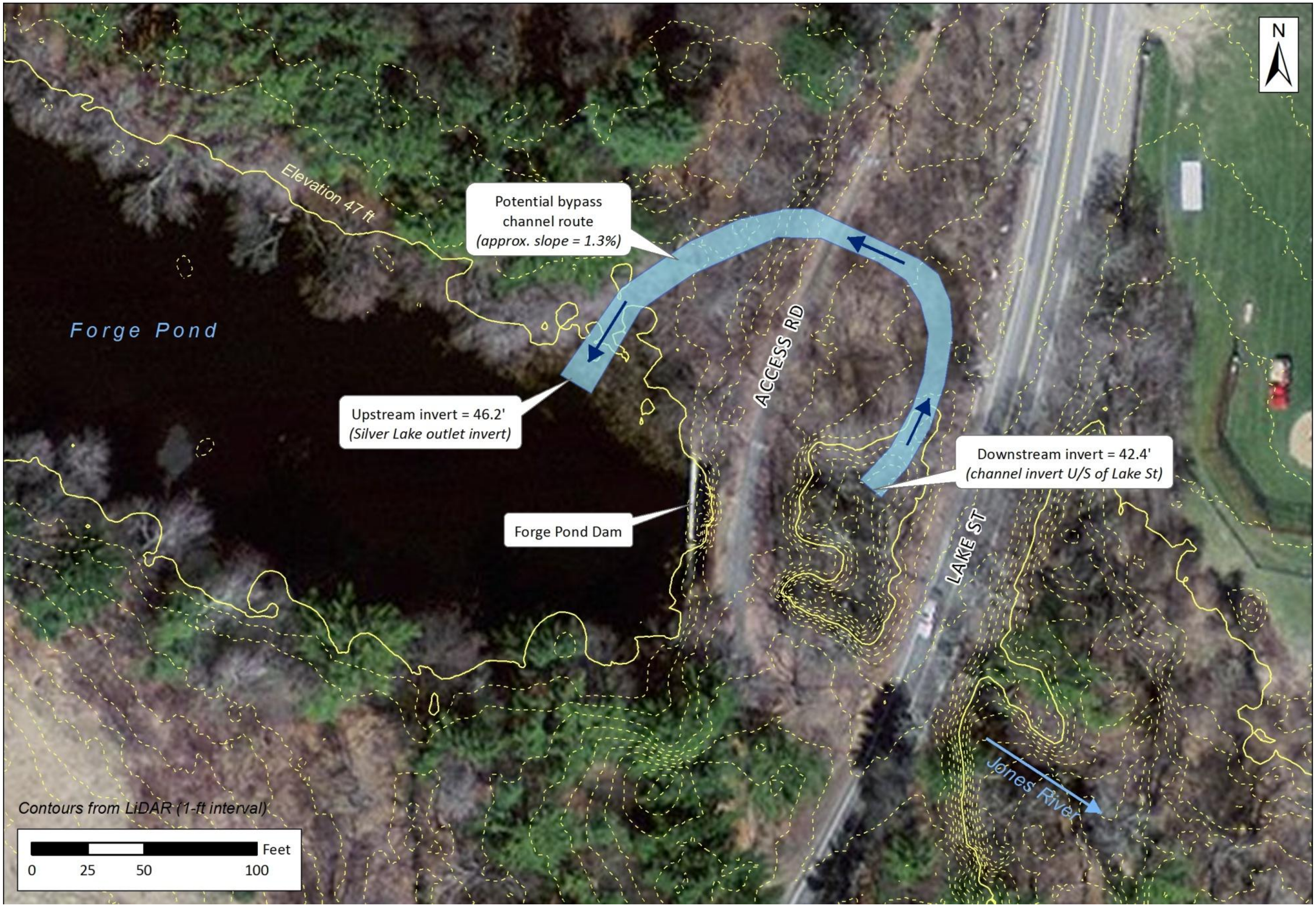
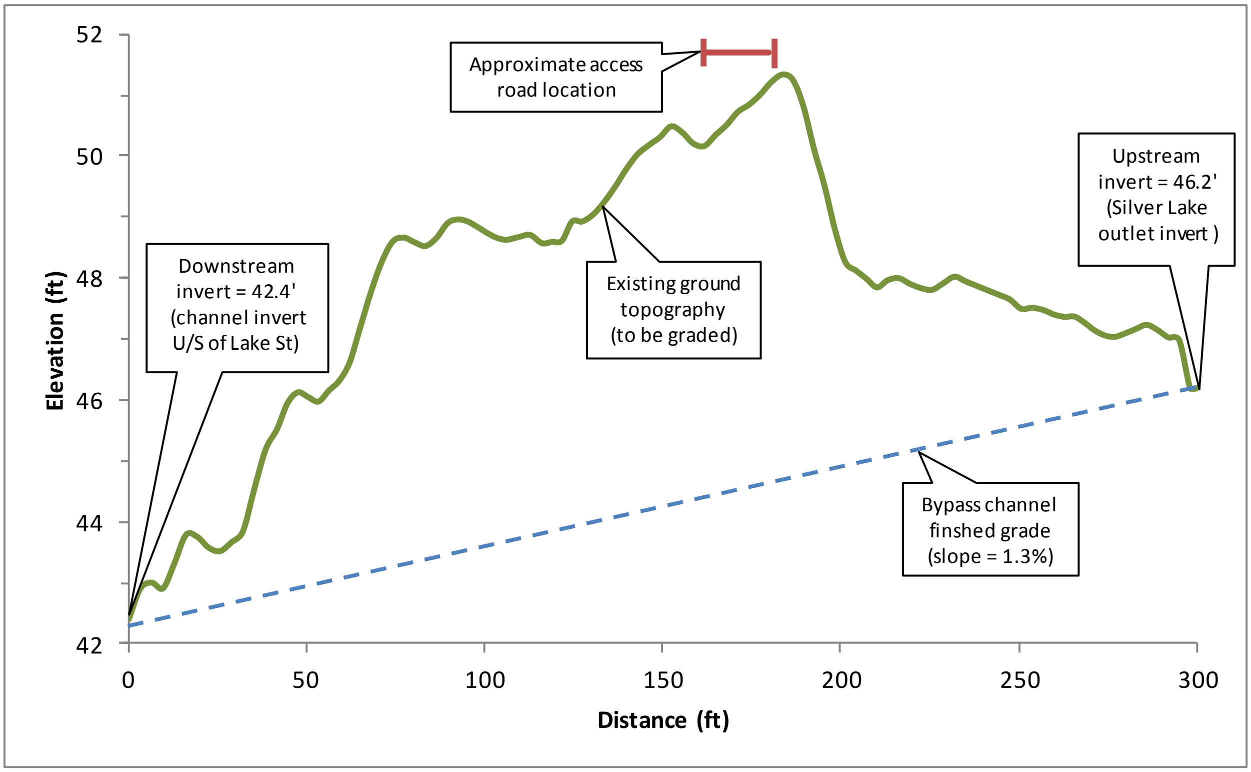


Figure 6.2.2-2 below depicts an elevation profile (green line) along the proposed bypass route shown in **Figure 6.2.2-1** based on the existing topography (from LiDAR).

Figure 6.2.2-2: Elevation Profile of Potential Bypass Channel



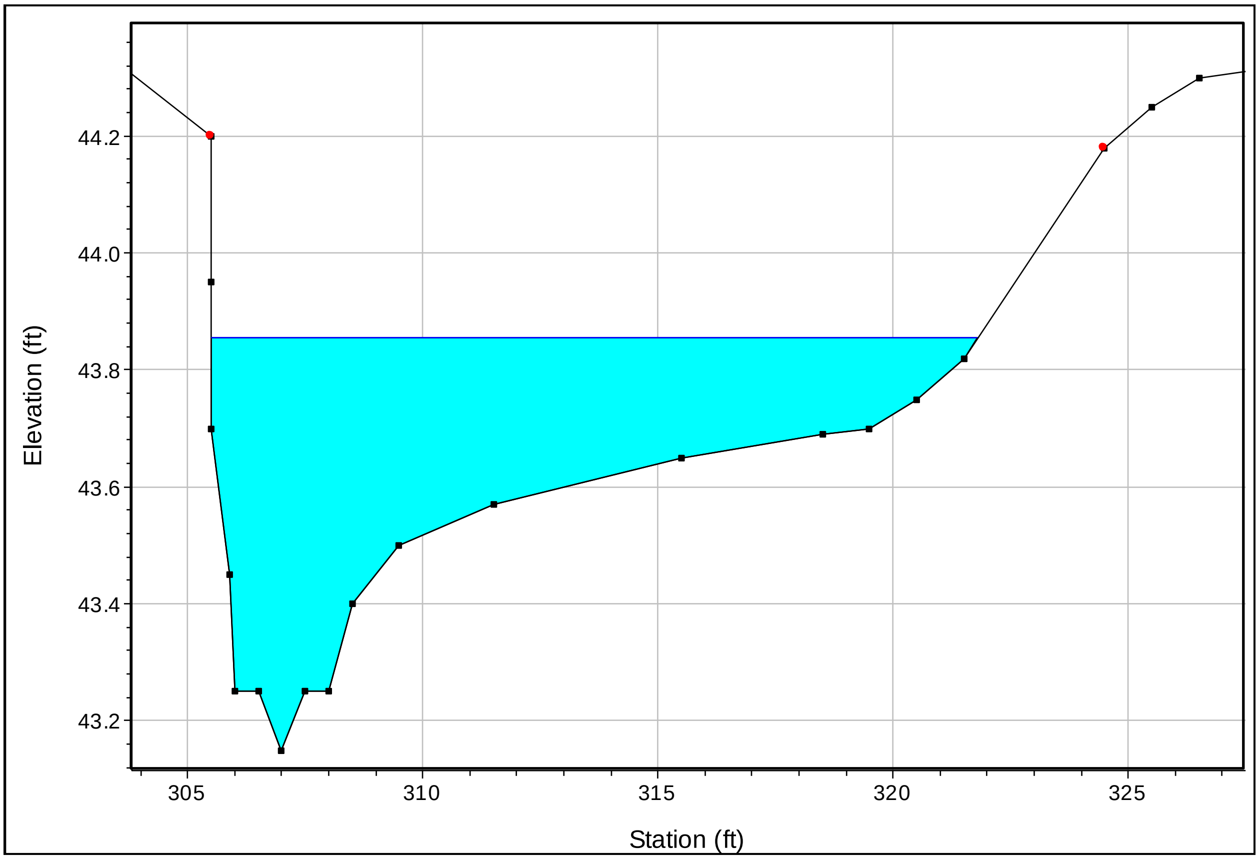
The downstream invert elevation would be set equal to the channel elevation downstream of the access road at approximately 42.4 feet. This would ensure a slight hydraulic drop into the pool present just downstream of the access road bridge opening (river left side) for the purposes of attraction flow. 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. This would require the excavation of approximately 300-500 CY of material assuming a width of 10-15 feet would have to be excavated. 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 could be significantly higher than those needed for the fish ladder. Using the parameters given above (slope = 1.3%, depth = 1.6 feet, top width = 10 feet) and assuming a trapezoidal channel with 2V:1H side slopes and cobble substrate, flows would be on the order of 80 cfs. This is equivalent to 52 mgd, which is more than Brockton's average withdrawal from Silver Lake or natural inflows, thus a continuous release of this magnitude would not be feasible.

However, it is possible that a smaller channel could be designed to meet minimum passage requirements with lower flows. For example, the representative riffle/run cross-section downstream of Lake Street identified by GZA (presented in **Table 4.1.5-1**) was found to have a maximum water depth of 0.7 feet when modeled under a flow of 3 cfs. This channel cross-section has a bottom width of approximately 2 feet and a top width (at 3 cfs) of about 16 feet**.** **Figure 6.2.2-3** below depicts what this conceptual bypass channel cross-section could look like.

Figure 6.2.2-3: Conceptual Bypass Channel Cross-Section at 3 cfs



The upstream entrance of a bypass channel at Forge Pond Dam would need to be fitted with a stoplog gate structure that could be used to close the bypass channel if needed or maintain flows within appropriate ranges under varying headpond fluctuations.

6.2.3 Ability to Meet Target Fish Passage Thresholds

Assuming the conceptual bypass channel design presented in **Figure 6.2.2-3** is feasible, a minimum flow of 3 cfs would be required during the upstream and downstream fish passage seasons (April through November). Because this is the same flow required by the fish ladder/downstream passage notch scenario, the ability to meet this target and the associated water depth and velocity impacts of this flow are identical. Refer to **Section 6.1.3** for a full discussion; major points are highlighted below.

Flow Volume

A continuous flow of 3 cfs can be provided and fish would be able to migrate over the outlet into Silver Lake during the spring upstream passage season under one or a combination of alternatives, such as:

- Brockton could purchase of up to 4.07 mgd of additional water from Aquaria during the fish passage season (April through November) as needed to maintain water levels above the natural outlet. Similar to for the fish ladder, this scenario would involve shifting approximately 566 MG of Brockton's annual demand from Silver Lake to Aquaria.

- The outlet channel could be dredged and/or allowed to erode naturally down to an elevation of approximately 45 feet[24]. Under these conditions, Silver Lake levels would be maintained just high enough to provide a continuous flow of 2 mgd and allow for passage over the outlet during the entire fish passage season without the purchase of additional water from Aquaria.

Flow Depth

As described above, if a bypass channel is designed with similar dimensions to the representative cross-section identified by GZA, a flow of 3 cfs would provide a maximum water depth of about 0.7 feet, as shown in **Figure 6.2.2-3**. This is barely above the minimum threshold of 6 inches for adult herring passage, and may not allow enough margin of error to account for water loss issues that are commonly seen in nature-like bypass channels due to porous or shifting sediment.

Under a flow of 3 cfs, depths elsewhere in the watershed may fall below the minimum target of 6 inches at two locations—under the former Lake Street bridge, and in the steep reach downstream of the Lake Street culvert. For this scenario, the depth under the access road bridge is not a concern as it would be circumvented by the proposed bypass channel. For the reach downstream of Lake Street, field observation under the proposed flow will be necessary to determine whether depths are actually too shallow. If so, minor hand adjustments of boulders, cobbles, and large woody debris should be adequate to create deeper pools.

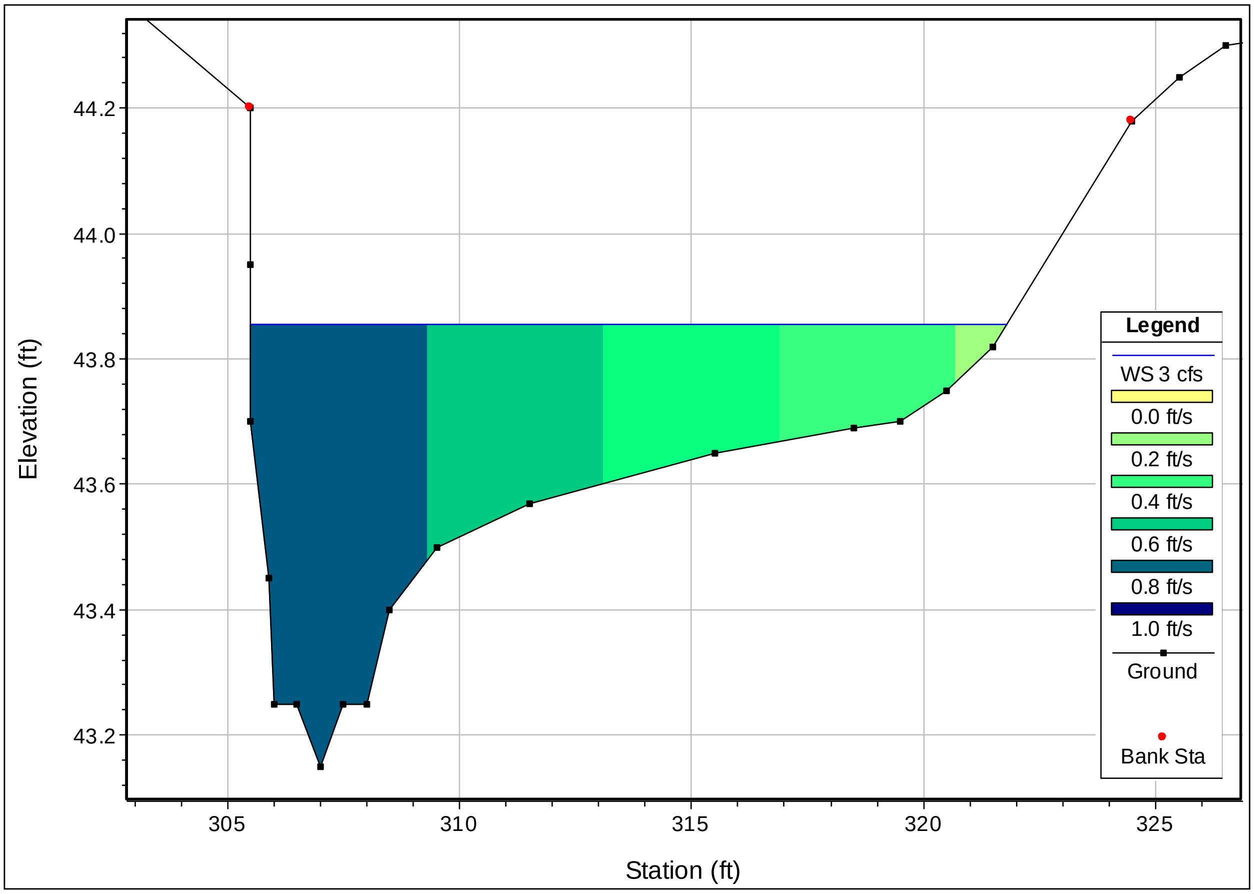
Flow Velocity

To evaluate velocity within the bypass channel, the velocity distribution for the representative cross-section identified by GZA was plotted for the target flow of 3 cfs, as shown in **Figure 6.2.3-1** below. The figure shows that the highest velocities within the deepest part of the channel would be in the 0.8 ft/s range. This is well below the adult river herring cruising speed of 2.8 ft/s and is not expected to pose a problem for upstream passage.

---

[24] The upstream invert of the bypass channel should be adjusted accordingly to match the invert of the Silver Lake outlet, to ensure adequate depths at both of these locations under the same flow.

Figure 6.2.3-1: Velocity Distribution of Conceptual Bypass Channel at 3 cfs



However, the Lake Street culvert is expected to present a velocity obstacle to upstream migrating fish. As presented earlier in **Table 6.1.3-2**, under the required flow of 3 cfs, approximately 55% of alewives and 74% of blueback herring are expected to pass through the culvert. It will be important to maintain flows within acceptable ranges to maximize the percent of river herring that are able to pass through the culvert. Proposed stoplogs at the upstream inlet to the bypass channel as well as existing stoplogs at the dam can help manage flows. Replacement of the Lake Street culvert with a more fish-passage-friendly crossing structure could mitigate the potential for a velocity barrier at this location.

6.2.4 Potential Benefits, Impacts, and Other Factors

Passage Effectiveness

Few nature-like fishways have been quantitatively evaluated in terms of overall passage performance, and results vary (Brownell et al., n.d.). However, failure of some bypass channels may be related to the difficulty for fish in locating the upstream and/or downstream entrances, which is not expected to be the case at Forge Pond, as the bypass channel will likely be the main source of flow. Downstream passage in the fall is not as predictable due to the discontinuity between Silver Lake and Forge Pond, but can be improved with dredging or natural erosion of the outlet channel. Passage of other aquatic species and overall connectivity of the river would improve as well, which is an advantage of the nature-like fishway over the fish ladder.

Water Supply

As described above, for this alternative to satisfy the full migratory period of April through November, an additional 2 mgd would need to be released to the Jones River. This would likely require the purchase of up to 4.07 mgd (when permitted) throughout the entire period and/or dredging of the outlet. Silver Lake water levels would have to be monitored and adjusted as needed to provide flows within an appropriate range to allow for effective fish passage and minimize the risk of velocity barriers.

Again, the option exists to develop alternative fish passage thresholds that accept the limited ability to pass fish downstream in July and August. Juvenile herring would in effect be held back from emigration until September and the conserved 2 mgd from those two months would be dedicated to September and October. This alternative would require explicit guidance in a Forge Pond Dam and Fishway Operations and Maintenance Plan.

Infrastructure

Construction of a bypass channel would likely require removal of a section of the existing access road. Although the road is no longer used for vehicle traffic, it is likely important for dam access and pedestrian use. If the road must be maintained, it would need to be fitted with a stream crossing structure to span the bypass channel, which could decrease the effectiveness of the fishway.

No modifications to the dam are proposed in this scenario.

Sediment

Minimal impact to the sediment accumulated in Forge Pond would occur with the construction of a bypass channel. As described above, a channel through the pond may naturally form as continuous flows transport sediment downstream. This will occur slowly over time and should not create a significant water quality impact.

If the outlet channel were to be dredged, sediment would have to be tested for contaminants and disposed of properly. Erosion and sediment control during construction would minimize impacts to water quality.

Natural & Historic Resources

No significant impacts or improvements to resources such as water quality, wetland habitat, wildlife, historical, and archeological resources are expected with the creation of a bypass channel, with the exceptions of potential improvements to connectivity, aquatic resources, and water quality that wood likely result from increases in released flow, as well as temporary minor construction impacts that will be mitigated.

Construction & Access

Construction access would be relatively straightforward for the construction of a bypass channel, requiring short sections of temporary access road in both the upstream and downstream directions from the existing former Lake Street. A construction easement may have to be obtained from a private landowner for this access route.

Access would be more difficult for the optional component of dredging the outlet channel. The Silver Lake Sanctuary (owned by the Town of Kingston) located just north of Forge Pond contains a network of dirt roads that lead to the outlet site. Assuming these roads can be utilized (both from a landowner easement and load capacity standpoint), a temporary access road would still have to be constructed along the length of channel to be dredged (approximately 600 feet). This area has extremely soft sediments and special access measures may be needed (e.g., draining the pond and allowing the sediment to dry out for 6-12 months, constructing access platforms, etc.). Alternately, hydro-dredging (using suction via boat) may be possible, which could significantly simplify access and reduce costs. However, erosion protection measures could not be applied underwater, and it is unknown how quickly a hydro-dredged channel would fill back in with sediment.

