

Weir River Smelt Habitat Restoration

DRAFT FINAL REPORT



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1 INTRODUCTION

Foundry Pond Dam is the lowermost dam on the Weir River, located in Hingham, Massachusetts, as shown in Figure 1. The Weir River is subject to tidal fluctuations a few hundred feet downstream of Foundry Pond Dam. The drainage area at the dam is about 15.1 square miles, and the dam impounds approximately six acres (Chase, 2009). Town personnel have noted that, over time, the impoundment has been filling in with sediment. Freshwater flows originate from several ponds (the largest being Triphammer Pond, at 17.4 acres) and swamps in the Town of Hingham.

Historically, the Weir River supported one of the largest smelt spawning runs in the region, and was used in the 1960s and 1970s as a donor run for smelt egg stocking efforts. The area just below Foundry Dam—referred to as the spillway basin—was monitored by the Massachusetts Division of Marine Fisheries (*Marine Fisheries*) in the 1990s to delineate smelt spawning habitat (Chase, 2006). That effort found moderate densities of smelt eggs deposited over 2,683 square meters of modified riffle habitat below Foundry Pond Dam.

Emergency repairs to Foundry Pond Dam in 1998 resulted in the destruction of a small island in the spillway basin, which had previously created two channels of high quality habitat for rainbow smelt spawning. The removal of the boulder, cobble, and earthen island in the spillway basin resulted in a homogeneous substrate that is poorly suited for spawning adult smelt or smelt egg survival. In addition, the loss of the instream substrate and islands resulted in an over-widened channel with reduced water depths and velocities, further degrading the spawning habitat. These poor habitat conditions resulted in observations of high smelt egg mortality in 1999 and 2000, and in April 2001 millions of dead smelt eggs were observed in the spillway basin as declining flows over the spillway were insufficient to maintain the survival of eggs during their approximately two-week incubation (Chase, 2006).

Given the impact on rainbow smelt spawning, the Massachusetts Division of Marine Fisheries is seeking to restore the in-channel island and the two channels with more appropriate depths and velocities to support rainbow smelt spawning. The island would be planted with vegetation to provide shade in the side channels.

Foundry Pond Dam also includes a fish ladder that formerly supported a modest run of river herring that spawned mainly in Triphammer Pond (Reback et al, 2005). The presence of river herring was confirmed during the spring of 2009 through Town of Hingham monitoring of a fish ladder trap installed by *Marine Fisheries*.

Figures 2 through 5 in Appendix A¹ provide aerial overviews of the project area.

¹ All figures referenced in this report can be found in Appendix A.

2 BACKGROUND INFORMATION

2.1 Project Layout and Current Dam Operations

Foundry Pond Dam is a historical mill dam that, according to the Town of Hingham, is managed for storage and flood control. It includes the following water conveyance structures as shown in Figure 4:

- An approximately 100-foot-long uncontrolled **spillway** with a crest elevation of 13.3 feet.
- A rehabilitated **fish ladder** located on river-right². The fish ladder has an inlet invert elevation approximately one foot below the spillway crest (at about 12.3 feet). When the pond is at an elevation of 13.3 feet (spillway elevation), the fish ladder passes about 4 cubic feet per second (cfs). Under flood conditions, when the pond is at least one foot higher, the fish ladder can pass up to about 10 cfs. These estimations are based on the weir equation, $Q = CLH^{1.5}$, where:
 - Q = flow in cfs
 - C = coefficient of discharge (unitless, estimated at 2.6 for a broad-crested weir)
 - L = width of inlet opening (1.5 feet)
 - H = depth of flow (1.0 feet at pond elevation of 13.3 feet; or height of opening, 1.9 feet, under flood conditions)
- A **side sluiceway** on river-left that bypasses a portion of the Weir River below the dam. The side sluiceway culvert through the earthen dam has a downstream opening approximately 5 feet wide and 1.8 feet high. The water level is controlled by stoplogs (see photograph). The outlet sill has an elevation of 10.9 feet, making the inlet slightly above 10.9 feet³. Therefore, it appears that the pond can be lowered to about 2.4 feet below the spillway crest by opening the sluiceway. The maximum amount of water that can pass through the side sluiceway is approximately 31 cfs, based on the weir equation given above and a weir coefficient of 2.6.
- A **low level inlet** located just left of the spillway. This structure conveys water 39 feet along the face of the dam via a 2-foot-diameter reinforced concrete pipe to a transition box. From the transition box, flow is conveyed via a 15-inch-high by 40-inch-wide granite culvert to the base of the dam. The low level inlet is at an elevation of 10.0 feet, and the granite outfall at the base of the dam is at 7.45 feet. Thus, it appears that the pond can be lowered to about 3.3 feet below the spillway crest using the low level inlet. The maximum amount of water that can pass through the opening is approximately 47 cfs, based on the orifice equation, $Q = CA\sqrt{2gh}$, where:
 - Q = flow in cfs
 - C = coefficient of discharge (unitless, estimated at 0.61)
 - A = area of rectangular opening (1.25 ft x 3.33 ft = 4.2 ft²)
 - g = acceleration due to gravity (32.2 ft/s²)
 - h = head from the spillway crest to the centerline of the rectangular outlet opening (13.3 ft – 8.08 ft = 5.23 ft)



² The right and left side of the river assumes one is looking in a downstream direction.

³ The inlet elevation could not be surveyed as it was inaccessible.

Since the dam reconstruction, it has been recognized that active management of flows at Foundry Pond is needed to prevent further reductions in Weir River fish runs. In 2008, *Marine Fisheries* drafted a dam management plan and submitted it to the Town of Hingham for consideration. The plan identified a routine spring and fall protocol that would manage flows for improved fish habitat while remaining compatible with dam operations and functions for other resources. A stated goal of this restoration project is to finalize a Foundry Pond Dam flow management plan that meets diadromous fish spawning and migratory requirements. The elements of the draft management plan are as follows:

1. Dominant flows should pass over the spillway crest to support smelt spawning habitat in the spillway basin and attract river herring and eel migrations. The side sluice should not be opened during March through June, unless essential for flood control.
2. If the side sluice is opened during the smelt spawning run, smelt will be attracted to the sluice channel and deposit eggs. If the side sluice is opened to pass flow during March through May, flow should be maintained to protect deposited eggs until hatching is complete. Weekly inspections can direct management actions on whether to close the sluice or maintain it open.
3. The fishway should be inspected weekly to clear debris and adjust the entry boards.
4. Juvenile herring will emigrate to the sea during August through October. Adult eels will emigrate on a fall spawning run to the sea during September through November. During these periods, the transition box should be opened to allow fish to safely pass below the dam. This passage option will be in addition to passive flow down the fish ladder.
5. Weekly records will be maintained on fish run observations and flow operations during March through June and August through October.
6. The management plan will take the form of a Memorandum of Understanding between the Division of Marine Fisheries and Town of Hingham that will be updated every five years.

