Forge Pond Dam Fish Passage Improvement
Conceptual Design of Site Elements

Jones River, Kingston, MA

FINAL REPORT

Prepared for: Jones River Watershed Association

As a project of the: Massachusetts Environmental Trust

By: Gomez and Sullivan Engineers, P.C.

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# Table of Contents

1. **BACKGROUND** ................................................................................................................................. 1

2. **CONCEPTUAL DESIGN OF SITE ELEMENTS** .................................................................................. 3
   2.1 Forge Pond – Dredging to Enhance Fish Passage ................................................................. 3
       2.1.1 Dredging Options .................................................................................................................. 3
       2.1.2 Dredging Methods ................................................................................................................. 6
       2.1.3 Disposal Options ................................................................................................................... 7
       2.1.4 Construction Access/Staging Areas ...................................................................................... 8
       2.1.5 Permitting Requirements ....................................................................................................... 11
       2.1.6 Additional Studies .................................................................................................................. 12
       2.1.7 Budgetary Opinion of Costs ................................................................................................. 12
   2.2 Forge Pond Dam – Fishway ............................................................................................................. 15
       2.2.1 Budgetary Opinion of Costs ................................................................................................. 17
   2.3 Former Lake Street Bridge – Retrofit to Provide Low Flow Passage ........................................... 19
   2.4 Lake Street Culvert – Retrofit/Replacement to Reduce Velocity Barrier .................................. 20
       2.4.1 Existing Culvert ..................................................................................................................... 21
       2.4.2 Culvert Retrofit Options ....................................................................................................... 22
       2.4.3 Culvert Replacement Options .............................................................................................. 27
       2.4.4 Cost Considerations ............................................................................................................... 32
       2.4.5 Summary ................................................................................................................................. 33
   2.5 Lake Street – Stormwater Management Improvements ............................................................... 34

3. **REFERENCES** .................................................................................................................................... 35
List of Tables

Table 2.1-1: Summary of Forge Pond Dredging Options .......................................................... 14
Table 2.2-1: Budgetary Opinion of Cost to Install Alaska Steeppass Fishway at Forge Pond Dam........ 18
Table 2.2-2: Budgetary Opinion of Additional Cost to Dredge Silver Lake Outlet Channel ............... 18
Table 2.4.2-1: Comparison of Grade Control Methods .............................................................. 27
Table 2.4.3-1: Massachusetts General and Optimum Stream Crossing Standards ........................... 29
Table 2.4.4-1: Installation Cost Increase of Improved Road-Stream Crossings vs. In-Kind Replacements 33

List of Figures

Figure 2.1.1-1: Profile of Potential Dredging of Silver Lake Outlet Channel ..................................... 5
Figure 2.1.4-1: Potential Construction Access Routes/Staging Areas for Forge Pond Dredging .......... 10
Figure 2.2-1: Monthly Forge Pond Elevation Duration Curves during Upstream Migration Showing Percent of Time within Effective Zone for Proposed Alaskan Steeppass Fishway .............................. 16
Figure 2.3-1: Proposed Low-Flow Channel Retrofit of Former Lake Street Bridge .......................... 19
Figure 2.4.1-1: Water Surface Profiles of FEMA FIS Flood Flows through Lake Street Culvert ........ 22
Figure 2.4.2-1: Corner Baffle Design Recommended for Circular Culverts .................................. 24
Figure 2.4.2-2: Water Surface Profiles of Existing vs. Baffled Lake Street Culvert ........................ 25
Figure 2.4.3-1: Elements of a Well Designed Stream Crossing .................................................. 28
Figure 2.4.3-2: Example Stream Crossing Structure Types Meeting Massachusetts Standards ........ 30
Figure 2.4.3-3: Stream Simulation Design Schematic for Stream Crossing Replacements .................. 31

List of Abbreviations

Brockton City of Brockton, MA
cfs cubic feet per second
MADEP Massachusetts Department of Environmental Protection
MADER Massachusetts Division of Ecological Restoration
economic evaluation Economic Evaluation of the Costs and Benefits of the Forge Pond Dam Fish Passage Improvement Alternatives (Industrial Economics, Inc., October 2013)
feasibility study Forge Pond Dam Fish Passage Improvement Feasibility Study and Preliminary Design (Gomez and Sullivan Engineers, July 2013)
FEMA Federal Emergency Management Agency
FIS Flood Insurance Study
JRWA Jones River Watershed Association
LiDAR Light Detection and Ranging
MarineFisheries Massachusetts Division of Marine Fisheries
MassGIS Massachusetts Office of Geographic Information
MET Massachusetts Environmental Trust
NHESP Natural Heritage & Endangered Species Program
NGVD National Geodetic Vertical Datum of 1929
NOAA National Oceanic and Atmospheric Administration
USFWS US Fish and Wildlife Service
USGS US Geological Survey
1. Background

Silver Lake is an approximately 634-acre lake in the towns of Kingston, Pembroke, and Plympton, MA 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. From the natural outlet of Silver Lake, water flows first through Forge Pond, a small (approximately 6-acre) impoundment created by Forge Pond Dam, before spilling to the Jones River. The dam is owned and managed by the City of Brockton as a water control structure for Silver Lake, which serves as part of the City’s water supply. The dam was constructed by the City circa 1905. With the completion of several successful restoration efforts on the Jones River downstream, including the removal of Wapping Road Dam in 2011, Forge Pond Dam presents the only major barrier to fish passage into 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.

Feasibility Study

In July 2013, Gomez and Sullivan Engineers, PC (Gomez and Sullivan) evaluated the feasibility of restoring populations of river herring and American eel to Silver Lake in Kingston, MA and produced the Forge Pond Dam Fish Passage Improvement Feasibility Study and Preliminary Design ("feasibility study") report for the Massachusetts Division of Marine Fisheries (MarineFisheries). The project received financial and in-kind support from the following partners: MarineFisheries, National Oceanic and Atmospheric Administration (NOAA), the City of Brockton, the Massachusetts Department of Fish and Game, the Massachusetts Division of Ecological Restoration (MADER), and the Jones River Watershed Association (JRWA).

The study demonstrated that fish passage into Silver Lake is feasible. The fish passage alternatives investigated included a fish ladder, a nature-like bypass channel, and partial as well as full dam removal. It was determined that a minimum flow of 3 cubic feet per second (cfs), identified as a target flow to meet certain fish passage biological thresholds, could be provided during fish passage seasons within the existing constraints of the water supply system. However, this feasibility study did not produce a preferred option based on recommendations of MarineFisheries, the project partners, and the City of Brockton. Instead, the study raised additional questions; in particular, how to reconcile restoration targets with water supply requirements.

A portion of funding secured from the Massachusetts Environmental Trust (MET) by the JRWA in 2012 has been used to conduct further analyses to begin to address these questions and advance the project, as discussed below.

Economic Evaluation

In October 2013, Industrial Economics, Incorporated (IEc) evaluated the potential financial impacts of fish passage alternatives on the City of Brockton and produced the Economic Evaluation of the Costs and Benefits of the Forge Pond Dam Fish Passage Improvement Alternatives ("economic evaluation") report for JRWA. This report also considered the potential economic benefits of ecological improvements generated by the fish passage improvements. The evaluation found that that the service Brockton provides to its residential customers is relatively inexpensive, compared to water rates in both the nearby communities and in similarly sized communities throughout the nation. Evaluation of incremental costs associated with the proposed fish passage alternatives indicated that all of the scenarios would result in only minor increases in the cost per household, and thus appear to be
affordable. Complicating factors, however, include the City’s current socio-economic conditions, the Brockton water department’s need to resume its maintenance and capital replacement activities, and the current lack of political support to institute rate increases.

**Conceptual Design of Site Elements**

The focus of this phase of the Forge Pond Dam Fish Passage Feasibility Study was to advance the conceptual design of certain elements of the entire site to aid discussions with project partners. This study addressed particularly challenging aspects of the site design that could apply to any alternative, including (from upstream to downstream order):

- **Forge Pond** – dredging to enhance fish passage
- **Forge Pond Dam** – fish passage alternative (see discussion below)
- **Former Lake Street Bridge** – retrofit to provide low flow passage
- **Lake Street Culvert** – retrofit/replacement to reduce velocity barrier
- **Lake Street** – stormwater management improvements

In terms of ecological benefit, the greatest improvement would be achieved through full dam removal. However, under the current water supply uses and practices, this option would not provide appropriate flow or other conditions to consistently pass the target species. Changes to water supply practices require long-term planning and coordination. Therefore, at this time, installing a fish ladder to provide passage above the dam in conjunction with dredging to attain water quality and depth improvements in Forge Pond is recommended as the most effective short-term remedy. This approach would provide the most rapid benefit to the target species and is an effective first step in a phased long-term restoration approach.