Water control during construction is not expected to be an issue. Silver Lake can be drawn down below the outlet level and Forge Pond can be drawn down to the level of the existing stoplog sill. Any minor inflows to Forge Pond can be routed through the stoplog bays. Sandbags can be placed as needed to isolate the relatively small areas needed for construction.

Operation & Maintenance

MarineFisheries requires O&M plans for all fishways in Massachusetts to be prepared in coordination with property owners to ensure efficient passage is compatible with existing uses. The O&M plan for a bypass channel would include guidance for regular inspection before and during the fish passage season to remove debris and check for damage. Stoplog management would involve removal and replacement of stoplogs in the upstream channel entrance and existing stoplog bays as needed to regulate flows. A water level sensor at the dam that can be monitored remotely would assist with stoplog management.

In the outlet dredging scenario, it is possible that the outlet could refill with sediment over time and need to undergo maintenance dredging periodically. However, it is likely that continuous releases will transport excess sediment downstream and maintain the channel naturally.

6.2.5 Cost Opinion

A budgetary cost estimate to construct a nature-like bypass channel around Forge Pond Dam is presented in **Tables 6.2.5-1 and 6.2.5-2** on the following page. The estimate is broken into two components – construction of the bypass channel only (Alternative 2A), and the optional component to dredge the outlet channel. The total of these estimates is considered Alternative 2B. Note that estimates for the optional dredging component reflect services in addition to those already being performed for the main bypass channel component. Economies of scale have been factored where appropriate (i.e., if a common permit is required for both components, it is assumed that they can be incorporated into one permit for minimal additional effort, rather than doubling the effort).

Assumptions for this preliminary budgetary cost estimate include the following (correspond to numbers in the cost estimate):

1. No water diversion is necessary as Silver Lake can be drawn down below outlet and natural inflows to Forge Pond can be routed through existing stoplog bays.
2. No new stream crossing structure is needed for former Lake Street access road.
3. The Town of Kingston allows for use of Silver Lake Sanctuary roads and approves of plan to access outlet site.
4. No sediment contamination is found in the outlet channel to be dredged.

Table 6.2.5-1: Estimated Cost to Construct Bypass Channel at Forge Pond Dam

Description	Est. Cost
ENGINEERING & PERMITTING	**$56,000**
Hydraulic computations to design erosion protection	$5,000
Resource delineation	$2,500
Engineering design, drawings, & technical specifications	$20,000
Permitting	$28,500
CONSTRUCTION	**$140,938**
Mobilization & demobilization (10% of construction subtotal)	$10,250
Erosion & sediment control (oil boom, silt fencing)[1]	$2,000
Temporary construction access (above and below dam)	$8,000
Excavation of bypass channel[2]	$10,000
Hauling of excavated material	$5,000
Bypass channel construction (bedform, placement of boulders/cobble, etc.)	$60,000
Bank stabilization	$2,500
Seeding & planting (incl. monitoring)	$5,000
Installation of water control structure with stop logs at upper entrance	$10,000
Construction contingency (25% of subtotal)	$28,188
TOTAL COST TO CONSTRUCT BYPASS CHANNEL (Alt 2A) *(Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$197,000**

Table 6.2.5-2: Optional – Estimated Cost to Dredge Silver Lake Outlet

Description	Est. Cost
ENGINEERING & PERMITTING *(in addition to services above for bypass channel)*	**$24,000**
Sediment testing (collection of 2 samples, lab analysis, interpretation of results)	$4,500
Additional hydraulic modeling to design erosion protection	$2,000
Resource delineation	$2,500
Engineering design, drawings, & technical specifications	$10,000
Permitting	$5,000
CONSTRUCTION	**$79,750**
Mobilization & demobilization (10% of construction subtotal)	$5,800
Erosion & sediment control (oil boom, silt fencing)[1]	$3,000
Temporary construction access (along outlet channel to be dredged)[3]	$45,000
Excavation of outlet channel[4]	$5,000
Hauling of excavated material	$1,000
Erosion protection for dredged channel	$4,000
Construction contingency (25% of subtotal)	$15,950
ADDITIONAL COST TO DREDGE LAKE OUTLET CHANNEL *(Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$104,000**
GRAND TOTAL (Alt 2B) *(Construct Bypass Channel + Dredge Lake Outlet Channel)*	**$301,000**

6.3 Alternatives 3 & 4 – Dam Removal (Partial & Full)

6.3.1 Background

Removal of Forge Pond Dam would meet the ultimate goal of 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 preferable option for fish passage at some dam barriers. Low head dams that no longer serve their function or present safety or liability hazards are often excellent candidates for removal. 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), as well as the physical feasibility of dam removal, were further investigated in this analysis.

6.3.2 Conceptual Design

This evaluation involved two alternatives—both a partial breach (Alternative 3) and full removal (Alternative 4) of the concrete dam structure. Either scenario is expected to cause a large drop in the water surface elevation throughout Forge Pond, due to the lack of backwater effect. Velocities will also increase through the impoundment. Assuming sediments in Forge Pond are free of contaminants, it may be feasible to allow them to be transported naturally downstream (known as passive sediment management), which would lead to a post-removal headcut, or unraveling of the accumulated sediment in a downstream to upstream direction. If sediments are not released downstream, either due to contaminants or for other reasons, a more active management approach can be taken to excavate the sediment and construct a stable natural channel through the former impoundment.

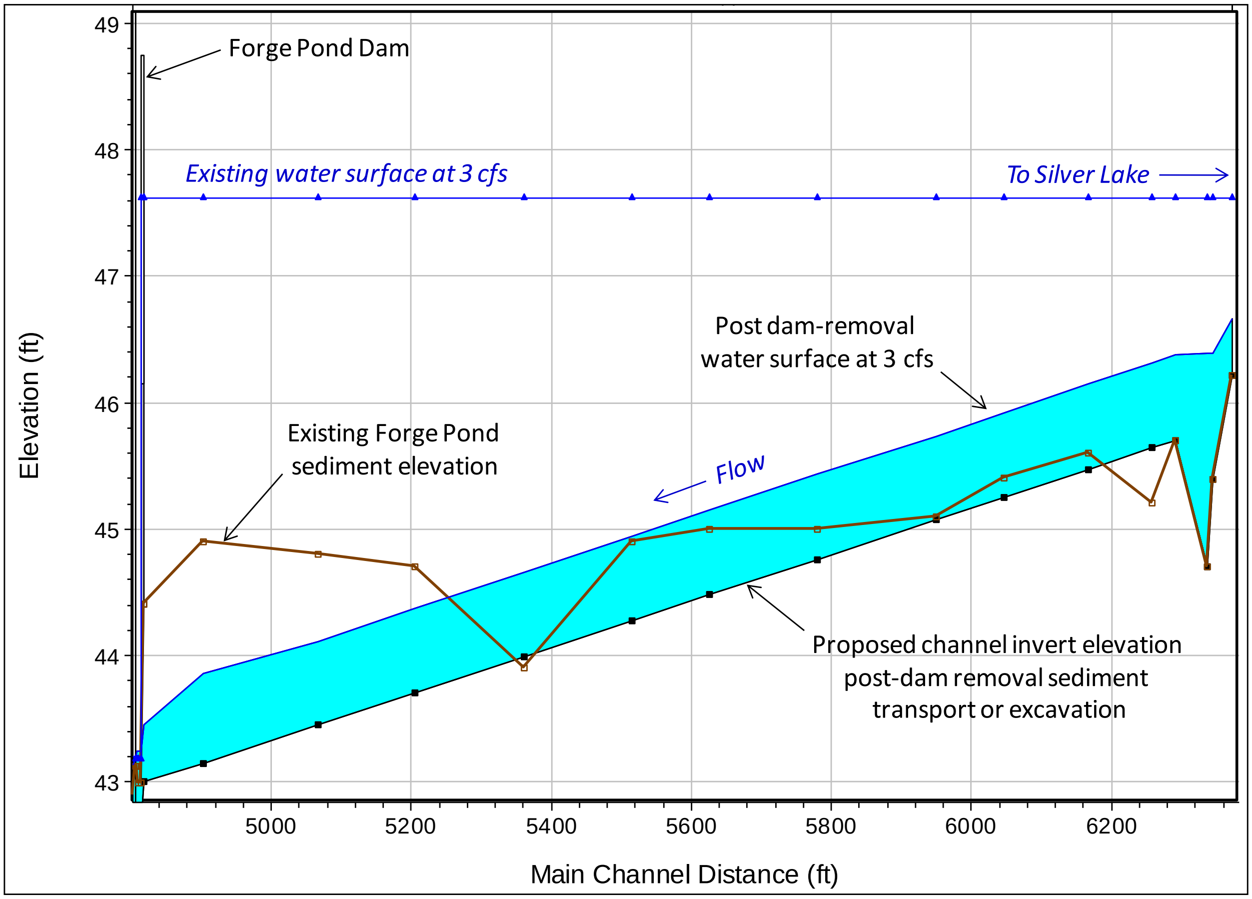
Therefore, to evaluate the dam removal options, the hydraulic model was updated within Forge Pond to reflect conditions with the sediment removed along a channel invert slope from the base of the existing dam to the Silver Lake outlet (approximately 0.2%). For modeling purposes, the representative riffle/run cross-section identified by GZA (2003) downstream of Lake Street (see **Figure 4.1.5-1**) was used to serve as a surrogate transect to simulate post-headcut or constructed channel conditions within Forge Pond. Each model cross-section through the pond was replaced with the representative transect and set to an invert elevation along the constant slope.

For the full dam removal option, the representative transect was also used to replace the cross-section at the existing dam, simulating removal of the main and overflow spillway sections. Concrete abutments between the dam and access road bridge were left in place to prevent scouring and undercutting of the bridge piers.

For the partial dam removal option, the dam cross-section was modified with a notch approximately 6 feet wide and the full height of the dam. Typically, the goal of partial dam removal is to avoid the high expense of full dam removal. However, in this case, Forge Pond Dam is relatively small and full removal would not be cost prohibitive. Instead, partial removal is being considered in this study because Forge Pond serves an important function to maintain storage for water supply. The relatively narrow notch in the dam selected for this conceptual design still presents the opportunity to manage water levels with stoplogs on a seasonal basis or as needed, while providing the benefit of full aquatic connectivity with stoplogs removed.

Figure 6.2.3-1 below displays the channel profile and water surface elevation at 3 cfs under existing and dam removal (either partial or full) conditions.

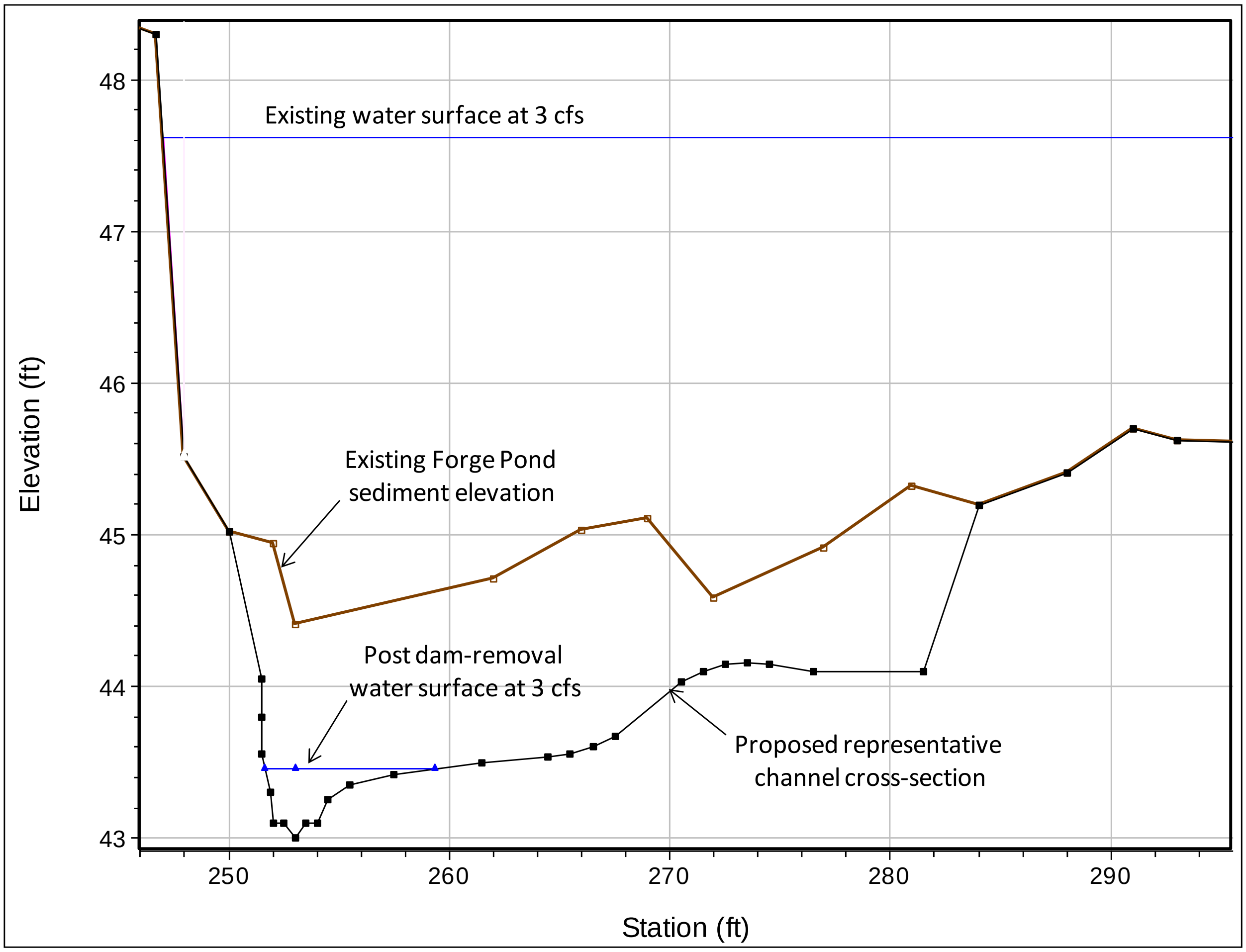
Figure 6.3.2-1: Existing and Post-Dam Removal Profile through Forge Pond at 3 cfs



In an active sediment management scenario (i.e., dredging to construct a stable channel), approximately 0.05 to 2.0 feet of sediment would need to be removed from the existing channel, with a small area to be filled in as well. For conceptual design purposes, it was assumed that an area approximately 10-15 feet wide would be excavated to allow machinery access and appropriate grading and erosion control measures to prevent scouring. The existing Silver Lake outlet elevation and plunge pool immediately downstream were left unadjusted because the feature would likely reform.

Figure 6.3.2-2 below shows the existing and proposed representative cross-section just upstream of Forge Pond Dam (XS 4817), also under a flow of 3 cfs.

Figure 6.3.2-2: Existing and Post-Dam Removal Cross-Section Just Upstream of Forge Pond Dam



6.3.3 Ability to Meet Target Fish Passage Thresholds

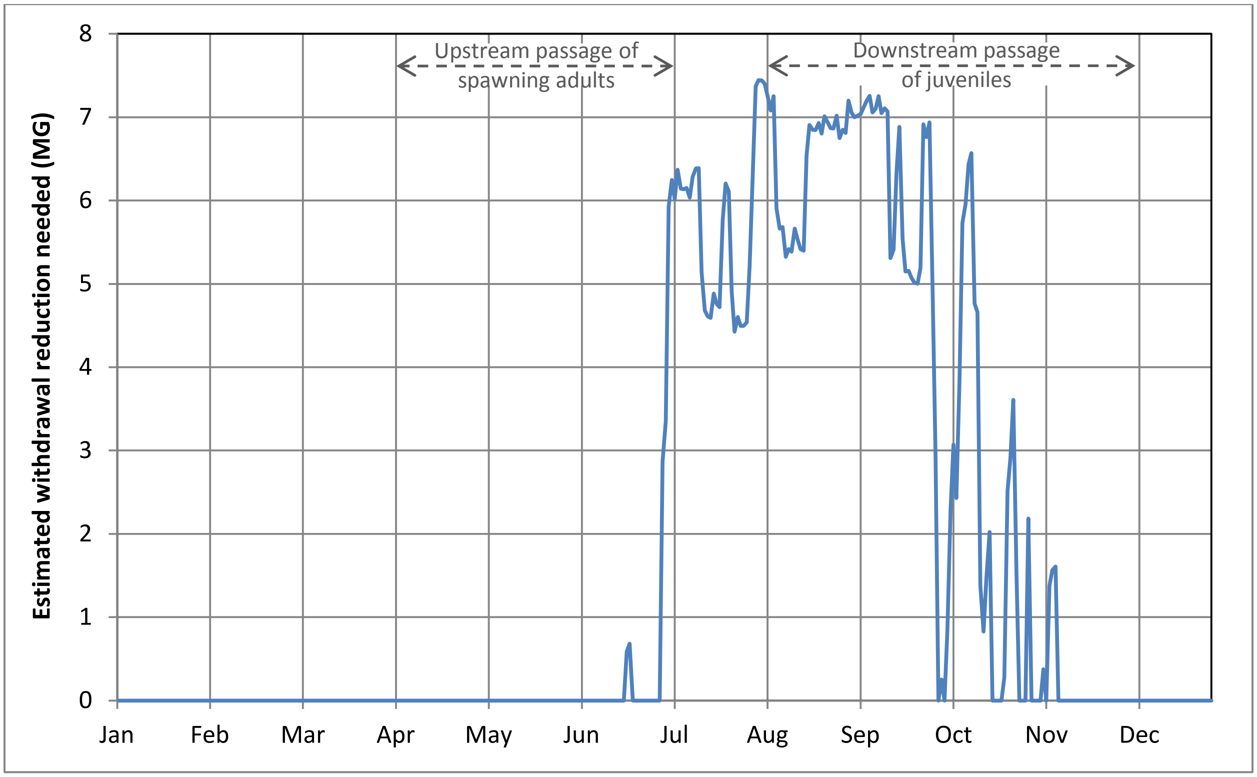
Flow Volume

For the purpose of this analysis, it was assumed that a channel similar to the representative cross-section identified by GZA can be constructed or will naturally form through the impoundment. As discussed previously, a flow of 3 cfs provides the minimum depth of 6 inches needed for fish passage in this cross-section.

However, unlike with previous alternatives, Silver Lake would not be able to provide a continuous release of 3 cfs through the fish passage seasons while still meeting Brockton's water supply demand under a dam removal scenario. The invert of the natural outlet would become the new water control for Silver Lake levels. If Brockton were to withdraw water in excess of natural lake inflows, the water level would drop below the outlet and fish would not be able to pass upstream. Thus, inflow must equal outflow in the post-dam removal system.

As before, the Silver Lake stage-storage curves and estimated inflows/outflows were used to project the amount by which water supply withdrawals would need to be reduced (e.g., offset by purchase from Aquaria) in order to maintain the elevation of the lake at the natural outlet (46.2 feet) and meet the minimum fish passage release of 3 cfs April through November. **Figure 6.3.3-1** below shows the estimated water supply withdrawal reductions needed for the dam removal scenario.

Figure 6.3.3-1: Estimated Withdrawal Reductions Needed for Fish Passage in Dam Removal Scenario



As the figure shows, withdrawal reductions exceeding 7 mgd would be needed, which exceeds the maximum amount that can be purchased from Aquaria at this time. This scenario would involve shifting approximately 627 MG of Brockton's annual demand from Silver Lake to Aquaria, mostly during July through October. Alternatives to make up the deficit were discussed in **Section 6.1.3** and include increasing the maximum amount that can be purchased from Aquaria, reducing UAW, reducing demand, and diverting water from Monponsett and/or Furnace Ponds.

Due to this finding, an additional alternative of constructing a new water control structure at the outlet of Silver Lake in conjunction with full dam removal was investigated. At a very conceptual level, this structure could take the form of an earthen and/or concrete dam with an integral fishway, such as a steeppass or bypass channel for upstream passage. A low level outlet could be used to provide releases and pass juvenile fish downstream when water surface elevations are low in the fall. The concerns of potential disconnect between two water bodies and sediment management that complicated other alternatives would be eliminated. With the construction of a new water control structure, water levels could be managed to meet the needs of both fish passage and water supply demands throughout the year as discussed in **Section 6.1.3**.

Flow Depth

As described in **Section 6.2.3**, if a bypass channel is designed with similar dimensions to the representative cross-section identified by GZA, a flow of 3 cfs would provide a maximum water depth of about 0.7 feet, as shown in **Figure 6.2.2-3**. This is barely above the minimum threshold of 6 inches for adult herring passage, and may not allow enough margin of error to account for water loss issues that are commonly seen natural channels due to porous or shifting sediment. More efficient channel designs could be investigated or additional flow may be needed to ensure adequate depth.

As discussed in **Section 6.1.3**, under a flow of 3 cfs, water depths elsewhere in the watershed may fall below the minimum target of 6 inches at two locations—under the former Lake Street bridge, and in the steep reach downstream of the Lake Street culvert. Minor dredging (3 CY) under the bridge is recommended to create a low-flow channel. For the reach downstream of Lake Street, field observation under the proposed flow is recommended to determine whether depths are actually too shallow. If so, minor hand adjustments of boulders, cobbles, and large woody debris should be adequate to create deeper pools.

<u>Flow Velocity</u>

The velocity distribution for the representative cross-section identified by GZA was plotted for the target flow of 3 cfs, as shown previously in **Figure 6.2.3-1**. The figure shows that the highest velocities within the deepest part of the channel would be in the 0.8 ft/s range. This is well below the adult river herring cruising speed of 2.8 ft/s and is not expected to pose a problem for upstream passage.