Note that although the management plan discusses flood control, it is not clear what, if any, flood control Foundry Pond Dam provides. Based on discussions with Town personnel, the pond created by the dam has been slowly filling in with sediment over time, reducing the pond's storage capacity. It appears that the pond can only be lowered approximately 3.3 feet below the spillway crest (via the low level outlet) prior to a forecasted flood event. With a reported pond surface area of approximately 6 acres, the storage capacity is only 19.8 acre-feet or 240 cfs-hours⁴. As discussed later, the 2-year flood at Foundry Pond Dam is estimated at 283 cfs. Thus, with only 240 cfs-hours of storage, the drawn-down pond would be refilled after less than one hour of inflow at 283 cfs (assuming no water is discharged downstream). Even with the fish ladder (10 cfs), side sluiceway (31 cfs), and low level outlet (47 cfs) releasing at their full capacity (total of 88 cfs), the pond still would refill within approximately one hour under the 2-year flood. Therefore, it appears that Foundry Pond Dam provides minimal to no flood control when comparing its storage capacity and the combined discharge capacity of auxiliary flow conveyance structures to the magnitude of flood flows.

Although outside the scope of this project, it should be noted that there may be some flood benefits realized upstream by lowering the pond prior to a flood event; however, the benefit is likely minimal given how quickly the drawn-down pond would refill under a storm event.

⁴ *The storage calculation assumes that the pond area is also 6 acres at a depth of 3.3 feet. In reality, the area would be less than 6 acres due to sloping shorelines; thus, the storage calculation is conservatively high.*

2.2 Target Fish Species & Characteristics

The primary goal of this project is to improve spawning habitat for rainbow smelt downstream of the dam within the spillway basin. Additionally, the needs of diadromous species utilizing the existing fish ladder (i.e., river herring and American eels) were also considered, by sizing the island within the spillway basin to create spawning channels for smelt while maintaining a zone of passage for river herring to find the ladder entrance. This involved ensuring that the fishway entrance hydraulics remained within acceptable ranges, and that diadromous species would still be ‘attracted’ to the entrance with appropriate velocities and water depths leading up to it.

Table 2-1 below outlines the timing of smelt spawning and river herring migration/emigration throughout the year, based on discussions with *Marine Fisheries*.

Table 2-1 – Timing of important fisheries events for the Weir River

Species	Event	Month									
		MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	
Rainbow smelt	Spawning & egg incubation										
River herring	Upstream migration										
	Downstream emigration										
American eel	Upstream migration										
	Downstream emigration										

Rainbow smelt eggs will adhere to the channel substrate and the eggs must remain inundated until fry emerge. If water levels drop, exposed eggs will suffer mortality. Based on discussions with *Marine Fisheries*, the targeted water velocity to support smelt spawning was set at 2.6 feet per second (ft/s), and velocities outside the range of 1 to 4 ft/s were considered unsuitable. The targeted water depth was set at least 0.5 feet. These values are acceptable for river herring migrations as well, although glass eels prefer somewhat slower velocities. These targets were used to size the island appropriately to create side channels with water velocities and depths within preferred ranges for smelt spawning.

2.3 Topographic Survey

The hydraulic model developed to size the island and side channels extended from immediately below the spillway to about 200 feet downstream, encompassing the area previously used by rainbow smelt for spawning. A topographic survey of the study area was conducted in October 2009. The following elements were surveyed:

- Planimetrics (footprint of the dam, intake location, spillway width, sluiceway location, fish ladder entrance, parking lot, etc.)
- Topography along the potential access route and within spillway basin of the proposed island
- Cross-sections of the river with water surface elevations (necessary to develop a hydraulic model)

To tie the survey into a reference datum, a known benchmark atop the left spillway abutment was used, taken from a January 1999 survey drawing developed by Bourne Consulting Company (see photograph at right). The benchmark elevation is given as 16.4 feet, based on a datum listed on the drawing as “NGVD as defined by the USGS.” It is assumed that “NGVD” refers to the North American Vertical Datum of 1929 (NGVD 29).



A base map was developed from the survey data, and is shown in Drawing 1 of the design drawings in Appendix C⁵.

2.4 Wetlands Delineation

A wetlands delineation was conducted by Abigail Childs of the Town of Hingham to support the Wetlands Act permit. The top of bank delineated by Ms. Childs was recorded during the survey and is shown on the base map in Drawing 1. Ms. Childs summarized her findings as follows.

Spartina alterniflora dominated the lower banks of the Weir River in the intertidal zone. *Spartina patens* dominated much of the upper intertidal zone close to the river. *Phragmites australis* has invaded much of the original upper *Spartina patens* salt marsh. The *Phragmites* has expanded into the upper tidal areas between the plunge pool below the dam and the Rockland Street culvert. At the base of the dam, a large bulrush grows, perhaps salt marsh bulrush (*Scirpus robustus*), common three square, or Chair-maker’s rush (*Scirpus americanus*). Most of the wetland delineation was estimated using the higher tides’ reach in or beyond salt marsh vegetation, or where a high bank (natural or constructed) restricted flood waters. During very large storms, the whole lower area at Rockland Street/Kilby Street is inundated.

⁵ All drawings referenced in this report can be found in Appendix C.

3 HYDROLOGIC ANALYSIS

A hydrologic analysis was conducted at Foundry Dam, including a review of the Flood Insurance Study (FIS) and U.S. Geological Survey (USGS) gage data. Two types of hydrologic data were important for this project. Estimates of flood flows were needed to evaluate the potential for scouring the material used to create the island, as well as the material lining the two spawning channels. Secondly, estimates of flow conditions during the smelt spawning period were needed to size the two channels appropriately to achieve velocities and depths that are conducive to spawning.

