Weymouth Herring Run – Jackson Square
DESIGN OF FISH BARRIER & CHANNEL IMPROVEMENTS

Herring Brook, Weymouth, MA

DRAFT FINAL REPORT JUNE 30, 2014

EXCERPT – INTRODUCTION & HYDROLOGIC ANALYSIS

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List of Abbreviations

ACEC	Area of Critical Environmental Concern
BVW	bordering vegetated wetlands
cfs	cubic feet per second
CY	cubic yards
D/S	downstream
DCR	Massachusetts Department of Conservation and Recreation
DEP	Massachusetts Department of Environmental Protection
DER	Massachusetts Division of Ecological Restoration
DFG	Massachusetts Department of Fish and Game
DFW	Massachusetts Division of Fisheries and Wildlife
DOT	Massachusetts Department of Transportation
ENF/EENF	Expanded Environmental Notification Form
el/elev	elevation
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
ft	feet
ft/s	feet per second
Gomez and Sullivan	Gomez and Sullivan Engineers, PC
LiDAR	Light Detection and Ranging
MAHW	mean annual high water
MassGIS	Massachusetts Office of Geographic Information
MEPA	Massachusetts Environmental Policy Act
MHC	Massachusetts Historical Commission
NHESP	Natural Heritage & Endangered Species Program
NAVD88	North American Vertical Datum of 1988 (all elevations given in NAVD88)
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
OHW	ordinary high water
OPCC	opinion of probable construction cost
ORW	Outstanding Resource Water
TMDL	total maximum daily load
TOB	top of bank
U/S	upstream
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey

Not all abbreviations appear in this excerpt.

1. Introduction

1.1 Project Overview & Goals

The Weymouth Back River (or Back River), located in Hingham and Weymouth, Massachusetts, supports one of the largest river herring runs in Massachusetts Bay. From the tidal waters in Hingham Bay, river herring ascend a total of six fishways on the Back River and Herring Brook to reach their spawning habitat in Whitman's Pond.

A flood control conduit located in the upper portion of the Back River watershed is used to bypass storm flows past Jackson Square in Weymouth. The tunnel inlet is located just below Whitman's Pond Dam at Iron Hill Dam, with the outlet discharging adjacent to the lowermost fishway in Jackson Square. An existing fish barrier swing gate at the tunnel outlet has been ineffective at preventing upstream migrating river herring from entering the conduit, where they may become trapped and perish.

The Town of Weymouth secured funding from the Massachusetts Division of Marine Fisheries (*MarineFisheries*) to contract Gomez and Sullivan Engineers, DPC (Gomez and Sullivan) to prepare design plans and permit applications for an alternative solution to the problem of fish accessing the flood control tunnel. Project goals include implementing the following fish passage improvements on Herring Brook at the flood control conduit outlet near Jackson Square:

- Replace the existing fish barrier gate at the tunnel outlet with a more effective design that will prevent fish from entering the tunnel.
- Reestablish substrate suitable for smelt spawning on the concrete pad downstream of the tunnel outlet and fish ladder.
- Reestablish a resting pool for river herring immediately downstream of the concrete pad.

1.2 Background

The existing fish barrier gate at the flood control conduit outlet was constructed in the early 1980s. The gate was designed to swing open during periods of high flows. However, the gate would swing open under moderate flows, which had the unintended consequence of river herring entering the tunnel unhindered. As there is no way for fish to gain access through to Whitman's Pond from the tunnel, the only exit for herring is at the outlet where they entered. Normally this would not be a significant issue, as fish would recede with the flow out of the tunnel following a high flow event; however, during two known events (2000 and 2010), a steady period of moderate to high flow occurred (i.e., flow was not decreasing; therefore river herring were not receding). The fish remained in the tunnel long enough to deplete the available dissolved oxygen, which led to the suffocation and eventual death of thousands of river herring.

Even when in the closed position, the original swing gate was also insufficient at preventing river herring from entering the system. In 2004, a cooperative effort was made by *MarineFisheries* and the Town to repair and improve the functionality of the gate. The repairs included adding a fine stainless steel mesh to the gate surface, installing stop logs, and performing concrete and steel repairs to the gate and superstructure. Since these modifications, the Town has observed that the gate now opens under even moderate flows, not just flood events, resulting in river herring entering the flood control tunnel much more frequently under a wide range of spring flows.

The gate is also experiencing corrosion, as it is now over 30 years old, and does not seal well and can remain stuck open and not return to a closed position when flows recede.

Regarding the channel downstream of the barrier, *MarineFisheries* has indicated that the existing concrete pad was previously covered with stone substrate. This material washed out during a flood event around 2005. It is thought that this material washed downstream and filled in a former river herring resting pool that had been located located immediately downstream of the concrete pad. The dimensions of this former pool were observed to be about 3-4 feet deep and on the order of 15-20 feet wide.