However, the Lake Street culvert is expected to present a velocity obstacle to upstream migrating fish under higher flows. As presented earlier in **Table 6.1.3-2,** under the required flow of 3 cfs, approximately 55% of alewives and 74% of blueback herring are expected to pass through the culvert. Under a full dam removal scenario, it will not be possible to manage flows to reduce velocity barriers and maximize the percent of river herring that are able to pass through the culvert. For partial dam removal, proposed stoplogs used in conjunction with the dam notch can be used to help manage flows. With the addition of a new water control structure at the outlet of Silver Lake, downstream releases could be managed within acceptable ranges. Replacement of the Lake Street culvert with a more fish-passage-friendly crossing structure could mitigate the potential for a velocity barrier at this location.

6.3.4 Potential Benefits, Impacts, and Other Factors

<u>Passage Effectiveness</u>

Full or partial dam removal would eliminate the last major barrier to fish passage in the Jones River from Kingston Bay to Silver Lake. Passage effectiveness will largely depend how sediment is managed to create (naturally or manually) a channel with appropriate depths and velocities under the range of flows expected. Passage success is expected to be better with full dam removal, as the partial dam removal notch could become clogged with debris or sediment, or create a velocity barrier under higher flows. Passage of other aquatic species and overall connectivity of the river would be fully restored as well under a dam removal scenario.

In the dam removal scenario where a new water control structure is constructed at the outlet of Silver Lake, passage effectiveness would depend on the means of passage provided. If a steeppass were utilized in conjunction with a low level outlet for downstream passage, passage effectiveness would be good for target species, but would not significantly improve river connectivity or passage for other species. However, this scenario may allow for a small sized pool and weir fishway. For small head dams, pool and weir fishways pass all sea-run and resident fish, and therefore have improved connectivity over a steeppass. Appropriate fishway options would depend on the specifics of the water control structure design.

Water Supply

As described above, full or partial dam removal without the addition of a new water control structure at the outlet would have a significant impact on Brockton's water supply. Brockton would have to obtain an average of 5 mgd from other sources during the months of July through October. Additionally, any withdrawals would have to be closely coordinated with inflows to ensure that the water level in Silver Lake does not drop below the outlet, which would prohibit fish passage.

However, with the construction of a new water control structure at the outlet, impacts to Brockton's water supply would be similar to other alternatives. For this alternative to satisfy the full migratory period of April through November, an additional 2 mgd would need to be released to the Jones River. This would likely require the purchase of up to 4.07 mgd (when permitted) throughout the entire period and/or dredging of the outlet. Silver Lake water levels would have to be monitored and adjusted as needed to provide flows within an appropriate range to allow for effective fish passage and minimize the risk of velocity barriers.

Again, the option exists to develop alternative fish passage thresholds that accept the limited ability to pass fish downstream in July and August. Juvenile herring would in effect be held back from emigration until September and the conserved 2 mgd from those two months would be dedicated to September and October. This alternative would require explicit guidance in a Forge Pond Dam and Fishway Operations and Maintenance Plan.

Infrastructure

The access road bridge (formerly Lake Street) was constructed prior to the dam, and therefore structural integrity of the bridge is not expected to be an issue. However, the higher flow through the bridge openings in a dam removal scenario would increase velocities in the structure and has potential to scour the piers and abutments. A scour analysis would need to be conducted.

Sediment

The 2003 C&C bathymetry map of Forge Pond (Appendix A) shows the depth of sediment longitudinally along Forge Pond, reporting total of 16 measurements. However, no information is available about sediment depths along transects. 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.

Wetlands, Wildlife, & Botanical Resources

Forge Pond is considered an open water wetland. Together with its surrounding marshes and wooded wetlands, the total existing wetland area created by the impoundment is approximately 280 acres. However, it is not considered a high value wetland and does not represent natural conditions. Although removal of the dam would technically result in a net loss of total wetland area, it is likely that high value wetland habitat will be created along the new channel, more closely approximating pre-dam conditions that were submerged by the impoundment. This transition would be an overall gain for the native plant and animal community.

If stoplogs are used in conjunction with a partial dam removal/notch scenario to manage water levels as needed for water supply, the effect on wetland and aquatic habitat could be significant. Upland plants that start to establish under fully drained conditions would be inundated if stoplogs are used to raise water levels. This potential fluctuation zone would likely not provide valuable habitat for upland or aquatic communities, and may be prone to erosion.

If dam removal is the preferred alternative, a formal wetland delineation would be required. Specifically, the size, 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.

The new riparian area created within the current impoundment should be monitored for erosion and for the establishment of invasive species. Native shrubs and trees should be planted along the banks of the new channel in the impoundment to provide additional bank stabilization and reduce the potential for the establishment of invasive species. A more passive approach could allow for natural revegetation. A vegetation inventory should be performed to determine existing fauna and likelihood of invasive encroachment.

Historical & Archeological Resources

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 European Americans settled near this portion of the river. If the Phase IA study indicates that the area was potentially utilized historically (e.g., as an iron forge), 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.

Construction & Access

Landowners abutting the pond may have a preference about the aesthetics of the ponds versus a stream channel and should be consulted in further feasibility analysis associated with dam removal.

Construction access would be relatively straightforward for the actual removal or notching of the dam, requiring a short section of temporary access road from the existing access road to each dam abutment. Construction easements may have to be obtained from a private landowner for this access route.

Access would be more difficult for the optional component of dredging and constructing a new channel through the former impoundment. For this assessment, it was assumed that a temporary access road could be constructed along the entire length of the impoundment (approximately 1500 feet). Construction easements would be needed for portions on private property. This area has extremely soft sediments and special access measures may be needed (e.g., draining the pond and allowing the sediment to dry out for 6-12 months, constructing access platforms, etc.). Alternately, hydro-dredging (using suction via boat) may be possible, which could significantly simplify access and reduce costs. However, a stable channel could not be constructed underwater, and it is unknown how quickly a hydro-dredged channel would fill back in with sediment.

For the optional component of constructing a new water control structure at the outlet, it is assumed the Silver Lake Sanctuary roads can be utilized, and temporary access roads would only need to be developed in the vicinity of the site.

Water control during construction is not expected to be an issue. Silver Lake can be drawn down below the outlet level and Forge Pond can be drawn down to the level of the existing stoplog sill. Any minor inflows to Forge Pond can be routed through the stoplog bays. Sandbags can be placed as needed to isolate the relatively small areas needed for construction.

Operation & Maintenance

Little ongoing maintenance would be associated with a full dam removal scenario, which is a major advantage. The channel should be inspected periodically to ensure it is not filling in with sediment or debris, but there would be no stoplogs to maintain. However, the result is that there will be little ability to manage flows in the Jones River, and the Lake Street culvert could create a velocity barrier more frequently than with other scenarios. Replacement of the Lake Street culvert with a more fish-passage-friendly crossing structure could mitigate the potential for a velocity barrier at this location.

Conversely, partial dam removal would require ongoing monitoring of the dam structure to ensure that the notch is structurally sound and to clear debris and any sediment that may have accumulated. If water level management is needed, the stoplogs would have to be inserted and removed accordingly. Due to the relatively large size and difficult access of the stoplogs, this task would likely require machinery.

If the impoundment is dredged, it is possible that the channel could refill with sediment over time and need to undergo maintenance dredging periodically. However, it is likely that continuous releases will transport excess sediment downstream and maintain the channel naturally.

A new water control structure at the outlet would need similar maintenance to that for the fish ladder and would require an O&M plan approved by *MarineFisheries*. The fishway would have to be inspected for debris, and any stoplogs or low level gates would have to be managed.

6.3.5 Cost Opinion

Budgetary cost estimates for the various alternatives associated with partial and full dam removal are provided on the following pages as follows:

- **Table 6.3.5-1:** Alternative 3A – Partial Dam Removal with Passive Sediment Management
- **Table 6.3.5-2:** Alternative 3B – Partial Dam Removal with Stable Channel Construction (builds on above)
- **Table 6.3.5-3:** Alternative 4A – Full Dam Removal with Passive Sediment Management
- **Table 6.3.5-4:** Alternative 4B – Full Dam Removal with Stable Channel Construction (builds on above)
- **Table 6.3.5-5:** Alternative 4C – Full Dam Removal with Stable Channel Construction and New Water Control Structure at Outlet (builds on above)

Economies of scale have been factored where appropriate (i.e., if a common permit is required for both components, it is assumed that they can be incorporated into one permit for minimal additional effort, rather than doubling the effort).

Assumptions for this preliminary budgetary cost estimate include the following (correspond to numbers in the cost estimate):

1. Minimal to no impacts to downstream structures are found.
2. No sediment contamination is found in the impoundment.
3. Existing hydraulic model can be used.
4. Sediment is allowed to be transported downstream naturally (applies to “A” alternatives).
5. No Memorandum of Agreement is needed relative to historic mitigation. No Phase 1B archeological field study is required (an additional $10,000 – $20,000).
6. No water diversion is necessary as Silver Lake can be drawn down below outlet and natural inflows to Forge Pond can be routed through existing stoplog bays.
7. The Town of Kingston allows for use of Silver Lake Sanctuary roads and approves of plan to access outlet site.

Table 6.3.5-1: Estimated Cost to Partially Remove Forge Pond Dam

Description	Est. Cost
ADDITIONAL FEASIBILITY ANALYSIS	**$66,000**
Infrastructure and safety evaluation[1]	$6,000
Bathymetry, sediment depth probing, & contaminant testing[2]	$15,000
Additional hydraulic modeling[3]	$2,000
Sediment transport and scour analyses[4]	$5,000
Wetlands delineation, RTE inventory, and wildlife documentation	$4,000
Historic (Phase 1A) & archeological resource assessments[5]	$20,000
Aesthetics (renderings)	$1,000
Final feasibilty report	$10,000
Public meetings	$3,000
ENGINEERING & PERMITTING	**$106,000**
Engineering design, drawings, & technical specifications	$30,000
Permitting	$40,000
Meetings	$8,000
Bidding assistance	$8,000
Construction phase services	$20,000
CONSTRUCTION	**$44,000**
Mobilization & demobilization (10% of construction subtotal)	$3,200
Erosion & sediment control (oil boom, silt fencing)[1]	$3,000
Temporary construction access (to left dam abutment)	$4,000
Concrete demolition (deep notch to base of dam)	$2,500
Hauling of demolition material	$500
Installation of water control structure with stop logs in notch	$10,000
Bank stabilization	$8,000
Grading under bridge opening to create low flow channel	$1,000
Seeding & planting (incl. monitoring)	$3,000
Construction contingency (25% of subtotal)	$8,800
TOTAL COST TO PARTIALLY REMOVE DAM (Alt 3A) *(Feasibility + Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$216,000**

Table 6.3.5-2: Optional – Estimated Cost to Construct Stable Channel through Forge Pond

Description	Est. Cost
ENGINEERING & PERMITTING *(in addition to services above for partial dam removal)*	**$30,000**
Engineering design, drawings, & technical specifications	$25,000
Permitting	$5,000
CONSTRUCTION	**$316,250**
Mobilization & demobilization (10% of construction subtotal)	$23,000
Erosion & sediment control (oil boom, silt fencing)[6]	$3,000
Temporary construction access (along length of Forge Pond)	$100,000
Excavation of pilot channel through Forge Pond	$50,000
Hauling of excavated material	$12,000
Grade control riffle construction	$15,000
Sloping of banks, fine grading, and erosion protection	$30,000
Seeding & planting (incl. monitoring)	$20,000
Construction contingency (25% of subtotal)	$63,250
ADDITIONAL COST TO CONSTRUCT STABLE CHANNEL THROUGH FORGE POND *(Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$347,000**
GRAND TOTAL (Alt 3B) *(Partially Remove Dam + Construct Stable Channel)*	**$563,000**

Table 6.3.5-3: Estimated Cost to Fully Remove Forge Pond Dam

Description	Est. Cost
ADDITIONAL FEASIBILITY ANALYSIS	**$66,000**
Infrastructure and safety evaluation[1]	$6,000
Bathymetry, sediment depth probing, & contaminant testing[2]	$15,000
Additional hydraulic modeling[3]	$2,000
Sediment transport and scour analyses[4]	$5,000
Wetlands delineation, RTE inventory, and wildlife documentation	$4,000
Cultural resource assessments[5]	$20,000
Aesthetics (renderings)	$1,000
Final feasibilty report	$10,000
Public meetings	$3,000
ENGINEERING & PERMITTING	**$106,000**
Engineering design, drawings, & technical specifications	$30,000
Permitting	$40,000
Meetings	$8,000
Bidding assistance	$8,000
Construction phase services	$20,000
CONSTRUCTION	**$100,375**
Mobilization & demobilization (10% of construction subtotal)	$7,300
Erosion & sediment control (oil boom, silt fencing)[1]	$5,000
Temporary construction access (from both banks)	$10,000
Concrete demolition (spillway, apron, stoplog sections)	$40,000
Hauling of demolition material	$2,000
Bank stabilization	$10,000
Grading under bridge opening to create low flow channel	$1,000
Seeding & planting (incl. monitoring)	$5,000
Construction contingency (25% of subtotal)	$20,075
TOTAL COST TO FULLY REMOVE DAM (Alt 4A) *(Feasibility + Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$273,000**

Table 6.3.5-4: Optional – Estimated Cost to Construct Stable Channel through Forge Pond

Description	Est. Cost
ENGINEERING & PERMITTING *(in addition to services above for full dam removal)*	**$30,000**
Engineering design, drawings, & technical specifications	$25,000
Permitting	$5,000
CONSTRUCTION	**$319,000**
Mobilization & demobilization (10% of construction subtotal)	$23,200
Erosion & sediment control (oil boom, silt fencing)[6]	$5,000
Temporary construction access (along length of Forge Pond)	$100,000
Excavation of pilot channel through Forge Pond	$50,000
Hauling of excavated material	$12,000
Grade control riffle construction	$15,000
Sloping of banks, fine grading, and erosion protection	$30,000
Seeding & planting (incl. monitoring)	$20,000
Construction contingency (25% of subtotal)	$63,800
ADDITIONAL COST TO CONSTRUCT STABLE CHANNEL THROUGH FORGE POND *(Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$349,000**

GRAND TOTAL (Alt 4B) *(Fully Remove Dam + Construct Stable Channel)*	**$622,000**

Table 6.3.5-5: Optional – Estimated Cost to Construct New Water Control Structure at Outlet

Description	Est. Cost
ENGINEERING & PERMITTING *(in addition to services above for full dam removal)*	**$70,000**
Additional field survey	$5,000
Geotechnical investigations (borings, etc.)	$8,000
Engineering design, drawings, & technical specifications	$60,000
Permitting	$10,000
CONSTRUCTION	**$259,875**
Mobilization & demobilization (10% of construction subtotal)	$18,900
Erosion & sediment control (oil boom, silt fencing)[6]	$5,000
Temporary construction access (to outlet site)[7]	$4,000
Excavation	$10,000
Hauling of excavated material	$5,000
Construction of new spillway and abutments	$100,000
Installation of low-level outlet gate integral to spillway	$30,000
Installation of Alaska steeppass fishway integral to spillway	$30,000
Seeding & planting (incl. monitoring)	$5,000
Construction contingency (25% of subtotal)	$51,975
ADDITIONAL COST TO CONSTRUCT NEW CONTROL STRUCTURE AT OUTLET *(Engineering & Permitting + Construction, rounded up to nearest $1000)*	**$330,000**
GRAND TOTAL (Alt 4C) *(Remove Dam + Construct Stable Channel + Install New Water Control Structure)*	**$952,000**

7. Summary and Next Steps

A summary of the fish passage improvements investigated in this feasibility analysis and their associated preliminary budgetary cost estimates is presented in **Table 7.0-1** on the following page. Generally, the alternatives display an increase in cost in the following order: fish ladder, bypass reach, partial dam removal, and full dam removal. The various optional components for each alternative increase costs accordingly.

Although the cost opinions do not include estimates for operation and maintenance associated with each alternative, including inspection, debris clearing, stoplog management, maintenance dredging, structural repairs, etc, the relative costs of these factors were considered in the alternatives analysis.

A summary of potential permitting requirements associated with the various alternatives is presented in **Table 7.0.2**. Particularly for the dam removal options, this conceptual analysis made many assumptions, and additional feasibility work will need to be conducted to provide necessary information for the consultation and permitting process.

A decision matrix is presented in **Table 7.0-3**. This table compares the relative benefit or impact of each alternative on various resources and considers other factors such as cost, permitting, operation and maintenance, etc. In future phases of this project, a weighted value could be given to each parameter as a means to rank the alternatives with consideration for the goals of project partners and other stakeholders.

This study has demonstrated that fish passage into Silver Lake is feasible. A minimum flow of 3 cfs can be provided during fish passage seasons within the existing constraints of the water supply system. An Alaska steeppass fishway at the dam would provide the simplest and least expensive solution to pass target species, but would not restore natural connectivity of the river system. Although full dam removal would restore important habitat and flows in the upper Jones River, this option would have a much more significant impact on water supply management for the City of Brockton, and reduced ability to manage flows would lead to more frequent occurrence of a velocity barrier to upstream fish passage at the Lake Street culvert. Construction of a new water control structure at the outlet of Silver Lake in conjunction with full dam removal would alleviate some of these issues, but would not fully restore habitat connectivity, is the most expensive alternative, and presents property ownership issues. Modifications to or replacement of the Lake Street culvert may need to be evaluated for any restoration scenario to ensure maximum fish passage efficiency.

Combinations of two or more alternatives together, implemented simultaneously or throughout several phases, may present many additional options for fish passage restoration. The economic and political considerations of water supply in three basins will influence the approach.

Progress and findings of this feasibility study were presented in two public informational sessions held at the Silver Lake Regional High School in Kingston on November 14, 2012 and April 3, 2013. Both meetings were well attended by the public, stakeholders, agency staff, and project partners. Comments received during and after the meetings were all in support of the project. On May 16, 2013, an update was presented at the meeting of the Brockton Water Commission. The Commission was in favor of providing fish passage from a physical standpoint, as long as significant financial burdens to the water supply system are not incurred.

This feasibility study did not produce a preferred option based on recommendations of *MarineFisheries*, the project partners, and the City of Brockton. The study raised additional questions on how to reconcile restoration targets with water supply requirements. The next phase of this project will involve continued communication with project partners, the City of Brockton, and the public. A portion of funding secured from the Massachusetts Environmental Trust (MET) in 2012 will be used to conduct further feasibility analyses, particularly regarding the economic impacts of reducing water supply withdrawals from Silver Lake to improve the effectiveness of certain fish passage scenarios. If a preferred alternative can be agreed upon, the project will advance to future phases of securing funding, additional feasibility work, design, and construction to improve passage of target species between the Jones River and Silver Lake.

Table 7.0-1: Budgetary Cost Estimates for Fish Passage Improvement Alternatives at Forge Pond

ESTIMATED COST	1A	1B	2A	2B	3A	3B	4A	4B	4C
	Fish Ladder		**Bypass Channel**		**Partial Dam Removal**		**Full Dam Removal**		
	Existing Lake Outlet	*Dredged Lake Outlet*	*Existing Lake Outlet*	*Dredged Lake Outlet*	*Passive Sediment Mgmt.*	*Stable Channel Const.*	*Passive Sediment Mgmt.*	*Stable Channel Const.*	*New Structure at Outlet*
Engineering & Permitting	$19,500	$68,500	$56,000	$80,000	$172,000	$202,000	$172,000	$202,000	$272,000
Construction	$43,164	$122,914	$140,938	$220,688	$44,000	$360,250	$100,375	$419,375	$679,250
TOTAL	**$63,000**	**$192,000**	**$197,000**	**$301,000**	**$216,000**	**$563,000**	**$273,000**	**$622,000**	**$952,000**

Table 7.0-2: Potential Permitting Requirements for Various Alternatives

Permit	Agency	Applicability	Potentially Required for Alternative			
			Fish Ladder	*Outlet Dredging*	*Bypass Channel*	*Removal (Full or Partial)*
Wetlands Protection Act Notice of Intent & Order of Conditions	MADEP / Town	Any construction in or near a wetland resource.	X	X	X	X
Environmental Notification Form	MA Environmental Policy Act (MEPA) Office	Alteration of 5,000+ SF of bordering or isolated vegetated wetlands, or alteration of one-half acre of other wetlands, or alteration of 1000+ SF of outstanding resource waters.		X	X	X
Project Notification Form	MA Historical Commission (MHC)	Projects that require state funding, licenses, or permitting.	X	X	X	X
Section 106 Historical Review	MHC	Projects that require federal funding, licenses, or permitting.		X	X	X
Rare Species Information Request Form	Natural Heritage and Endangered Species Program	Projects proposed in estimated rare or endangered species habitat, as delineated on the NHESP database.	X	X	X	X
401 Water Quality Certificate	MADEP	Any activity that would result in a discharge of dredged material, dredging, or dredged material disposal greater than 100 CY that is also subject to federal regulation.		X	X	X
Chapter 91 Waterways License	MADEP	Removal of a licensed structure or dredging of a navigable waterway (most rivers & streams in MA).		X		X
Chapter 253 Dam Permit	MADCR Office of Dam Safety	Any project to construct, repair, materially alter, breach, or remove a dam.	X			X
Clean Water Act Section 404 Programmatic General Permit	US Army Corps of Engineers (USACE)	Discharge of dredged or fill material in a water of the United States, or instream construction activities. Requires Category II review for greater than 25,000 CY dredging or any fill.		X	X	X
National Pollutant Discharge Elimination System (NPDES) Permit	Environmental Protection Agency	Discharges from certain construction sites, including clearing, grading, and excavation activities.		X	X	X
Fishway Permit	*MarineFisheries*	Issued upon approval of engineering plans for structural fishway or passageway designed to pass diadromous fish.	X		X	(partial only)

Table 7.0-3: Decision Matrix for Fish Passage Improvement Alternatives at Forge Pond