A plan view of the site depicting the locations of these elements is shown in Drawing 1 of Appendix A. Conceptual design alternatives for these site elements are discussed in more detail below.
2. Conceptual Design of Site Elements

2.1 Forge Pond – Dredging to Enhance Fish Passage

Sediment has accumulated in the natural outlet channel of Silver Lake and throughout Forge Pond due to the backwater effect of the dam, which raised the level of the Jones River and Silver Lake, lack of flow, and prevailing westerly wind which causes wave run-up from Silver Lake. It is possible that the outlet and/or flow path channel through the pond may naturally lower over time due to the proposed more continuous flow regime throughout the year. However, dredging to restore the naturally lower thalweg of the outlet channel would reduce the water surface elevation at which the disconnect between the two water bodies occurs, thus improving fish passage. Furthermore, dredging along the main flow path or perhaps throughout the pond may enhance the navigability of the pond for fish.

As shown in the aerial image of Forge Pond below, dense aquatic vegetation typically grows across its surface during much of the year, making it more of a flooded wetland than an open water body. The narrower channel of the former Jones River can also be seen in this image.

![Source: Google Maps](image)

A bathymetry survey of Forge Pond was conducted in 2003 by Coler & Colantonio (see Appendix A of the feasibility report for a map). A series of water depth transects were collected throughout the pond. In addition, 17 sediment depth measurements were collected, typically along the main flow path. According to the survey, water depths were shallow—between approximately 1 and 3 feet across much of the pond. 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.

2.1.1 Dredging Options

The following dredging options were investigated in this study:

1. Passive sediment management (no dredging)
2. Dredging of Silver Lake outlet channel only
3. Dredging of main flow path through pond
These options are discussed in more detail below. A summary of the discussion is provided in Table 2.1-1 at the end of this section.

**Option 1 – Passive Sediment Management (no dredging)**

Passive sediment management is the “no action” alternative to dredging. This option would involve allowing sediment to be transported downstream naturally over time due to the increased flow volume and velocity of a fish passage release. This approach could be taken in either a scenario where the dam remains in place (e.g., a fish ladder), or in a dam removal scenario. In a dam-in scenario, sediment volumes expected to mobilize and permitting requirements would be similar to Option 2 below (dredging of Silver Lake outlet channel only); whereas a dam-out scenario would be similar to Option 3 below (dredging of main flow path through pond). In either case, sediment could be passively managed as the first step in a phased approach, after which the need for dredging could be reassessed if project targets for flow depths and velocities are not achieved.

**Option 2 – Dredging of Silver Lake Outlet Channel Only**

Using the 2003 bathymetry data, it was determined in the feasibility report that the lowest elevation to which the outlet channel could be dredged, without dredging the entire pond, would be approximately 45 feet¹ (NGVD 29). This scenario would involve shallow dredging (about 1.2 feet maximum) along approximately 600 feet of channel below the outlet. See Figure 2.1.1-1 below for a profile and Drawings 2 and 3 in Appendix A for plan and cross-sectional views of the potential dredging area.

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¹ Elevations in this report are given in North American Vertical Datum of 1929 (NGVD 29).
Note that the "Main Channel Distance" is relative to the downstream end of the HEC-RAS hydraulic model developed for the feasibility study (just below the Grove Street and railroad culverts). Labeled cross-section stations correspond to those shown on the plan and sectional views of the proposed dredging plan in Drawings 2 and 3 of Appendix A, respectively. Sediment elevations are approximate as they are based on a 2003 survey Coler & Colantonio.

Rather than dredging to a uniform depth across the entire width of the channel in this area, it is envisioned that the dredged channel would be of similar dimensions to the reference cross-section identified in the feasibility report (Figure 4.1.5-1 in that report). This approach will focus flow in a narrower area resulting in higher depths and velocities, which will likely help to reduce the future deposition of sediment and the need for maintenance dredging. Assuming an approximately 2-foot bottom width and 4:1 (vertical to horizontal) side slopes to meet existing grade, it was estimated that a total volume of about 50 cubic yards (CY) would need to be removed. See cross-sections of proposed dredging area in Drawing 3 of Appendix A.

Based on discussions with dredging contractors, it does not appear to be common practice to apply bank stabilization measures to a dredged channel that will remain submerged underwater. However, channel sides may be sloped to help prevent ‘slumping’ of sediment back into the dredged channel. Due to the nature of underwater dredging methods (described below), slopes and channel dimensions will be approximate, and some slumping may still occur depending on the sediment composition. It is suggested that a slightly wider and deeper channel be dredged to accommodate for potential slumping. This will likely increase the sediment volume estimate for this option above 50 CY; however, it would be
beneficial to keep the volume under the threshold of 100 CY, which triggers certain permitting requirements (discussed below).

**Option 3 – Dredging of Main Flow Path through Pond**

The option of dredging the main flow path through the pond from the natural outlet of Silver Lake to Forge Pond Dam was originally considered for both dam-in and dam-out scenarios, but early investigations eliminated its viability if the dam remains in place. Due to the limitations of the existing elevation of sediment throughout much of Forge Pond (below 45 feet, see Figure 2.1.1-1 above), the proposed invert elevation of a potential fish ladder within the dam spillway (45.5 feet, see Drawing 4 in Appendix A), and the minimum projected Silver Lake/Forge Pond water surface elevation with a seasonal fish passage release (approximately 45.2 feet, see Figure 6.1.3-3 in the feasibility report), there is not much benefit to be gained by dredging a channel below the elevation of 45 feet through the pond. Therefore, Option 2 above (dredging the outlet channel only) is the recommended dredging plan for dam-in alternatives, with consideration also given to passive sediment management (Option 1) as a first phase.

However, for a potential dam removal scenario, if sediment is not permitted to transport naturally downstream (which may be the case due to potential impacts of sedimentation on habitat and/or infrastructure), this option may be the best alternative. In a dam-out scenario, it would be considered more of an excavation than a dredging project, because the pond would likely be dewatered first. In addition, stabilization of the channel, banks, and new floodplain with stone protection, bioengineering methods, and/or plantings would be recommended to ensure the sustainability of the project and the achievement of target fish passage parameters.

In the feasibility study, this scenario was modeled by replacing existing cross-sections with the reference cross-section (see Figure 4.1.5-1 of the feasibility report) along a constant channel invert slope from the Silver Lake outlet to the base of the existing dam (approximately 0.2%). 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 stabilization measures. It was determined that approximately 0.05 to 2.0 feet of sediment would need to be removed from the existing channel, yielding a total conservative volume estimate of 1,000 to 2,000 CY (1,500 feet long x 10-15 feet wide x 2 feet deep, which is conservative due to anticipated reuse of sediment for grading of channel slopes).

### 2.1.2 Dredging Methods

Dredging involves mechanically raking or hydraulically scouring the bottom of a waterway to dislodge sediment, which is then lifted out of the water either mechanically, as with buckets, or hydraulically, through a pipe. Mechanical dredges offer the advantage of removing the sediments at nearly the same solids content as the in situ material. In contrast, hydraulic dredges remove and transport sediment in slurry form (i.e., sediment and water mixture), greatly increasing the total volume of material to be moved. However, hydraulic dredging is much less invasive to the environment than traditional (mechanical) methods, and can be conducted in areas that cannot be easily or economically accessed with heavy equipment (USEPA, 1994).

Suction dredges are a simple type of hydraulic dredge that do not employ a “cutterhead,” or mechanical means of facilitating the initial loosening and gathering of bottom sediment. Such dredges may use water jets to help loosen sediments, but this may generate more turbidity (USEPA, 1994). Hydraulic pumps can be operated from barges or from shore with the assistance of operators to guide the suction
hose for smaller applications, as shown below. The size of the pump used depends on the distance to the spoils area, length of the suction hose, and the type material being removed. Booster pumps can be used to help maintain slurry velocities over longer distances.

Hydraulic pumps for suction dredging can be operated from a floating barge (left) or from shore (right) with hand operation of the hose for smaller applications. Sources: Aquacleaner Environmental (www.aquacleaner.com); AE Commercial Diving (www.aquaticinvasivecontrol.com)

Based on discussions with dredging contractors, Forge Pond is likely too shallow to allow for efficient use of an automated barge-mounted system. Instead, an operator-assisted suction dredging method is recommended, in which the suction hose would be operated by hand. The pumps that would be used for this project would be small enough in size that if brought near the shore (e.g., via former Lake Street) they could be easily hand-carried by crew members to the pond where they would be mounted on floats. The floats would be assembled on site in order to eliminate the need for a boat launch or crane.