1.3 Design Criteria

Due to poor functioning of the gate, the Town was not interested in a gate rehabilitation alternative to deal with the declining condition of the gate. Through discussions with project partners, the following attributes were identified as design criteria for a replacement fish barrier:

- Provide the ability to be fully closed such that herring cannot access the tunnel via gaps or other openings
- Be a barrier of sufficient height to exclude herring from gaining access to the tunnel over the top of the barrier as close to 100% of the time as possible
- Provide sufficient open area (above or through the barrier) to safely pass anticipated flow conditions
- Provide the ability to fully drain the tunnel, such that water behind the barrier structure does not become stagnant
- Provide an opening of sufficient size and geometry to allow any herring that may become trapped to exit the tunnel with limited stress
- Contain a structure to exclude American eel from moving over the barrier

Alternatives that could potentially meet these criteria were identified as either a replacement gate or a wall with a gated opening located at the floor elevation. As construction costs associated with a full gate replacement were estimated to be notably higher than a barrier wall, the selected design concept consisted of a concrete wall with a gated opening.

1.4 Target Species

The primary target species for the redesign of the fish barrier were the anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), known collectively as river herring. The barrier redesign also considered the catadromous American river eel (*Anguilla rostrata*). Additional project goals include establishing spawning substrate for rainbow smelt (*Osmerus mordax*) on the concrete pad downstream of the barrier, as well as a resting pool for river herring below the concrete pad.

Table 1.4-1 outlines the timing of important life cycle events for target species throughout the year, based on discussions with the Massachusetts Division of Marine Fisheries (*MarineFisheries*).

Table 1.4-1: Timing of important life cycle events for target diadromous species

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							■	■	■

For the primary project goal of redesigning the fish barrier, the main hydraulic design consideration (from a fisheries perspective) is ensuring that the barrier is high enough to exclude river herring from passing over it during the range of flows expected throughout the immigration season. Because the site is tidally influenced, this parameter is more a factor of the site hydrology than river herring physiology; see **Section 2.4** for further discussion.

However, physiology is an important consideration for the design of the rainbow smelt spawning habitat. 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 *MarineFisheries*, water depth should be at least 0.5 feet in the smelt spawning habitat area. Additionally, the target water velocity to support smelt spawning should be 2.6 ft/s, and velocities outside the range of 1 to 4 ft/s are considered unsuitable. These values are acceptable for river herring migrations as well, although glass eels prefer somewhat slower velocities.

2. Hydrologic & Hydraulic Analysis

The following types of hydrologic and hydraulic data were important for this project:

Channel Improvements

- **Flood Flows –** To check that the stone size to be used for the smelt spawning substrate and river herring resting pool can withstand the design flood

- **Typical Fish Passage Season Flows** – To check whether target flow depths and velocities (identified in **Section 1.4**) are achieved the majority of the time in the smelt spawning area

Fish Barrier

- **Tidal Surge Depths –** To determine the maximum water surface elevation at the downstream face of the proposed fish barrier in order to set the minimum barrier height to exclude herring

- **Flow Capacity of Existing Flood Control Conduit –** To ensure that the redesigned fish barrier can pass the maximum flow that could be passed by the flood control conduit upstream

These analyses parameters are discussed in the following sections.

2.1 Stream Flow Gages

The Back River is a short, primarily tidal river in the towns of Hingham and Weymouth, Massachusetts that flows northward into Hingham Bay. According to the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS), the Back River technically begins at a point approximately 1,000 feet downstream of the railroad bridge located below the project site. From this point upstream to the base of Whitman's Pond Dam (including the project site), the stream is known as Herring Brook. Whitman's Pond is fed primarily by Old Swamp River (which is considered the source of the Back River) and Mill River (which drains Weymouth Great Pond).

Four United States Geological Survey (USGS) stream gages are located in the Back River watershed near the site. A summary of the gages is presented in **Table 2.1-1** on the following page. In the table, flows are given in cubic feet per second (cfs).

Table 2.1-1 shows that there are three gages in the vicinity of the Whitman's Pond and Iron Hill Dams. The Whitman's Pond Dam gage is located just upstream of the inlet to the flood bypass tunnel and thus represents the total flow at the upstream extent of Herring Brook. The two gages located just downstream near Iron Hill Dam—one at the inlet of the flood bypass tunnel and one at the fish ladder—could theoretically be summed to equal flow at the Whitman's Pond Dam gage. However, these three gages have relatively short periods of record (12-13 years), and limited peak discharge data[1].

In contrast, the Old Swamp River gage upstream of Whitman's Pond has a relatively long period of record (48 years) and is above points of water withdrawals/diversions. To evaluate the appropriateness of using the Old Swamp River gage instead of the Whitman's Pond Dam gage to estimate flows at the project site, a regression analysis was performed for average daily flows at the two sites during their common period of record (2002 to present). The results, shown in **Figure 2.1-1**, do not indicate a very strong correlation (R^2 value of 0.70).