	0	1A	1B	2A	2B	3A	3B	4A	4B	4C
	No Action	**Fish Ladder**		**Bypass Channel**		**Partial Dam Removal**		**Full Dam Removal**		
		Existing Lake Outlet	*Dredged Lake Outlet*	*Existing Lake Outlet*	*Dredged Lake Outlet*	*Passive Sediment Mgmt.*	*Stable Channel Const.*	*Passive Sediment Mgmt.*	*Stable Channel Const.*	*New Structure at Outlet*
POTENTIAL BENEFITS										
Upstream passage of target fish species	None	Good	Good	Good	Good	Good	Excellent	Good	Excellent	Excellent
Downstream passage of target species	N/A	Good	Excellent	Poor	Excellent	Good	Excellent	Good	Excellent	Good
Passage of other species (connectivity)	None	Good	Good	Good	Good	Good	Good	Good	Excellent	Poor
Restoration of natural wetland habitat	None	None	None	None	None	Poor	Poor	Good	Excellent	Good
Improved water quality	None	None	None	None	None	Poor	Poor	Good	Excellent	Good
Improved aesthetics	N/A	Poor	Poor	Good	Good	Poor	Poor	Good	Excellent	Good
POTENTIAL IMPACTS										
Infrastructure (bridge scour)	None	None	None	None	None	Unknown	Unknown	Unknown	Unknown	Unknown
Spillway capacity	None	Low	Low	None	None	Low	Low	N/A	N/A	N/A
Water supply	None	Moderate	Low	Moderate	Low	Moderate	Moderate	High	High	Low
Rare/threatened/endangered species	None	None	None	None	None	Unknown	Unknown	Unknown	Unknown	Unknown
Historical resources (dam)	None	Low	Low	None	None	Unknown	Unknown	Unknown	Unknown	Unknown
Archaeological resources (sediment artifacts)	None	None	Low	None	Low	Unknown	Unknown	Unknown	Unknown	Unknown
Sediment (removal, contamination)	None	None	Low	Moderate	Moderate	High	High	High	High	High
OTHER FACTORS										
Flow requirements (~3 cfs for all)	N/A	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Velocity barriers (less ability to manage)	N/A	Low	Low	Moderate	Moderate	Low	Low	High	High	Low
Permitting	N/A	Low	Moderate	Moderate	Moderate	High	High	High	High	High
Land ownership issues	N/A	None	None	High	High	Low	Low	Low	Low	Low
Construction access issues	N/A	Low	Moderate	Moderate	Moderate	Moderate	High	Moderate	High	High
Operation & maintenance	Moderate	Moderate	High	Moderate	High	High	High	Low	Low	Moderate
Estimated cost (engr. & const.)	N/A	$63,000	$192,000	$197,000	$301,000	$216,000	$563,000	$273,000	$622,000	$952,000

Ratings are based on best professional judgment and take into account several factors including relative benefit or impact. Refer to ***Section 6*** *for more details on the feasibility of each alternative.*

8. References

Archfield, S. A., Vogel, R. M., Steeves, P. A., Brandt, S. L., Weiskel, P. K., and Garabedian, S. P. (2010). *The Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts* (Scientific Investigations Report 2009–5227). Reston, VA: US Geological Survey. Retrieved from pubs.usgs.gov/sir/2009/5227/

ASMFC. (2013). *2012 Annual report of the Atlantic States Marine Fisheries Commission*. Arlington, VA: Atlantic States Marine Fisheries Commission. Retrieved from www.nero.noaa.gov/hcd/docs/FishPassagePrimer.pdf

Belding, D. L. (1921). *A report upon the alewife fisheries of Massachusetts*. Boston: Commonwealth of MA, Dept. of Conservation, Div. of Fisheries and Game.

Bovee, K. D. (1992). *Using the computer based physical habitat simulation system* (IFG 210). Fort Collins, CO: US Fish and Wildlife Service, Aquatic Systems Branch.

Brockton. (2002, May 22). *Water purchase agreement between the City of Brockton and Inima, Servicios Europeos de Medio Ambiente, S. A. jointly with Bluestone Energy Services, Inc*.

Brockton. (2009). *Comprehensive water management plan*. Brockton, MA: Public Works Department, Water Commission. Prepared by CDM.

Brockton. (2009, Nov 13). Request for General Permit Authorization to Discharge Wastewater – Potable Water Treatment Facility (PWTF) – NPDES General Permit No. MAG640000 and NHG640000. Submitted to USEPA, Region 1. Retrieved from www.epa.gov/region1/npdes/pwtf/noi/2009/BrocktonWaterFiltrationPlant.pdf

Brownell, P. et al. (n.d.). Diadromous fish passage: A primer on technology, planning and design for the Atlantic and Gulf Coasts. NOAA National Marine Fisheries Service in cooperation with the USGS Conte Anadromous Fish Research Center. Retrieved from www.nero.noaa.gov/hcd/docs/FishPassagePrimer.pdf

Castro-Santos, T. (2006). Modeling the effect of varying swim speeds on fish passage through velocity barriers. *Transactions of the American Fisheries Society*, 135: 1230-1237. Retrieved from www.fws.gov/southeast/fisheries/SEFishPassage/TedCastroSantosTAFS2006.pdf

Chase, B. C. (2010). *Quality Assurance Program Plan (QAPP) for water quality measurements conducted for diadromous fish habitat monitoring: Version 1.0, 2008-2012* (Tech. Rep. No. TR-42). MA Div. of Marine Fisheries. Retrieved from www.mass.gov/dfwele/dmf/publications/tr_42.pdf

Chase, B. C., Mansfield, A., DuBois, P. (2013). *River herring spawning and nursery habitat assessment – Silver Lake, 2008-200p* (Tech. Rep. No. TR-54). MA Div. of Marine Fisheries. Retrieved from *http://www.mass.gov/eea/agencies/dfg/dmf/publications/technical.html*

Coler & Colantonio (C&C). (2003). *Bathymetric mapping of Silver Lake and Forge Pond*. Prepared for JRWA.

Collins, M. J. (2011). *Flood frequency estimates for New England river restoration projects: Considering climate change in project design* (FS-2011-01). National Oceanic and Atmospheric Administration, Fisheries Service.

EEA (Massachusetts Executive Office of Energy and Environmental Affairs). (2012). *Massachusetts sustainable water management initiative – Framework summary*. Retrieved from www.mass.gov/eea/air-water-climate-change/preserving-water-resources/sustainable-water-management/framework/sustainable-water-management-framework-summary.html

JRWA. (2011a). *Jones River* (river herring fact sheet). Kingston, MA: Jones River Watershed Association.

JRWA. (2011b). *Brockton water supply: Impacts and role of Aquaria desalinization plant in solutions*. Kingston, MA: Jones River Watershed Association. Retrieved from web.massaudubon.org/site/DocServer/BrocktonWaterfactsheetfinal.pdf?docID=2863

DEP. (2005). *South Shore Coastal Watersheds 2001 water quality assessment report* (Report No. 94-AC-2). Worcester, MA: Dept. of Environmental Protection, Div. of Watershed Mgmt. Retrieved from www.mass.gov/dep/water/resources/94wqar1.pdf

DEP. (2007). *Massachusetts surface water quality standards* (Revision of 314 CMR 4.00). Westborough, MA: Dept. of Environmental Protection, Div. of Water Pollution Control, Technical Services Branch. Retrieved from www.mass.gov/dep/service/regulations/314cmr04.pdf

ESS Group (2004). *Silver Lake water quality assessment: A Silver Lake community awareness project*. Prepared for the Jones River Watershed Association and the Town of Kingston.

FEMA. (1985). *Flood insurance study: Town of Kingston, Massachusetts, Plymouth County*. Federal Emergency Management Agency.

GZA. (2003). *Jones River watershed study: Final report*. Norwood, MA: GZA GeoEnvironmental, Inc. Prepared for MA Dept. of Environmental Management.

Haro, A., Castro-Santos, T., Noreika, J., and Odeh, M. (2004). Swimming performance of upstream migrant fishes in open-channel flow: A new approach to predicting passage through velocity barriers. *Canadian Journal of Fisheries and Aquatic Science*, 61: 1590-1601. Retrieved from www.stream.fs.fed.us/fishxing/fplibrary/Haro%20and%20others-2004.pdf

HMA (Hanson, Murphy & Associates). (2006). *Silver Lake water supply system overview report*. Prepared for the Brockton Water Commission.

MarineFisheries. (2007). *Massachusetts American Eel Compliance Report: 2007 to the Atlantic States Marine Fisheries Commission*. Boston: MA Div. of Marine Fisheries.

McCoy, K., Collupy, E., and Curry, K. (2002). *Silver Lake Sanctuary mussel shell survey – Spring 2002* (presentation). Bridgewater State College Watershed Access Lab.

Milone & MacBroom. (2009). *Wapping Road Dam feasibility study*. Prepared for JRWA. Retrieved from www.jonesriver.org/getfile/wappingrdstudy/final/WappingRoadDamFINALFeasibilityStudy.pdf

Nelson, G. A., Brady, P. D., Sheppard, J. J., and Armstrong, M. P. (2011). *An assessment of river herring stocks in Massachusetts* (Tech. Rep. No. TR-46). Gloucester, MA: MA Div. of Marine Fisheries. Retrieved from www.mass.gov/dfwele/dmf/publications/tr_46.pdf

NHESP (Natural Heritage and Endangered Species Program). (2009a). *Eastern pondmussel* – Ligumia nasuta. Westborough, MA: MA Div. of Fisheries and Wildlife. Retrieved from www.mass.gov/dfwele/dfw/nhesp/species_info/nhfacts/ligumia_nasuta.pdf

NHESP (Natural Heritage and Endangered Species Program). (2009b). *Tidewater mucket* – Leptodea ochracea. Westborough, MA: MA Div. of Fisheries and Wildlife. Retrieved from www.mass.gov/dfwele/dfw/nhesp/species_info/nhfacts/leptodea_ochracea.pdf

Reback, K.E., Brady, P.D., McLaughlin, K.D., and Milliken, C.G. (2005). *A survey of anadromous fish passage in coastal Massachusetts: Part 3 – South Coastal* (Tech. Rep. No. TR-17). MA Div. of Marine Fisheries. Retrieved from www.mass.gov/dfwele/dmf/publications/tr17_anad_p3_south_shore.pdf

Teal. (2000). *Silver Lake and Jones River watershed study*. Prepared for JRWA.

US Department of Labor. (2012). *Producer price index for series ID #WPSSOP3400 (commodities → stage of processing → finished goods, excluding food → seasonally adjusted)*. Bureau of Labor Statistics. Retrieved from www.bls.gov/ppi/data.htm

USDOT. (1965). *Hydraulic charts for the selection of highway culverts* (HEC-5). US Dept. of Transportation, Federal Highway Administration. Retrieved from www.fhwa.dot.gov/engineering/hydraulics/pubs/hec/hec05.pdf

USEPA. (2000a). *Ambient water quality criteria recommendations: Rivers and streams in nutrient ecoregion XIV* (Document EPA 822-B-00-022). Washington, DC: US Environmental Protection Agency, Office of Water. Retrieved from www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_14.pdf

USEPA. (2000b). *Nutrient criteria technical guidance manual: Lakes and reservoirs* (Document EPA 822-B000-001). Washington, DC: US Environmental Protection Agency, Office of Water. Retrieved from water.epa.gov/scitech/swguidance/standards/criteria/nutrients/lakes/upload/2009_04_22_criteria_nutrient_guidance_lakes_lakes.pdf

Persky, J. H. (1991). *Yields and water quality of stratified-drift aquifers in the Southeast Coastal Basin, Cohasset to Kingston, Massachusetts* (WRI Report No. 91-4112). Marlborough, MA: US Geological Survey. Retrieved from pubs.usgs.gov/wri/1991/4112/report.pdf

Shallenberger, J. and Cooper, P. (2013). Sustainable Water Management Initiative Report: Monponsett Pond and Silver Lake Water Use Operations and Improvement (SWMI Project No. BRP 2012-06). Prepared by Princeton Hydro, LLC for the Town of Halifax and MA DEP.

WAA. (2006). *South Coastal watershed action plan*. Marshfield, MA: Watershed Action Alliance of Southeastern Massachusetts. Retrieved from www.jonesriver.org/getfile/southcoastal/5duxburyjones.pdf

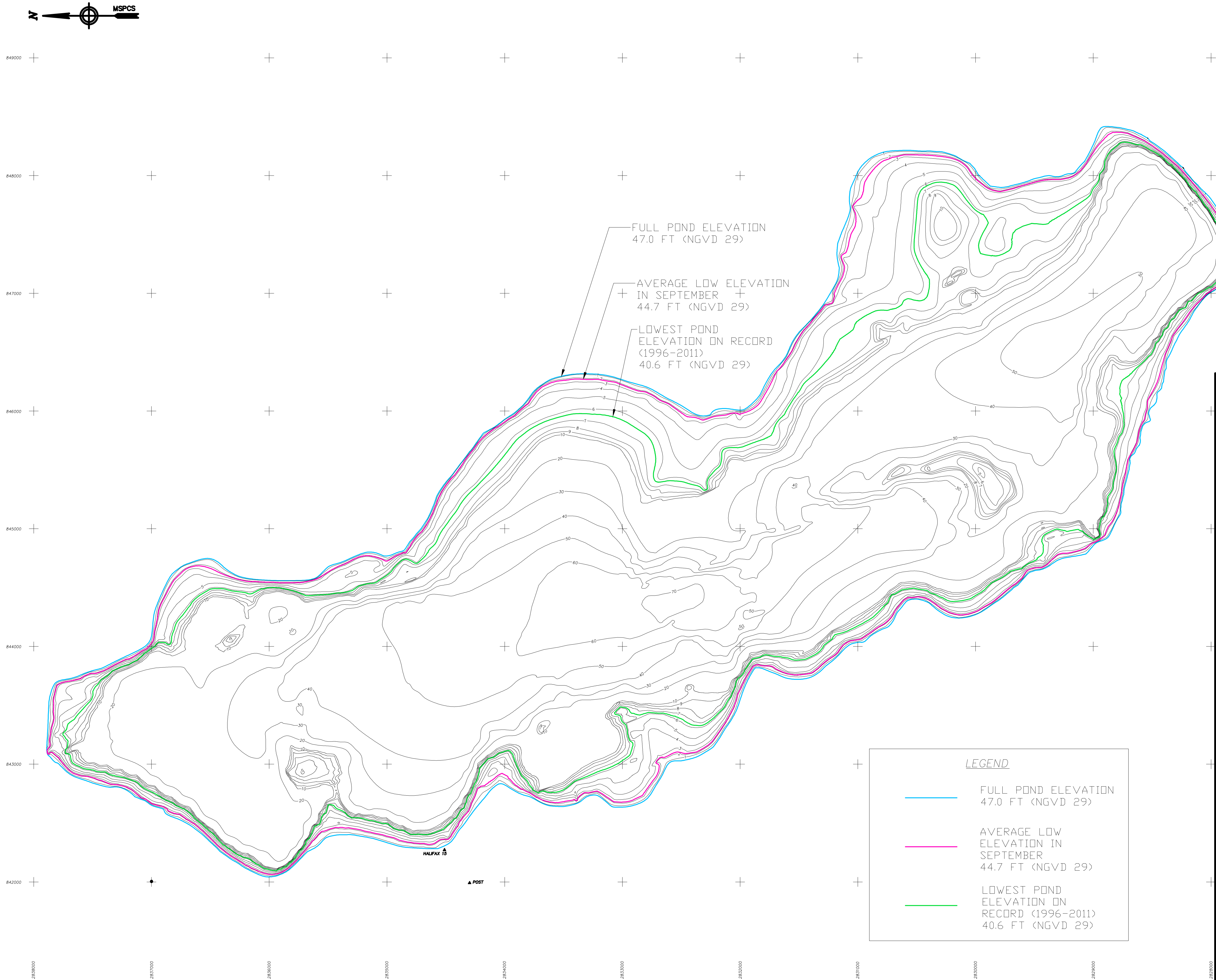
Wandle, S. W. Jr. (1983). *Estimating peak discharges of small, rural streams in Massachusetts* (USGS Water-Supply Paper 2214). Alexandria, VA: US Geological Survey. Retrieved from pubs.usgs.gov/wsp/2214/report.pdf

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



LEGEND

FULL POND ELEVATION
47.0 FT (NGVD 29)

AVERAGE LOW
ELEVATION IN
SEPTEMBER
44.7 FT (NGVD 29)

LOWEST POND
ELEVATION ON
RECORD (1996-2011)
40.6 FT (NGVD 29)

REVISIONS:

No.	DATE	
1.	02/25/03	NEW COLOR ORTHOPHOTO

GENERAL NOTES:

1. DEPTHS ARE EXPRESSED IN FEET AND TENTHS AND ARE REFERENCED TO THE NAVD 88 VERTICAL DATUM. THE BENCHMARK USED FOR THIS PROJECT WAS "HALIFAX 15", A TOWN MONUMENT LOCATED AT THE BROCKTON WATER FILTRATION PLANT AT SILVER LAKE IN HALIFAX, MA. THE NAVD 88 ELEVATION IS 54.52 FEET.

2. THE HORIZONTAL COORDINATES AND VERTICAL ELEVATIONS OF CONTROL POINTS "HALIFAX 15" AND "POST" WERE ESTABLISHED BY GPS STATIC SURVEYING METHODS BY COLER & COLANTONIO, INC. DURING THE PERIOD STARTING MAY 2, 2001 AND ENDING JULY 30, 2001.

3. COLER & COLANTONIO, INC. PERFORMED THE HYDROGRAPHIC SURVEY OF SILVER LAKE DURING THE PERIOD STARTING JUNE 21, 2002 AND ENDING JULY 7, 2002.

4. THE INFORMATION SHOWN ON THIS PLAN REPRESENTS THE RESULTS OF SURVEYS MADE DURING THE PERIOD INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME.

5. LOCATIONS OF ANY EXISTING UNDERWATER UTILITIES OR OBSTRUCTIONS ARE UNKNOWN AT THIS TIME.

6. HORIZONTAL COORDINATES ARE BASED ON THE MASSACHUSETTS STATE PLANE COORDINATE SYSTEM OF 1983 (SPCS 83), MAINLAND ZONE 2001, AND ARE EXPRESSED IN U.S. SURVEY FEET. THE HORIZONTAL REFERENCE DATUM IS THE NORTH AMERICAN DATUM OF 1983 (NAD 83). THE REFERENCE ELLIPSOID ASSOCIATED WITH NAD 83 IS BASED ON THE GEODETIC REFERENCE SYSTEM OF 1980 (GRS 80).

7. THE BASE MAP AND SHORELINE SHOWN ON THIS PLAN WAS OBTAINED FROM 1:5,000 COLOR ORTHO IMAGERY ACQUIRED BY MASSGIS FROM AERIAL PHOTOGRAPHS OBTAINED IN APRIL 2001. THE SHORELINE LOCATION IS APPROXIMATE AND IS ASSUMED TO REPRESENT THE FULL RESERVOIR LEVEL OF 46.2 FEET REFERENCED TO THE NAVD 88 VERTICAL DATUM.

8. FOR ADDITIONAL INFORMATION REFER TO THE FINAL REPORT TITLED: "BATHYMETRIC MAPPING OF SILVER LAKE AND FORGE POND", REVISED MARCH 1, 2003.

COLER & COLANTONIO INC
ENGINEERS AND SCIENTISTS
781-982-5400
Fax: 781-982-5490
101 Accord Park Drive
Norwell, MA 02061-1685

TITLE:

SILVER LAKE
STEWARDSHIP PROJECT

BATHYMETRIC MAPPING
OF SILVER LAKE

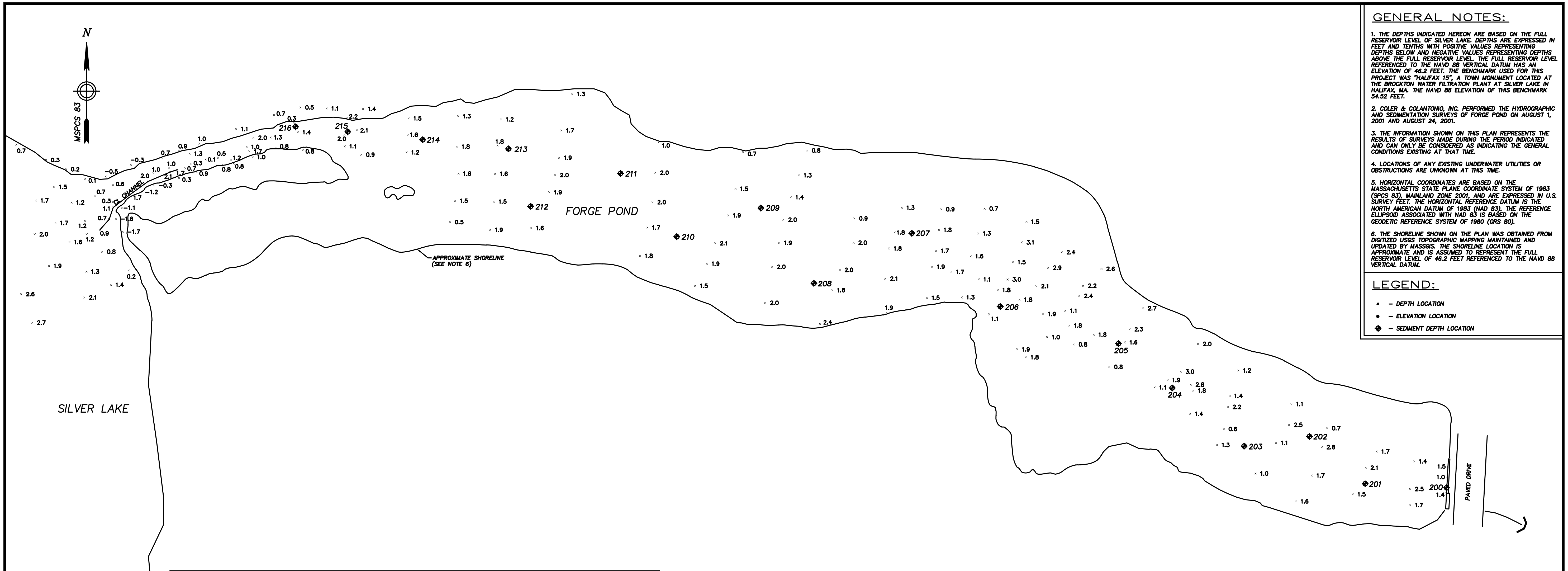
KINGSTON, MA

PREPARED FOR:

JONES RIVER
WATERSHED ASSOCIATION
P.O. BOX 73
KINGSTON, MA 02364

DATE: DECEMBER 30, 2002
COMP./DESIGN: MWR
CHECK: MWR
DRAWN: BEC
SCALE: 1" = 250'
JOB NO.: CONTOURS2002
DWG NO.: 2-361
SHEET 1 OF 1

250 125 0 250 500



GENERAL NOTES:

1. THE DEPTHS INDICATED HEREON ARE BASED ON THE FULL RESERVOIR LEVEL OF SILVER LAKE. DEPTHS ARE EXPRESSED IN FEET AND TENTHS WITH POSITIVE VALUES REPRESENTING DEPTHS BELOW AND NEGATIVE VALUES REPRESENTING DEPTHS ABOVE THE FULL RESERVOIR LEVEL. THE FULL RESERVOIR LEVEL REFERENCED TO THE NAVD 88 VERTICAL DATUM HAS AN ELEVATION OF 46.2 FEET. THE BENCHMARK USED FOR THIS PROJECT WAS "HALIFAX 15", A TOWN MONUMENT LOCATED AT THE BROCKTON WATER FILTRATION PLANT AT SILVER LAKE IN HALIFAX, MA. THE NAVD 88 ELEVATION OF THIS BENCHMARK 54.52 FEET.