2.1.3 Disposal Options

Disposal of dredged sediment must be managed in accordance with 314 CMR 9.07 (9), (10), and (11). In suction dredging operations, the sediment slurry is typically first pumped to a processing area for separation of the water from the sediment. The most common processing method for smaller applications involves the use of dewatering bags or tubes, which are made of geotextile filtration fabric to allow for the release of water but not sediment. One or a series of dewatering bags are placed upon a flat, prepared surface near the dredging operation and fitted with a discharge pipe to receive the sediment slurry from the hydraulic pump. The bags are normally filled to a specified percentage of their rated capacity and then allowed to drain for an extended period of time. Reduction rates vary depending on the sediment composition, organic content, and other site conditions. Once the sediment has drained and consolidated, the bags may be refilled, continuing the cycle until the volume of consolidated solids reaches the rated capacity. The consolidated sediment can then be transported to an off-site location for disposal or use as fill or compost, depending on any contaminants that may be present.
Dewatering areas must be very level, particularly across the width of the bag to prevent rolling. Grading or temporary placement of fill may be necessary to prepare a level pad. A plastic underlayment may be specified. The bags may be bordered by a trench area to control return flow back to the waterbody and/or additional filtration materials such as hay bales. The area must be accessible by heavy machinery to allow for unloading of the dredging equipment and removal of the consolidated sediment bags.

As an alternative disposal option, 314 CMR 9.07 (9) allows for shoreline placement of dredged material at a location proximal to the dredging activity that lies within the 100-year floodplain or buffer zone as defined in 310 CMR 10.00 (e.g., 100 feet from the shoreline of Forge Pond), whichever is greater. This approach could significantly reduce the costs of obtaining sediment dewatering bags, time and labor associated with the dewatering process, and hauling and disposal fees. In particular, the buffer area along the northwest edge of the pond owned by the Town of Kingston (Silver Lake Sanctuary) could serve as a potential shoreline placement area for sediment dredged sediment. This area is shown in Figure 2.1.4-1 presented in the next section.

In a shoreline placement approach, a sediment retention area would be set up with erosion control methods, such as hay bales and silt fencing and possibly stone, to temporarily contain the pumped sediment-water slurry and allow the water to drain into the ground. The remaining material would essentially be a layer of fertile topsoil.

2.1.4 Construction Access/Staging Areas

At Forge Pond, the area accessible by trucks and equipment is the former Lake Street at the western edge of the pond near the dam. If shoreline placement can be used for sediment disposal, the only construction access need would be an area to unload and operate the dredging equipment (e.g., pumps), for which the former Lake Street will likely suffice.

If the dewatering bag disposal method is used, a dewatering/staging area will also be needed. The former roadway itself is fairly level and may be sufficient for several long, narrow dewatering bags to be placed in series. Although the bags can be manufactured in many sizes, Geo-Synthetics, a manufacturer of sediment bags and other geotextile products, recommended a size of 30 feet by 100 feet for this project. Only one bag was specified by Geo-Synthetics, but in case additional bags are needed, it is possible that up to three bags of this size might fit along the former Lake Street, avoiding the bridge itself due to potential structural concerns (e.g., two bags north of the bridge and one bag south). However, this area is relatively far (about 1,500 feet) from the primary area of interest for dredging (the Silver Lake outlet area), which may complicate the logistics of sediment pumping. One dredging
contractor noted that although the distance is farther than typical operations, booster pumps may be used to help move the sediment to the dewatering area, but costs will likely be higher.

Alternate access and staging areas may be available. Two primary areas of interest include the town-owned Silver Lake Sanctuary along the northwest shoreline of the pond and the Wingate property along the south shoreline. The Silver Lake Sanctuary contains a network of trails leading to the outlet site, but the trails are considered “cart paths” that would need to be significantly improved for heavy equipment traffic (including a culvert crossing below Bass Pond), which is not likely to be permitted. Several areas of the Wingate property may be more suitable for equipment traffic with minor improvements, if access is granted. A former access route leads west from Chipman Way to the Silver Lake shoreline, then north to the outlet site. Minor clearing of downed trees may be necessary. Additionally, several relatively flat areas of the Wingate property along the south shoreline of Forge Pond may provide staging/dewatering area options.

Options for construction access and sediment disposal/dewatering areas for dredging of the outlet channel (Option 2) are shown in Figure 2.1.4-1 below.

It should be noted that construction access for excavation and construction of a stable channel through the pond (Option 3 above) may pose more of a hurdle. It is likely that a temporary access road would need to be constructed along the length of channel to be excavated/stabilized through the pond. Upon dewatering, this sediment in this area would likely still be extremely soft and special access measures may be needed (e.g., allowing the sediment to dry out for several months, working during winter when sediment is frozen, constructing access platforms, etc.), which would significantly increase costs.
Figure 2.1.4-1: Potential Construction Access Routes/Staging Areas for Forge Pond Dredging
2.1.5 Permitting Requirements

Table 7.0-2 in the feasibility report presents a list of environmental permits in Massachusetts and their applicability for various project conditions.

The primary factor in determining how sediment removal and disposal (or passive instream management, which is considered in the same way as dredging) is regulated in Massachusetts is the volume of sediment expected to be removed (or mobilized). Volumes greater than 100 CY require additional studies to analyze the sediment and are subject to additional permitting reviews, notably a 401 Water Quality Certification by the Massachusetts Department of Environmental Protection (MADEP). Under the 401 review process, initial screening studies must be conducted according to 314 CMR 9.07 (2) to determine whether further sediment analysis is required, including a due diligence review to determine the potential for sediment contamination, and a sieve analysis. If the due diligence review indicates the area is likely to contain anthropogenic concentrations of oil or hazardous materials, or if the sediment contains greater than 10% by weight of particles passing the No. 200 sieve, chemical and physical testing of the sediment is required in accordance with 314 CMR 9.07 (2)(b) (MADEP, 2007).

Sediment removal and disposal of volumes less than 100 CY does not require the submittal of a 401 WQC application, provided that a Final Order of Conditions has been issued by the local Conservation Commission or the MADEP. In such cases, the proposed work must qualify for a US Army Corps of Engineers (USACE) Category I Programmatic General Permit (PGP). Project proponents must demonstrate (and it is recommended that Conservation Commissions require evidence) that disposal of dredged sediment is managed in accordance with 314 CMR 9.07 (9), (10) and (11) (MADEP, 2007).

Dredging of a volume less than 100 CY, which would likely be the case for Option 2, may require the following permits:

- Wetlands Protection Act Notice of Intent & Order of Conditions (NOI) (MADEP / Town)
- Project Notification Form (PNF) (MA Historical Commission (MHC))
- Rare Species Information Request (Natural Heritage and Endangered Species Program (NHESP))
- Clean Water Act Section 404 Programmatic General Permit (PGP) (USACE)

Dredging of volumes greater than 100 CY (i.e., Option 3) would also require the following permit:

- 401 Water Quality Certificate (MADEP)

The following permits may be required for either scenario, but their applicability is less clear:

- Environmental Notification Form (ENF) (MA Environmental Policy Act (MEPA) Office) – required for alteration of 5,000+ square feet (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 Silver Lake and its watershed are considered outstanding resource waters, which may overlap slightly with the proposed dredging area)
- Section 106 Historical Review (MHC) – required for projects that require state funding, licenses, or permitting
- Chapter 91 Waterways License (MADEP) – required for removal of a licensed structure or dredging of a navigable waterway, which is considered to be most rivers & streams in MA
• National Pollutant Discharge Elimination System (NPDES) Permit (US Environmental Protection Agency (USEPA)) – required for discharges from certain construction sites, including clearing, grading, and excavation activities

2.1.6 Additional Studies

Additional studies may be needed to support these regulatory reviews and engineering design. For volumes less than 100 CY (Option 2), it is possible that only a resource delineation of potential construction access areas may be necessary. For volumes greater than 100 CY (e.g., Option 1 or 3 in a dam removal scenario), the following studies may be needed:

• Due diligence review of potential for contaminants
• Updated bathymetry & sediment depth mapping to refine volume estimates
• Sediment testing (typically one sample per 1,000 CY is required)
• Hydraulic modeling & engineering to design stable channel
• Resource delineations (e.g., wetlands, habitat) for construction access areas
• Cultural surveys

Table 2.1-1 at the end of this section presents a summary of the anticipated additional study and permitting requirements for each dredging alternative.

2.1.7 Budgetary Opinion of Costs

Budgetary opinions of costs for each dredging alternative are given in Table 2.1-1 at the end of this section. These costs were obtained through discussions with dredging contractors as discussed below as well as original estimates presented in the feasibility report.