Flood Flows

The FIS estimated the 10-, 50-, 100-, and 500-year floods at Foundry Dam. These four flows were used to conduct a regression analysis to extrapolate the 2-year flood, commonly known as the bankfull flow or channel-forming flow. A power curve was fit⁶ to the existing FIS flows, and the curve equation was used to calculate the 2-year flood. A graph of the flood flows is shown in Figure 6, and the values are presented in Table 3-1 below.

A USGS gage (No. 01105638) located on the Weir River upstream of Foundry Pond Dam at Leavitt Street in Hingham, MA was active from April 2006 through August 2009, but is now discontinued. Because at least 10 years of data are needed to conduct a flood frequency analysis and the Weir River gage was only in service for about three years, the FIS represents the best available flood frequency data. However, the instantaneous annual peak flows were reviewed to ensure that the FIS flood flows were reasonable. To prorate flows at the gage to the Foundry Pond Dam downstream, they were multiplied by a ratio of drainage areas at the two sites (15.1 square miles at Foundry Pond Dam / 14.1 square miles at the gage, or 1.07). Generally, the peak flows, as adjusted to Foundry Dam, are between 220 and 260 cfs—slightly less than the 2-year flood flow of 283 cfs estimated by the FIS.

Mean Monthly Flows

Monthly flow duration curves were developed using the USGS gage mean daily data adjusted to Foundry Pond Dam as shown in Figure 7. The average mean daily flow for March, April, May, and June (the important months for smelt spawning and river herring passage) based on the approximately three years of record were 57 cfs, 43 cfs, 41 cfs, and 33 cfs, respectively (under non-ice-cover conditions). Thus, flows during spawning are expected to range from 33 cfs in June to 57 cfs in March, which were the flows chosen to size the island and spawning channels within the hydraulic model. The extents of this range are shown on Figure 7 (along with a line representing the side sluiceway capacity, which will be discussed in the construction details in Section 5.3).

Because the mean monthly flows were derived from only three years of data, a similar analysis of mean daily flows was conducted on a nearby gage with a longer record to evaluate whether the 2006-2009 period was relatively wet, dry, or average. USGS Gage No. 01101000 on the Parker River in Byfield, MA, with a drainage area of 21.3 square miles, has been in service since 1945. The annual mean monthly flow at the Parker River gage for the entire period of record (1945-2009) was 38 cfs, whereas for 2006-2009 (the period during which the Weir River gage was in service), it was 53 cfs. A similar trend was seen in mean daily flows for the smelt spawning months of interest. Therefore, the 2006-2009 period from which the modeled flows were derived was a relatively wet time in the context of the last 60 years.

⁶ The R-squared term, which is a measure of fit, was 0.997 for the power curve; a perfect fit is 1.0.

It is desirable to have the island designed for conservatively high mean daily flows, because it will be easier to increase velocities in the side channels as needed based on field observations by hand placement of large cobbles and boulders in the spawning channels, rather than trying to reduce velocities if the island footprint was too large. A summary of all modeled flows is given in Table 3-1 below.

Table 3-1 – Summary of modeled flows at Foundry Pond Dam

	Recurrence Interval/Mo.	Flow (cfs)
<i>Flood Flows</i>	2-yr	283
	10-yr	417
	50-yr	688
	100-yr	836
<i>Mean Monthly Flows</i>	March	57
	June	33

Looking at the flow duration curves in Figure 7, it can be seen that the low end of modeled flows (33 cfs) for which target smelt spawning velocities and depths will be met, will be equaled or exceeded approximately 22% of the time in June, and up to 77% of the time in March. Conversely, target velocities and depths may be exceeded with large flows about 14% of the time in May, up to 41% of the time in March. A summary of these exceedence probabilities is given in Table 3-2 below.

Table 3-2 – Percent of time modeled flows will be equaled or exceeded

		Mar	Apr	May	Jun
Mean Daily Flow (cfs)		57	43	41	33
% of Time Flow is Equaled/Exceeded	<i>Low End of Modeled Flows (33 cfs)</i>	77%	49%	29%	22%
	<i>High End of Modeled Flows (57 cfs)</i>	41%	21%	14%	17%

Note that this analysis was conducted using historic and current flow data and sea level information. Further analysis would be needed to explore how the island might respond under forecasted climate change scenarios. An increase in the frequency and severity of storm events, as predicted by some models, would lead to higher velocities and depths in the island side channels—another reason it was desirable to design the island for conservatively high flows and towards the lower end of the preferred velocity range. An increase in sea level may have a greater effect, as the proposed island area currently only receives minor and infrequent saline influence (according to *Marine Fisheries* data), but the tide is restricted by a grade control less than 100 feet downstream, the top of which is just 0.3 feet below the channel elevation at the downstream end of the proposed island. An increased tidal influence could affect the suitability of the site for smelt spawning.

4 HYDRAULIC ANALYSIS

4.1 Hydraulic Model Set-Up

To evaluate various island/side channel layouts, a hydraulic model was developed using the HEC-RAS program. The hydraulic model extends from immediately below the spillway to about 200 feet downstream of the spillway (which includes the return flow from the side sluiceway). Cross-sections of the river in this reach were surveyed for inclusion in the hydraulic model. The model was used to estimate depths and velocities at each of the cross-section locations under given flows.

The purpose for developing the hydraulic model was to:

- Simulate existing conditions (no island) and calibrate the hydraulic model to known water surface elevations measured at each cross-section during the survey, and to document depths and velocities during the smelt spawning period
- Simulate various island configurations with the goal of creating suitable habitat for rainbow smelt spawning within the preferred velocity and depth ranges (see Section 2.2)

The hydraulic modeling involved simulating different island footprints and heights and then evaluating the depths and velocities in the newly created channels relative to the preferred velocities and depths. A 'trial-and-error' method was used with the goal of limiting the island size while striving to maintain velocities and depths in the range that supports smelt spawning.