2. COLER & COLANTONIO, INC. PERFORMED THE HYDROGRAPHIC AND SEDIMENTATION SURVEYS OF FORGE POND ON AUGUST 1, 2001 AND AUGUST 24, 2001.

3. THE INFORMATION SHOWN ON THIS PLAN REPRESENTS THE RESULTS OF SURVEYS MADE DURING THE PERIOD INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME.

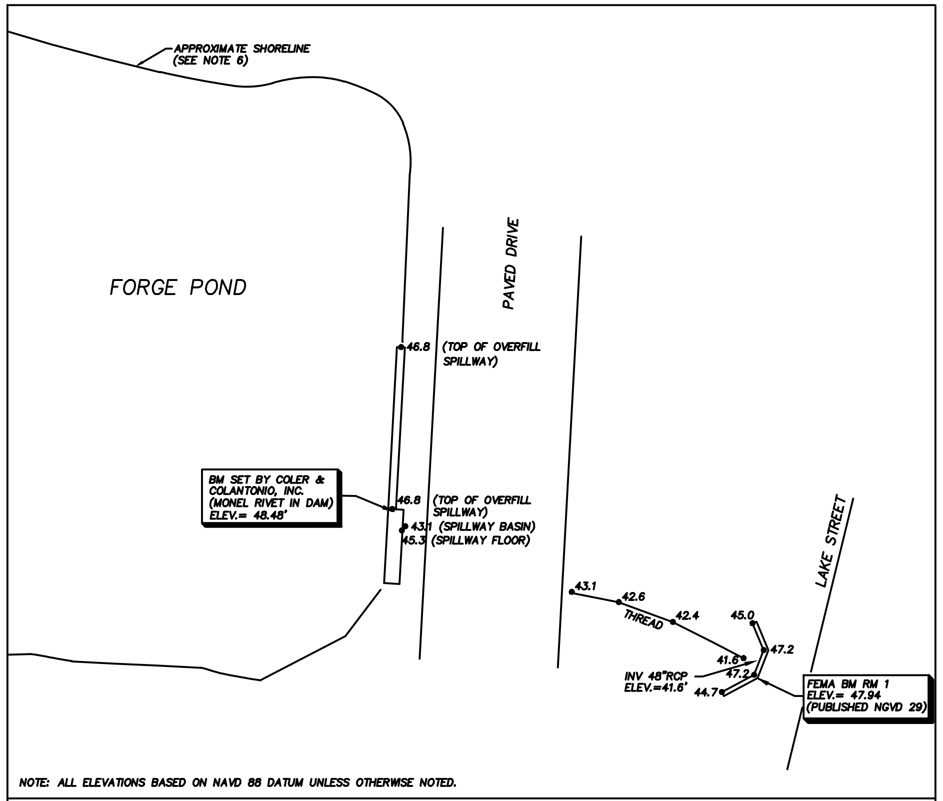
4. LOCATIONS OF ANY EXISTING UNDERWATER UTILITIES OR OBSTRUCTIONS ARE UNKNOWN AT THIS TIME.

5. HORIZONTAL COORDINATES ARE BASED ON THE MASSACHUSETTS STATE PLANE COORDINATE SYSTEM OF 1983 (SPCS 83), MAINLAND ZONE 2001, AND ARE EXPRESSED IN U.S. SURVEY FEET. THE HORIZONTAL REFERENCE DATUM IS THE NORTH AMERICAN DATUM OF 1983 (NAD 83). THE REFERENCE ELLIPSOID ASSOCIATED WITH NAD 83 IS BASED ON THE GEODETIC REFERENCE SYSTEM OF 1980 (GRS 80).

6. THE SHORELINE SHOWN ON THE PLAN WAS OBTAINED FROM DIGITIZED USGS TOPOGRAPHIC MAPPING MAINTAINED AND UPDATED BY MASSGIS. THE SHORELINE LOCATION IS APPROXIMATE AND IS ASSUMED TO REPRESENT THE FULL RESERVOIR LEVEL OF 46.2 FEET REFERENCED TO THE NAVD 88 VERTICAL DATUM.

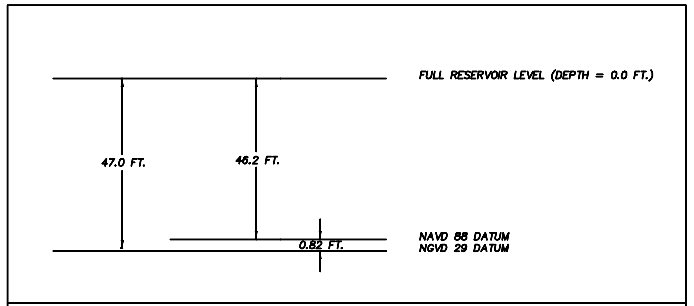
LEGEND:

× – DEPTH LOCATION
● – ELEVATION LOCATION
⌖ – SEDIMENT DEPTH LOCATION



NOTE: ALL ELEVATIONS BASED ON NAVD 88 DATUM UNLESS OTHERWISE NOTED.

DETAIL SKETCH – FORGE POND DAM AREA
SCALE: 1"= 20'



VERTICAL DATUM OFFSETS
(NOT TO SCALE)

Point	Sediment Depth (ft.)	Northing (ft.)	Easting (ft.)
200	2.4	2,830,602	849,604
201	3.1	2,830,606	849,516
202	3.1	2,830,658	849,456
203	2.4	2,830,647	849,385
204	3.0	2,830,710	849,307
205	1.3	2,830,758	849,249
206	1.9	2,830,798	849,121
207	2.7	2,830,877	849,025
208	2.1	2,830,823	848,919
209	1.6	2,830,905	848,862
210	2.2	2,830,874	848,771
211	2.3	2,830,942	848,710
212	1.6	2,830,907	848,612
213	2.5	2,830,969	848,588
214	1.9	2,830,979	848,496
215	1.3	2,830,987	848,414
216	0.7	2,830,993	848,358

COLER &
COLANTONIO INC
ENGINEERS AND SCIENTISTS
781-982-5400
Fax: 781-982-5490
101 Accord Park Drive
Norwell, MA 02061-1685

TITLE:

HYDROGRAPHIC AND SEDIMENTATION SURVEY

FORGE POND
KINGSTON, MA

PREPARED FOR:

JONES RIVER
WATERSHED ASSOCIATION
P.O. BOX 73
KINGSTON, MA 02364

DATE: JANUARY 14, 2002
COMP./DESIGN: MWR/JFS
CHECK: EJP/MWR
DRAWN: BEC
SCALE: 1"= 50'
JOB NO.: 2-361.00
DWG NO.: F:\PROJECT\JONES RIVER\SILVER LAKE\DWG\FORGE POND-DEPTH.DWG