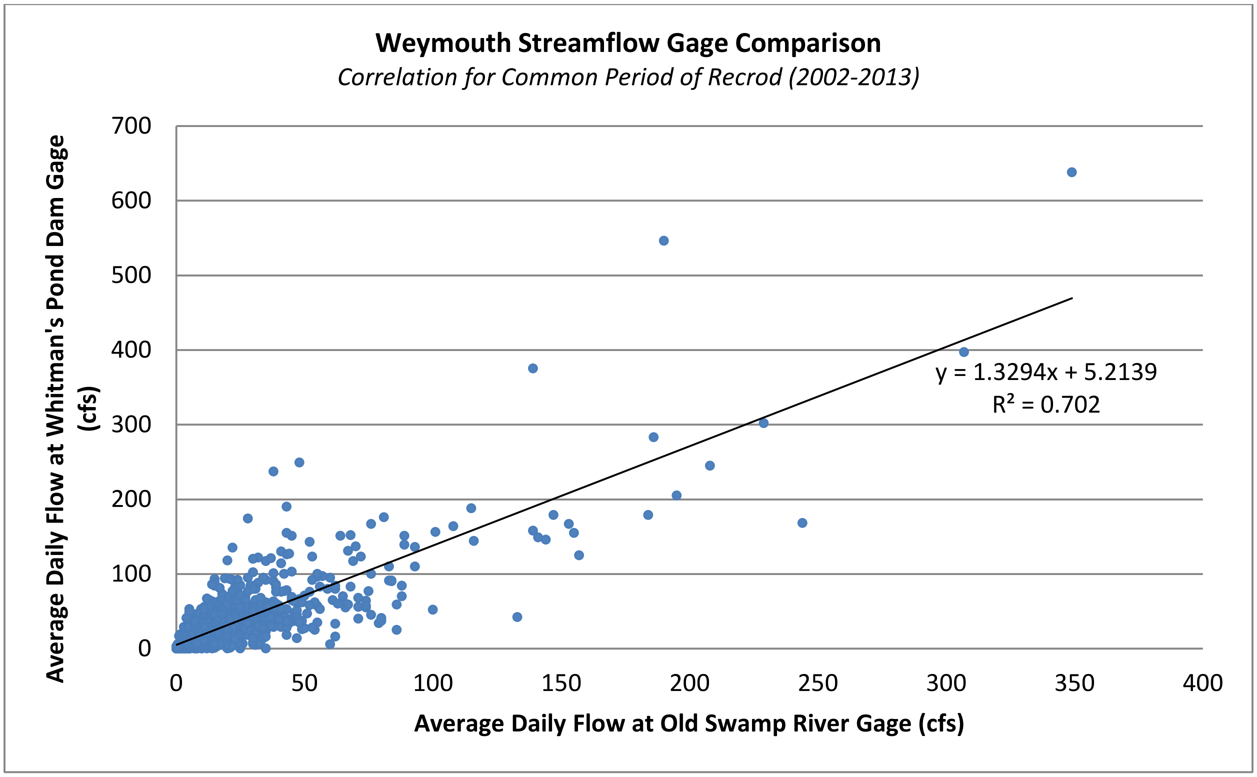
Therefore, the Whitman's Pond Dam gage represents the best available data that should be used to estimate average daily flows at the project site. Because this gage does not provide peak discharges, the FEMA FIS is the best available data for flood flow estimates at the site, as discussed in the following sections. However, for both cases, flows based on the Old Swamp River gage are also provided in this report for comparison purposes.

[1] At least 10 years of peak discharge values are recommended to perform a log-Pearson Type III flood frequency analysis according to USGS Bulletin 17B. No published peak discharge values were located for the Whitman's Pond Dam gage, and the flood bypass tunnel gage has recorded only 5 peak values. The fish ladder gage has recorded 12 peak values, but they do not represent the combined flow in Herring Brook and thus cannot be used.

Table 2.1-1: Summary of USGS Gages in the Vicinity of the Project Site

Water Body	Old Swamp River	Whitman's Pond		
Location	0.4 mi upstream of Whitman's Pond (at State Route 3 southbound lane)	Whitman's Pond Dam	Flood Bypass at Iron Hill Dam (~850 ft downstream of Whitman's Pond Dam)	Fish Ladder (~1450 ft downstream of Whitman's Pond Dam)
Gage No.	1105600	1105606	1105607	1105608
Drainage Area (mi^2)	4.5	12.4	12.4	12.5
Daily Flow Data	1966-present (48 yrs)	2001-present (13 yrs)	2002-present (12 yrs)	2001-present (13 yrs)
Peak Flow Data	1967-2013 (47 yrs)	None	2002-2005 (5 yrs)	2002-2013 (12 yrs)
Annual Mean Flow (cfs)	9.18	18.1	11.5	6.61
Max Peak Flow (cfs)	590 (5/31/84)	811 (3/15/10)	632 (3/15/10)	94 (10/15/05)
Accuracy	Records good except those for estimated daily discharges, which are poor. Gage is upstream of points of water withdrawals and diversions.	Records fair except those for flows less than 5 cfs and those for estimated daily discharge, which are poor. Periods of missing gage height record are not estimated. Flow affected by diversions for municipal use.	Records poor. Discharge affected by board changes in fish ladders at Whitman's Pond Dam and Iron Hill Dam, and by diversions from Whitman's Pond for municipal supply of Weymouth.	Records good except estimated daily discharges and discharges less than 0.2 cfs, which are fair. Includes flow through fish-ladder system. Discharge affected by gate changes at Whitman's Pond Dam, board changes at fish ladders, and diversions from Whitman's Pond for municipal supply of Weymouth. High flows affected by diversions to flood bypass system.
Notes	Closest FIS location: "At State Route 3 Northbound lane" (drainage area of 4.7 mi^2).	Daily mean discharge records previously published under Station No. 011056081, "Whitman's Pond Combined By-Pass and Fish-Ladder Flow," from water years 2002 through 2009, are now included in the daily and historical statistics for this streamgage.	Sum of these two gages is approximately equal to gage at Whitman's Pond Dam. Flow rejoins at project site.	