Figure 8 shows an overview of the study area and hydraulic model setup, including locations of the following: cross-sections, river flowpath, bank lines, concrete/stone structures, fishway, gates, and existing riprap below the spillway. Under current operating conditions and a flow level similar to that encountered during the May 2010 site visit (see photos), it is estimated that approximately 95% of the total flow in Foundry Pond Dam flows into the main channel via the spillway and low level intake, with the remainder being diverted through fish ladder and flowing through the sluiceway due to leakage. (Note that this percentage was calculated from field measurements and could vary depending on the flow.) The fish ladder flow re-enters the main channel at cross-section (XS) #3, and the sluiceway joins at XS #10 (see Figure 8).

The river cross-sections and the corresponding water surface elevations at each were surveyed on October 27, 2009. Although the Leavitt Street USGS gage is discontinued, the staff gage at the Leavitt Street Bridge is still visible, and its level was recorded on the date of the survey. Using the rating curve for the gage as provided by the USGS, the flow at Leavitt Street was estimated, and then adjusted by a ratio of drainage areas to give an approximate flow of 68 cfs at Foundry Pond Dam on the date of the survey.

Shown in Table 4-1 below are the surveyed water surface elevations, water surface elevations produced by the model, and the difference between them for each cross-section.

Table 4-1 – Surveyed vs. modeled water surface elevations at each cross-section

Cross-Section	Water Surface Elevation (ft)		
	Survey	Model	Difference
1		4.90	
2	5.7	4.33	-1.37
3	5.5	4.19	-1.31
4	4.1	4.19	0.09
5	4.1	4.18	0.13
6	4.1	4.16	0.11
8	3.3	3.87	0.62
9	2.8	2.79	-0.01
10	1.7	1.73	0.03
11	1.7	1.70	0.00

The hydraulic model can be considered calibrated when the surveyed and modeled water surface elevations are within +/- 0.1 feet of each other. This is true for all cross-sections in the Weir River model except three, highlighted in grey above: the two cross-sections (XS) through the riprap at the base of the dam, as well as one at the ‘pinch point’ where the remains of stone retaining walls on river left and right encroach on the river. The discrepancies on the riprap apron (XS #1 & 2) can be disregarded because they are upstream of the proposed island area of interest, and thus do not have an effect on model results in this area (because HEC-RAS is a backwater model that computes hydraulic data in an upstream direction). Additionally, the surface is very irregular in this area due to the large riprap substrate, so it was not possible to obtain an accurate water surface elevation during the survey. Likewise, the discrepancy at the pinch point (XS #8) can also be disregarded because it is directly upstream of the hydraulic grade control at XS #9, and thus is not the major contributor to model results in the area of interest upstream.

For this analysis, it was assumed that flow to the sluiceway would be minimized during the smelt spawning season (unless necessary for flood control) for two purposes. First, it would be undesirable to attract river herring and eels to the sluiceway channel and away from the fishway. Secondly, by maintaining the flow directly below the dam instead of diverting it through the sluiceway, flows will be increased in the smelt spawning area, reducing the size that the island will have to occupy to create the desired velocities. This is in accordance with the guidelines of the draft dam management plan (see Section 2.1) and is reflected in our operation recommendations as well (Section 5). Note that although stoplogs are currently in place at the intake to the sluiceway (see Plate 23 in Appendix B⁷), leakage is occurring from within the dam (Plate 24), which should be repaired.

Because the flow through the sluiceway and fishway is small compared to that in the main channel, and because it would be desirable to minimize flows to the sluiceway during smelt spawning season, for the purposes of the model, the entire flow at Foundry Pond Dam (e.g., 57 cfs for the March mean) was assumed to flow through the main channel via the spillway and low level outlet. This approach is also more conservative for the design of riprap revetment to protect the island during flood flows. Although it is slightly less conservative in ensuring that appropriate depths and velocities are reached during smelt spawning season, a quick check was performed with spawning flows divided among the spillway, fishway, and sluiceway appropriately to confirm that target water depths and velocities would still be met.

⁷ All photographs referenced in this report can be found in Appendix B.

The island geometry is defined by four cross-sections—#3, 4, 5, and 6 (note that there is no XS #7). The island was designed to mirror the triangular shape of the main channel below the dam, with one edge being flush against the existing large stone riprap at the base of the dam, creating two approximately equal-sized channels rejoining before XS #8. In general, the existing bank slopes were matched, and the new island was given side slope ratios of 1:3. At cross-sections #3, 4, and 5, additional fill was added along the river left bank, to further increase velocities in the channel and more closely match prior conditions, as well as bring the slope to a 1:3 ratio that could support plantings. The height of the island was set approximately 1.75 feet above the proposed thalweg elevation for each cross-section. The left and right channels on either side of the island were lowered to an elevation at or slightly below the existing thalweg elevation. The bottom substrate in these side channels would be augmented with 3- to 6-inch cobble to improve spawning habitat.

Figure 9 is a close-up of the proposed island layout. The filled-in brown area shows the top surface of the island, with the hatched area showing the approximate footprint including side slopes, as well as the new left bank side slope area. (Note that although the side slopes may extend into the left and right channels in places, they angle down to meet the thalweg and still allow passage of flow.) The island is divided into two main portions—a protective, permeable area at the head of the island filled entirely with large stone riprap (depicted with a ‘stone’ pattern on the figure) through which flow in the center of the spillway can be diverted safely into the side channels, and the main, plantable area of the island downstream. This section will be filled with a gravel borrow material comprised of gravels, sands, and silts so that the center of the island can be planted, and will be armored on its outside surfaces with protective riprap. Note that at the time the survey was taken (October 2009), sands and gravels were already beginning to build up in the area of the former island, and grass was growing in the channel at the indicated location.

4.2 Hydraulic Model Results

Figures 10 through 13 show each cross-section passing through the island—#3, 4, 5, and 6, respectively. Note that these cross-sections are viewed in the downstream direction, and are zoomed in to the area of interest (main channel) for simplicity. The green lines represent the existing ground surface, the black lines represent the proposed island geometry, and the blue lines represent the water surface elevations of the 100-year flood, the 2-year flood, the March mean flow, and the June mean flow, from top to bottom. The 100-year flood was chosen as the discharge for which to design the island protection, the 2-year flood is shown for reference, and the March and June mean flows were chosen for target velocity/depth analysis because they bracket the range of mean monthly flows expected during the smelt spawning season.