50 25 0 50 100

APPENDIX B – Hydrology Graphs

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

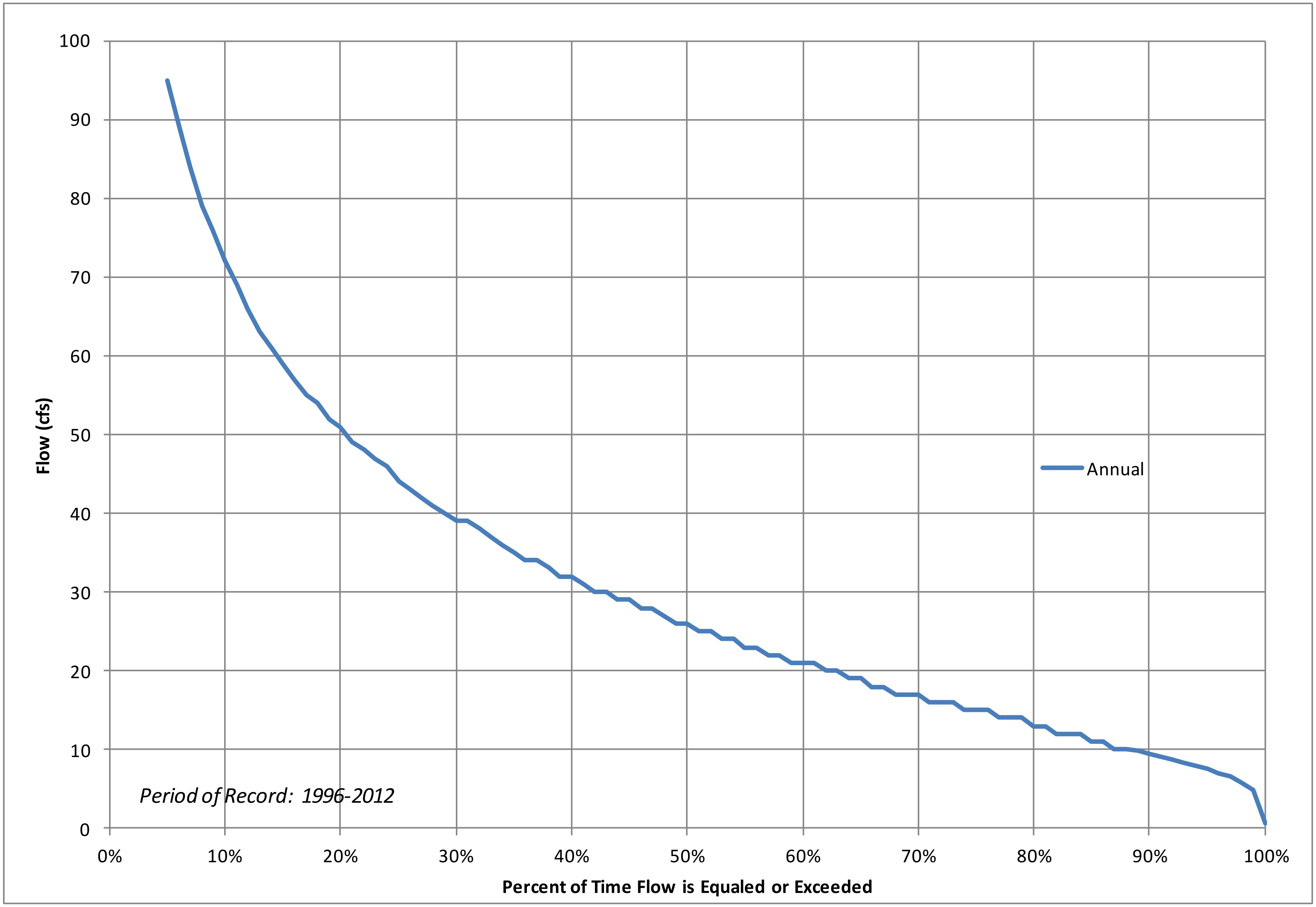


Figure 4.1.1-2: Jan-Mar Flow Duration Curves for Jones River at USGS Gage

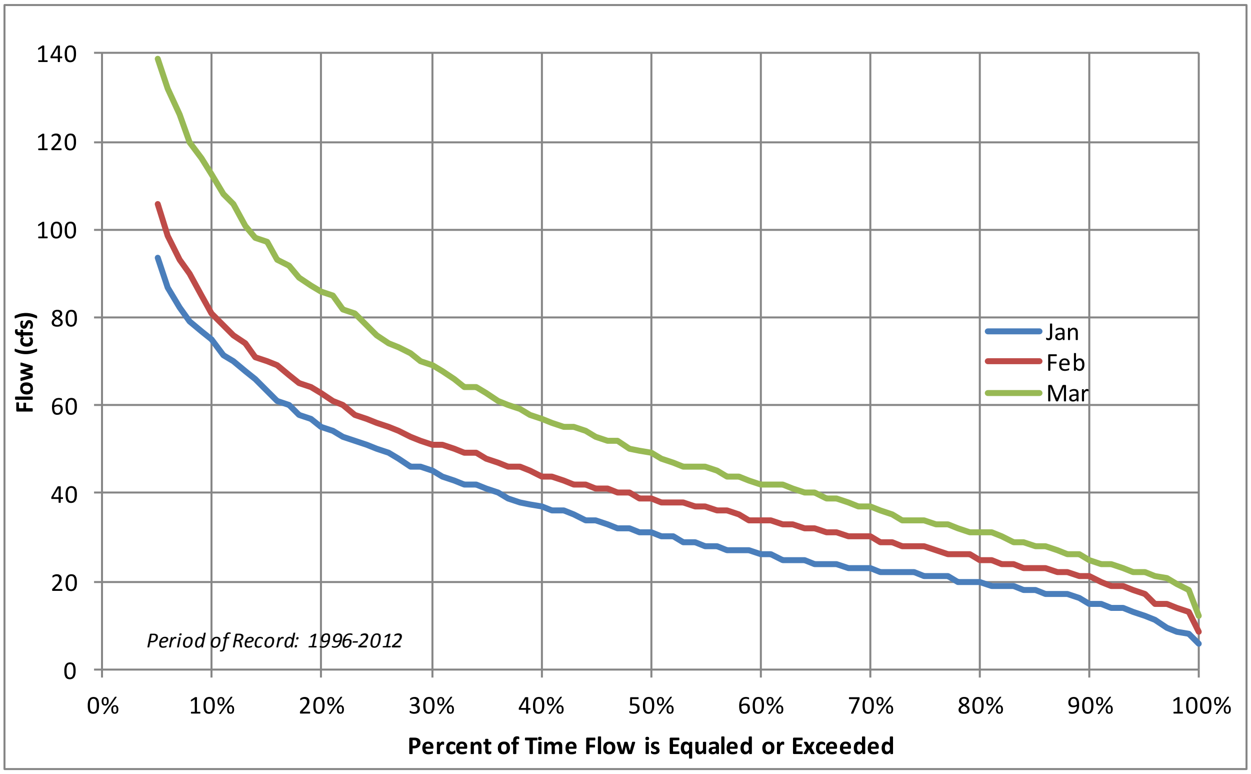


Figure 4.1.1-3: Apr-Jun Flow Duration Curves for Jones River at USGS Gage

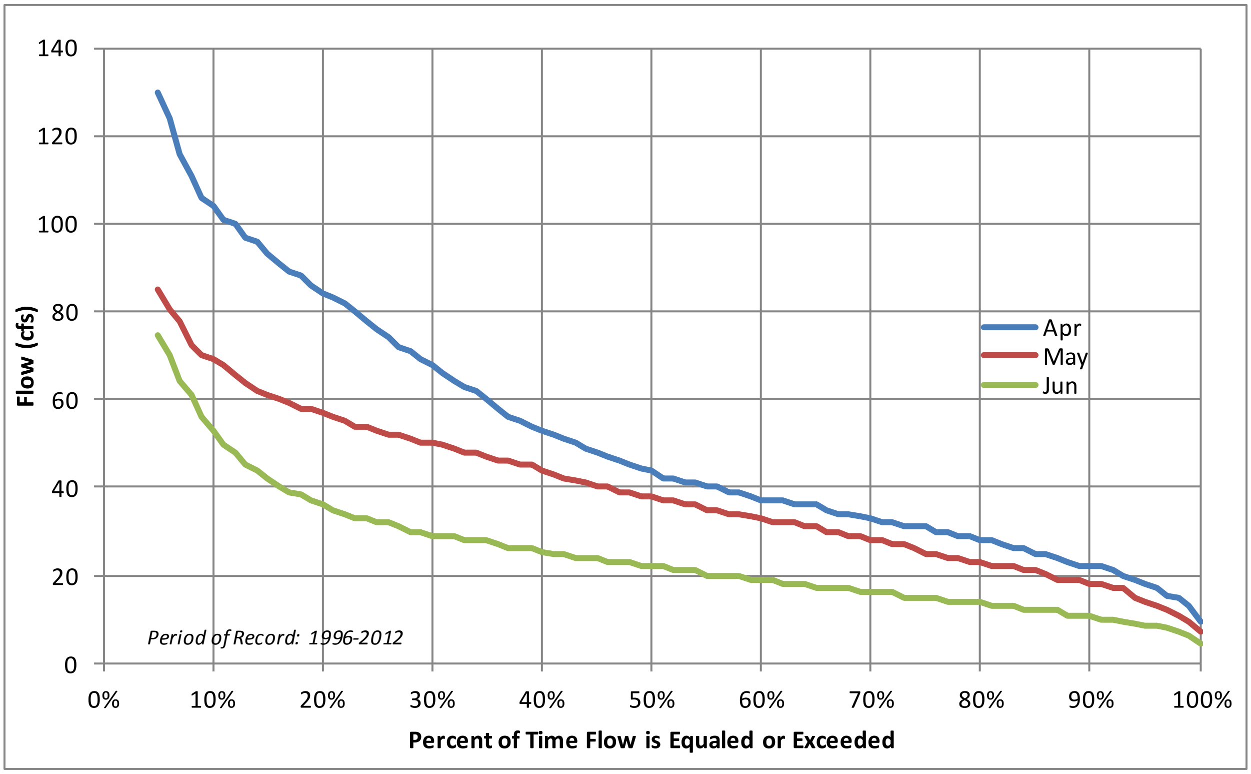


Figure 4.1.1-4: Jul-Sep Flow Duration Curves for Jones River at USGS Gage

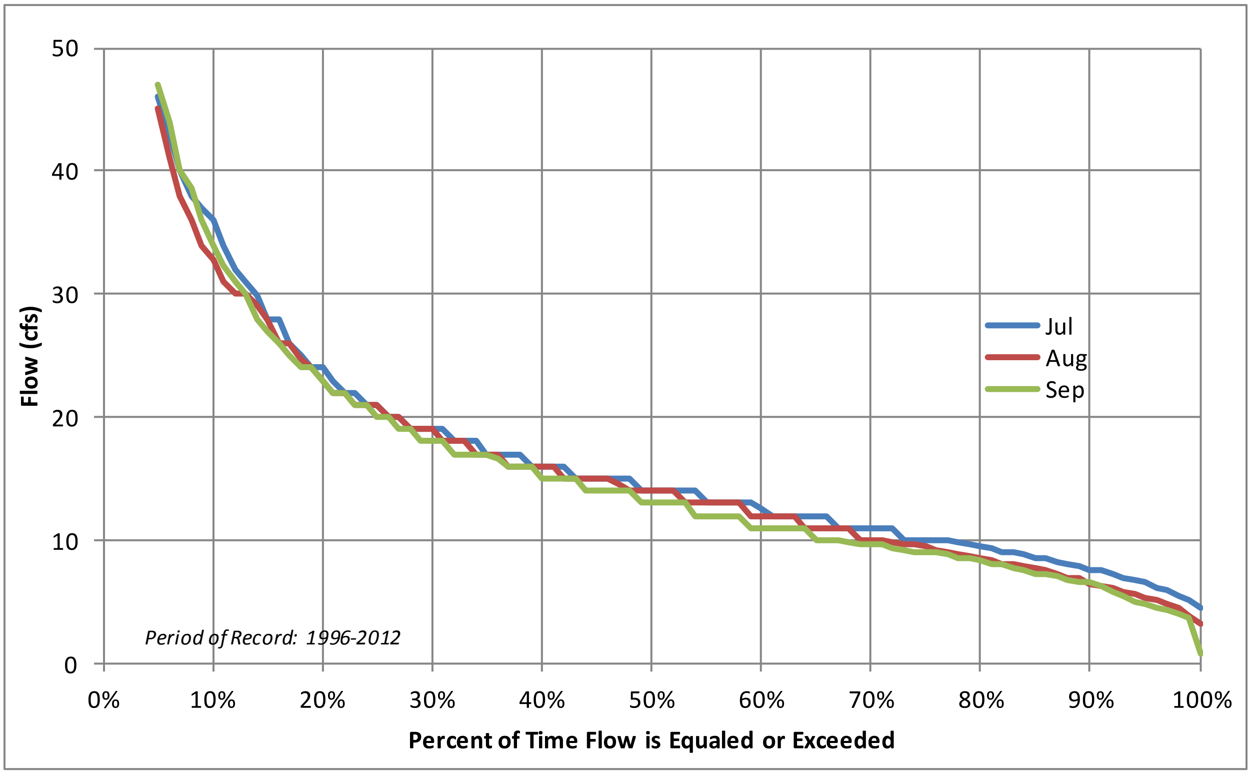


Figure 4.1.1-5: Oct-Dec Flow Duration Curves for Jones River at USGS Gage

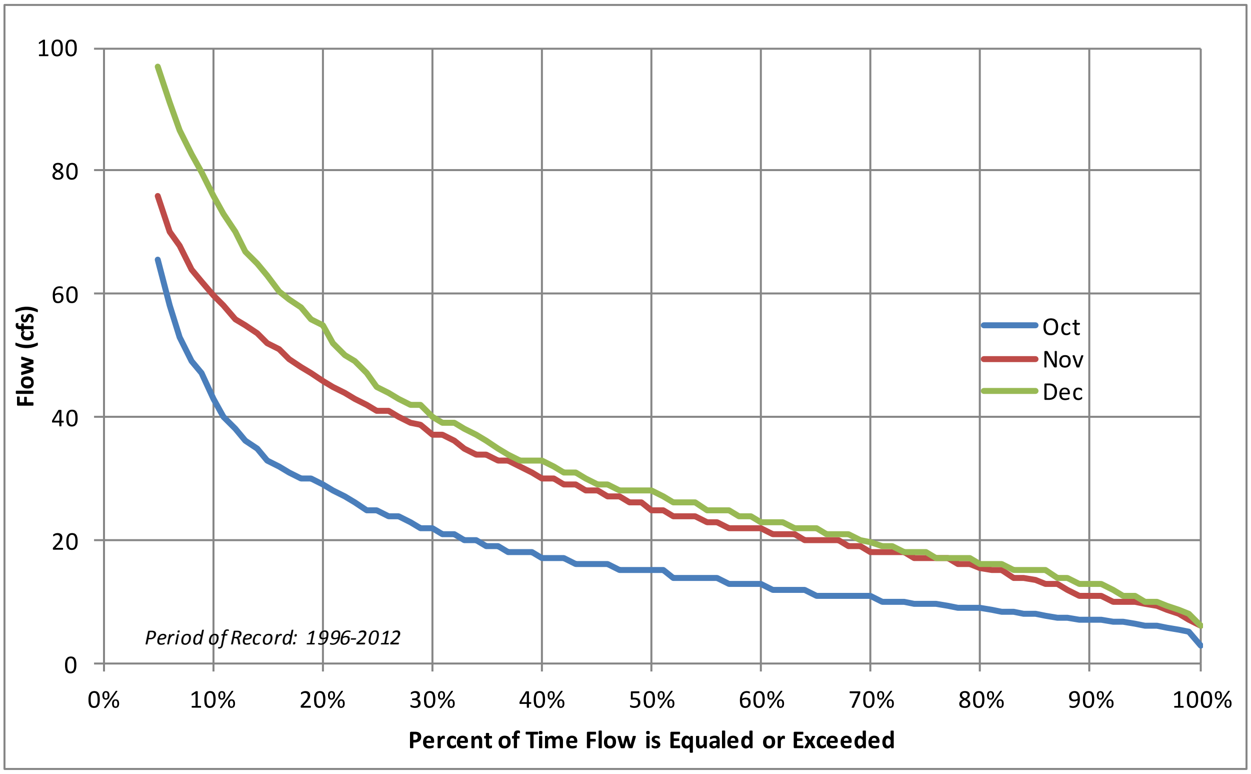


Figure 4.2.1-1: Annual Elevation Duration Curve for Silver Lake

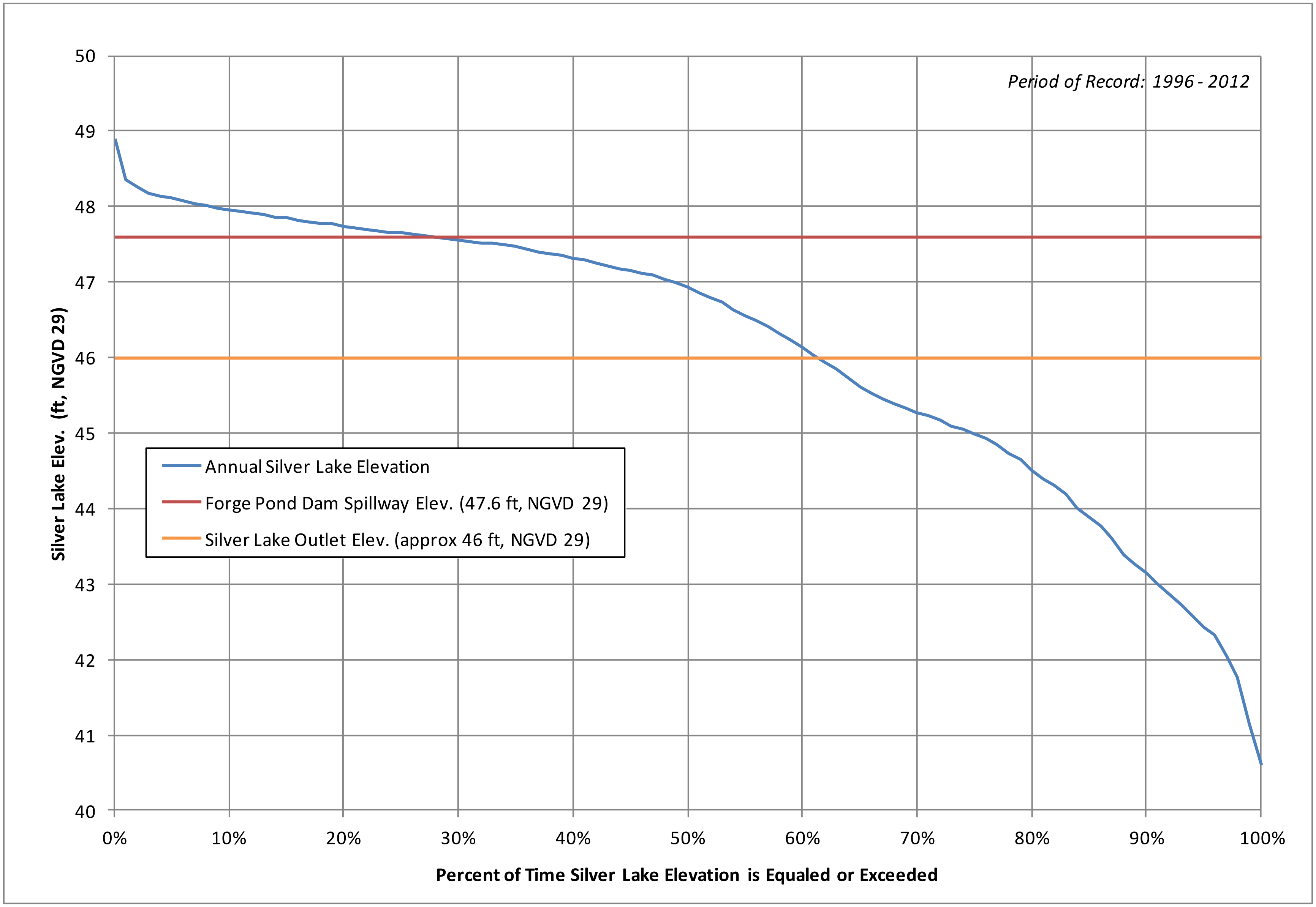


Figure 4.2.1-2: Jan-Mar Elevation Duration Curves for Silver Lake

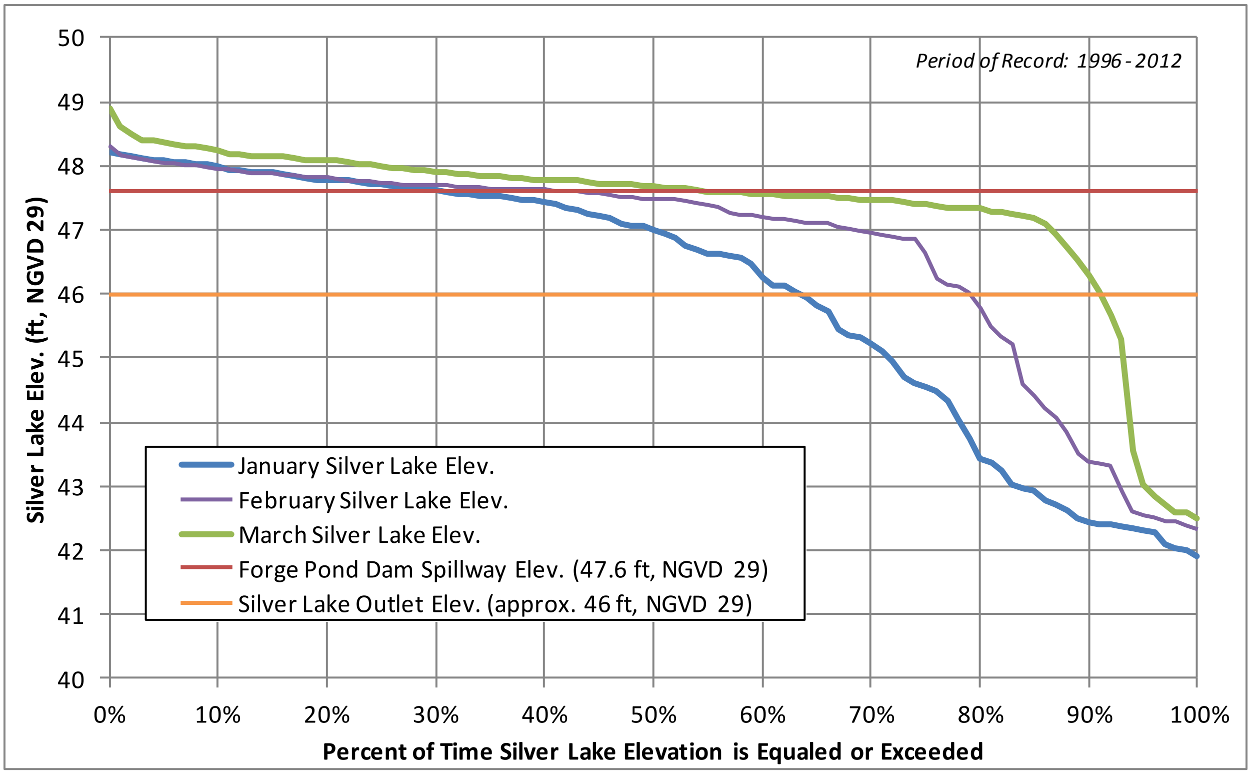


Figure 4.2.1-3: Apr-June Elevation Duration Curves for Silver Lake

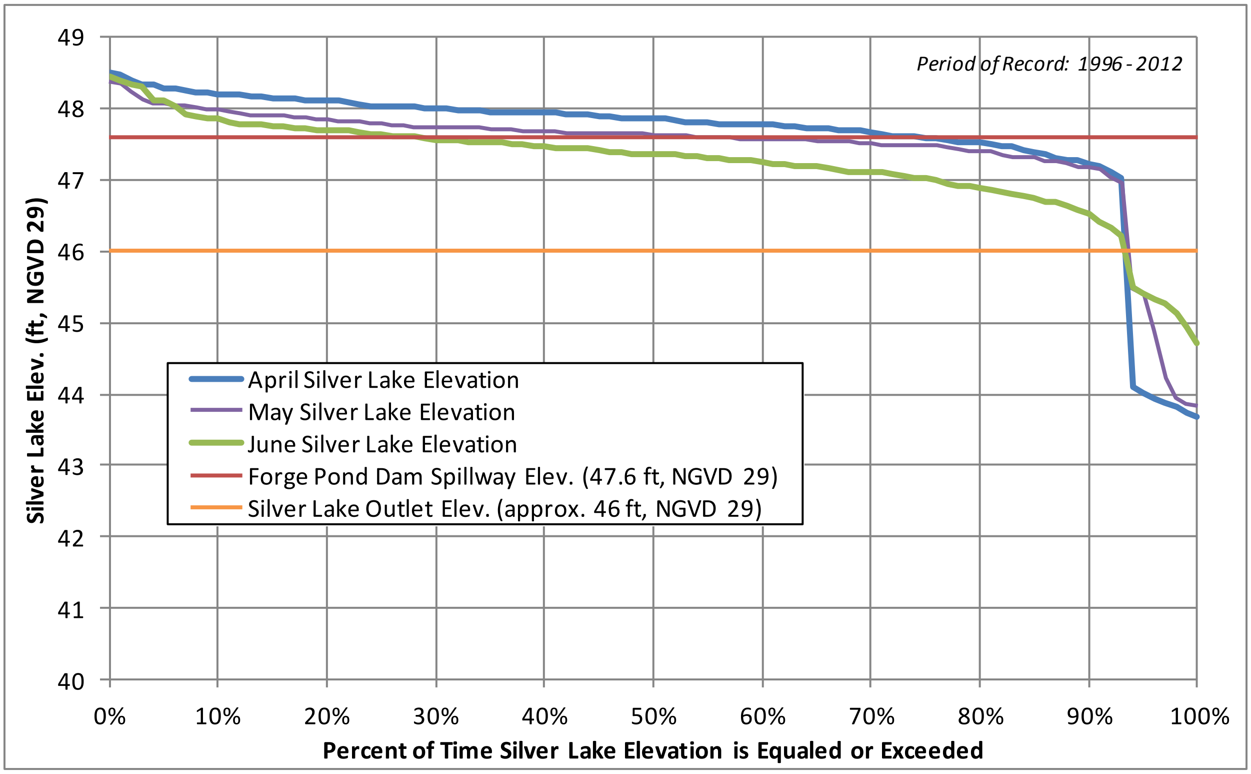


Figure 4.2.1-4: Jul-Sep Elevation Duration Curves for Silver Lake

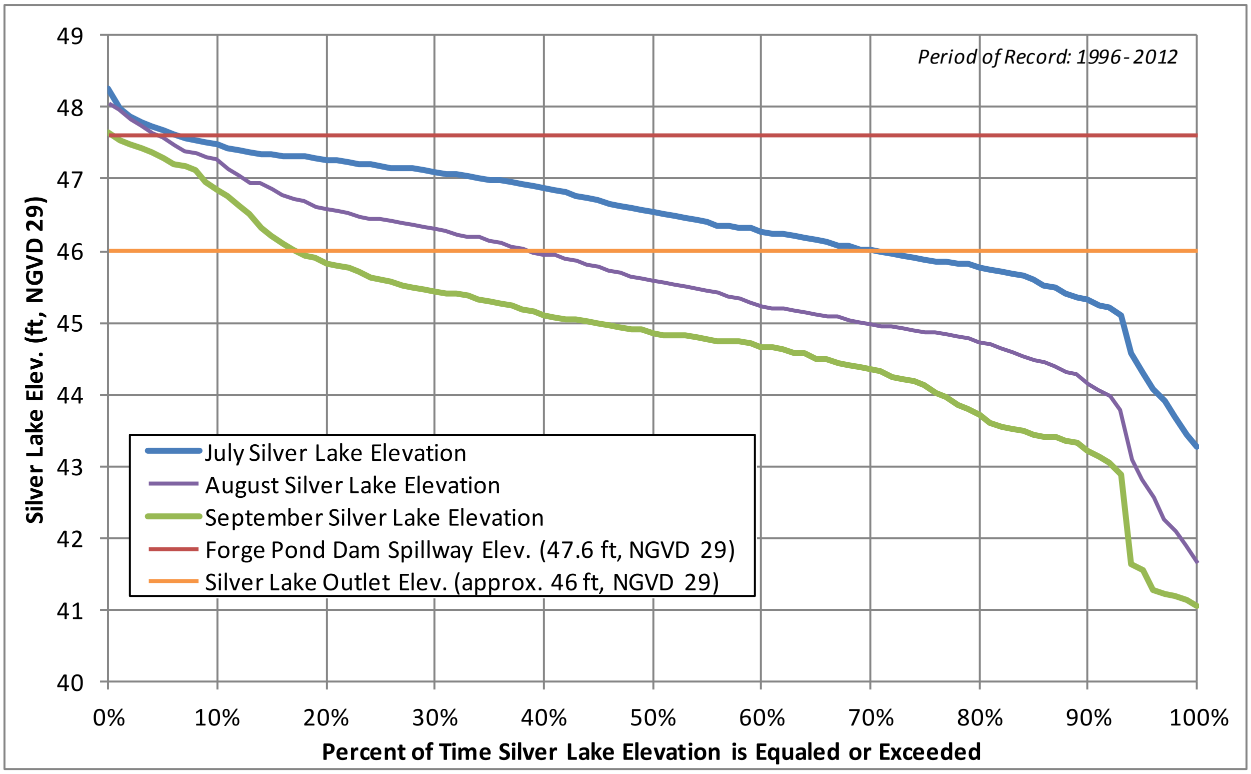


Figure 4.2.1-5: Oct-Dec Elevation Duration Curves for Silver Lake

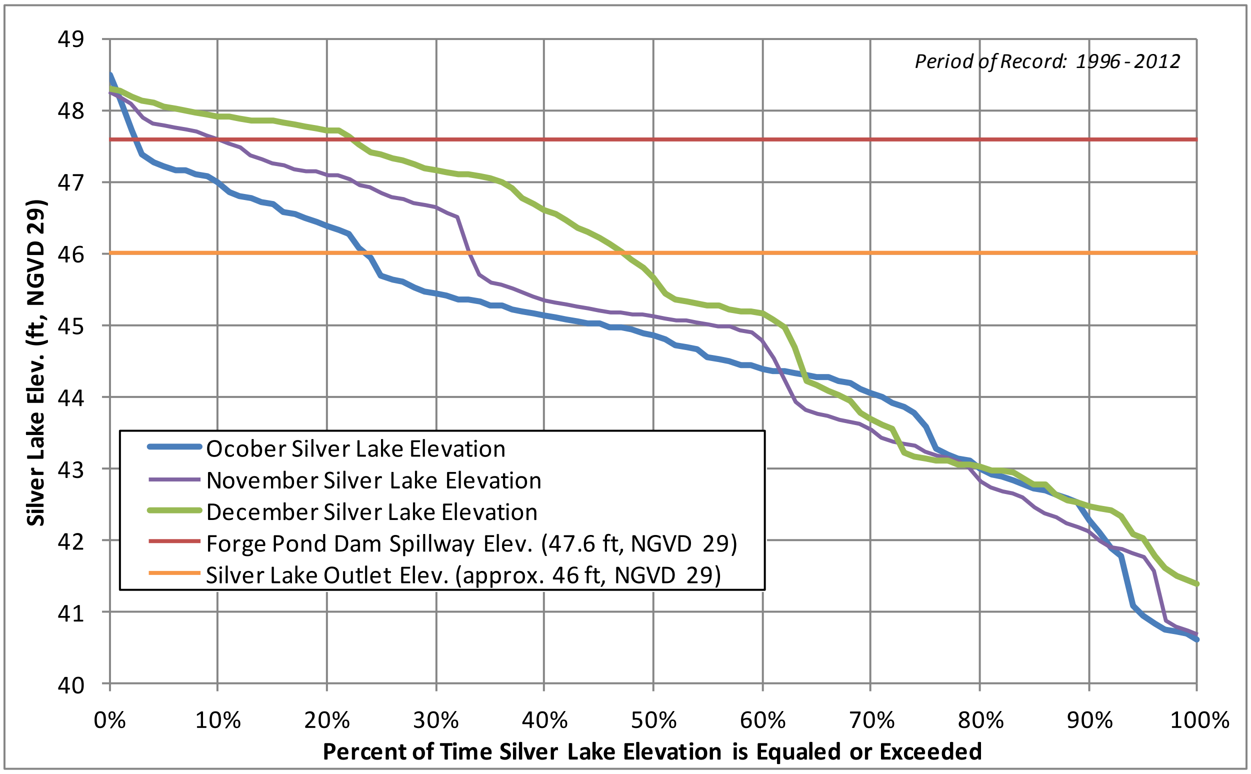


Figure 4.2.1-6: Average Silver Lake Elevation

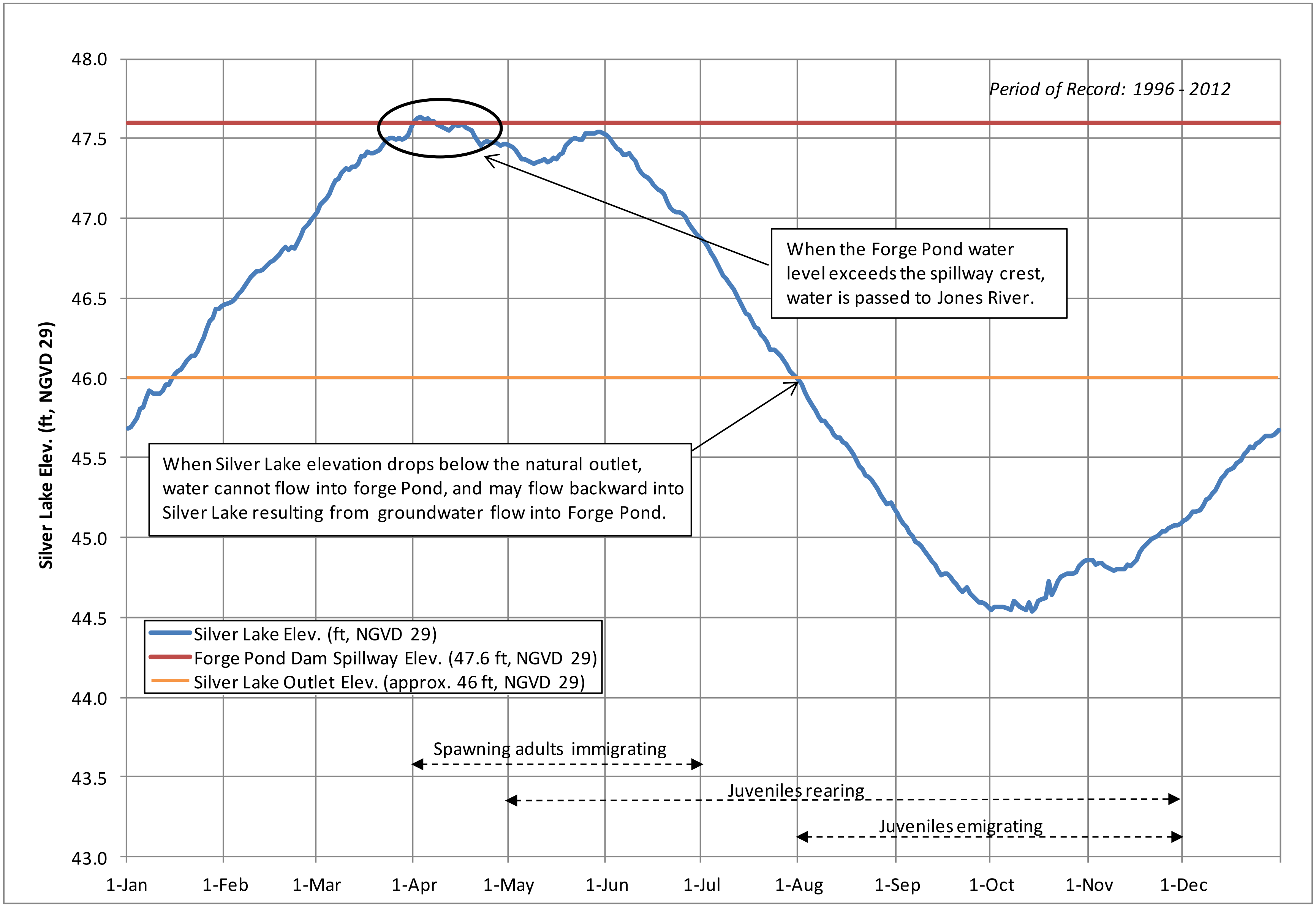


Figure 4.2.2-1: Average Water Supply Diversions into and Withdrawals out of Silver Lake