Figure 2.1-1: Weymouth Streamflow Gage Comparison



2.2 Flood Flows

For this project, it was important to have an estimate of flood flows (e.g., the 1 percent annual chance exceedance or 100-year flood) for the design of the proposed channel improvements. Flow velocities associated with estimated peak discharges were used to ensure that the smelt spawning substrate and river herring resting pool can withstand the design flood (i.e., to determine the minimum stone size needed for these improvements). However, flood flow estimates were not as relevant for the design of the fish barrier, as flows reaching the barrier are regulated by the flood control conduit upstream. Instead, the flow capacity of the existing flood conduit was used as the design flow for the proposed barrier (see **Section 2.5**).

Flood Insurance Studies provide one source of information on local flood flows. The effective FEMA FIS for the Town of Weymouth (No. 25021CV001) was published on July 17, 2012. The FIS is in the process of being updated (draft preliminarily released October 15, 2012 with an anticipated effective date of June 9, 2014) to include more detailed tidal surge information. Upon review of both the effective and preliminary FIS, it does not appear that any major changes are proposed that would affect the analysis of the project area.

The hydrologic analysis for the Back River and Herring Brook in the FIS was initially conducted in 1980. A multiple regression analysis, developed by Johnson and Tasker, was applied to find runoff discharges for riverine flooding in Weymouth. Standard USGS topographic maps were used to determine watershed areas and local topography. An annual precipitation value of 3.67 feet per year, representative of the southeastern Massachusetts region, was obtained from the US Weather Bureau Technical Paper 40 (TP-40). By determining values for slope and area and using them in conjunction with the precipitation value in the Johnson-Tasker formulas, values for runoff from 10-, 2-, and 1-percent-annual-chance exceedance (i.e., 10-, 50-, and 100-year) storms were predicted. Exponents for the 0.2-percent-annual-chance (500-year) storm frequency equation were extrapolated. A check with a log-Pearson Type III analysis of the Old Swamp River gage data (using 10 years of record available at the time) found the discharge values computed using the Johnson and Tasker method to be within expected ranges.

The National Oceanic and Atmospheric Administration (NOAA) Fisheries Service has published guidance for considering climate change when developing flood frequency estimates for river restoration projects (Collins, 2011). The publication recommends extending the flood record beyond dated FEMA studies and recalculating flood flows. Thus, an updated flood frequency analysis was conducted to compare with the FIS estimates for Herring Brook. Annual peak flows at the Old Swamp River gage for the period of record (published data available for water years 1967-2013) were entered into the USGS's PeakFQ program to estimate storm events for various recurrence intervals using the Bulletin 17B methodology, which creates a Log Pearson Type III statistical evaluation of the data. The results were prorated to Herring Brook at the project site based on a ratio of drainage areas (4.5 square miles at Old Swamp River Gage vs. 14.1 square miles at project site).

A summary of flood discharges from updated flood frequency analysis as well as the effective FIS for Herring Brook at Broad Street[2] is given in **Table 2.2-1** and **Figure 2.2-1** below. Note that these values represent the total flow in both the bypass tunnel and surface channel (i.e., fishway and adjacent canal). This is appropriate for the design of the smelt spawning substrate and herring resting pool, which would experience the combined flow. Based on the three common peak flow events on record for the gages at the inlet of the bypass tunnel and fish ladder upstream near Whitman's Pond Dam, approximately 84% of flood flows are diverted through the tunnel.

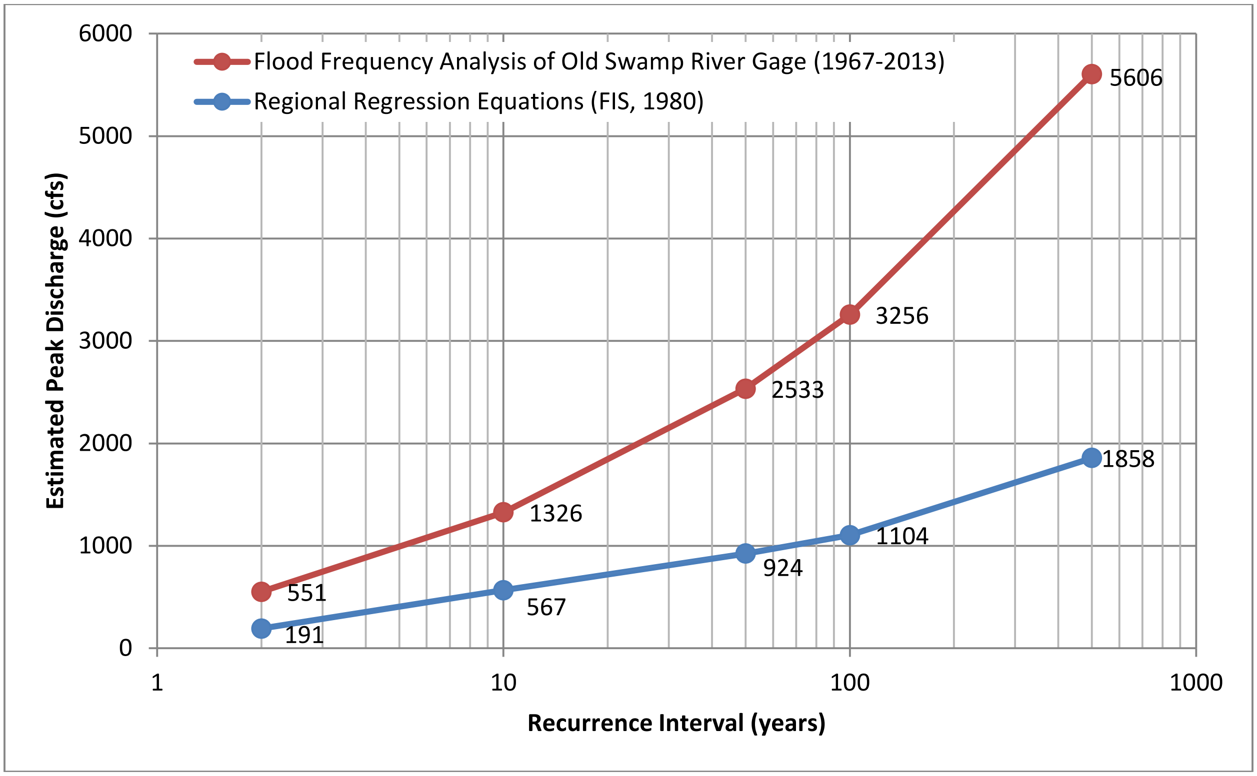
Table 2.2-1: Summary of Flood Frequency Estimates for Herring Brook at Broad Street