One dredging contractor, New England Aquatic Services out of Milford, CT, provided several quotes for the proposed dredging of the outlet channel (Option 2) assuming a conservative sediment volume of 100 CY. For the shoreline placement option, in which the sediment would be pumped directly to the upland area delineated in Figure 2.1.4-1, their estimated cost would be approximately $62,700. To pump the sediment instead to a dewatering area, including the cost of the dewatering bags and transportation/disposal of the sediment offsite, their estimated cost would be approximately $94,400.

Another dredging contractor, AE Commercial Diving Services out of Manchester Center, VT, provided a quote of $1,700 per day for equipment and labor for hand-operated suction dredging. Based on their preliminary analysis of the site, they estimated that the proposed dredging would take about 5 to 10 days to complete using the shoreline placement method (approximately $8,500 to $17,000 total) or up to 15 days using the dewatering bag method (approximately $25,500 total). The latter estimate considers the additional labor time needed when using sediment dewatering bags, but does not include the costs of the dewatering bags, dewatering site setup (e.g., plastic underlayment, silt fencing, etc.), or transportation and disposal of the sediment.

Geo-Synthetics, LLC, based out of Waukesha, WI, is a manufacturer of dewatering bags recommended by both AE Commercial Diving Services and New England Aquatic Services. Based on the proposed dredging plan, Geo-Synthetics specified a 30-foot-wide by 100-foot-long ‘Geostrux Geotextile Tube’ for the project, though many other configurations are available. The quoted price for the recommended model was $1,500 plus $500 in freight, for a total of $2,000.
Given the varying sources of information, construction costs for the proposed outlet channel dredging plan are expected to range from approximately $10,000 to $63,000 for the shoreline placement option, or $30,000 to $95,000 for the dewatering bag option\(^2\).

A breakdown of estimated costs for the proposed dredging option (Option 2) is also included in Table 2.2-2 in the following section.

\(^2\) Budgetary estimates rounded up to the nearest thousand from the dredging quotes, with additional costs added to AE Commercial Diving Services’ quotes to account for materials.
<table>
<thead>
<tr>
<th>Description</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive Sediment Management (no dredging)</td>
<td>Dredging of Silver Lake Outlet Channel Only</td>
<td>Dredging of Main Flow Path through Pond</td>
<td></td>
</tr>
<tr>
<td>Allow sediment to be transported downstream naturally due to increased flow volume &amp; velocity (could apply in both a dam-in or dam-out scenario)</td>
<td>Dredge Silver Lake outlet &amp; channel immediately downstream to approximate elevation 45 ft (NGVD 29)</td>
<td>Restore the natural channel of the Jones River through Forge Pond by excavating &amp; constructing stable channel sloping from the natural outlet of Silver Lake to the base of dam</td>
<td></td>
</tr>
<tr>
<td>Estimated Sediment Volume</td>
<td>~50 CY (assuming 600-ft length, 2-ft bottom width, &amp; 4:1 side slopes to meet existing grade; may increase to account for slumping, but limit to under 100 CY to avoid permit triggers)</td>
<td>~1,000-2,000 CY (assuming 1,500-ft length, 10-15-ft-wide x 2-ft-deep excavation area; conservative due to reuse of sediment for grading of channel banks)</td>
<td></td>
</tr>
<tr>
<td>Dredging Method(s)</td>
<td>N/A</td>
<td>Suction (operator-assisted)</td>
<td>Dewatered excavation &amp; construction of stable channel</td>
</tr>
<tr>
<td>Construction Access/ Staging Areas</td>
<td>N/A</td>
<td>Former Lake St and/or other options (e.g., Wingate, Silver Lake Sanctuary)</td>
<td>Former Lake St plus temporary access road along pond shoreline</td>
</tr>
<tr>
<td>Sediment Disposal Options</td>
<td>Instream</td>
<td>Pump to dewatering bags &amp; reuse or dispose of according to 314 CMR 9.07; shoreline placement may be possible</td>
<td>Reuse or disposal based on sediment testing results according to 314 CMR 9.07</td>
</tr>
<tr>
<td>Need for Additional Studies</td>
<td>Dam-in alternatives: None</td>
<td>If under 100 CY, sediment analyses not required; updated bathymetry/probing would help refine estimates, but not necessary; resource delineations for construction access areas</td>
<td>Due diligence, bathymetry, sediment probing, sediment testing (2-3 samples), hydraulic modeling &amp; engineering to design stable channel, resource delineations</td>
</tr>
<tr>
<td>Permitting Requirements</td>
<td>Dam-in alternatives: None if under 100 CY is expected to mobilize Dam-out alternatives: NOI, ENF, PNF, Sect. 106, Rare Species Info Request, 401 WQC, Ch. 91, Cat. 1 PGP (no 401 WQC if under 100 CY); ENF, Sect. 106, Ch. 91, or NPDES also possible</td>
<td>NOI, PNF, Rare Species Info Request, Cat. 1 PGP, NPDES</td>
<td>NOI, ENF, PNF, Rare Species Info Request, 401 WQC, Ch. 91, Cat. 1 PGP, NPDES</td>
</tr>
<tr>
<td>Maintenance Requirements</td>
<td>Reassessment of need for dredging if passive approach does not meet project goals</td>
<td>Maintenance dredging possibly needed in the short term, depending on effectiveness of sediment transport under fish passage flow</td>
<td>Little maintenance needed with a fully restored channel; may require periodic inspections for debris or failing channel stabilization measures</td>
</tr>
<tr>
<td>Budgetary Opinion of Costs</td>
<td>Dam-in alternatives: None Dam-out alternatives: Engineering: $15,000* Permitting: $5,000* *In addition to costs associated with the dam removal itself</td>
<td>Engineering: $7,500 Permitting: $5,000</td>
<td>Engineering: $25,000* Permitting: $5,000* Construction: $320,000</td>
</tr>
<tr>
<td>Recommendation</td>
<td>Should be considered for all alternatives based on additional study findings</td>
<td>Recommended for dam-in alternatives only</td>
<td>Recommended for dam-out alternatives only</td>
</tr>
</tbody>
</table>

**Table 2.1-1: Summary of Forge Pond Dredging Options**
2.2 Forge Pond Dam – Fishway

In the feasibility study, an Alaska steepass was selected as the most appropriate fishway option for the Forge Pond Dam site and target species. The conceptual design drawings have been reproduced on Drawing 4 in Appendix A of this report. A discussion of the design follows.

Forge Pond Dam is approximately 4.5 feet high from the channel bed to the spillway crest in the proposed fishway location. The spillway basin between the dam and the former Lake Street bridge downstream is approximately 6.5 feet wide. A slope of 20% (within the range of appropriate slopes for an Alaska steepass) would allow the downstream invert of the fish ladder to be placed just inside one of the former Lake Street bridge openings, while still allowing the structure to clear the top of the bridge opening and meet the spillway at an appropriate height. The left bridge opening (looking downstream) is the most feasible location due to a deeper channel invert on that side of the spillway basin and through that bridge opening, continuing into the pool downstream of the bridge.

The selected specific steepass design (Model A40) measures 27 inches deep by 23 inches wide, and has 14-inch-wide openings between the baffles. Typically, the depth of flow 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).

To select a preliminary upstream invert elevation for the fishway, monthly Silver Lake water surface elevation duration curves developed for the feasibility study were consulted. Figure 2.2-1 below shows the monthly elevation curves for April, May, and June (upstream adult herring migration season) overlaid with elevations associated with the proposed preliminary fishway design. In this layout, the maximum effective fishway water surface elevation was set equal to the spillway crest at an elevation of 47.6 feet, which equates to an upstream fishway invert elevation of 45.5 feet. Based on the historical record (1996-2012) of Silver Lake elevations, the minimum effective fishway elevation of 46.9 feet would be exceeded approximately 93% of the time in April and May and 80% of the time in June. Conversely, the maximum effective elevation would be exceeded approximately 50% of the time in April, 70% of the time in May, and 30% of the time in June.

However, the advantage in setting the maximum effective elevation equal with the spillway crest is that when water levels reach this point, water will begin to flow over the spillway, effectively self-regulating the elevation within the effective range (except under very high flows in which the water surface would continue to rise several inches above the dam). In addition, the JRWA seeks to work with the City of Brockton to reduce diversions from nearby Monponsett and Furnace Ponds during periods of already high flow. Regardless, the upstream invert elevation is a crucial point of fishway designs and should be re-evaluated thoroughly during final design. The possibility of making the invert adjustable with modifications such as a bolted hinge plate (as utilized in a recent prototype at Hathaway Pond in Rochester) should also be investigated.
The preliminary proposed invert elevation of 45.5 feet would also ensure that through the range of effective fish passage depths at the fish ladder, the depth of flow at the existing natural outlet from Silver Lake would be approximately 9 to 12 inches (or approximately 1.2 feet deeper, if the outlet channel is dredged to elevation 45 feet as proposed in dredging Option 2 above), allowing herring to pass through to the lake.