Figures 14 through 25 show velocity distribution plots for three different flows. Again, the cross-sections are viewed in the downstream direction and are zoomed in to the area of interest. The first set (Figures 14 through 17) show the velocity distributions for the four island cross-sections under the 100-year flood, for which the stone protection was designed. The next two sets show velocity distributions during March mean and June mean flows, respectively, which bracket the range of mean flows experienced during smelt spawning season. Key velocities are noted on the plots in feet per second. Note that velocities for the river-right channel will be slightly higher than those shown because the effective cross-sectional area in the right channel is slightly smaller than that depicted in the HEC-RAS model due to the skewed angle of the cross-sections across that channel (see Figure 9). Thus, attraction flow to the right channel will be maintained for river herring utilizing the fishway.

Table 4-2 below compiles the detailed velocity data from Figures 14 through 25 for the cross-sections of interest in the proposed island area. Values are given for the left, center, and right portions of the two channels, as well as along the top of the island, as applicable. Blank cells indicate an area of the channel that is not wetted under the given flow. Note that although the velocity and depth near the outlet of the fish ladder will increase (to meet smelt spawning requirements), these values will remain within the acceptable range for river herring to enter the fishway during their migration period.

Table 4-2 – Detailed velocity distributions for island cross-sections

XS ID	River Station	Flow Profile	Average Channel Velocity (ft/s)							
			LEFT CHANNEL			TOP OF ISLAND	RIGHT CHANNEL			OVERALL AVG.
			Left	Center	Right		Left	Center	Right	
3	189.7	June Mean	0.94	2.73	2.53		2.22	2.73	0.94	2.62
Head of island (toe of rip-rap)		March Mean	1.20	2.95	2.60		2.20	2.95	1.20	2.75
		Q2	2.78	4.50	3.85	1.00	3.29	4.50	3.01	3.04
		Q100	3.41	7.06	6.06	2.53	5.28	7.06	3.72	4.48
4	177.9	June Mean	0.86	2.02	1.39		1.00	2.01	0.83	1.84
Island #2		March Mean	1.14	2.50	1.62		1.20	2.50	1.10	2.20
		Q2	2.42	4.39	2.71	1.23	2.43	4.37	2.49	2.75
		Q100	3.62	7.51	4.82	2.83	4.49	7.48	3.70	4.66
5	164.6	June Mean	0.95	2.19	1.78		0.68	2.04	0.97	1.96
Island #3		March Mean	1.25	2.69	2.10		0.92	2.52	1.13	2.34
		Q2	2.66	4.86	3.81	1.32	2.30	4.58	3.25	3.21
		Q100	5.29	10.43	8.23	3.54	5.37	9.85	6.51	6.77
6	152.8	June Mean	0.64	1.85	1.05		1.19	1.85	0.77	1.66
D/S end of island		March Mean	0.88	2.40	1.30		1.46	2.40	1.05	2.09
		Q2	1.86	4.18	2.34	1.18	2.75	4.18	2.54	2.99
		Q100	4.33	10.19	5.84	3.27	6.79	10.19	6.20	7.21

Note: Blank cells represent areas of the channel that are not wetted under the given flow. The targeted water velocity to support smelt spawning is 2.6 ft/s, and the acceptable range is 1 to 4 ft/s.

5 PROPOSED ISLAND DESIGN & CONSTRUCTION

5.1 Characteristics of Proposed Island and Spawning Channels

The results of the hydraulic analysis—particularly velocities and water depths experienced under the 100-year flood—were used to design the types, thicknesses, and quantities of stone protection needed to construct the island. See Appendix D for an excerpt from the Design Brief discussing the details of the riprap design. Chosen materials included dumped riprap (with a D_{50} ⁸ of 1.3 feet) for the island permeable area and sides as well as the left bank, modified rockfill ($D_{50} \approx 5$ inches) for the island top and side channel bottom substrate, and gravel borrow, type ‘b’⁹ ($D_{100} = 3$ inches) for the core of the plantable area of the island, and also to fill out the left bank as needed.

The larger riprap for the island sides is to extend the entire way around the perimeter of the island at a thickness of 2.5 feet. Additionally, a protective area at the head of the island will be comprised entirely of the larger riprap, rather than being filled with the gravel borrow material. This permeable area will allow flow from the center of the spillway to drain away from the head of the island at approximately 45° angles into the side channels. Refer back to Figure 9 for a plan view of the island, and see Drawing 4 of the design drawings for typical cross-sections through the plantable and permeable areas of the island.

Section 4.1 provided a general description of the layout, dimensions, and composition of the island. Table 5-1 below gives a summary of various dimensions and other parameters of the two spawning channels to the left and right of the proposed island.

Table 5-1 – Characteristics of the two spawning channels under the range of modeled flows

Parameter	Mean Flow	XS #3		XS #4		XS #5		XS #6	
		Left	Right	Left	Right	Left	Right	Left	Right
Avg. velocity (center, ft/s)	JUN	2.7	2.7	2.0	2.0	2.2	2.0	1.9	1.9
	MAR	3.0	3.0	2.5	2.5	2.7	2.5	2.4	2.4
Water surface elevation (ft)	JUN	3.81		3.79		3.74		3.72	
	MAR	4.14		4.12		4.06		4.03	
Thalweg elevation (ft)		3.16		2.75		2.67		2.55	
Depth of flow (ft)	JUN	0.7		1.0		1.1		1.2	
	MAR	1.0		1.4		1.4		1.5	
Wetted top width (ft)	JUN	12.7	11.5	12.5	11.9	13.0	11.4	11.28	12.7
	MAR	14.6	13.9	14.5	14.0	14.9	15.4	12.8	14.4
Bottom width (ft)		8.8	6.7	6.3	5.5	6.6	6.1	5.6	
Flow area (ft ²)	JUN	7.0	5.9	9.8	9.0	10.5	9.3	9.9	7.4
	MAR	11.5	10.1	14.2	13.3	14.9	14.9	13.6	10.7

⁸ D_{50} refers to the opening size of a sieve through which 50% of the stone passes.

⁹ Note that gravel borrow type ‘a’ was originally proposed in the design brief, but type ‘b’, with a maximum size of 3” (vs. 6” for type ‘a’) was deemed more appropriate for the island core to support eventual shrub roots growth.