Annual Exceedance Probability	**Recurrence Interval** (yrs)	**Estimated Peak Discharge** (cfs)	
		Regional Regression Equations (FIS, 1980)	**Log Pearson Type III Analysis of Old Swamp Gage** (1967-2013)
50%	2	191[1]	551
10%	10	567	1326
2%	50	924	2533
1%	100	1104	3256
0.2%	500	1858	5606

[1] 2-year flood flow for FIS series extrapolated from natural log best fit line of 10-, 50-, and 100-year flows.

[2] Broad Street is just upstream of the project site with a published drainage area of 14.1 square miles in the FIS. The difference in drainage area between Broad Street and the tunnel outlet is negligible; thus the published FIS data was used. The FIS peak discharges at this location consider the combined flow of both the flood bypass tunnel and Herring Brook.

Figure 2.2-1: Summary of Flood Frequency Estimates for Herring Brook at Broad Street



Note: 2-year flood flow for FIS series extrapolated from natural log best fit line of 10-, 50-, and 100-year flows.

The 100-year flood flow is generally adequate for the design of channel improvements such as those proposed for the project site. As indicated in the table and figure, the regulatory (FIS) 100-year flood flow for Herring Brook at the project site is 1104 cfs. The 100-year peak discharge estimated by the updated flood frequency analysis of the Old Swamp River gage is significantly higher at 3256 cfs. The more conservative value of 3256 cfs was used for analysis of depth and velocity targets for channel improvements.

Based on recommendations by *MarineFisheries*, the recommended stone size to meet the needs for smelt spawning habitat as well as withstand flood flows is 6-12 inches. The closest Massachusetts Department of Transporation standard size meeting these requirements is “modified rockfill”, with a median size of approximately 5 inches and a range of about 2.5-9 inches. Using the Manning’s equation, the depth and velocity of the 100-year flood flow (3256 cfs) in the 24-foot-wide channel downstream of the fish barrier were estimated as 15.6 feet and 5 ft/s, respectively. The US Department of Transportation’s HEC-11 – Design of Riprap Revetment (1989) was used to verify that the modified rockfill stone size proposed for the smelt spawning substrate is anticipated to withstand the 100-year flood.

2.3 Typical Fish Passage Season Flows

The range of flows experienced at the project site during fish passage season were important for the design of the both barrier and channel improvements. These flows were estimated using nearby stream flow gages. Average daily discharges from both the Whitman's Pond Dam (drainage area 12.4 square miles) and Old Swamp River (drainage area 4.5 square miles) gages were adjusted to the project site (Herring Brook at Jackson Square, drainage are 14.1 square miles) by ratio of drainage areas. Annual average daily flow duration curves are shown in **Figure 2.3-1**. **Figures 2.3-2** and **2.3-3** show flow duration curves for the period of March 1 to June 30 only, which covers the typical river herring immigration and smelt spawning seasons. (**Figure 2.3-3** is a close-up of the high flow range for the fish passage period.) Monthly and annual flow statistics are shown in **Table 2.3-1** at the end of this section.

Based on the Whitman's Pond Dam gage, the median flow at the project site during the river herring immigration period is approximately 18 cfs, and typically ranges from 5 to 55 cfs (90 and 10 percent exceedance values, respectively). These values are similar to those for the smelt spawning period (March through May) and were used for the smelt spawning habitat and river herring resting pool hydraulic design targets.

Figure 2.3-1: Average Daily Flow Duration Curves for Herring Brook at Jackson Square (Annual)