Based on the selected slope of 20% and upstream invert elevation of 45.5 feet, the required fishway length would be approximately 7 to 9 feet, depending on final grade elevation at the base of the fishway to accommodate the required plunge pool and a proposed low flow channel through the bridge (see Section 2.3). A preliminary length of 9 feet is shown in Drawing 4 of Appendix A.

An inlet section with stoplogs would be built at the fishway entrance. 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 necessary for water supply considerations. The steeppass and inlet sections would be bolted together using joining plates.

For herring outmigrating in the fall, safe downstream passage must also be provided. The feasibility study determined that the most feasible option for downstream passage would be to cut a small notch (approximately 1 foot wide by 2.6 feet deep) in the spillway adjacent to the proposed fishway to take advantage of the existing small plunge pool (which currently has an approximate elevation of 43 feet).
With a proposed invert elevation of 45 feet\(^3\), flow depths through the notch would be approximately equal to depths in the proposed dredged outlet channel. 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.

Minor excavation would be needed to deepen the plunge pool and connect the downstream notch path to the fishway entrance. According to MarineFisheries, a plunge pool depth of 2 feet is often targeted.

### 2.2.1 Budgetary Opinion of Costs

Table 2.2-1 below presents a budgetary opinion of costs to install a fish ladder and downstream passage notch at Forge Pond Dam, including a breakdown of engineering and permitting costs. This estimate includes costs for excavation and grading to create the plunge pool below the downstream passage notch and the proposed low flow channel through the former Lake Street bridge (see Section 2.3 below), as it is assumed that these relatively minor modifications would be conducted concurrently with fish ladder installation.

Table 2.2-2 below presents a budgetary opinion of additional costs to dredge the Silver Lake outlet channel (Option 2 in Section 2.1 above). It is assumed that if pursued, this project would be designed and permitted in conjunction with the fish ladder, and thus economies of scale have been considered where appropriate (i.e., if a common permit is required for both projects, it is assumed that they can be incorporated into one permit for minimal additional effort, rather than doubling the effort). Note that for the actual labor and equipment costs for the suction dredging, the high estimate provided by AE Commercial Diving Services was used. The estimates provided by New England Aquatic Services include mobilization/demobilization, erosion control, and other costs, and are more comparable to the total dredging cost in Table 2.2-2 than the suction dredging line item.

---

\(^3\) The only change from the fishway design presented in the feasibility study was to lower the invert elevation of the downstream passage notch from 45.7 feet to 45 feet, based on the recommendation of this study to dredge the Silver Lake outlet channel to elevation 45 feet (Option 2 in Section 2.1.1 above).
### Table 2.2-1: Budgetary Opinion of Cost to Install Alaska Steeppass Fishway at Forge Pond Dam

<table>
<thead>
<tr>
<th>Description</th>
<th>Est. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENGINEERING &amp; PERMITTING</strong></td>
<td>$19,500</td>
</tr>
<tr>
<td>Engineering design, drawings, &amp; technical specifications</td>
<td>$10,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$9,500</td>
</tr>
<tr>
<td><strong>CONSTRUCTION</strong></td>
<td>$43,164</td>
</tr>
<tr>
<td>Mobilization &amp; demobilization (10% of construction subtotal)</td>
<td>$3,270</td>
</tr>
<tr>
<td>Erosion &amp; sediment control (oil boom, silt fencing)</td>
<td>$2,000</td>
</tr>
<tr>
<td>Temporary construction access (to left dam abutment)</td>
<td>$4,000</td>
</tr>
<tr>
<td>Fabricated aluminum steeppass fishway section</td>
<td>$7,500</td>
</tr>
<tr>
<td>Fabrication of inlet section</td>
<td>$3,000</td>
</tr>
<tr>
<td>Timber stop logs</td>
<td>$200</td>
</tr>
<tr>
<td>Notching of dam to accept fishway and stoplogs for downstream passage</td>
<td>$5,000</td>
</tr>
<tr>
<td>Installation of fishway, inlet section, and stoplog slots</td>
<td>$10,000</td>
</tr>
<tr>
<td>Excavation/grading to create plunge pool &amp; low flow channel through bridge</td>
<td>$1,000</td>
</tr>
<tr>
<td>Construction contingency (20% of subtotal)</td>
<td>$7,194</td>
</tr>
<tr>
<td><strong>TOTAL COST TO INSTALL FISH LADDER</strong></td>
<td>$63,000</td>
</tr>
<tr>
<td><em>(Engineering &amp; Permitting + Construction, rounded up to nearest $1000)</em></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2.2-2: Budgetary Opinion of Additional Cost to Dredge Silver Lake Outlet Channel

<table>
<thead>
<tr>
<th>Description</th>
<th>Est. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENGINEERING &amp; PERMITTING</strong></td>
<td>$12,500</td>
</tr>
<tr>
<td>Wetland delineation</td>
<td>$2,500</td>
</tr>
<tr>
<td>Engineering design, drawings, &amp; technical specifications</td>
<td>$5,000</td>
</tr>
<tr>
<td>Permitting</td>
<td>$5,000</td>
</tr>
<tr>
<td><strong>CONSTRUCTION</strong></td>
<td>$50,875</td>
</tr>
<tr>
<td>Mobilization &amp; demobilization (10% of construction subtotal)</td>
<td>$3,700</td>
</tr>
<tr>
<td>Erosion &amp; sediment control (oil boom, silt fencing, hay bales)</td>
<td>$3,000</td>
</tr>
<tr>
<td>Preparation of access/staging areas</td>
<td>$1,000</td>
</tr>
<tr>
<td>Suction dredging of outlet channel (labor + equipment)</td>
<td>$30,000</td>
</tr>
<tr>
<td>Sediment dewatering bags (optional)</td>
<td>$2,000</td>
</tr>
<tr>
<td>Hauling of excavated material (optional)</td>
<td>$1,000</td>
</tr>
<tr>
<td>Construction contingency (25% of subtotal)</td>
<td>$10,175</td>
</tr>
<tr>
<td><strong>ADDITIONAL COST TO DREDGE OUTLET CHANNEL</strong></td>
<td>$64,000</td>
</tr>
<tr>
<td><em>(Engineering &amp; Permitting + Construction, rounded up to nearest $1000)</em></td>
<td></td>
</tr>
</tbody>
</table>

| **GRAND TOTAL**                                                            | $127,000   |
| *(Install Fish Ladder + Dredge Outlet Channel)*                           |            |
2.3 Former Lake Street Bridge – Retrofit to Provide Low Flow Passage

One area of potential concern in meeting the minimum target water depth of 0.5 feet for fish passage is the former Lake St access road bridge immediately below Forge Pond Dam, where the deepest opening (left side) has a water depth of approximately 0.3 feet under the recommended Alaska steeppass fishway flow of 3 cfs. This would require a relatively simple fix to re-grade the flat channel under the bridge opening to create a deeper, narrower thalweg that can be utilized by fish during lower flows.

In the feasibility report, 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. The feasibility study roughly estimated that creation of this low-flow channel would involve excavation of about 3 CY of material from the area directly under the bridge. The channel would be widened at the upstream end of the bridge to accommodate the base of the fishway and connect to the proposed plunge pool.

A concept of the proposed former Lake Street bridge retrofit is shown in Figure 2.3-1 below, and a detail is provided on Drawing 5 in Appendix A. A separate cost estimate was not developed, as this is a minor element of the design that would likely be absorbed by other construction activities at the dam site. Estimated costs for this work are included in the budgetary opinion of cost to install the fish ladder presented in Table 2.2-1 above.

Figure 2.3-1: Proposed Low-Flow Channel Retrofit of Former Lake Street Bridge
2.4 Lake Street Culvert – Retrofit/Replacement to Reduce Velocity Barrier

The feasibility study found that the Lake Street culvert below Forge Pond Dam may pose a concern for high velocities that could impede fish passage under certain flows. Using available scientific literature\(^4\), it was estimated that about 55% of alewives and 74% of blueback herring would be expected to pass through the approximately 55-foot-long by 4-foot-diameter concrete circular culvert under the required fish passage flow of 3 cfs. Passage percentages continue to drop off as flows increase. Careful management of flows within acceptable ranges would help maximize the percent of river herring that are able to pass through the culvert. However, retrofitting or 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.