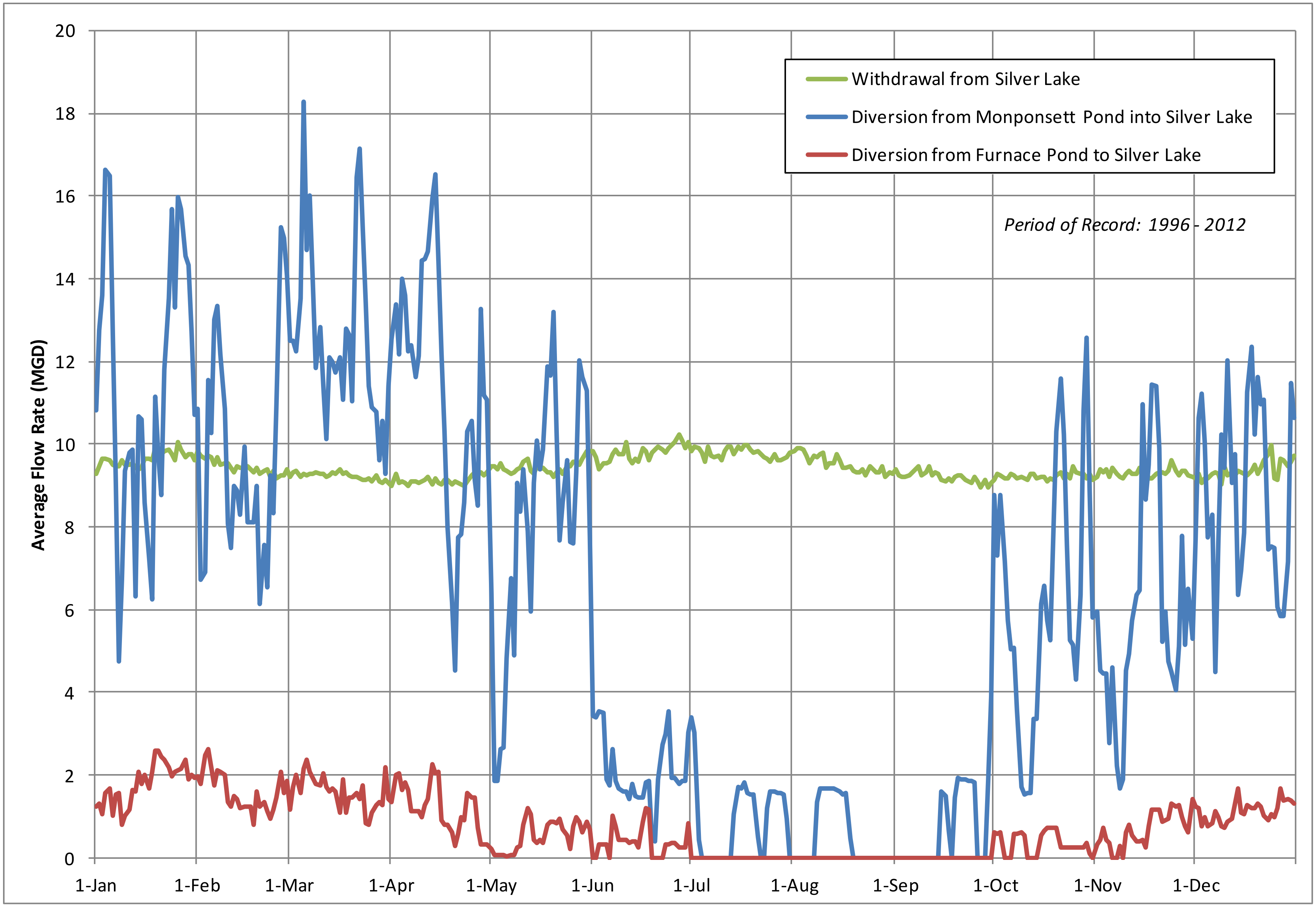


Figure 4.2.2-2: 2002 Silver Lake Elevation with Monponsett and Furnace Pond Diversions

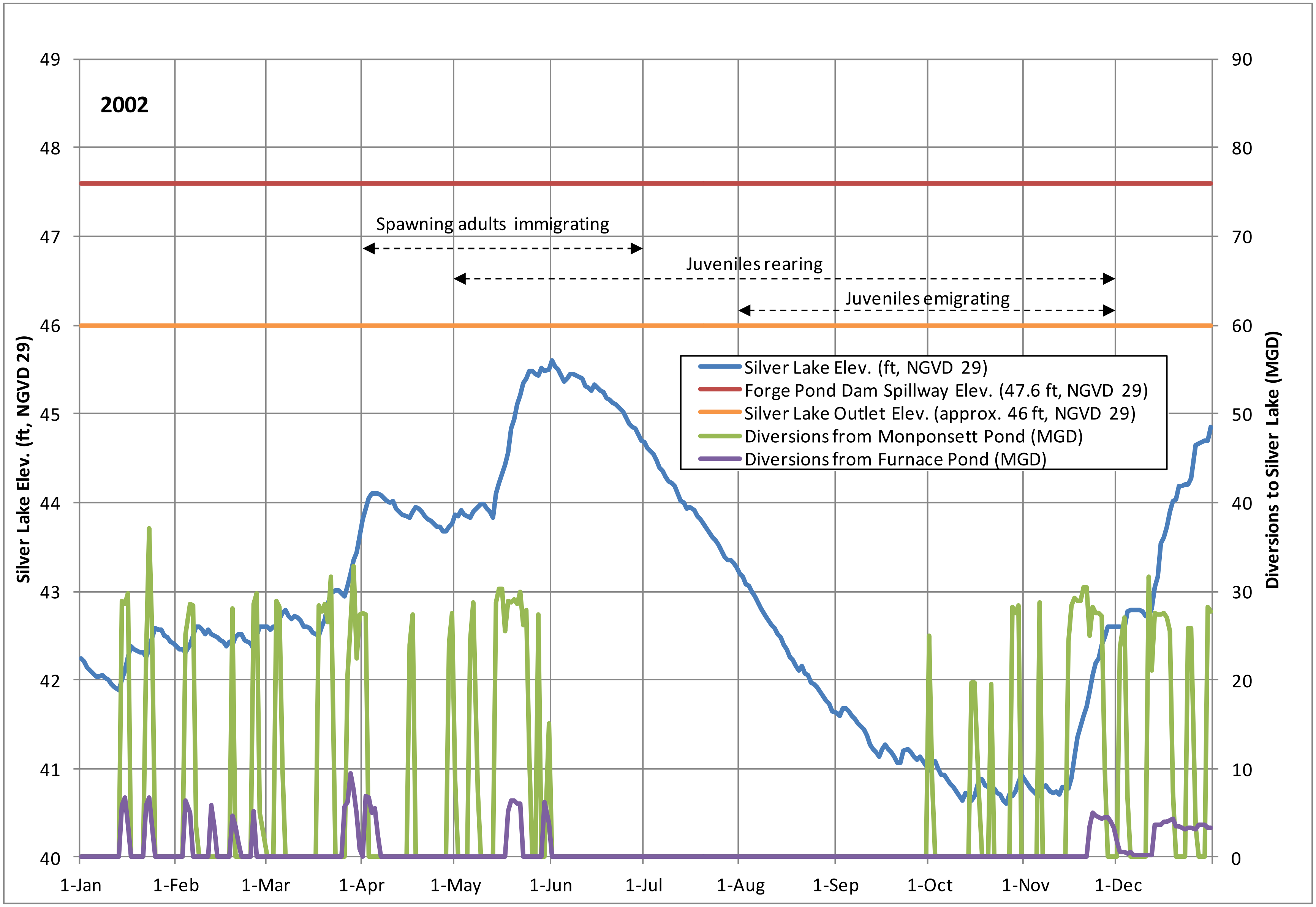


Figure 4.2.2-3: 2003 Silver Lake Elevation with Monponsett and Furnace Pond Diversions