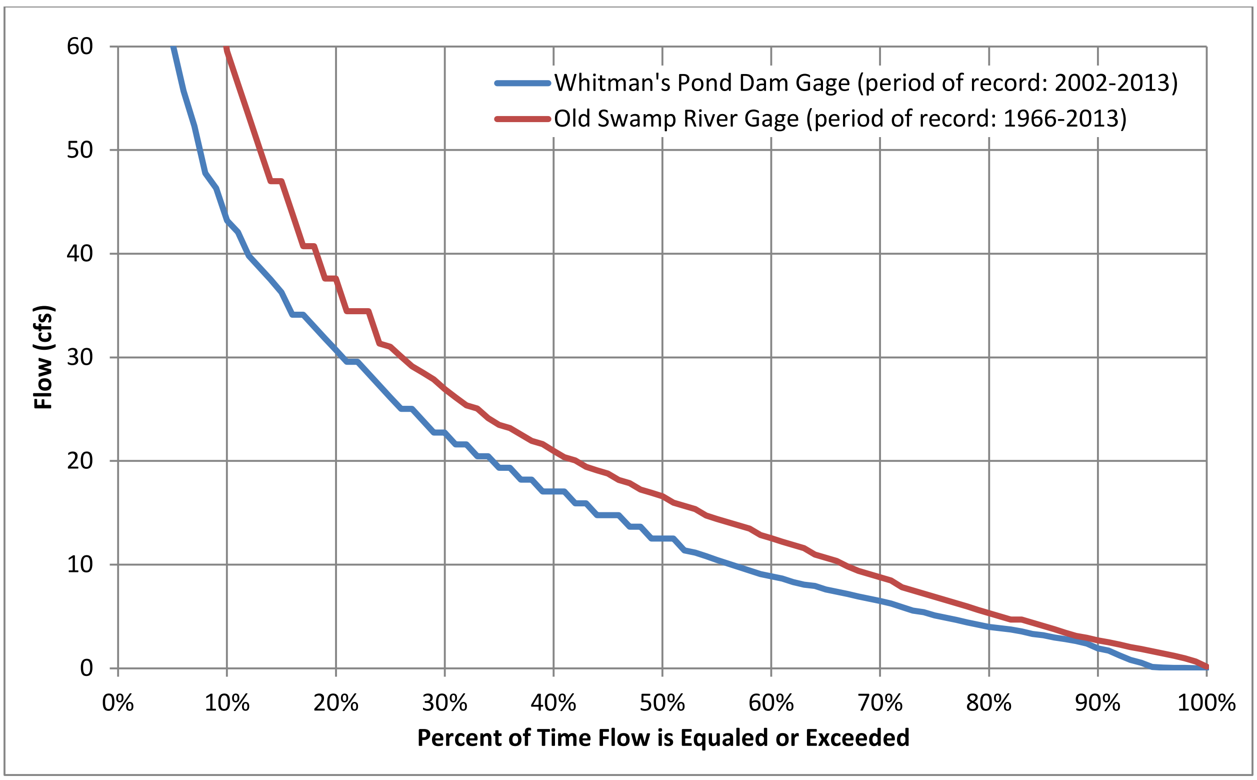


Figure 2.3-2: Average Daily Flow Duration Curves for Herring Brook at Jackson Square (Mar – Jun)

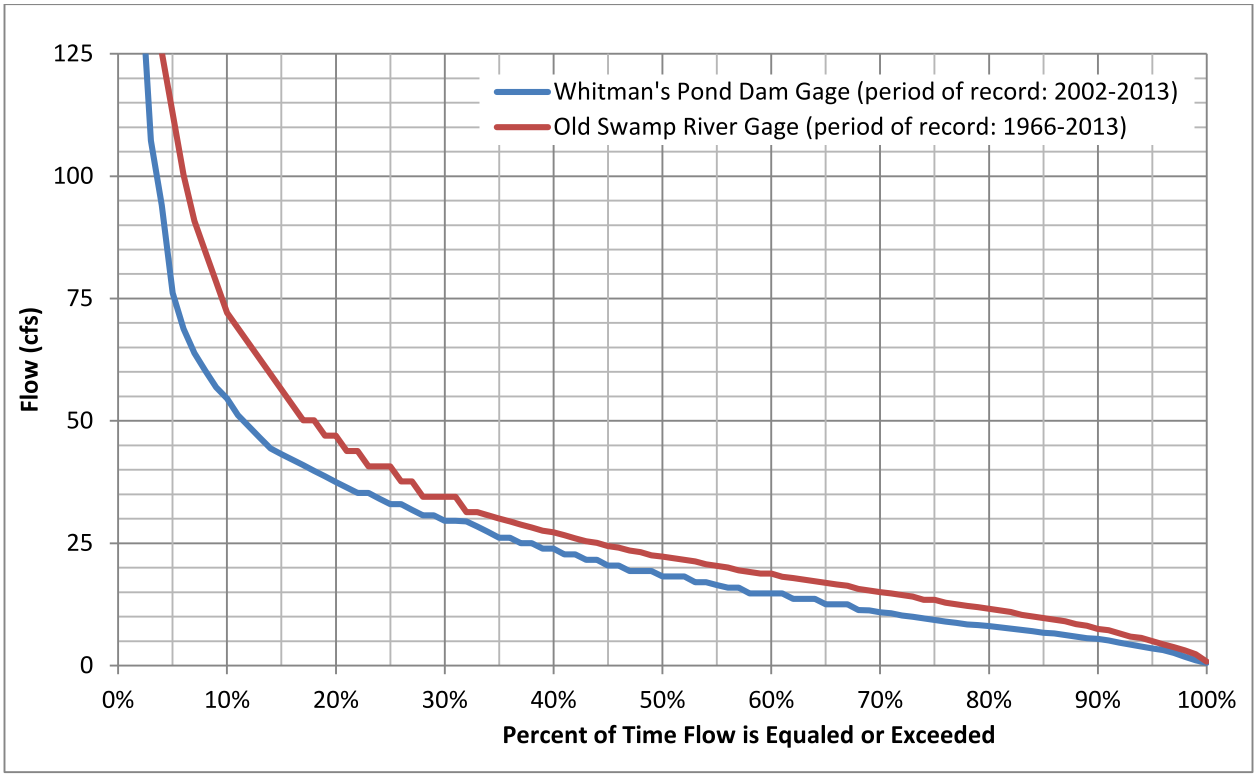


Figure 2.3-3: Average Daily Flow Duration Curves for Herring Brook at Jackson Square (Mar – Jun, High Flows)