The volume of the island and the additional fill on the left bank will total approximately 100 cubic yards (about 58 cubic yards for the island and 34 cubic yards for the bank). Note that these estimates are simply fill above existing grade; they do not incorporate the slight dredging that will occur or the material needed to 'key in' the toe of the riprap. The total footprint of the island (including side slopes) would be about 1,700 square feet.

Note that while every effort has been made to create an accurate representation of the Weir River and proposed island, a hydraulic model can only approximate actual conditions. It is recommended that water velocities and depths in the side channels be monitored periodically during the first few spawning seasons. The site is small enough that velocities can be fine tuned by hand placement and rearrangement of cobbles and boulders in the side spawning channels.

5.2 Proposed Plantings Plan

The proposed plantings plan and details are shown in Drawing 5. The downstream portion of the island will be 'plantable fill,' which will consist of gravel borrow core, overlaid with filter fabric, and protected with riprap on the side slopes and modified rockfill on top. Approximately 730 square feet of the top surface of the island would be able to support plantings. Shrubs will be planted in holes two times the diameter of the plant containers (which are about seven inches) and filled with supplemental soil. A cut will be made in the filter fabric below the shrub and roots will be able to extend into the gravel borrow. Modified rockfill will be hand placed back on top of the soil, keeping rocks about three inches away from shrub stems to prevent soil from washing away while not encouraging stem rot.

Based on photographs and other observations by the Town of Hingham, it appears that the proposed island area experiences some tidal influence at least during low flows. Therefore, salt-tolerant species have been selected for all of the plantings. Although *Marine Fisheries* data indicates the occurrence of saline water will be infrequent with low concentrations, these species are still appropriate for freshwater and are a more conservative approach. Species recommended in the plantings plan include red chokeberry, buttonbush, sweet pepperbush, red-osier dogwood, inkberry, northern bayberry, elderberry, highbush blueberry, and arrowwood viburnum.

If grasses or other herbaceous species were to be planted on the island surface, an approximately four-inch layer (9 cubic yards) of soil would have to be spread on top of the protective rock and seeded. This could be done after the spring floods with hopes that the grasses have a chance to establish themselves during the summer. However, there is a chance that this material could be washed away, leading to sedimentation issues downstream. Therefore, this design does not incorporate the planting of grasses; instead, they will be allowed to establish themselves naturally over time, by the collection of sediment/water/seeds in the concave surface of the island.

Originally, the proposed shrub spacing was four feet apart (on center). However, when grasses were excluded from the plantings plan, it was discovered that shrub spacing could be reduced to three feet without significantly increasing the percent of open area in the stone protection (from about 3% to 5% open area, assuming three-inch-diameter stem clusters with three-inch buffer zones). This would increase the total number of shrubs from 47 to 83. Although not completely necessary (since shrubs at four-foot spacing would eventually fill in the whole space), three-foot spacing will make the island appear more densely vegetated early on while the shrubs are still young, which will be especially beneficial until grasses can get established. Also, it will provide extra coverage to compensate for any plants that don't survive. According to current prices available from New England Wetland Plants, total

shrub cost (contractor cost for shrubs only) would be about \$540 for four-foot spacing versus \$950 for three-foot spacing. Three-foot spacing is the option recommended in this plantings plan.

5.3 Construction Details

Due to the amount of leakage and the short distance between the top of the earthen dam and the top of the sluiceway culvert (see photograph at right), it is recommended that access to the area below the dam should not occur from atop the earthen dam. There is concern about the structural integrity of the sluiceway culvert to support fully loaded trucks. Although not within the scope of this project, the leakage observed in the sluiceway culvert from within the earthen dam should be evaluated.



Instead, to access the river below the dam with heavy equipment (i.e., trucks depositing fill, excavator), a temporary access road will be built through the wooded area in the river left floodplain. The road will travel north from the gravel parking area, turn east along a stone retaining wall, cross the sluiceway on steel plates atop a temporary culvert backfilled with crushed stone (just upstream of the existing footbridge), continue to the earthen portion of the dam, then follow it east to the bank. See Drawings 1 and 2 for details.

Access for previous work on the Foundry Pond Dam may have occurred without the installation of a temporary road or culvert, with steel plates laid to cross the sluiceway. Analysis to design a steel plate crossing could not be conducted because the integrity of the sluiceway's stone walls could not be accurately determined; existing drawings were not available, and the methods by which the wall was constructed were not known. However, the temporary culvert and stone fill crossing may potentially be replaced with appropriate elevated and reinforced steel plates, at the contractor's discretion and liability. Additionally, the contractor may opt to eliminate the temporary gravel access road as long as regulations for the Town and permitting agencies are met.

It is recommended that construction of the island take place in early summer—after the majority of spring flooding and the migration of river herring, but early enough that plantings have a chance to become established before high flows return in the fall. From a water management perspective, late summer (August or September) would be the ideal to construct the island, but this would leave little time for the plants to take hold. Because construction of the island itself (after the access road is set up and the materials are stockpiled) could likely occur over just a few days, it is likely that the contractor can schedule the work in the early summer and monitor flows and weather forecasts to complete the work during a dry period.

To divert flows for the purposes of construction, it is recommended that the pond first be drawn down to an elevation below the sluiceway inlet invert (about 2.5 feet below the spillway crest) via the low level outlet. During this time, the side sluiceway should remain blocked with stoplogs so that the temporary access culvert can be placed in the sluiceway and the construction access road can be built. When the access road, erosion and sediment control structures, and materials are in place and construction of the island is ready to commence, the low level inlet should be closed, and the upper entrance to the fish ladder should be blocked with sandbags. Then, the stoplogs blocking the side sluiceway can be removed, allowing any incoming flows (up to 31 cfs, the approximate capacity of the sluiceway spillway) to bypass the island construction site and re-enter the channel downstream.

If inflow exceeds 31 cfs, the pond level will rise until the elevation of the spillway (13.3 feet) is reached and water will be conveyed into the spillway basin. It will be up to the contractor’s discretion, but it is recommended that a portion of the spillway be sandbagged to prevent water from entering work area in the spillway basin. Sandbags may also be needed around the work area in the spillway basin. Flow diversion could be conducted in stages, if necessary, by sandbagging half of the spillway and half of the downstream island area while the island is constructed and then moving the bags to the opposite side.