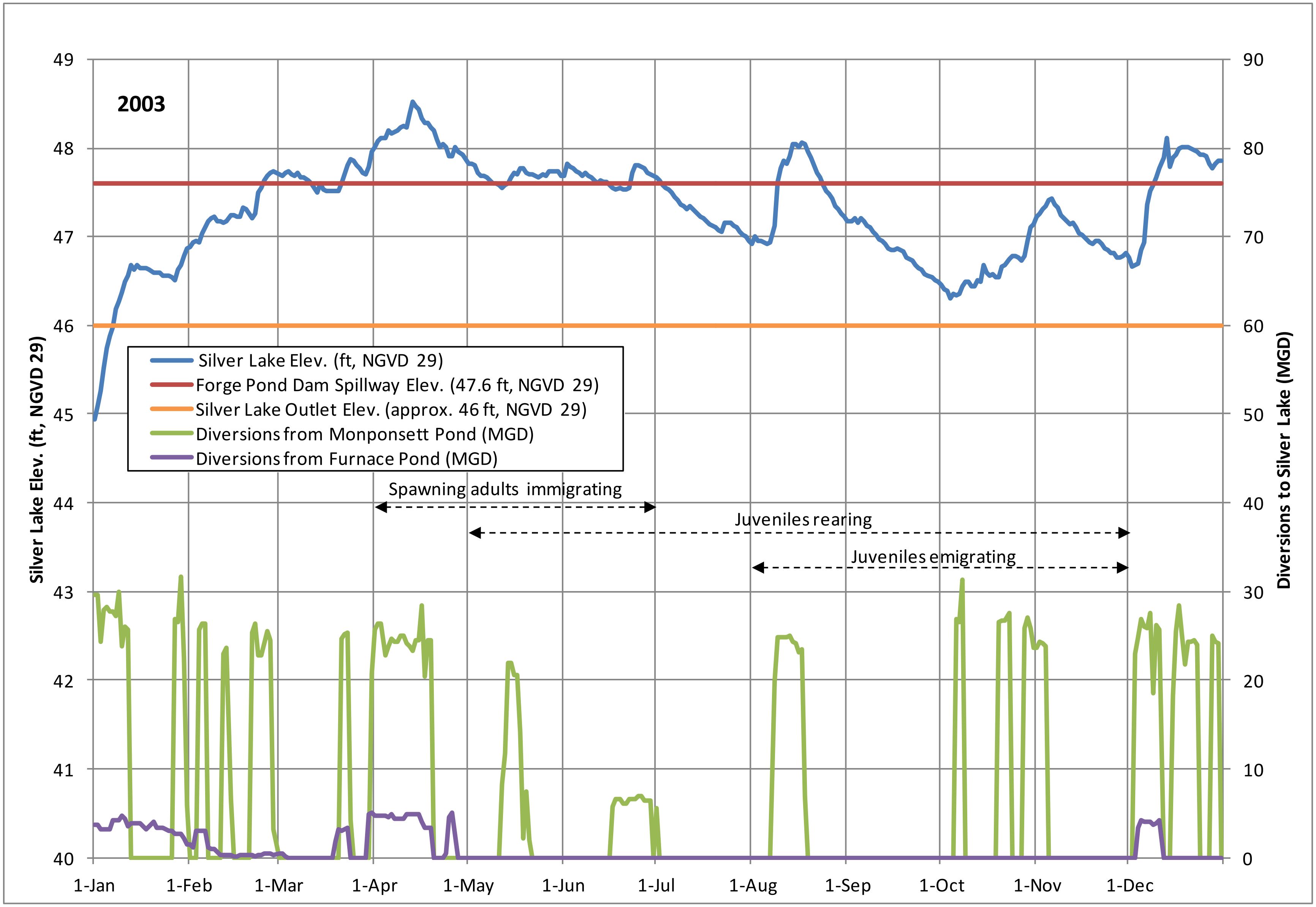


Figure 4.2.2-4: 2004 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

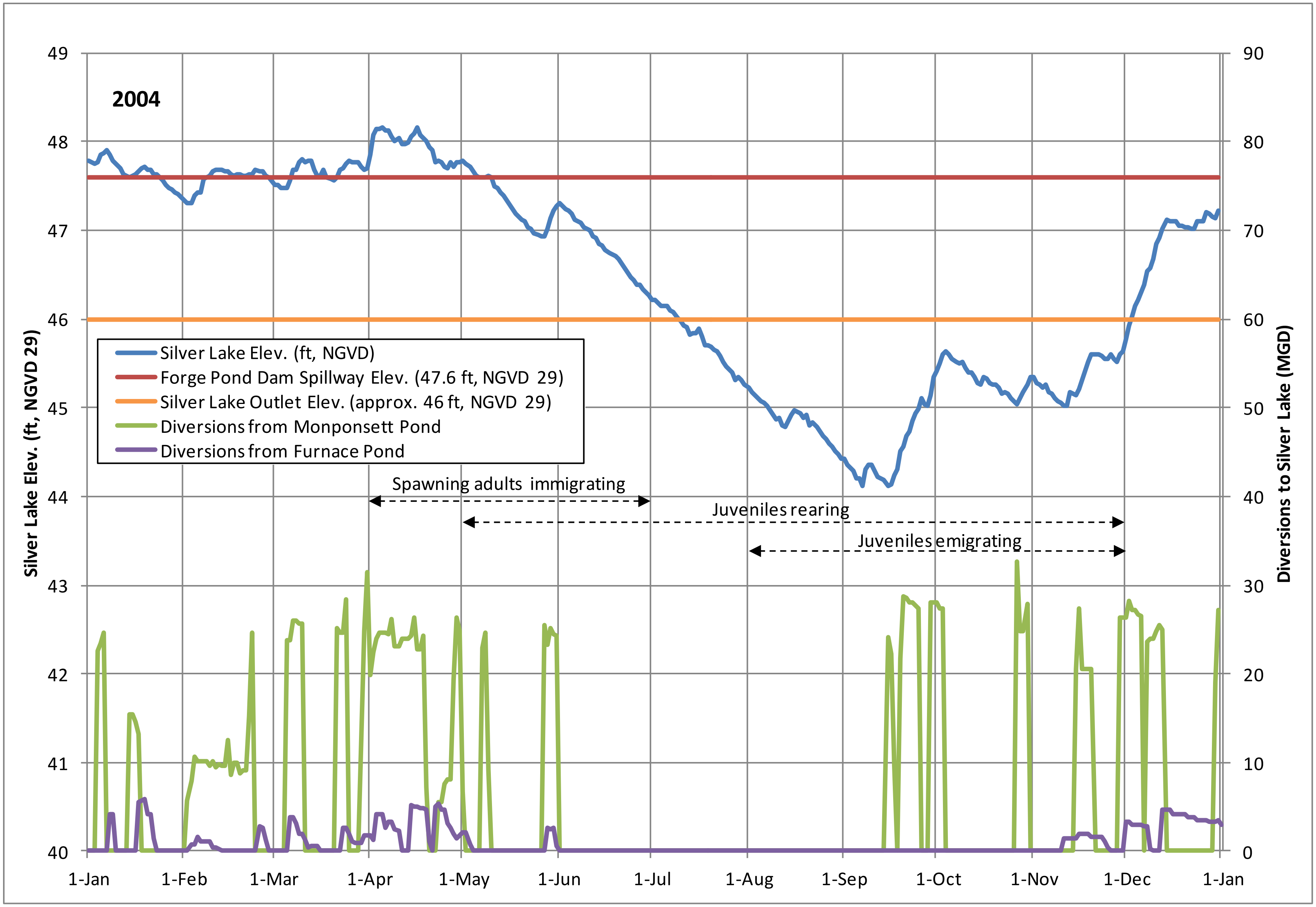


Figure 4.2.2-5: 2005 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

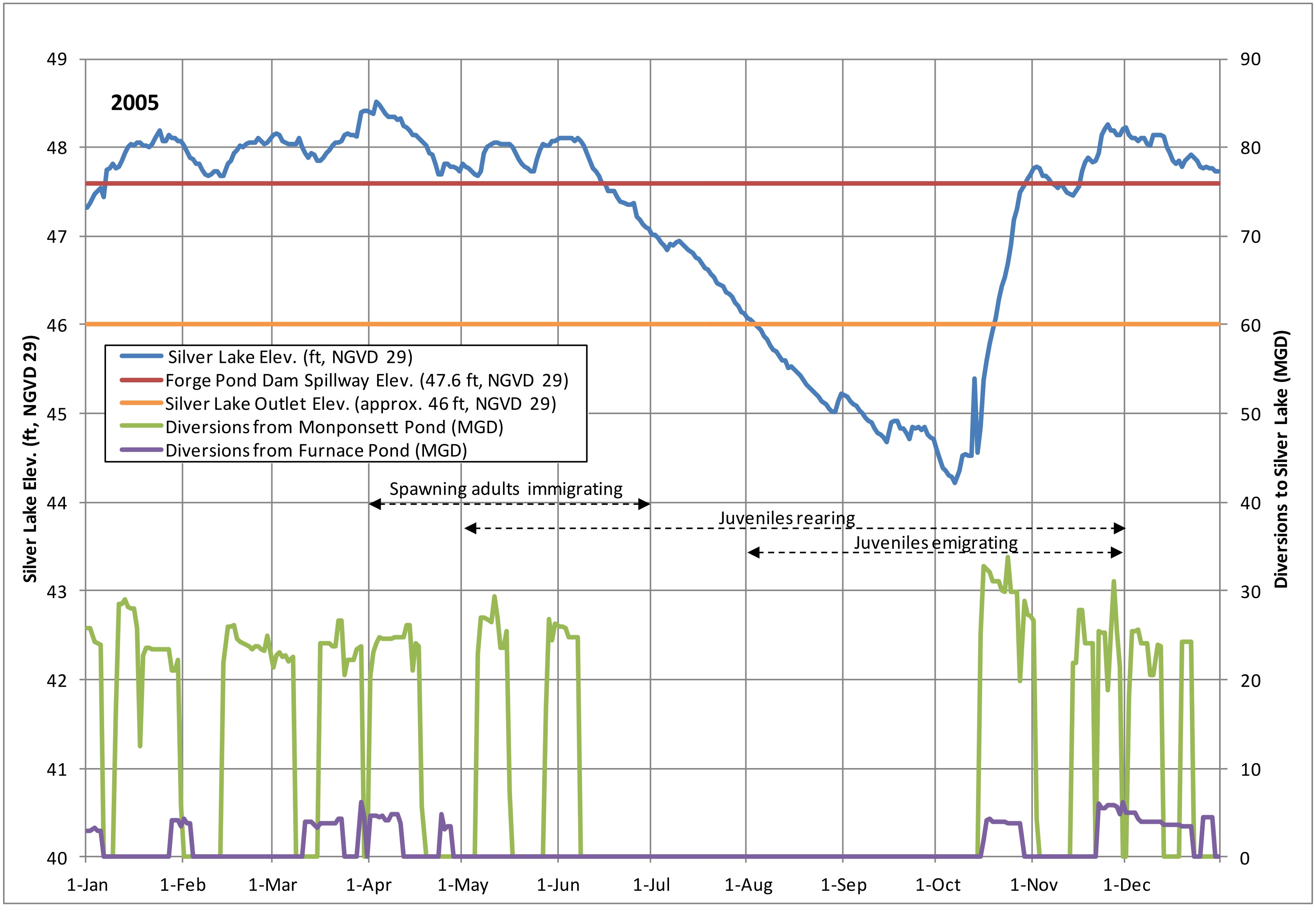


Figure 4.2.2-6: 2006 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

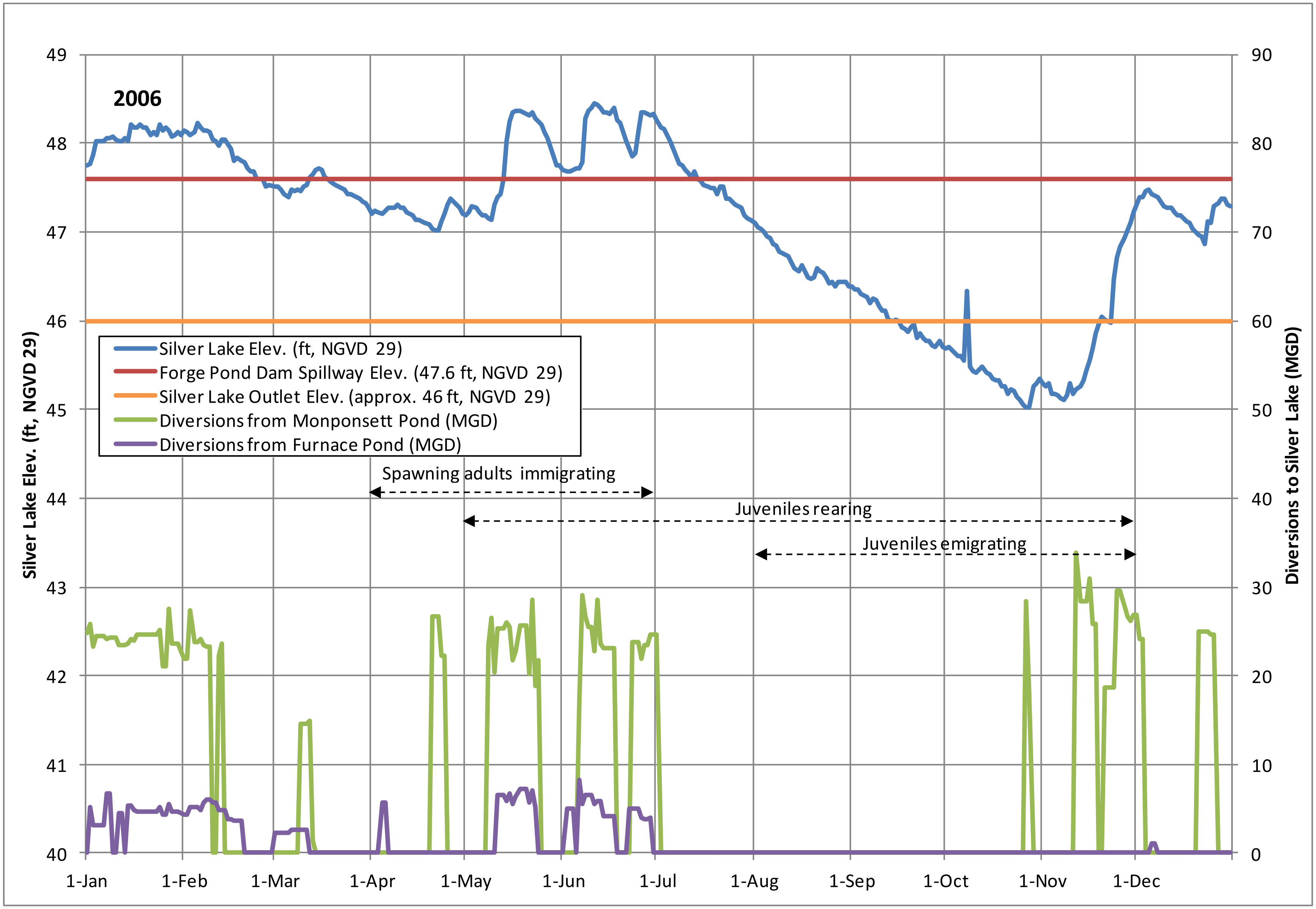


Figure 4.2.2-7: 2007 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

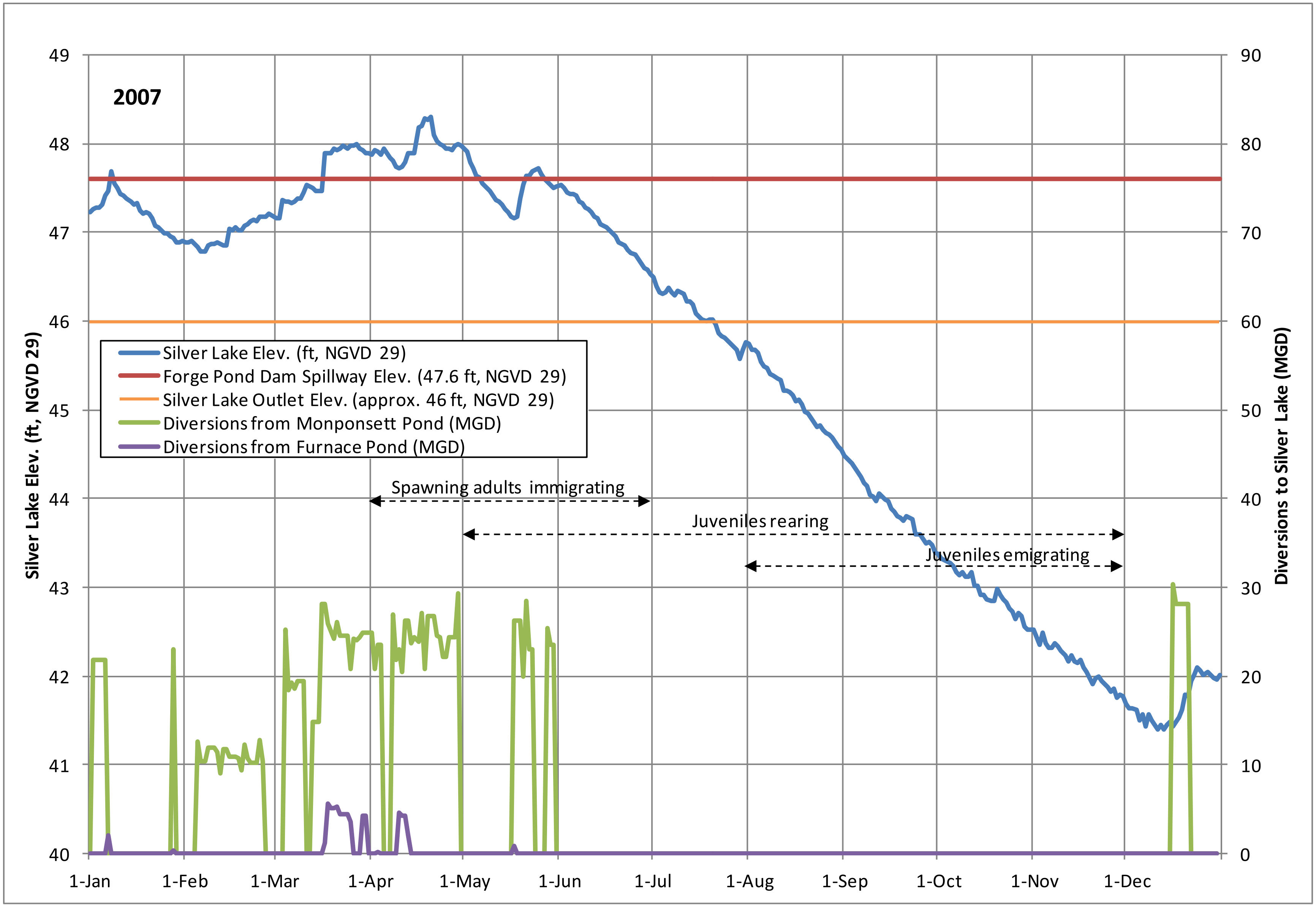


Figure 4.2.2-8: 2008 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

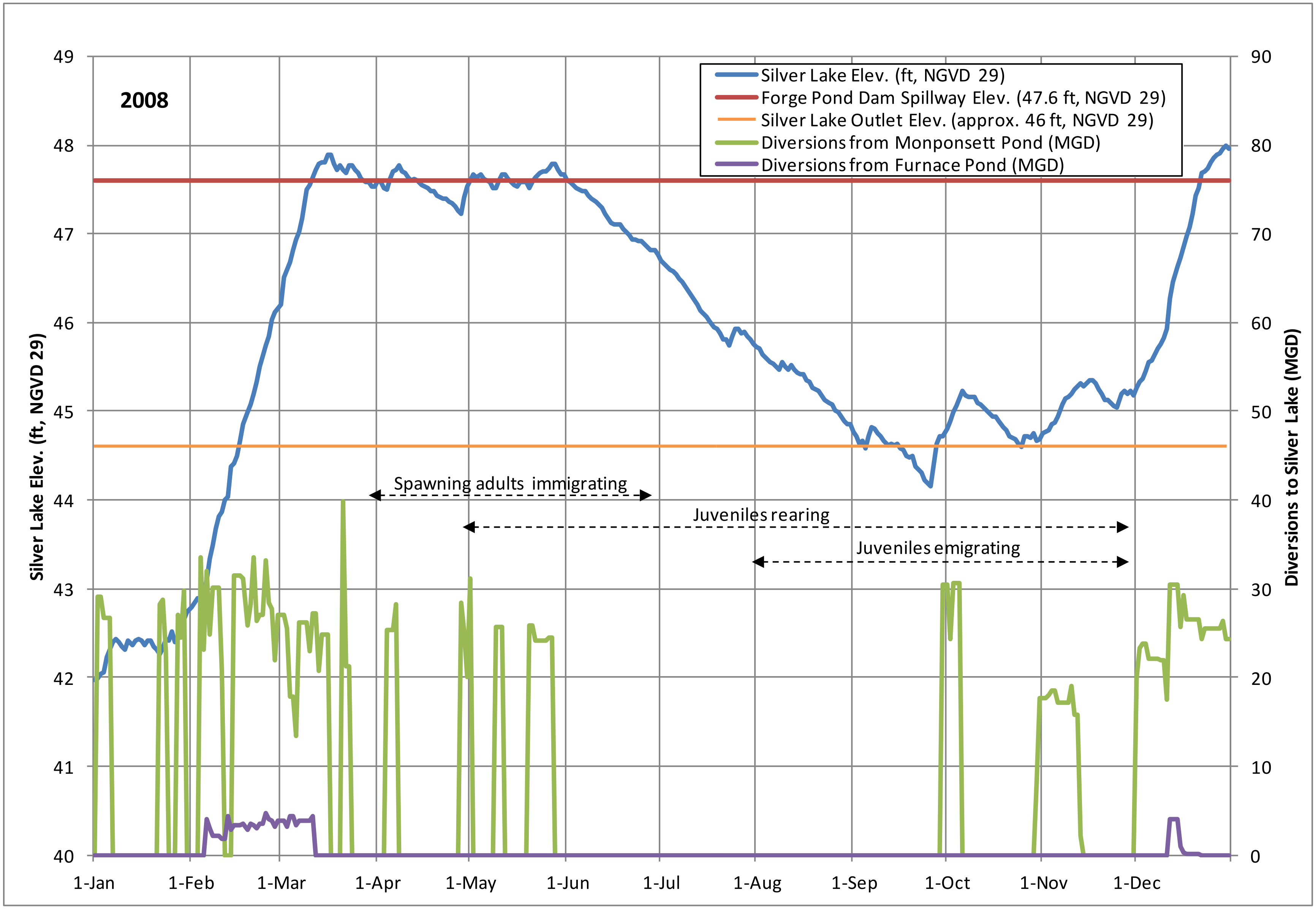


Figure 4.2.2-9: 2009 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

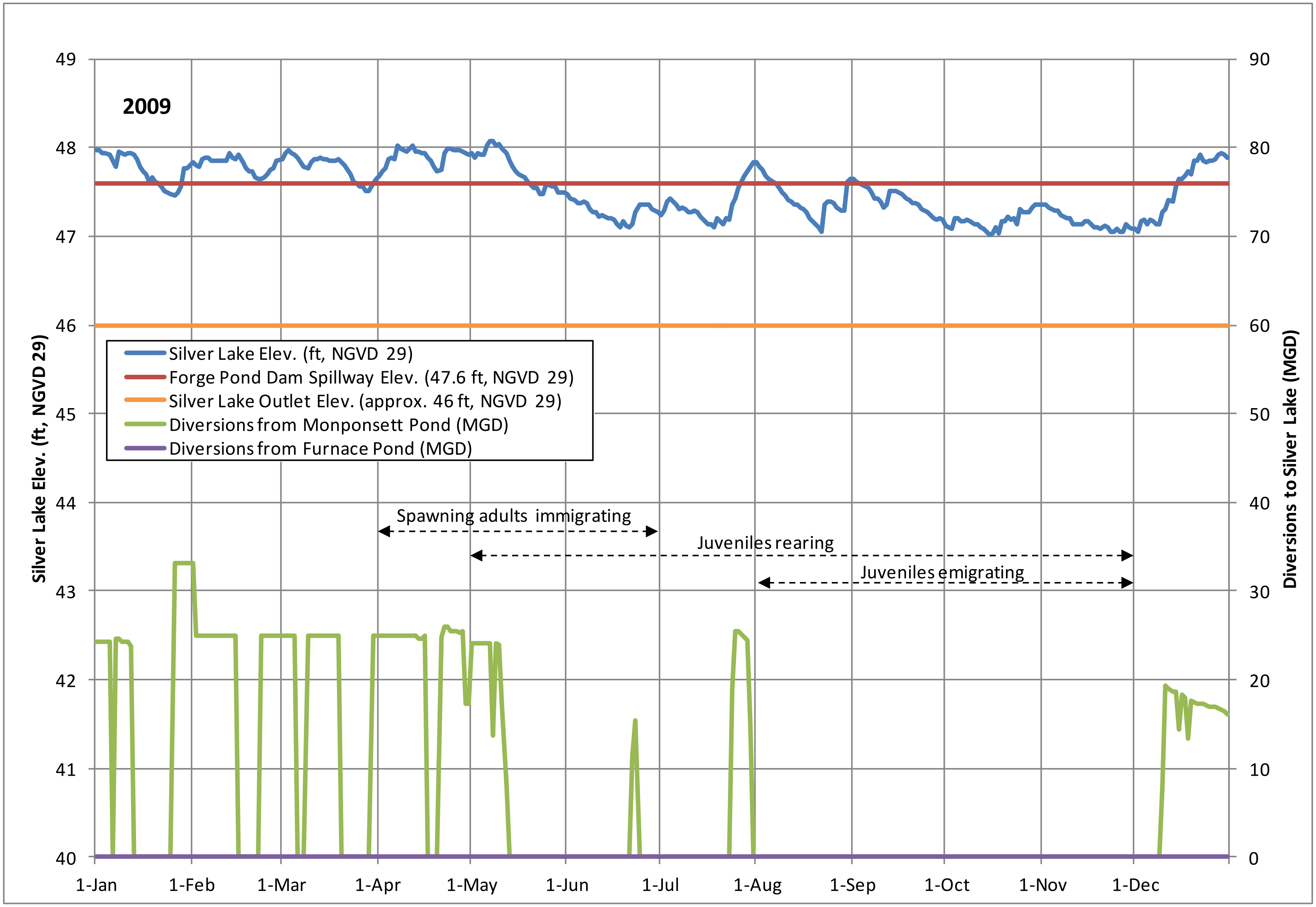


Figure 4.2.2-10: 2010 Silver Lake Elevations with Monponsett and Furnace Pond Diversions

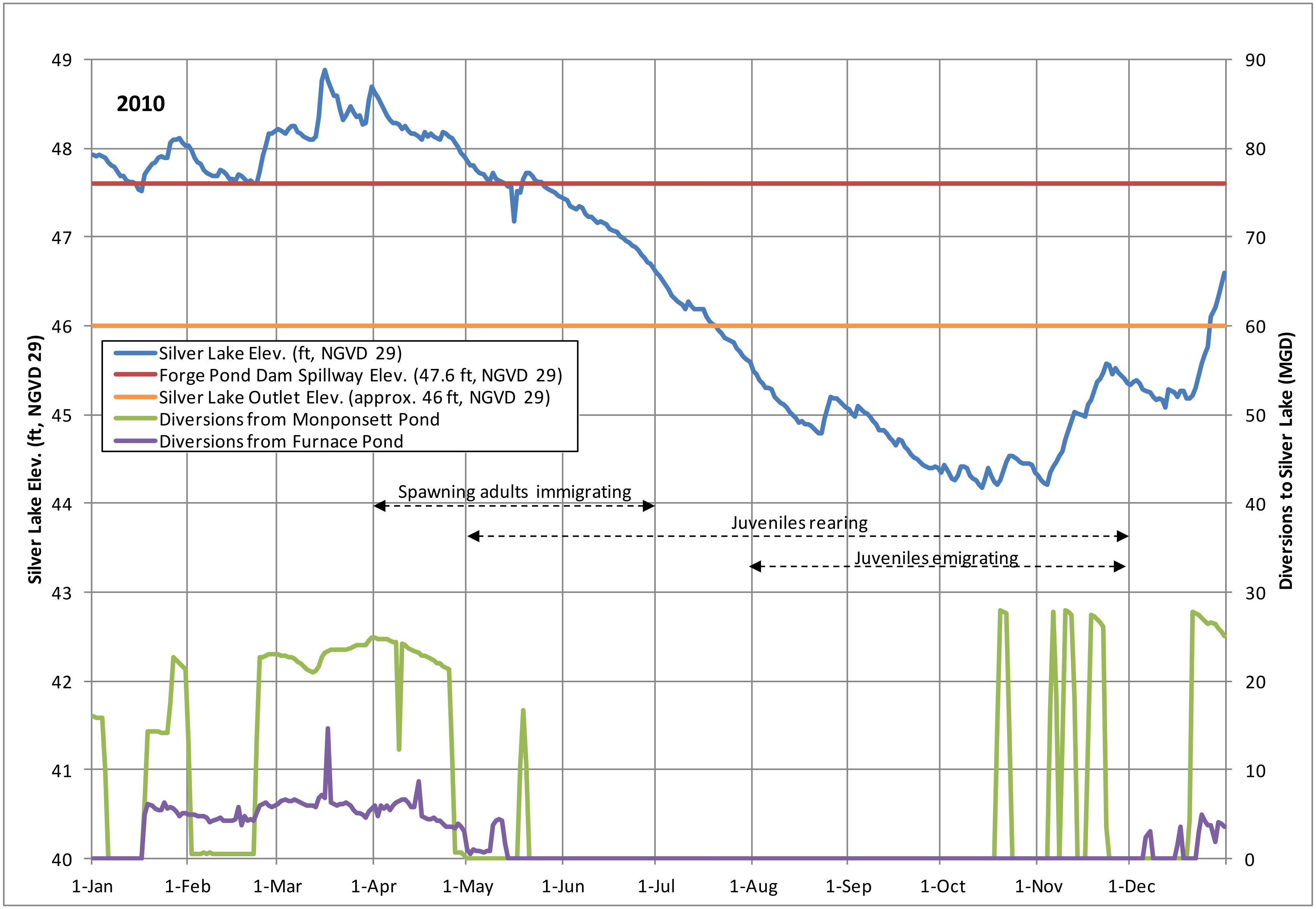


Figure 4.2.2-11: 2011 Silver Pond Elevations with Monponsett and Furnace Pond Diversions

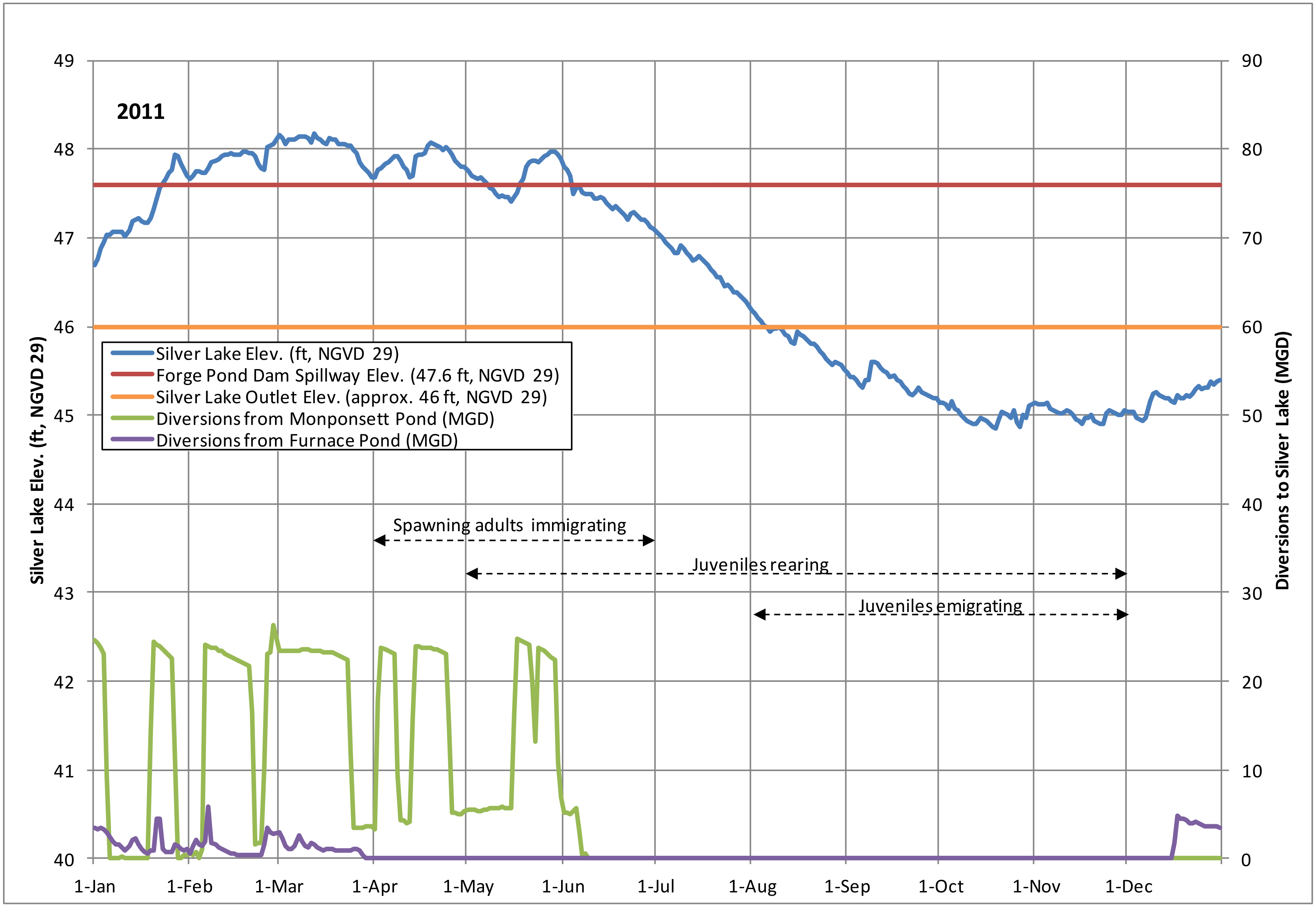


Figure 4.2.2-12: 2012 Silver Lake Elevations with Monponsett and Furnace Pond Diversions