\(^4\) According to MarineFisheries, the fish swimming performance data used in this analysis are generally recognized to be conservative, but are the best available data.
2.4.1 Existing Culvert

According to JRWA, the relocation of Lake Street to a more downstream crossing of the Jones River occurred in the 1950s, which is likely when the existing culvert was built. Neither the town nor MassDOT were able to locate any drawings or plans of the Lake Street culvert, the former Lake Street bridge, or Lake Street itself when the road was relocated. A more detailed survey of the culvert, roadway, and adjacent channel, including a geomorphic assessment, would need to be conducted prior to designing a retrofit or replacement option.

Condition and Life Expectancy

The expected lifespan of a culvert depends upon a variety of factors, including the material used, slope of the site, size of the structure, and acidity of the stream. The Lake Street culvert is made of concrete, which typically has a life expectancy of 70 to 100 years (estimates vary among different sources). Assuming it was built in approximately 1950, replacement may be warranted from a structural standpoint beginning around year 2020. Although no major signs of deterioration of the culvert material itself were observed during 2012 site visits, the fill behind the river right wingwall on the downstream face is eroding (see photo above).

Hydraulic Capacity

Stream crossings are typically designed to pass a certain flood flow without impacting existing water surface elevations. According to the most recent Massachusetts bridge design manual, crossings on urban minor arterial, collector, and local streets should be designed to pass a minimum of the 10% annual exceedence probability flow, also referred to as the 10-year flood (MassDOT, 2010). A slightly older (2005) version of the bridge manual indicates that crossings on urban local streets may only have been designed to the 20% annual exceedence flow, or the 5-year flood (MassDOT, 2005). Although it is not known what design storm guidelines were in effect at the time the Lake Street culvert was built, it is likely that it was designed to pass a smaller storm such as the 5- or 10-year flood.

A detailed analysis of the complex hydrology at the site was provided in Section 4 of the feasibility report, including various methods of flood frequency estimation. Although it is difficult to select an appropriate estimate of flood frequencies in the upper Jones River where data is limited and flow is transferred both out of and into the basin, anecdotal evidence and preliminary hydraulic modeling indicate that the Lake Street culvert may be undersized for current conditions. As an example, the photograph below shows the culvert submerged during the March 2010 flood, during which the Jones River US Geological Survey (USGS) gage at Elm Street recorded instantaneous peak flows of 400 cfs, which is just under the 10-year flood estimation of 479 cfs for that location.
Additionally, hydraulic modeling conducted in the feasibility study (Section 5) indicates that the culvert causes an increase in upstream water surface elevations at all flood flows estimated by the Federal Emergency Management Agency (FEMA) in the 1985 Flood Insurance Study (FIS), and may become submerged at flows greater than the 10-year flood, as shown in Figure 2.4.1-1 below. Undersized culverts are more likely to be damaged or destroyed during large storm events, causing additional costs of roadway closures and repair.

Figure 2.4.1-1: Water Surface Profiles of FEMA FIS Flood Flows through Lake Street Culvert

2.4.2 Culvert Retrofit Options

Typically, retrofitting is considered a viable alternative to culvert replacement when the existing crossing is structurally sound, is large enough to pass high flows, allows the passage of wildlife, and does not

Upstream face of Lake St culvert during low flow (left) and submerged during the March 15, 2010 flood (right).
negatively affect critical wetlands (MADER, 2012). It is likely that only the first criterion applies to the Lake Street culvert.

Retrofitting an existing culvert involves modifications to the structure itself and/or surrounding streambed to facilitate and improve aquatic organism passage. The hydraulic method is the most common design approach in retrofitting culverts for fish passage. This approach involves modifications to adjust heights of vertical transitions, flow velocities, and flow depths within ranges that can be negotiated by the target fish species (MassDOT, 2010).

Retrofit options may include installation of baffles within the culvert to slow water velocities, placement of natural streambed material within the culvert to increase roughness, and/or construction of grade controls up- and/or downstream of the culvert to address flow transitions (USDOT, 2007). Each of these options is discussed in more detail below.

**Baffles**

Baffles are a series of features that can be installed within a culvert to increase the hydraulic roughness and thereby decrease flow velocity. Unlike hydraulic control structures that function individually, such as weirs, baffles work together to reduce the average cross-section velocity inside the culvert. Flow passing over a series of baffles during high water conditions creates a streaming pattern rather than, in the case of weirs, a plunging pattern (WDFW, 2013).

Although several baffle configurations are available, one basic style, referred to as a corner baffle, is suggested for round culverts (shown in Figure 2.4.2-1 below). This style is designed with a continuous alignment of the low flow point along one wall rather than alternating from one wall to the other, which provides less resistance to high flows and an uninterrupted line of fish passage along one or both sides. This is particularly important for weak fish, which would be forced to cross the high-velocity zone at every baffle in an alternating-baffle design (WDFW, 2013).
Figure 2.4.2-1: Corner Baffle Design Recommended for Circular Culverts

Example of a corner baffle retrofit in an existing 5.5-foot diameter culvert on John Hatt Creek in northern California. The baffle height provides 6 inches of water depth at the juvenile low passage design flow (left). At higher flows (right), the baffles slow water velocities while producing minimal turbulence. Along the low side of the baffles, velocities are swift, improving passage of sediment and debris, while the high side of the baffles experiences slower velocities suitable for both adult and juvenile fish (Source: USFS, 2006).

In concrete culverts the best design is a cast-in-place baffle, in which rebar dowels are placed within drilled holes in the culvert wall and tied into the baffle reinforcement, and the baffle is formed around the reinforcement. However, more often in retrofits, bent steel plates are used, with one leg bolted to the floor and pointing downstream. Generally, ¼-inch steel plate is used for conservative design and
long baffle life. Gussets are added to stiffen and strengthen baffles. Bolt anchor systems for existing culverts are difficult to install though, and consequently often fail. Expansion-ring anchors have been used in round pipes and can be installed without diverting flow from the work area. These baffles are prone to failure in larger streams and culverts and should be used only for short term fish passage, with the understanding that the culvert will be replaced within a year or two (WDFW, 2013).

The Washington Department of Fish and Wildlife’s (WDFW) 2013 Water Crossing Design Guidelines provide hydraulic analysis methods and design guidelines for baffles in culverts. The baffle height ($Z_0$) and spacing ($L$) shown in Figure 2.4.2-1 above, as well as Manning’s $n$ roughness coefficients, are selected as a function of the culvert slope. Although the exact slope of the Lake Street culvert is not known, it was estimated at about 0.5% in the feasibility study. Given this, baffles for the Lake Street culvert would be in the range of 6 to 8 inches high, spaced approximately 20 inches apart, with a Manning’s $n$ value of 0.04 to 0.05 (WDFW, 2013).

A major concern when installing culvert barrel retrofits for fish passage is the impact on the hydraulic capacity of the culvert at flood flows due to reduced flow area and increased roughness. If capacity is significantly decreased, increased headwater depth may damage the road crossing, increase erosion in the upstream channel, or impact upstream and near-channel structures (WDFW, 2013). Given that the Lake Street culvert may already be undersized, the addition of any structure within or around the culvert to slow water velocities will likely reduce the culvert’s hydraulic capacity.

A preliminary hydraulic analysis in which the Manning’s $n$ roughness coefficient within the culvert was adjusted from the existing value of 0.011 (smooth concrete) to the possible value of 0.05 (baffles) in the model developed for the feasibility study indicates that the addition of baffles may increase upstream water surface elevations significantly during flood flows, as shown in Figure 2.4.2-2 below. As the figure shows, the road may be overtopped during the 100-year flood by backwater from the baffled culvert, which is not shown to be the case for the existing culvert.

Figure 2.4.2-2: Water Surface Profiles of Existing vs. Baffled Lake Street Culvert

Note: In the legend, “Calibration_High” refers to existing water surface profiles, which are the lower two blue lines. Flood flows are those published in the FEMA FIS.
However, more detailed survey of the culvert and formal hydraulic analysis would be needed to further assess the effect of baffles on hydraulic capacity and determine whether the modified culvert will be able to safely pass the design flood.

The tendency for baffles to catch woody debris exacerbates the culvert capacity problem, potentially creates a fish barrier, and may eventually plug the culvert, which could lead to a road fill failure. The need for frequent inspection and maintenance of baffled culverts is widely acknowledged, but few maintenance programs establish the protocol or budget for adequate maintenance. Maintenance is usually impossible during high-flow fish-passage seasons, so if culverts fail or plug, fish-passage capability is lost when it is most needed. Because of the requirement for maintenance access, baffles should not be installed in culverts with less than 5 feet of headroom, which is a criterion the Lake Street culvert does not meet (WDFW, 2013).

The design should also consider the passage of debris and sediment under normal flows. Most culverts retrofitted with baffles have slopes less than 3.5%, but in those with slopes less than 2% (as with the Lake Street culvert), bedload will likely deposit between the baffles and reduce the intended hydraulic effect of the baffles (VTFW, 2009).