For the purposes of estimating the percent of time the side sluice spillway capacity (31 cfs) would be exceeded during potential construction months, flow duration curves for June, July, August, and September were reviewed. These curves are shown in Figure 7 along with those for March, April, and May. The red dashed line on this graph represents the side sluice spillway capacity of 31 cfs. Table 5-2 below provides a summary of mean daily flows for the potential construction months, as well as the percent of time the side sluiceway capacity would be equaled or exceeded, which is approximately 24% of the time in June and 20% of the time in July. Therefore, there is a relatively small likelihood that the main spillway will have to be sandbagged to keep a portion of the construction area dry. However, this is dependent on how quickly the contractor can complete the work, as much of the material to construct the island can be stockpiled on site until placement occurs.

Table 5-2 – Summary of mean daily flows and % of time threshold flows are equaled or exceeded

		Jun	Jul	Aug	Sep
Mean Daily Flow (cfs)		33	10	8	11
% of Time Flow is Equaled/Exceeded	<i>Side Sluice Spillway Capacity (31 cfs)</i>	24%	20%	0%	4%

5.4 Cost Estimate

A conceptual cost estimate was developed and is shown in Table 5-3 on the following page. The majority of item costs were derived from the Massachusetts Department of Transportation's (MassDOT) published weighted average bid prices from the period of November 2009 to November 2010. MassDOT's Standard Specifications for Highways and Bridges provide more detail about methods and included services for each item. The following assumptions were made:

- Mobilization/demobilization and other general tasks were assumed to cost 10% of the subtotal.
- Costs for sediment/contaminant control materials (silt fence, turbidity curtain, oil boom) include placement and removal of those materials.
- Clearing and grubbing includes restoration (i.e., mulching, seeding, and planting as appropriate) of all cleared areas.
- Costs for structures (temporary culvert, steel plates) include placement (excluding excavation or backfill). A separate item was added for removal of the temporary culvert upon completion of the project.
- Costs for fill materials include placement according to specifications.
- Cost for shrubs includes supplemental soil mixture, excavation of planting holes, planting, watering, and monitoring/care.
- A 10% contingency was added to the subtotal and the total was rounded up to the nearest \$100.

As mentioned in Section 5.3 above, the temporary culvert and stone fill crossing may potentially be replaced with appropriate elevated and reinforced steel plates at the contractor's discretion and liability. Additionally, the contractor may opt to eliminate the temporary gravel access road as long as regulations for the Town and permitting agencies are met. These measures could reduce the overall cost estimate by up to approximately \$17,000.

Table 5-3 – Conceptual cost estimate to construct island in Weir River below Foundry Pond Dam

Category	Item	MassDOT Item No.	Location/Purpose	Unit	Qty	Unit Cost	Ext. Cost
General	Mobilization/demobilization, on-site facilities, etc. (10% of subtotal)	748	N/A	LS	10%	\$39,110	\$3,911
Sediment & Contaminant Control	Sedimentation fence	697	Along access road near bank	LF	125	\$3.50	\$438
	Floating silt fence	697.2	Across channel D/S of site	LF	25	\$25.00	\$625
	Oil containment boom	-	Across channel D/S of site	LF	25	\$25.00	\$625
	TOTAL Erosion/Sediment Control						
Earthwork	Clearing & grubbing (incl. restoration)	101	Temp. access road	SY	500	\$2.75	\$1,375
	Channel excavation	143	Island/channel area	CY	55	\$40.00	\$2,200
	Earth excavation	120	Removal of temp. access fill	CY	175	\$24.00	\$4,200
	TOTAL Earthwork						
Geotextile Fabric	For separation (Mirafi HP270)	698.3	Temp. access	SY	500	\$5.00	\$2,500
	For erosion control (Mirafi FW404)	698.4	Island, bank	SY	450	\$4.25	\$1,913
	TOTAL Geotextile Fabric						
Structures	42" CMP culvert	230 (M5.03.0)	Temp. culvert	LF	30	\$100.00	\$3,000
	Steel plate, 1-1/4" (2 3x10' pcs)	-	Temp. culvert	SF	60	\$3.25	\$195
	Drainage structure removal	146	Removal of temp. culvert	EA	1	\$400.00	\$400
	TOTAL Structures						
Fill	Dumped riprap	983.01 (M2.02.2)	Island, bank	CY	75	\$95.00	\$7,125
	Modified rockfill	983.52 (M2.02.4)	Island, channels	CY	60	\$80.00	\$4,800
	Crushed stone, 1-1/4"	156 (M2.01.3)	Temp. entrance, temp. culvert	CY	40	\$33.00	\$1,320
	Gravel borrow, Type B	151 (M1.03.0 b)	Island, temp. access road	CY	150	\$30.00	\$4,500
	Sand borrow, Type A	154 (M1.04.0 a)	Temp. culvert	CY	2	\$35.00	\$70
	TOTAL Fill						
Plantings	Shrubs, 3-4' height (incl. soil mix)	785 - 795	Island	EA	85	\$45.00	\$3,825
	TOTAL Plantings						
SUB-TOTAL							\$43,021
CONTINGENCY (10%)							\$4,302
TOTAL ESTIMATED CONSTRUCTION COST <i>(rounded up to nearest \$100)</i>							\$47,400

5.5 Permit Requirements

A meeting was held in May 2010 with Jim Sprague of the Massachusetts Department of Environmental Protection (MassDEP) to discuss potential permitting requirements for the project. Table 5-4 below lists the permits identified during the meeting.

Table 5-4 – Potential permitting requirements

Permit	Agency	Contact	Required	Comments
Order of Conditions	Town of Hingham	Abigail Childs	Yes	
Section 401 Water Quality Certification	MassDEP	Jim Sprague	Yes	
Environmental Notification Form (ENF)	Massachusetts Environmental Policy Act (MEPA)	Holly Johnson?	Yes	File expanded version. Process typically takes 60 days, including public notice & comment period.
Environmental Impact Report (EIR)			Possibly	May be avoided if expanded ENF receives support
Section 404 Permit to Discharge Fill Material	USACE	Sharon Adams? Dave Cadell?	Possibly	
Notice of Intent (NOI)	Town of Hingham	Abigail Childs	Yes	

To summarize the above table, the following permits are known to be required at this time: Order of Conditions, Section 401 Water Quality Certification, ENF, and NOI. It is recommended to file an expanded ENF in hopes of receiving positive comments of support from stakeholders such as Weir River Watershed Association and the North and South River Watershed Association, which might result in a waiver of requirement for an EIR. If not, an EIR may need to be filed. Also, note that the Area of Critical Environmental Concern (ACEC) for the Weir River extends upstream to the line of the dam, which could have an effect on some permits.