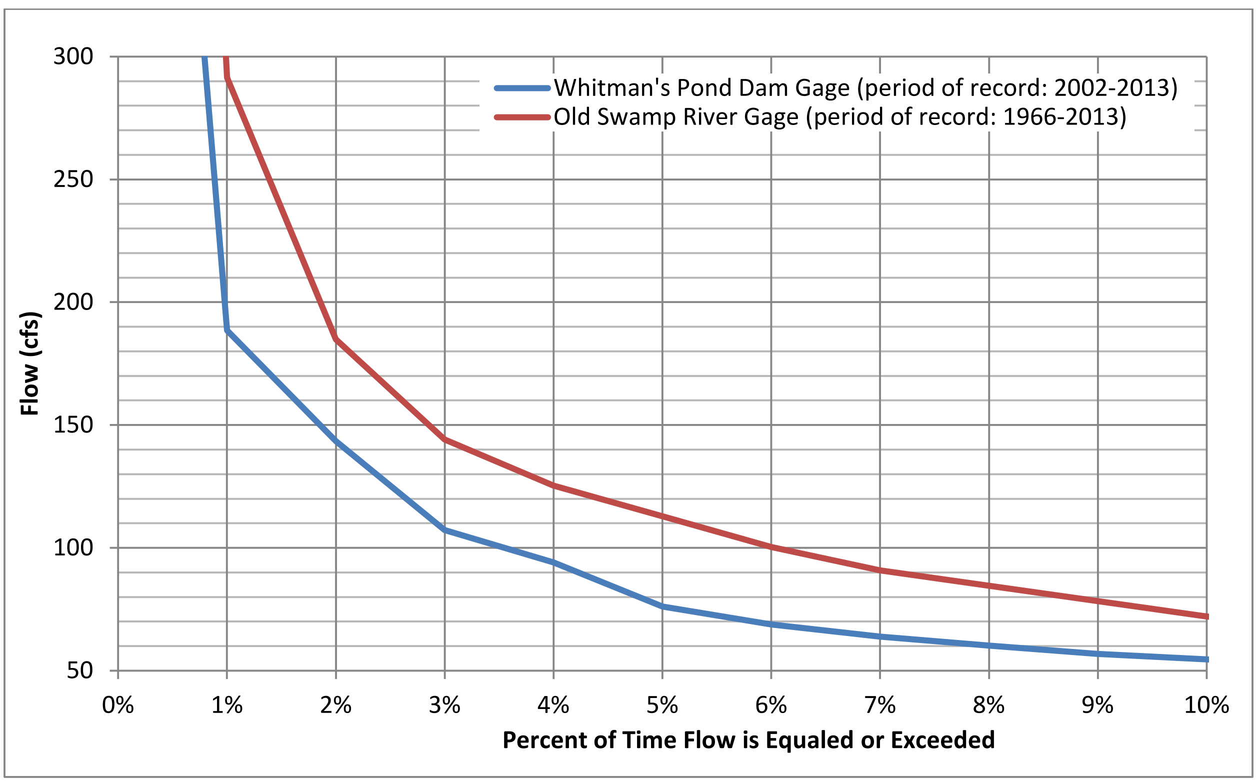


Table 2.3-1: Summary of Average Daily Flow Statistics for Herring Brook at Jackson Square from Various Sources

	Flow (cfs) for Time Period														
	JAN	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*	*ANNUAL*	*River Herring Immigration (MAR-JUN)*	*Smelt Spawning (MAR-MAY)*
Data Source: Whitman's Pond Dam at USGS Gage No. 01105606 *(adjusted to project site based on drainage area ratio)*															
Mean	23	27	42	30	23	19	8	8	8	16	19	26	21	29	32
Minimum	3	3	3	2	4	0.5	0.05	0.02	0.01	0.01	0.01	0.03	0.01	0.5	2
90% exceeds	7	10	8	6	8	2	0.3	0.06	0.1	0.03	3	3	2	5	8
50% exceeds (median)	18	19	30	25	16	8	4	5	4	6	11	23	13	18	22
10% exceeds	43	51	69	53	39	39	19	15	17	40	39	52	43	55	56
Maximum	125	190	725	269	204	279	102	125	81	451	725	173	725	725	725
Data Source: Old Swamp River at USGS Gage No. 01105600 *(adjusted to project site based on drainage area ratio)*															
Mean	37	41	55	42	29	24	9	11	11	19	30	39	29	38	42
Minimum	5	5	8	4	5	0.8	0.4	0.2	0.2	0.4	0.2	3	0.2	0.8	4
90% exceeds	11	13	16	13	10	3	1	1	1	3	7	10	3	8	12
50% exceeds (median)	23	26	34	27	19	10	4	4	4	8	15	23	17	22	26
10% exceeds	72	81	103	85	53	41	19	22	22	38	60	78	60	72	81
Maximum	655	479	1131	624	849	1009	291	260	470	962	1131	965	1131	1131	1131

The Manning's equation was used to estimate flow depths and velocities associated with the typical flows experienced at the project site during herring immigration season with the proposed channel improvements in place. **Figures 2.3-4** and **2.3-5** show the proposed depths and velocities, respectively. Two curves are shown—one for the narrow section of channel immediately downstream of the existing fish ladder and adjacent to the proposed fish barrier (with a width of 11 feet), and another for the wider section of channel downstream of the proposed barrier (24 feet).