Another disadvantage to hydraulic retrofits is that they may be of limited value for general stream continuity, as they typically only facilitate passage for a narrow range of target species, age classes, and/or swimming/jumping abilities (MassDOT, 2010). Generally, baffles are installed inside a culvert as a temporary retrofit to dissipate flow energy until a permanent solution can be found.

Channel Roughening

The addition of roughening material has also been a method of reducing velocity within existing culverts. The goal is to provide a continuous and immobile channel constructed of a well-graded mix of rock and sediment. However, increased roughness is not necessarily a solution to passage of aquatic species because roughness converts velocity to turbulence, and the combination of turbulence intensity and scale can be a barrier to passage. The type of roughness (material size) used can greatly affect passage success (VTFW, 2009). Because the Lake Street culvert may already be undersized, and roughening bed material would significantly reduce available flow area, this option was not considered further.

Grade Controls

Tailwater control structures or weirs can be added up- or downstream of an existing culvert to address flow transitions and reduce velocities. Grade controls installed downstream of a culvert are intended to backwater the outlet, thereby reducing water velocities within the culvert. Weirs added above a culvert are intended to slow the velocity of water as it enters the culvert. Structures may be constructed of logs, boulders, concrete, or other material and arranged in a variety ways. However, although weirs and tailwater control structures can reduce water velocity within the culvert, they are largely intended for stream channel profile control.
Table 2.4.2-1: Comparison of Grade Control Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructed cascade</td>
<td>Can be designed to replicate natural channel structure. Provide passage for all fish. Robust, redundant structure (less likely to degrade).</td>
<td>Technical design and construction expertise required. Large and expensive engineering projects.</td>
<td>Applicable to higher channel gradient.</td>
</tr>
<tr>
<td>Constructed riffle</td>
<td>Can be designed to replicate natural channel structure. Provide passage for all fish. Robust, redundant structure (less likely to degrade).</td>
<td>Technical design and construction expertise required. Will not maintain specific water surface elevation.</td>
<td>Applicable to lower channel gradient.</td>
</tr>
<tr>
<td>Boulder control</td>
<td>Can be designed to replicate natural channel structure. Good fish passage for most species.</td>
<td>Not redundant – simple adjustments may result in failure. Will degrade over time. Technical design and construction expertise required.</td>
<td>Maximum water surface drop of 9” between structures.</td>
</tr>
<tr>
<td>Rigid sill</td>
<td>Extensive design history. Exact control of water surface elevation</td>
<td>Poor fish passage for many species. Rigid structure in dynamic stream profile. Not redundant – small adjustments may result in failure. Will degrade over time. Precast structures are not aesthetic</td>
<td>Minimum spacing of 15 feet. Limited to &lt; 5% gradient. Allowable drop depends upon fish requiring passage. Cost can be high for precast structures.</td>
</tr>
<tr>
<td>Fishway</td>
<td>Provides durable fish passage for design species. Highest slope passage available for grade controls. Extensive design history.</td>
<td>Expensive. Technical expertise and site-specific, flow-regime data required. Debris and bedload may damage or clog structure. Precludes most natural stream processes.</td>
<td>Narrow range of operating flow - difficult to provide passage for all fish, all of the time. Requires ongoing maintenance</td>
</tr>
</tbody>
</table>

Source: WDFW, 2013.

A combination of one or more grade control methods may be applied up- and/or downstream of the Lake Street culvert in conjunction with an in-culvert velocity reduction retrofit such as corner baffles. A geomorphic assessment of the adjoining channel reaches would be necessary to inform the design.

No information was found on retrofitted culverts similar in design to the Lake Street culvert concerning the ability to pass anadromous river herring. Retrofitted culverts configured with baffles and weirs have been used to successfully pass fish, particularly salmonids, but are typically larger than the Lake Street culvert (Gregory et al., 2004).

2.4.3 Culvert Replacement Options

The preferable method to improve fish and aquatic organism passage through culverts is replacement with a properly designed culvert or bridge. Replacing the existing Lake Street culvert with a well designed crossing would likely improve adult and juvenile river herring passage success. Due to the larger opening area associated with crossings designed for aquatic organism passage, water velocities would be decreased, the potential for clogging with debris would be reduced, and higher flood flows
could be accommodated, lowering the risk of the road being overtopped or damaged. In addition, multiple upstream pathways and resting areas could be constructed within the crossing with natural streambed materials, further enhancing passage effectiveness across a range of flows and species.

Overall, open-bottom arch culverts and bridges are the preferred replacement structure type in Massachusetts (MADER, 2012). Elements of a well designed crossing are shown in the figure below.

**Figure 2.4.3-1: Elements of a Well Designed Stream Crossing**

![Figure 2.4.3-1: Elements of a Well Designed Stream Crossing](image)

Note: Openness ratio is a factor of cross-sectional area divided by length of the crossing. (Source: MADER, 2012).

In Massachusetts, most new and replacement culverts must adhere, where feasible, to specific guidelines described in the Massachusetts River and Stream Crossing Standards (River and Stream Continuity Partnership, 2012). Two levels of standards are specified—general and optimum, as shown in **Table 2.4.3-1** below. General standards provide for fish passage, stream continuity, and some wildlife passage. Optimum standards also meet these goals, but are to be used in areas of statewide or regional significance, such as streams that provide critical habitat for rare or threatened species. The general and optimum stream crossing standards are intended to balance the cost and logistics of crossing designs with the degree of stream protection warranted in ecologically sensitive areas (MADER, 2012).

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5 According to MarineFisheries, these standards may not be required for some coastal rivers, or when replacing culverts as part of fishways. Specific requirements for this project would need to be confirmed in future phases.
Table 2.4.3-1: Massachusetts General and Optimum Stream Crossing Standards

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>General Standards</th>
<th>Optimum Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embedment</td>
<td>If a culvert, then it should be embedded:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minimum of 2 ft for all culverts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minimum of 2 ft and at least 25% for round pipe culverts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• When embedment material includes elements &gt; 15 inches in diameter, embedment depths should be at least 2 x the D84 of the embedment material</td>
<td></td>
</tr>
<tr>
<td>Crossing Span</td>
<td>Minimum 1.2 x bankfull width</td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>Openness ratio*: 0.82 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*cross-sectional area / crossing length</td>
<td></td>
</tr>
<tr>
<td>Substrate</td>
<td>Matches stream substrate, resists displacement during floods, and maintain an appropriate depth during normal flows</td>
<td></td>
</tr>
<tr>
<td>Banks</td>
<td>• On both sides of the stream</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Match the horizontal profile of the existing stream and banks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Constructed so as not to hinder use by riverine wildlife</td>
<td></td>
</tr>
<tr>
<td>Water depth/velocity</td>
<td>Matches water depth &amp; velocity in natural stream over a range of flows</td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted from River and Stream Continuity Partnership, 2012.

As shown in the table, the openness ratio is the relationship between the cross-sectional area to the length of the culvert. Using this equation, the openness ratio of the existing Lake Street culvert was estimated as approximately 0.23 feet. This confirms that the Lake Street culvert is undersized from an ecological standpoint according to both the general (0.83 feet) and optimum (1.64-2.46 feet) standards.

To determine whether the Lake Street culvert is located within an area designated to be of statewide or regional significance, and thus which set of standards would apply, the NHESP’s BioMap2 was consulted. According to the map, the site is located within Core Habitat Area 837, where the spotted turtle (Clemmys guttata), a state listed species of conservation concern, may be located. Consequently, any replacement design for the Lake Street culvert should follow the optimum standards given in Table 2.4.3-1 above if feasible; thus the preferred structure type would be a bridge. However, if a bridge is not determined to be a feasible option for the site, other structure types may still be used to meet the general standards, as shown in Figure 2.4.3-2 below.
Both new and replacement culverts and bridges are typically designed using either the low-slope or stream simulation design method, but not the hydraulic method, which is typically only applied to the retrofitting of existing culverts as described above. The low-slope option is appropriate only for low risk situations with a stable but mobile bed, low slope (less than 1%), and short culvert length (less than 50 feet) (VTFW, 2009). Because the Lake Street culvert is longer than 50 feet (approximately 55 feet), the low-slope design method may not be the most appropriate option. In contrast, the stream simulation option is a geomorphic approach focusing on the continuation of the natural channel dimensions, slope, bed, and banks through the crossing. This approach is appropriate for any channel slope and is the recommended design method if the Lake Street culvert is to be replaced.