Proof of a former island may be required for permitting purposes. Plates 27 and 28 show upstream and downstream views of the island as it existed in 1991 prior to the reconstruction of the dam in 1998. Note that, according to *Marine Fisheries*, these photos were taken in late winter and do not depict the dense plant growth and small trees observed in the years leading up to 1998. It is believed that plant material below the dam steadily increased from the late 1980s until reconstruction, possibly as a result of a long-term trend of declining discharge due to watershed changes.

6 RECOMMENDATIONS FOR DAM OPERATION

Current dam operation guidelines from the 2008 dam management plan are given in Section 2.1. As stated in the original plan (Item No. 1), dominant flows should spill over the spillway crest (and fish ladder) to support smelt spawning habitat in the spillway basin and attract river herring and eel migrations. It is recommended that flow to the sluiceway be minimized at all times, unless essential for flood control¹⁰. Additionally, although there are stoplogs currently in place at the intake to the sluiceway to restrict flow (see Plate 23), leakage is occurring from within the dam (Plate 24). It is recommended that the leaks be repaired to maximize flow over the dam spillway and minimize fish attraction to the sluiceway channel. As noted in the existing plan, if the sluiceway must be opened during March through May (or if leakage is substantial enough to support spawning), the sluiceway flow should be maintained to protect deposited eggs until hatching is complete. If no eggs are observed in the sluiceway channel, the stoplogs can be reset.

Note that the island was designed to meet target water depths and velocities for smelt spawning under the range of mean monthly flow conditions experienced from March through June. As seen in Figure 7 and Table 3-2, the low end of this range (33 cfs) is equaled or exceeded 77% of the time in March, but only 29% of the time in May. It should be recognized that in some years, inflows of 33 cfs or greater may not occur due to natural hydrologic variability. In these instances, there are two potential options to consider relative to smelt spawning. The recommended alternative is to maintain the low level outlet in a closed position, and allow smelt spawning to occur under natural inflows, which may be less than 33 cfs. A second alternative would be to supplement natural inflows by opening the low level outlet to maintain a higher flow in the spawning channels. However—given that the estimated storage capacity of the pond is approximately 240 cfs-hours—a flow of 33 cfs could only be maintained from storage for just over 7 hours (if natural inflows were zero cfs). Because low flow periods can have long durations, a potential concern is that spawning may occur when the low-level outlet is opened; however, storage could be quickly depleted and leave deposited eggs to become dewatered. In addition, consideration should be given to aquatic, wetlands, and wildlife resources in the pond that could be impacted by pond draw-downs.

Relative to downstream emigration of river herring and eels (Item No. 4 in the existing dam management plan), fish that do not enter the fishway will currently pass over the spillway and drop several feet before hitting the large rip rap at the pass of the dam, most likely leading to mortality. A potential option that was considered but dismissed is passage through the low level inlet/outlet. The invert of the low level inlet is at an elevation of 10.0 feet, which is 3.3 feet below the spillway crest (elevation 13.3 feet). Because river herring are surface orientated and will not successfully find a submerged intake, this is not a feasible alternative. The side sluiceway is also not an option because of the large vertical drop to the sluiceway channel. In addition, it is likely that river herring will approach the location where the majority of water is passing downstream, which is at the spillway.

In addition to passive downstream passage via the fish ladder, another option would be to cut a notch in the spillway directly above the low level outlet discharge location, where a small plunge pool already exists at the toe of the dam (this area is void of large riprap). This plunge pool could be improved slightly at the time of island construction by rearranging the existing large rocks to create a deeper

¹⁰ As noted earlier, it is not apparent that the sluiceway provides significant flood protection given that it has minimal hydraulic capacity to pass flood flows.

pool.¹¹ The notch should be approximately 1 foot deep and 1.5 feet wide to accommodate river herring without significantly affecting the pond elevation. With the notch flowing full (one foot depth of water), the flow would be approximately 4.2 cfs. Stoplogs installed in the notch would remain in place to maintain normal pond elevations for most of the year, and would be removed during the late summer/fall emigration of river herring and eels spanning August through November.

To summarize, the items of the existing dam management plan should be modified/supplemented as indicated below in red:

1. Dominant flows should spill over the dam crest to support smelt spawning habitat in the spillway basin and attract river herring and eel migrations. The side sluiceway stoplogs should remain in place, unless they must be removed for emergency conditions. Existing sources of leakage flow to the side sluice should be repaired, then checked on an annual basis and repaired as needed. Eliminating leakage will prevent river herring from being falsely attracted to the sluiceway channel and rainbow smelt from spawning in the sluiceway channel.
2. If sluiceway leakage is not repaired, or the sluiceway is opened for any reason, spawning smelt may be attracted to the sluiceway channel when flowing during their spring spawning run. If smelt eggs are deposited in the side sluice, sufficient flows must be maintained through the sluiceway to prevent egg exposure. Weekly inspections of the sluiceway channel for eggs can direct management actions.
3. The fishway should be inspected weekly to clear debris and adjust the entry boards.
4. Juvenile herring will emigrate to the sea during August through October. Adult eels will emigrate on a fall spawning run to the sea during September through November. During these periods, the stoplogs at the dam notch should be removed to allow fish to safely pass below the dam. This passage option will be in addition to passive downstream fish passage along the fish ladder.
5. Weekly records will be maintained on fish run observations and flow operations during March through June and August through October.
6. The management plan will take the form of a Memorandum of Understanding between the Division of Marine Fisheries and Town of Hingham that will be updated every five years.

¹¹ Note that the impact of modifying the plunge pool on dam hydraulics and safety is beyond the scope of this study.

7 REFERENCES

Chase, B.C. (2009). *Request for responses: Design and planning of Weir River smelt habitat restoration*. Massachusetts Division of Marine Fisheries, RFR No. DMF-10002.

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