Figure 2.3-4 shows that the minimum flow depth of 0.5 feet recommended for smelt spawning or river herring immigration is met at flows of about 5 cfs below the fish ladder or 10 cfs below the fish barrier. These flows are exceeded approximately 90% and 73% of the time during herring immigration season, respectively.

Figure 2.3-5 shows that the minimum flow velocity of 1 ft/s recommended for smelt spawning is met at flows of about 8 cfs below the fish ladder or 16 cfs below the fish barrier. These flows are exceeded approximately 80% and 56% of the time during herring immigration season, respectively.

In summary, the median herring immigration season flow of 18 cfs will meet all flow depth and velocity targets for smelt spawning and river herring passage.

Figure 2.3-4: Estimated Flow Depth in Channel Downstream of Proposed Barrier

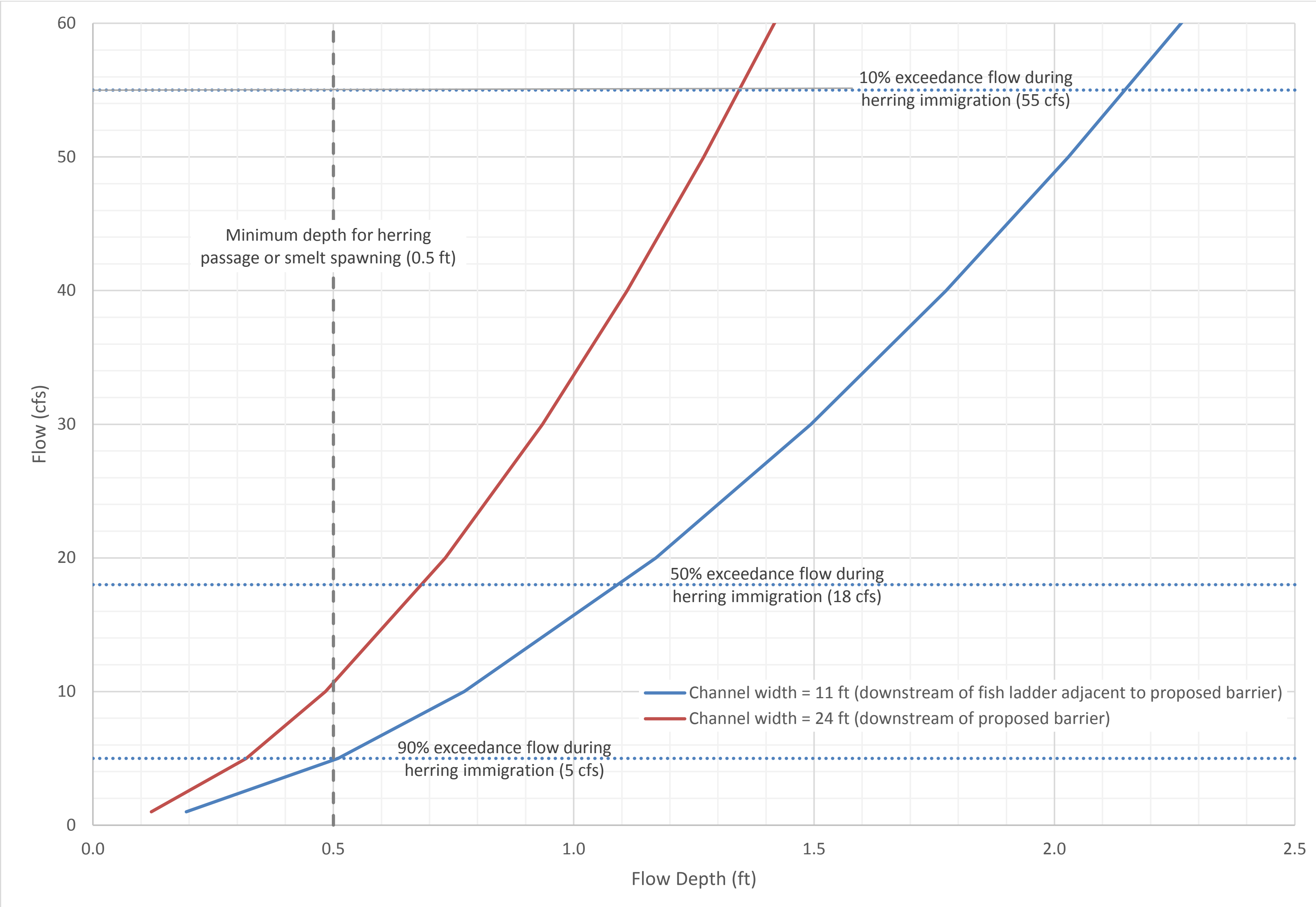


Figure 2.3-5: Estimated Flow Velocity in Channel Downstream of Proposed Barrier