The US Forest Service Stream Simulation Working Group describes this design method in detail (USFS, 2008). A schematic of major design elements is presented in Figure 2.4.3-3 below.
Dimensions for the stream simulation method, including the bankfull width, are based on a geomorphologic evaluation of the existing streambed near or at the crossing, or a comparable reference stream with a drainage area, slope, and morphology similar to the proposed section of constructed streambed. This geomorphic assessment would need to be performed for the upper Jones River prior to designing a replacement structure. However, preliminary dimensions may be estimated from the reference cross-section downstream of the site identified in the feasibility report (Figure 4.1.5-1 in that report), in which the bankfull width appears to be on the order of 15-20 feet. According to the stream simulation guidelines shown in Figure 2.4.3-3 above, this would equate to a minimum crossing span of about 18-24 feet (1.2 x 15-20 feet). Assuming a similar length of around 55 feet is maintained, the required openness ratio would result in a cross-sectional area of about 45 square feet (general standards) to 90 square feet (optimum standards). Assuming that Lake Street does not significantly inhibit wildlife passage over the road, the required height according to optimum standards would be 6 feet (otherwise 8 feet if passage is inhibited, or no requirement for general standards).

Selection and design of a bridge or culvert should consider long-term maintenance requirements, which may affect the choice of structure type. Structures that are prone to clogging by debris should be avoided, where feasible. Embedment designs must consider the long-term sustainability of bed materials. Structures that provide for a full-span of the bankfull channel and properly designed bed materials within the structures are anticipated to require less waterway-related maintenance than more conventional designs that constrict flows, trap debris, and promote channel scour (MassDOT, 2010).
2.4.4 Cost Considerations

Culvert Retrofit Costs

Little information was found regarding typical costs to retrofit culverts for fish passage. A case study presented by the US Fish and Wildlife Service (USFWS), in which concrete baffles were installed within an existing concrete box culvert (pictured at right) was reported to cost about $35,000 (USFWS, 2008). The John Hatt Creek (northern California) case study presented in Section 2.4.2, which involved installation of a metal liner fitted with 43 corner baffles within the existing 5.5-foot-diameter corrugated steel pipe culvert, as well as construction of three concrete weirs in the channel below the outlet, had a total project cost of $140,000 and was completed in 2003. Given that the retrofit design that would likely be applied at the Lake Street culvert, if feasible (i.e., corner baffles with possible grade controls downstream) would be less complex than either of these case studies, costs would be expected to be lower.

Culvert Replacement Costs

An economic analysis of improved road-stream crossings was recently conducted by The Nature Conservancy (TNC) (Levine, 2013). This study found that replacing culverts with larger and more fish-friendly crossings can be expensive in the short term. The initial installation cost for an improved road-stream crossing culvert upgrade can be 50% or even 100% more than a traditional crossing designed only to pass water under a road. However, upgraded crossings require less frequent maintenance and are expected to last longer. Accordingly, when maintenance and replacement are factored in, the average annual cost of an upgraded crossing can be lower over its lifetime than that of an undersized crossing over the same time frame. If the impacts of climate change are included in cost considerations, particularly the increased frequency of intense storms that scientists predict for the Northeast, undersized stream crossings will become even more costly, since they will require yet more maintenance and replacement, and are more likely to experience sudden failure during large storms. Improved crossings can therefore help communities to avoid expensive unplanned repairs to their infrastructure resulting from both flooding and stream crossing failure (Levine, 2013).

The upfront installation costs of larger stream crossings that mimic natural stream channels are almost always higher than the costs of smaller, more traditional pipe culverts designed to meet hydraulic standards. Given the wide variety of culvert materials, designs and sizes, there is considerable disparity in just how much more expensive upgraded culverts are. Cost comparisons vary widely based on what kind of crossing is in place and what kind of crossing is chosen as a replacement, as well as site characteristics and required construction practices. For example, a major cost element in many projects is the requirement that the stream segment be de-watered during the construction project (Levine, 2013). However, this may not be a large factor for the Lake Street culvert, as flow can be easily regulated by the Forge Pond dam upstream.

Table 2.4.4-1 below summarizes information from several studies discussed in the TNC report on the installation costs—including materials, labor, and equipment—of upgrading crossings. The table indicates the cost increase for replacing existing culverts with improved designs that allow for aquatic
organism passage and/or accommodate future flows, rather than in-kind replacement with the same design and size (Levine, 2013).

Table 2.4.4-1: Installation Cost Increase of Improved Road-Stream Crossings vs. In-Kind Replacements

<table>
<thead>
<tr>
<th>Location</th>
<th>% Cost Increase for Improved Crossing vs. In-Kind Replacement Mean / (range of values)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Mountain National Forest, Vermont</td>
<td>14% (9% - 22%)</td>
<td>Compares stream simulation culvert costs with cost of replacement based on hydraulic design</td>
</tr>
<tr>
<td>Maine (statewide)</td>
<td>Mean not available (80% - 295%)</td>
<td>Improved culvert widths in this study are 200% to 300% of that of existing culvert</td>
</tr>
<tr>
<td>Oyster River Watershed, New Hampshire</td>
<td>42% (24% - 75%)</td>
<td>Compares cost to upgrade undersized culverts for a range of climate change/precipitation change scenarios and land use scenarios with cost of in-kind replacement</td>
</tr>
<tr>
<td>Minnesota (statewide)</td>
<td>10% (1% - 33%)</td>
<td>Compares cost of replacing existing culvert with improved “MESBOAC” design; costs considered are those of structures only</td>
</tr>
<tr>
<td>Tongass National Forest, Alaska</td>
<td>17% (-5% - 38%)</td>
<td>Compares stream simulation culvert cost with hydraulic design cost; stream simulation culverts are 25% - 83% wider than hydraulic design culverts; cost increase insignificant for streams of slope less than 3%</td>
</tr>
</tbody>
</table>


In one case study presented in the TNC report, the construction costs for replacement of two failing 5-foot-diameter by 36-foot-long metal pipe culverts in the Adirondacks with a 10-foot-wide by 5-foot-high by 44-foot-long concrete box culvert were approximately $220,000 (26% labor, 37% equipment and operation, and 37% materials) (Levine, 2013).

In another case study in Worthington, MA, a concrete double-box culvert (each box 10 feet wide by 6 feet high) was replaced with a 40-foot-span open-bottom arch culvert using the stream simulation design method. The project cost was approximately $408,000 and planning through construction occurred from 2004 to 2007 (Graber, 2007).

2.4.5 Summary

Culvert replacement or retrofitting requires careful planning and sound engineering to evaluate the potential impacts concerning downstream flooding, upstream and downstream habitat, erosion (e.g., head cutting), and stream stability (River and Stream Continuity Partnership, 2012). Retrofitting the Lake Street culvert with baffles and possibly grade controls to reduce water velocities should improve passage success for river herring but may compromise the culvert’s ability to pass high flows. The replacement of the Lake Street culvert with a bridge or open bottom arch culvert is likely to provide the best passage success during both adult and juvenile migration periods, while still being able to pass high flows during significant storm events, accomplishing the restoration goal of returning anadromous river herring to Silver Lake.
2.5 Lake Street – Stormwater Management Improvements

In 2003, a conceptual design for remediation of stormwater draining from Lake Street to the Jones River was prepared for the JRWA by Mainstream Engineering, Inc. The proposed improvements were designed to complement other modifications to the existing drainage system in Lake Street proposed by others (i.e., Silver Lake High School and the Massachusetts Highway Department). The design included elimination of existing scuppers and restoration and stabilization of the erosion channels created by the scuppers. This would eliminate a source of sediment to the Jones River and allow untreated stormwater runoff to be redirected to two proposed water quality basins.

Although some of the recommendations were implemented during stormwater improvements along Route 27 and the on the Silver Lake High Regional School property, there are still elements of the proposed plan to be addressed.

Because the proposed stormwater management improvements would likely enhance water quality and thus increase the potential for effective fish passage, they have been incorporated into this proposed site design. The conceptual plan for proposed stormwater management improvements is provided in Drawing 6 of Appendix A6.

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6 Note that the Pine Brook diversion pipe shown on the plan is no longer continuous. Also note that the diameter of the Lake Street culvert is shown as 54 inches, but it is actually 48 inches.
3. References


Forge Pond Dam Fish Passage Improvement

Conceptual Design of Site Elements


APPENDIX A: Conceptual Drawings

- Drawing 1 – Site Plan
- Drawing 2 – Proposed Forge Pond Dredging Plan
- Drawing 3 – Proposed Forge Pond Dredging Cross-Sections
- Drawing 4 – Proposed Forge Pond Dam Fishway Details
- Drawing 5 – Proposed Road Crossing Retrofit/Replacement Details
- Drawing 6 – Proposed Stormwater Management Improvements (Mainstream Engineering, 2003)